AUDELS HANDY BOOK OF PRACTICAL ELECTRICITY WITH WIRING DIAGRAMS

READY REFERENCE FOR PROFESSIONAL ELECTRICIANS STUDENTS AND ALL ELECTRICAL WORKERS

BY

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AUDELS HANDY BOOK OF PRACTICAL ELECTRICITY

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AUTHOR'S NOTE

In the preparation of this *Handy Book*, which is virtually a *Key* to the Science of Electricity and all its many practical applications, the aim of the author has constantly been to make it

1. Simple
2. Brief
3. Complete
4. Graphic
5. Accurate.

The presentation of principles and their application, descriptions of machines, are given in the simplest language possible, because no matter how well informed the reader may be, he absorbs the information he desires much more readily when presented in simple language, than he would when confronted with an unnecessary display of technicalities.

The language is not only simple, but *brief*. In fact, simplicity and brevity are the two vital essentials of convincing presentation; moreover, it is only *by a rigid economy of words* that the author has been able to give a vast amount of information on each of the many subjects which otherwise would have to be omitted.

By this economy of words, space is made available for a very large number of illustrations, which in many instances, serve to bring out some point much clearer than could be presented by the text alone.

The greatest care has been taken that the work should be accurate.

The aim throughout has been to supply in exhaustive and condensed form, first hand reliable information essential to the student, electrical worker or the searcher for practical knowledge of any phase of the subject.

FRANK D. GRAHAM.

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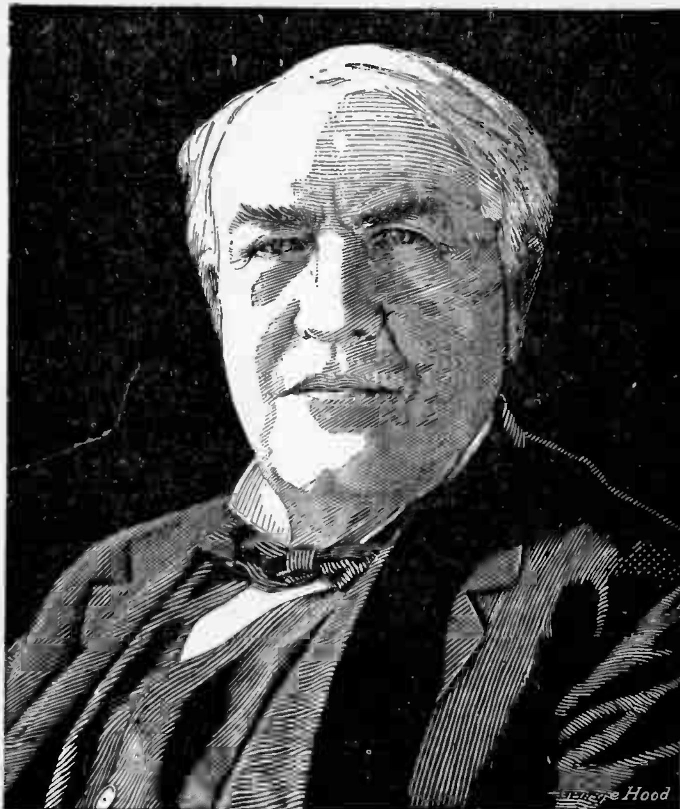

THOMAS ALVA EDISON

EXEMPLAR OF
ELECTRICAL PROGRESS

READY REFERENCE INDEX

and

READERS' GUIDE

An hour with a book would have brought to your mind,
The secret that took the whole year to find;
The facts that you learned at enormous expense,
Were all on a library shelf to commence.

To the Reader and Student:

Read over this index occasionally and get the habit of looking for *unexpected information*. The ready reference index tells you on what pages to find the information sought for.

When you are interested and want information quickly on a problem in Electricity, if you have the habit of consulting this ***"Handy Book"*** it will answer many problems.

Learn to use the index; all subjects covered are listed under their proper headings; it is also suggested to look up closely allied subjects for side lights on your problems.

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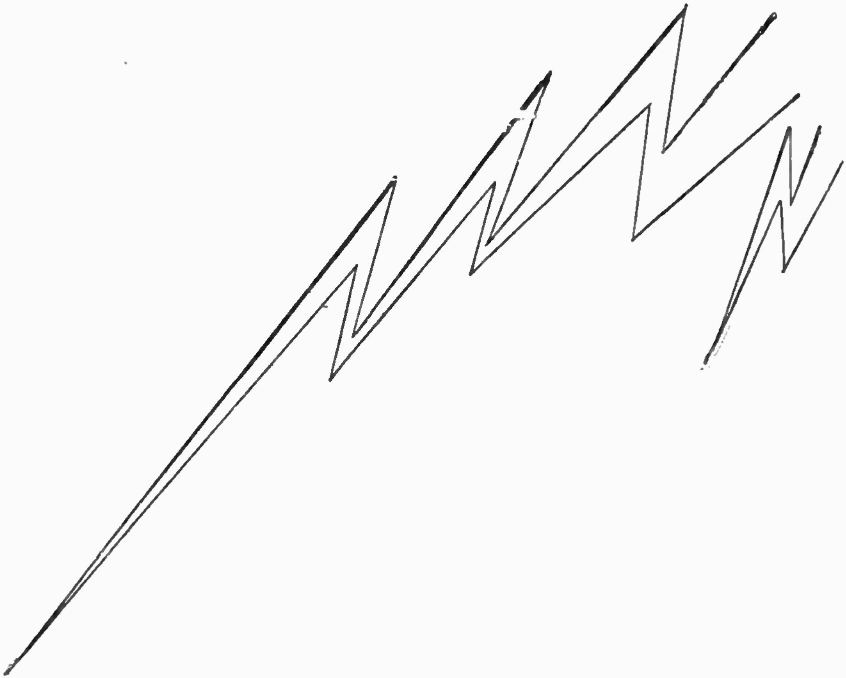
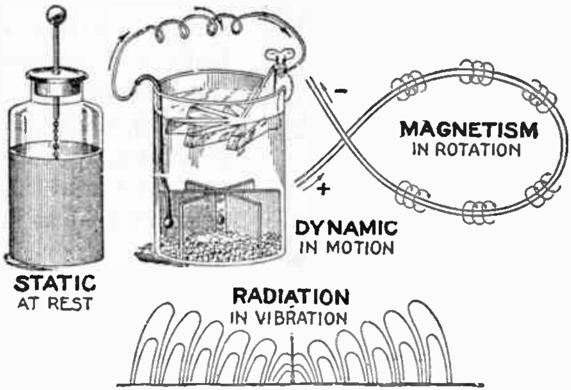


CHAPTER 1

Electricity

The name electricity is applied to an invisible agent known only by the effects which it produces, and the many ways in which it manifests itself. There are four principal forms of electricity:



FIGS. 6,103 to 6,106.—The four kinds of electricity.

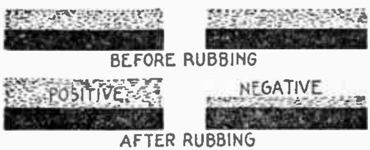
1—Static electricity *at rest.*
2—Dynamic electricity *in lineal motion.*
3—Magnetism electricity *in rotation.*
4—Radiation electricity *in vibration.*

1. Static Electricity

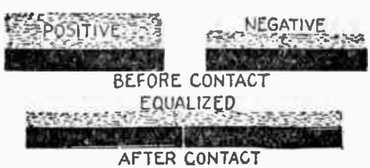
If two unlike bodies be rubbed together, electricity will be concentrated on the surfaces and when in this condition they are said to be charged or electrified.

Thus, if a glass rod be rubbed with silk in dry air, it becomes *charged*

Figs. 6,107 and 6,108.—The Leyden jar and discharger. Its discovery is attributed to the attempt of Musschenbrock and his pupil Cuneus to collect the supposed electric "fluid" in a bottle half filled with water. The bottle was held in the hand and was provided with a nail to lead the "fluid" down through the cork to the water from the electric machine. The invention of the Leyden jar is also claimed by Kleist, Bishop of Pomerania.



Figs. 6,109 to 6,112.—Positive and negative electricity. The rubbing process removes electricity from one body transferring it to the other.



Figs. 6,113 to 6,115.—Equilization of oppositely charged bodies by contact.

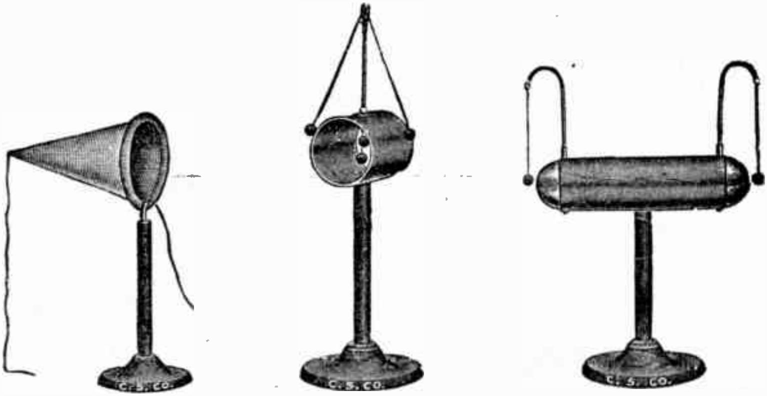
with *electricity* called *positive* electricity, while a rod of sealing wax or other resinous substance rubbed with wool or fur becomes *negatively* charged.

Positive and Negative Electricity.—These terms signify that one body is charged to a higher pressure than the other, that is, by rubbing some of the charge is taken from one body and transferred to the other as in figs. 6,109 to 6,112, the higher charge is arbitrarily called positive (+) and the lower negative (—) as in simile, *hot* and *cold*.

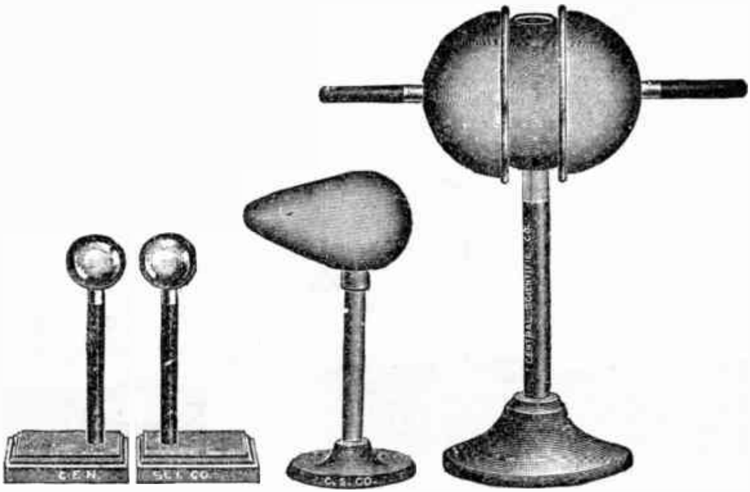
Rule 1. — *If oppositely charged bodies be brought into contact with each other, the pressure will be equalized by the passing of the charge from the higher to the lower one.*

When the pressures are thus equalized the bodies are said to be discharged. Where the pressure difference is small, contact is necessary (figs. 6,113 to 6,115), but where it is great, it is only necessary to bring the bodies close together as in fig. 6,112.

Electrical Attraction and Repulsion. — Two balls of light material as



FIGS. 6,116 to 6,118.—Electrostatic apparatus. Fig. 6,116, Faraday's bag. When the bag is charged and pulled inside out, the static charge always remains on the outside. Fig. 6,117 hollow cylinder with pith balls, showing that electricity resides only on the outer surfaces of bodies. Fig. 6,118, induction cylinder with removable pith ball holders.



FIGS. 6,119 to 6,121.—Electrostatic apparatus. Fig. 6,119 induction spheres so mounted on insulating support that they can be brought into contact. Useful in connection, with fig. 6,118 for showing the separation of positive and negative electricity by induction. Fig. 6,120, ellipsoidal conductor for showing unequal distribution. Fig. 6,121 Biot's hemispheres with pair of their nickel plated brass hemispheres with rubber handles. Charge on outside of globe may be removed by placing hemispheres in position shown.

pith are attracted to a charged glass rod, adhere to it, become charged, and then are repelled and fly off (as in figs. 6,124 to 6,126). They also repel each other but are attracted by a charged rod of sealing wax. From this follows:

***Rule 2.**—A body charged with one kind of electricity repels one charged with the same kind, and attracts one charged with the opposite kind.*

Whenever two bodies are rubbed together the body rubbed receives a charge unlike that of the rubbing body, as stated.

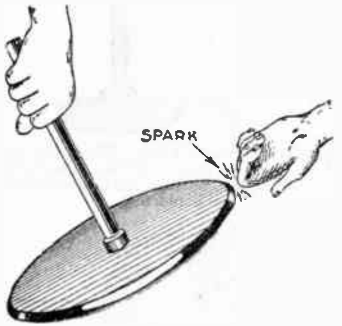
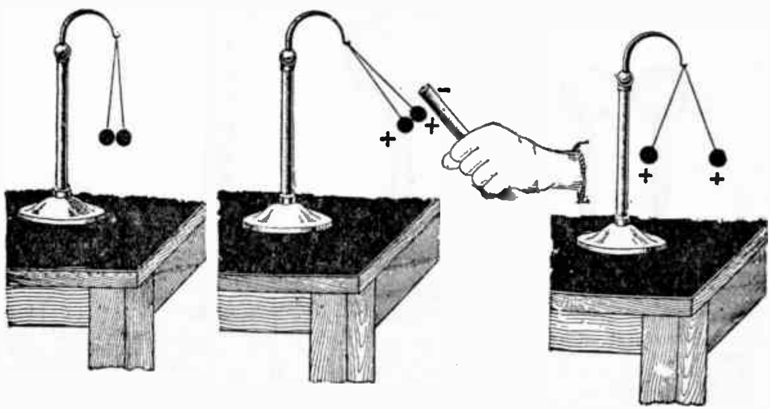


FIG. 6,122.—Production of spark with highly charged body.

FIG. 6,123.—Gold leaf electroscope; it consists of two strips of gold foil suspended from a brass rod within a glass jar. Used to detect the presence and sign of an electric charge.

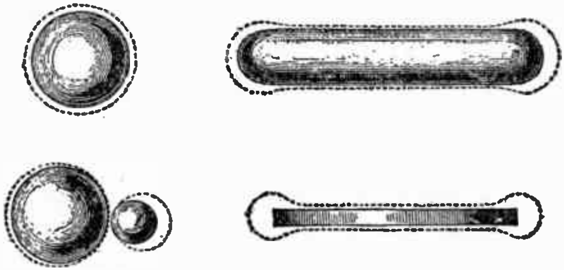


FIGS. 6.124 to 6.126.—Electrical attraction and repulsion.

Rule 3.—Whenever a positive charge is developed an equal negative charge is developed, and vice-versa.

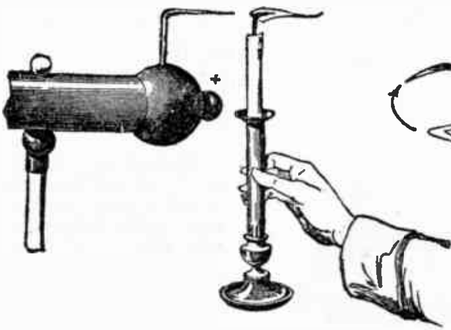
The Charge.—The quantity of electrification of either kind produced by friction or other means is called the *charge*.

Distribution of the Charge.—*This resides on the surface*



Figs. 6,127 to 6,130.—Distribution of the charge on conductors of various shapes.

of the body and hence depends on the *extent* of the surface and not on the mass of the body. Certain bodies, or material like glass, paper, etc., have the property of retaining this charge at whatever point attained; such are known as insulators.



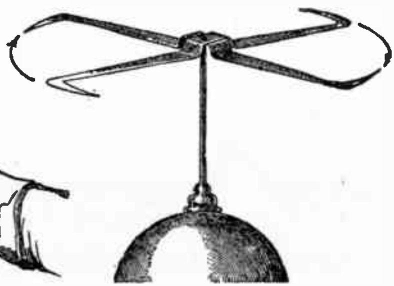


Fig. 6,131.—Experiment to illustrate the effect of pointed conductors.

Fig. 6,132.—Electric wind mill which operates by the reaction due to the escape of the electric charge from the points.

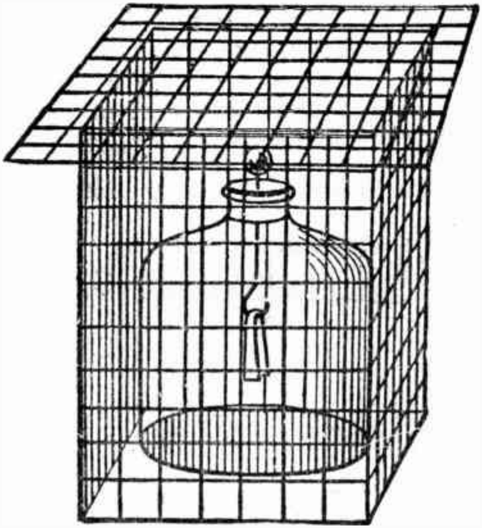


FIG. 6,133.—The electric screen. A screen of wire gauze surrounding a delicate electrical instrument will protect it from external electrostatic induction.

"Free" and "Bound" Electricity.—Electricity upon a charged conductor not in the presence of a charge of the opposite kind is called *free* and if a conductory path be provided, it will flow away to earth: if in the presence of a neighboring charge of opposite kind it is called *bound.*

Electric Screen.—Faraday showed that the charge on the outside of a conductor distributes itself in such a way that there is no electric force without the conductor.

Thus in fig. 6,133, the gold leaf electroscope covered with a bird cage failed to detect the pressure of powerfully charged bodies outside.

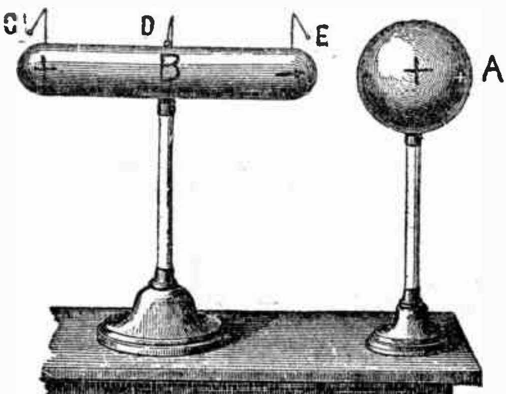
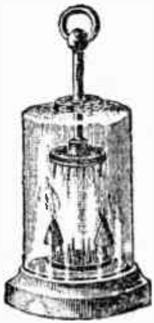
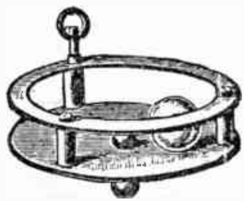
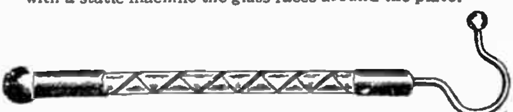
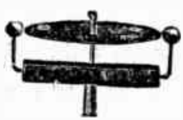
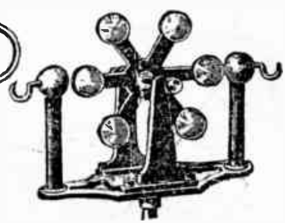


FIG. 6,134.—Experiment illustrating the nature of an induced charge. The apparatus consists of a metal ball and cylinder, both mounted on insulated stands, pith balls being placed on the cylinder at points C, D, and E.



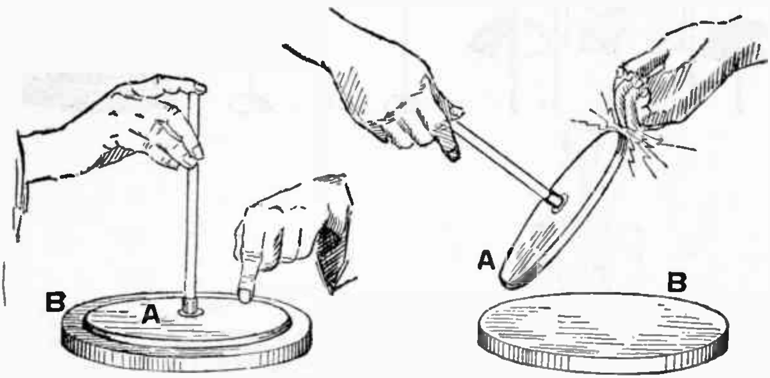




FIGS. 6,135 to 6,139.—Electrostatic apparatus. Fig. 6,135, electrical chimes to illustrate attraction and repulsion of charge. Fig. 6,136. electrical chime arranged to be suspended from static machine. Fig. 6,137. Volta's hail storm or dancing balls. The charge from static machine causes balls to dance rapidly. Fig. 6,138. smoke condenser. The glass shade is filled with smoke from a punk candle, which is condensed upon the glass, when a charge from a static machine is applied. Fig. 6,139, electrical circus or racing ball. When connected with a static machine the glass races around the plate.

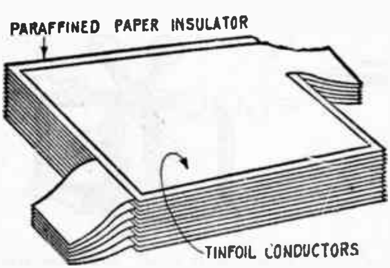
FIGS. 6,140 to 6,142.—Electrostatic apparatus. Fig. 6,140, spiral tube. A charge sent through the tube will show a series or sparks where it crosses the gaps. Fig. 6,141, rotating disc. It will rotate rapidly when connected to a static machine. Fig. 6,142, electrostatic motor. It will rotate at high speed when connected to static machine.

Charge by Induction.—If two bodies, as brass balls both insulated and one electrified, the other not, be placed near together, the one not electrified will become electrified by *induction.*



FIGS. 6,143 and 6,144.—The electrophorus and method of using. Charge B; place A, in contact with B, and touch A (fig. 6,143). The disc is now charged by *induction* and will yield a spark when touched by the hand, as in fig. 6,144.

Condenser, Lyden Jar.—An apparatus for condensing a large quantity of electricity on a comparatively small surface. *It consists of two insulated conductors, separated by an insulator and the working depends on the action of induction.*



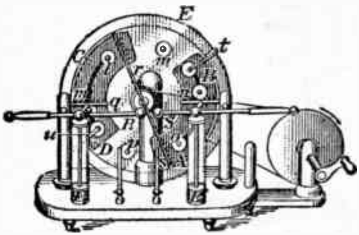
Electric Machines.—Various machines have been devised for producing electric charges such as

FIG. 6,145—Condenser for induction coil. *In construction,* numerous sheets of tin foil are prepared and placed on top of each other with a thin layer of insulating material between as shown.

have been described. The ordinary "static" or electric machine, is nothing but a *continuously acting electrophorus*.

Fig. 6,146 represents the socalled Toepler-Holtz machine. Upon the back of the stationary plate E, are pasted paper sectors beneath which are strips of tinfoil AB, and CD, called inductors.

In front of E, is a revolving glass plate carrying disc *l,m,n,o,p*, and *q*, called carriers. To the inductors AB, and CD, are fastened metal arms *t*, and *u*, which bring B, and C, into electrical contact with the discs *l, m,n,o,p*, and *q*, when these discs pass beneath the tinsel brushes carried by *t*, and *u*. A stationary metallic rod *rs*, carries at its ends stationary



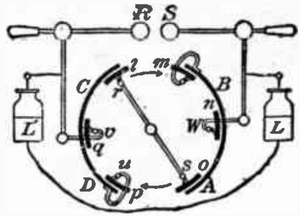


FIG. 6,146.—The Toepler-Holtz electric machine.

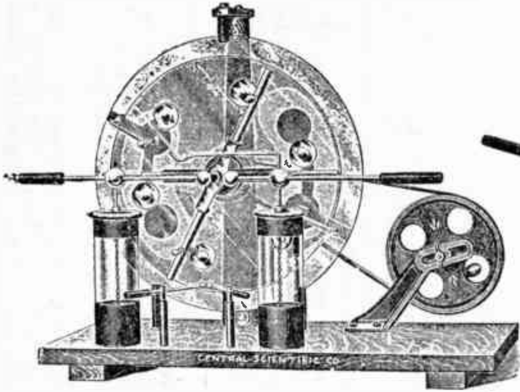
FIG. 6,147.—Principle of Toepler-Holtz electric machine.

brushes as well as sharp pointed metallic combs. The two knobs R, and S, have their capacity increased by the Leyden jars L, and L'A, small + charge to be originally placed on the inductor CD. Induction takes place in the metallic system consisting of the discs *l*, and *o*, and the rods *rs*, *l*, becoming negatively charged and *o*, positively charged.

As the plate carrying *l,m,n,o,p,q*, rotates in the direction of the arrow the negative charge on *l*, is carried over to the position *m*, where a part of it passed over to the inductor AB, thus charging it negatively. When *l*, reaches the position *n*, the remainder of its charge, being repelled by the negative electricity which is now on AB, passes over into the Leyden jar, L.

When *l*, reaches the position *o*, it again becomes charged by induction this time positively, and more strongly than at first, since now the negative charge on AB, as well as the positive charge on CD, is acting inductively upon the rod *rs*. When *l*, reaches the position *u*, a part of its now strong positive charge passes to CD, thus increasing the positive charge upon its inductor.

In the position *v*, the remainder of the positive charge on *l*, passes over to L'. This completes the cycle for *l*. Thus, as the rotation continues AB, and CD, acquire stronger and stronger charges, the inductive



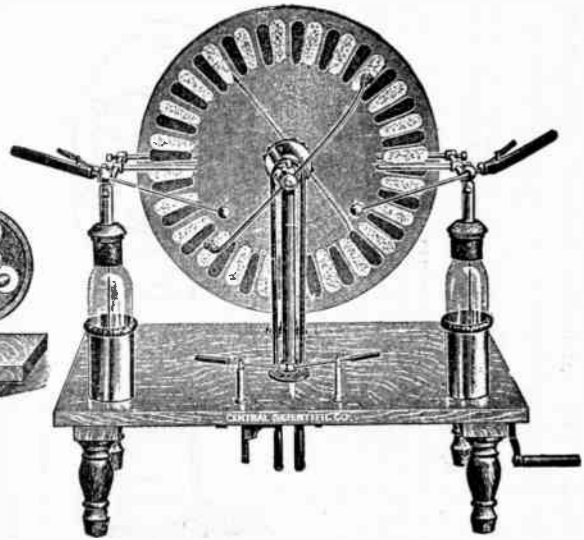


FIG. 6,148.—Mars Toepler-Holtz electric machine. ***In construction,*** the belt tension is adjustable, the brushes are made of tinsel, which is claimed to be superior to wire. The condensers are of the Leyden jar type. There is a current breaker which permits the intensity and rate of discharge to be varied. The machine is equipped with a pair of nickel plated shocking handles and chains and an attachment for holding accessories such as bell chimes, image plates, etc. A 3 to 6 inch spark may be produced, depending upon weather conditions. Revolving plate 12 in.; stationary plate 14 in.

FIG. 6,149.—Wimshurst self-charging static machine, new design. The machine works without change of poles, and is accordingly more satisfactory than the Toepler-Holtz type in which the poles may reverse at any moment. For this reason it is especially adapted to X ray work. The machine is provided with a spark gap attachment, and there is a current breaker, by means of which the outer coils of the Leyden jar may be either connected or disconnected, thus allowing either an intermittent spark discharge or a continuous discharge. Spark range from ¼ to ½ the plates diameter.

action upon rs, becomes more and more intense, and positive and negative charges are continuously imparted to L', and L, until a discharge takes place between the knobs R and S.

2. Dynamic Electricity

When static charges are equalized by means of a spark, the energy takes on the form of a *current*, but dynamic or current

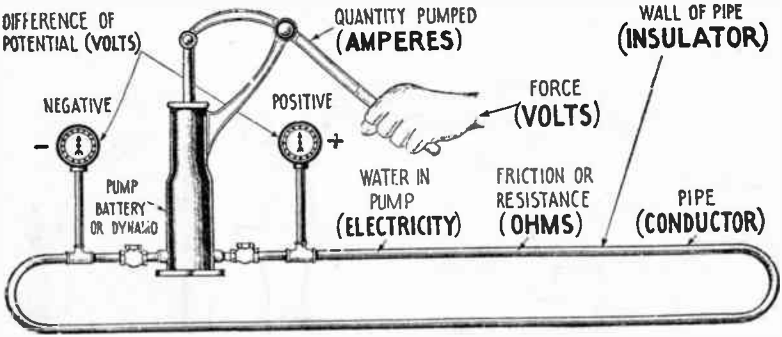
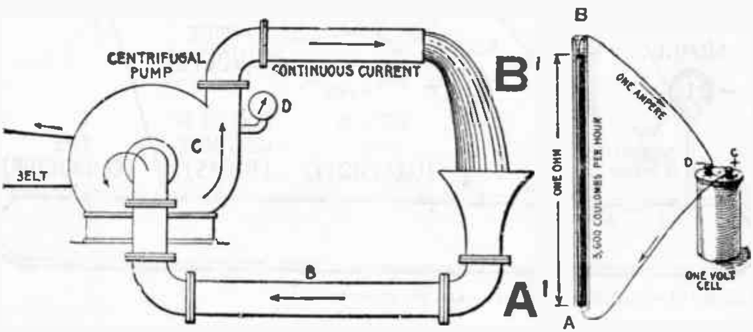


FIG. 6,150.—Hydraulic analogy of electric current.

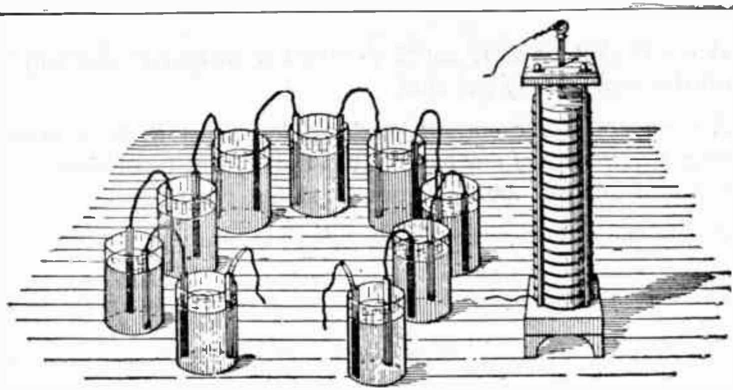
electricity is usually understood to mean energy of *considerable* current strength and *long duration* as compared with a static discharge.

Electrical currents are said to flow through conductors.

These offer more or less resistance (*ohms*) to the flow, depending on the material. Copper wire is generally used as it offers little resistance. It is now thought that the flow takes place along the surface and not through the metal. The current must have pressure volts to overcome the resistance of the conductor and flow along its surface. This pressure is called *voltage* caused by what is known as difference of potential between the source and terminal. An electric current has often been compared to water flowing through a pipe. The pressure under which the current flows is measured in *volts* and the quantity that passes in *amperes*. The resistance with which the current meets in flowing along the conductor is measured in *ohms*. The flow of the current is proportional to the voltage and inversely proportional to the resistance. The latter depends upon the material, length and diameter of the conductor. Since the current will always flow along the path of least resistance, it must be so guarded that there will be no leakage. Hence, to prevent leakage, wires are *insulated*, that is, covered by wrapping them with cotton, silk thread, or other insulating material. If the insulation be not effective, the current may leak, and so return to the source without doing its work. This is known as a *short circuit*. The conductor which received the current from the source is called the *lead*, and the one by which it flows back, the *return*. When wires are used for both lead and return, it is called a *metallic circuit;* when the ground is used for the return, it is called a *grounded circuit*.



FIGS. 6,151 and 6,152.—Diagrams showing hydraulic analogy illustrating the difference between amperes and coulombs. If the current strength in fig. 6,152 be one ampere, the quantity of electricity passing any point in the circuit per hour is $1\times60\times60=3,600$ coulombs. The *rate* of current flow of one ampere in fig. 6,152 may be compared to the rate of discharge of a pump as in fig. 6,151. Assuming the pump to be of such size that it discharges a gallon per revolution and makes 60 revolutions per minute, the quantity of water discharged per hour (coulombs in fig. 6,152) is $1\times60\times60=3,600$ gallons. Following the analogy further (in fig. 6,152), the pressure of one volt is required to force the electricity through the resistance of one ohm between the terminals A and B. In fig. 6,151, the belt must deliver sufficient power to the pump to overcome the friction (resistance), offered by the pipe and raise the water from the lower level A′ to the higher level B′. The difference of pressure between A and B in the electric circuit corresponds to the difference of pressure between A′ and B′. The cell furnishes the energy to move the current by maintaining a difference of pressure at its terminals C and D: similarly, the belt delivers energy to raise the water.



FIGS. 6,153 and 6,154.—Courane de Tasses and Volta's pile, the first of all batteries (1800). The Courone de tasses (crown of cups) was a battery of simple cells in series. Each cell was composed of a plate of silver or copper and one of zinc immersed in brine. Volta's pile consisted of a series of alternate discs of zinc and copper, separated by moistened felt. Surprising results were obtained with this pile.

OHM'S LAW

$$\text{CURRENT} = \frac{\text{ELECTROMOTIVE FORCE}}{\text{RESISTANCE}}$$

$$I = \frac{E}{R} \qquad \text{AMPERES} = \frac{\text{VOLTS}}{\text{OHMS}}$$

$$\text{RESISTANCE} = \frac{\text{ELECTROMOTIVE FORCE}}{\text{CURRENT}}$$

$$R = \frac{E}{I} \qquad \text{OHMS} = \frac{\text{VOLTS}}{\text{AMPERES}}$$

ELECTROMOTIVE FORCE = CURRENT X RESISTANCE

$$E = I\,R \qquad \text{VOLTS} = \text{AMPERES} \times \text{OHMS}$$

A volt is that pressure which produces a current of one ampere against a resistance of one ohm.

An ampere is the current produced by one volt in a circuit having a resistance of one ohm. It is that quantity of electricity which will deposit .001118 gram of silver per second.

A coulomb is one ampere flowing for one second.

Rule 4.—OHM'S LAW. *In a given circuit, the amount of current in amperes is equal to the pressure in volts divided by the resistance in ohms, that is:*

$$\text{current} = \frac{\text{pressure}}{\text{resistance}} \text{ or, amperes} = \frac{\text{volts}}{\text{resistance}} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

from which

$$\text{volts} = \text{amperes} \times \text{resistance; resistance} = \frac{\text{volts}}{\text{amperes}}$$

Equation (1) may be expressed by symbols, thus:

$$I = \frac{E}{R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

in which

I = current strength in *amperes*,
E = pressure in *volts*,
R = resistance in *ohms*.

from (2) is derived the following:

$$E = IR \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$R = \frac{E}{I} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Example.—A circuit having a resistance of 5 ohms is under a pressure of 110 volts. How much current will flow?

From Ohm's law, amperes = volts ÷ resistance (equation 2) = 110 ÷ 5 = 22 amperes.

Example.—If the resistance of a circuit be 10 ohms, what voltage is necessary for a flow of 20 amperes?

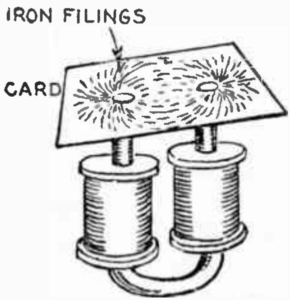
From Ohm's law, volts = amperes × resistance (equation 3) = 20 × 10 = 200 volts.

Example.—On a 110 volt circuit what resistance is necessary to obtain a flow of 15 amperes?

From Ohm's law, resistance = volts ÷ amperes (equation 4) = 110 ÷ 15 = 7⅓ ohms.

3. Magnetic Electricity

The latest theory of magnetism, well supported by facts,



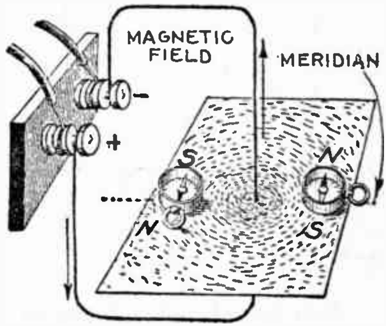


FIG. 6,155.—Ordinary horse shoe magnet with iron filings showing magneto field.

FIG. 6,156.—Electromagnetic field surrounding a conductor with current flowing.

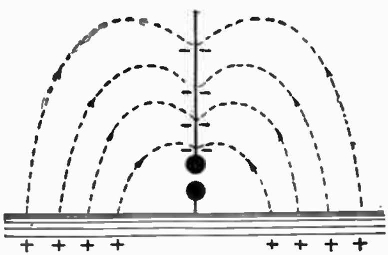


FIG. 6,157.—Electrostatic field about aerial pressures to spark discharge.

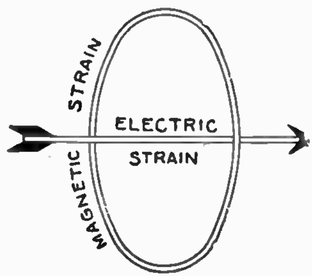


FIG. 6,158.—Strains in the ether.

assumes that the molecules of a magnetic substance are minute magnets by nature, each having two poles.

In a bar magnet, each molecule at the two ends may be supposed to have the attraction of its inward pointing pole neutralized more strongly than that of the outward pointing pole, which, therefore, is free to attract other bodies.

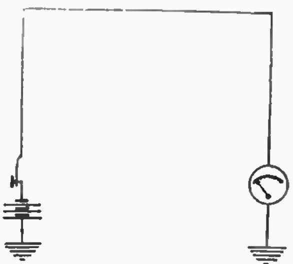


Fig. 6,159.—The wire telegraph.

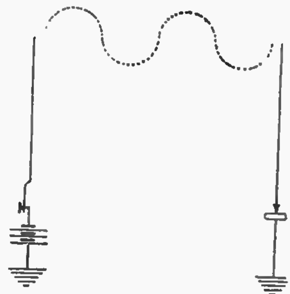


Fig. 6,160.—The wireless telegraph.

***Rule 5.**—Like poles repel, unlike poles attract each other.*

A close relation exists between magnetism. Oersted, a Danish investigator, in 1819, *announced that a compass needle is disturbed by the neighborhood of an electric current.* If the wire through which the current flows be held above and parallel to the needle, the needle tends to set itself at right angles to the wire. The lines of this electromagnetic force must necessarily be concentric circles around the wire, as was shown in fig. 6,105.

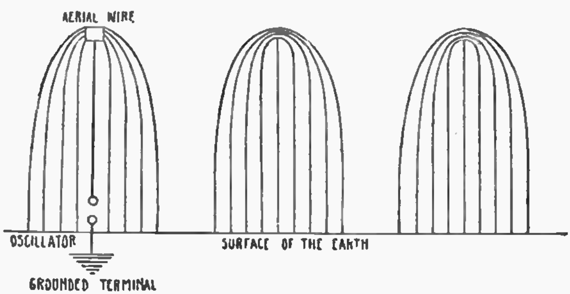


Fig. 6,161.—Fessenden sliding half waves; theory based on the experiment made by Hertz.

4. Radio Electricity

In wireless work the electric waves representing the messages are transmitted, or propagated, from the sending station to the receiving station through the ether, the latter performing the same functions as the wire does in ordinary telegraphy and telephony as in figs. 6,159 and 6,160.

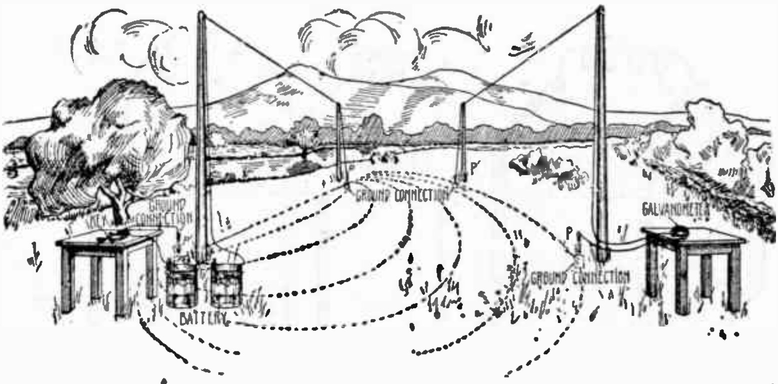
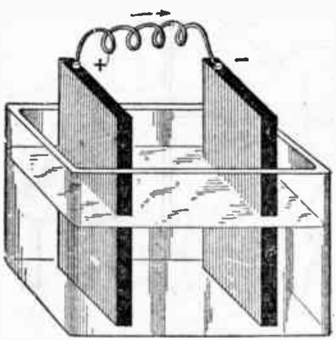


FIG. 6,162.—Conductivity method of wireless telegraphy; *earth the medium.* Steinheil of Bavaria discovered that the earth could be utilized in place of the usual return conductor of a wire telegraph line as here shown. By placing earth plates *p p'* and P, P' connected together and having a galvanometer in circuit parallel with the first, which included a battery and a key, Steinheil found that there was enough leakage of current from one to the other to deflect the needles of the galvanometer. The dotted lines represent current in the earth.

CHAPTER 2

Primary Cells

Production of the Current.—To produce current electricity it is only necessary to immerse a piece of zinc and a piece of



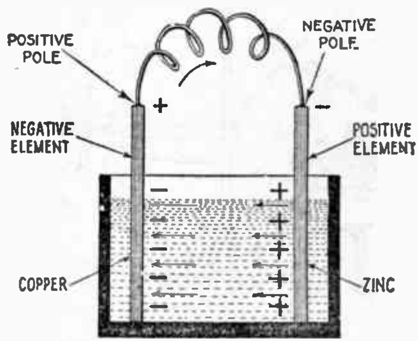


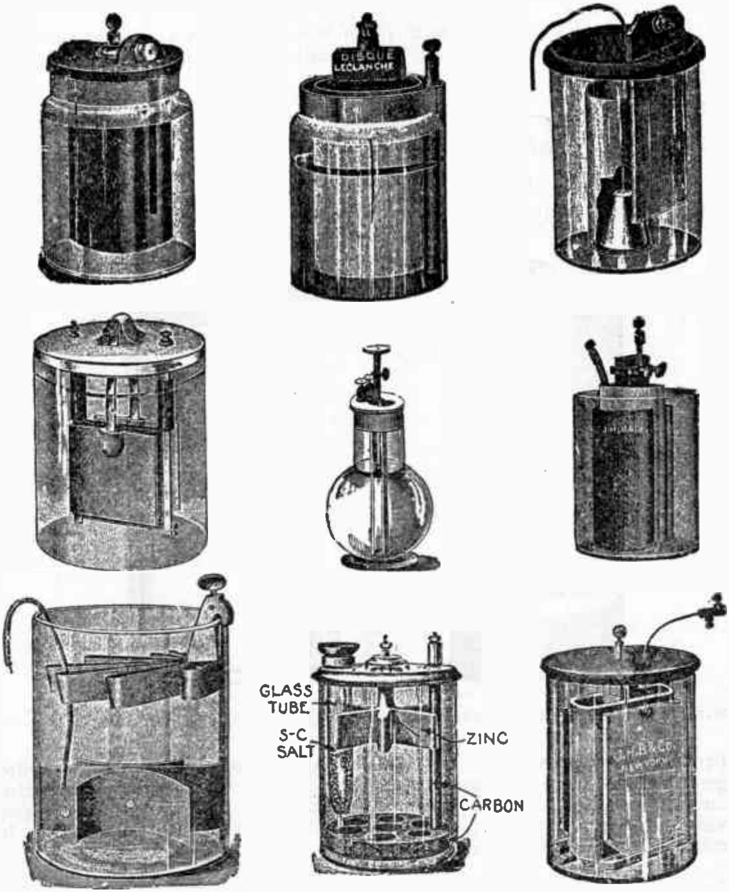
FIG. 6,163.—Simple primary cell. *It consists of* two dissimilar metal plates (such as copper and zinc which are called the *elements*) immersed in the electrolyte or exciting fluid contained in the glass jar.

FIG. 6,164.—Simple primary cell illustrating the terms poles and elements. *Carefully note that the negative element has a positive pole, and the positive element a negative pole.*

copper or carbon in an acid or salt solution called the *electrolyte*, thus forming a primary cell as in figs. 6,163 and 6,164.

If the copper and zinc electrodes be connected with a wire, a current will flow from the copper to the zinc, the copper being positively charged and the zinc negatively charged, although *inside the cell the action is reversed, the current flowing from the zinc to the copper*, as shown in fig. 3,164.

Primary cells may be classed: 1, according to their chemical features as, *a*, one fluid, and *b*, two fluid, and 2, according to service, as, *a*, open circuit, for intermittent work, and *b*, closed circuit, for furnishing current continuously as in telegraphy.



FIGS. 6,165 to 6,173.—Various primary cells. Fig. 6,165, carbon cell; fig. 6,166, Disque Leclanche cell (single fluid with solid depolarizer); fig. 6,167, Fuller telephone standard cell (adapted to long distance telephoning); fig. 6,168, Edison single fluid cell (caustic soda electrolyte; suitable for ignition and R. R. signal work); fig. 6,169, Grenet cell (suitable for experimental work); fig. 6,170, Bunsen two fluid cell (suitable for experimental work); fig. 6,171, Daniell gravity "crow foot" pattern two fluid cell (*gravity* instead of a porous cup is depended upon to keep the liquids separate; suitable for closed circuit work); fig. 6,172, Partz acid gravity cell with depolarizer (the effective depolarizer permits both open and closed circuit work); fig. 6,173, Wheelock cell (carbon and zinc elements).

In *one fluid* cells both metal plates are immersed in the same solution.

In *two fluid* cells each metal plate is immersed in a separate solution, one of which is contained in a porous cup which is immersed in the other liquid.

Polarization.—In the operation of the simple primary cell *hydrogen is formed.*

Some bubbles of the gas rise to the surface of the electrolyte and so escape into the air, *but much of it clings to the surface of the copper element which thus gradually becomes covered with a thin film of hydrogen,* thus partly

FIGS. 6,174 and 6,175.—Round and rectangular types of the so called "dry" cell.

because the effective plate area is decreased and partly because the hydrogen tends to set up a reverse current, the output is considerably diminished and the cell is said to be polarized. Because of this, some cells are provided with a *depolarizer,* or substance, which prevents polarization by combining with the hydrogen.

So called "Dry" Cells.—A dry cell is composed of two elements, usually zinc and carbon, and a liquid electrolyte. A zinc cup closed at the bottom and open at the top forms the negative electrode; this is lined with several layers of blotting paper or other absorbing material.

FIG. 6,176.—Polarity indicator. It indicates the negative and positive poles when connected in circuit.

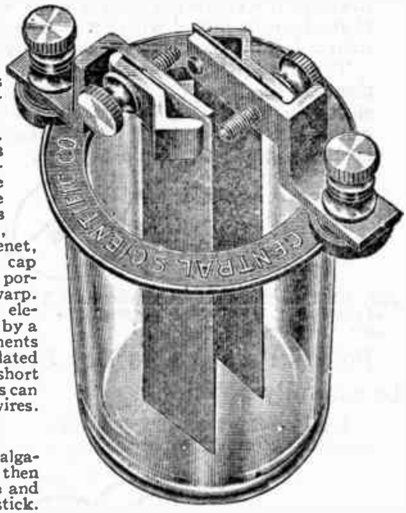


FIG. 6,177.—Students demonstration battery. An excellent battery for studying the laws of the voltaic cell, such as internal resistance, effects of amalgamating the zinc, use of various solutions, etc. With a complete set of elements the various forms of batteries in common use are readily assembled, namely; Simple voltaic, Bunsen, Grenet, Daniell gravity and LeClanche. The cap which fits the glass tumbler is made of porcelain, which is acid proof and will not warp. The clamps will hold either flat or round elements and, as they are attached to the cap by a swivel joint, the distance between the elements can be varied at will. The clamps are insulated from each other so that there can be no short circuit between the elements. The elements can be removed without disconnecting the lead wires.

BATTERY DIRECTIONS

Amalgamating.—A good method for amalgamating the zinc element is to dip it into acid, then pour a few drops of mercury on the surface and rub in with a piece of cloth attached to a stick. This is perhaps the best and quickest method although the most expensive.

Amalgamating Fluid.—Two-ounces mercury, 1 ounce aqua regia, 10 ounces water Dip zinc into solution and then wash with water. No need of brush or rag.

LeClanche Cell.—Place 6 ounces ammonium chloride into jar and fill with water to two-thirds its capacity. Stir well until the salt is entirely dissolved. Place elements with zinc outside porous cup as illustrated.

Carbon Cylinder Cell.—Directions furnished under LeClanche cell apply to this type of cell, except that zinc rod is placed inside carbon cylinder.

Samson Cell.—Directions furnished under carbon cylinder cell apply to this type of cell.

Grove Cell.—Outer cell contains amalgamated zinc plate dipping into dilute sulphuric acid (by weight 10 parts water to 1 part acid). In inner porous cup, a piece of platinum dips into nitric acid of full strength. Obnoxious nitrogen oxide fumes may be suppressed in a large measure by the addition of a small quantity of potassium dichromate.

Bunsen Cell.—This cell is merely a modification of the Grove cell, in which the expensive platinum is replaced by an electrode of gas carbon.

In both the Grove and Bunsen cells the nitric acid may be replaced by a chromic acid solution.

Grenet Cell.—In this cell the zinc plate between two carbon plates dips into a chromic acid solution (see below). When this cell is exhausted, the rich reddish color of chromic acid will be replaced by a muddy dark green color.

Chromic Acid Solution.—There are many different formulæ, but the most convenient method of making a generally useful acid is by simply dissolving prepared chromic acid salt in water. A useful formula is, 30 parts sodium dichromate, 100 parts water and 23 parts sulphuric acid (sp. gr. 1.845) all by weight.

Plunge Battery.—Elements and directions under Grenet type apply to this type of battery

Daniell Battery.—The zinc element is placed in a porous cup containing sulphuric acid (1 part acid to 20 parts water, by weight). The copper element encircles a porous cup and dips into saturated solution copper sulphate, kept continually saturated by the addition of an excess of copper sulphate crystals on bottom of jar. Solution is more effective by addition of few cubic centimeterx sulphuric acid.

The positive electrode consists of a carbon rod placed in the center of the cup; the space between is filled with carbon—ground coke and dioxide of manganese mixed with an absorbent material. This filling is moistened with a liquid, generally sal-ammoniac.

The top of the cell is closed with pitch to prevent leakage and evaporation. A binding post for holding the wire connections is attached to each electrode and each cell is placed in a paper box to protect the zincs of adjacent cells from coming into contact with each other when finally connected together to form a battery.

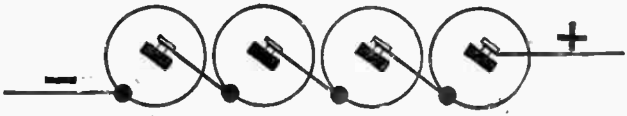


FIG. 3,178.—Series battery connection: The pressure between the (+) and (—) terminals of the *battery* is equal to *the product of the voltage of a single cell multiplied by the number of cells.*

Points Relating to Dry Cells.—The following items should be carefully noted:

1.—Never accept dry cells from a dealer without testing them with *your own* ammeter. 2.—Never use more cells in series than is necessary to do

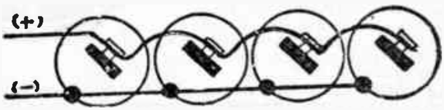


FIG. 6,179.—Multiple or parallel connection. The voltage *is the same as that of a single cell,* but the current is equal to the *amperage of a single cell multiplied by the number of cells.*

the work. 3.—Where there is vibration (as around gas engines) do not connect cell with heavy wire. 4.—If the cells be allowed to become moist or wet they will be ruined. 5.—Cells deteriorate with age, hence demand fresh cells, and do not fail to test them before buying. 6.—To strengthen weak cells in emergency, punch small holes in cup, place in sal-ammoniac solution, allowing cell to absorb all it will take up; close holes with shellac, or solder,

BATTERY DIRECTIONS—Continued

Gravity Battery.—This type of battery is merely a form of Daniell cell, where the two solutions are kept separate by their difference in gravity. Place 2 pounds copper sulphate crystals in bottom of jar with copper element. Add clear water to fill the jar when elements are in position. Allow to stand for 2 hours, unless desired for use at once, in which case add 1 ounce zinc sulphate to solution and suspend zinc over edge of jar when liquids are sufficiently separated.

Fuller Cell.—Fill glass jar half full of chromic acid solution, place 1 teaspoonful mercury and 2 tablespoons full of common salt in the porous cup and fill with water to 1½ inches of top. The carbon element containing the porous cup is then placed in the glass jar, the zinc is placed in the glass jar and the cover over it. The solution should fill the glass jar to within an inch of the top.

Edison Cell.—Dissolve contents of can of caustic soda in jar filled with water to mark. Insert the elements, taking care that the copper oxide plate is at least 1 inch below the surface of the liquid. Carefully pour contents of bottle of oil on surface of solution. Oil excludes all air and keeps salts from forming.

wipe and replace in cover. 7.—A dry cell when new should show 1½ volts, and from 25 to 30 amperes. 8.—An ammeter test should be made as quickly as possible. 9.—An idea of the condition of a cell can be obtained by taking one terminal wire and snapping it across the other terminal and noting the intensity of the spark.

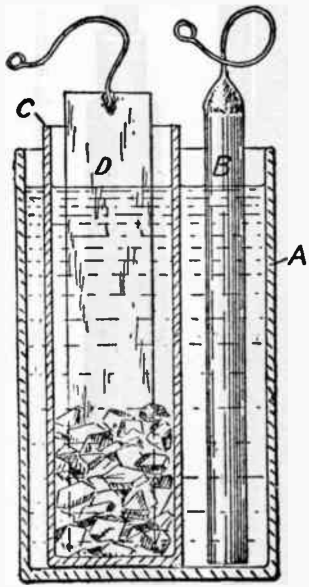


FIG. 6,180.—Simple Daniell cell for closed circuit work. To maintain a constant current for an indefinite time, it is only necessary to maintain the supply of copper crystals and zinc. ***Directions for making:*** The outer vessel A, consists of a glass jar (an ordinary glass jam jar will do) containing a solution of sulphuric acid (1 part in 12 to 20 parts of water), and a zinc rod B. Inside the jar is placed a porous pot C, containing a strip of thin sheet copper D, and a saturated solution of sulphate of copper (also called "blue stone" and "blue vitrol"). The zinc is preferably of the Leclanche form. The porous pot should be dipped in melted paraffin wax, both top and bottom to prevent the solution mingling too freely and "creeping." A few crystals of copper sulphate are placed in the pot as shown. In mixing the sulphuric acid and water, *the acid should be added to the water—never the reverse.* Zinc sulphate is sometimes used instead, as it reduces the wasteful consumption of the zinc, but it should be pure. With care a cell will last for weeks. When it weakens or "runs down" an addition of sulphuric acid to the outer jar and a few more crystals placed in the porous pot will renew its energy.

Battery Connections.—When two or more cells are connected together, the arrangement is called a *battery; most people persist in* ***erroneously*** *calling a single cell a battery.* Cells may be connected in several ways, as:

1. In series.
2. In parallel.
3. In series parallel.

These methods of connecting cells are illustrated in the accompanying cuts.

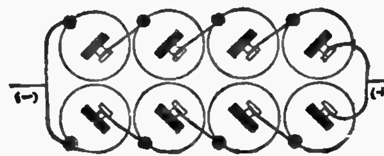
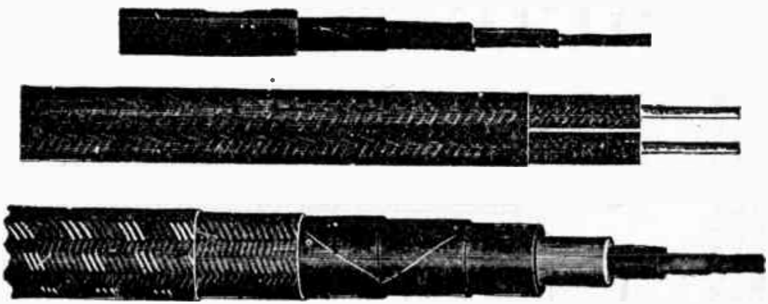


FIG. 6,181.—Series parallel connection. The pressure equals *the voltage of one cell, multiplied by the number of cells in one battery,* and the amperage, *that of one cell multiplied by the number of batteries.* This form of connection is objectionable unless all the cells be of equal strength.

CHAPTER 3

Conductors and Insulators

A conductor is a substance which permits the flow of electricity especially one which conducts electricity with great ease.



FIGS. 6,182 to 6,184.—Various covered wires. Fig. 6,182, single; fig. 6,183, duplex; fig. 6,184, automobile high tension cable.

Conductors offer more or less *resistance* to the flow depending upon the material. Copper wire is generally used as it offers but little resistance.

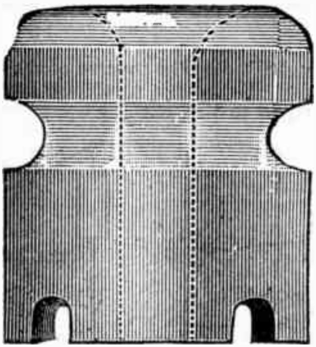
An insulator is a material (*erroneously called non-conductor*) which offers great resistance to the flow of the current

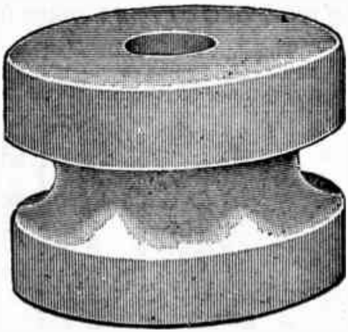
There is, however, no substance so good a conductor as to be devoid of resistance, and no substance of such high resistance as to be a *non-conductor*.

A conductor is said to be insulated when it is supported or insulated in such a way that it does not touch any other conductor and hence so that electricity cannot flow from it.

The series in the following table possess conducting power in different degrees in the order in which they stand, the most efficient conductor being first, and the most efficient insulator being last in the list.

Good Conductors	Fair Conductors	Partial Conductors	*Insulators*
Silver	Charcoal and coke	Water	Slate
Copper	Carbon	The body	Oils
Aluminum	Plumbago	Flame	Porcelain
Zinc	Acid solutions	Linen	Dry paper
Brass	Sea water	Cotton	Silk
Platinum	Saline solutions	Mahogany	Sealing wax
Iron	Metallic ores	Pine	Gutta percha
Nickel	Living vegetable substances	Rosewood	Ebonite
Tin		Lignum Vitæ	Mica
Lead	Moist earth	Teak	Glass
		Marble	*Dry* air





FIGS. 6,185 to 6,187.—Standard porcelain insulators. Fig. 6,185, tube type; figs. 6,186, and 6,187, grooved insulators.

Resistance and Conductivity.—A current of electricity always flows in a conducting circuit when its ends are kept at different pressures in the same way that a current of water flows in a pipe when a certain pressure is supplied.

The same electrical pressure does not, however, always produce a current of electricity of the same strength, nor does a certain pressure of water always produce a current of water of the same volume or quantity. In both cases the strength or volume of the currents is dependent not only upon the pressure applied, but also upon the *resistance* which the conducting circuit offers to the flow in the case of electricity, and on the friction (which may be expressed as resistance) which the pipe offers to the flow in the case of water.

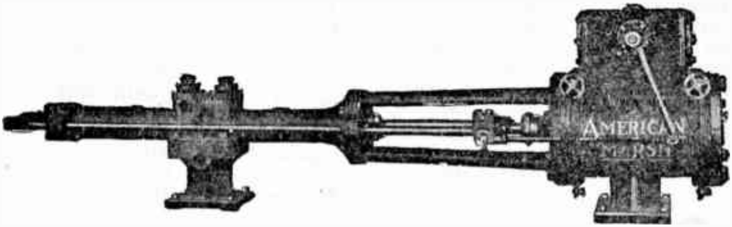
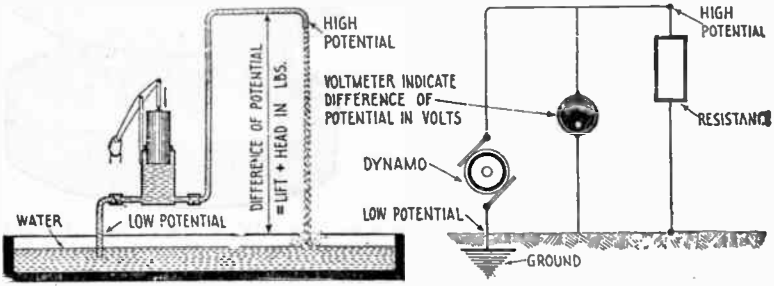


FIG. 6,188.—Hydraulic analogy of *resistance*. The hydraulic pump here shown with its steam cylinder of very large diameter as compared with the water cylinder is capable of pumping water against great pressure, caused by something, as a valve nearly closed, placed in the path of the flowing water which *opposes* its flow and thus is the cause of the pressure pumped against. ***Similarly***, a dynamo pumps electricity through a circuit which opposes more or less its flow, this opposition being called *resistance*.

Resistance is that property of a substance that opposes the flow of an electric current through it.

The unit of resistance is the ohm already defined. The inverse of resistance is known as conductance or *conductivity*. That is if a conductor have a resistance of R ohms, its conductivity is equal to 1 ÷ R.



FIGS. 6,189 and 6,190.—Hydraulic analogy illustrating *potential*. When the pump is operated the water is forced up from a low level (low potential) to a high level (high potential) whence energy for the end of the pipe it falls back by gravity to the low level. ***Similarly***, in fig. 6,190. the dynamo forces up electricity from a low potential to a high potential by interposing a resistance in the circuit passing through the resistance its potential falls to low potential. ***The author objects to the term "potential" as the simple word pressure is more easily understood.***

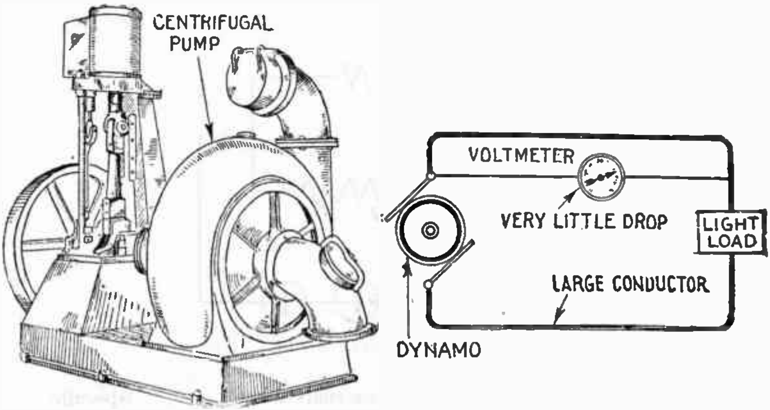
The unit of conductance is the *mho*, which is the conductance offered by a column of pure mercury 106.3 *cm.* long and 14.4521 grams in mass at the temperature of melting ice.

Rule 6.—Resistance varies directly as the length of a conductor.

Example.—If the resistance of 15 ft. of wire be 5 ohms, what is the resistance of 1,000 ft. of the same wire?

$$\text{resistance 1,000 ft. of the wire} = 5 \times \frac{1{,}000}{15} = 333\tfrac{1}{3} \text{ ohms}$$

Rule 7.—The resistance varies inversely as the cross section of a conductor.



FIGS. 6,191 and 6,192.—Hydraulic analogy of *conductivity*. The direct connected centrifugal pump set (fig. 6,191) with its small engine and large pump suggests the pumping of a large volume of water against low pressure—*easy flow*. *Similarly*, in fig. 6,192, a dynamo having an external circuit of very large copper wires "pumps" the electricity against very little resistance, thus a voltmeter connected as shown would show very little drop indicating high conductivity. Now if resistance wires were substituted for the copper wires, the voltmeter would show a large drop indicating low conductivity.

Example.—A conductor .01 sq. in. in cross sectional area has a resistance of .075 ohm per ft. What is the resistance of a conductor of the same material .04 sq. in. and one foot long?

The ratio between the two areas is .04 ÷ .01 = 4, hence, since the resistance varies inversely with the areas

$$\text{resistance of large wire} = .075 \div 4 = .01875$$

Conductivity or Conductance.—This is *the inverse of* *resistance*. The term expresses *the capability of a substance to conduct the electric current.*

Good conductors of heat are also good conductors of electricity.

Specific Conductivity.—By definition this is *the figure which indicates the relation between one substance and another as to their capacity to conduct electricity.*

The following table gives the data for a few metals:

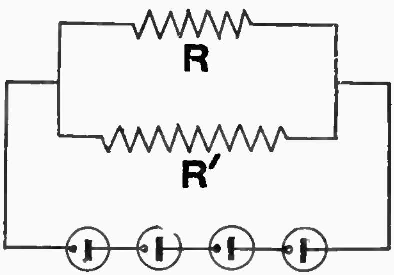


FIG. 6,193.—Divided circuit with two conductors *in parallel.*

Substance	Specific resistance in microhms	Specific conductivity
Silver	1.609	100.
Copper	1.642	96.
Gold	2.154	74.
Iron (soft)	9.827	16.
Lead	19.847	8.
German silver	21.470	7.5
Mercury (liquid)	96.146	1.6

Divided Circuits.—If a circuit be divided, as in fig. 6,193, into two branches R and R′, the current will also be divided, part flowing through one branch and part through the other.

***Rule 8.**—In a divided circuit the relative strength of the current in the several branches is proportional to their conductivities.*

Example.—If, in fig. 6,193, the resistance of R=10 ohms, and R′=20 ohms, the current through R, will be to the current through R′, as $1/10$ is to $1/20$; or. as 2:1, or, in other words, $2/3$ of the total current will pass through R, and $1/3$ through R′. The joint resistance of the two branches will be less than the resistance of either branch singly, because the current has increased facilities for travel. In fact, the joint conductivity will be the sum of the two separate conductivities.

Taking again the resistance of R = 10 ohms and R′ = 20 ohms, the joint conductivity is

$$\frac{1}{10}+\frac{1}{20}=\frac{3}{20}$$

and the joint resistance is equal to the reciprocal of $3/20$ or $6\ 2/3$.

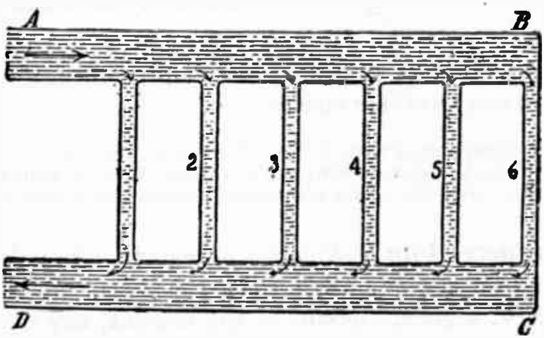


FIG. 6,194.—Hydraulic analogy for divided circuits. *In the system* of pipes shown, water flows from A B to C D through the six vertical pipes 1 to 6, the greatest amount going through the one which offers the least resistance. The electrical circuit presents the same conditions. the greater the number of parallel connections (corresponding to the pipes 1 to 6) the less is the resistance encountered by the current.

Example.—A current of 42 amperes flows through three conductors in *parallel* of 5, 10 and 20 ohms resistance respectively. Find the current in each conductor.

$$\text{joint conductance}=\frac{1}{5}+\frac{1}{10}+\frac{1}{20}=\frac{7}{20}$$

Supposing the current to be divided into 7 parts, 4 of these parts would flow in the first conductor, 2 in the second and 1 in the third.

The whole current is 42 amperes.

$4/7$ of 42 = 24	Current in first conductor = 24 amperes.	Ans
$2/7$ of 42 = 12	" " second " = 12 "	
$1/7$ of 42 = 6	" " third " = 6 "	

CHAPTER 4

Electrical and Mechanical Energy

The production of electricity is simply *a transformation of energy from one form into another.*

The electrical unit of work is the volt coulomb and is equal to amount of work performed *when* **one ampere** *of current flows for* **one second** *in a circuit whose resistance is* **one ohm**, *when the pressure is* **one volt**.

The Ampere-Hour.—A gallon of water may be drawn from a hydrant *in a minute* or *in an hour;* it is still one gallon. So in electricity, a given amount of the current, say one *coulomb*, may be obtained in a second or in an hour.

The ampere is the unit ***rate*** *of flow*, that is

one ampere* = *one coulomb per second

For commercial purposes the *ampere hour* which is a larger unit of electrical quantity than the coulomb is used. An ampere hour is the quantity of electricity passed by one ampere of current in one hour, or its equivalent, that is, since one

ampere = one coulomb × one second, and one hour = 60 × 60 = 3,600 sec.

$$\therefore \text{one ampere hour} = 1 \text{ ampere} \times 3{,}600 \text{ seconds}$$
$$= 60 \text{ amperes} \times 60 \text{ seconds}$$
$$= 3{,}600 \text{ amperes} \times 1 \text{ second}$$

which means that one ampere hour = one ampere flowing one hour, or 60 amperes flowing one minute, or 3,600 amperes flowing one second, or any other equivalent.

Example.—It is sometimes estimated that the quantity of electricity in a flash of lightning is $^1/_{10}$ coulomb, and the duration of the discharge $\frac{1}{20,000}$ part of a second. What is the current in amperes?

Now since

$$\text{coulombs} = \text{amperes} \times \text{seconds} \quad \text{(1)}$$

solving (1) for the current,

$$\text{amperes} = \frac{\text{coulombs}}{\text{seconds}} \quad \text{(2)}$$

substituting the given values in (2),

$$\text{amperes} = \frac{^1/_{10}}{\frac{1}{20,000}} = 2,000$$

Watts and Kilowatts.—One watt is the *power due to a current of one ampere flowing at a pressure of one volt.*

That is, one watt = one ampere × one volt
= (one coulomb × one second) × one volt
= (one coulomb × one volt) × one second

and since one *joule* is the amount of work done when one coulomb of electricity flows under a pressure of one volt,

one watt = one joule per second

Since the watt is too small a unit for convenience in some commercial ratings, as for instance the output ratings of dynamos, motors, etc., a thousand watts or one kilowatt (abbreviated *kw.* is used), thus a 50,000 watt dynamo is called a 50 *kw.* dynamo.

The Watt Hour.—*This unit represents the amount of work done by an electric current of one ampere strength flowing for one hour under a pressure of one volt; that is,*

One watt hour = One ampere × one hour × one volt;
= 3,600 coulombs × one volt.

Example.—An incandescent lamp taking one-half an ampere of current on a circuit having a pressure of 100 volts, or a lamp taking one ampere on a circuit having a pressure of 50 volts, would each be consuming 50 watts of energy, and this multiplied by the number of hours would give the total number of watt-hours for any definite time.

Electrical Horse Power.—One watt is equivalent to one joule per second or 60 joules per minute. One joule in turn, is equivalent to .7374 ft. lbs., hence 60 joules equal:

$$60 \times .7374 = 44.244 \text{ ft. lbs.}$$

Since one horse power = 33,000 ft. lbs, per minute, the electrical equivalent of one horse power is

$$33{,}000 \div 44.244 = 746 \text{ watts.}$$

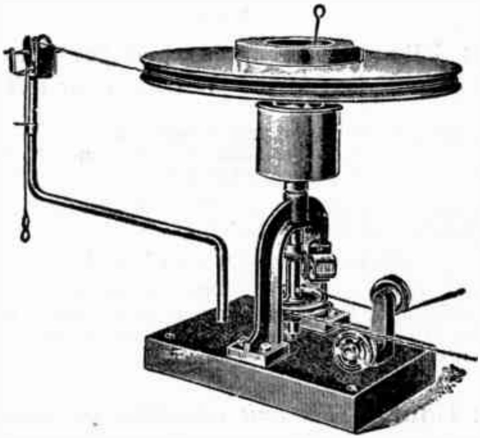


FIG. 6,195.—Callendar's mechanical equivalent of heat apparatus (Central Scientific Co.) With this apparatus a lecturer can obtain in about ten minutes in the presence of a class of students, a value of "J" correct to ⅛ per cent. Joules experiments 1843-50, gave the figure 772, known as "Joules equivalent," more recent experiment by Prof. Rowland (1880) and others give high figures: 778 is generally accepted. Marks and Davis value is 777.54 ft. lbs.

or,

$$\frac{746}{1{,}000} = .746 \text{ kilowatts}$$

Again one kilowatt (*kw.*) or 1,000 watts is equivalent to

$$1{,}000 \div 746 = 1.34 \text{ horse power.}$$

Heat.—By definition, ***heat*** is a form of energy. Heat is produced in the agitation of the molecules of matter—the energy expended in agitating these molecules is transformed into heat.

Heat is measured in *calories* or British thermal units (abbreviated *B.t.u.*).

A calorie is the *amount of heat necessary to raise the temperature of one gram of water from* 0° *to* 1° *Centigrade;* sometimes called the *smaller calorie* or *therm.*

A British thermal unit (*B.t.u.*) is $\frac{1}{180}$ of the heat required to raise 1 lb. of water from 32° to 212° Fahr. (*Marks and Davis.*)

The calorie is used for calculation in Physics and the British thermal unit for commercial calculation.

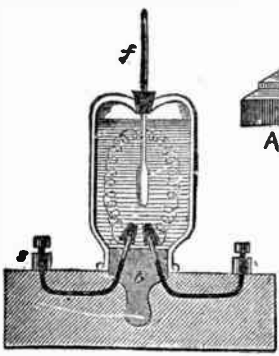
CHAPTER 5

Current Effects

Electricity being *an invisible agent, known only by its effects,* it is important to note these effects. They are:

1. Thermal effect.
2. Magnetic effect.
3. Chemical effect.
4. Mechanical effect.

Thermal Effect.—The conductor along which the current



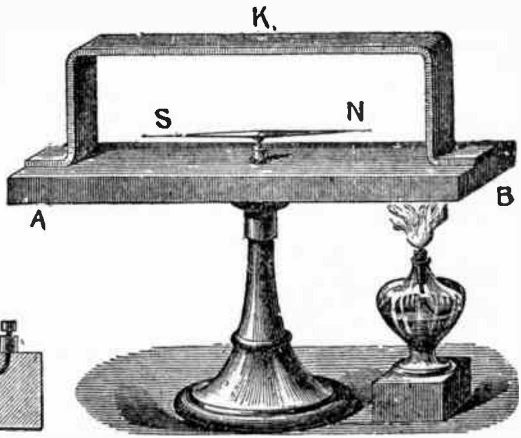


Fig. 6,196.—Lenz's apparatus for measuring the heat given off by an electric current. It consisted of a wide mouthed stoppered bottle fixed upside down, with its stopper, *b* in a wooden box; the stopper was perforated so as to give passage to two thick platinum wires, connected at one end with binding screws, *s*, while their free ends were provided with platinum cones by which the wires under investigation could be readily affixed; the vessel contained alcohol, the temperature of which was indicated by a thermometer fitted in a cork

Fig. 6,197.—The Seebeck effect: If, in a complete metallic circuit having junctions of dissimilar metals, the junctions be at different temperatures, then a steady current will flow in the circuit as long as the differences of the temperatures of the junction is maintained. To demonstrate this, a piece of copper K, bent in the shape seen in the figure, was placed on a block of bismuth AB, carrying a pivoted magnetic needle NS. As soon as the equality flows becomes heated. The rise of temperature may be small or great according to circumstances, but some heat is always produced.

Rule 9.—JOULE'S LAW:—*The heat generated in a conductor by an electric current is proportional to: 1, the resistance of the conductor. 2, the time during which the current flows, and 3, the square of the strength of the current.*

***Case I.**—Volts given.*

The quantity of heat in calories may be calculated by use of the equation,

calories per second = volts × amperes × .24*............(1)

The total number of calories developed in a given interval of time is found by the equation,

heat = volts × amperes × seconds × .24..............(2)

Example.—If a current of 10 amperes flow in a wire whose terminals are at a pressure difference of 12 volts, how much heat will be developed in 5 minutes?

Substituting in equation (2):

$$10 \times 12 \times (60 \times 5) \times .24 = 8{,}640 \text{ calories}$$

***Case II.**—Volts not given.*

Since by Ohm's law the pressure difference, or

volts = amperes × ohms

Substituting in equation (2)

heat = amperes ^{2} × ohms × seconds × .24 ....(3)

FIG. 6,196.—*Text continued.*

inserted in a hole made in the bottom of the vessel. The current was passed through the platinum wires, and its strength measured by means of a galvanometer interposed in the circuit.

FIG. 6,197.—*Text continued.*

of temperatures was altered by either heating or cooling one of the junctions of the two metals, the needle indicated a current which continued to flow as long as the difference of temperature was maintained at the junctions.

*NOTE.—Heat amounting to .24 calorie equals the work represented by one joule.

Example.—An incandescent lamp of 150 ohms resistance uses one ampere. How much heat does it give off in one half hour in calories and in *B.t.u.?*

Substituting in (3)

$$\text{heat} = 1^2 \times 150 \times (60 \times 30) = 64{,}800 \text{ calories}$$

and since 1 calorie = 3.968 *B.t.u.*,

$$\text{heat} = 64{,}800 \times 3.968 = 257{,}126 \ B.t.u.$$

Heat Produces Electricity.—When a rod, say of bismuth is soldered, end to end, to a rod of antimony, and the two free ends are connected to a wire, then when the junction is heated, a

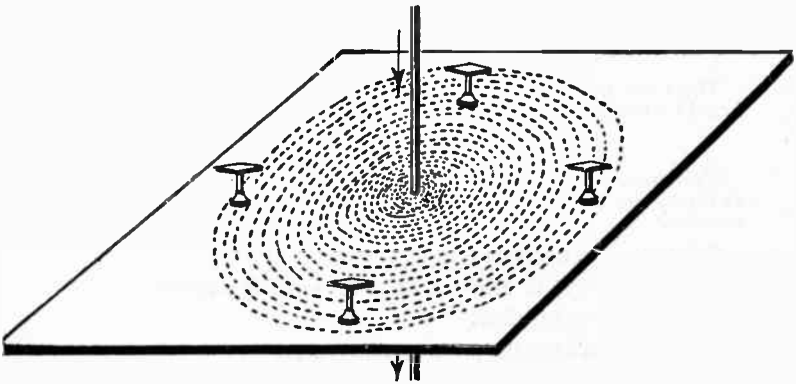


FIG. 6,198.—Magnetic field surrounding a wire in which a current is flowing. The magnetic field consists of lines of force which are circles concentric with the wire as indicated by a compass which will point in a direction perpendicular to the radius joining the compass and wire.

current will flow through the whole circuit in the direction from bismuth to antimony. If the junction be cooled, the current will flow from antimony to bismuth.

Again, if a current be sent through such a rod in the direction from bismuth to antimony, the junction becomes cooled; when from antimony to bismuth, the junction is heated. Two dissimilar metals soldered together is called a *thermo-electric couple.*

Magnetic Effect.—The space both outside and inside the substance of the conductor, but more especially the former, becomes a "magnetic field" in which delicately pivoted or suspended magnetic needles will take up definite positions and magnetic materials will become magnetized.

Chemical Effect.—If the conductor be a liquid which is a chemical compound of a certain class called *electrolytes*, the liquid will be decomposed at the places where the current enters and leaves it.

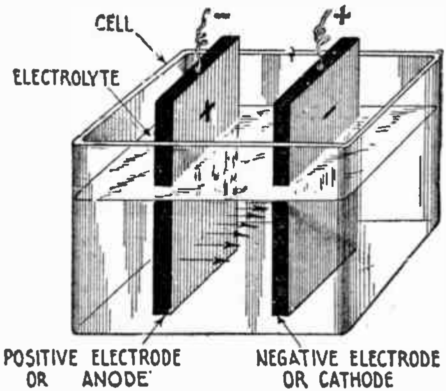


FIG. 6,199.—Electrolyte cell showing essential parts.

Rule 10.—GROTTHUSS' THEORY (announced in 1806). *The molecules in an electrolyte have their individual electro-positive and electro-negative atoms charged positively and negatively respectively.*

Faraday stated several laws of electrolysis as follows:

Rule 11.—LAW NO. 1.—*The quantity of an ion liberated in a given time is proportional to the quantity of electricity that has passed through the voltameter* in that time.*

Rule 12.—LAW NO. 2.—*The quantity of an ion liberated in a voltameter is proportional to the electro-chemical equivalent of the ion.*

Rule 13.—LAW NO. 3.—*The quantity of an ion liberated is equal to the electro-chemical equivalent of the ion multiplied by the total quantity of electricity that has passed.*

Mechanical Effect.—*Like poles repel each other and unlike poles attract each other, thus producing mechanical movement.* Upon these phenomena depend the operation of motors, dynamos and most other electrical apparatus.

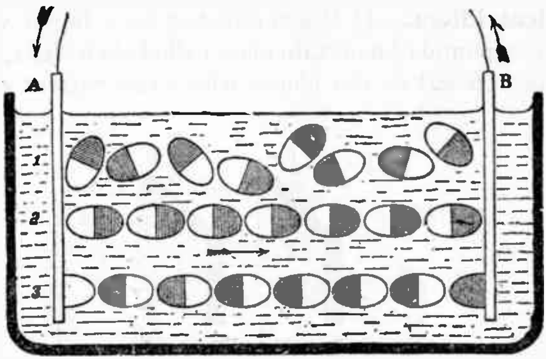
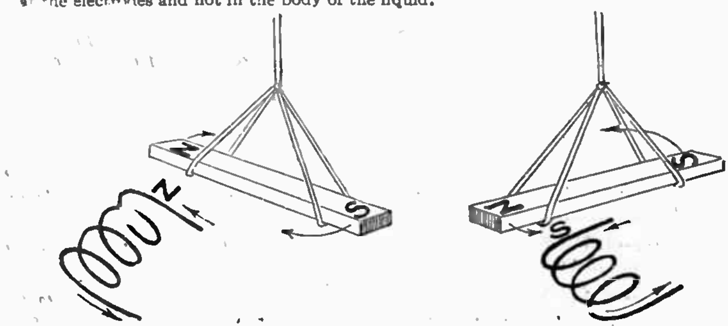
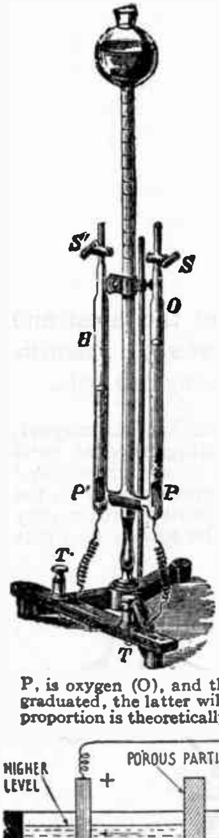


FIG. 6,200.—Electrolytic cell, illustrating Grotthuss' theory. In an ordinary liquid, for instance in water, the molecules are arranged indifferently, like row 1, with their positive and negative ends pointing in all directions. When the charged plates A and B connected to the + and — poles of a battery are inserted in the water, the molecules turn as shown in row 2, so that all the hydrogen or shaded ends (+) are turned towards the (—) plate B and all the oxygen or unshaded ends (—) towards the (+) plate A. All along the row the electrical forces are supposed to tear the molecules asunder, depositing H, on B, and O, on A. The atoms in the middle of the liquid, however, recombine, for the hydrogen atoms in their journey towards B, meet the oxygen atoms traveling in the opposite direction, and we get the state of affairs represented in row 3. The next step is to rotate once more the atoms into the positions shown in row 2, and so on. In this way the theory accounts for the products only appearing at the electrodes and not in the body of the liquid.



FIGS. 6,201 and 6,202.—Mechanical effect of the current: *Like poles repel each other; unlike poles attract each other.*



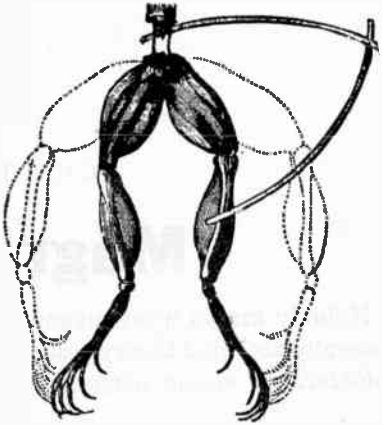


FIG. 6,203.—Galvani's experiment upon frogs' legs illustrating ***muscular contractions.*** It was discovered in 1678 that when a portion of a muscle of a frog's leg, hanging by a thread of nerve bound with a silver wire, was held over a copper support so that both nerve and wire touched the copper, the muscle immediately contracted.

FIG. 6,204.—Decomposition of water by electrolyses. Fill apparatus with acidulated water through central tube allowing air to escape through cocks S and S'. Now if terminal T, be attached to the positive and T', to the negative pole of a suitable battery, bubbles of gas will be observed to rise from the plates P and P', and finding their way to the top of the respective tubes, will displace the liquid, which will be driven into the open central tube. The gas rising from the anode P, is oxygen (O), and that rising from the kathode P', is hydrogen (H). If the tubes be graduated, the latter will be found to occupy about twice the volume of the former. The proportion is theoretically 2 to 1.

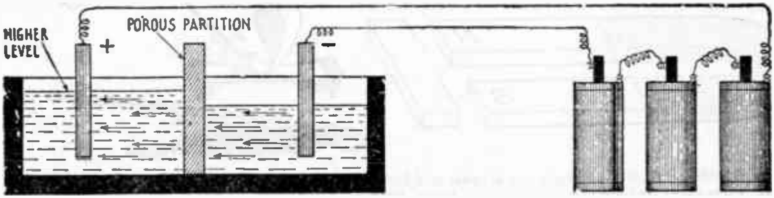


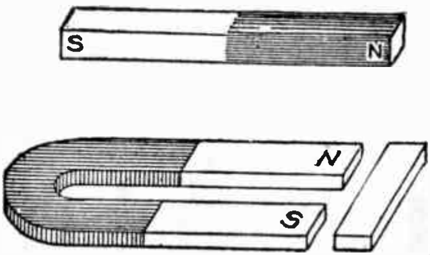
FIG. 6,205.—Electrolyte cell with porous partition illustrating ***electric osmosis.*** Porret observed that if a strong current be led into certain liquids, a porous partition being placed between the electrodes, the liquid is carried by the current through the porous partition, until it is forced up to a higher level on one side than on the other. This electric action is most pronounced when the experiment is made with liquids, which are poor conductors The movement of the liquid takes place in the direction of the current.

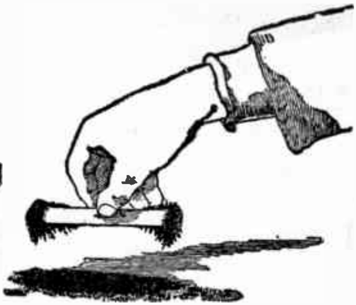
CHAPTER 6

Magnetism

Nobody knows what magnetism really is, but the latest and generally accepted theory assumes that *the molecules of a magnetic substance are minute magnets by nature, each having two poles.*

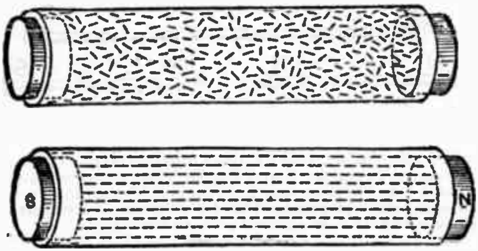
A magnet has two kinds of magnetism residing in the ends of the magnet. These ends are called the *poles.* These poles are distinguished as *north* and *south*, because if the magnet were suspended by a thread or balanced on a pivot free to turn, the north pole would point approximately to the earth's geographical north, while the south pole would point approximately to the earth's geographical south. The north pole is the *positive* (+) pole and the south pole the negative (—) pole.





FIGS. 6,206 and 6,207.—Simple *bar magnet* and *horse shoe magnet* with *keeper*. These are known as *permanent magnets* in distinction from *electro-magnets*. The horse shoe magnet will attract more than the bar magnet because both poles act together. A piece of soft iron, or keeper is placed across the ends of a horse shoe magnet to assist in preventing the loss of magnetism.

FIG. 6,208.—***Magnetic poles.***—If a bar magnet be plunged into iron filings and then lifted, as illustrated in the figure, a mass of filings will cling to the ends of the magnet but not to the middle. The ends are called the *poles* of the magnet.



FIGS. 6,209 and 6,210.—Experiment illustrating the molecular theory of magnetism. Coarse steel filings are placed inside a small glass tube and the contents magnetized. It will be found that filings which at first had no definite arrangement will rearrange themselves under the influence of magnetic force, and assume symmetrical positions, each one lying in line with, or parallel to its neighbor, as shown in fig. 6,210.

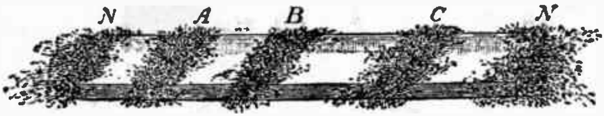
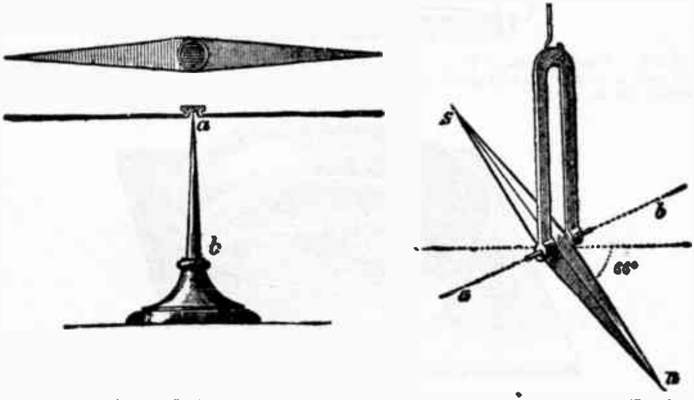
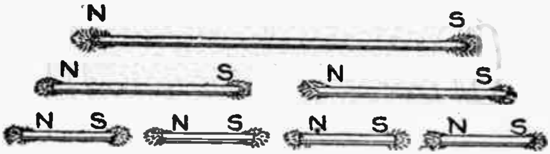


FIG. 6,211.—Badly magnetized bar. If an abnormal magnet with more than two poles be dipped into iron filings, the latter will adhere at places other than the two ends, as shown. The polarities are alternately N and S; that is, the regions N, B, N, have north polarity, while A and C, have south polarity. These are known as *consequent poles*.



FIGS. 6,212 and 6,213.—Horizontal magnetic needle and magnetic *"dip"* needle. The horizontal needle indicates the magnetic meridian, and the dip needle indicates the angle which the lines of force make with the horizontal. In the northern hemisphere the N pole of the needle is depressed, in the southern hemisphere the S pole is similarly affected.



FIGS. 6,214 to 6,220.—Effect of breaking a magnet into several parts. ***Each part*** will be found to be a complete magnet having an N and S pole. The sub-division may be continued indefinitely, but always with the same result. This is evidence of the correctness of the molecular theory of magnetism, which states that *the molecules of a magnet are themselves minute magnets arranged in rows with their opposite poles in contact.*

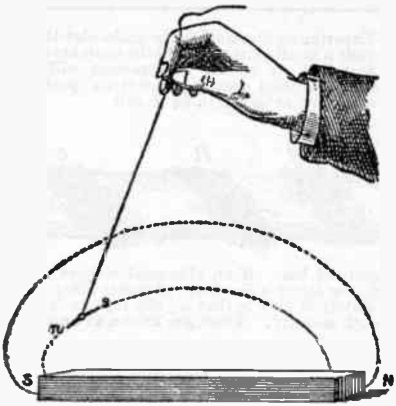


FIG. 6,221.—Tracing lines of force. If a small magnetic needle, suspended by a thread, be held near a magnet, it will point in some fixed direction depending on the proximity of the poles of the magnet.

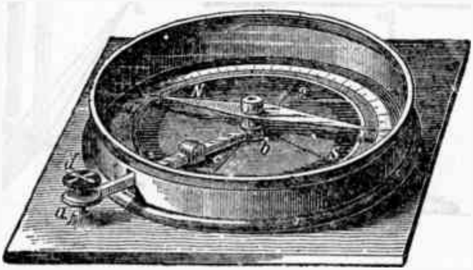
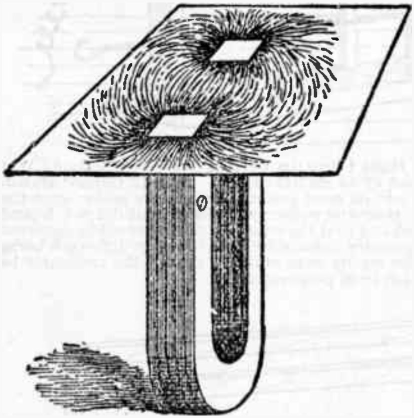


FIG. 6,222.—Simple compass. ***It consists of*** a magnetic needle resting on a steel pivot, protected by a brass case covered with glass and a graduated circle marked with the letters N, E, S, W, to indicate the cardinal points. *ab* is a lever which protects the needle when out of use by pushing it against the glass when the button *d*, is pressed.

Magnetic Field.—*This comprises the region around a magnet through which magnetic forces act.*

The magnetic field is said to be composed of *lines of force;* these lines are of circular form. The field is most intense near the poles of the magnet, becoming weaker and weaker as the distance from the magnet is increased until they finally disappear.

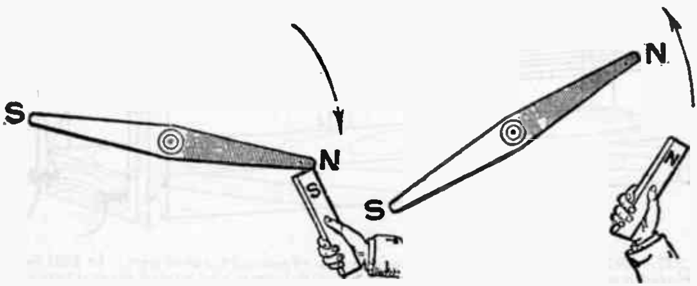


Magnetic Force.—*This is the force with which a magnet attracts or repels on the magnet another piece of iron or steel.*

***Rule 14.**—Like magnetic poles repel one another; unlike magnetic poles attract one another.*

***Rule 15.**—The force exerted between two magnetic poles varies inversely as the square of the distance between them.*

FIG. 6,223.—*The Magnetic Field.*—This may be represented graphically by sprinkling iron filings on a cardboard placed over a magnet and shaking the card. These will place themselves in curves reaching from pole to pole, these curves being called *lines of force*, and the space in which a magnet may create such lines is called the *magnetic field*.



FIGS. 6,224 and 6,225.—Mutual action of poles: 1, *unlike poles attract each other* (fig. 6,224); *like poles repel each other* (Fig. 6,225).

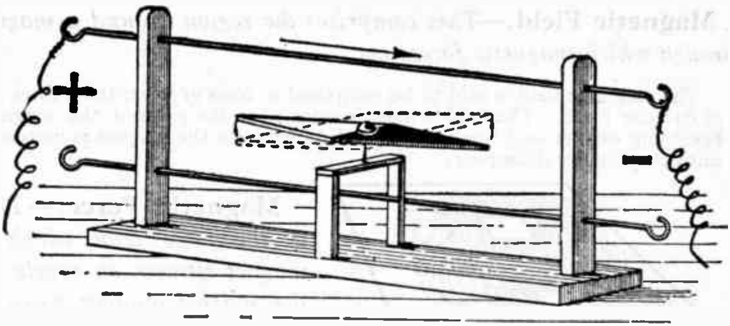


FIG. 6,226.—Oersteds discovery. In 1820 Hans Christian Oersted (1777-1851), found that *a magnetized needle was affected by the action of an electric current.* In 1813 Oersted stated: "It must be determined whether electricity in its most latent state has any action upon the magnet as such." Oersted found that the magnetic property of the current did not depend upon the kind or form of metal he employed and that the magnetic needle would be deflected by using any conductor, even a litre of mercury being effectual, the only difference being in the quantity of effect produced, and the results were obtained even if the conductor be interrupted by water, unless the interruption be of great extent.

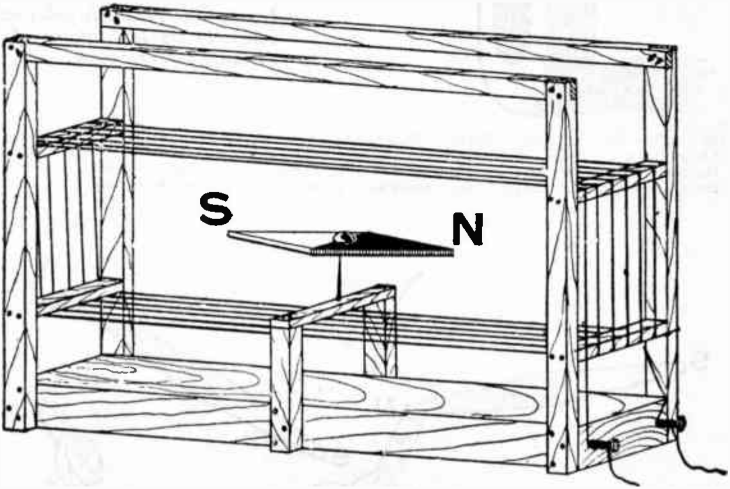


FIG. 6,227.—Schweigger's experiment, showing effect of several turns of wire. In 1821 Schweigger placed a compass needle in the center of a parallelogram and wound several turns of wire around it, as shown, each turn being insulated. Movable magnet galvanometers utilize the principle of Schweigger's apparatus for their operation. Schweigger's apparatus was called Schweigger's multiplier.

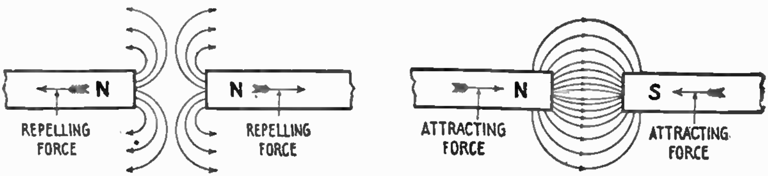
Magnetic Circuit.—*The path taken by the magnetic lines of force is called the magnetic circuit;* the greater part of such a circuit is usually in magnetic material, but there are often one or more air gaps included.

The following definitions should be carefully noted:

Magnetic Flux.*—The total number of lines of force in the magnetic circuit*

Reluctance.*—The resistance offered to the magnetic flux by the substance magnetized; magnetic resistance.* It is equal to the ratio of the magnetic force to the magnetic flux.

Oersted.*—The unit of reluctance being the reluctance offered by a cubic centimeter of vacuum.*



FIGS. 6,228 and 6,229.—Mutual effect of *like* and *unlike* poles; *like poles repel each other; unlike poles attract each other*

Maxwell.*—The amount of magnetism passing through every square centimeter of a field of unit density.*

****Gauss.****—The intensity of field which acts on a unit pole with a force of one dyne. It is equal to one line of force per square centimeter.*

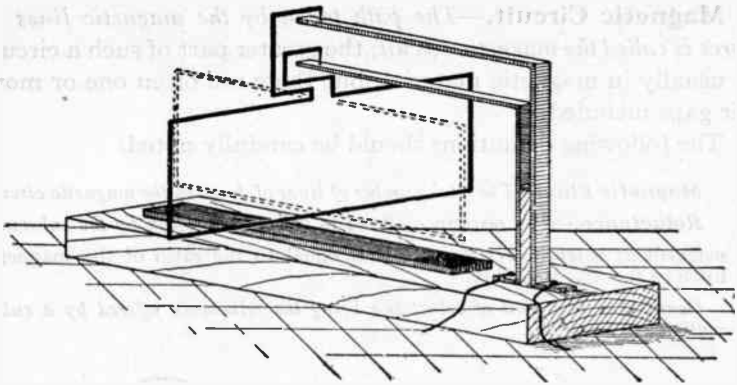
Magnetic Effect of the Current.—Much is due to Hans Christian Oersted, who made numerous experiments in magnetism.

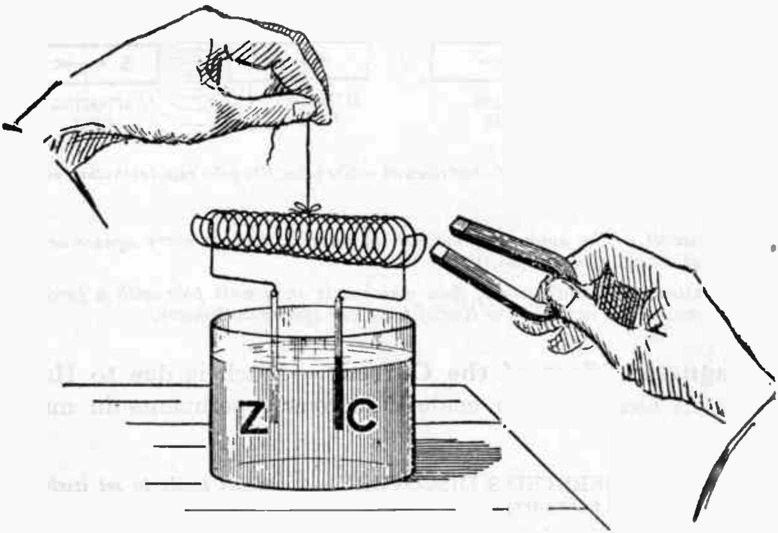
Rule 16.—OERSTED'S DISCOVERY—*A magnet tends to set itself at right angles to a wire carrying an electric current.*

Oersted also found that the way in which the needle turns, whether

NOTE.—***Hans Christian Oersted,*** born 1777, died 1851, the Danish physicist, was noted for his experiments on the magnetic needle with the electric current.

*NOTE.—***Karl Friedrich Gauss,*** born 1777, died 1855. He was a German mathematician, founder of the mathematical theory of electricity and inventor of the bifilar magnetometer. The unit *gauss* was named after him.

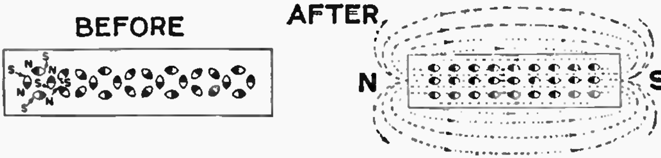




FIGS. 6,230 and 6,231.—Ampere's experiments. Following Oersted's discovery, Ampere began his investigations. He reversed Oersted's experiment (fig. 6,230) and showed the action of a magnet on a movable circuit by means of a rectangular movable frame suspended from mercury cups. When a magnet is placed near this frame and current is flowing, the frame will be attracted by the magnet. Another experiment performed by Ampere was with a solenoid whose ends were attached to copper and zinc electrodes immersed in an acid solution thus forming a cell as in fig. 6,231. When suspended as shown one end of the solenoid will be attracted by a magnet.

to the right or left of its usual position, depends: 1, upon the position of the wire that carries the current, whether it be above or below the needle, and 2, on the direction in which the current flows through the wire.

Rule 17.—CORKSCREW RULE—*If the direction of travel of a right handed corkscrew represent the direction of the current in a straight conductor, the direction of rotation of the corkscrew will represent the direction of the magnetic lines of force.*



FIGS. 6,232 and 6,233.—Arrangement of molecules in iron bar *before* and *after* magnetization according to the generally accepted theory.

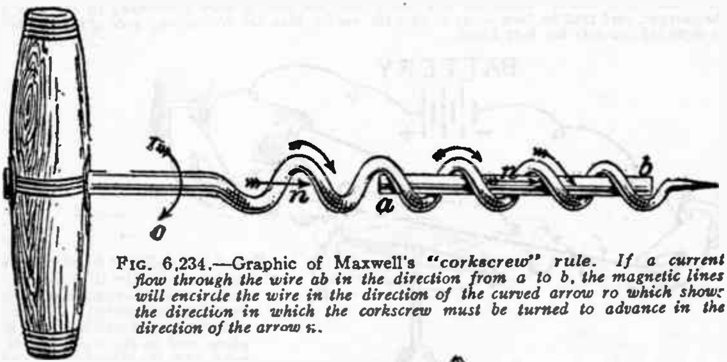


FIG. 6,234.—Graphic of Maxwell's "*corkscrew*" rule. *If a current flow through the wire ab in the direction from a to b, the magnetic lines will encircle the wire in the direction of the curved arrow ro which shows the direction in which the corkscrew must be turned to advance in the direction of the arrow n.*

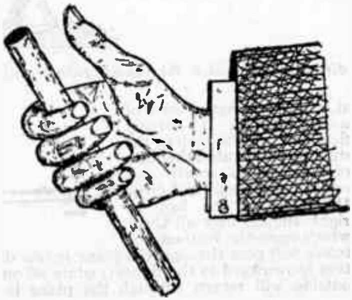
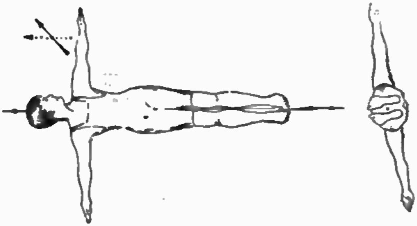


FIG. 6.235.—***Right hand rule*** for direction of magnetic field around a conductor carrying a current. *The thumb of the right hand is placed along the conductor, pointing in the direction in which the current is flowing, then, if the fingers be partly closed, as shown in the illustration, the finger tips will point in the direction of the magnetic whirls.*

Rule 18.—RIGHT HAND RULE—*The thumb of the right hand is placed along the conductor, pointing in the direction in which the current is flowing —then, if the fingers be partly closed, the finger tips will point in the direction of the magnetic whirls.*

Rule 19.—AMPERE'S RULE—*Suppose yourself to be in the wire, floating with the current and facing the needle; its north pole will turn toward your left hand.*



FIGS. 6,236 and 6,237.—Amperes left hand rule: *Suppose a man swimming in the wire with the current, and that he turn so as to face the needle, then the N.-seeking pole of the needle will be deflected towards his left hand.*

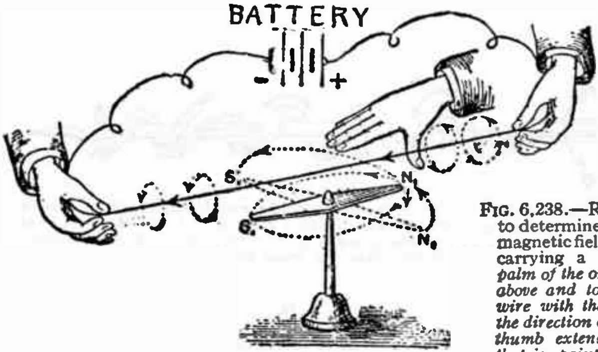


FIG. 6,238.—Right hand palm rule to determine the direction of the magnetic field around a conductor carrying a current. *Place the palm of the outstretched right hand above and to the right side of the wire with the fingers pointing in the direction of the current and the thumb extended at right angles, that is, pointing downward. The direction in which the thumb points will indicate the direction of the magnetic whirls.*

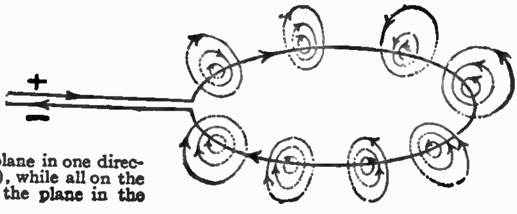


FIG. 6,239.—Lines of force of a circular loop. If a current flow through the loop in the direction indicated the lines of force both inside and outside the loop, will cross the plane of the loop at right angles, and all those which cross the loop on the inside will pass through the plane in one direction (downward in the figure), while all on the outside will return through the plane in the opposite direction.

Rule 20.—Magnetic lines of force tend to occupy a position in which they are parallel with each other and run in the same direction.

Solenoids.—A solenoid consists of a spiral of conducting wire wound cylindrically so that, when an electric current passes through it, its turns are nearly equivalent to a succession of

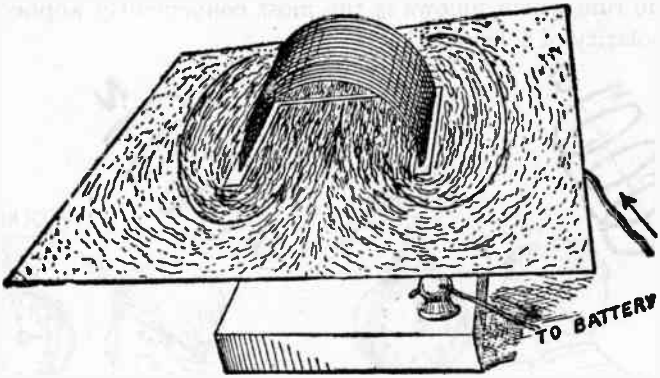


FIG. 6,240.—Magnetic field of a solenoid. If iron filings be sprinkled on the cardboard and a current passed through the solenoid, the character of the field is as indicated.

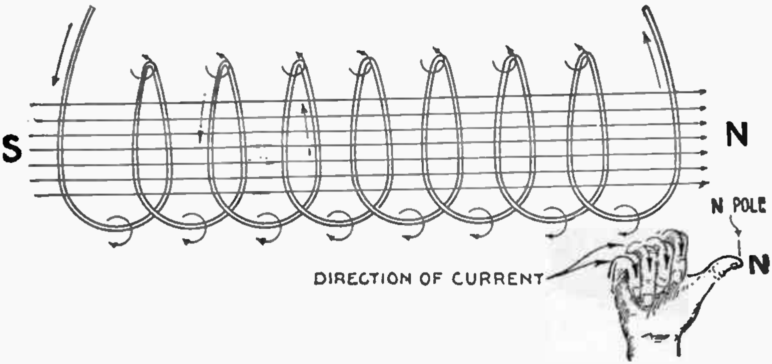
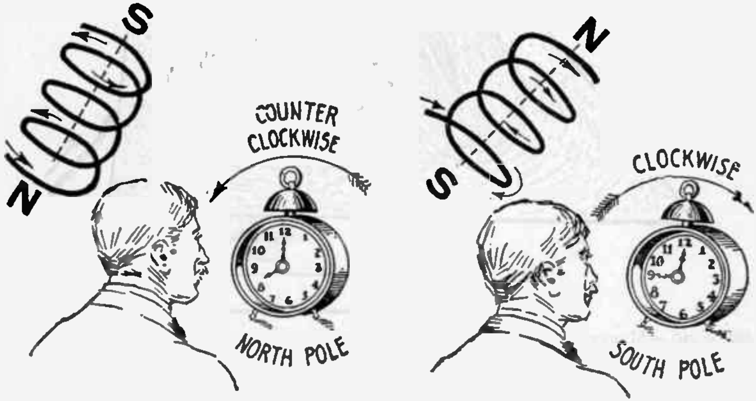


FIG. 6,241.—***Right hand palm rule*** to determine the direction of the magnetic field around a conductor carrying a current: *Place the palm of the outstretched right hand above and to the right side of the wire with the fingers pointing in the direction of the current, that is, pointing downward, and the thumb extended at right angles.* ***The direction in which the thumb points will indicate the direction of the magnetic field.***

parallel circular circuits, and it acquires magnetic properties similar to those of a bar magnet.

Rule 21.—Upon the direction in which the current flows through a solenoid depends its polarity.

The rule which follows is the most conveniently applied rule for polarity of solenoids.



FIGS. 6,242 and 6,243.—Application of the clock rule for polarity of solenoids. *It will be noted* that the polarity depends upon the direction of the current and the *order* of winding.

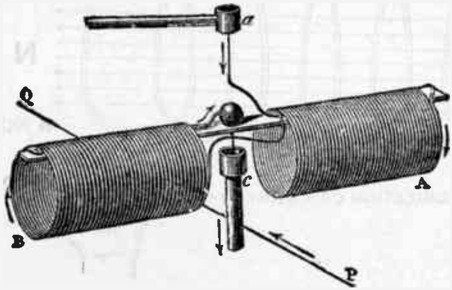
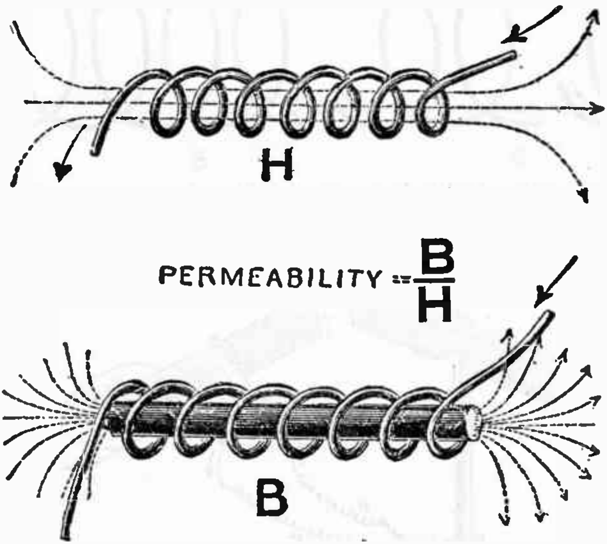


FIG. 6,244.—Action of currents on solenoids. *To demonstrate* this fact experimentally, a solenoid is constructed as shown, so that it can be suspended by two pivots in the cups *a* and *c*. The solenoid is then movable about a vertical axis, and if a rectilinear current QP, be passed beneath it, which at the same time traverses the wires of the solenoid, the latter is seen to turn and set at right angles to the lower current; that is, in such a position that its circuits are parallel to the fixed current; moreover, the current in the lower part of each of the circuits is in the same direction as in the rectilinear wire. If, instead of passing a rectilinear current below the solenoid, it be passed vertically on the side, an attraction or repulsion will take place, according as the two currents in the vertical wire, and in the nearest part of the solenoid, are in the same or in contrary directions.

Rule 22.—RIGHT HAND RULE—*If the solenoid be grasped in the right hand, so that the fingers point in the direction in which the current is flowing in the wires, the thumb extended will point in the direction of the north pole.*

Rule 23.—CLOCK RULE—*For a person standing at the south pole of a solenoid, the current flows in the direction in which the hands of a clock turn*, from the left *over* to the right; if he stand at the north pole, the current *will flow counter clockwise.*

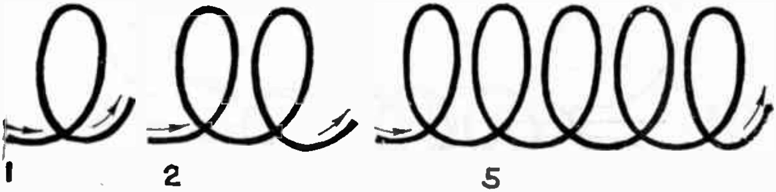


FIGS. 6,245 and 6,246.—Illustrating the effect of introducing an iron core into a solenoid. Few lines pass through the air core, while many pass through the iron core. The number of lines B, passing through a unit cross section of the iron core divided by the number of lines H, passing through a unit cross section of the air core is called the *permeability* and designated by the Greek letter μ.

Permeability.—This is a measure of the ease with which magnetism passes through any substance. It is defined **as:** *the ratio between the number of lines of force per unit area passing through a magnetizable substance, and the magnetizing force which produces them.*

Rule 24.—The permeability of any piece of material increases with the increase of cross section and decreases with the increase of length.

Magnetic Saturation.—For all practical purposes, magnetic saturation may be defined as: *That point of magnetism where a very large increase in the magnetizing force does not produce any perceptible increase in the magnetization;* that is, the state of a



FIGS. 6,247 to 6,249.—*Ampere turns. By definition* the ampere turns is equal to the *product of the current passing through a coil multiplied by the number of turns in the coil.* Thus, in fig. 6,247, ampere ×1 turn = 1 ampere turn; in fig. 6,248, 5 amperes ×2 turns =10 ampere turns; in fig. 6,249, 2 amperes ×5 turns =10 ampere turns.

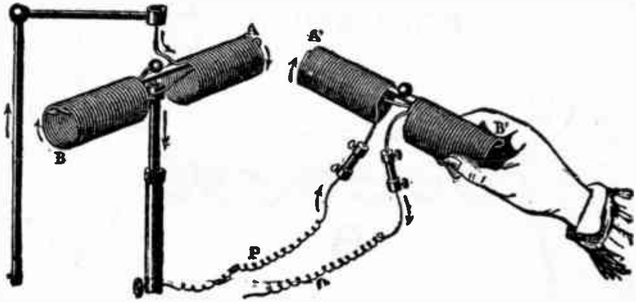


FIG. 6,250.—Mutual action of solenoids. When two solenoids traversed by a current are allowed to act on each other, one of them being held in the hand and the other being movable about a vertical axis, as shown in the figure, attraction and repulsion will take place just as in the case of two magnets (see figs. 6,224 and 6,225).

magnet which has reached the highest practical degree of magnetization.

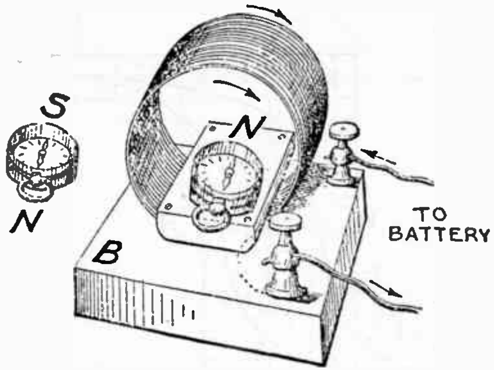
Ampere Turns.—When a coil passes around a core several times, its magnetizing power is proportional both to the strength of the current and to the number of turns in the coil. *The product of the current passing through the coil multiplied by the number of turns composing the coil is called the* ***ampere turns.***

By experiment, one ampere turn produces 1.2566 units of magnetic pressure, hence:

$$\text{magnetic pressure} = 1.2566 \times \text{turns} \times \text{amperes}$$

The unit of magnetic pressure is the *gilbert* (named after William Gilbert, the English physicist) and is equal to

$$1 \div 1.2566 \text{ ampere turn} = .7958 \text{ ampere turn}$$



FIGS. 6,251 and 6,252.—Magnetic conditions inside and outside of a solenoid. If magnetic needles be placed inside and outside the solenoid as shown and a current be passed through the coil, it will be found that the magnetic force inside the coil is in a direction opposite to that outside the coil as indicated by the magnetic needles.

Comparison of Electric and Magnetic Circuits.—The total number of magnetic lines of force, or magnetic flux, produced in any magnetic circuit will depend on the magnetic pressure (*m.m.f.*) acting on the circuit and the total reluctance of the circuit, just as the current in the electrical circuit depends upon the electrical pressure and the resistance of the circuit, that is:

NOTE.—***William Gilbert,*** born 1540, died 1603. He was an English physicist, noted for his experiments in magnetism, and for the publication in 1600 of his chief work "De Magnete" which marked an epoch in the science of magnetism, and earned for its author the title of the "founder of the science of magnetism and electricity." *The practical unit of magnetic force* (the ***gilbert***) was named after him.

Electric circuit	**Magnetic circuit**
$\text{amperes} = \dfrac{\text{volts}}{\text{ohms}}$	$\text{maxwells} = \dfrac{\text{gilberts}}{\text{oersteds}}$

It should be noted that in the electric circuit, resistance causes heat to be generated and therefore energy to be wasted, but in the magnetic circuit *reluctance does not involve any similar waste of energy.*

***Rule 25.**—The reluctance is directly proportional to the length of the circuit and inversely proportional to its cross sectional area.*

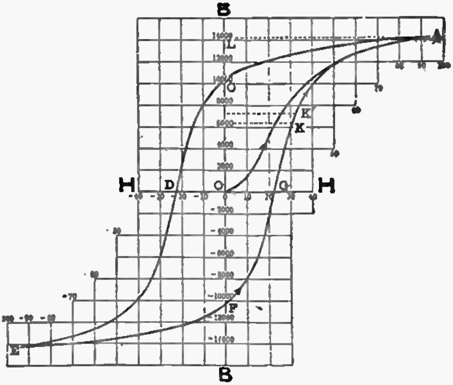


Fig. 6,253.–Hysteresis loop or curve showing how B, changes when H, is periodically varied. *In the figure* H = number of lines of force per sq. cm. (strength of field) and B = number of lines of induction per sq. cm. If now H, be gradually diminished to zero, it is found that the value of B, for any given value of H, is considerably greater when that value of H, was reached by *decreasing* H, from a higher value, than when the same value was reached by *increasing* H, from a lower value; that is, to say, the curve AC, when H, is decreased, is very different from the curve OA, when it is increased. Take for instance, the value H = 20. When this is reached by increasing H, from 0 to 20, the corresponding value of B, is 5,100, but when it is reached by decreasing H, from 94 to 20, the value of B, is 12,200. It may be noted, too, that when H, is reduced to zero, B, still has a value OC, or 10,300, which is nearly three quarters the value it had when H, was 94. This induction is the "residual magnetism" mentioned already. *In soft iron* it will nearly all disappear on tapping, but without this it can also be removed by reversing the current in the magnetising coil, so as to demagnetise the iron. The curve shows that a demagnetising force of H = 23 is required to make B, zero at the point D. This force is called the *coercive force* of the iron, and measures the tenacity with which it holds the residual magnetism. As the magnetising force is still further increased in reverse direction, the curve goes from D, to E, where the iron becomes saturated negatively. On gradually returning, H, to zero, the curve goes from E, to F, along a similar but opposite path to AC, OF, being again the residual magnetism. The magnetising force has now passed round a cycle from O, to a positive value, back to O, to a negative value, and again back to O, and if this cycle be repeated several times, the B-H curve becomes a loop *FGACDE*, which is symmetrical about the center O.

The reluctance of a magnetic circuit is calculated according to the following equation:

$$\text{reluctance} = \frac{\text{length in centimetres}}{\text{permeability} \times \text{cross section in square centimetres}}$$

Hysteresis.—The term hysteresis has been given by Ewing to the subject of *lag of magnetic effects behind their causes*.

It is a peculiar quality of an iron core, such as an armature core undergoing rapid reversals of magnetism, by which there occurs an expenditure of energy which is converted into heat. This loss of energy is due to the work required to change the position of the molecules of the iron and takes place both in the process of magnetizing and demagnetizing; the magnetism in each case lagging behind the force: *static* hysteresis as distinguished from *viscous* hysteresis.

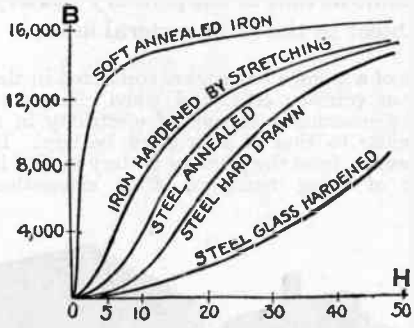


FIG. 6,254.—*BH* curves for iron and steel.

Residual Magnetism.—When a mass of iron has once been magnetized, it becomes a difficult matter to entirely remove all traces when the magnetizing agent has been removed, and, as a general rule, a small amount of magnetism is permanently retained by the iron. This is known as *residual magnetism*, and it varies in amount with the quality of the iron.

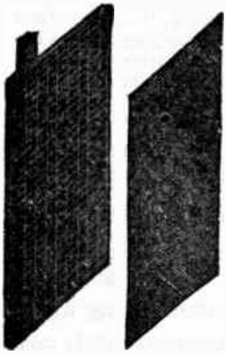
Residual magnetism in iron is of great importance in the working of the *self-exciting* dynamo, and is, indeed the essential principle of this class of machine.

Without residual magnetism in the field magnet core, the dynamo when started would not generate any current unless it received an initial excitation from an external source.

NOTE.—*Ewing's theory of magnetism.*—A theory of magnetism advanced by Ewing, that molecular magnets are held together, not by friction but by mutual magnetic attraction, their poles pointing in every direction till some outside magnetic force draws them into a common direction.

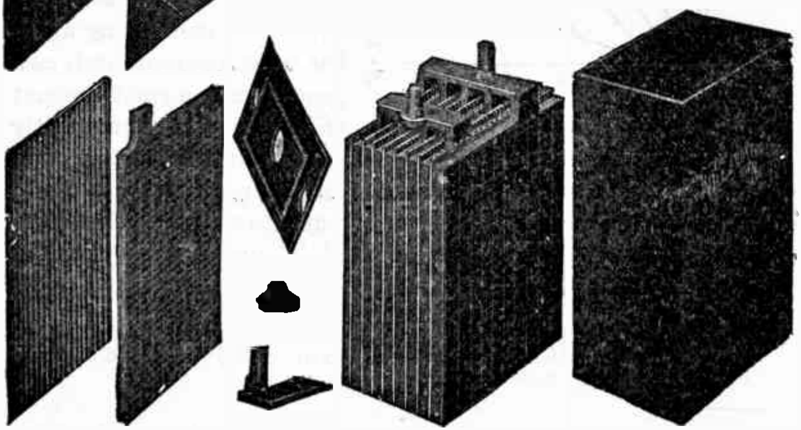
CHAPTER 7

Storage Batteries



The action of the storage battery is practically the same as that of the primary battery and it is subject to the same general laws.

The cells of a storage battery are connected in the same way as primary cells, and when charged is capable of generating a current of electricity in a manner similar to that of a primary battery. It differs, however, from the primary battery in that it is capable of being recharged after exhaustion



Figs. 6,255 to 6,263.—Automobile storage battery parts. Fig. 6,255, positive plate; fig. 6,256, perforated separator; fig. 6,257, word separator; fig. 6,258, negative plate; fig. 6,259, hard rubber cover; fig. 6,260, vent plug; fig. 6,261, pillar connecting strap; fig. 6,262, hard rubber jar; fig. 6,263, complete element.

by passing an electric current through it in a direction opposite to that of the current on discharge. This difference constitutes the principal advantage of the storage battery over the primary battery.

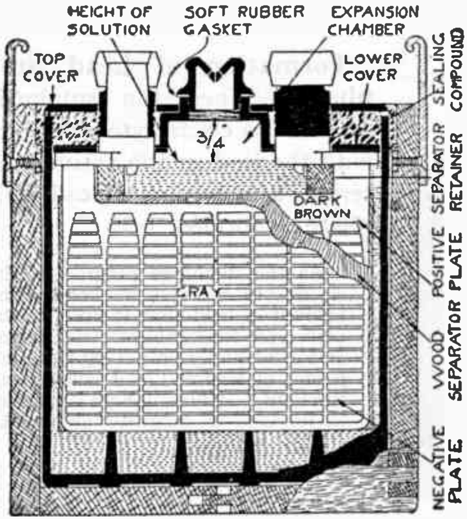
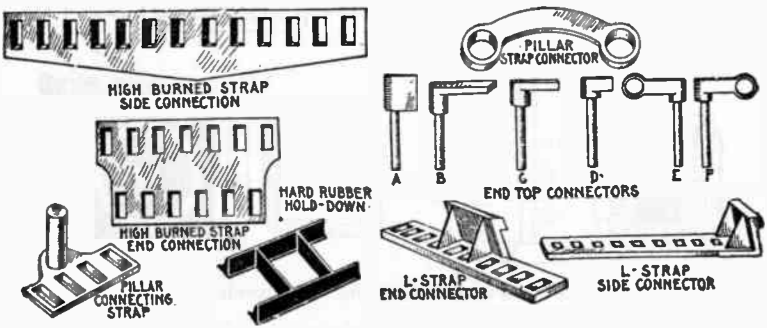


FIG. 6,264.—Sectional view of Gould cell showing various parts.

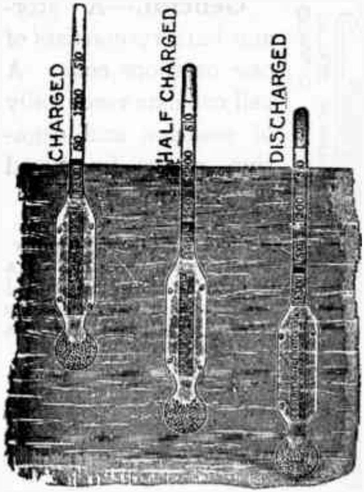
General.—A storage battery consists of one or more cells. A cell consists essentially of positive and negative plates immersed in electrolyte.

The electrolyte generally used consists of a mixture of sulphuric acid and water. The voltage of one cell is about two volts.



FIGS. 6,265 to 6,277 —Willard connecting straps and connectors.

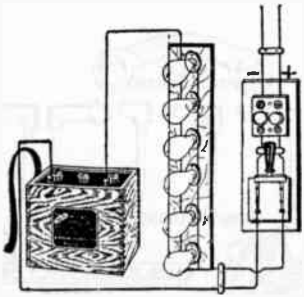
When a cell is put on discharge, the current is produced by the acid in the electrolyte going into and combining with the lead of the porous part of the plates called "active material." In the positive plate, the active material is lead peroxide, and in the negative plate, it is metallic lead in a spongy form.



Formation of Lead Sulphate.—When the sulphuric acid in the electrolyte combines with the lead in the active material, a compound, lead sulphate, is formed.

As the discharge progresses, the electrolyte becomes weaker by the amount of acid that is used in the plates, producing the electric current and incidentally producing the compound of acid and lead called "lead sulphate." This sulphate continues to increase in quantity and bulk,

FIG. 6,278.—State of charge as indicated by hydrometer reading of density of the electrolyte.



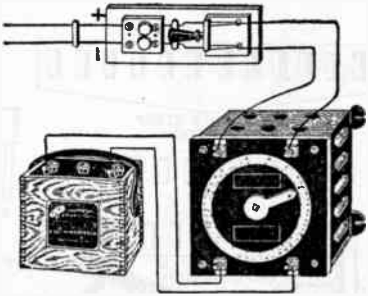
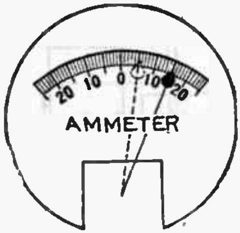


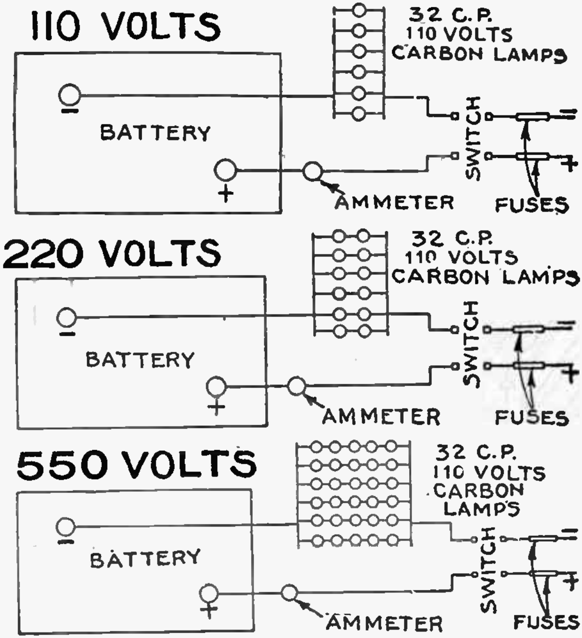
FIG. 6,279.—Diagram illustrating method of charging with lamps in parallel or direct current circuit.

FIG. 6,280.—Diagram illustrating method of charing with rheostat on direct current circuit.



thereby filling the pores of the plates. As the pores of the plates become thus filled with the sulphate, the free circulation of acid into the plates is retarded; and since the acid cannot then get into the plates fast enough to maintain the normal action, the battery becomes less active, as is indicated by the drop in voltage.

FIG. 6,281.—Method of reading ammeter when the current is unsteady. Owing to the irregularity of the explosion in a hit-and-miss engine, it is almost impossible to maintain a steady reading of the ammeter, as the ammeter hand will swing forward at each impulse of the engine and drop back until the next explosion. In this case, adjust the rheostat so that the ampere reading will be equal to the designated charging rate. If the hand oscillate for instance, between 5 to 15, the current value is ½ (5+15) = 10 amperes.



FIGS. 6,282 to 6.284.—Charging through bank of lamps on 110, 220, and 550 volt circuit.

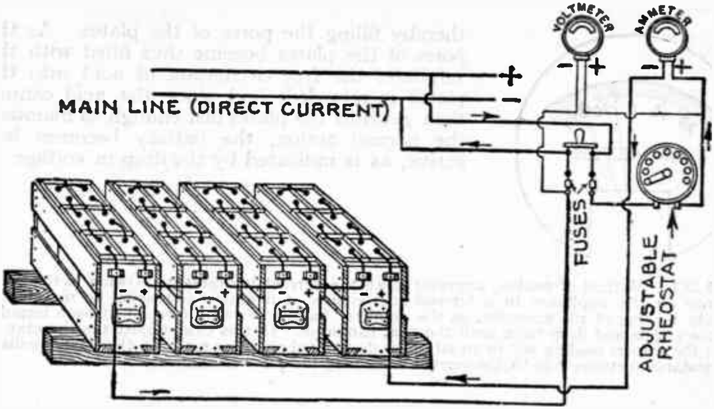


FIG. 6,285.—Charging several batteries, **rheostatic control.** *The trays are first connected in series. The current flows from the positive wire of the current supply, into the positive terminal of the first tray (in this case on the right); through the positive and out the negative of each cell and each tray in turn and returns to the current supply from the negative of the last cell. The voltmeter is connected between the resistance and the battery in order to show battery voltage.*

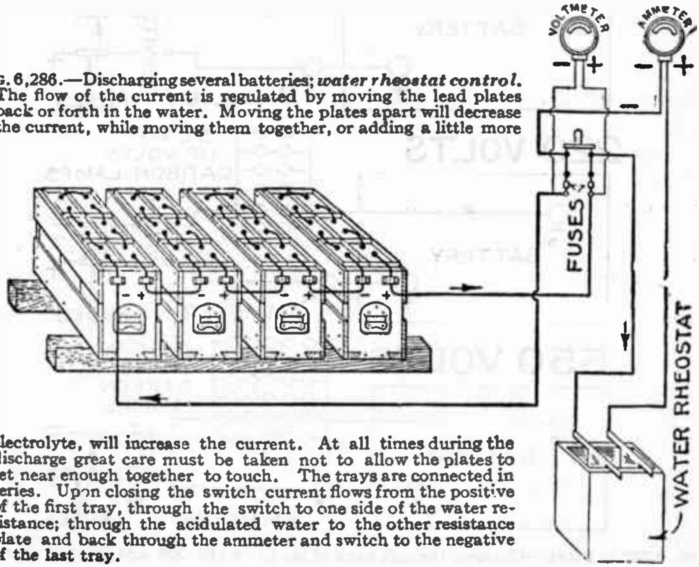


FIG. 6,286.—Discharging several batteries; ***water rheostat control.*** The flow of the current is regulated by moving the lead plates back or forth in the water. Moving the plates apart will decrease the current, while moving them together, or adding a little more electrolyte, will increase the current. At all times during the discharge great care must be taken not to allow the plates to get near enough together to touch. The trays are connected in series. Upon closing the switch current flows from the positive of the first tray, through the switch to one side of the water resistance; through the acidulated water to the other resistance plate and back through the ammeter and switch to the negative of the last tray.

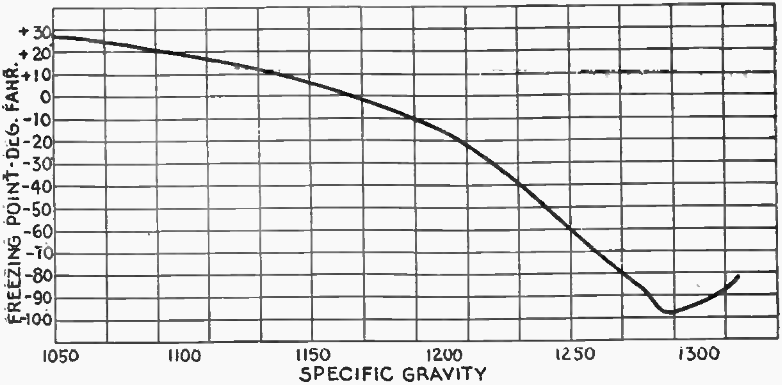


FIG. 6,287.—Freezing points of electrolyte. The freezing point of a battery depends upon its strength. For instance, a solution with a strength or specific gravity of 1.250 will not freeze until cooled to a temperature of 62° below zero Fahr. A strength of 1.150 will freeze at 5° above zero, hence there is little danger of freezing except when the battery is completely discharged. Moreover, at these freezing points, the solution is slushy and does not become hard until the temperature goes still lower. *If water be added* to a battery in freezing weather and then not stirred in with the solution by charging the battery, it will remain on top of the solution and may freeze.

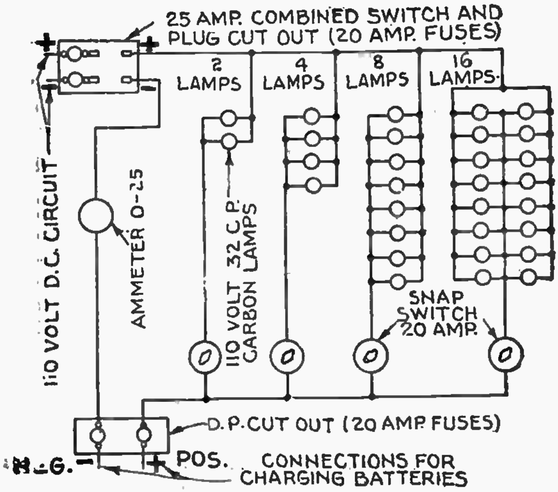
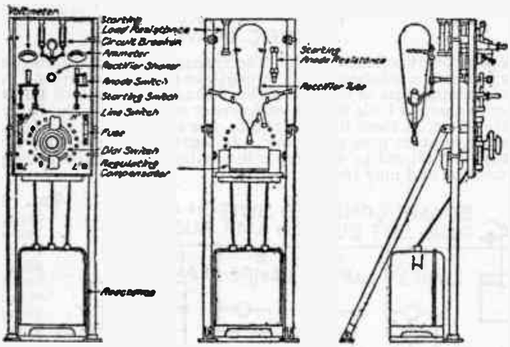


FIG. 6,288. — Trickle charge. When a number of batteries are to be held in wet storage, the most satisfactory results can be obtained by charging continuously at a very low rate. which is so low that gassing is avoided and yet gives enough charge. to maintain the batteries in good condition. This charge is called a *trickle charge* and in many cases will be found more convenient to arrange for them the perodic charge. It has the added advantage of keeping the batteries in condition for put ting into use at any time on short notice. ***To apply trickle charge;*** 1, give bench charge; 2, Connect a tungsten lamp or lamps of appropriate resistance, in series with the cells, across a charging system adapted for continuous charging. 3, Every two months interrupt the trickle charge, remove filling plug, add water to bottom of filling tubes, replace and tighten filling plug and continue trickle charge.

Specific Gravity Drop During Discharge.—During a normal complete discharge, the amount of acid used from the electrolyte in a cell will cause the specific gravity to drop about 150 points (.150 sp. gr.)

Thus if the gravity of a fully charged cell be 1.300, it will, at the end of discharge, be about 1.150. The battery should receive charge before it is discharged below this point.

Charging.—To charge, direct current is passed through the cells in a direction opposite to that of discharge.

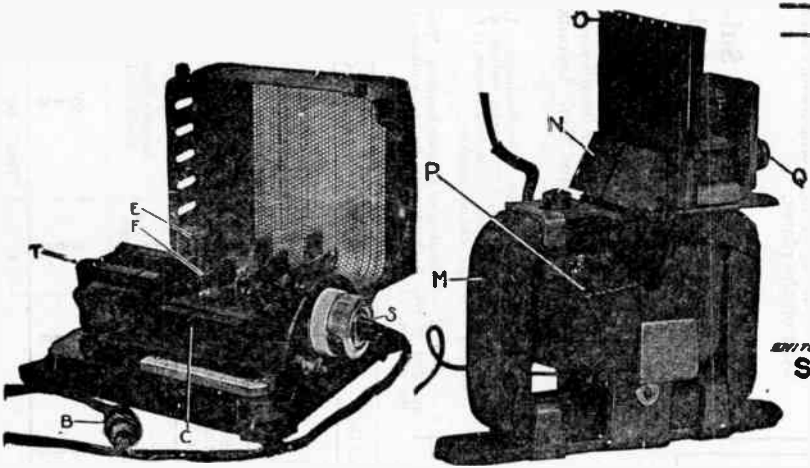


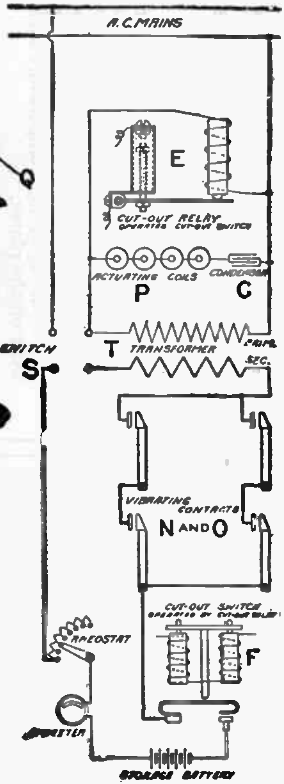
FIGS. 6,289 to 6,291.—Mercury arc rectifier outfit, or charging set. The cut shows front, rear and side views of the rectifier, illustrating the arrangement on a panel, of the rectifier tube with its connection and operating devices.

This current, passing through the cells in the reverse direction, will reverse the action which took place in the cells during discharge.

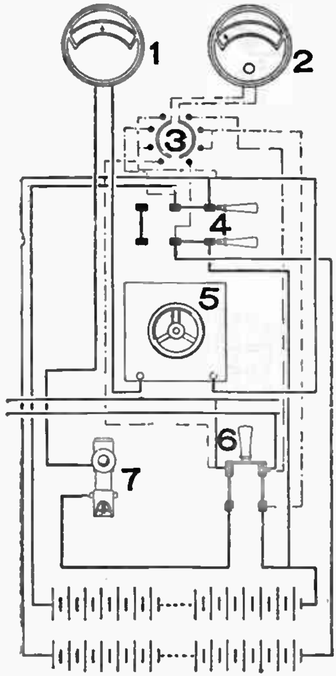
Object of Charging.—*The acid absorbed by the plates during discharge is, during charge, driven from the plates by the charging current and restored to the electrolyte. This is the whole object of charging.*

Gassing.—When a battery is fully discharged, it can absorb current at the highest rate. As the charge progresses, the plates





FIGS. 6,292 to 6,294.—Edison rectifier and diagram of connections. ***In operation***, the primary circuit taken from the alternating current mains by the cord B, embraces the primary winding of the transformer T, a condenser C, and the coils P, of the vibrating units, fig. 6,293. The secondary circuit from the transformer embraces the massive carbon and copper contacts (N and O, fig. 6,294) which pass only the positive waves of the alternating current for charging batteries or other duty. An ammeter and rheostat may be placed in this charging circuit if the current is to be varied, or a fixed connection may be substituted on the base of the rectifier if it is to be used for the maximum duty of 8 or 16 amperes. The vibrating unit (fig. 6,293), which operates in a manner similar to the well known action of a polarized relay, includes a permanent magnet M; the coil in the primary circuit P; the vibrating armature of steel with removable carbon contact N; the stationary copper contact with comb top for heat radiation O, and the screw Q, for adjusting the amplitude of the armature vibration. The vibrating armature of each unit is divided into two parts, which gives flexibility, affords increased current capacity and minimizes sparking, the two leads shown being connected together in one circuit. A primary relay and a secondary switch (E and F, figs. 6,292 and 6,294), close their contacts when current is flowing. Upon failure of the main alternating current line they operate to open the charging circuit. A storage battery is thus prevented discharging through the rectifier. Upon resumption of the main alternating current, the rectifier starts automatically.



can no longer absorb current at the same rate and the excess current goes to form gas.

In a battery which is charged or nearly charged, the plates can absorb current without excessive gassing only at a low rate, and a high charge rate will be almost entirely used in forming gas, resulting in high temperature and wear on the plates.

Normal and Abnormal Sulphating.—The sulphating which takes place during an ordinary discharge is entirely normal.

If, however, charging be insufficient, the sulphate increase and become

FIG. 6,295.—Parallel charge, series discharge. 1, ammeter; 2, voltmeter; 3, voltmeter switch; 4, series parallel switches; 5, battery rheostat; 6, battery switch; 7, circuit breaker.

NOTE.—*Selection of proper battery.* The number of *cells* is determined by the voltage of the system. Thus, according to Gould:

Voltage of System	Number of Cells	Voltage of System	Number of Cells
110 115 125	60 64 70	220 230 250	120 126 138

NOTE.—The size of a 110 volt battery can be determined thus, assuming that the battery will be charged at any time during the day convenient to operate the dynamo and that the battery will be able to furnish current for lamps as follows:

Time	Number of Lamps	3 Amperes	4 Number of hours	Ampere Hours col. 3 Xcol. 4
5 p.m. to 10 p.m. 10 p.m. to 6 a.m. 6 a.m. to 8 a.m.	Twenty 16 *c.p.* Two 8 *c.p.* Six 16 *c.p.*	10 ½ 3	5 8 2	50 4 6
				Total 60

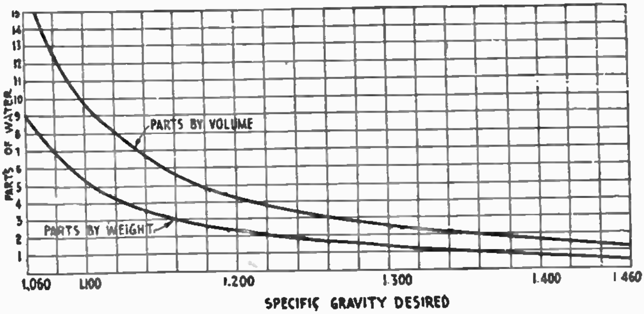


FIG. 6,296.—Curves for mixing full strength acid and water. Full strength or concentrated sulphuric acid is a heavy, oily liquid, having a strength (specific gravity) of about 1.835. If put into the battery, it would quickly ruin it, and must therefore *first* be diluted with pure (distilled) water to the proper strength for the particular type of battery, to which it is to be added. ***In mixing***, take the following precautions: 1, Use a glass, china, earthenware, rubber or lead vessel; never metallic other than lead. 2, *Carefully pour the acid into the water; **not** the water into the acid.* 3, Stir thoroughly with a wooden paddle and allow to cool before taking a hydrometer reading. The electrolyte like most substances expands with rise of temperature; this affects the hydrometer reading. ***Correction for hydrometer reading; Add one point to hydrometer reading for every 3° Fahr. increase in temperature above 70°.***

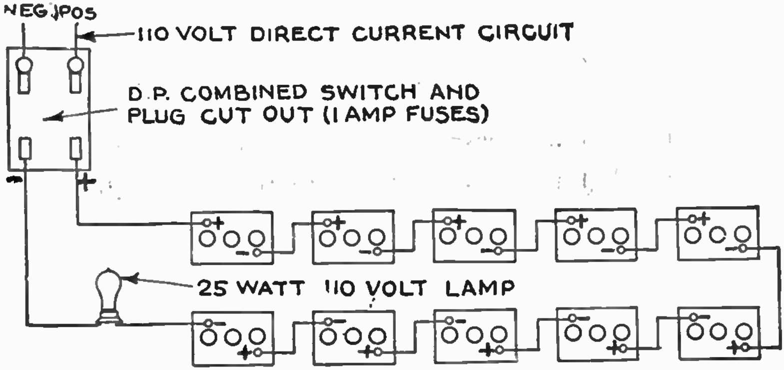


FIG. 6,297.—Wiring diagram for charging one to twelve 6-volt batteries from 110 volt bus. With this equipment regulation of the current through various numbers of batteries is obtained by means of the switches. Instead of lamps, *resistance units*, of approximately 35 ohms resistance and 3.3 amperes capacity each may be used. This equipment will occupy less space than the lamps and serve the same purpose, each resistance unit replacing two lamps. Instead of either a lamp resistance or unit resistance panel, a special form of *rheostat* may be used. However lamps are advisable where the light for same may serve for illumination. otherwise the energy spent in heating the resistance is a total loss.

hard and the plates become lighter in color, lose their porosity and are not easily charged; this is the abnormal condition usually referred to as "sulphated." This condition is usually the result of "starvation" of the battery.

Overdischarge.—It is not ***discharge*** at any rate which injures a battery, but ***overdischarge***, or, what in time amounts to the same thing, undercharge or "starvation."

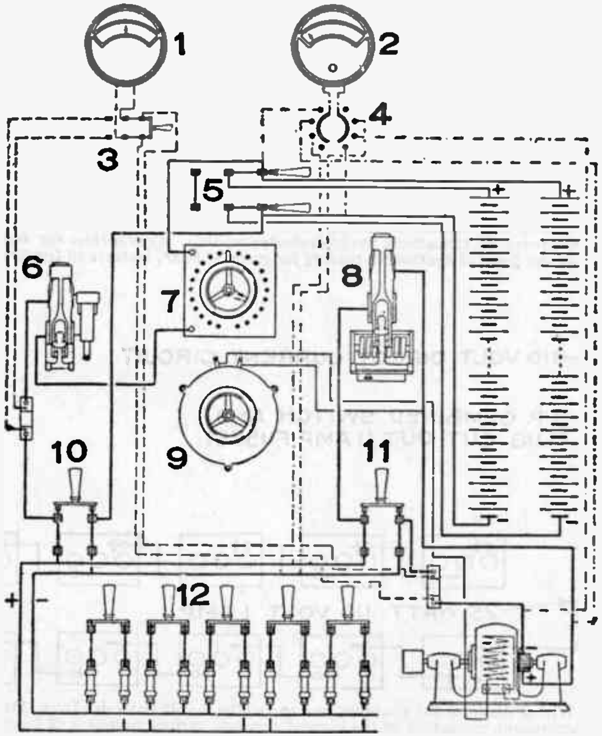


FIG. 6,298.—Parallel charge, series discharge including dynamo and distribution circuits. 1, ammeter; 2, voltmeter; 3, ammeter switch; 4, voltmeter switch; 5, series parallel switches; 6, battery circuit breaker; 7, battery rheostat; 8, overload and reverse current circuit breaker (discriminating cut out); 9, dynamo field rheostat; 10, battery switch; 11, dynamo switch; 12, switches to distribution circuits.

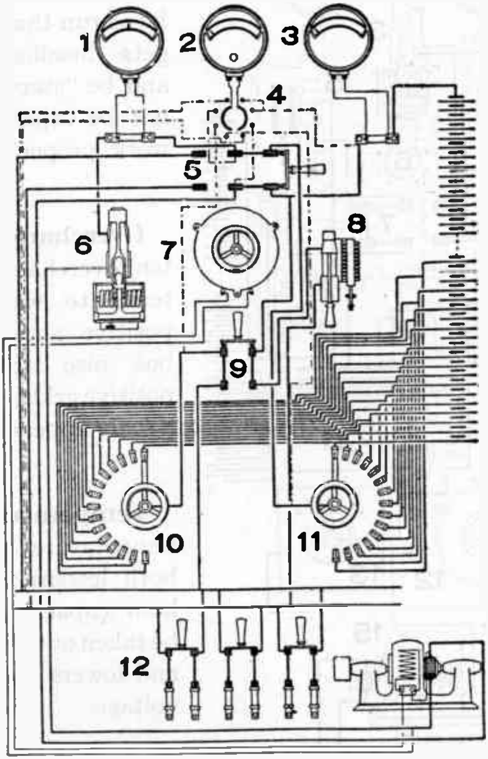
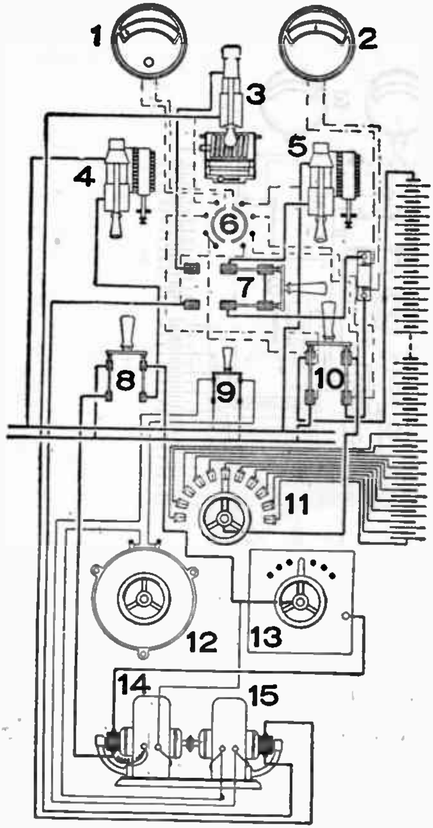


FIG. 6,299.—High voltage charge. End cell regulation. 1, dynamo ammeter; 2, voltmeter; 3, battery ammeter; 4, voltmeter switch; 5, dynamo switch; 6, dynamo circuit breaker over load and reverse; 7, dynamo field rheostat; 8, battery circuit breaker; 9, battery switch; 10, discharge end cell switch; 11, charging end cell switch; 12, switches to distributing circuits. The battery is charged in one series directly from the dynamo, which has a pressure range to 155 volts, and the charging current is controlled by the dynamo field rheostat. Two end cell switches are required so that the lighting circuits may be supplied while the battery is charging, the power voltage for the lamps being obtained by adjusting the position of the end cell switch connected to the lighting circuit. This is an overload breaker in the battery circuits and an overload breaker with reverse current trip in the dynamo circuit, the latter protecting the dynamos against overload and reversal of current.



Starvation.—In automobile batteries, if a car be so run that the battery gets insufficient charge and be "starved," it cannot be expected to do its work properly.

Overcharge. — Persistent overcharging not only tends to wash out the positive active material, but also acts on the positive grids, giving them a scaly appearance.

Temperature. — Low temperature temporarily both lessens the ampere hour capacity which can be taken out of the battery and lowers the discharge voltage.

FIG. 6,300.—Shunt booster charge, and cell discharge. 1, voltmeter; 2, ammeter; 3, under load circuit breaker; 4, booster motor circuit breaker; 5, battery circuit breaker; 6, voltmeter switch; 7, booster switch; 8, booster motor switch; 9, booster field switch; 10, battery switch; 11, end cell switch; 12, booster field rheostat; 13, motor starter; 14, motor; 15, dynamo.

NOTE.—*Charging rates.* In selecting the size of battery to give a certain discharge rate, care should be taken that the dynamo is large enough to charge the battery at a rate not lower than the normal eight hour rate. In the case when two halves of a battery are charged in parallel each half taking the normal rate, the dynamo must have a current capacity double that at which each half is to be charged. Moreover the dynamo should have capacity to charge the battery occasionally at a higher rate, as this not only improves the condition of the cells, but permits a shorter cnarging period

Keep battery unusually well charged in winter and not expose it unnecessarily to low temperatures. There is no danger of the electrolyte freezing in a fully charged cell; but in one which is over discharged or has had water added without subsequent charging this is liable to occur.

High temperature is to be avoided from the standpoint of life. 110 degrees Fahr. is usually given as the limiting temperature, and even this would be harmful if maintained steadily. Heating is ordinarily the result of charging at too high a current rate.

The effects of continued high temperature are to distort and buckle the plates, to char and weaken the wood separators, to soften and sometimes injuriously distort the jars and covers.

Points on Storage Battery Care.—The following should be specially noted:

1. Add nothing but pure distilled water to the cells and do it often enough to keep the plates covered.

2. Take frequent hydrometer readings.

3. Give the battery a special charge whenever the gravity readings show it to be necessary.

4. Charge at the proper rate.

5. Keep the filling plugs and connections tight and the battery clean.

6. To prevent corrosion of terminals and connections, wipe with a rag moistened with household ammonia solution.

7. Keep battery well charged in cold weather.

BATTERY REPAIRS

1. Double Cover Batteries

The type battery here considered to illustrate battery repair methods is a ***Gould*** 6 volt 81 ampere hour size of the double cover sealed type. Before starting to dismantle a battery a sketch should be made showing the inter-cell connections and position of terminals for guidance in reassembling.

NOTE.—The author is indebted to the Gould Storage Battery Co. for the accompanying instructive series of cuts illustrating ***Storage Battery Repairs.***

Battery Repairs

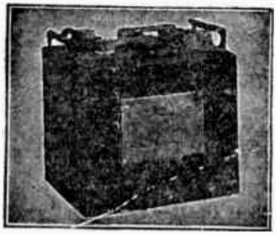


FIG. 6,301.—*Battery repairs. 1.* Gould 6 volt 81 ampere hour storage battery as received for repairs.

FIG. 6,302.—*Battery repairs 2.* To remove terminal or connecting link, center punch the tops of terminals and connectors over the terminal posts and drill down to a depth of ¾ inch, using a ⅝ inch drill for ¾ inch posts and a ⅞ inch drill for 1 inch posts. Do not drill deeper than necessary so as to minimize the labor of building up the post.

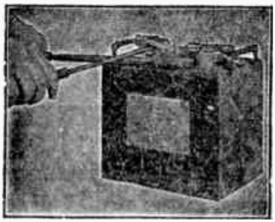
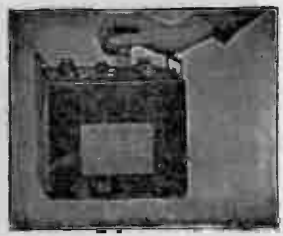


FIG. 6,303.—*Battery repairs 3.* In removing the top connectors place a file or a flat piece of steel along the edge of the case. Place an ordinary screw driver underneath the connector and pry it off. The object of the file or piece of steel is to protect the wood case from breakage.

FIG. 6,304.—*Battery repairs 4.* Brush off the accumulation of lead and dirt from the top of the battery. Care should be exercised to keep foreign substances from the inside of the battery, especially metal which may become lodged between the plates and separators and eventually cause short circuiting.



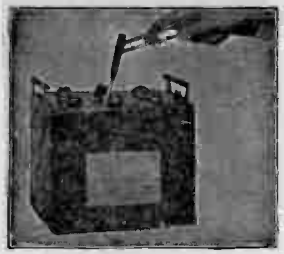
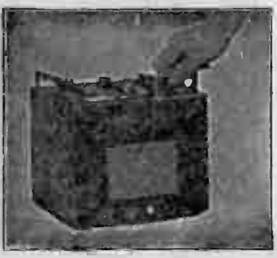


FIG. 6,305.—***Battery repairs 5.*** Unscrew and remove the vent plugs. In all cases be sure that the vent plugs are removed before using a flame around the battery. As hydrogen gas is generated in a battery its presence may result in an explosion. This gas can be quickly expelled by blowing into the cells with a bellows. As the vent plugs are made of hard rubber, which is easily broken, do not attempt to remove them with a pair of pliers.

FIG. 6,306.—***Battery repairs 6.*** Soften the sealing compound around the edges of the covers by playing a gas or torch flame over the compound. Care must be taken that the flame does not burn or scorch the covers. It is best to play the flame back and forth and not steadily in one place.



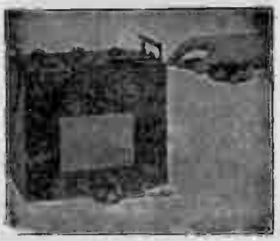


FIG. 6,307.—***Battery repairs 7.*** Using a heated screw driver, chisel or a plumber's lead scraper dig out the compound around the edges of the covers.

FIG. 6,308.—***Battery repairs 8.*** Again using a flame, heat the top of the covers to soften the underlying compound. Insert a screw driver under the covers and pry them off gently. Do not attempt to force them off but use more heat until they lift easily.

FIG. 6,309.—***Battery repairs 9.*** After the top covers have been removed, heat the underlying compound with the illuminating gas flame or blow torch. Do not allow the flame to play in one place long as this would cause the compound to melt and run. A small flame used for several minutes will bring better results than a strong flame. After softening the compound it may be removed by using a heated screw driver.

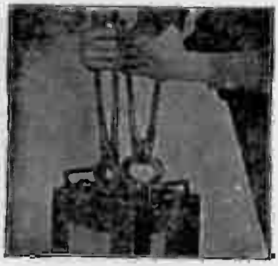


FIG. 6,310.—*Battery repairs 10.* Apply the gas flame to the inside of the jar for an instant, then run a hot putty knife around the edges between jar and cover. Now place the battery on the floor, and holding it firmly between the feet, grasp the terminal posts with two pairs of pliers and lift the element and inside cover out together.

FIG. 6,311.—*Battery repairs 11.* Let the elements rest at an angle on top of the jars to drain. While the elements are draining apply a flame around the terminal posts and remove covers. The covers may have warped from the heat. If so, they should be placed in boiling water and flattened out on a smooth surface to cool.

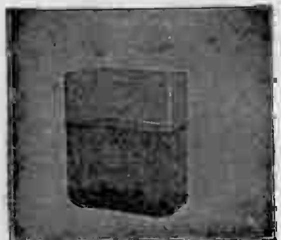
FIG. 6,312.—*Battery repairs 12.* If separators be in good condition, and a jar replacement only is to be made, set the element, with bottom cover, in electrolyte or water till ready to replace. If separation is to be renewed and plates examined, separate the positive and negative groups. Grasp the elements firmly and work the groups gently back and forth.

FIG. 6,313.—*Battery repairs 13.* Remove separators. Take a putty knife and run it between the plate and the separator. It is always best to renew the separators. When a new battery is received for replacement of a leaky jar the separators will generally be found in good condition so as not to require renewal. Separators should never be allowed to dry but should be kept immersed in water.

FIG. 6,314.—*Battery repairs 14.* Plates should be inspected to determine whether or not they require replacement. If battery has been overheated through overcharging or short circuiting this will be indicated by brittle and buckled plates with active material granular and falling away from the grid. Plates in this condition will have to be replaced. If electrolyte has not been kept above the plates the tops of the plates will show a white substance known as sulphate. If the battery has been allowed to remain in a discharged condition for any length of time it will be indicated by sulphated plates. This sulphation is susceptible to removal by charging at a low rate for a long period. This rate should be about one-half the normal charging rate continued until the specific gravity and voltage reaches a maximum value.

Fig. 6,315.—*Battery repairs 15.* Positive group showing buckled plates. A group of buckled plates which, when reassembled, will not go into the jar readily, should be replaced with a new group. Buckled plates if otherwise serviceable can be strengthened thus: Insert boards of suitable thickness between the plates and over each outside plate; place the pile in a vise, apply a gradual pressure, exercising care that the plates are not subjected to a severe strain. The condition of the negative plates is sometimes such that they may be used again with new positives. In this case the negative group should be immersed in water to prevent the plates drying out through heating or exposure to the air. If the positive plate be fairly hard, and has not lost much of its surface, it may be used again. Occasionally it happens that one or two plates in a group require replacement while the balance of the plates are in good condition. In this case new plates may be used in replacement.

Fig. 6,316.—*Battery repairs 16.* Having examined the groups, pour the electrolyte into a large jar or vessel. A glass jar is best adapted to the purpose so as to disclose the sediment which will settle at the bottom. Sometimes impurities get into the electrolyte, and as a precautionary measure it is not advisable to use old solution.



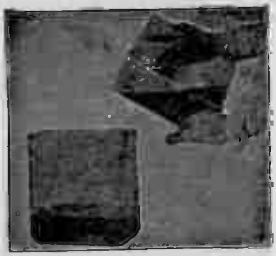


Fig. 6,317.—*Battery repairs 17.* Note the sediment which has settled at the bottom of the jar containing electrolyte. Under normal usage this sediment will not be considerable. A large amount of it indicates that the cell has been overheated, and that the solution has not been kept above the plates by adding distilled water at regular intervals.

Fig. 6,318.—*Battery repairs 18.* This shows the pouring off of the clear electrolyte. Never allow the sediment to get into the battery as it would impair the efficiency of the separators.

FIG. 6,319.—*Battery repairs 19.* Invert the case over a sink and thoroughly clean the cells by inserting a hose and injecting a stream of water upward into each cell. Be sure that all sediment and foreign matter is removed from the cells before installing the plates.

FIG. 6,320.—*Battery repairs 20.* Inspect the jars carefully for cracks or other imperfections. Jars exhibiting such defects should be replaced with new ones.

FIG. 6,321.—*Battery repairs 21.* To remove a jar fill it with boiling water and allow it to stand for at least five minutes. This will loosen the sealing compound surrounding the jar.

FIG. 6,322.—*Battery repairs 22.* Grasp the edges of the jar to be removed with two pairs of pliers as illustrated and pull it straight up. Care should be exercised so as not to damage adjacent jars.

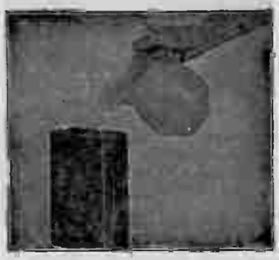
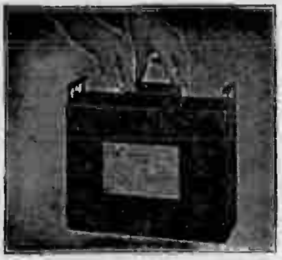


FIG. 6,323.—*Battery repairs 23.* Before putting in a new jar examine the space in the case and remove the shims and sealing compound so as not to hinder the jar being placed properly.

FIG. 6,324.—*Battery repairs 24.* The jar should be heated before being placed in the case. This may be accomplished by pouring boiling water in the jar. If hot water be not available play a light flame around the outside of the jar.



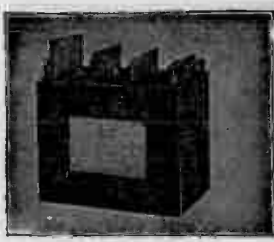


FIG. 6,325.—*Battery repairs 25.* When the jar has been heated it should be pushed into place, taking care to see that the top of the jar is level with the others. If the tops are not lined up, the top connectors will be uneven, and as a result present a very poor looking job.

FIG. 6,326.—*Battery repairs 26.* To secure the proper spacing and a tight fit, place a paraffined wood veneer shim between the jars.

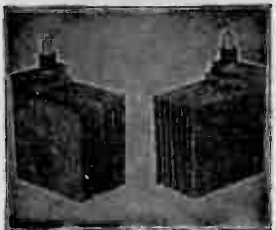


FIG. 6,327.—*Battery repairs 27.* To replace an element the first step is to take the positive and negative groups to a clean, flat table. Always make sure that the work table is free from lead scrapings or foreign substances of any kind as these substances will adhere to wet separators, and if not removed will cause short circuiting of the plates.

FIG. 6,328.—*Battery repairs 28.* Intermesh the positive and negative group. As the negative group contains one more plate than does the positive, both outside plates will be negative.

FIG. 6,329.—*Battery repairs 29.* This illustrates a complete element ready to receive separators.

FIG. 6,330.—*Battery repairs 30.* Lay the element on its side and put the separator retainers in position. Insert the separators between each pair of plates. If wood separators only be used, the grooved side of the separator should be next to the positive plate. If wood separators and rubber sheets be used, they should be inserted together, the rubber sheet between the positive plate and the grooved side of the wood separator. See that the separators are against the retainers and that they extend equally on either side of the element. Carefully check up separators after assembling as to omit a separator would cause considerable trouble

FIG. 6,331.—*Battery repairs 31.* A complete element. Grasping the element by the pillar posts, lower gently into the jar. This should be done very carefully to avoid breaking the jar.

FIG. 6,332.—*Battery repairs 32.* To clean the covers, heat a putty knife.

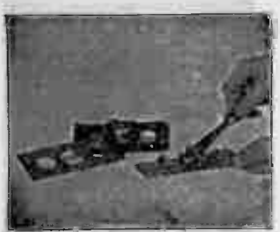


FIG. 6,333.—*Battery repairs 33.* After heating the putty knife clean all the compound off the covers.

FIG. 6,334.—*Battery repairs 34.* Sometimes the bottom cover will not fit properly over the element. By using a pair of pliers in the manner illustrated, it will be an easy matter to locate the centers.

FIG. 6,335.—*Battery repairs 35.* If the bottom cover do not fit close to the terminal posts, or the wall of the jar, the openings should be calked with hemp twine or tow to prevent the melted sealing compound flowing into the jar.

FIG. 6,336.—*Battery repairs 36.* Small gas stove and ordinary coffee pot used for melting and pouring sealing compound.

FIG. 6,337.—*Battery repairs 37.* Always pour the compound so that it will fill all spaces and reach to a height level with the top of the case. Also see that it flows evenly over the whole surface.

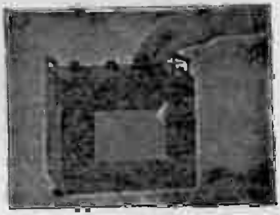


FIG. 6,338.—*Battery repairs 38.* Before putting on the top cover slightly heat it with a gas flame. Also heat the surface of the compound.

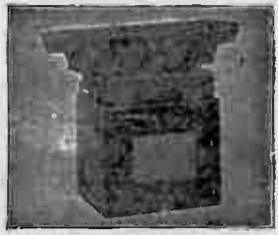
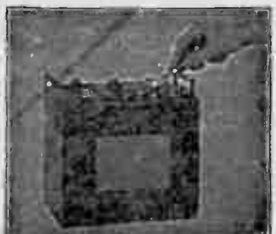


FIG. 6,339.—*Battery repairs 39.* Wooden form used for properly holding the covers down while the compound is cooling.

FIG. 6,340.—*Battery repairs 40.* Place the wooden form over the covers and place a heavy weight on top of the form. The battery should stand for ten or fifteen minutes until the sealing compound has set.



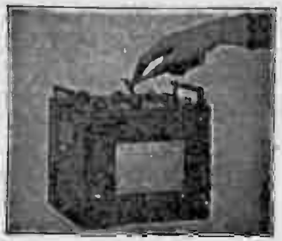
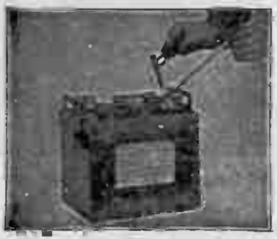


FIG. 6,341.—*Battery repairs 41.* After the form is removed there is always an excess of sealing compound. This can be scraped off with a hot putty knife.

FIG. 6,342.—*Battery repairs 42.* Before applying terminals see that the terminal posts are scraped clean of all compound and dirt. It is practically impossible to do a good job of burning if all parts are not properly cleaned.

FIG. 6,343.—***Battery repairs 43.*** Using an ordinary pocket knife, clean the inside of the connectors, removing all dirt and oxides. Clean the tops of the connectors with a rasp file to remove dirt and oxide.

FIG. 6,344.—***Battery repairs 44.*** Before applying the terminal connectors test all cells with a voltmeter to see if they be set up properly. If a voltmeter be not handy, scrape the rubber bushings on each post. The red bushing is positive and the black is negative. The connectors should be applied so that the positive of one cell is connected to the negative of the next cell.



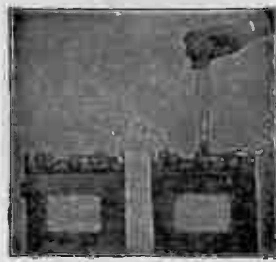


FIG. 6,345.—***Battery repairs 45.*** In burning connectors and terminals to the posts, melt the top of the post, then the edges of the hole in the connector. Melt strips of antimonious lead and allow the molten metal to run into the hole in the connector. Care must be taken to see that the top of post and inside edges of the connector are melted together before applying additional lead. If this be not done, the connection will surely pull loose. Care should also be taken not to melt the outer edges of the connector. Practice will be found necessary.

FIG. 6,346.—***Battery repairs 46.*** After burning, the connectors and terminals, mark the positive terminal with a stamp "POS" and the negative "NEG." If a stamp be not available use a blunt instrument and mark the positive (+) and the negative (—).

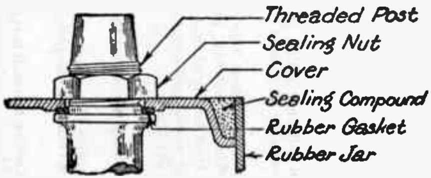
Repairing Batteries With Single Covers

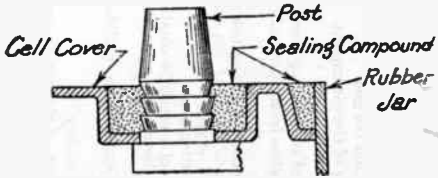
A great many batteries are now constructed with single moulded covers with a depression around the edge into which the sealing compound is poured.

In order to remove the elements from such cells it is only necessary to remove the connecting links as previously described and remove the compound from the channel around the jar formed by the depression of the cover. The element can then be removed with the cover attached to the posts.

Removal of the cover from the element can be effected according to the means by which it is attached and sealed to the posts.

The most usual methods are shown in the accompanying cuts.





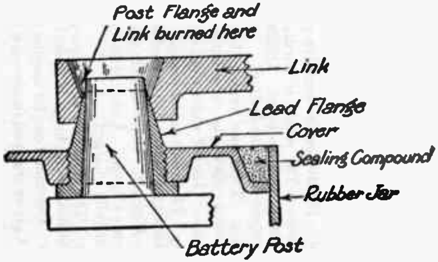


FIG. 6,347.—***Battery repairs 47.*** The battery post is threaded and provided with a flange on which the cover rests, with a soft rubber sealing gasket between. A lead or hard rubber nut secures the cover to the post. To remove cover simply unscrew the nuts on positive and negative post. In replacing a cover of this type the nut should be prevented backing off by breaking the thread in the post, just above the nut, by means of a prick punch.

FIG. 6,348.—***Battery repairs 48.*** Sealing around posts is made by means of sealing compound. There are several designs of this kind but it is in any case necessary to remove the compound or to soften it by heating before cover can be removed.

FIG. 6,349.—***Battery repairs 49.*** A lead flange is screwed into the cover from the lower side. The inside of this flange fits the battery post and the outside tapers above the top of the cover so that when the cell connector is placed in position the three parts, namely—post, flange and connecting link—are burned together at the top. When the connecting links are removed from both posts by drilling, the cover is free and can be lifted off. In replacing the cover on such a battery great care must be taken that the edge of the lead flange is burned into the joint; a new flange being used if necessary. Aside from the points described above repairs to a single cover battery are to be handled as before described.

GLOSSARY

Acid: Term frequently used to describe the liquid in cells, in place of the more correct one —*Electrolyte.*

Active Material: The "formed" paste which fills the grid.

Ampere: The unit of measure of quantity of electric current

Ampere-Hours: Product of amperes and hours.

Battery: Any number of cells when connected and used together.

Bridge (or rib): Wedge-shaped vertical projection from bottom of rubber jar on which plates rest and by which they are supported.

Burning: A term used to describe the operation of joining two pieces of lead by melting them at practically the same instant so they may run together as one continuous piece. Usually done with mixture of oxygen and hydrogen gases, hydrogen and compressed air, or oxygen and illuminating gas.

Cadmium. A metal used in about the shape of a pencil for obtaining voltage of positive or negative plates. It is dipped in the electrolyte but not allowed to come in contact with plates.

Capacity: The rating of cell or battery in ampere-hours, qualified by the rate or time of discharge.

Case: The box which holds the cells of a battery

Cell: Unit of storage battery practice; consists of element, electrolyte and jar.

Charge: Passing direct current through a battery, in order to replace energy used on discharge.

Charging Rate: The proper rate of current, expressed in amperes, to use in charging a battery.

Connector: Solid or flexible part for connecting positive pole of one cell to negative pole of another, etc., or to terminal.

Cover: Cover for cell to retain electrolyte and exclude foreign material.

Cycle: One charge and discharge.

Density: Specific gravity.

Developing: The first cycle or cycles of a new or rebuilt battery to bring about proper electrochemical conditions to give rated capacity

Diffusion: Pertaining to movement of acid within the pores of plates. (See *Equalization.*)

Discharge. The flow of current from a battery through a circuit, opposite of "charge."

Dry: Term frequently applied to cell containing insufficient electrolyte.

Electrolyte: The conducting fluid of electro-chemical devices: for lead-acid storage batteries consists of about two parts of water to one of chemically pure sulphuric acid, by weight.

Element: Positive group, negative group and separators.

Equalization: The result of circulation and diffusion within the cell which accompanies charge and discharge. Difference in capacity at various rates is caused by the time required for this feature.

Equalizing: Term used to describe the making uniform of varying specific gravities in different cells of the same battery, by adding or removing water or electrolyte..

Evaporation: Loss of water from electrolyte from heat or charging.

Forming: Electro-chemical process of making pasted grid or other plate types into storage battery plates. (Often confused with *Developing.*)

Foreign Material: Objectionable substances

Freshening Charge: A charge given to a battery which has been standing idle, to keep it fully charged.

Gassing: The giving off of oxygen gas at positive plates and hydrogen at negatives, which begins when charge is something more than half-completed—depending on the rate.

Gravity: Common term for specific gravity.

Grid: Cast or stamped frame-work in which active material is retained

Group: Any number of positive or negative plates properly joined together.

Hold-down: Device for keeping separators from floating or working up.

Jar: Container for element and electrolyte. Usually of hard rubber.

Lug. Vertical projection from grid for connecting with and burning to strap.

Mud: (See *Sediment.*)

Over-Charge: Continuance of charge beyond that apparently or supposedly necessary to improve condition of cells.

Over-Discharge: The carrying of discharge beyond proper cell voltage; shortens life if carried far enough and done frequently

Paste: The mixture of lead oxide or spongy lead and other substances which is put into grids

Plate. The combination of grid and paste properly "formed." Positives are reddish brown and negatives slate gray

Polarity: An electrical condition. The positive terminal (or pole) of a cell or battery or electrical circuit is said to have positive polarity; the negative, negative polarity

Post. The vertical cylindrical part of strap which receives connector.

Potential Difference: Abbreviated P.D. Found on test curves. Synonymous with voltage

Rate: Number of amperes for charge or discharge. Also used to express *time* for either

Rib: (See *Bridge.*)

Ribbed: (See *Separator.*)

Reversal: That which occurs to voltage readings when cells are discharged below a certain critical point or charged in the wrong direction.

Sealing: Making tight joints between jar and cover; usually with a black, thick, acid-proof compound.

Sediment: Loosened or worn out particles of active material fallen to the bottom of cells; frequently called "mud."

Sediment Space: That part of jar between bottom and top of bridge.

Separator: An insulator between plates of opposite polarity; usually of wood, rubber or combination of both. Separators are generally corrugated or ribbed to insure proper distance between plates and to avoid too great displacement of electrolyte.

Spray. Fine particles of electrolyte carried up from the surface by gas bubbles. (See *Gassing.*)

Strap: That part to which all plates of one group are burned.

Sulphate. Common term for lead sulphate. (Pb SO4.)

Sulphated: Term used to describe cells in an under-charged condition, from either over-discharging without corresponding long charges or from standing idle some time and being self-discharged.

Sulphate Reading: A peculiarity of cell voltage when plates are considerably sulphated, where charging voltage shows abnormally high figures before dropping gradually to normal charging voltage.

Terminal: Part to which outside wires are connected.

Vent or *Vent-Cap:* Hard or soft rubber part inserted in cover to retain atmospheric pressure within the cell, while preventing loss of electrolyte from spray.

Voltage: Electrical pressure or potential difference, expressed in volts.

Wall: Jar sides and ends.

Washing: Removal of sediment from cells after taking out elements; usually accompanied by rinsing of groups, replacement of wood separators and renewal of electrolyte.

Watts: Product of amperes and volts.

Watt-Hours: Product of amperes, volts and time in hours

CHAPTER 8

Electrolysis

This term signifies the *decomposition of a chemical compound in solution, called the* **electrolyte**, *into its constitutent elements,* called ***ions***, by the *passage of an electric current through it.*

There are two kinds of ions: 1. The electro-positive ions called *cations* and, 2. The electro-negative ions called *anions*.

The former appear at the cathode and the latter at the anode. The current may be regarded as being carried through the electrolyte by the ions; since an ion is capable of carrying a fixed charge only of + or — electricity, any increase in the current strength necessitates an increase in the number of ions.

Alkali and Bleach.—When an electric current is passed through a solution of sodium chloride in water, using electrodes which are not attacked by the chloride or by free clorine, the *chloride is split up into its constituent parts, the metal sodium is separated at the cathode, while the gas chlorine forms in minute bubbles at the surface of the anode and rises to the surface of the liquid in the cell.*

The metal sodium, however, has a great affinity for the hydroxyl constituent of water, and it at once enters into union with this, and produces sodium hydrate and hydrogen gas at the surface of the cathode. These changes are the basis of all the patented processes and cells for the production of alkalies and chlorine products by electrolysis.

Aluminum.—The process of aluminum manufacture consists in the *electrolysis of a fused mixture of the fluorides of sodium,* *calcium and aluminum, in which alumina (aluminum oxide) is dissolved.*

When an electric current is passed through such a mixture of fused salt, using carbon electrodes, aluminum separates as drops of molten metal at the cathode, while oxygen is liberated at the anode and at once unites with it to form carbonic acid gas. The bath is kept in the fused state by the heating action of the current. The action taking place in the electrolytic bath is therefore, virtually, a reduction of the alumina or aluminum oxide by the carbon of the anode; but this reduction would be impossible without the aid of the current to first separate the oxygen and aluminum, which have great affinity one for the other.

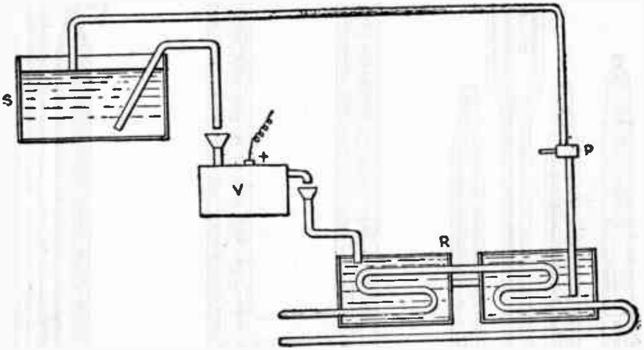
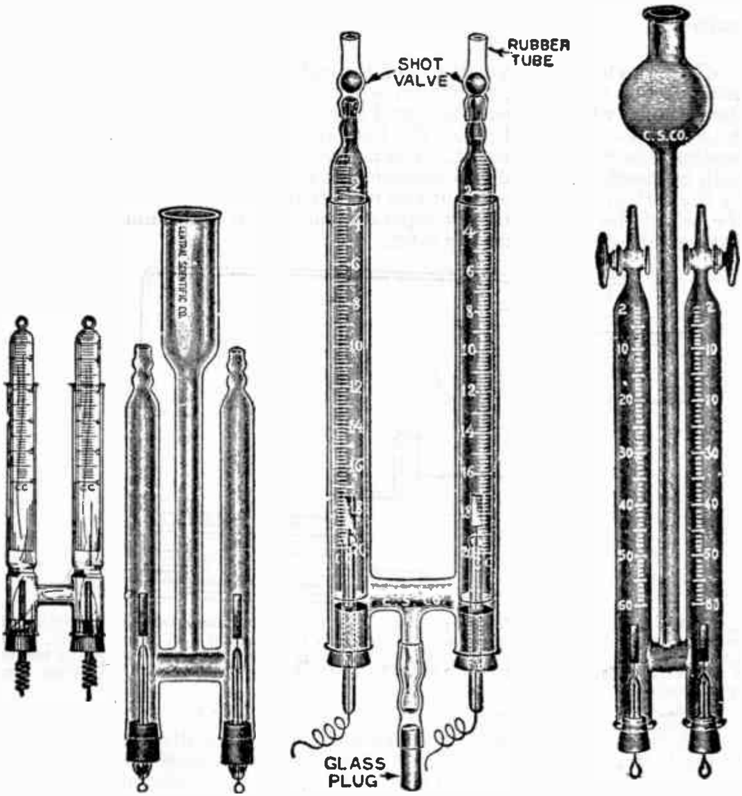


FIG. 6,350.—Arrangement of Gibb's process. The process *consists in* the electrolysis of potassium chloride solutions, using a copper or iron cathode and a platinum anode. S is the supply tank; V, the electrolytic cell; R, the refrigerators; and P, the pump by means of which the exhausted electrolyte is returned to the supply tank, while the chlorate precipitates out as crystals.

The aluminum separated at the cathode is in the molten state and falls to the bottom of the bath, and it is allowed to collect there, being removed at stated intervals, either by a syphon or by tilting. Fresh alumina is fed into the bath at short intervals to replace that which has been decomposed by the current; and the process is, therefore, a continuous one.

Bullion Refining.—The general principle of electrolytic bullion refining is *to use the alloy of precious metals, or bullion, as an anode in an electrolyte which dissolves only one of the two metals to be separated, and to use a sheet of the pure metal that is being deposited, as cathode.*

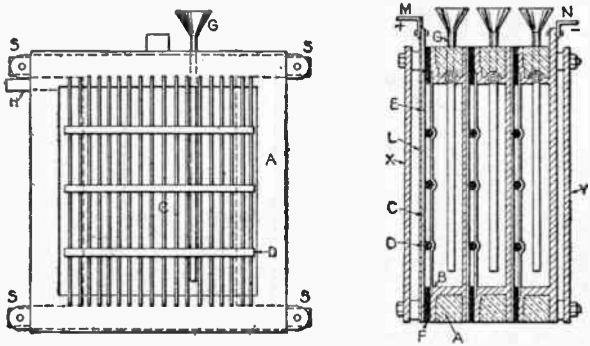


FIGS. 6,351 to 6,354.—Electrolysis apparatus. Fig. 6,351, electrolysis of water, simple form with sliding graduated tubes and platinum electrodes. Fig. 6,352, electrolysis of water, improved form with platinum electrodes that may be easily replaced by copper electrodes or by carbon electrodes for electrolysis of hydrochloric acid. Fig. 6,353, electrolysis apparatus (Osborne form), for study of conductivity of liquids, ionization, electroplating, electrolysis of water, and principles involved in the theory of electrolytic dissociation. *It consists of* an outer U tube with graduated sliding tubes, shot valves, glass plug and platinum electrodes which are easily replaced by carbon or copper electrodes. Fig, 6,354, Hoffman's improved form of electrolysis of water apparatus with graduated tubes, glass stop cocks and removable platinum electrodes

For silver deposition an acid solution of nitrate is employed as the electrolyte (the Moebius process), while for gold an acid solution of gold chloride is found to yield the best results (the Wohlwill process).

Chlorates.—Chlorate of potash or of soda is produced electrolytically by the electrolysis of the corresponding chloride.

The electrolytic and chemical changes which first occur when a solution of sodium or potassium chloride is electrolyzed by the aid of electrodes not acted on by the products of the electrolytic decomposition, have been already described under *Alkali and Bleach*



FIGS. 6,355 and 6,356.—Gibb's cell and battery of three cells. The cells *consists of* a wooden frame A, covered with some metal B, such as lead, not attacked by the electrolyte. The cathode consists of a gird of vertical copper wire C, kept in position by cross bars D, of some insulating material. The grid is placed in a vertical position against one side of the cell frame, and kept in place by the anode of the adjoining cell, from which it is insulated by the strips, F, and bars D. The opposite side of the cell from that occupied by the cathode is partially closed by the anode indicated by dotted lines. This consists of a thick lead plate L, covered with platinum foil on the outer side E, (fig. 6,356), and is held in position by the cathode and framework of the following cell. G, is a pipe, reaching to the bottom of the cell, by which the potassium chloride is continuously supplied, and it is the overflow pipe to convey the mixed solution of the chloride and chlorate as well as the liberated hydrogen gas away from the cell. S,S,S,S, are lugs projecting from the framework by means of which any number of cells can be bolted together to form a series of cell. In fig. 6,356, the heavy plates X and Y, are used to close the ends of the wooden framework and form a fully closed series of cell with only the openings at the various supply and overflow points. Current connections are made at the points M and N.

Hypochlorite.—If the cell designed for chlorate production be worked with a low current density, and at a temperature which does not rise above 68° Fahr., little chlorate will be produced and sodium hypochlorite will be formed in its place.

Ozone.—This can be produced by chemical methods, but it is also produced by *the sparkless discharge of electricity through dry air or oxygen from conductors charged at a high pressure and it is always formed when a frictional electric machine of the old plate type is worked with an air discharge.*

Oxygen and Hydrogen.—Dilute sulphuric acid is employed in one form of apparatus as electrolyte, namely, that patented by Schoop, the more customary electrolyte being a solution of caustic soda.

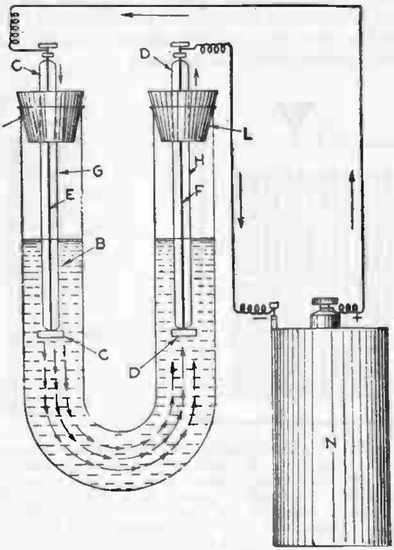


FIG. 6,357.—Electrolysis of copper. Fill the U shaped glass tube shown above, with a solution B, made by dissolving some crystals of copper sulphate or bluestone. Immerse in the solution two platinum electrodes C and D, attached to the copper wires E and F, sealed in the glass tubes G and H, which are held in the tube openings by loosely fitting rubber corks K and L. Attach the positive pole of the battery N, to the terminal of the electrode C, and the negative pole of the battery to the upper terminal of the electrode D. The electric current from the battery will then pass from the platinum *anode* C, through the copper sulphate electrolyte B, to the platinum *cathode* D, thence to the negative terminal of the battery. The passage of the current through the electrolyte will result in the liberation of the constituent ions of the latter, oxygen gas being liberated at the anode C, metallic copper deposited on the cathode D, and the copper sulphate solution B, changed to sulphuric acid.

The primary products of electrolysis in this case are hydroxyl (OH) and the metal sodium (Na) but these immediately enter into secondary chemical changes which produce oxygen gas at the anode and hydrogen gas at the cathode. The gases obtained in this way are not quite free from impurity, but for industrial requirements they are sufficiently pure, and this method of manufacture is much cheaper and more cleanly than the usual chemical methods of production.

Sodium and Potassium.—It is necessary to work with a *fused electrolyte in place of an aqueous solution in this case.*

Owing to the readiness of sodium and potassium to enter into combination with water, the difficulties of operating the process upon a commercial scale are chiefly due to this great chemical activity of the alkali metals.

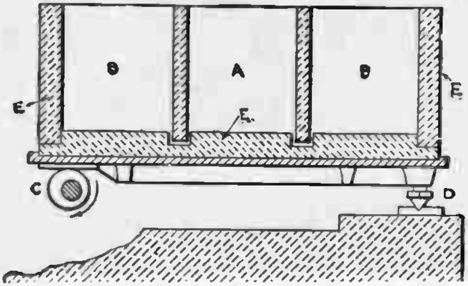


FIG. 6,358.—Castner cell. ***The parts are:*** A, cathode chamber; BB, anode chambers; C, eccentric for producing a rocking movement of cell; D, pivot support for framework of cell; E, slate walls of cell. The Castner cell is of the mercury type in which advantage is taken of the property possessed by mercury of forming an alloy with sodium, fluid at the ordinary temperature, this alloy being known chemically as an amalgam. When the amalgam is heated with water it is decomposed, and a solution of sodium hydrate is formed, while the mercury is restored to its original condition of purity. Hence, if a layer of mercury be employed as cathode on the floor of a cell in which a solution of sodium chloride is being decomposed by the current, the sodium liberated at the surface of the mercury will at once enter into union with it, and will be kept safe from further chemical or electrolytic changes. The layer of mercury, in fact, acts as a reservoir for the sodium atoms, or ions, brought to its surface, and stores up these until they are wanted.

Wet Extraction Process for Metals.—Copper, nickel, tin and zinc have all been extracted from their ores or slags by the use of electrolytic processes, and in many cases these processes are still being worked upon an industrial scale.

Copper.—The principle of the wet copper extraction processes is as follows: The ore is roasted to drive off the sulphur, and then leached in suitable vats with a solution which will dissolve the copper and leave the other metals and impurities undissolved. This solution is then electrolyzed in order to recover the copper as a cathode deposit.

Nickel.—The roasted ore is leached with a solution containing both copper and calcium salts as chlorides, and the copper is first deposited by electrolysis. The last traces of copper are then removed from the electrolyte by chemical means, and the nickel is in turn deposited by use of a higher voltage from the remaining solution.

Tin.—The Böhne process depends upon the use of sulphuric acid as a leaching agent and upon electrolytic deposition of the tin, from the sulphate solution so obtained. In the recovery of tin from old tin cans and tin scrap by electrolysis, sodium hydrate is used as the electrolyte.

Zinc.—A great amount of investigation and large sums of money have been spent upon processes for extracting zinc from its ores, by aid of elec-

FIG. 6,359.—Electrolysis in lower New York. The figure illustrates current movements as discovered. The power house is located near the navy yard in Brooklyn. A portion of the returning currents, as shown by arrows, flows over the New York and Brooklyn bridge to Manhattan, thence north to Williamsburg bridge via underground mains, subway structures, and other metals, and passes over that bridge back to Brooklyn, thence through mains to rails and negatives, to power house. In this case damage may be expected at three points: 1, where currents leave bridge metals on the Manhattan side; 2, where they leave pipes to enter Williamsburg bridge; 3, where they leave same bridge for pipes in Brooklyn side. When the two bridge structures are connected in Manhattan as proposed, then there will be further changes in the direction of current. Before the Williamsburg bridge was built, these currents recrossed through the river bed, leaving mains all along the docks in the Manhattan side, for the river, and leaving the river for mains or other metals along the docks of the Brooklyn side. Traces of these currents have been found as far north as 23rd St., a distance of over two miles from the Brooklyn bridge. Since the Williamsburg bridge has been built, nearly all traces of these currents flowing north of it have disappeared, showing that the mass of metal composing the structure acts as a short circuit or path of lower resistance which carries practically all of the returning currents flowing from Manhattan back to Brooklyn.

trolysis, but only two of these have achieved any industrial success. The Hoepfner process depends upon the use of the waste calcium chloride solution from ammonia soda works, and was worked out chiefly as a process for recovery and utilization of the chlorine from this waste product; zinc, testing 99.96 per cent. purity, and bleach being the products finally obtained. The Swinburne-Ashcroft method (the other successful process) is not a wet extraction process, but depends upon the electrolytic separation of zinc from fused zinc chloride.

CHAPTER 9

Electro-plating

This process consists in obtaining *an electro-deposit of one metal, used as an anode, upon some metallic article which is connected to form the cathode in an electrolytic bath*, that is the substance upon which it is desired to deposit the metal is connected with the negative pole of the source of current, and the metal which is to be plated upon is connected with the positive pole.

The chemical nature of the *electrolyte* employed depends upon the kind of plating. For plating with gold or with silver, the electrolyte is always alkaline, for plating with nickel or with copper, it is usually acid.

Substances other than metal can be electroplated by first coating their surfaces with powdered graphite or plumbago, as in the case of *electrotyping*.

An essential condition in electroplating is cleanliness.

The merest trace of grease or dirt is sufficient to completely spoil the plating; in fact, the presence of even the small amount of grease caused by handling the article with the naked hand is often sufficient to prevent an adherent deposit.

The articles to be plated are cleaned by means of emery paper or wet cand, and by scrubbing with a scratch brush.

Next they are treated with caustic soda and then thoroughly rinsed in running water.

Sometimes they are dipped in acid, partly for cleansing purposes, and partly to slightly roughen or frost the surfaces.

Stripping.—Worn articles of electro-plate, which are to be re-plated, require therefore to have the whole of the previous plating removed before receiving a new coat. This process of removal, which is accomplished by various acids, is technically known as *stripping*.

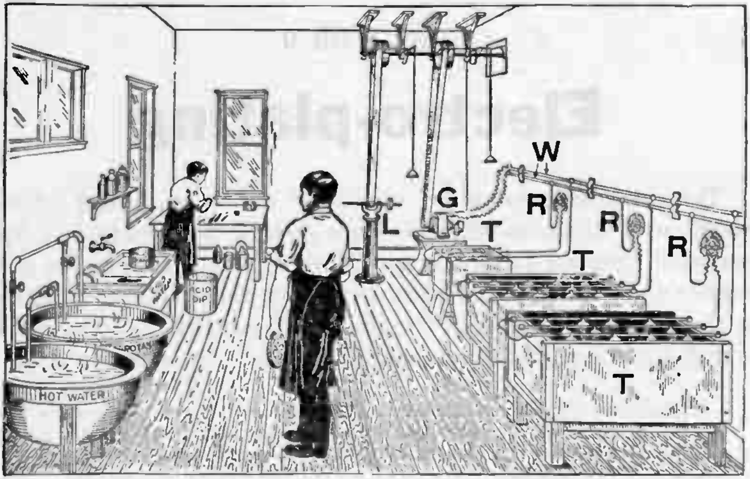


FIG. 6,360.—Electro-plating outfit with ***two wire*** system of distribution.

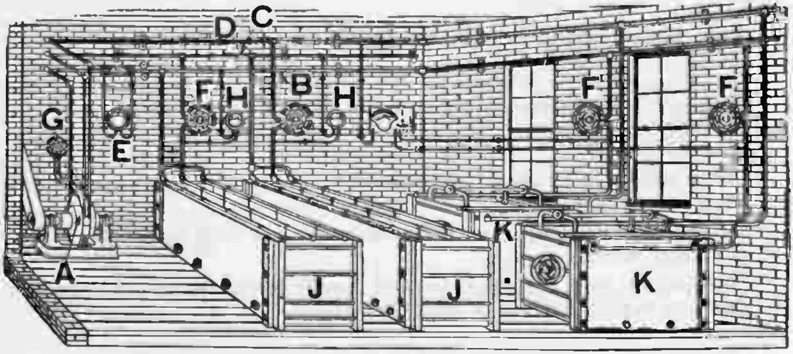


FIG. 6,361.—Electro-plating outfit with ***three wire*** system of distribution. The apparatus consists of: A, multipolar dynamo; B, positive line; C, neutral line; D, negative line; E, ammeter; F, tank rheostat; G, field rheostat; H, tank volt-meters; I, Starrett volt-meter; J, still solution; K, plating apparatus.

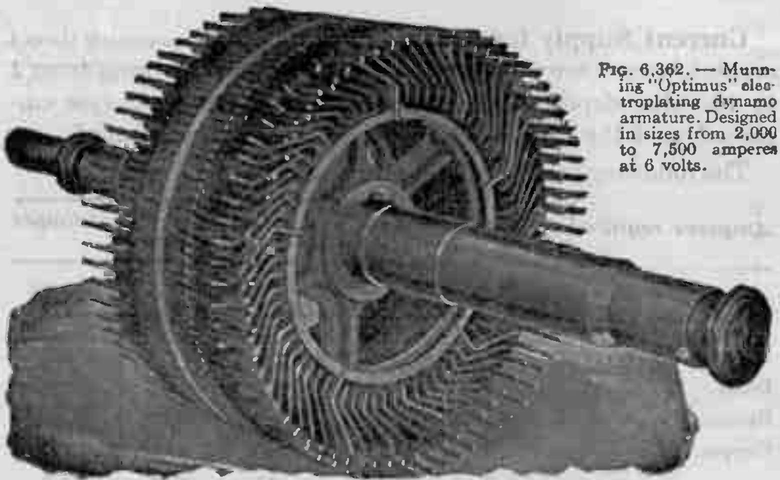


FIG. 6,362. — Munning "Optimus" electroplating dynamo armature. Designed in sizes from 2,000 to 7,500 amperes at 6 volts.

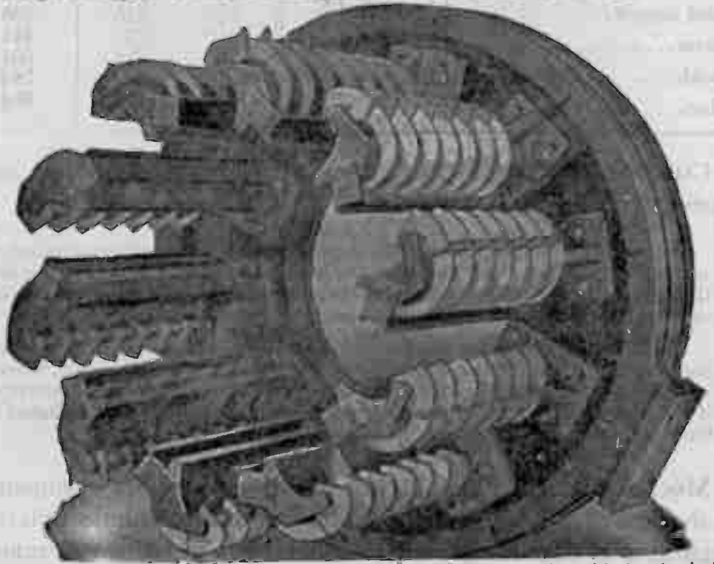


FIG. 6,363.—Munning "Optimus" electroplating dynamo brush yoke with brush rigging. 5,000 ampere size.

Current Supply for Electro-plating.—Low pressure direct current is used for this purpose, the pressure used being from 1 to 16 volts, depending upon the nature of the electrolyte employed, and the rate at which the plating is accomplished.

The following tables will be found useful:

Amperes required to plate one square foot.		*Carrying capacity of copper wire.*	
Solution and metal.	Average amperes.	Size.	Amperes.
Nickel	4	1/16"... .0625	3
Brass	6 to 8	1/8"... .125	12
Bronze	6 to 8	3/16"... .1875	27
Copper	6 to 8	1/4"... .250	49
Acid copper	10 to 12	5/16"... .3125	76
Silver	2	3/8"... .375	110
Gold	1½	1/2"... .500	196
Zinc	10	5/8"... .625	306
		3/4"... .750	441
		7/8"... .875	601
		1"...1.000	785
		1⅛"...1.125	994

Current Density.—The current density is important and varies with different metals.

With a high current density the deposit may be crystalline or powdery, and will not adhere well to the cathode. What is required is to regulate the current so that the deposited metal may be smooth and adherent, and capable of being burnished without being detached.

Hard and fast lines cannot be laid down, but, generally speaking, with high current densities the deposit is powdery, and of a dark color, when it is said to be "burnt." Much higher current densities can be employed if the solution be rapidly circulated by means of a pump or agitated by blowing in air.

Mechanical Electro-plating Apparatus.—The cheapening in the cost of plating has been so marked that mechanical plating apparatus is now recognized as a necessity in the metal manufacturing industry.

The Tanks, or Vats.—These vessels are for holding the plating solutions, and should be made of well seasoned wood, liquid tight, and lined with some suitable material which will not be acted upon by the solution the tank is intended to contain.

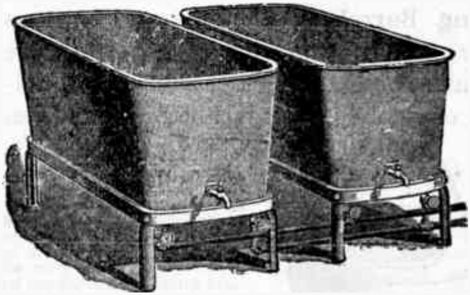
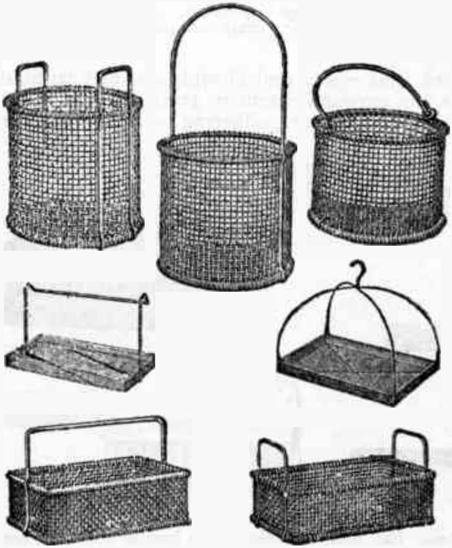


FIG. 6,364.—Heating tanks. Small shops usually depend upon gas or oil stoves placed under the various tanks or jars containing solutions that must be kept hot, such as lye, rinsing water, gold solutions, etc., as either offers a means of keeping up the desired temperature with very little trouble or expense. Larger establishments, however, find it cheaper and better in every way to use steam jacketed tanks, as here shown.

Dipping Vessels.—These are employed for holding the articles and dipping them into the various solutions used in cleaning the articles preparatory to the plating.

All dipping vessels used in acid solutions should be made of vitrified or glazed stoneware or glass.



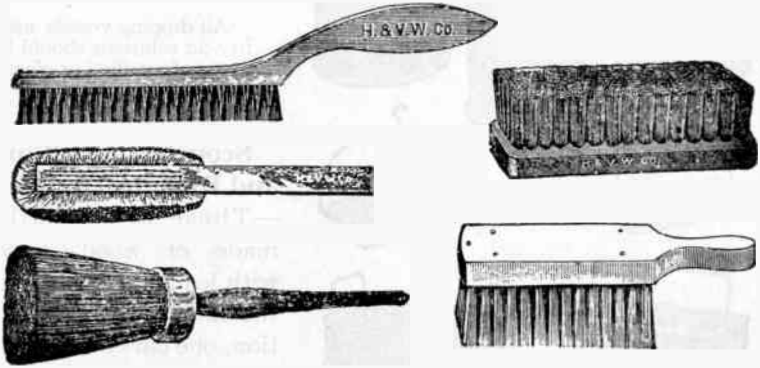
FIGS. 6,365 to 6,371.—Various dipping baskets.

Scouring, Swilling and Rinsing Troughs.—These are usually made of wood, lined with lead and divided in the middle by a partition, one part being used for scouring and the other for holding clean water for rinsing the articles after they have been scoured clean.

Tumbling or Rattling Barrels.—Small objects, such as small castings, stampings, etc., that are not required to have square edges, are best cleaned by tumbling, or rattling, as it is called in foundries.

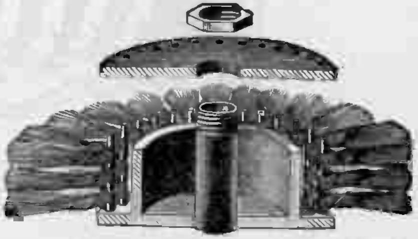
FIGS. 6,372 and 6,373.—Various dipping vessels. Fig. 6,372, deep glazed earthenware dipping basket; fig. 6,373, shallow glazed earthenware dipping basket. The aluminum basket is adapted for use in washing and dipping in all acid solutions, but cannot be used in potash solutions. Different shapes and sizes of basket are required for various kinds of work. Successful dipping depends, however, chiefly upon quick and careful handling rather than upon the shapes of the dip, therefore, the holes in these baskets should be as large as possible, so as to allow the acid or cyanide solution to drain out quickly.

Large quantities of work are thus easily and cheaply cleaned without much manual labor, which is the expensive item in polishing. If rough castings are being worked, the sand, scale, etc., adhering to them is allowed

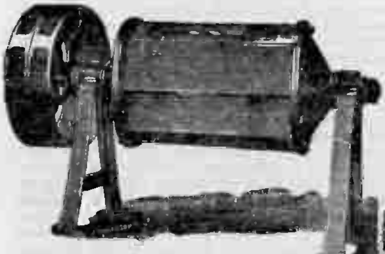


FIGS. 6,374 to 6,378.—Various brushes. Fig. 6,374, jeweler's shoe handle wash out hand brush; fig. 6,375, flat scouring brush; fig. 6,376, cotton potash brush; fig. 6,377, sawdust brush; fig. 6,378 wire foundry brush.

to remain in the barrel, where it acts as a polishing powder, brightening the parts which are not reached by the metal of other castings; but when tumbling for a bright finish, the sand, dirt, etc., are exhausted by means of the blower, so that the surfaces are finely polished by friction only—burnished, as it were, by rubbing against other metal of the same kind. A strong exhaust should be kept up when polishing in this way or the finish will be dead instead of bright.



FIGS. 6,379 and 6,380.—Hanson and Van Winkle swing type, circular steel wire, casting brush. The steel wires are twisted in knots and the knots are hung on rods around the hub, as shown in fig. 6,379, so that they will turn around the rods if the work be held too close to the brush wheel. In using the brush the work should be held so as to be just in contact with the ends of the wires. The brush shown is about 15 inches in diameter, and should not be run much faster than 1,000 *r.p.m.*



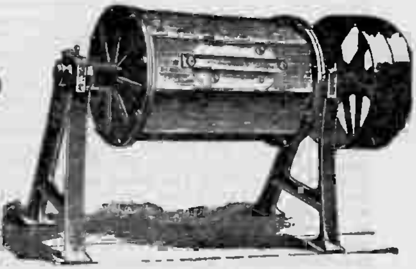


FIG. 6,381.—Hanson and Van Winkle tumbling barrel with convex head for dry tumbling. The type of barrel is especially adapted for removing burrs and for smoothing small castings. This barrel gives three distinct motions to the articles: rolling, shaking, and spreading.

FIG. 6,382.—Hanson and Van Winkle tumbling barrel for wet grinding or polishing. It is intended for sand and water grinding, washing out core sand, etc., and is adapted for brass castings. The barrel is provided with a gland for connecting a water pipe to supply a constant flow of water.

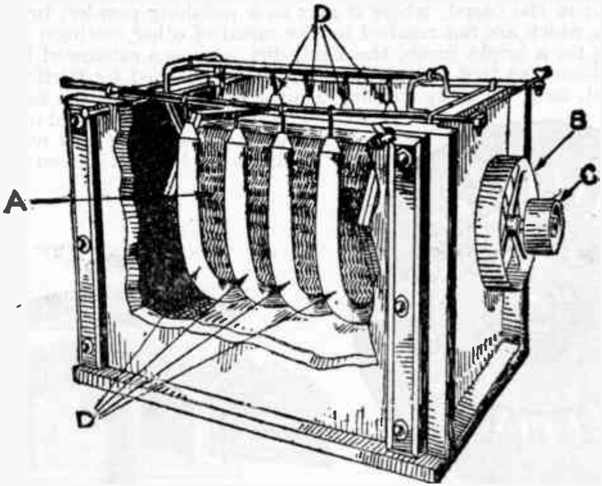


FIG. 6,383.—Mechanical electro-plating apparatus. ***It consists of*** a barrel A, in which are placed the articles to be plated. This barrel is revolved by belt device over the pulleys B or C, which provide two speeds. The barrel is removable at any time without interfering with the device. The anodes D, D, are curved to fit the periphery of the revolving barrel, and when the anodes are hung at each side of the tank, as shown, the work is always equidistant from the anodes, thereby insuring a regular deposit of even depth. ***In setting up and operating*** the mechanical electro-plating apparatus, connect the anode rod to the positive wire of the main line, and the cathode rod to the negative wire. Use suitable size wires for this purpose, as shown by the branch holes in the rod connections. Insert a rheostat in the negative line between the tank and the main line. When the barrel is being filled or emptied move the rheostat lever to the *off* point, so as to prevent the burning or blackening of the work when it is being removed from the tank. This should receive particular attention when a high voltage current is used. All contact points should be kept perfectly clean. A strip of thin sheet lead, or a split length of rubber hose, bent into the shape of a U, should be placed over the entire length of the anode rod to prevent the slop and dirt from the solution impairing the contact of the anode hooks with the positive rod. The revolving barrel may be operated at two speeds. In order to obtain the correct speeds, the countershaft should be driven at the rate of 10 revolutions per minute. ***The following voltages should be used*** with the various solutions: Acid copper solution, 18° Baume, 2½ to 5 volts; cyanide copper and brass solution, 12°–15° Baume, 4 to 5 volts; nickel solution, 10° Baume, 4 to 5 volts; zinc solution, 20° Baume, 6 to 10 volts. ***With the lower speed,*** almost any kind of article which will not hang to the periphery of the barrel, may be handled with the lower voltages. ***The higher speed*** and the higher voltages should be used for round articles, or those having no sharp edges or corners, with a consequent shortening of the time of deposition. The best results are obtained when the articles fill about one-half the barrel. The average length of time required to obtain a good deposit of the different metals under proper working conditions is approximately as follows: Acid copper solution, 20 to 40 minutes; cyanide copper and brass solutions, 30 to 45 minutes; nickel solution on brass, 15 to 30 minutes; nickel solution on steel, 45 to 60 minutes; zinc solution, 1½ to 2 hours. In the case of all solutions, the crystallization of the salts during cold weather tend to give a great deal of trouble. Therefore, all solutions should be kept at a temperature of 70 to 80 degrees Fahr., thereby permitting the use of denser and more highly conductive solutions, with a consequent shortening of the time of deposition. A loop of bare steam pipe immersed in the solution will serve to supply the necessary heat.

Bright work can only be obtained by long continued tumbling, and the bright finish comes rather quickly after all the pieces in the barrel become smooth, accordingly, it is necessary not to add any pieces once the barrel is charged, or the work will not finish evenly.

Steel Ball Burnishing Barrels.—Burnishing with steel balls is done both on small articles preparatory to plating and also on articles that have been plated and require a highly burnished finish.

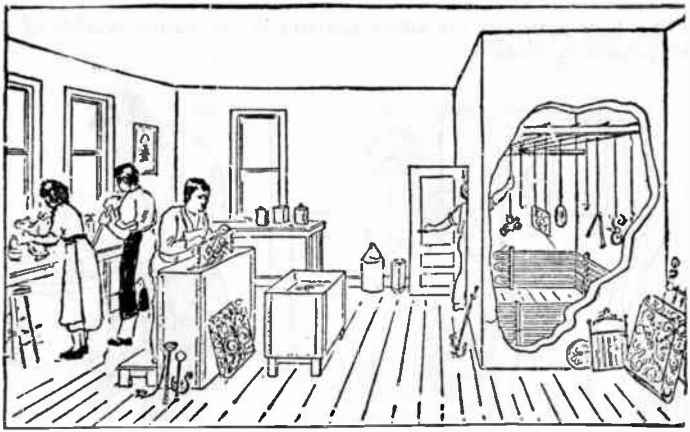


FIG. 6,384.—The lacquer room. When possible, a separate room should be used for lacquering, or a portion of the shop may be partitioned off for the purpose in order to avoid all dust or moisture. If the room be heated by steam pipes, it is advisable to have the regulating valves outside. The lacquer room should be light, dry, and well ventilated. When it is necessary to use artificial light, it is safer and better to use incandescent lamps. Do not have a stove or gas light near the lacquer room, as both the lacquer and thinner, as well as the gases which arise from them, are very inflammable.

Polishing Powders.—In order to hold fine powders on the wheels and buffs, they must be mixed with some medium that will perform this office and at the same time act as a lubricant to the work.

The polishing compositions generally employed are various preparations of rouge, tripoli, crocus, white rouge. Vienna lime and powdered pumice stone.

Solutions for Electro-plating with Different Metals.—These may contain the necessary constituents in various percentages. The following solutions are considered the best in general practice.

A good 14 carat gold plating solution is composed of water, 1 gallon; potassium cyanide, 10 ounces; gold chloride, 10 pennyweights; and a sufficient amount of carbonate of copper to give the desired shade. A 14 carat gold anode should be employed, composed of fine gold and the latter being composed of 80 parts of copper, 83 parts zinc, and 6 parts nickel.

The best solution for silver plating is the double cyanide of silver and potassium solution.

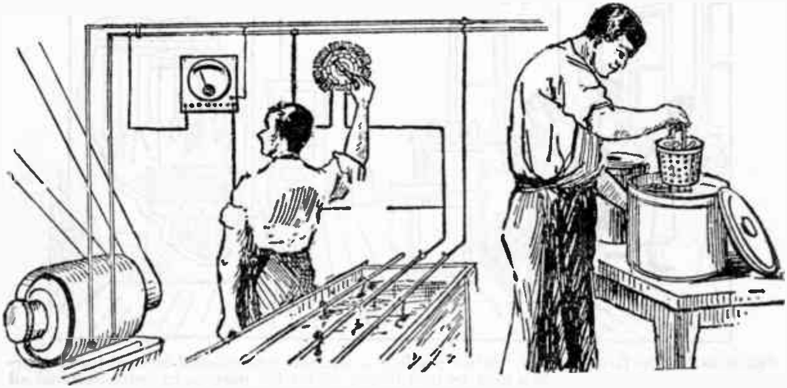


FIG. 6,385.—Connections and manipulation of rheostat on large copper, brass, and bronze solutions where variations of voltage are necessary to secure different colors.

FIG. 6,386.—Dipping or immersion; a method of chemically cleaning many articles consisting of dipping them in solutions which dissolve the grease scale, etc. Successful dipping depends chiefly upon quick and careful handling rather than upon the dips themselves, and the holes in these baskets should be as large as possible to allow the rapid escape of acid or cyanide. The usual sizes of hole in dipping baskets are ⅛, to 1 inch in diameter.

The single cyanide of silver is prepared by adding a solution of cyanide of potassium to a solution of nitrate of silver until a precipitate ceases to form.

The double cyanide of silver and potassium is prepared by dissolving an equivalent of silver cyanide (134 parts) in a solution containing an equivalent of cyanide of potassium (65 parts). The silver plating solution is made up with distilled water, the proportion by weight of silver per gallon of water varying from ½ ounce to 5 ounces or more.

The best nickel plating solution is that which is made up of the double sulphate of nickel and ammonium, in the proportion of 12 ounces to one pound of the double salt to each gallon of solution. The crystals should be dissolved in boiling water in a wooden tub, frequently stirred and cold water added to make up the desired quantity. After the solution has become cool it should be filtered through a large volume, 1,000 gallons or more, held in large lead lined tanks.

Electro-plating with copper is employed chiefly to form a coating on iron, steel, tin, zinc, lead, Brittania metal and pewter articles preparatory to silver plating the same, for the reason that silver will not

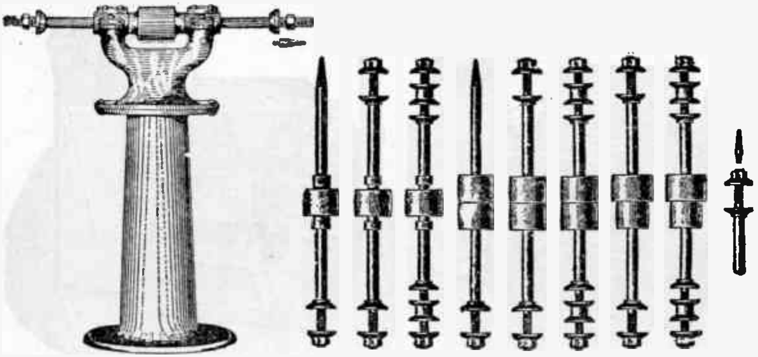


FIG. 6,387.—Polishing and buffing head. Polishing and buffiing heads range in size from those sufficiently strong to run wooden polishing wheels up to 16 inches in diameter, and those designed to run 9 or 10 inch buffs at 3,000 revolutions per minute, to those known as light polishing heads, capable of being operated on a bench without the use of a counter shaft.

FIGS. 6,397 to 6,388.—Steel spindles used with polishing head.

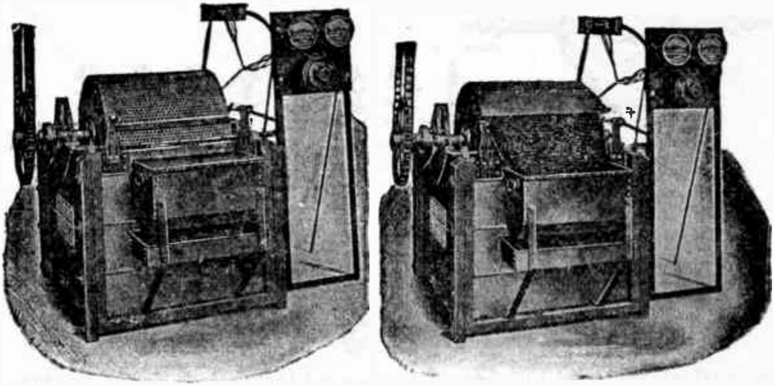
adhere perfectly to those metals, while on the other hand, silver will adhere perfectly to copper and copper to the soft metals.

The copper plating solutions employed for this purpose, and for electrotyping are acid solutions of copper sulphate.

Polishing and Grinding Machines.—These machines, or heads consist of a stand carrying a small pulley between two bearings with shaft extended at each end to take the various buffing, polishing and grinding wheels, brushes, etc.

Polishing Wheels.—These are made of canvas, wood, felt, leather, and walrus hide. Rough heavy castings are first ground upon coarse solid emery or carborundum wheels, usually run at a slow speed, not exceeding 1,000 revolutions per minute

Canvas wheels are used fcr roughing out. Felt wheels can be used for roughing, grinding, polishing and finishing. Walrine wheels are used chiefly in giving a fine polish to silverware, brass goods, etc. They can be used with crocus, emery, rouge, or rotten stone, and] give a smooth fine finish to the work.



FIGS. 6,398 and 6,399.—U.S. electro-plating barrel. Fig. 6,398, view while plating; fig. 6,399, view while emptying. It empties by lifting a lever which reverses the motion of the barrel.

Pickles and Dips.—While the best polish is secured by grinding and wheel polishing, many articles are best cleaned chemically by *immersing them in solutions which dissolve the scale, grease, etc., adhering to them, leaving a clean but rough surface which must be polished afterwards.*

Black Pickle for Iron:—Sulphuric acid 66° Baume, 1 part; water, 15 parts. Used chiefly for removing scale from castings and forgings.

Bright Pickle for Iron:—Water, 10 quarts; concentrated sulphuric acid, 28 oz.; zinc, 2 oz.; nitric acid, 12 ozs. Mix in the order named. The pickle leaves the metal bright.

Dip for Copper, Brass, etc.:—Sulphuric acid, 66° Baume, 50 parts by weight; nitric acid, 36° Baume, 100 parts by weight; common salt, 1 part by weight; lamp black, 1 part by weight. Forgings, punchings, etc., are pickled in dilute sulphuric acid to remove scale, and then cleaned and brightened by dipping in the above solution.

Cyanide Dip for Brass:—Potassium cyanide in ten times its weight of water is used as a preliminary dip when plating articles that would have the polish injured by the acid dips. The work must be allowed to remain longer in this than in the acid solutions.

Pickle for German Silver:—German silver may be cleaned in the bright dip for brass, or in a preliminary pickle of dilute nitric acid and water (12 to 1), followed by a dip of equal parts of sulphuric and nitric acids, and then by rinsing in boiling water and drying in sawdust. Use sawdust that contains no tannin.

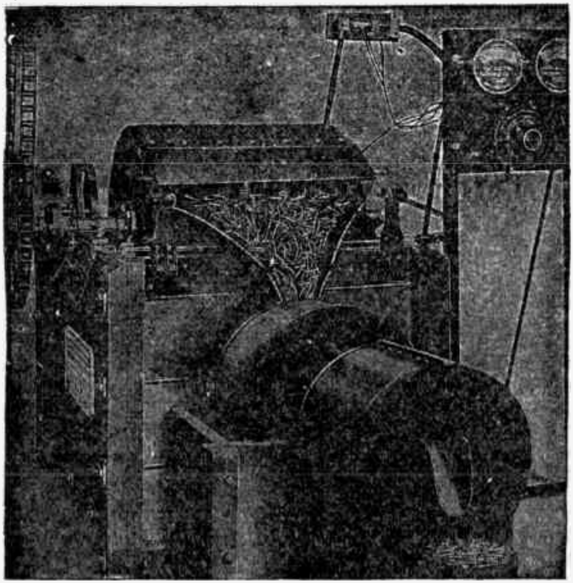


FIG. 6,400.—U. S. electro-plating and self-emptying barrel for brass, nickel, copper, tin, zinc, etc. ***Method of galvanizing:*** After pickling and cleaning the material, the galvanizing barrel is then filled by means of pails, shovels, etc., with from 150 to 200 lbs. of material at a time and is then started to turn slowly "in the galvanizing direction," and in about 40 to 50 minutes the material is finished. Upon reversing the motion of the barrel, it thereupon empties the galvanized material (in from three to four minutes) into the washing drum of the washing and drying apparatus and gradually goes into draining drum, from there to drying drum, from there into whatever receptacle is placed for receiving the material ready for shipment. ***Quality and thickness of coating:*** The thickness of the coating can be regulated according to requirements, and depends upon the length of time the material is allowed to remain in the galvanizing barrel while galvanizing. The coating deposited consists of chemically pure zinc, uniformly smooth. With the apparatus, one laborer can attend to two barrels and turn out from 3,000 to 5,000 lbs. of material per day; two men and a boy will be able to attend to about six barrels. ***Range of the barrel:*** The barrel will galvanize any kind of small material as, for instance: bolts and nuts (from the smallest size to 8 in. long), nails, rivets, spikes, screws, small castings and fittings, stampings, sash pulleys, lag screws, washers, springs, etc., in fact all such material excepting that having very deep recesses or hollow material which requires inside galvanizing.

Nickel Plating.—Nickel does not adhere very well to iron or steel articles, and furthermore, if after being plated upon steel, the article becomes scratched, the steel rusts, and the rust, getting beneath the nickel film, causes it to peel off.

It is, therefore, very usual to first coat the iron with a film of copper, which, being a soft metal, is not readily removed by scratching. The nickel is then deposited upon the copper coating. Nickel cannot be deposited from solutions containing more than a trace of acid; most nickel plating solutions consist of a solution of the double salt of ammonium sulphate and nickel sulphate, which is rendered alkaline with ammonia.

In order to obtain a thoroughly satisfactory and brilliant deposit of nickel, the articles which are to be plated must be very carefully prepared, and should have a burnished surface.

Electrotyping.—In preparing electrotypes *a wax impression is taken of the form, which is made up usually of type, or illustrations, or both.*

In order to do this a metal plate is evenly coated with a wax composition, and this is placed with the wax face downward upon the form. The form with the wax upon it is then placed in a hydraulic press and subjected to a steady pressure of about two tons to the square inch. To prevent the type adhering to the wax, it is dusted over with finely powdered graphite. After being taken out of the press, the wax is carefully removed from the form. The mould is next coated with black lead to give it a metallic surface, as the wax is a non-conductor; the mould is then subjected to the process of electro deposition, resulting in the formation of a film of copper on the prepared surface.

A battery or dynamo is used to generate the current. The positive terminal of the source of current is connected to a rod extending across a trough or tank containing the plating bath. Suspended from the rod are anodes of copper, from which a deposit is desired. The other terminal of the source is connected with another rod across the trough, to which are suspended the articles to be plated.

The copper shell is removed from the mould by applying hot water; the shell is then backed up with electrotype metal to render it strong enough for use.

Galvanizing.—A bath containing zinc sulphate, which must only be slightly acid, is employed; as the electrolysis proceeds the solution becomes acid by the zinc being deposited out, and in order to keep the strength of the solution constant, it is circulated through a filter bed containing zinc dust.

Zinc anodes are not generally used because they are apt to disintegrate; the anodes usually employed are of lead, but iron is sometimes used. In fact, the presence of a trace of iron in the bath improves the deposit.

CHAPTER 10

Alternating Currents

An alternating current is defined as: *A current which reverses its direction in a periodic manner, rising from zero to maximum*

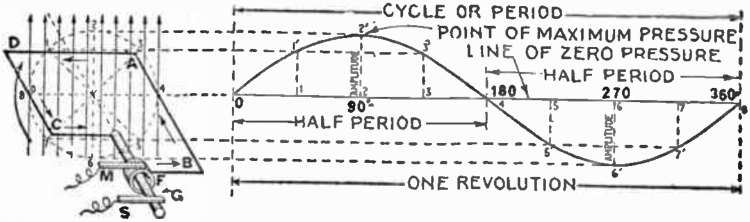


FIG. 6,401.—Alternating current represented by the *sine curve.* As the elementary alternator rotates the induced electric pressure will vary in such a manner that *its intensity at any point of the rotation is proportional to the sine of the angle corresponding to that point.* Hence, on the horizontal line which passes through the center of the dotted circle, take any length as 08, and divide into any number of equal parts representing fractions of a revolution, as 0°, 90°, 180°, etc. Erect perpendiculars at these points and from the corresponding points on the dotted circle project lines (parallel to 08) to the perpendiculars; these intersections give points, on the sine curve. The curve lies above the horizontal axis during the first half of the revolution and below it during the second half, which indicates that the current flows in one direction for a half revolution, and in the opposite direction during the remainder of the revolution.

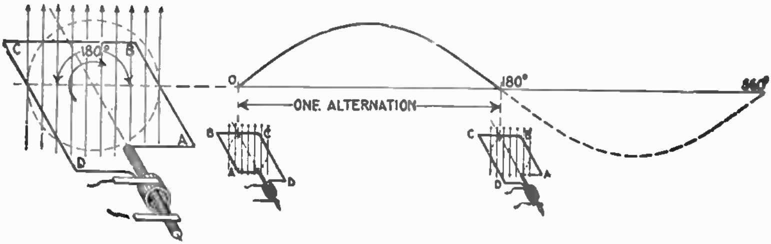


FIG. 6,402.—Diagram showing one *alternation* of the current in which the latter varies from zero to maximum and back to zero while the generating loop ABCD makes one half revolution.

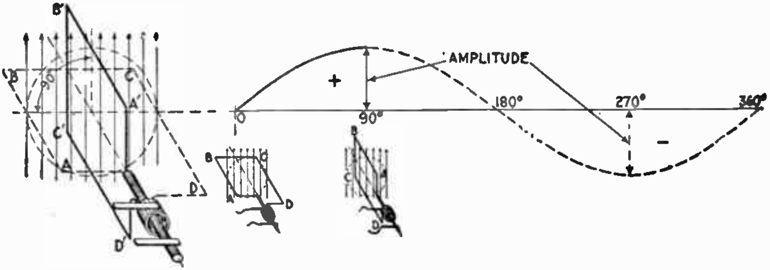


FIG. 6,403.—Diagram illustrating *amplitude* of the current. The current reaches its amplitude or maximum value in one quarter period from its point of zero value, as, for instance, while the generating loop moves from position ABCD to A'B'C'D'. At three-quarter revolution, the current reaches its maximum value in the opposite direction.

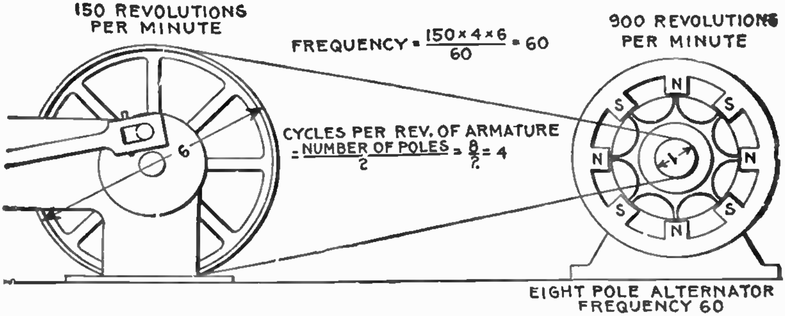


FIG. 6,404.—Diagram illustrating *frequency*. The frequency or *cycles per second* is equal to *the revolutions of armature per second* × ½ *number of poles per phase*.

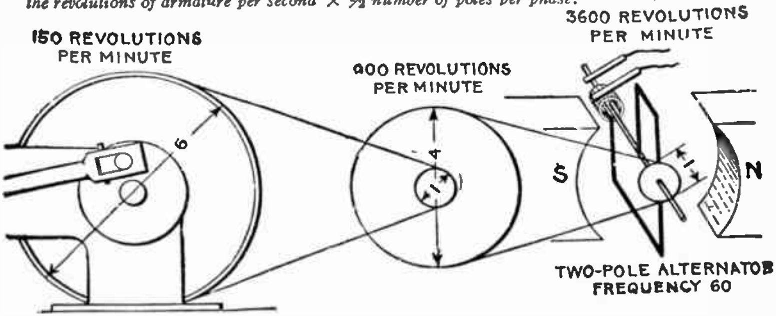
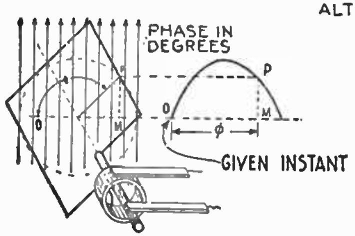


FIG. 6,405.—Diagram illustrating *why alternators are built multi-polar*. Evidently the excessive speed of the bi-polar alternator would require such great velocity reduction that an intermediate reduction gear would be necessary requiring extra space and adding complication.

strength, returning to zero, and then going through similar variations in strength in the opposite direction; these changes comprise the *cycle* which is repeated with great rapidity.



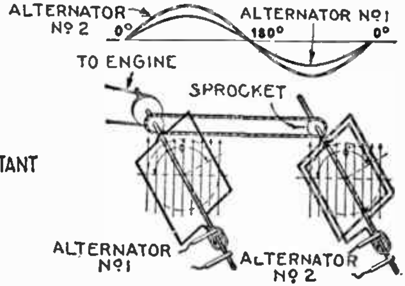
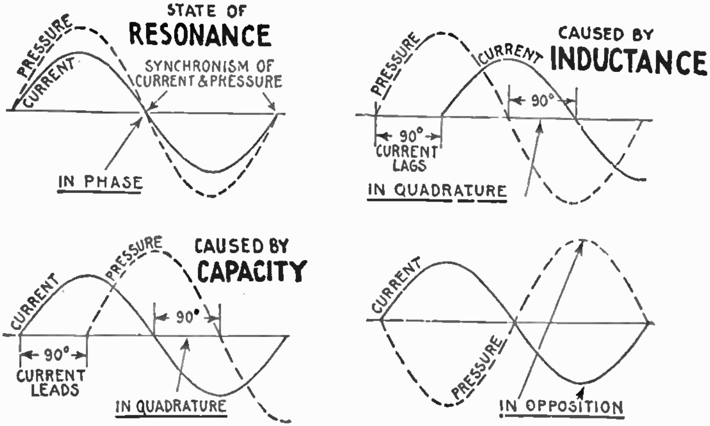


FIG. 6,406.—Diagram illustrating ***phase.*** By definition *phase is the angle turned through by the armature reckoned from a given instant.*

FIGS. 6,407 and 6,408.—Diagrams illustrating ***in phase*** or ***synchronism.*** If two alternators with coils in parallel planes be made to rotate "in step" with each other as by chain connection, they will then operate *in phase* or *in synchronism*, and the alternating pressure or current in one will vary in step with that in the other.



FIGS. 6,409 to 6,412.—Phase relations of the current.

The advantage of alternating current (*a.c.*) over direct current (*d.c.*) lies in the reduced cost of transmission by use of high voltages and transformers, greater simplicity of alternators and *a.c.* motors, facility of transforming from one voltage to another (either higher or lower) for different purposes.

The disadvantages of alternating current are: 1, the high pressure at which

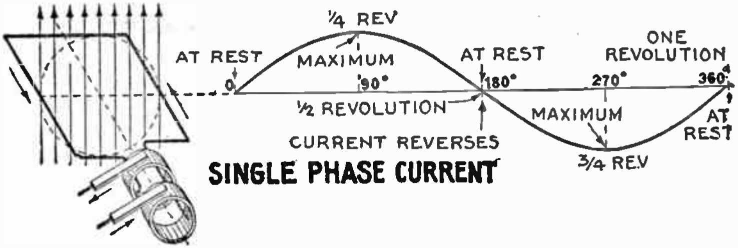


Fig. 6,413.—*Single phase current.*—There are three points during the cycle at which there is no current and no pressure: 0°, 180°, and 360°. The current reaches a maximum at 90°, reverses at 180°, and reaches a maximum in the reverse direction at 270°.

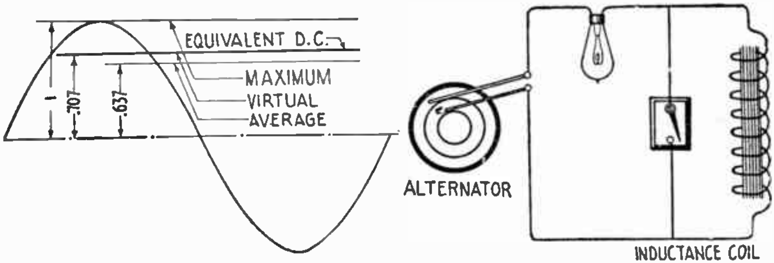


Fig. 6,414.—Maximum, *virtual* and average volts. *The virtual value of an alternating pressure or current is equivalent to that of a direct pressure or current which would produce the same effect.* If a Cardew voltmeter be placed on an alternating circuit in which the volts are oscillating between maxima of + 100 and — 100 volts, it will read 70.7 volts, though the arithmetical mean is really only 63.7; 70.7 steady volts would be required to produce an equal reading. The word *effective is commonly used erroneously for virtual.*

Fig. 6,415.—Diagram illustrating *virtual* and *effective* pressures. When switch is closed the whole of the impressed pressure will be effective in causing current to flow around the circuit. In this case the virtual and effective pressures will be equal. If the coil be switched into circuit, the reverse pressure due to self induction will oppose the virtual pressure; hence, the effective pressure (which is the difference between the virtual and reverse pressures) will be reduced, the virtual or impressed pressure remaining constant all the time.

NOTE.—*A Cardew voltmeter* indicates electric pressure by the passage of the current through a slender wire of platinum silver which thereupon expands and moves the index needle upon the scale.

it is used renders it dangerous, requiring more efficient insulation, alternating current cannot be used for such purposes as electroplating, charging storage batteries, etc.

The various terms relating to alternating current illustrated in the accompanying cuts should be thoroughly understood.

Single or Monophase Current.—This is produced by an

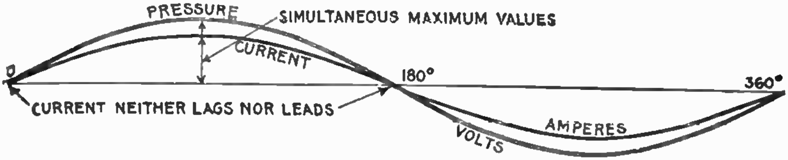


FIG. 6,416.—Pressure and current curves illustrating the term "in phase." The current is said to be *in phase* with the pressure when it *neither* lags nor leads.

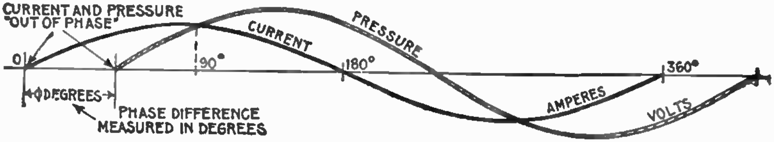


FIG. 6,417.—Pressure and current curves illustrating the term "out of phase." The current is said to be *out of phase* with the pressure when it *either* lags or leads, that is when the current is not in synchronism with the pressure. In practice the current and pressure are nearly always out of phase.

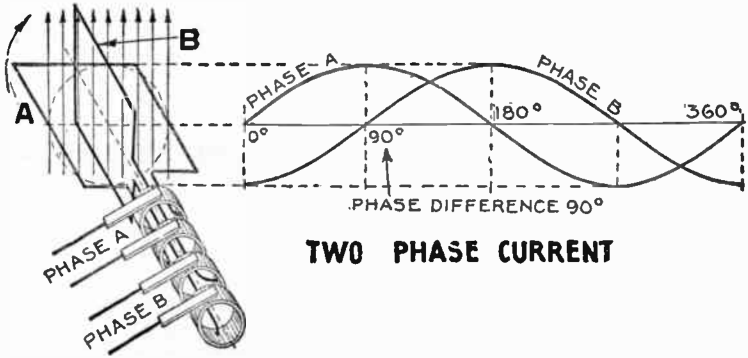
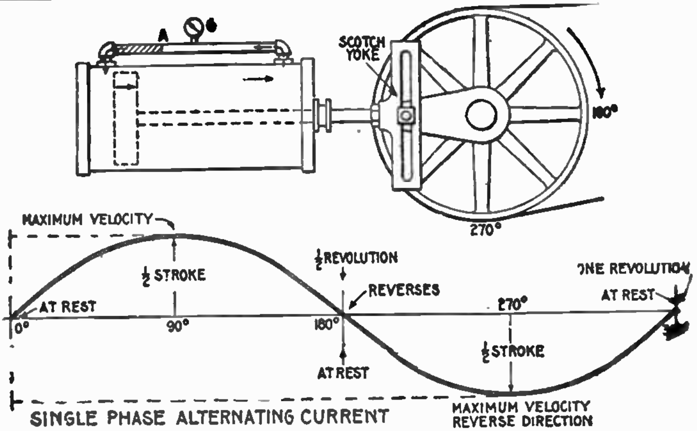
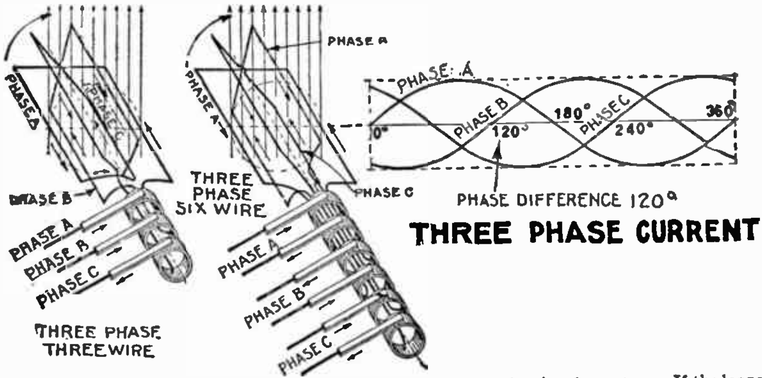


FIG. 6,418.—*Two phase current.*—If the loops be placed on the alternator armature at 90 magnetic degrees, a single phase current will be generated in each of the windings, the current in one winding being at its maximum value when the other is at zero. In this case four transmission conductors are generally used, two for each separate circuit.



FIGS. 6,419 and 6,420.—Hydraulic analogy of single phase current. If the cylinder and pipe be full of water, a current of water will begin to flow through the pipe in the direction indicated as the piston begins its stroke, increasing to maximum velocity at one-quarter revolution of the crank, decreasing and coming to rest at one-half revolution, then reversing and reaching maximum velocity in the reverse direction at three-quarter revolution, and coming to rest again, at the end of the return stroke. A pressure gauge at G. will register a pressure which varies with the current. Since the alternating electric current undergoes similar changes, the sine curve will apply equally as well to the pump cycle as to the alternating current cycle.



FIGS. 6,421 and 6,422.—*Three phase current* with three and six wire alternators. If the loops be placed on the alternator armature at 120 magnetic degrees from one another, the current in each will attain its maximum at a point one-third of a cycle distant from the other two. The arrangement shown in fig. 6,422 gives three independent single phase currents and requires six wires for their transmission. A better arrangement and the one generally used is shown in fig. 6,421. Here the three ends (one end of each of the loops) are brought together to a common connection as shown, and the other ends, connected to the collector rings giving only three wires for the transmission of the current.

alternator, whose armature has a single winding as in fig. 6,413. Two wires, a lead and return are used.

Two-Phase Current.—Usually these are two distinct single phase currents flowing in separate circuits. There is often no electrical connection between them.

They are of equal periods and amplitude but differ in phase by ¼ of a period, as shown in fig. 6,418. With this phase relation one of them will be at a maximum when the other is at zero.

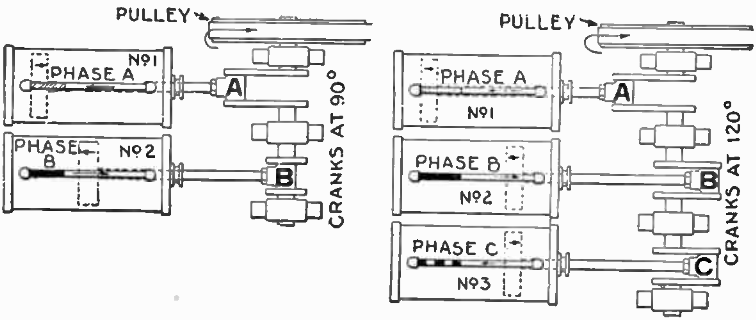


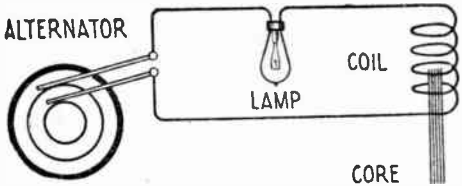
FIG. 6,423.—Hydraulic analogy of two phase current. The same cycle of water flow takes place as in figs. 6,419 and 6,420. Since the cranks are at 90°, the second piston is one-half stroke behind the first; the flow of water in No. 1 (phase A) is at a maximum when the flow in No. 2 (phase B) comes to rest, the current conditions in both pipes for the entire cycle being represented by two sine curves whose phase difference is 90°.

FIG. 6,424.—Hydraulic analogy of three phase current. Three cylinders are here shown with pistons connected through Scotch yokes to cranks placed 120° apart. The same action takes place in each cylinder as in the preceding cases, the only difference being the additional cylinder, and difference in phase relation.

Three Phase Currents.—This consists of *three alternating currents of equal frequency and amplitude, but differing in phase from each other by ⅓ of a period.*

When any one of the currents is at its maximum the other two are of half their maximum value and are flowing in the opposite direction.

Induction.—Each time a current is started, stopped or



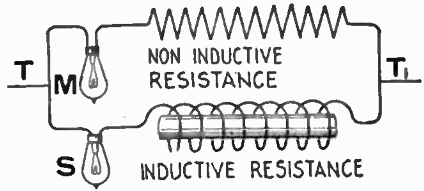
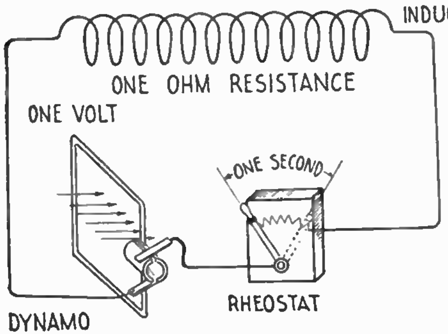


FIG. 6,425.—***Self-induction*** in *a.c.* circuit. Lamp burns dimly before core is inserted into the coil, and assuming the coil to be made of one pound of No. 20 magnet wire, lamp will go out when core is inserted owing to the self-induction of the coil which is greatly increased by the presence of the iron core.

FIG. 6,426.—***Non-inductive*** and ***inductive resistances.*** If *d.c.* be applied at TT′ (the two ohmic resistances being the same) the lamps M and S, will burn with equal brilliancy. If *a.c.* be applied at TT′, M, will burn brightly while S, will give little or no light owing to the inductance of the inductive resistance.



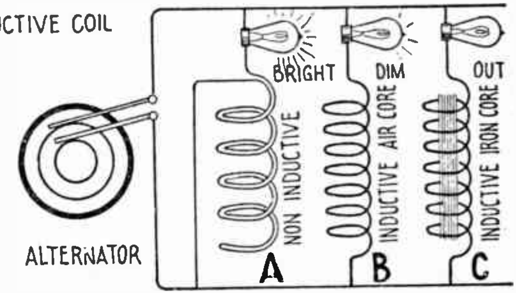
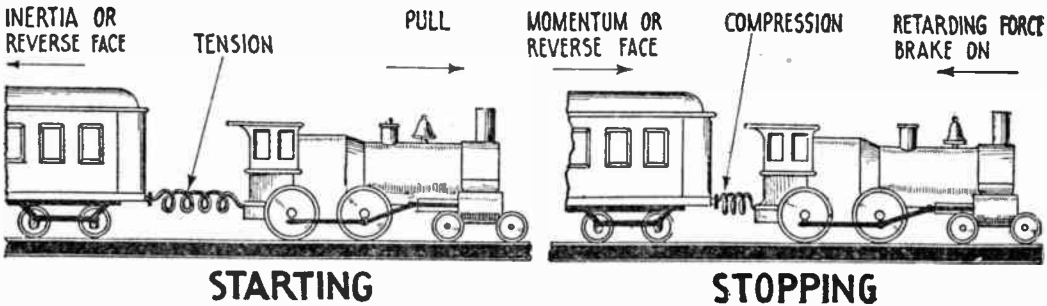


FIG. 6,427.—Diagram illustrating the ***henry.*** By definition: *A circuit has an inductance of one henry when a rate of change of current of one ampere per second induces a pressure of one volt.* It is assumed that the resistance of the dynamo and connecting wires is zero.

FIG. 6,428.—Effect on *a.c.* of various coils. Assuming each coil has the same (ohmic) resistance, a lamp will burn brightly, be dimmed, or go out when joined in series with coils A, B, or C respectively. Note the method of winding coil A, to make it *non-inductive.*



FIGS. 6,429 and 6,430.—Mechanical analogy of self-induction in an *a.c.* circuit. ***In starting,*** the locomotive first moves and stretches the spring before the car begins to move thus producing an initial force necessary to overcome the opposition or inertia of matter which resists the effort to change it from a state of rest to a state of motion. ***In stopping,*** the opposite conditions obtain. ***Similarly,*** like conditions are present each time electricity is set in motion or brought to rest. This opposition is visibly presented on opening a switch, the current momentarily ***arcing the gap,*** against the enormous resistance thus introduced.

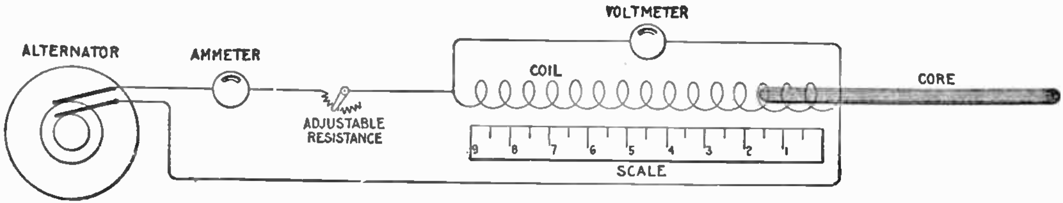
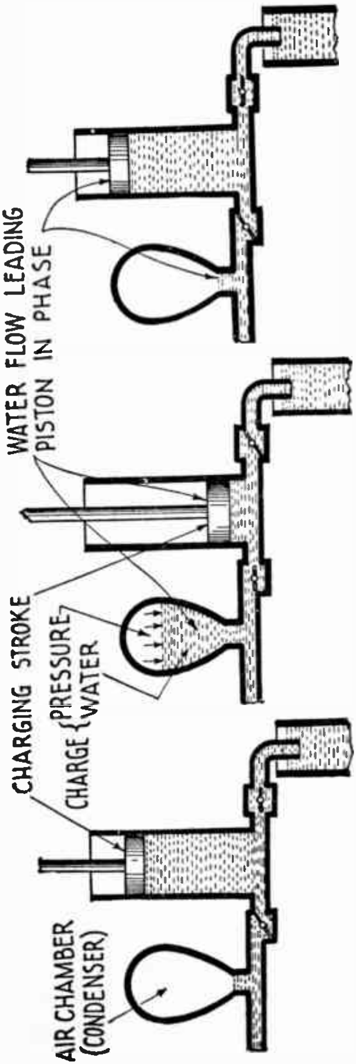


FIG. 6,431.—Inductance test, illustrating the self-induction of a coil which is gradually increased by moving an iron wire core inch by inch into the coil. The current is kept constant with the adjustable resistance throughout the test and readings taken first without the iron core, and again when the core is put in the coil and moved to the 1, 2, 3, 4, etc., inch marks. By plotting the voltmeter readings and the position of the iron core on section paper, a curve is obtained showing graphically the effect of the self-induction.



FIGS. 6,432 to 6,434.—Hydraulic analogy of **capacity**. The pressure pump on the down stroke (figs. 6,432 and 6,433) forces (*impressed pressure*) the water into the air chamber (*condenser*) charging it against an increasing back pressure, which, at the end of the stroke is *in excess* of the pressure due to the head (*resistance*) pumped against. This accumulation of pressure in the air chamber keeps the water (*current*) flowing while the piston is on the return stroke (figs. 6,433 and 6,434), and the impressed pressure (volts) is zero, the *water flow* (current) *leading* in phase the power stroke (*volts*) of the pump.

varied in strength, *the magnatism changes, and* **induces** *a reverse pressure that opposes the pressure which produces the current.*

This self-induced reverse pressure tends to weaken the main current at the start and prolong it when the circuit is opened.

Evidently since an alternating current is continually varying in strength and reversing, there will always be more or less opposition due to the reverse pressure, this opposition being called the ***spurious resistance*** as distinguished from the ***ohmic resistance*** or ***true*** resistance. Hence in the flow of alternating current in a circuit there will be two retarding effects, due to the spurious and ohmic resistances.

The spurious resistance depends upon the frequency, shape of the conductor, and nature of the surrounding medium.

The expression *inductance* is frequently used in the same sense as *coefficient of self-induction*, or the capacity which an electric current has of producing induction within itself. *The unit of inductance is the henry*, named after Joseph Henry.* The ohmic equivalent of inductance, or

$$X_l = 2\pi f L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

in which f = frequency; L = henrys.

Capacity.—When an electric pressure is applied to a condenser, the current plays in and out, charging the condenser in alternate directions.

As the current runs in at one side and out at the other, the dielectric becomes charged, and tries to discharge itself by setting up an opposing electric pressure. This opposing pressure rises just as the charge increases.

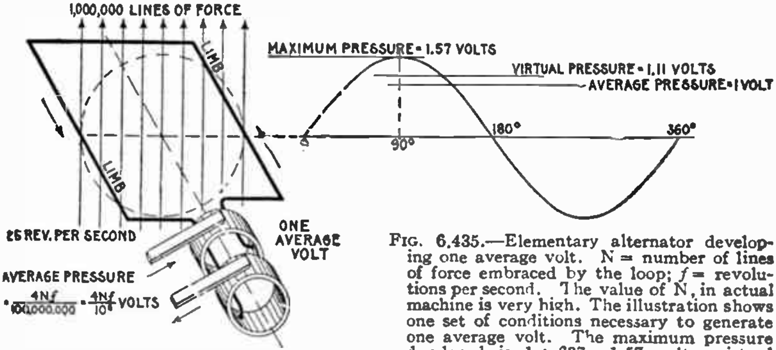


FIG. 6,435.—Elementary alternator developing one average volt. N = number of lines of force embraced by the loop; f = revolutions per second. The value of N, in actual machine is very high. The illustration shows one set of conditions necessary to generate one average volt. The maximum pressure developed is 1 ÷ .637 = 1.57 volts; virtual pressure = 1.57 × .707 = 1.11 volts.

*NOTE.—*Joseph Henry*, the American physicist, was born 1797, died 1878. He was noted for his researches in electromagnetism. In 1831, he employed a mile of fine copper wire with an electromagnet, causing the current to attract the armature and strike a bell, thereby establishing the principle employed in modern telegraph practice. He was made a professor at Princeton in 1832, and during his experimenting then, he devised an arrangement of batteries and electromagnets embodying the principle of the telegraph relay which made possible long distance transmission. *He was the first to observe magnetic self-induction*, and performed important investigations in oscillating electric discharges (1842), and other electrical phenomena. Henry enjoyed an international reputation, and is acknowledged to be one of America's greatest scientists.

NOTE.—"I adhere to the term *virtual*, as it was in use before the term *efficace* which was recommended in 1889 by the Paris Congress to denote the *square root of mean square* value. The corresponding English adjective is *efficacious;* but some engineers mistranslate it with the word *effective*. I adhere to the term *virtual* mainly because the adjective *effective* is required in its usual meaning in kinematics to represent the resolved part of a force which acts obliquely to the line of motion, the effective force being the whole force multiplied by the cosine of the angle at which it acts with respect to the direction of motion. Some authors use the expression 'R. M. S. value' (meaning 'root mean square') to denote the virtual or quadratic mean value."—*S. P. Thompson.*

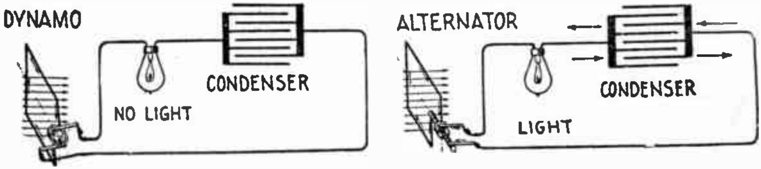
The effect of capacity is the opposite of inductance, that is, *it assists the current to rise to its maximum sooner than it would otherwise.*

A condenser is said to have a capacity of one farad *when one coulomb of electricity stored in the plates of the condenser will cause a pressure of one volt across its terminals.* Every alternating current circuit acts as a condenser.

The ohmic equivalent of capacity or capacity reactance

$$X_c = \frac{1}{2\pi f C} \quad \text{.........................(2)}$$

in which f = frequency; C = capacity of standard condenser.



FIGS. 6,436 and 6,437.—Effect of condenser on *d.c.* and *a.c.* circuits. In fig. 6,436 the condenser prevents the flow of direct current, hence no light. In fig. 6,437 the condenser gap does not hinder the flow of *a.c.* in the metallic portion of the circuit, hence lamp will light. *In fact* the alternator produces a continual surging of electricity backwards and forwards from the plates of the condenser around the metallic portion of the circuit, similar to the surging of waves against a bulkhead which projects into the ocean.

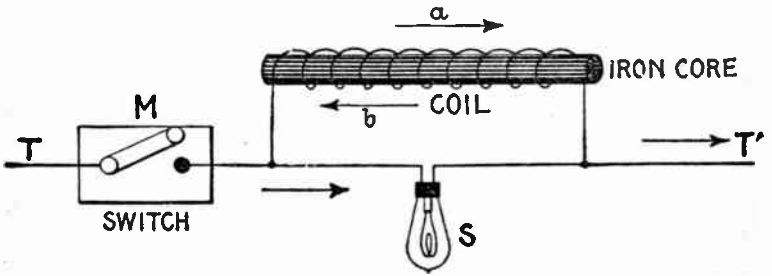
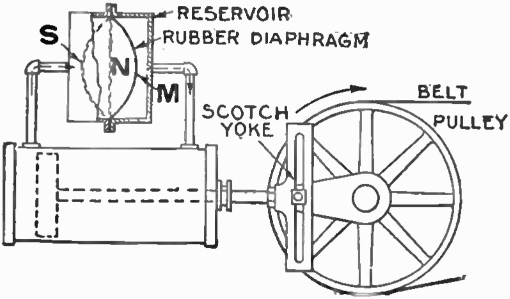


FIG. 6,438.—Inductance experiment with intermittent direct current. A lamp is connected in parallel with a coil of fairly fine wire having a removable iron core, and the terminals T, T' connected to a source of direct current, a switch M, being provided to interrupt the current. The voltage of the current and resistance of the coil are of such values that when a steady current is flowing, the lamp filament is just perceptibly red. *At the instant of making the circuit, the lamp will momentarily glow more brightly than when the current is steady; on breaking the circuit the lamp will momentarily flash with great brightness.* In the first case, the reverse pressure, due to inductance, as indicated by arrow *b*, will momentarily oppose the normal pressure in the coil, so that the voltage at the lamp will be momentarily increased, and will consequently send a momentarily stronger current through the lamp. On breaking the main circuit at M, the field of the coil will collapse, generating a momentary much greater voltage than in the first instance, in the direction of arrow *a*, the lamp will flash up brightly in consequence.



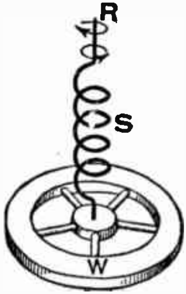


FIG. 6,439.—Hydraulic analogy illustrating capacity in an alternating current circuit. A chamber containing a rubber diaphragm is connected to a double acting cylinder and the system filled with water. ***In operation,*** as the piston moves, say to the left from the center, the diaphragm is displaced from its neutral position N, and stretched to some position M, in so doing offering increasing resistance to the flow of water. On the return stroke the flow is reversed and is assisted by the diaphragm during the first half of the stroke, and opposed during the second half. The diaphragm thus acts with the flow of water one-half of the time and in opposition to it one-half of the time. This corresponds to the electrical pressure at the terminals of a condenser connected in an alternating current circuit, and it has a maximum value when the current is zero and a zero value when the current is a maximum.

FIG. 6,440.—Mechanical analogy illustrating effect of capacity in an alternating circuit. If an alternating twisting force be applied to the top R, of the spring S, the action of the latter may be taken to represent capacity, and the rotation of the wheel W, alternating current. The twisting force (impressed pressure) must first be applied *before* the rotation of W (current) will begin. The resiliency or rebounding effect of the spring will, in time, cause the wheel W, to move (amperes) in advance of the twisting force (voltage), thus representing the current *leading in phase.*

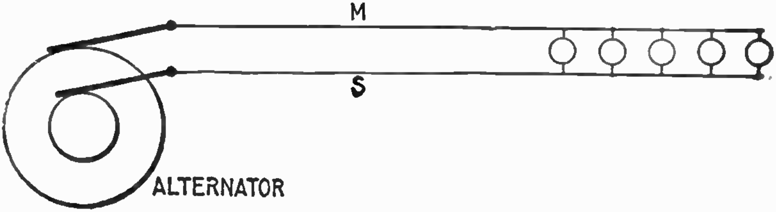


FIG. 6,441.—Diagram illustrating effect of capacity in an alternating circuit. Considering its action during one cycle of the current, the alternator first "pumps", say from M to S; electricity will be heaped up, so to speak, on S, and a deficit left on M, that is, S will be + and M −. If the alternator be now suddenly stopped, there would be a momentary return flow of electricity from S, to M, through the alternator. If the alternator go on working, however, it is obvious that the electricity heaped up on S, helps or increases the flow when the alternator begins to pump from S, to M, in the second half of the cycle, and when the alternator again reverses its pressure, the + charge on M, flows round to S, and helps the ordinary current. The above circuit is not strictly analogous to the insulated plates of a condenser, but, as is verified in practice, that with a rapidly alternating pressure, the condenser action is not perceptibly affected if the cables be connected across by some non-inductive resistance as for instance incandescent lamps.

Example.—What is the resistance equivalent of a 50 microfarad condenser to an alternating current having a frequency of 100?

Substituting in formula (2), the given values in the expression for ohmic value

$$X_c = \frac{1}{2\pi f C} = \frac{1}{2 \times 3.1416 \times 100 \times .000050} = \frac{1}{.031416} = 31.8 \text{ ohms.}$$

If the pressure of the supply be, say 100 volts, the current would be 100 ÷ 31.8 = 3.14 amperes.

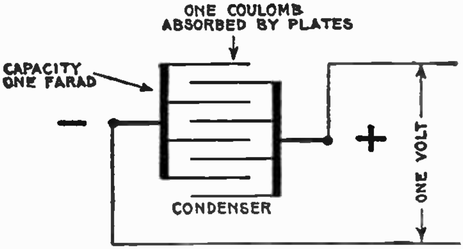
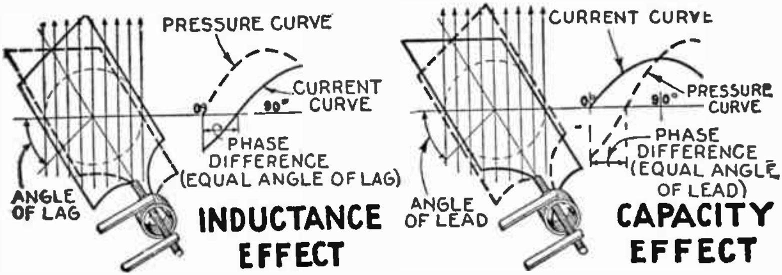


Fig. 6,442.—Diagram illustrating the ***farad.*** By definition, *a condenser is said to have a capacity of one farad if it will absorb one coulomb of electricity when subjected to a pressure of one volt.* This is a unit of large size and for convenience the ***microfarad,*** or one millionth of a farad is generally used.

Lag and Lead.—The alternating current does not always keep in step with the alternating volts which produce the current.



Figs. 6,443 and 6,444.—Diagrams illustrating ***lag*** and ***lead.*** The effect of inductance is to retard the current cycle, that is to say, if the current and pressure be in phase, the introduction of inductance will cause a phase difference, the current wave "lagging" behind the pressure wave as shown in fig. 6,443. The effect of capacity is to cause the current to rise to its maximum value sooner than it would otherwise do, as in fig. 6,444; capacity produces an effect exactly the opposite of inductance.

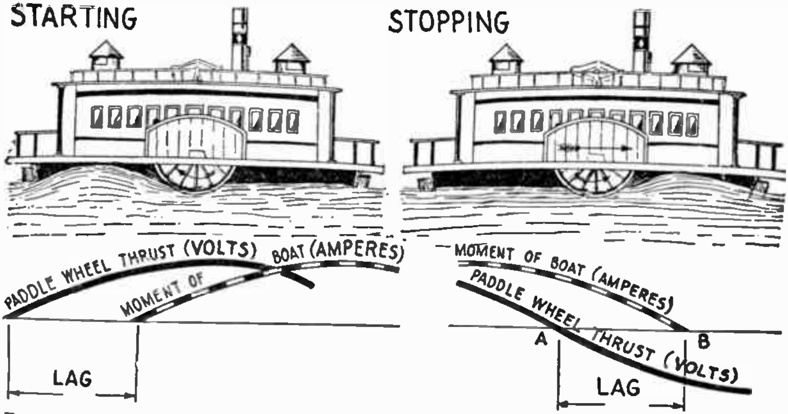
If there be **inductance** *in the circuit, the current will* **lag;** *if there be* **capacity** *the current will* **lead** *in phase.*

Lag and lead are measured in degrees. The angle of lag (symbol ϕ) is the angle where the tangent of the angle of the lag is equal to the quotient of the spurious resistance divided by the ohmic resistance, that is

$$\tan \phi = \frac{\text{spurious resistance}}{\text{ohmic resistance}} = \frac{2\,\pi f L}{R} \tag{3}$$

in which f = frequency; L = inductance in henrys; R = ohmic resistance.

Example.—An alternating circuit has an inductance of 6 ohms and a resistance of 2.5 ohms. What is the angle of lag?



FIGS. 6,445 to 6,448.—Ferry boat analogy of *lag.* ***In starting,*** the paddle wheels make an appreciable movement (*volts*) before the boat begins to move (*amperes*). Thus the movement of the boat (*amperes*) *lags* behind the thrust of the paddle wheels (*volts*). ***In stopping,*** the paddle wheels make several reverse turns (*reversal of a.c. volts*) before the movement of the boat (amperes) ceases, thus lagging behind the thrust of the paddles (*volts*).

Substituting in formula (1)

$$\tan \phi = \frac{6}{2.5} = 2.4$$

Referring to a table of natural tangents, the corresponding angle is approximately 67°.

The angle of lag may be anything up to 90°.

Reactance.—The *spurious resistance or inductance as* *distinguished from the ohmic resistance is called reactance and is expressed in ohms.*

Example.—If an alternating current whose frequency is 60, have an inductance of .5 henry, what is the reactance?

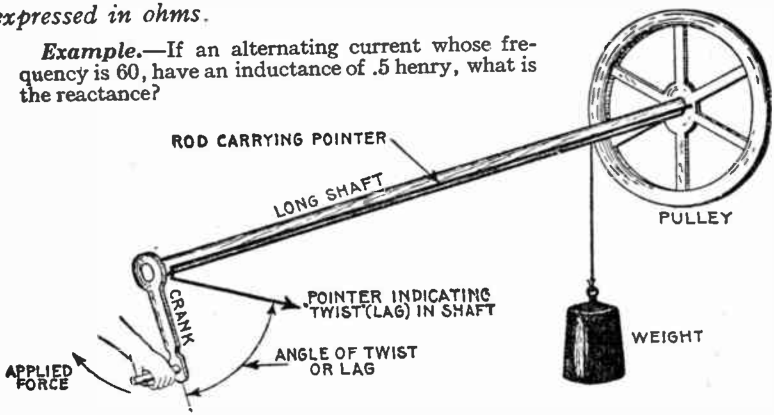


FIG. 6,449.—Mechanical analogy of lag. If at one end force be applied to turn a very long shaft, having a loaded pulley at the other, the torsion thus produced in the shaft will cause it to twist an appreciable amount which will cause the movement of the pulley to *lag* behind that of the crank. This may be indicated by a rod attached to the pulley and terminating in a pointer at the crank end, the rod being so placed that the pointer registers with the crank when there is no torsion in the shaft. The angle made by the pointer and crank when the load is thrown on, indicates the amount of lag which is measured in degrees.

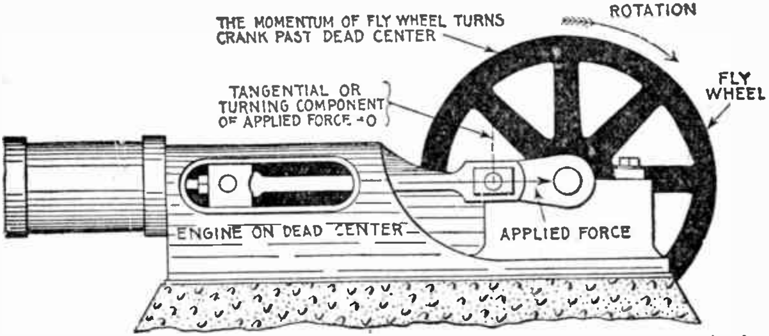
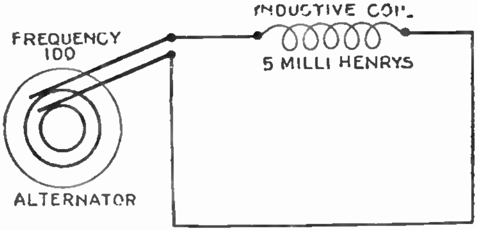


FIG. 6,450.—Steam engine analogy of current flow at zero pressure. When the engine has reached the dead center point the full steam pressure is acting on the piston, the valve having opened an amount equal to its lead. The force applied at this instant, indicated by the arrow is perpendicular to the crank pin circle, that is, the tangential or *turning* component is equal to zero, hence there is no pressure tending to turn the crank. The latter continues in motion past the dead center because of the momentum previously acquired. Similarly, the electric current, which is here analogous to the moving crank, continues in motion, though the pressure at some instants be zero, because it acts as though it had weight, that is, it cannot be stopped or started instantly.



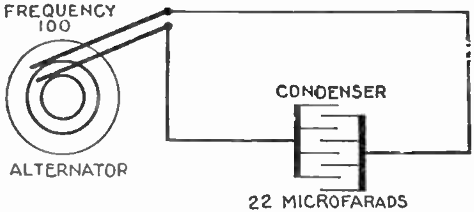
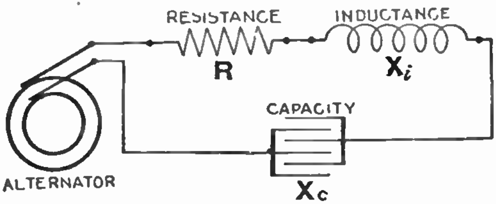


Fig. 6,451.—Diagram showing alternating circuit containing inductance. Formula for calculating the ohmic value of inductance or "inductance reactance," is $X_i = 2\pi fL$ in which X_i = inductance reactance; π = 3.1416; f = frequency; L = inductance *in henrys* (not Millihenrys). L 15 = millihenrys = 15 ÷ 1000 = .015 henrys. Substituting, $X_i = 2 \times 3.1416 \times 100 \times .015 = 9.42$ ohms.

Fig. 6,452.—Diagram showing alternating circuit containing capacity. Formula for calculating the ohmic value of capacity or "capacity reactance" is $X_c = 1 \div 2\pi fC$, in which X_i = capacity reactance; π = 3.1416; f = frequency; C = capacity *in farads* (not microfarads). 22 microfarads = 2 ÷ 1,000,000 = .000022 farad. Substituting, $X_c = 1 \div (2 \times 3.1416 \times 100 \times .000022) = 72.4$ ohms.



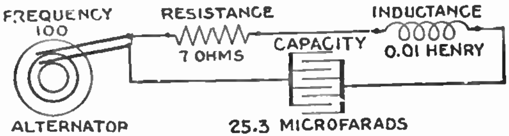


Fig. 6,453.—Diagram showing alternating circuit containing resistance, inductance, and capacity. Formula for calculating the impedance of this circuit is $Z = \sqrt{R^2 + (X_i - X_c)^2}$, in which Z = impedance; R = resistance; X_i = inductance reactance X_c = capacity reactance. Example: What is the impedance when R = 4, X_i = 92.4, and X_i = 72.4. Substituting $Z = \sqrt{4^2 + (94.2 - 72.4)^2} = 22.2$ ohms. Where the ohmic values of inductance and capacity are given as in this example, the calculation of impedance is very simple, but when inductance and capacity are given in millihenrys and microfarads respectively, it is necessary to first calculate their ohmic values as in figs. 6,451 and 6,452.

Fig. 6,454.—Diagram of a resonant circuit. A circuit is said to be resonant when the inductance and capacity are in such proportion that the one neutralizes the other, the circuit then acting as though it contained only resistance. In the above circuit $X_i = 2\pi fL = 2 \times 3.1416 \times 100 \times .01 = 6.28$ ohms; $X_c = 1 \div (2 \times 3.1416 \times 100 \times .000253) = 6.28$ ohms whence the resultant reactance $= X_i - X_c = 6.28 - 6.28 = 0$ ohms. $Z = \sqrt{R^2 + (X_i - X_c)^2} = \sqrt{7^2 + 0^2} = 7$ ohms.

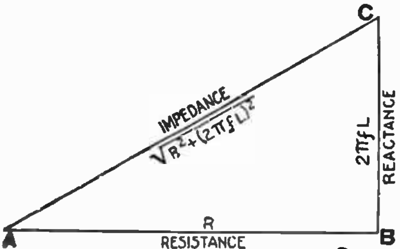
Substituting in formula (1)

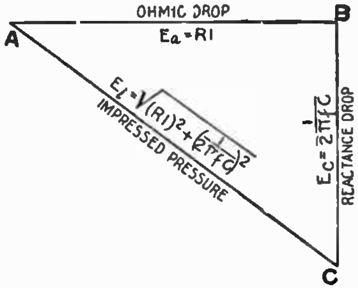
$$X_l = 2\pi f L = 2 \times 3.1416 \times 60 \times .5 = 188.5 \text{ ohms}$$

Impedance.—This term means *the total opposition in an electric circuit to the flow of an alternating current.*

1. When the circuit contains only resistance and reactance.

$$\text{impedance} = \sqrt{\text{resistance}^2 + \text{reactance}^2} \ldots\ldots\ldots\ldots\ldots (4)$$





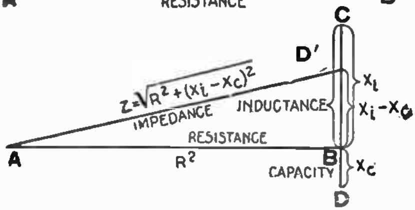


FIG. 6,455.—Graphical method of obtaining the impedance in circuits containing resistance and inductance, having given the resistance and reactance, that is, the ohmic resistance and spurious resistance. With any convenient scale lay off AB = *resistance*, and erect the perpendicular BC = *reactance* (using the same scale); join AC, whose length (measured with the same scale) will give the *impedance*.

FIG. 6,456.—Graphical method of obtaining the impressed pressure in circuits containing resistance and capacity, having given the ohmic drop and reactance drop due to capacity. With any convenient scale, lay off AB = *ohmic drop*, and at right angles to AB draw BC = *reactance drop* (using the same scale). Join AC, whose length (measured with the same scale) will give the *impressed pressure*. The mathematical expressions for the three quantities are given inside the triangle, and explained in the text.

FIG. 6,457.—Impedance diagram for circuit containing resistance, inductance and capacity. The symbols corresponding to those used in equation (1) below. In constructing the diagram from the given values, lay off AB = resistance; at B, draw a line at right angles, on which lay off above the resistance line, BC = inductive reactance, and below, BD = capacity reactance; then the resultant reactance = BC − BD = BD′. Join A and D′ then AD′ = impedance.

Example.—If an alternationg pressure of 100 volts be impressed on a coil of wire having a resistance of 6 ohms and inductance of 8 ohms, what is the impedance of the circuit and how many amperes will flow through the coil? In the example here given, 6 ohms is the resistance and 8 ohms the reactance. Substituting these in equation (4)

$$\text{impedance} = \sqrt{6^2 + 8^2} = \sqrt{100} = 10 \text{ ohms}$$

The current in amperes which will flow through the coil is, by Ohm's law using impedance in the same way as resistance.

$$\text{current} = \frac{\text{volts}}{\text{impedance}} = \frac{100 \text{ volts}}{10 \text{ ohms}} = 10 \text{ amperes.}$$

2. When the circuit contains resistance, reactance and capacity.

$$\textit{impedance} = \sqrt{\textit{resistance}^2 + (\textit{inductance reactance} - \textit{capacity reactance})^2}$$

or using symbols,

$$Z = \sqrt{R^2 + (X_i - X_c)^2} \qquad (5)$$

Example.—A current has a frequency of 100. It passes through a circuit of 4 ohms resistance, of 150 milli-henrys inductance, and of 22 microfarads capacity. What is the impedance?

a. The ohmic resistance R, is 4 ohms.

b. The inductance reactance, or

$$X_i = 2\pi f L = 2 \times 3.1416 \times 100 \times .15 = \mathbf{94.2} \text{ ohms.}$$

150 milli-henrys are reduced to .15 henry before substituting in the formula.

c. The capacity reactance, or

$$X_c = \frac{1}{2\pi f C} = \frac{1}{2 \times 3.1416 \times 100 \times .000022} = 72.4 \text{ ohms.}$$

22 microfarads are reduced to .000022 farad before substituting in the formula.

Substituting values as calculated in equation (5),

$$Z = \sqrt{4^2 + (94.2 - 72.4)^2} = \sqrt{491} = 22.2 \text{ ohms.}$$

Resonance.—Inductance and capacity oppose each other *when the effect of inductance neutralizes that of capacity the circuit is in a state of* ***resonance;*** that is, when X_i and X_c are equal in formula (5) the circuit is resonant.

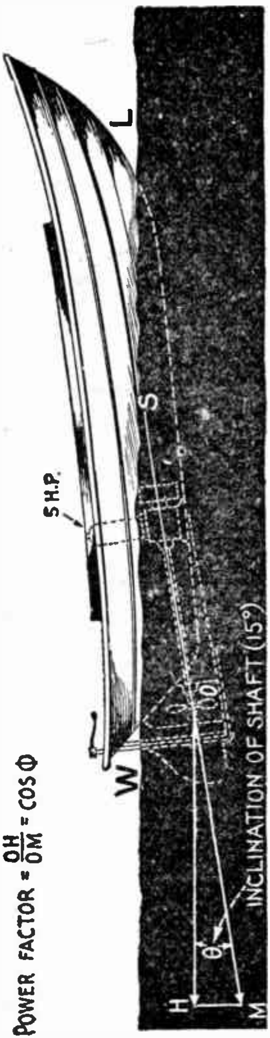


FIG. 6,458—Marine analogy of *power factor*. Usually the propeller shaft in a dory is at a considerable angle to the surface of the water, hence the full thrust of the propeller wheel is not effective in propelling the dory. The power of the engine then must be multiplied by a coefficient (less than unity) called the *power factor* to obtain the true or net power. On MS, take OM = thrust and draw from M, a vertical line to meet a horizontal line from O, at H. OH, then is the active component of the thrust serving to move the boat the power of the engine being reduced in the proportion of OH ÷ OM, but this is the *cosine* of angle ϕ, hence power factor = *cos* ϕ. ***Example***, The dory has a 5 *h.p.* engine (*kva*÷746) with shaft inclined 15° (angle ϕ), what is the power factor, and net power (*true watts*÷746) effective in propelling the dory? Power factor = cos ϕ = (from table), .966. Net power = (*kva*÷746 × *power factor*) = 5×.966 = 4.83 *h.p.*, 5−4.85 = .17 *h.p.* being lost because of inclination of shaft; this loss corresponds to the *wattless* components. The foregoing neglects the additional loss due to inefficiency of the propeller.

CHAPTER 11

Power Factor

When the alternating current is not in phase with the pressure, the product must be multiplied by a coefficient called the *power factor* in order to obtain the *true watts*, or actual power available.

By definition the power factor is: *the number of watts indicated by a watt meter, divided by the product of the ammeter reading, multiplied by the volt meter reading.*

The watt meter reading gives the ***true watts*** and the product of the ammeter and volt meter readings, the ***apparent watts.***

The power factor depends upon the relative amount of resistance, inductance and capacity in the circuit, and it may vary from one to zero.

When the current and pressure are in synchronism, the power factor is unity; *when there is lag or lead the power factor is less than unity.* Its usual value is slightly less than one. *The power factor is numerically equal to the cosine of the angle of phase difference between current and pressure.*

Example.—A circuit having a resistance of 3 ohms, and a resultant reactance of 4 ohms, is connected to a 100 volt line. What is: 1, the impedance, 2, the current, 3, the apparent power, 4. the angle of lag, 5, the power factor, and 6, the true power?

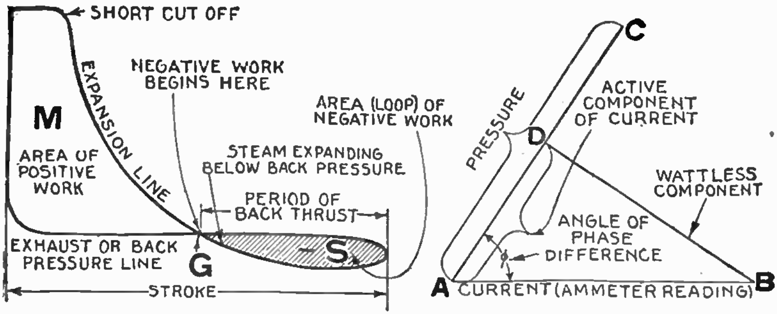


FIG. 6,459.—Steam engine analogy of power factor. In the card, the steam distribution is such that the steam is expanded below the back pressure line, that is below the pressure of the exhaust. This results in *negative work* which must be overcome by the *momentum* or *kinetic energy* previously stored in the fly wheel, and which is represented on the diagram by the shaded loop S. If the exhaust valve had opened at G, the amount of work done during the revolution would be represented by the area M, but continuing the expansion below the back pressure line, the work done is M − S. This latter case as compared with the first when expansion does not continue below the back pressure line gives an efficiency (power factor) of (M − S) ÷ M, the shaded area representing so much loss.

FIG. 6,460.—Method of obtaining the *active component* of the current; diagram illustrating why the power factor is equal to cos ϕ. If AB and AC be respectively the given current and pressure, or readings of the ammeter and voltmeter, and ϕ the angle of phase difference between current and pressure, then drawing from B, BD perpendicular to AC will give AD the active component. Now, true power = AC × AD, but AD = AB cos ϕ, hence true power = AC × AB cos ϕ. Again, apparent power = AC × AB, and since true power = apparent power × power factor, the power factor = cos ϕ.

1. *The impedance of the circuit.*

$$Z = \sqrt{3^2 + 4^2} = 5 \text{ ohms.}$$

2. *The current.*

current = volts ÷ impedance = 100 ÷ 5 = 20 amperes.

3. *The apparent power.*

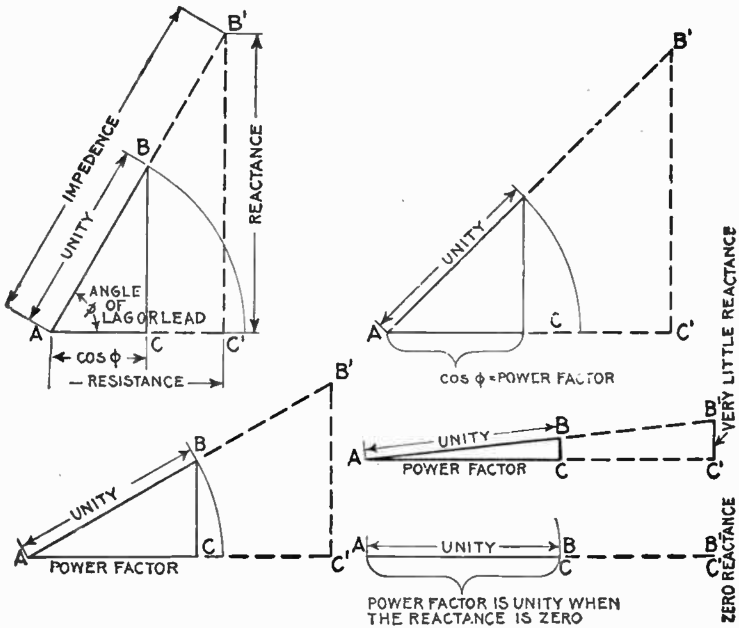
apparent power = volts × amperes = 100 × 20 = 2,000 watts.

4. *The tangent of the angle of lag.*
   tan ϕ = reactance ÷ resistance = 4 ÷ 3 = 1.33. From a table of natural tangents, ϕ = 53°.

5. *The power factor.*
   The power factor is equal to the cosine of the angle of lag, that is, power factor = cos 53° = .602 (from table).

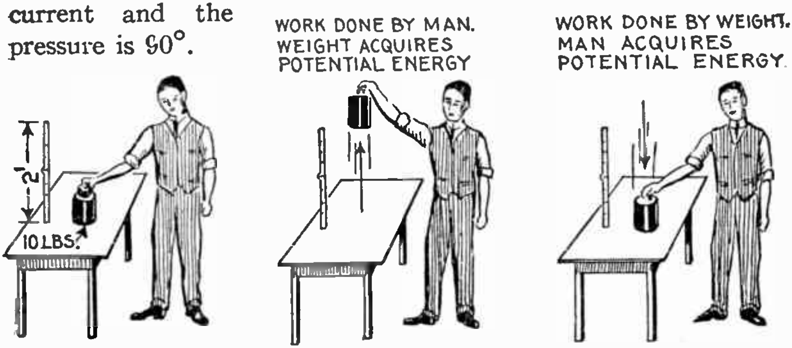
6. *The true power.*
   The true power is equal to the apparent watts multiplied by the power factor, or

$$\text{true power} = \text{volts} \times \text{amperes} \times \cos\phi$$
$$= 100 \times 20 \times .602 = 1{,}204 \text{ watts.}$$



FIGS. 6,461 to 6,465.—Diagrams illustrating *why the power factor is unity* when there is no resultant reactance in the circuit, that is, when the circuit is resonant, or has only resistance. The power factor is equal to the cosine of the angle of lag (or lead). In the figures this angle is BAC or ϕ and the value of the *natural cosine* AC gives the power factor. ***By inspection*** of the figures, it is evident that decreasing the reactance decreases the angle ϕ and increases cos ϕ or the power factor. The circular arc in each figure being at unity distance from the center A, the power factor with decreasing reactance evidently approaches unity as its limit, this limit being shown in fig. 6,465 where the reactance B'C' = O.

"Wattless Current"; Power Factor Zero.—When the power factor is zero, it means that the phase difference between the current and the pressure is 90°.



FIGS. 6,466 to 6,468.—Mechanical analogy of wattless current. If a man lift a weight any distance as from the position of fig. 6,466 to position of fig. 6,467, he does a certain amount of work on the weight giving it potential energy. When he lowers it to its original position, as in fig. 6,468, the weight loses the potential energy previously acquired, that is, it is given back to the man, the "system" (man and weight) having returned to its original condition as in fig. 6,466. During such a cycle, the work done by the man on the weight is equal to the work done by the weight on the man and no useful external work has been accomplished.

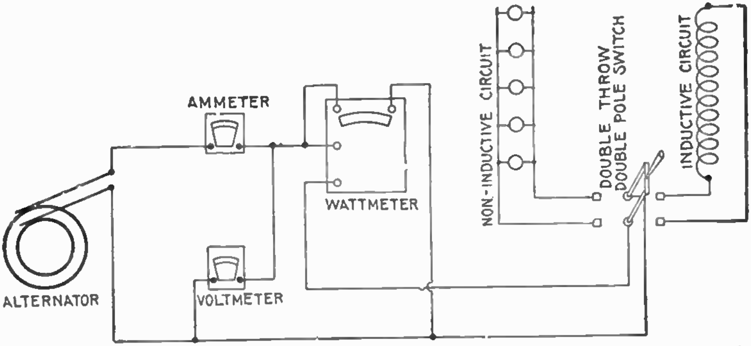


FIG. 6,469.—Diagram illustrating power factor test, when on non-inductive and inductive circuits. The instruments are connected as shown and by means of the double throw switch can be put on either the non-inductive or inductive circuit. First turn switch to left so that current passes through the lamps; for illustration, the following readings are assumed: ammeter 10, voltmeter 110, and wattmeter 1,100. The power factor then is wattmeter reading ÷ volts × amperes = 1,100 actual watts ÷ 1,100 apparent watts = 1, that is, on non-inductive circuit the power factor is unity. Now throwing the switch to the right connecting instruments with the inductive circuits, then for illustration the following readings may be assumed: ammeter 8, voltmeter 110, and wattmeter 684. Now, as before, power factor = wattmeter reading ÷ volts × amperes = 684 ÷ (8 × 110) = 684 ÷ 880 = .78.

The term *wattless current*, as understood, does not indicate an absence of electrical energy in the circuit; its elements are there, but not in an available form for external work. The false power due to the so-called wattless current pulsates in and out of the circuit without accomplishing any useful work.

If an alternator supply current to a circuit having a very small resistance and very large inductance, the current would lag nearly 90° behind the pressure. The primary current of a transformer working with its secondary on open circuit is a practical example of a current which represents very little energy.

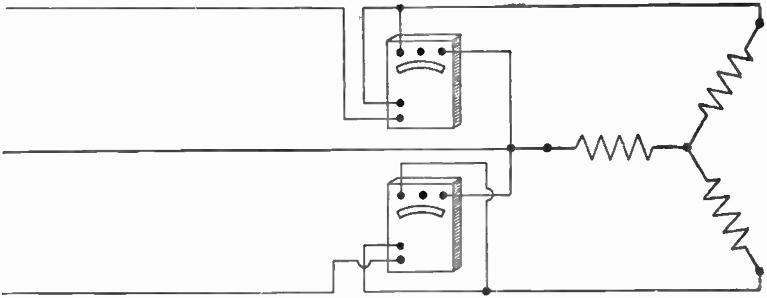


FIG. 6,470.—Wattmeter method of three phase power measurement. Two wattmeters are required in unbalanced systems as shown in the illustration. The total power transmitted is then the algebraic sum of the readings of the two wattmeters. If the power factor be greater than .5, the power is the arithmetical sum, and if it be less than .5, the power is the arithmetical difference of the readings.

Power Factor in Station Operation.—Commercially, it is desirable to keep the power factor as near unity as possible, because with a low power factor, while the alternator may be carrying its full load and operating at a moderate temperature, the consumer is paying only for the actual watts which are sent over the line to him.

NOTE.—*To avoid disputes* manufacturers usually rate their alternators in kilovolt amperes (*kva.*) instead of watts, a kilovolt ampere being a unit of apparent power in an *a.c.* current which is equal to one kilowatt when the power factor is equal to one.

NOTE.—*A power factor meter* is important in station operation when rotary converters are used on *a.c.* lines for supplying direct current and the sub-station operators are kept busy adjusting the field rheostat of the rotary to maintain a high power factor and prevent over heating of the alternators during the time of day when there is the maximum demand for current that is at the time of the peak of the load.

For instance, if a large alternator supplying 1,000 kilowatts at 6,600 volts in a town where a number of induction motors are used on the line be operating with a power factor of say .625 during a great portion of the time, the switchboard instruments connected to the alternator will give the following readings:

Voltmeter 6,600 volts; ammeter 242.4 amperes; power factor meter .625.

The apparent watts would equal 1,600,000 watts or 1,600 kilowatts, which, if multiplied by the power factor .625 would give 1,000,000 watts or 1,000 kilowatts which is the actual watts supplied. The alternator

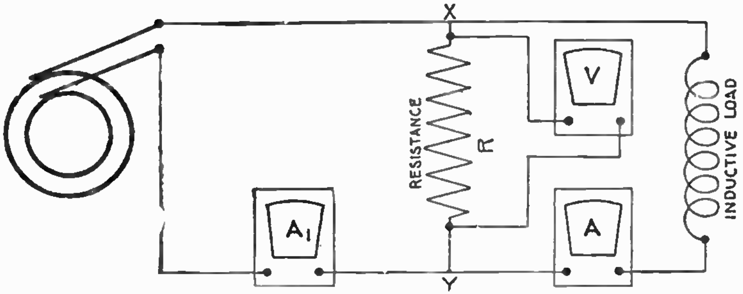


FIG. 6,471.—Fleming's combined voltmeter and ammeter method of measuring power in alternating current circuits. It is quite accurate and enables instruments in use to be checked. In the figure, R is a non-inductive resistance connected in shunt to the inductive load. The voltmeter V measures the pressure across the resistance XY. A and A_1 are ammeters connected as shown. Then true watts $=\left(A_1^2-A^2\left(\frac{V}{R}\right)^2\right)\times\frac{R}{2}$. If the voltmeter V take an appreciable amount of current, it may be tested as follows: disconnect R and V at Y, and see that A and A_1 are alike; then connect R and V at Y again, and disconnect the load. A_1 will equal current taken by R and V in parallel.

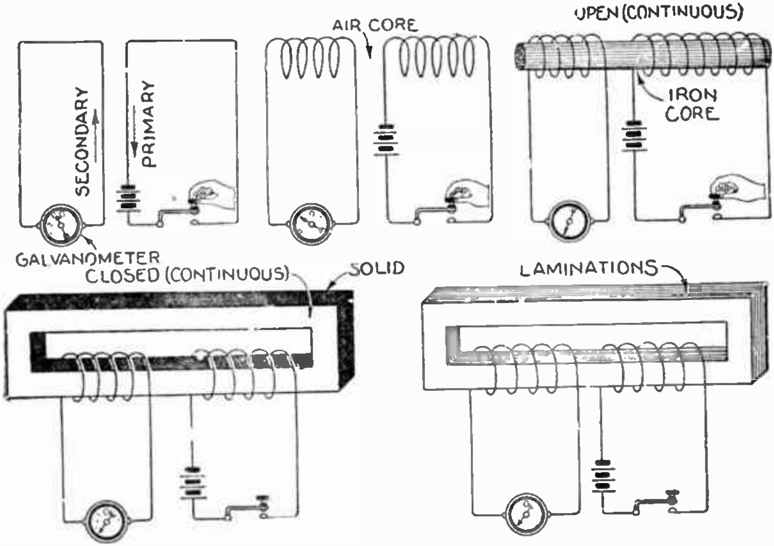
and line must carry 242.4 amperes instead of 151 amperes and the difference 242.4 — 151 = 91.4 amperes represents a *wattless current* flowing in the circuit which causes useless heating of the alternator.

In station operation the power factor is determined, not by calculation, but by reading a power factor meter.

CHAPTER 12

Transformers

The transformer is one of the essential devices in effecting the economical distribution of electric energy, and may be defined as *an apparatus used for changing the voltage and current of an alternating circuit*. A transformer consists essentially of



FIGS. 6,472 to 6,476.—Elementary transformers illustrating basic principles. Fig. 6,472, primary and secondary windings of only a single turn—induction very feeble; fig. 6,473, coils with air core—induction feeble; fig. 6,474, coils with *open* iron core—induction strong; fig. 6,475, coils with *closed* iron core—induction stronger; fig. 6,476, coils with closed *laminated* iron core to prevent eddy currents and resulting loss through heating.

1. A primary winding; 2. secondary winding; 3. An iron core.

Basic Principle.—The working of a transformer is due to what is known as ***mutual induction*** *between two circuits when an intermittent or alternating current flows in one of the circuits.*

The effect of mutual induction may be explained by the aid of fig. 6,472. Whenever circuit A, is closed by the switch allowing

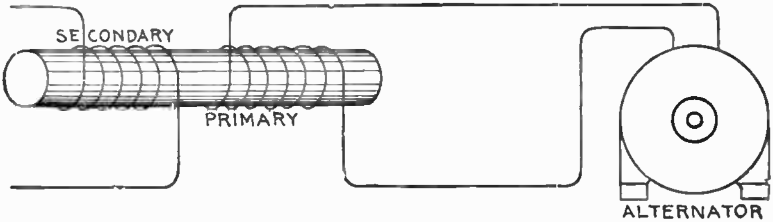


FIG. 6,477.—Diagram of elementary transformer with non-continuous core and connection with single phase alternator. The three essential parts are: primary winding, secondary winding, and an iron core.

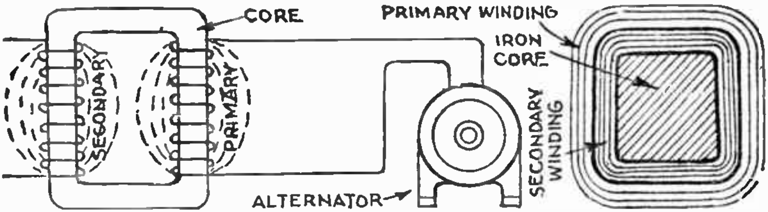
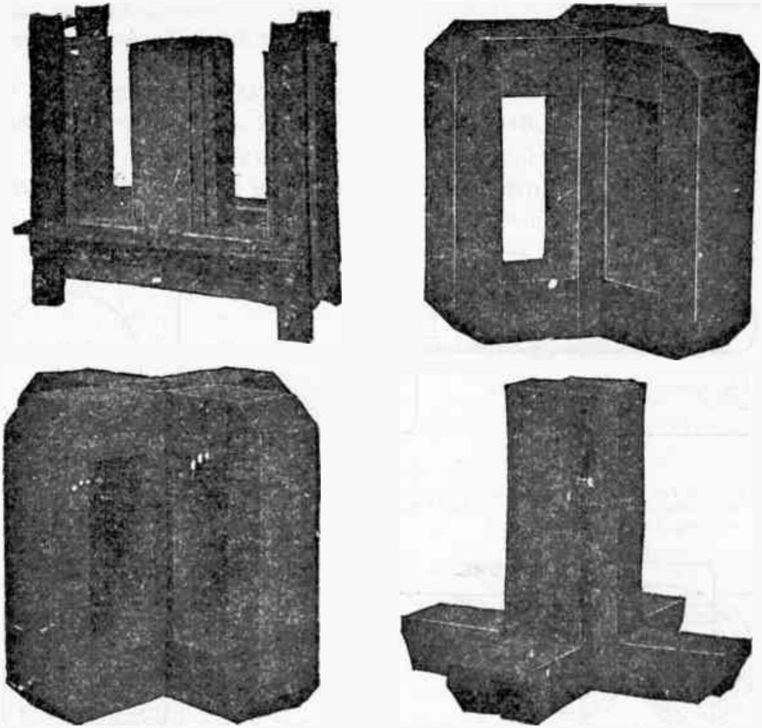


FIG. 6,478.—Diagram of elementary transformer with continuous core and connections with alternator. The dotted lines show the leakage of magnetic lines. To remedy this the arrangement shown in fig. 6,479 is used.

FIG. 6,479.—Cross section showing commercial arrangement of primary and secondary windings on core. One is superposed on the other. This arrangement compels practically all of the magnetic lines created by the primary winding to pass through the secondary winding.

a current to pass in a given direction, a momentary current will be induced in circuit B, as indicated by the galvanometer.

A similar result will follow on the opening of circuit A, the difference being that the momentary induced current occurring at closure moves in a direction opposite to that in the battery circuit, while the momentary



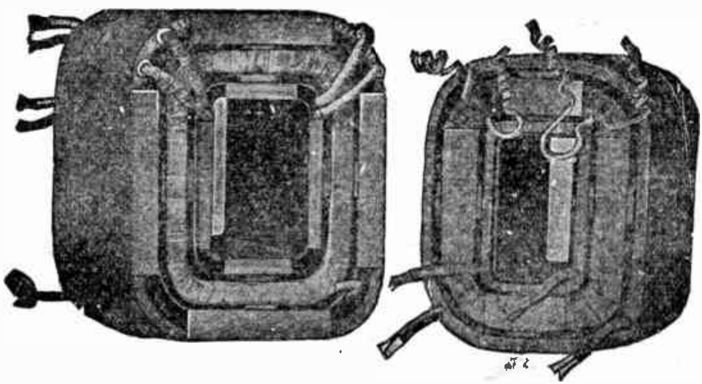
FIGS. 6,480 to 6,483.—General Electric core construction. Fig. 6,480, two part distributed core partially assembled; fig. 6,481, three part distributed core, fig. 6,482, four part distributed core; fig. 6,483, four part distributed core partly assembled. ***The two part*** distributed cores are assembled from straight laminations so that the center leg is of cruciform section and the two outer legs of rectangular section. The end laminations are inserted after the windings have been assembled. These cores are strongly clamped by means of structural steel parts which are also utilized in securing the core and coils in the tanks. ***The three and four part*** cores are built up using L shaped laminations assembled in such a manner as to secure a comparatively large center section with magnetic circuits radiating at 120 degrees or 90 degrees, respectively. These laminations are interlocked in the center section. The use of L shaped punchings materially improves the designs by reducing the number of joints in the magnetic circuit to two, and thus materially lowering the exciting current. The three part core is so assembled that a nine sided center leg is produced which gives practically a circular form on which the coils are wound. In the four part core, a center leg having four sides with well rounded corners is secured so that the winding makes no sharp bends, and is either circular or nearly circular in form depending on the details of design of the core. The outer laminations closing the magnetic circuits are assembled after the winding operation is completed. The three part core is clamped by means of metal plates being held together by a bolt passing through the center of the core. In the four part core metal straps around the outer legs serve to hold these clamping plates together. These clamping plates in addition serve as a means of clamping the core and coils in the tank.

current at opening moves in the same direction. Currents besides being induced in circuit **B**, at *make* or *break* of circuit **A**, are also induced when the current in circuit **A**, is fluctuating in intensity. This intermittent or alternating current is necessary for the operation of a transformer.

With intermittent current most marked results are observed when the make or break is sudden. Since the current can be stopped quicker than it can be started, the induction is greatest at *break*, hence ignition apparatus is designed to produce a spark at break.

In fig. 6,472 the inductive effect is very feeble and successively better results are obtained in figs. 6,473 to 6,476.

In fig. 6,472, circuit **A**, in which a current is passed is called the *primary circuit*, and circuit **B**, in which a current is induced, the *secondary*



FIGS. 6,484 and 6,485.—Assembled coils of Westinghouse 10 and 15 *kva*. transformers; views showing ventilating ducts.

circuit. Similarly, in fig. 6,476 the coil of circuit **A**, is called the *primary winding*, and that of circuit **B**, the *secondary winding*.

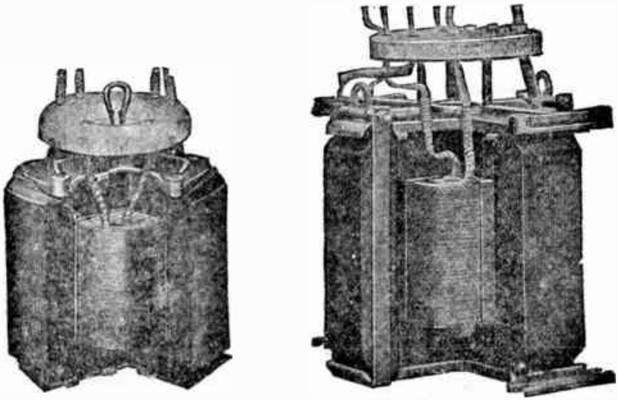
The property of a transformer that makes it of great value for most purposes is that *the voltage of the induced currents may be increased or diminished to any extent depending on the relation between the number of turns in the primary and secondary winding*

***Rule 26.**—The voltage of the secondary current is (approximately)* to the voltage of the primary current as the number of turns of the secondary winding is to the number of turns of the primary winding.

Example.—If ten amperes flow in the primary winding and the transformation ratio be 10, then $10 \times 10 = 100$ amperes will flow through the secondary winding.

Thus, a direct proportion exists between the pressures and turns in the two windings and an inverse proportion between the amperes and turns, that is:

primary voltage: secondary voltage = primary turns: secondary turns
primary current: secondary current = secondary turns: primary turns



FIGS. 6,486 and 6,487.—General Electric Core and windings assembly. Fig. 6,486, single phase, 60 cycle 2,300 volt, transformer using three part distributed core; fig. 6,487, core and coils of single phase, 2,300 volt transformer using four part distributed core. ***Windings.*** These are of two general types, those wound directly on the core, and those wound on forms, and later assembled on the core. Windings made directly on the core have the advantage of rigid support, the insulations being placed in final fixed positions by the winder and not disturbed or distorted by an assembly process. These advantages are especially desirable in the small units as here the clearances required by economical design are smallest. The coils of the three part distributed core transformers are wound on the core. One half of the low voltage coils are usually wound directly over the core insulation. The high voltage coils and outer low voltage coils are in turn wound over the inner low voltage coils with an insulating pad between all coils. The windings are provided with suitable coil ducts for uniform cooling—the number and location of the ducts varying with the size of the transformer. The coils of the four part distributed core transformers may be either core wound or form wound, depending upon the size and voltage of the transformer. Those wound on the core are wound in the same manner as those of the three part distributed core transformers.

From the above equations it is seen that the watts of the primary circuit equal the watts of the secondary circuit.

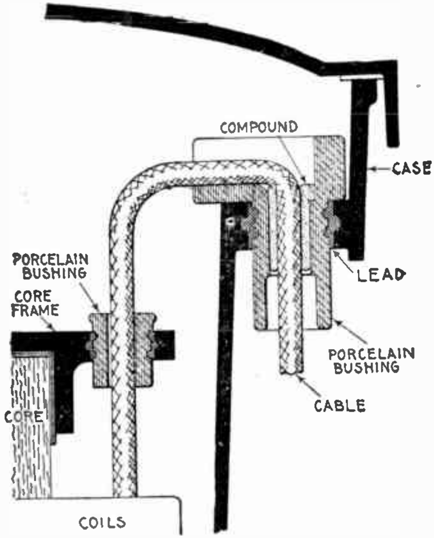


FIG. 1,954.—Method of bringing out the secondary leads in Wagner central station transformers. Each primary lead is brought into the case through a similar bushing. Observe the elimination of al possibility of grounding the cable on the case or core.

In the above example, the total wattage in the primary circuit is 1,000 × 10 = 10 *kw.*, and that in the secondary circuit is 100 × 100 = 10 *kw.* Hence, while both volts and amperes are widely different in the two circuits, the watts for each are the same in the ideal case, that is, assuming perfect transformer action or 100% efficiency. Now, the usual loss in commercial transformers is about 3% at full load, so that the actual watts delivered in the secondary circuit is (100 × 100) × 97% = 9.7 *kw.*

The No Load or Exciting Current.—When the secondary winding of a transformer is open or disconnected from the secondary circuit no current will flow in the winding, but a very small current called the *no load or exciting current* will flow in the primary circuit.

The reason for this is as follows: The current flowing in the primary winding causes repeated reversals of magnetic flux through the iron core. These variations of flux induce pressures in both coils; that induced in the primary called the *reverse pressure* is opposite in direction and very nearly equal to the impressed pressure, that is, to the pressure applied to the primary winding. Accordingly the only force available to cause current to flow through the primary winding is the difference between the impressed pressure and reverse pressure, the *effective pressure*.

The Magnetizing Current.—The magnetizing current of a transformer is sometimes spoken of as that current which the primary winding takes from the mains when working at normal pressure. The *true magnetizing current* is that component of this total no load current which is in quadrature with the supply pressure. The remaining component has to overcome the various iron losses, and is therefore "in phase" with the supply pressure. The relation between these two components determines the power factor of the "no load current."

This component is very small if the transformer be well designed, and be worked at low flux density.

Action of Transformer with Load.—If the secondary winding of a transformer be connected to the secondary circuit

FIG. 6,489.—Rear view of Fort Wayne distributing transformer showing hanger irons for attaching to pole cross arms.

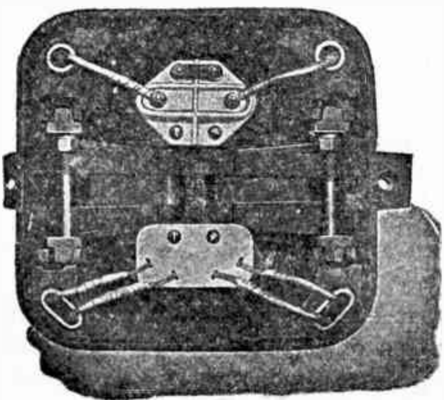
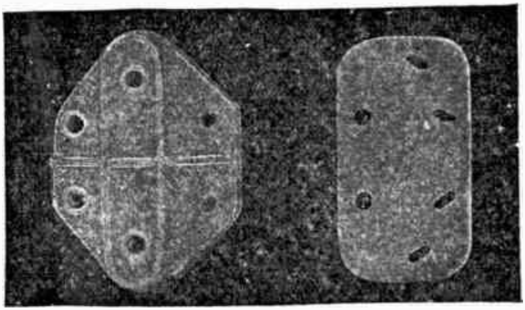


FIG. 6,490.—Top view showing core and coils in place of Westinghouse distributing transformer. The coils are wound from round wire in the smaller sizes of transformers and from strap copper in the larger sizes. Strap wound coils allow a greater current carrying conductor section than coils wound from large round wire, as there is little waste space between the different turns of the conductor. The coils are arranged concentrically with the high tension winding between the two low tension coils, the object being to improve the *regulation*. The low tension coils are wound in layers which extend across the whole legnth of the coil opening in the iron, while the high tension coils are wound in two parts and placed end to end. This construction reduces the normal voltage strains to a value which will not give trouble under any condition of service. Leads with means of preventing creeping of oil by capillary action are attached to these studs and brought out of the core through porcelain bushings.

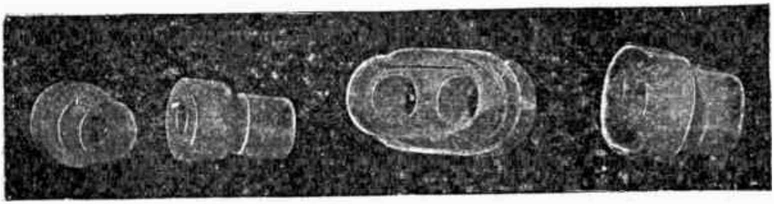
by closing a switch so that current flows through the secondary winding, the transformer is said to be *loaded*.

The action of this secondary current is to oppose the magnetizing action of the slight current already flowing in the primary winding, thus decreasing the maximum value reached by the alternating magnetic flux in the core, thereby decreasing the induced pressure in each winding.



Figs. 6,491 and 6,492.—Westinghouse transformer terminal blocks for high and low tension conductors.

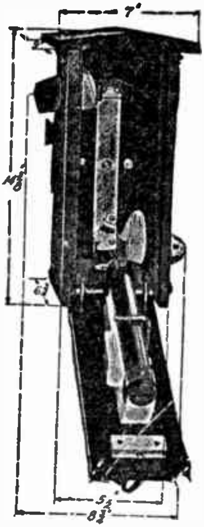
The amount of this decrease, however, is *very small*, inasmuch as a very small decrease of the induced pressure in the primary coil greatly increases the difference between the pressure applied to the primary coil and the opposing pressure induced in the primary coil so that the primary current is greatly increased. In fact, *the increase of primary current due to the loading of the transformer is just great enough* (*or very nearly*) *to exactly balance the magnetizing action of the current in the secondary coil;* that is, the flux in the core must be maintained approximately constant by the primary current whatever value the secondary current may have.



Figs. 6,493 to 6,496.—Porcelain bushing for Westinghouse transformers.

When the load on a transformer is increased, the primary of the transformer automatically takes additional current and power from the supply mains in direct proportion to the load on the secondary.

When the load on the secondary is reduced, for example by turning off lamps, the power taken from the supply mains by the primary coil is automatically reduced in proportion to the decrease in the load. This automatic action of the transformer is due to the balanced magnetizing action of the primary and secondary currents.



FIGS. 6,497 to 6,499.—General Electric transformer cut outs. Fig. 6,497, expulsion cut out for 6,600 volts; fig. 6,498, plug cut out; fig. 6,499, expulsion cut out for pressures above 6,600 volts. ***The plug cut out*** is suitable for mounting on the cross arm and may be used on 2,500 volt circuits for currents up to 30 amperes, or 3,500 volt circuit for currents up to 15 amperes. ***The expulsion cut out,*** is suitable for installation on the cross arm and is used for voltages and currents higher than those for which the plug type cut out is suitable. One type of expulsion cut out consists of a box of treated ash with hinged door and a tubular fuse holder which is supported on a porcelain fastened to the door, making connection with the line through springs when the door is closed. Upon opening the door the fuse holder is automatically disconnected from the circuit. A card holder is provided on the bottom of the box just beneath the gas outlet of the fuse holder. When the fuse blows, the expulsion of the gas either punctures the card or forces it out of the holder, thus indicating a blown fuse. This indication may be seen from the ground, making it unnecessary for linemen or inspectors to climb the pole to determine if the fuse be blown. These cut outs are suitable for use on circuits of 6,600 volts and below, 100 amperes and less. A modification of this cut out is made for circuits of 15,000 to 45,000 volts and currents up to 50 amperes. Although no covering is provided with this cut out, it is suitable for outdoor installation.

Classification of Transformers.—As in the case of motors, the great variety of transformer makes it necessary that a classification, to be comprehensive, must be made from several points of view, as:

1. With respect to the transformation, as

   a. Step up transformers;
   b. Step down transformers.

2. With respect to the arrangement of the coils and magnetic circuit, as

   a. Core transformers;
   b. Shell transformers;
   c. Combined core and shell transformers.

3. With respect to the kind of circuit they are to be used on, as

   a. Single phase transformers;
   b. Polyphase transformers.

4. With respect to the method employed in cooling, as

   a. Dry transformers;
   b. Air cooled transformers { natural draught; forced draught, or air blast;
   c. Oil cooled transformers;
   d. Water cooled transformers.

5. With respect to the nature of their output, as

   a. Constant pressure transformers;
   b. Constant current transformers;
   c. Current transformers;
   d. Auto-transformers.

6. With respect to the kind of service, as

   a. Distributing;
   b. Power.

7. With respect to the circuit connection that the transformer is constructed for, as

a. Series transformers; *b*. Shunt transformers.

8. With respect to location, as

a. Indoor, *b*. Outdoor.

Step Up and Step Down Transformers.—At the station the low voltage current from the alternators is transformed to

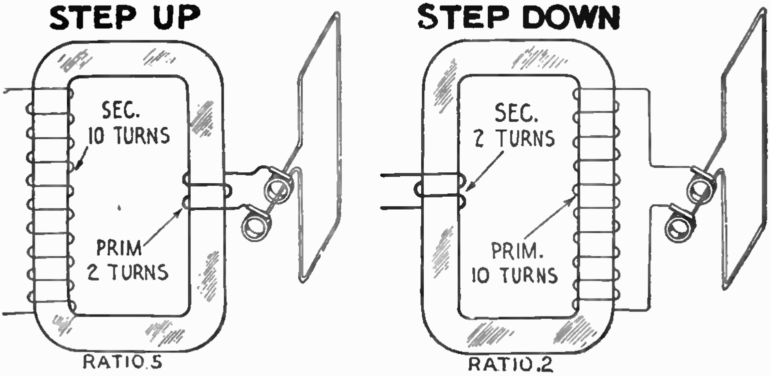


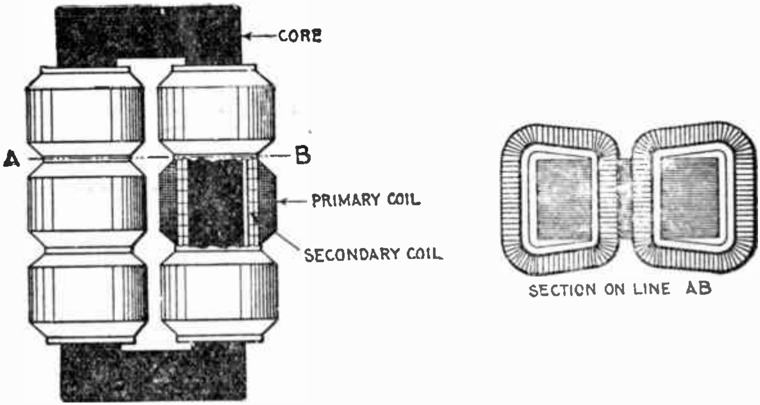
FIG. 6,500.—Diagram of elementary *step up* transformer. As shown the primary winding has two turns and secondary 10 turns, giving a ratio of voltage transformation of 10 ÷ 2 = 5. Since only ⅕ as much current flows in the secondary winding as in the primary, the latter requires heavier wire than the former.

FIG. 6,501.—Diagram of elementary step down transformer. As shown the primary winding has 10 turns and the secondary 2, giving a ratio of voltage transformation of 2 ÷ 10 = .2. The current in the secondary being 5 times greater than in the primary will require a proportionately heavier wire.

high voltage current so that it may be transmitted to considerable distances with small wires, and at each point of distribution it is stepped down to low voltage as is required for lighting, etc. In this way there is a considerable saving in copper as must be evident.

Thus, since watts = amperes × volts (from which amperes = watts ÷ volts) to transmit say 1,000 watts at 100 volts the wire must be large enough to carry 1,000 ÷ 100 = 10 amperes, whereas if the pressure be increased to 1,000 volts, the wire would only have to carry 1,000 ÷ 1,000 = 1 ampere, hence a much smaller wire could be used.

Core Transformers.—This type of transformer may be defined as one having an iron core, upon which the wire is wound in such a manner that the iron is enveloped within the coils, the outer surface of the coils being exposed to the air as shown in figs 6,502 and 6,503.



FIGS. 6,502 and 6,503.—Core type transformer. *It consists of* a central core of laminated iron around which the coils are wound. A usual form of core type transformer consists of a rectangular core, around the two long limbs of which the primary and secondary coils are wound, the low tension coil being placed next the core.

Shell Transformers.—In the shell type of transformer, as shown in fig. 6,504, the core is in the form of a shell, being built around and through the coils. A shell transformer has, as a rule, fewer turns and a higher voltage per turn than the core type.

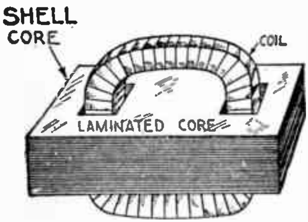
Comparison between Shell and Core Transformers.—The choice between shell and core transformers depends upon manufacturing convenience rather than upon operating characteristics

The major insulation in a core type transformer consists of several large pieces of great mechanical strength.

In the shell type, there are required an extremely large number of relatively small pieces of insulating material, which necessitates careful workmanship to prevent defects in the finished transformer, when thin or fragile material is used.

Both core and shell transformers are built for all ratings. For small ratings the core type possesses certain advantages with reference to insulation, while for large ratings, the shell type possesses better cooling properties, and has less magnetic leakage than the core type.

Distributed Core Transformers.—An improved type of



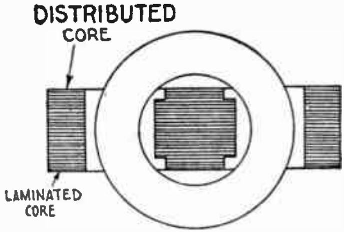


FIG. 6,504.—Shell type transformer. *In construction,* the laminated core is built around and through the coils as shown. For very heavy current ratings at low voltage this type has some advantages with respect to mechanical construction of windings whereas in other ratings, especially at high voltages, the core type is preferable, both in this respect and with respect to insulation.

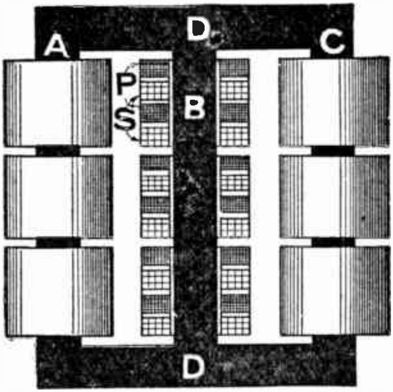
FIG. 6,505.—Plan of core of General Electric distributed core type transformer. The core used contains four magnetic circuits of equal reluctance, in parallel; each circuit consisting of a separate core. In this construction one leg of each circuit is built up of two different widths of punchings forming such a cross section that when the four circuits are assembled together they interlock to form a central leg, upon which the winding is placed. The four remaining legs consist of punchings of equal width. These occupy a position surrounding the coil at equal distances from the center, on the four sides; forming a channel between each leg and coil, thereby presenting large surfaces to the coil and allowing its free access to all parts of the winding. The punchings of each size transformer are all of the same length, assembled alternately, and forming two lap joints equally distributed in the four corners of the core, thereby giving a magnetic circuit of low reluctance.

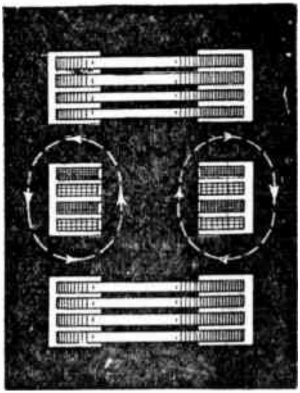
transformer has been introduced which can be considered either as two superposed shell transformers with coils in common, or as a single core type transformer with divided magnetic circuit and having coils on only one leg.

It is best considered however, as a distributed core type transformer, and for small sizes it possesses most of the advantages of both types. It can be constructed at less cost than can either a core or a shell transformer having the same operating characteristics and temperature limits.

Single and Polyphase Transformers.—A single phase transformer may be defined as *one having only one set of primary and secondary terminals, and in which the fluxes in the one or more magnetic circuits are all in phase*, as distinguished from a polyphase transformer, or combination in one unit of several one phase transformers with separate electric circuits but having certain magnetic circuits in common.

In polyphase transformers there are two or more magnetic circuits through the core, and the fluxes in the various circuits are displaced in phase.





FIGS. 6,506 and 6,507.—Core and shell types of three phase transformer. *In the core type,* fig. 6,506, there are three cores A, B, and C, joined by the yokes D and D′. This forms a three phase magnetic circuit, since the instantaneous sum of the fluxes is zero. Each core is wound with a primary coil P, and a secondary coil S. As shown, the primary winding of each phase is divided into three coils to ensure better insulation. The primaries and secondaries may be connected *star* or *mesh*. The core B, has a shorter return path than A and C, which causes the magnetizing current in that phase to be less than that in A and C phases. This has sometimes been obviated by placing the three cores so their corners form an equilateral triangle (as in fig 6,481), but the extra trouble involved is not justified, as the unbalancing is a no load condition, and practically disappears when the transformer is loaded. *The shell type,* fig. 6,507, consists practically of three separate transformers in one unit. The flux paths are here separate, each pair of coils being threaded by its own flux, which does not, as in the core type, return through the other coils. This gives the shell type an advantage over the core type, for should one phase burn out, the other two may still be used, especially if the faulty coils be short circuited. The effect of such short circuiting is to prevent all but a very small flux threading the faulty coil.

Polyphase current may be transformed either by a polyphase transformer or by using a single phase transformer for each phase. The polyphase transformer is however preferable, because less iron is required than would be with the several single phase transformers. The polyphase transformer therefore is somewhat lighter and also more efficient.

Cooling of Transformers.—There are various methods of cooling transformers, the cooling mediums being

1. Air. 2. Oil. 3. Water.

The means adopted for getting rid of the heat which is inevitably developed in a transformer by the waste energy is one of the important considerations with respect to its design.

Air Cooled Transformers.—In this type of transformer there are two methods of circulating the air as by, 1, natural draught, and 2, forced draught or blast. As designed for natural draught, the case containing the windings is open at the top and bottom. The column of air in the case expands as its temperature rises, becoming lighter than the cold air on the outside and is consequently displaced by the latter, resulting in a circulation of air through the case. The process is identical with furnace draught.

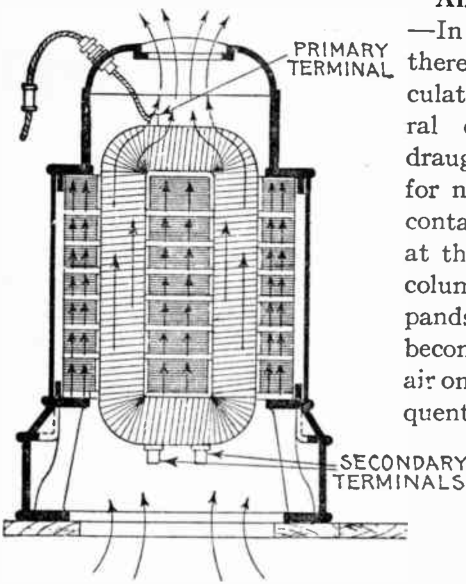
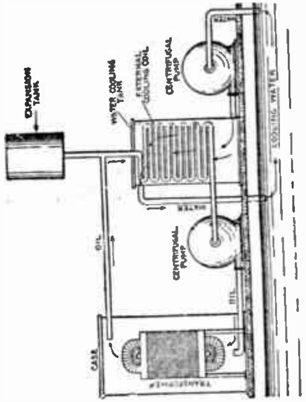


FIG. 6,508.—Forced draught or "air blast" transformer. *As is indicated* by the classification, this type of transformer is cooled by forcing a current of air through ducts, provided between the coils and between sectionalized portions of the core. The cold air is forced through the interior of the core containing the coils the air passing vertically by a blower, through the coils and out through the top. The amount of air going through the coils may be controlled independently by providing dampers in the passages. About 100 cu. ft. of air per minute per total *kw.* loss is ordinarily used for transformers which are not designed to operate above their rated capacity.



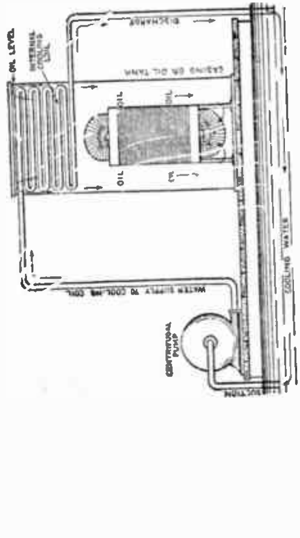


FIG. 6,509.—Water, cooled transformer with internal cooling coil, that is, with cooling coil within the transformer case. In this type, the cooling coil, through which the circulating water passes, is placed in the top of the case or tank, the latter is filled with oil so that the coil is submerged. The oil acts simply as a medium to transfer the heat generated by the transformer to the water circulating through cooling coil. ***In operation*** a continual circulation of the oil takes place, as indicated by the arrows, due to the alternate heating and cooling it receives as it flows past the transformer coils and cooling coil respectively.

FIG. 6,510.—Water cooled transformer with external cooling coil. ***In this arrangement*** the cooling coil is placed in a separate tank as shown. Here forced circulation is employed for both the heat transfer medium (*oil*) and the cooling agent (*water*), two pumps being necessary. The cool oil enters the transformer case at the lowest point and absorbing heat from the transformer coils, it passes off through the top connection leading to the cooling coil and expansion tank. Since the transformer tank is closed, an expansion tank is provided to allow for expansion of the oil due to heating. The water circulation is arranged as illustrated.

In forced draught transformers the case is closed at the bottom and open at the top. A current of air is forced through from bottom to top as shown in fig. 6,508 by a fan.

For air cooling, the coils are built up high and thin and assembled with spaces between them for the circulation of the air. In forced draught transformers the air pressure required is from one-half to one ounce per sq. in. The larger transformers require greater pressure to overcome the resistance of larger air ducts. Ordinarily 150 cu. ft. of air per minute is used per *kw.* of load.

Oil Cooled Transformers.—In this type of transformer the coils and core are immersed in oil and provided with ducts to allow the oil to circulate by convection and thus serve as a medium to transmit the heat to the case, from which it passes by radiation.

Oil cooling is used especially for lighting transformers.

In such transformers, the large volume of oil absorbs considerable heat so that the rise of temperature is retarded. Hence, for moderate periods of operation, say 3 or 4 hours, the average lighting period, the maximum temperature would not be reached.

The oil, besides being a cooling agent, is a good insulator, preserves the insulation from oxidation, increasing the breakdown resistance of the insulation, and generally restores the insulation in case of puncture. A special objection to oil, however, is danger of a central station fire being augmented by the presence of the oil. Due to the high flash point of transformer oil, this affords but little extra hazard.

Good transformer oil should not contain moisture, acid, alkali, or sulphur compounds. It should have low viscosity and should not decompose or throw down sludge under operating conditions.

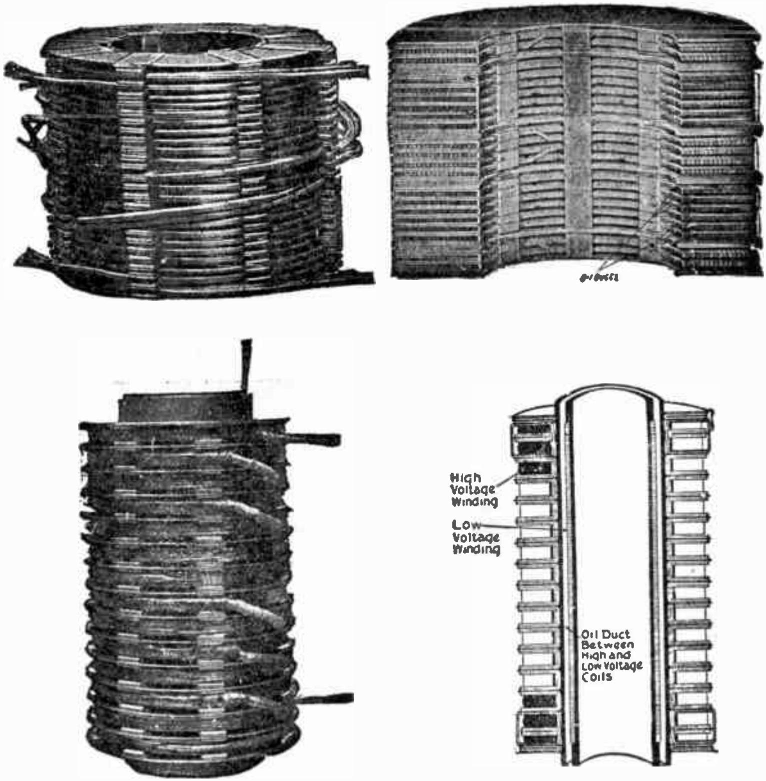
The presence of moisture can be detected by thrusting a red hot nail in the oil; if the oil "crackle," water is present. Moisture may be removed by raising the temperature slightly above the boiling point, 212° Fahr., but the time consumed (several days) is excessive.

Water Cooled Transformers.—A water cooled transformer is one in which water is the cooling agent, and, in most cases, oil is the medium by which heat is transferred from the coils to the water. In construction, pipes or a jacketed casing is provided through which the cooling water is passed by forced circulation, as shown in figs. 6,509 and 6,510.

The surface of the cooling coil should be from .5 to 1.3 sq. in. per watt of total transformer loss, depending upon the amount of heat which the external surface of the transformer case will dissipate.

For a water temperature rise of 43° Fahr., 1.32 lbs. of water per minute is required per *kw.* of load.

Transformer Insulation.—Transformers are provided with *major* and *minor* insulation. The major insulation is placed between the core and secondary (low pressure) coils, and between the primary and secondary coils.



FIGS. 6,511 to 6,514.—General Electric Coil Structures. Various coil constructions have been developed to meet the particular requirements of designs depending upon unit-size and voltage rating. In the larger sizes, circular coils of either disc or cylindrical shape are used on account of their greatly superior mechanical qualities, and the facilities they give for rigid mechanical support. In transformers using form wound coils, the insulation between the high voltage and low voltage windings, and between the high voltage winding and core, depends upon the voltage and type of winding. For transformers using disc voltage and cylindrical low voltage coils, the insulation between the high voltage and low voltage windings is composed of oil ducts and a cylinder of "573 compound" which, in addition to its high insulating properties, possesses great mechanical strength. The insulation between the high voltage winding and the core consists of specially treated fiber barriers and oil ducts. For transformers using disc high voltage and disc low voltage coils assembled interleaved, the insulation between the high voltage and the low voltage windings is composed of fiber barriers and oil ducts the number of barriers and dimensions of the ducts varying with the voltage. The insulation between the high voltage winding and the core is composed of oil ducts and a cylinder of "573 compound." As sections of the low voltage windings are placed

It consists usually of mica tubes, sometimes applied as sheets held in place by the windings, when no ventilating ducts are provided, or moulded to correct form and held between sheets of tough insulating material where ducts are provided for air or oil circulation.

The minor insulation is the insulation placed between adjacent turns of the coils.

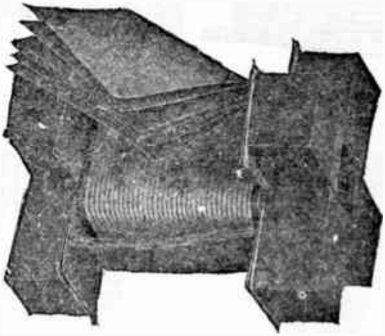


FIG. 6,515.—General Electric partly assembled transformer showing mica pad. Experience has shown the necessity of fire proof insulation in smaller sizes in order to insure protection to the lower voltage circuit. in case of burn out from abnormal operating conditions. A similar mica pad is used between ends of the high voltage coils and cores. In these transformers, therefore, the high voltage winding is practically surrounded by fireproof insulation.

FIGS. 6,511 to 6,514.—*Text continued.*

at both ends of the coil attached next to the core, the ends of the high voltage winding are well insulated from the core. The insulation between the low voltage winding and the core in all core wound transformers is made up from a specially treated fiber which possesses suitable insulating properties and is not injured by the mechanical stress incident to the winding process. In the interleaved disc type of winding (fig. 6,511) both high and low voltage coils are wound in the form of discs assembled with the high voltage and low voltage coils interleaved. These coils are wound on a form and assembled over a cylinder of "573 compound" this cylinder furnishing the foundation for the winding. This is later assembled over the core and also serves as an insulation between the windings and the core. The coils are separated from each other by means of specially treated fiber spacers, furnishing generous oil ducts between coils for cooling purposes. Between high and low voltage windings and where required between coils of either winding, one or more fiber collars are inserted with oil ducts between. In the disc-cylinder type of winding (fig. 6,512) the low voltage coils are cylindrical in shape and are wound on a cylinder of "573 compound." The high voltage coils are disc coils assembled over another cylinder of the same material which is in turn assembled over the low voltage winding with an oil duct between the low voltage winding and the outer cylinder. In the cylindrical construction both high and low voltage coils are cylinders wound on forms and assembled concentrically with generous oil ducts between coils.

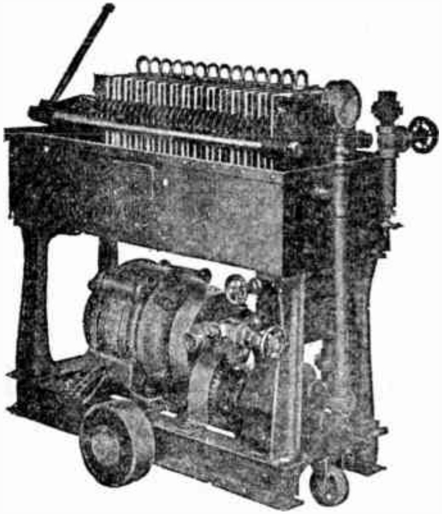


FIG. 6,516.—General Electric transformer oil dryer and filter for freeing the oil from moisture, slime and sediment. *In operation,* the oil is forced through several layers of dry blotting paper. The complete equipment consists of a filter press with motor driven oil pump, electric drying oven for thoroughly drying the filter paper before placing it in the press.

Since the difference of pressure is small between the adjacent turns, the insulation need not be very thick. It usually consists of a double thickness of cotton wrapped around each conductor. For round conductors, the ordinary double covered magnet wire is satisfactory.

Mica is the most efficient insulating material.

It has a high dielectric strength, is fire proof, and is the most desirable insulator where there are no sharp corners.

Oil Insulated Transformers.—High voltage transformers are insulated with oil, as it is very important to maintain careful insulation not only between the coils, but also between the coils and the core. In the case of high voltage transformers, any

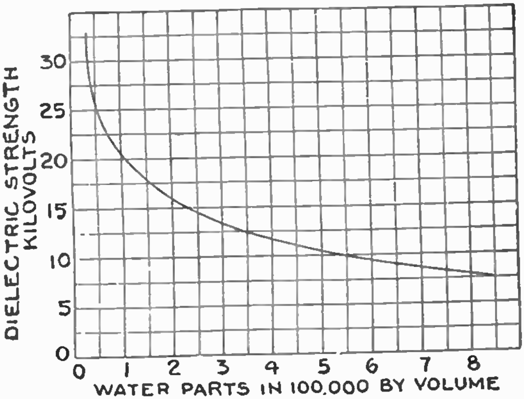


FIG. 6,517.—Curve showing the great reduction in dielectric strength produced by the presence of water in amounts up to 8 parts in 100,000.

accidental static discharge, such as that due to lighting, which might destroy one of the air insulated type, might be successfully withstood by one insulated with oil, for if the oil insulation be damaged it will mend itself at once.

By providing good circulation for the oil, the transformer can get rid of the heat produced in it readily and operate at a low temperature, which not only increases its life but cuts down the electric resistance of the copper conductors and therefore the I^2R loss.

Auto-transformers.—In this class of transformer, there is

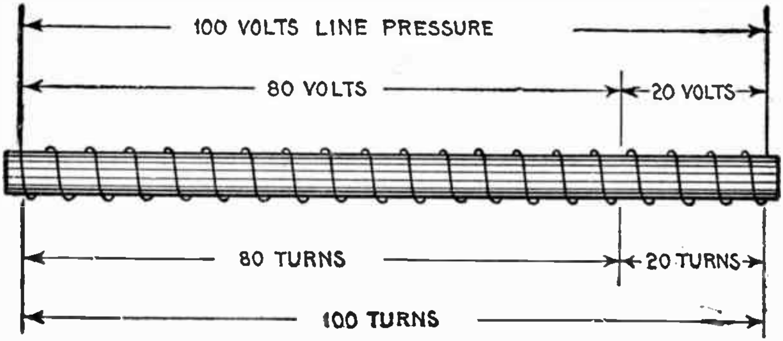


FIG. 6,518.—Diagram illustrating connections and principles of auto-transformers as explained in the accompanying text.

only one winding which serves for both primary and secondary. On account of its simplicity it is made cheaply.

Auto-transformers are used where the ratio of transformation is small, as a considerable saving in copper and iron can be effected, and the whole transformer reduced in size as compared with one having separate windings.

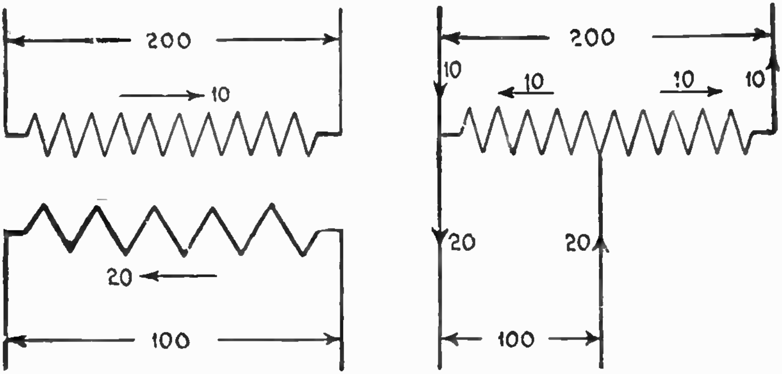
Fig. 6,518 illustrates the electrical connections and the relations between the volts and number of turns.

By using the end wire and tapping in on turn No. 20 a current at 20 volts pressure is readily obtained which may be used for starting up motors requiring a large starting current and yet not draw heavily on the line.

Constant Current Transformers for Series Lighting.—The principle of the constant current transformer as used for series lighting is readily understood by reference to the elementary diagram shown in fig. 6,521.

In this system the alternator and regulating transformer supply a constant current and variable voltage.

Constant current incandescent lighting systems for use in small towns also use this method for automatically regulating the current.



FIGS. 6,519 and 6,520.—Two winding transformer and single winding or auto-transformer. Fig. 6,519 shows a 200:100 volt transformer having a 10 amp. primary and a 20 amp. secondary, the currents being in opposing directions. If these currents be superposed by using one winding only, the auto transformer shown in fig. 6,520 is obtained where the winding carries 10 amp. only and requires only one-half the copper (assuming the same mean length of turn). If R, be the ratio of an auto-transformer, the relative size of it compared with a transformer of the same ratio and output is as $\frac{R-1}{R}$:1. *For instance:* a 10 *kw.* transformer of 400 volts primary and 300 volts secondary could be replaced by an auto-transformer of $10\times\frac{1.33-1}{1.33} = 2.5$ *kw.*; or, in other words, the amount of material used in a 2½ *kw.* transformer could be used to wind an auto transformer of 400 :300 ratio and 10 *kw.* output.

Since the primary is connected directly to the secondary it would be dangerous to use an auto-transformer on high pressure circuits. This type of transformer has only a limited use, usually as compensator for motor starting boxes.

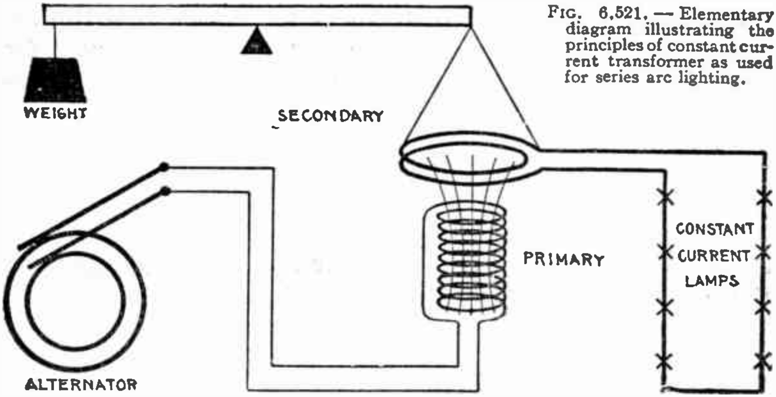


FIG. 6,521. — Elementary diagram illustrating the principles of constant current transformer as used for series arc lighting.

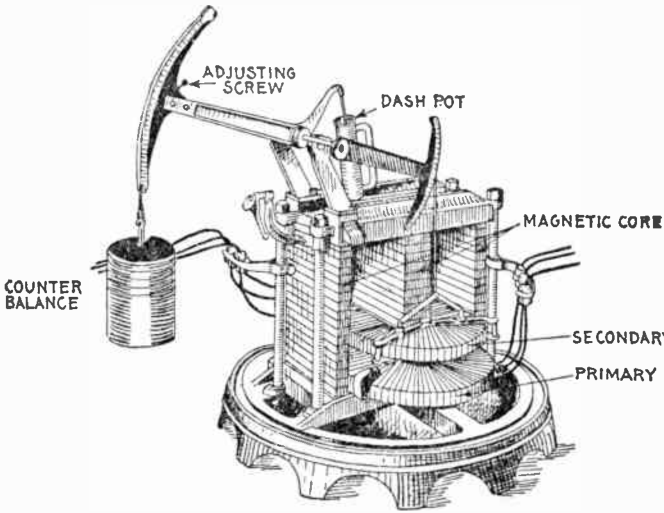


FIG. 6,522.—Mechanism of General Electric air cooled constant current transformer. *It operates* on the principle explained in the accompanying text and is built to supply 25 to 100 arc lamps at 6.6 to 7.5 amperes. The transformers are interchangeable and will operate on 60 or 125 cycles. The relative positions of the two coils may be changed in order to regulate the strength of the current more closely, by shifting the position of the arc carrying the counterbalance by means of the adjusting screw on it. A dash pot filled with special oil prevents sudden movements of the secondary coil and keeps the current through the lamps nearly constant, when they are being cut in or out of the circuit. In starting up a

Regulation.—This term applies to the means adopted either to obtain constancy of pressure or current. In the transformer, regulation is *inherent*, that is, the apparatus automatically effects its own regulation. The regulation of a transformer means, *the change of voltage due to change of load on the secondary;* it may be defined more precisely as: *the percentage increase in the secondary voltage as the load is decreased from its normal value to zero.* Thus, observation should be made of the secondary voltage, at full load and at no load, the primary pressure being held constant at the normal value.

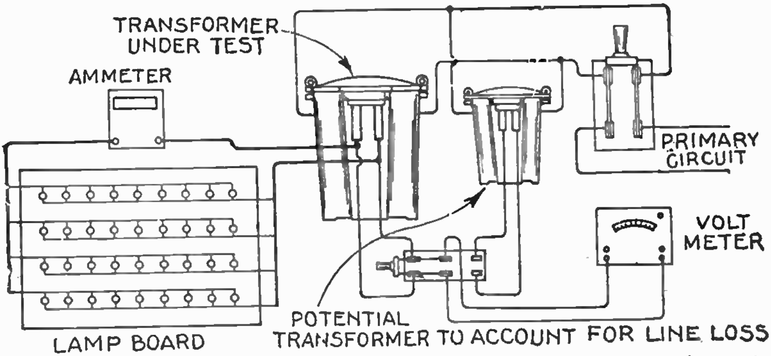


FIG. 6,523.—Diagram of connections for regulation test. *Connect* transformer under test to high tension supply circuit. A second transformer with same or other known change ratio is also to be connected up, as illustrated. By means of a double pole double throw switch, the voltmeter can be made to read the pressure on the secondary of either transformer. Supposing the same change ratio, it is evident that if both remain unloaded the voltmeter will indicate the same pressure. A gradually increasing lamp load up to the limit of the transformer capacity, will be attended by a drop in pressure at the terminals. This drop can be read as the difference of the voltmeter indications, and when expressed in per cent. of secondary voltage stands for "regulation." *Remarks:* The auxiliary transformer is necessary in order to make sure of the high tension line voltage. A large transformer under test may cause primary drop in taking power. This must be set down against it in testing regulation. The second transformer gives notice of such drop, whatever be the cause.

FIG. 6,522.—*Text Continued*

constant current transformer, it is necessary to separate the two coils as far as possible and then close the primary circuit switch and allow the two coils to come together. If the primary circuit be thrown directly on the alternator, the heavy rush of current which will follow due to the two coils being too close together might injure the lamps.

The regulation is said to be "good" or "close," when this change is small. In the design of a transformer, good regulation and low iron losses are in opposition to one another when the best results are desired in both. A well designed transformer, however, should give good results, both as to regulation and iron losses, the relative value depending upon the class of work it has to do. and size.

For 100% or unity power factor per cent regulation = % C R volts

$$=100\left\{\frac{I_p R_p}{E_p}+\frac{I_s R_s}{E_s}\right\}$$

in which I = amperes, R, ohms, E, volts, and p and s, primary and secondary.

Transformer Losses.—The commercial transformer is not a perfect converter of energy, that is, the ***input***, or watts applied to the primary circuit is always more than the ***output*** or watts delivered from the secondary winding.

This is due to the various losses which take place, and the difference between the input and output is equal to the sum of these losses which are:

1. The *iron* or *core* loss

Due to *a*, hysteresis; *b*, eddy currents; *c*, magnetic leakage (negligibly small).

2. The *copper* losses

Due to *a*, heating the conductors (the I^2R loss); *b*, eddy currents in conductors.

Hysteresis.—In transformer operation the rapid reversal of magnetism in the core requires an expenditure of energy which is converted into heat.

This loss of energy is due to the work required to change the position of the molecules of the iron in reversing the magnetization. Extra power then must be taken from the line to make up for this loss, thus reducing the efficiency of the transformer.

The hysteresis loss depends upon the quality of the iron in the core, the magnetic density at which it is worked and the frequency.

To obtain minimum hysteresis loss the softest iron is used for the core and a low degree of magnetization is employed.

Eddy Currents.—These currents are produced in the transformer core similarly as in a generator core and are reduced to a minimum by the usual method of lamination. The thickness of the laminæ depend upon the frequency, being about from .014 to .025 in. according as the frequency is respectively high or low.

When the secondary of a transformer is open, a *no load* current passes

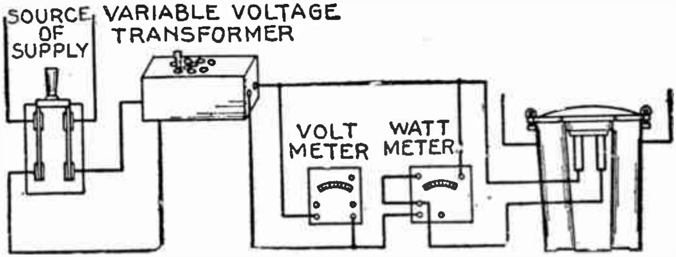


FIG. 6,524.—Method of determining core loss. *Connect* voltmeter and wattmeter as shown in the illustration to the low tension side of the transformer. By means of a variable voltage transformer bring the applied voltage to the point for which the transformer is designed. The wattmeter indicates directly the core loss, which includes a very small loss due to the current in the copper. *Cautions:* 1, Make sure of the voltage and frequency. The manufacturers' tabulated statements refer to a definite voltage and frequency and these have a decided influence upon the core loss. 2, The high tension circuit must remain open during the test.

through the primary; the energy thus supplied balances the core losses. The iron losses may be reduced to a minimum by having short magnetic paths of large area and using iron or steel of high permeability. The design and construction must keep the eddy currents as low as possible.

Copper Losses.—Since the primary and secondary windings of a transformer have resistance, some of the energy supplied will be lost by heating the copper. The amount of this loss is proportional to square of the current, and is usually spoken of as the I^2R loss. The copper losses are the sum of the I^2R losses of both the primary and secondary windings, and the eddy current loss in the conductors.

The eddy current loss is very small, and may be disregarded, so that the sum of the I^2R losses of primary and secondary can be taken as the total copper loss for practical purposes.

Efficiency of Transformers.—The efficiency of transformers is *the ratio of the electric power delivered at the secondary terminals to the electric power absorbed at the primary terminals.*

Accordingly, the output must equal the input minus the losses. If the iron and copper losses at a given load be known,

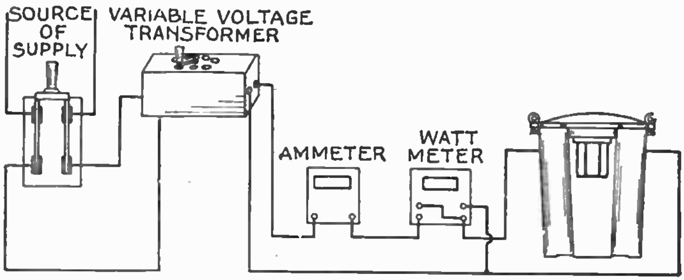


FIG. 6,525.—Method of determining copper loss. Connect ammeter and wattmeter to high tension side of transformer short circuit secondary leads, as shown in illustration, and by means of a variable voltage, adjust current to the full load value for which the transformer is intended. The wattmeter reading shows the copper loss at full load. The full load primary current of any transformer is found from the following equation

full load current = full load watts ÷ primary volts

Example.—To find proper full load current on a five kw. 2,200 volt transformer, divide 5,000 watts by 2,200 volts, the full load current will then be 2.27 amperes. A slight variation in primary current greatly increases or decreases the copper loss.

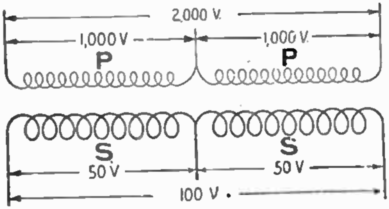
Remarks.—Copper loss increases with temperature because the resistance of the metal rises. Do not overload the current coil of the wattmeter. For greater accuracy the I^2R drop of potential method should be used.

their values and consequently the efficiency at other loads may be readily calculated.

Example.—If a 10 kilowatt constant pressure transformer at full load and temperature have a copper loss of .16 kilowatt, or 1.6 per cent., and the iron loss be the same, then its

$$\text{efficiency} = \frac{\text{output}}{\text{input}} = \frac{10}{10 + .16 + .16} \times 100 = 96.9 \text{ per cent.}$$

Figs. 6,526 to 6,530.—Westinghouse low tension transformer connectors for connecting the low tension leads to the feeder wires. The transformers of the smaller capacities have knuckle joint connectors and those of the larger sizes have interleaved connectors. These connectors form a mechanically strong joint of high current carrying capacity. Since the high tension leads are connected directly to the cut out or fuse blocks, connectors are not required on these leads. The use of these connectors allows a transformer to be removed and another of the same or a different capacity substituted usually without soldering or unsoldering a joint. The connectors also facilitate changes in the low tension connections.



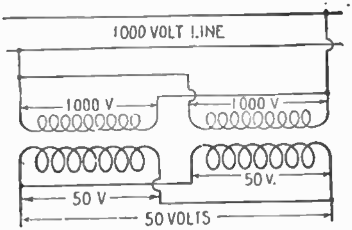


Fig. 6,531.—Diagram of single phase transformer having primary and secondary windings in two sections, showing voltages per section *with series connections.*

Fig. 6,532.—Diagram of single phase transformer with primary and secondary windings of two sections each, showing voltages per section *with parallel connection.*

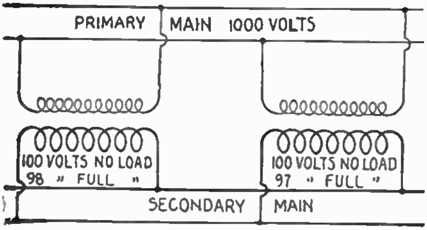
Figs. 6,533 and 6,534.—Methods of altering the secondary connections of a transformer having two sections in the secondary to obtain a different voltage. Fig. 6,533 shows the two sections *in parallel* giving say 100 volts; fig. 6,534 shows the two sections *in series* giving 200 volts.

At three-quarters load the output will be 7.5 kilowatts; and as the iron loss is practically constant at all loads and the copper loss is proportional to the square of the load, the

$$\text{efficiency} = \frac{\text{output}}{\text{input}} = \frac{7.5}{7.5 + .16 + .09} \times 100 = 96.8 \text{ per cent.}$$

The copper loss is measured by placing a wattmeter in circuit with the primary when the secondary is short circuited, and when enough pressure is applied to cause full load current to flow.

If it be desired to separate the load losses from the true I^2R loss, the resistances can be measured, and the I^2R loss calculated and subtracted from the wattmeter reading. The losses being known, the efficiency at



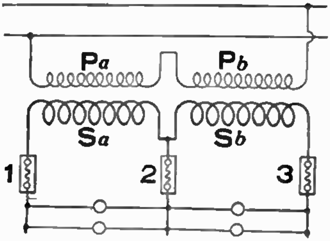
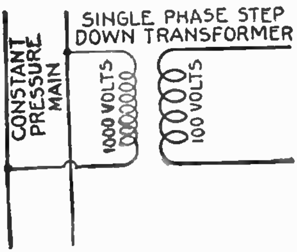


FIG. 6,535.—Diagram showing unlike single phase transformers in parallel.

FIG. 6,536.—Three wire connections for transformer having two secondary sections on different legs of the core. If the secondary terminals be connected up to a three wire distribution, as here shown diagrammatically, it is advisable to make the fuse, 2, in the middle wire, considerably smaller than necessary to pass the normal load in either side of the circuit, because, should the fuse, 1, be blown, the secondary circuit through the section, Sa, will be open, and the corresponding half of the primary winding, Pa, will have a much higher impedance than the half of the primary winding, Pb, the inductance of which is so nearly neutralized by the load on the secondary winding, Sb. The result will be that the voltage of the primary section, Pa, will be very much greater than that of the section, Pb, and as the sections are in series the current must be the same through both halves of the winding; the drop or difference of pressure, therefore, between the terminals of Pa will be much higher than that between the terminals of Pb, consequently, the secondary voltage of Sb will be greatly lowered and the service impaired. As the primary winding, Pa, is designed to take only one-half of the total voltage, the unbalancing referred to will subject it to a considerably higher pressure than the normal value; consequently, the magnetic density in that leg of the transformer core will be much higher than normal, and the transformer will heat disastrously. If the fuse, 2, in the middle wire be made, say, one-half the capacity of each of the other fuses, this condition will be relieved by the blowing of this fuse, and as the lamps in the live circuit would not be anywhere near candle power if the circuit remained intact, the blowing of the middle fuse will not be any disadvantage to the user of the lamps. Some makers avoid the contingency just described by dividing each secondary coil into two sections and connecting a section on one leg in series with a section on the other leg of the core, so that current applied to either pair of the secondary terminals will circulate about both legs of the core any load is readily found by taking the core loss as constant and the copp- loss as varying proportionally to the square of the load.

All Day Efficiency of Transformers.—This denotes the ratio



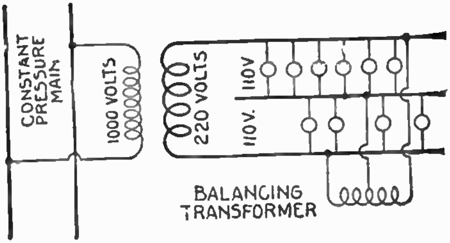
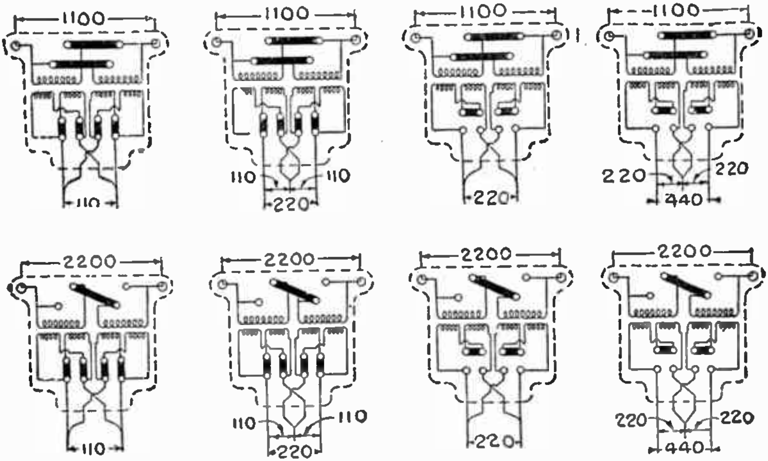
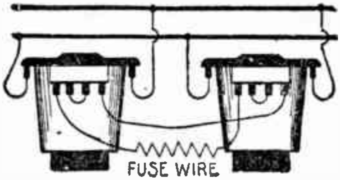


FIG. 6,537.—Single phase transformer connection with *constant* pressure main.

FIG. 6.538.—Usual method of single phase transformer connections for residence lighting with three wire secondaries. A balancing transformer is connected to the three wire circuit near the center of distribution as shown.



FIGS. 6,539 to 6,546.—Connections of standard transformers. All stock transformers are wound for some standard transformation ratio, such as 10 to 1, but various leads are brought out by means of which ratios of 5, 10 and 20 to 1 may be obtained for one transformer. The figures show the voltage combinations possible with a standard transformer.



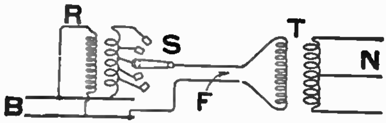
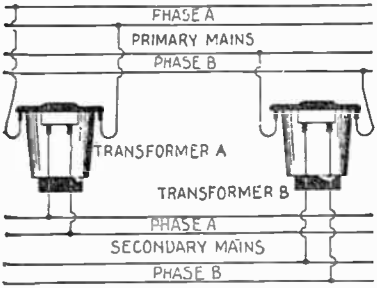


FIG. 6,547.—Method of comparing instantaneous polarities. Two of the terminals are connected as shown by a small strip of fuse wire, and then touching the other two terminals together. If the fuse blow, then the connections must be reversed; if it do not, then they may be made permanent.

FIG. 6,548.—Diagram of static booster or regulating transformer. It is used for regulating the pressure on feeders. In the figure, B, are the station bus bars, R, the regulable transformer, F, the two wire feeders, and T, a distant transformer feeding into the low pressure three wire distributing network N. The two ends of the primary, and one end of the secondary of R, are connected to the bus bars as shown. The other end of the secondary, as well as a number of intermediate points, are joined up to a multiple way switch S, to which one of the feeder conductors is attached, the other feeder main being connected to the opposite bus bar. As will be evident from the figure, by manipulating S extra volts may be added to the bus bar pressure at will, and the drop along F, conpensated for. R, is a step transformer for the total secondary difference of pressure being comparatively small. The above device possesses rather serious drawbacks, in that the switch S, has to carry the main current, and that the supply would be stopped if the switch got out of order. Kapp improved on the arrangement by putting the switch in the primary circuit.



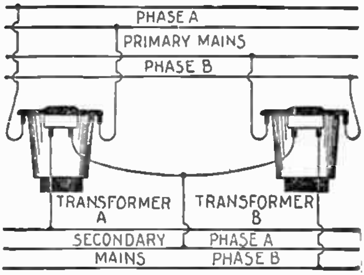
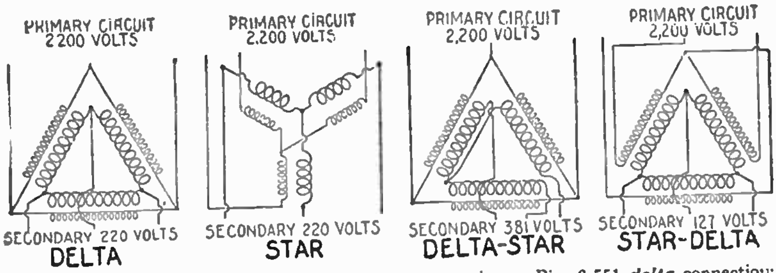
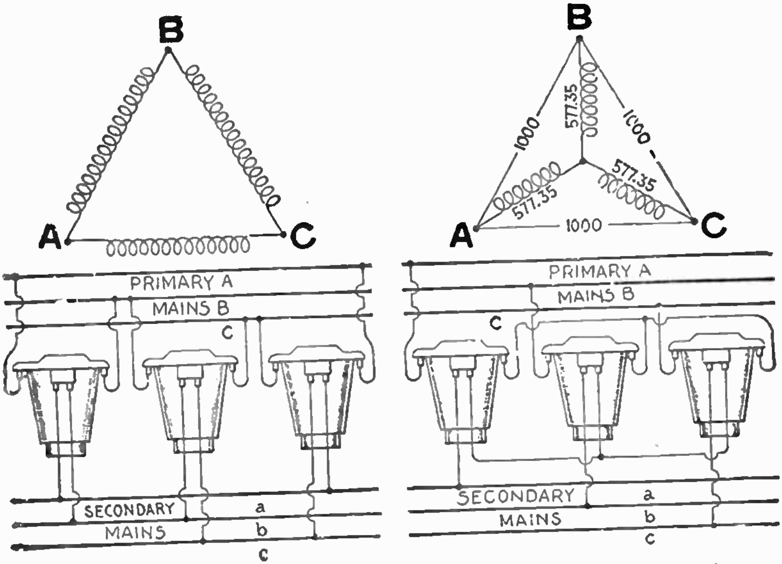


FIG. 6,549.—Two phase transformer connections. Two single phase transformers are used and connections made just as though each phase were an ordinary single phase system.

FIG. 6,550.—Two phase transformer connections, with secondaries arranged for three wire distribution, the primaries being independently connected to the two phases. In the three wire circuit, the middle or neutral wire is made about one-half larger than each of the two outer wires. In fig. 6,549 it makes no difference which secondary terminal of a transformer is connected to a given secondary wire, so long as no transformers are used in parallel. For example, referring to the diagram, the left hand secondary terminal of transformer A, could just as well be connected to the lower wire of the secondary phase A, and its right hand terminal connected to the upper wire, the only requirement being that the two pairs of mains shall not be "mixed." In the case shown by fig. 6,550, there is not quite so much freedom in making connections. One secondary terminal of each transformer must be connected to one of the outer wires and the other two terminals must be both connected to the larger middle wire of the secondary system. It makes no difference, however, which two secondary terminals be joined and connected to the middle wire so long as the other terminal of each transformer is connected to an outer wire of the secondary system.



FIGS. 6,551 to 6,554.—Three phase transformer connections. Fig. 6,551 *delta* connection; fig. 6,552, *star* connection; fig. 6,553, *delta-star* connection; fig. 6,554 *star-delta* connection.



FIGS. 6,555 to 6,558.—Three phase delta, and star connections using three transformers; There are two ways of connecting up the primaries and secondaries, one known as the "delta" connection, and illustrated diagrammatically by fig. 6,555, and the other known as the "star" connection, and illustrated by fig. 6,557. In both diagrams the line wires are lettered, A, B and C. Fig. 6,556 shows the primaries and secondaries connected up delta fashion, corresponding to fig. 6,555, and fig. 6,558 shows them connected up star fashion, corresponding to fig. 6,557. In both of the latter sketches the secondary wires are lettered to correspond with the respective primary wires. When the primaries are connected up delta

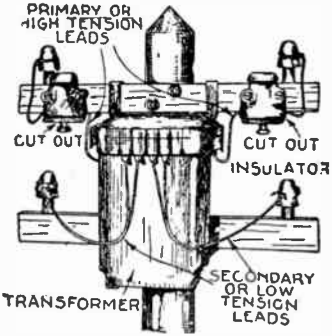


FIG. 6,559.—Installation of a transformer on pole; view showing method of attachment and disposition of the primary and secondary leads, cut outs, etc.

of the total watt hour output of a transformer to the total watt hour input taken over a working day. To compute this efficiency it is necessary to know the load curve of the transformer for a day.

Suppose that this is equivalent to 5 hours at full load, and 19 hours at no load. Then, if W_1 be the core loss in watts, W_2 the copper loss at rated load, and W the rated output,

$$\begin{aligned} \text{output} &= 5 \times W, \\ \text{losses} &= 5\,(W_1 + W_2) + 19\,W_1, \\ \text{input} &= 5\,(W + W_1 + W_2) + 19\,W_2, \end{aligned}$$

and the all day efficiency is equal to

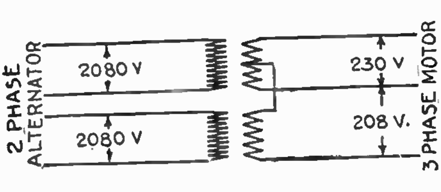
FIGS. 6,555 to 6,558—*Text continued*

fashion, the voltage between the terminals of each primary winding is the same as the voltage between the corresponding two wires of the primary circuit, and the same is true of the secondary transformer terminals and circuit wires. The current, however, flowing through the transformer winding is less than the current in the line wire for the reason that the current from any one line wire divides between the windings of two transformers. For example, in figs. 6,555 and 6,556, part of the current from the line wire A, will flow from A, to B, through the left hand transformer, and part from A, to C, through the right hand transformer; if the current in the line wire A, be 100 amperes, the current in each transformer winding will be 57.735 amperes. When transformers are connected up star fashion, as in figs. 6,557 and 6,558, the current in each transformer winding is the same as that in the line wire to which it is connected, but the voltage between the terminals of each transformer winding is 57.735 per cent. of the voltage from wire to wire on the circuit. For example, if the primary voltage from A, to B, be 1,000 volts, the voltage at the terminals of the left hand transformer (from A to star point) will be only 577.35 volts, and the same is true of each of the other transformers if the system be balanced. These statements apply, of course, to both primary and secondary windings, from which it will become evident that if the three transformers of a three phase circuit be connected up star fashion at the primaries, and delta fashion at the secondaries, the secondary voltage will be lower than if both sides be connected up star fashion. ***For example,*** if the transformers be wound for a ratio of 10 to 1, and are connected up with both primaries and secondaries alike, no matter whether it be delta fashion or star fashion, the secondary voltage will be one-tenth of the primary voltage; but if the primaries be connected up star fashion on a 1,000 volt circuit, and the secondaries be connected up delta fashion, the secondary voltage will be only 57.735 volts, instead of 100 volts. The explanation of the difference between the voltage per coil in a delta system and that in a star system is that in the former each winding is connected directly across from wire to wire; whereas in the star system, two windings are in series between each pair of line wires. The voltage of each winding is not reduced to one-half, however, because the pressures are out of phase with each other, being 120°, or one-third of a cycle, apart; consequently, instead of having 500 volts at the terminals of each coil in fig. 6,557 the voltage is 577.35. The same explanation applies to the current values in a delta system. The current phase between A and B, in fig. 6,555, is 120° removed from that in the winding between A and C; consequently, the sum of the two currents, in the wire A, is 1.732 times the current in each wire; or, to state it the opposite way, the current in each winding is 57.735 per cent of the current in the wire, A. It will be well for the reader to remember that in all cases pressures differing in phase when connected in series, combine according to the well known law of the parallelogram of forces; currents differing in phase, and connected in parallel, combine according to the same law.

$$\frac{5\,W \times 100}{5\,(W + W_1 + W_2) + 19\,W_1} \text{ per cent.}$$

Commercial or all day efficiency is a most important point in a good transformer. The principal factor in securing a high all day efficiency is to keep the core loss as low as possible.

Transformer Connections.—The alternating current has the advantage over direct current, in the ease with which the



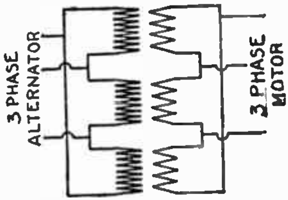
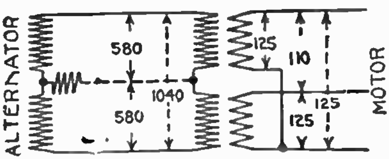


FIG. 6,560.—Diagram showing a method of operating a three phase motor on a two phase circuit, using a transformer having a tap made in the middle of the secondary winding. so as to get the necessary additional phase. While this does not give a true balanced three phase secondary, it is close enough for motor work. In the above arrangement, the main transformer supplies 54 per cent. of the current and the other with the split winding 46 per cent.

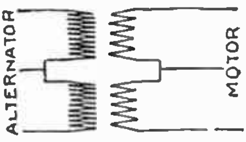
FIG. 6,561.—Three phase motor transformer connections; the combined Delta connected transformers.



pressure and current can be changed by different connections of transformers.

On single phase circuits the transformer connections

FIG. 6,562.—Diagram of transformer connections for motors on the monocyclic system.



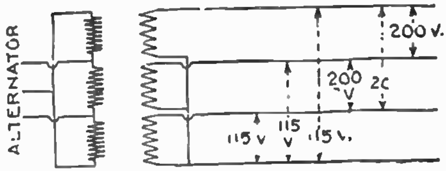
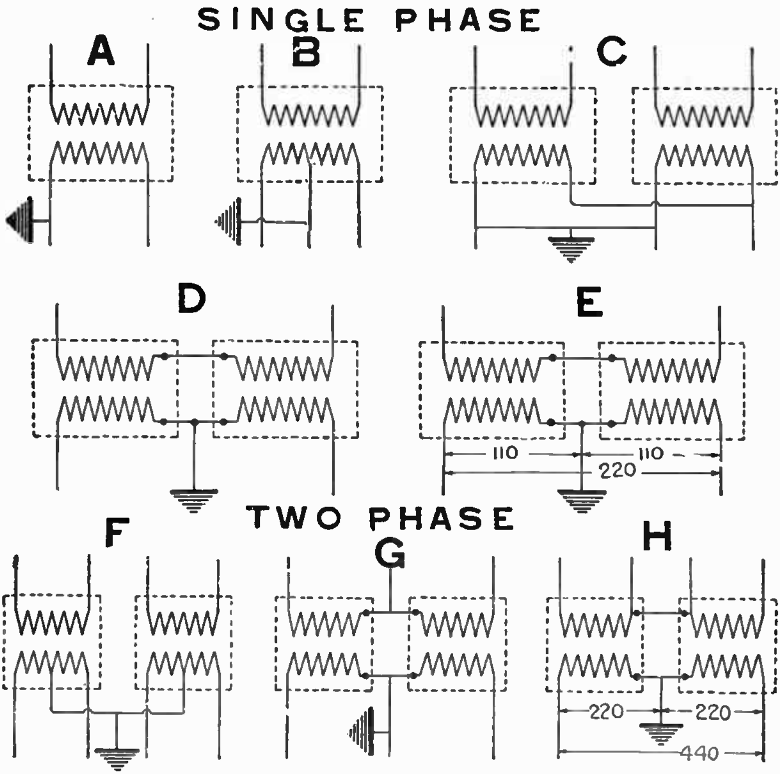


FIG. 6,563.—Three phase motor connections using two transformers.

FIG. 6,564.—Delta-star connection of three transformers for low pressure, three phase. four wire system.

can be varied to change current and pressure, and in addition on polyphase circuits the phases can also be changed to almost any form.

Fig. 6,531 shows a transformer with each winding divided into two sections. Each primary section is wound for 1,000 volts, and each secondary section for 50 volts. By connecting the entire primary winding in series,

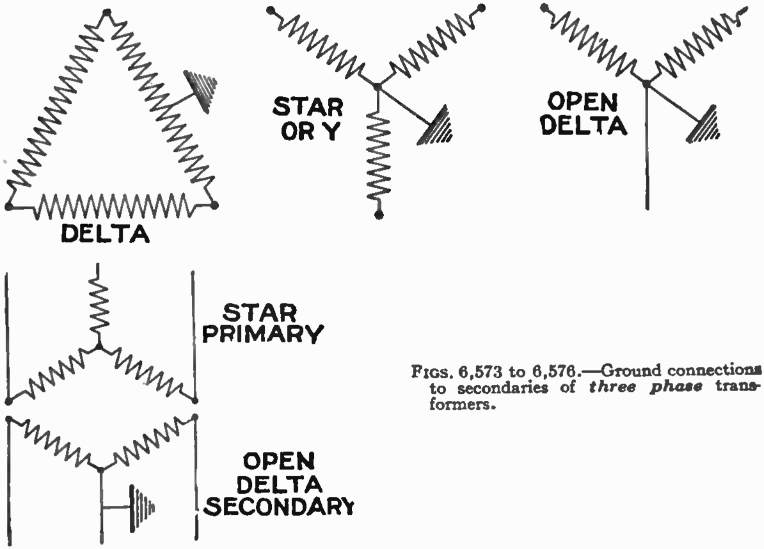


FIGS. 6,565 to 6,572.—Ground connections to secondaries of *single phase* transformers. A, two wire; B, three wire; C, two separate 110 volt transformers in parallel, the secondary ground is attached to either wire; D, two windings, two wire; E, two windings, three wire; F, four wire; G, three wire; H, three wire with four wire primary.

the transformer may be supplied from a 2,000 volt main, as indicated, and if the secondary winding be also connected all in series, as shown, the no load voltage will be 100 between the secondary terminals.

The sections of the primary winding may be connected in parallel to a 1,000 volt main, and 100 volts obtained from the secondary, or the primary and secondary windings may be connected each with its two sections in parallel, and transformations made from 1,000 to 50 volts as represented in fig. 6,532.

This is a very common method of construction for small transformers, which are provided with convenient terminal blocks for combining the sections of each winding to suit the requirements of the case. When the two sections of either winding are connected in parallel as shown in fig. 6,532, *care must be taken to connect* **corresponding** *ends of the two sections together.*



FIGS. 6,573 to 6,576.—Ground connections to secondaries of *three phase* transformers.

Combining Transformers.—Two or more transformers built to operate at the same pressure and frequency may be connected together in a variety of ways; in fact, the primary and secondary terminals may each be considered exactly as the terminals of direct current dynamos. with certain restrictions.

TRANSFORMER CONNECTIONS

CIRCUIT CONNECTIONS & DEFINITIONS OF VOLTAGE AND CURRENTS IN THREE-PHASE SYSTEMS.

In a three-phase system, (Transformer-circuit or apparatus) there are two voltages between which a sharp distinction must be made: The voltage

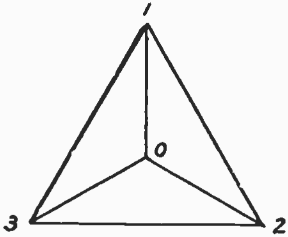


Fig. 1

between the phase conductors, and the voltage from phase conductor to neutral (or ground where the neutral is at ground potential).

In the usual diagrammatic representation as in fig. 1, these voltages are denoted as the delta-voltage and the star-voltage.

If then, 1, 2 and 3 are the three phase conductors of a three-phase circuit, O the neutral, (regardless of whether it actually exists as conductor or not) the DELTA-VOLTAGES 1-2, 2-3, 3-1 are variously called the, Line Voltage, Voltage Between Lines, Voltage Between Conductors, or simply the Three-phase Voltage or the voltage of the system; The STAR-VOLTAGES O-1, O-2, O-3 are similarly called the Voltage To Ground, Voltage To Neutral, or Neutral Voltage, etc.

Delta-voltage = 1.73 times Star-voltage.

$$\text{Star-voltage} = \frac{\text{Delta-voltage}}{1.73}$$

Thus the delta-voltage is the higher one, the star voltage being a part only of the delta-voltage.

Similarly a distinction is made between the delta-current and the star-current in a three-phase system. The DELTA-CURRENT is the current which flows from phase to phase: From 1 to 2, from 2 to 3, from 3 to 1.

The STAR-CURRENT is often simply denoted as the Current, Current Per Phase, Line Current is the Current flowing in the phase conductors in 1, or 2, or 3 and may be supposed to flow towards the neutral O.

Star-current = 1.73 times delta-current

$$\text{Delta-current} = \frac{\text{Star-current}}{1.73}$$

When speaking of the Voltage and the Current or Line Voltage and Line Current of a three-phase system, without further qualifications, the Delta Voltage and the Star Current are understood.

In the conventional denotations, voltage and current in the three-phase system thus do not correspond to each other; and therefore are not in phase with each other on non-inductive load, but show a phase displacement of 30 degrees: the angle 0-1-2 in fig. 1.

TRANSFORMERS & CONNECTIONS

A transformer is defined as a form of stationary induction apparatus in which the primary and secondary windings are ordinarily insulated one from another. A transformer does not generate power, but merely changes the power from one voltage to another.

The three-phase transformer consists of three primary and three secondary windings,(see fig. 1)usually connected in star or delta respectively.

Single-phase transformers (see fig. 2), connected in star or delta are often preferable to three-phase transformers because of the fact that single-phase reverse units are less expensive; and also because damage to one single-phase transformer may be repaired, while another identical spare-transformer is inter-connected in the three-phase unit without loss of service.

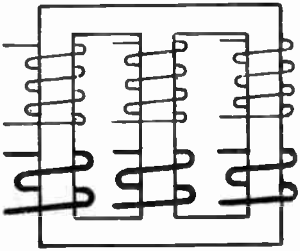


Fig. 1

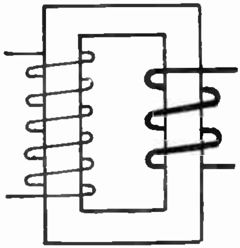
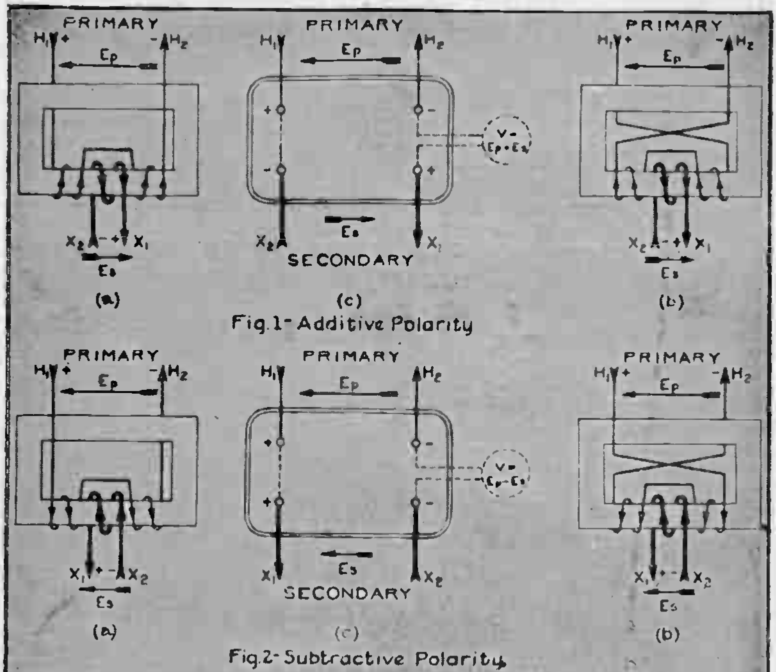


Fig. 2

When two sets of transformers are connected in parallel to the primary and secondary circuits of a three-phase system, any combination of delta and star may be used in each set except that, with one set of transformers connected in delta-star or star-delta, the other set may not be connected delta-delta or star-star.

For example of transformer connections,
See the following pages.



Elementary Transformer showing derivation of terms *Additive* and *Subtractive* polarity.

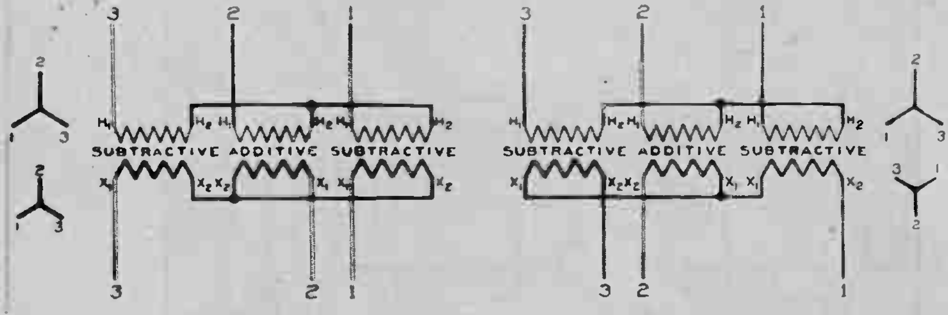


Diagram showing connections for star-star power transformer group to obtain additive or subtractive line polarity.

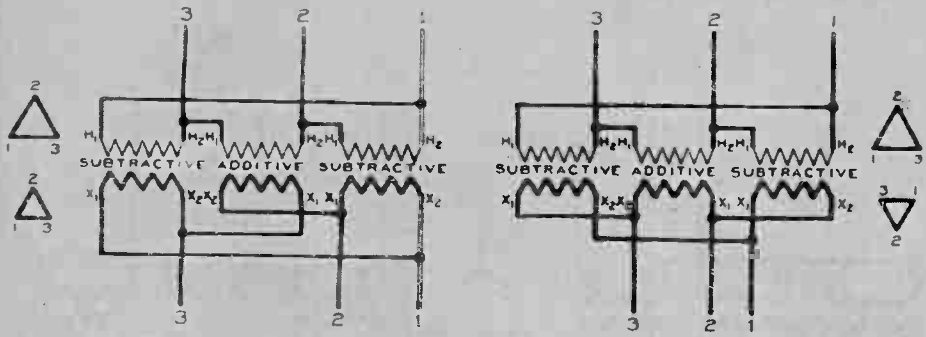
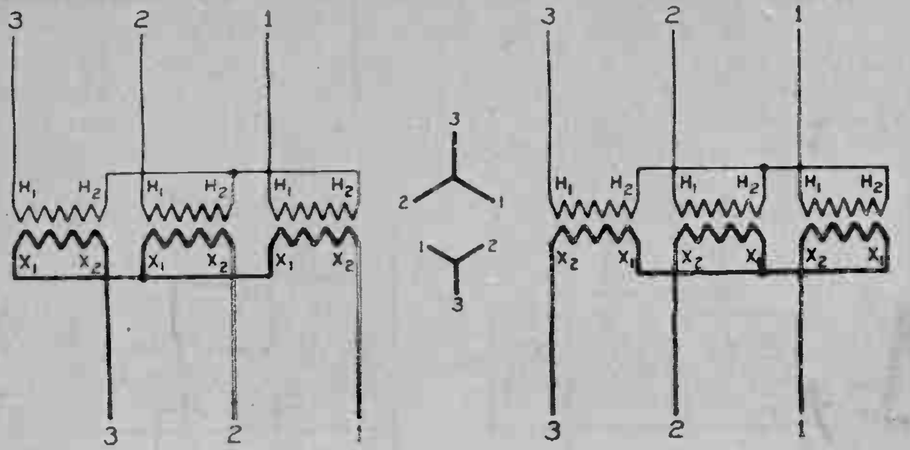


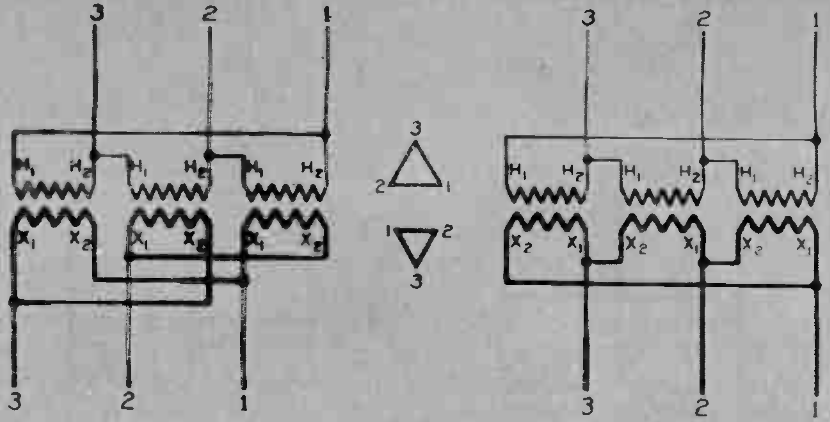
Diagram showing connections for delta-delta power transformer group to obtain additive or subtractive line polarity.



(a) SUBTRACTIVE POLARITY UNITS

(b) ADDITIVE POLARITY UNITS

Vector and wiring diagram showing connections for obtaining additive line polarity with transformer units of either additive or subtractive polarity in star-star groups.



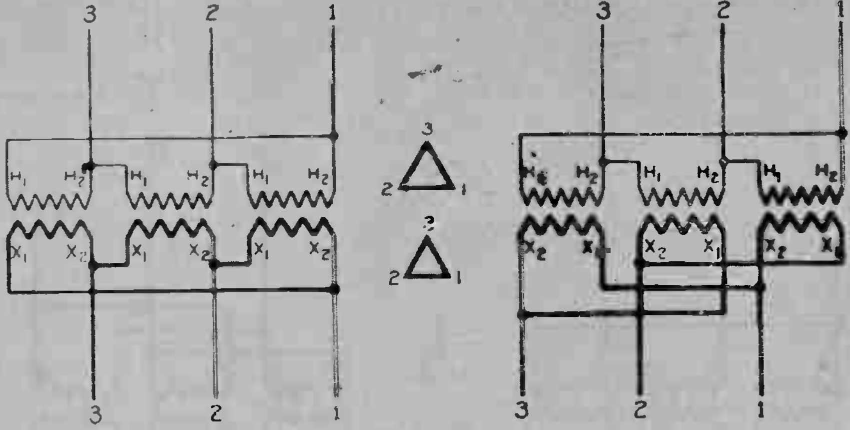
(a)

SUBTRACTIVE POLARITY UNITS

(b)

ADDITIVE POLARITY UNITS

Vector and wiring diagram showing connections for obtaining additive polarity with transformer units of either additive or subtractive polarity in delta-delta groups.



(a)

SUBTRACTIVE POLARITY UNITS

(b)

ADDITIVE POLARITY UNITS

Vector and wiring diagram showing connections for obtaining subtractive line polarity with transformer units of either additive or subtractive polarity in delta-delta groups.

POWER FACTOR INDICATOR CONNECTION

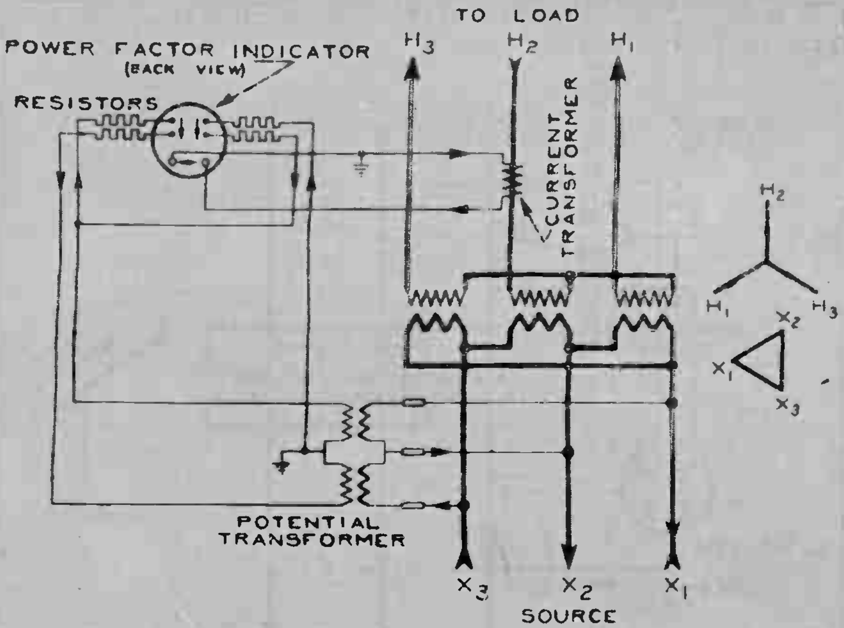
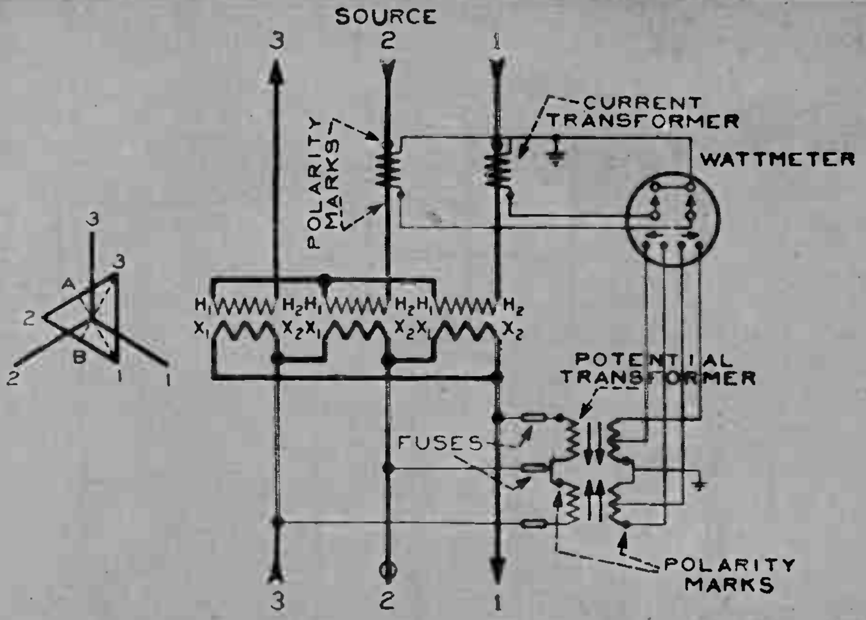
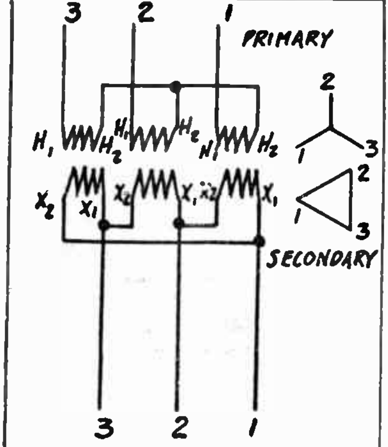


Diagram of connections for power factor indicator connected across a star-delta transformer bank.

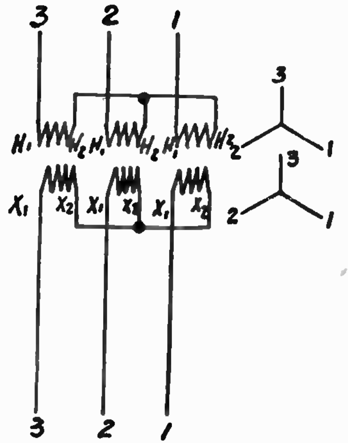


Vector and wiring diagram of connections for indicating wattmeter connected across a star-delta group of power transformers.

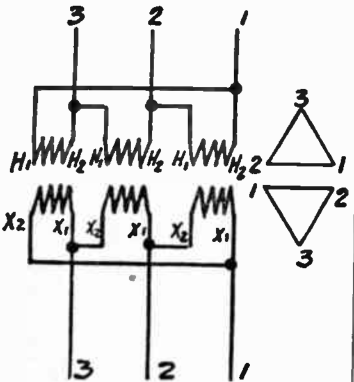
TRANSFORMER CONNECTIONS



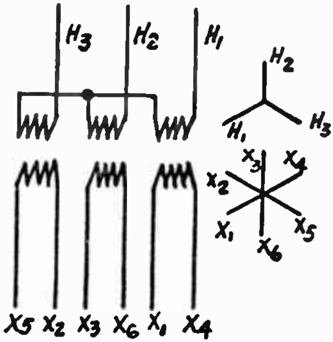
CONNECTIONS OF STAR-DELTA TRANSFORMER BANK, WITH ADDETIVE POLARITY UNITS



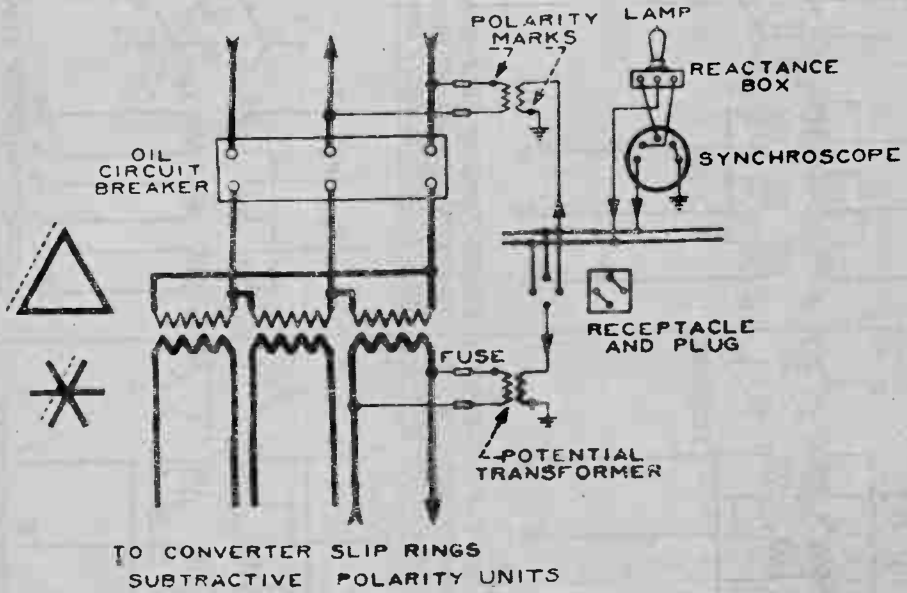
CONNECTIONS OF STAR-STAR TRANSFORMER BANK, WITH SUBTRACTIVE POLARITY UNITS



CONNECTIONS OF DELTA-DELTA TRANSFORMER BANK WITH ADDETIVE POLARITY UNITS.



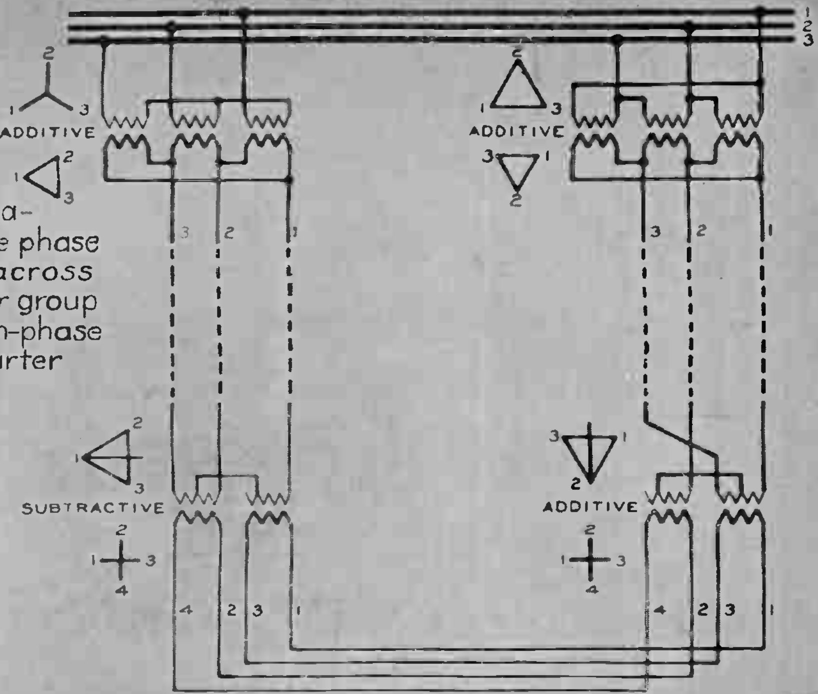
CONNECTION OF STAR-DIAMETRICAL TRANSFORMER BANK FOR ROTARY CONVERTER SERVICE.



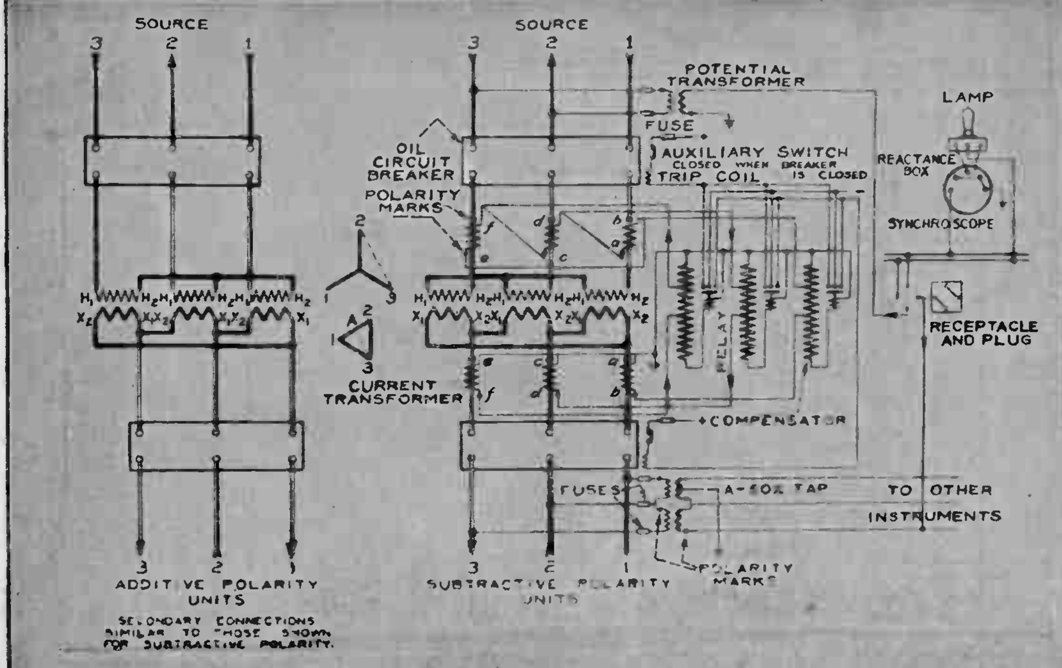
Vector and wiring diagram showing synchronizing connections across a delta-diametrical bank of transformers consisting of subtractive polarity units.

TRANSFORMER CONNECTION

Vector and wiring diagram showing three phase voltages carried across various transformer group forms resulting in in-phase voltages on the quarter phase system.

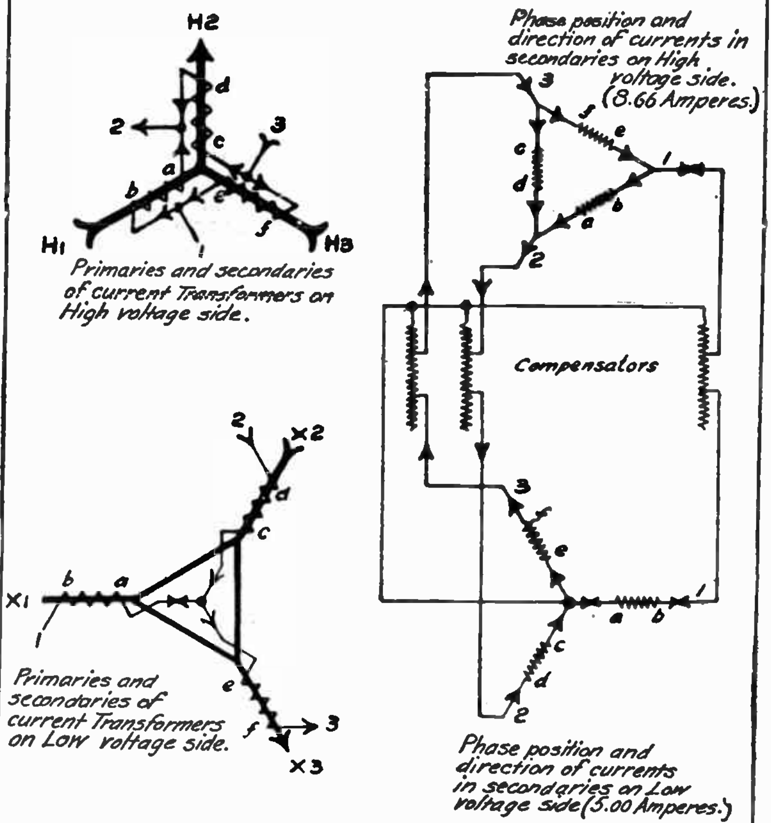


DIFFERENTIAL CURRENT AND SYNCHRONIZING CONNECTION



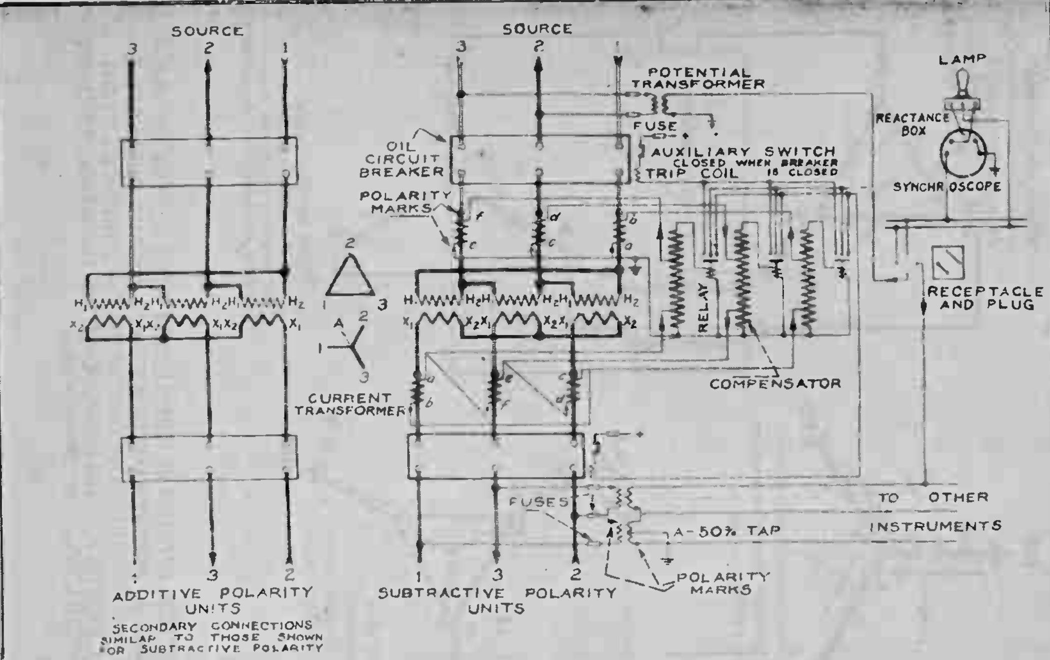
Vector and wiring diagram showing connections for differential protection and synchronizing across a star-delta transformer bank.

VECTOR DIAGRAM



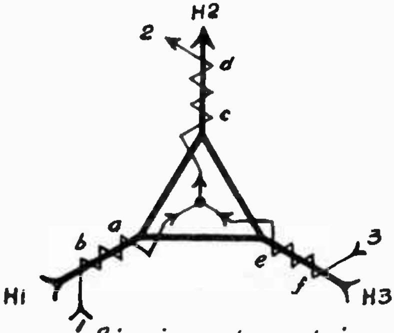
VECTOR DIAGRAM REPRESENTING CURRENT RELATIONS AT A GIVEN INSTANT IN CURRENT TRANSFORMERS ARRANGED FOR DIFFERENTIAL PROTECTION WITH POWER TRANSFORMERS CONNECTED IN STAR-DELTA. SEE OPPOSITE PAGE.

DIFFERENTIAL CURRENT AND SYNCHRONIZING CONNECTION



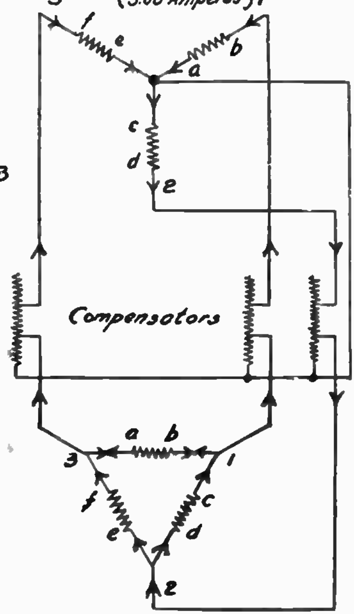
Vector and wiring diagram showing typical connections for differential protection and synchronizing across a delta-star transformer bank

VECTOR DIAGRAM

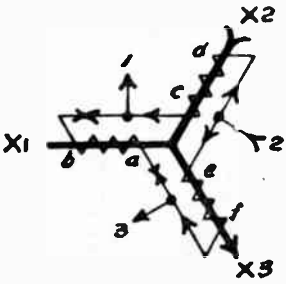


Primaries and secondaries of current transformers on High Voltage side.

Phase position and direction of currents in secondaries on High Voltage side.
(5.00 Amperes)

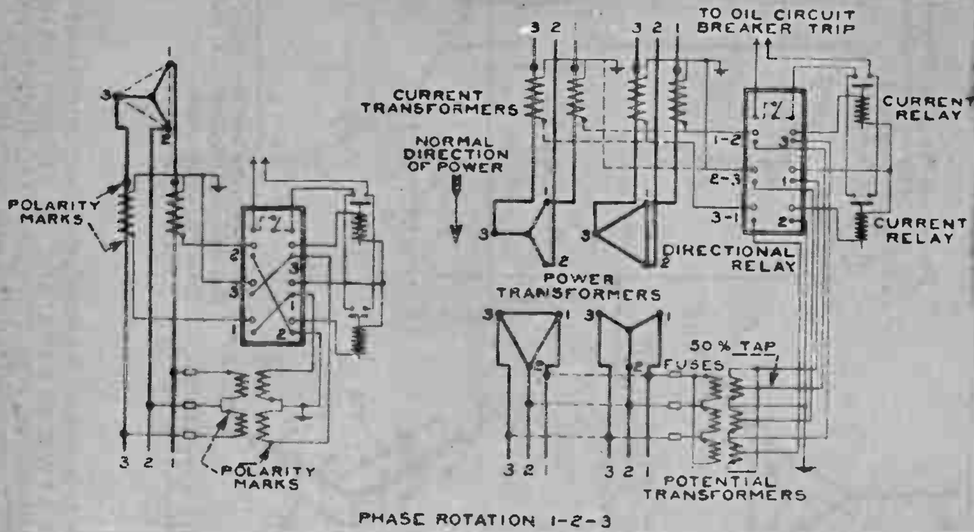


Phase position and direction of currents in secondaries on Low Voltage side.
(8.66 amperes.)

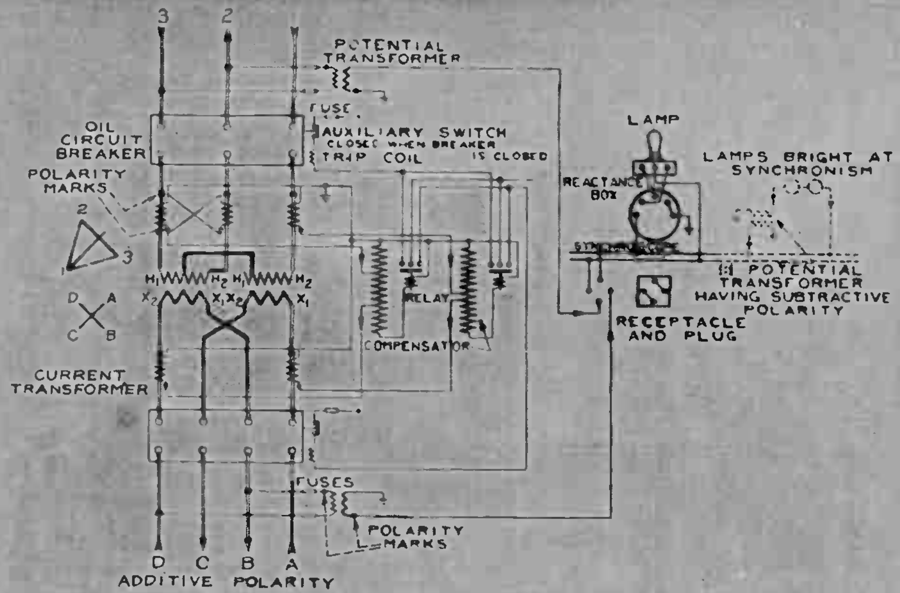


Primaries and secondaries of current transformers on Low Voltage side.

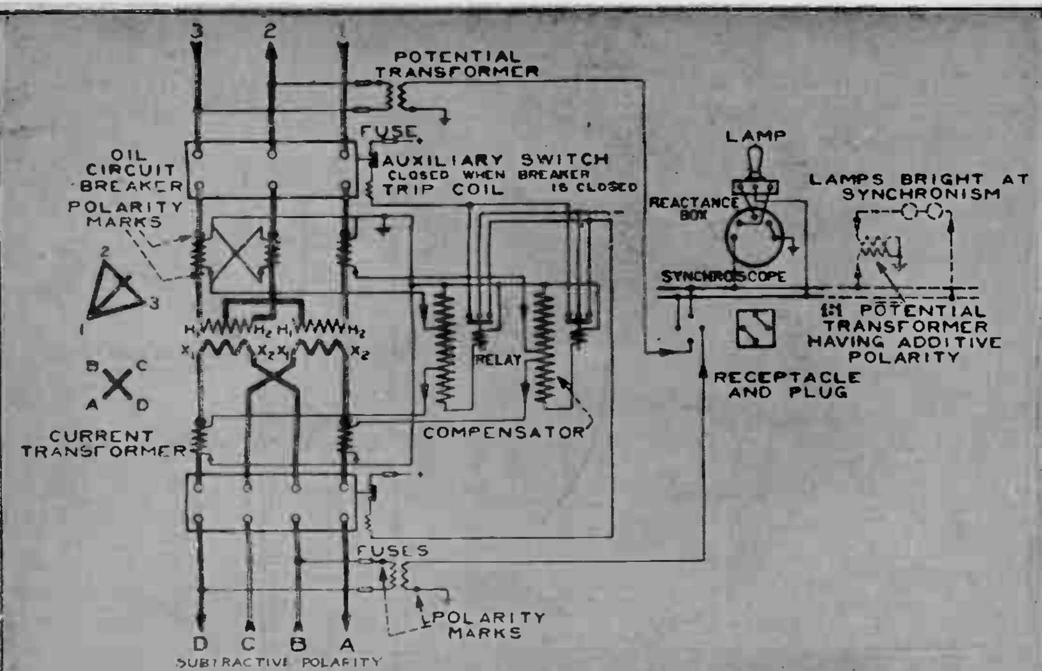
VECTOR DIAGRAM REPRESENTING CURRENT RELATIONS AT A GIVEN INSTANT IN CURRENT TRANSFORMERS ARRANGED FOR DIFFERENTIAL PROTECTION WITH POWER TRANSFORMERS CONNECTED IN DELTA-STAR. SEE OPPOSITE PAGE.



Vector and wiring diagram showing how a low differential relay may be connected across a star-delta or delta-star group of power transformers.

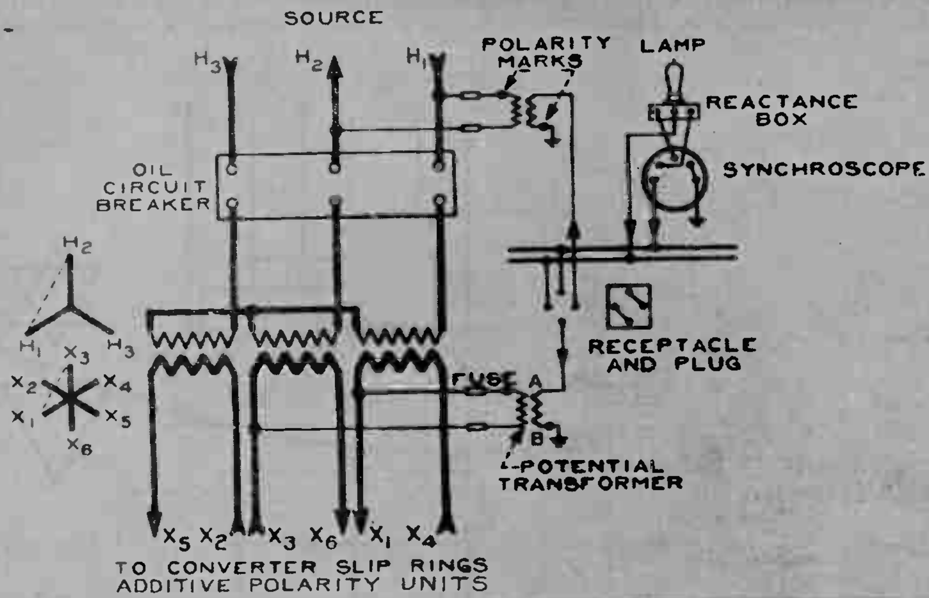


Vector and wiring diagram showing connection for differential protection and synchronizing across a scott-connected bank of additive polarity transformers.

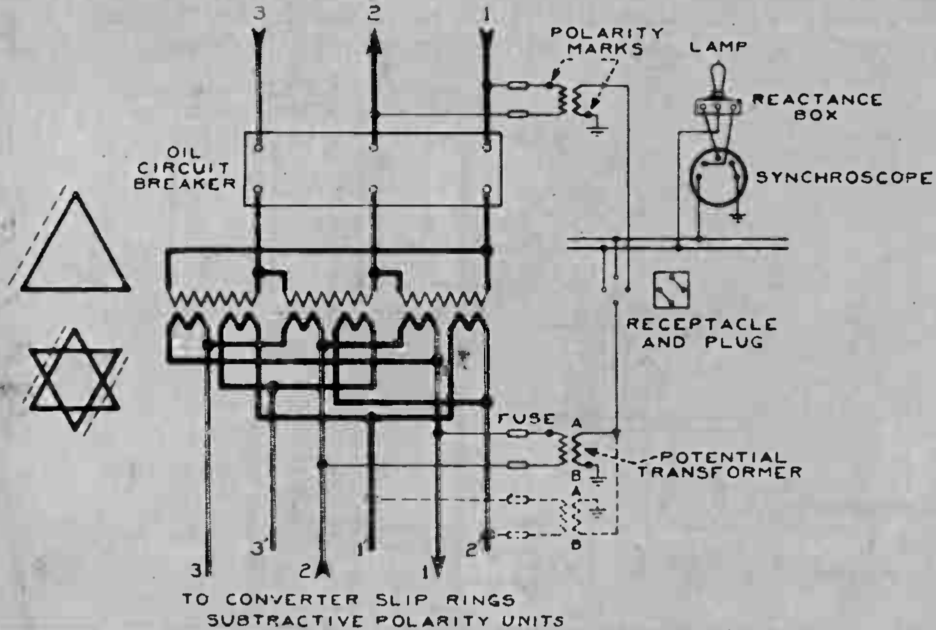


Vector and wiring diagram of connections for differential protection and synchronizing across a scott-connected bank of subtractive polarity transformers.

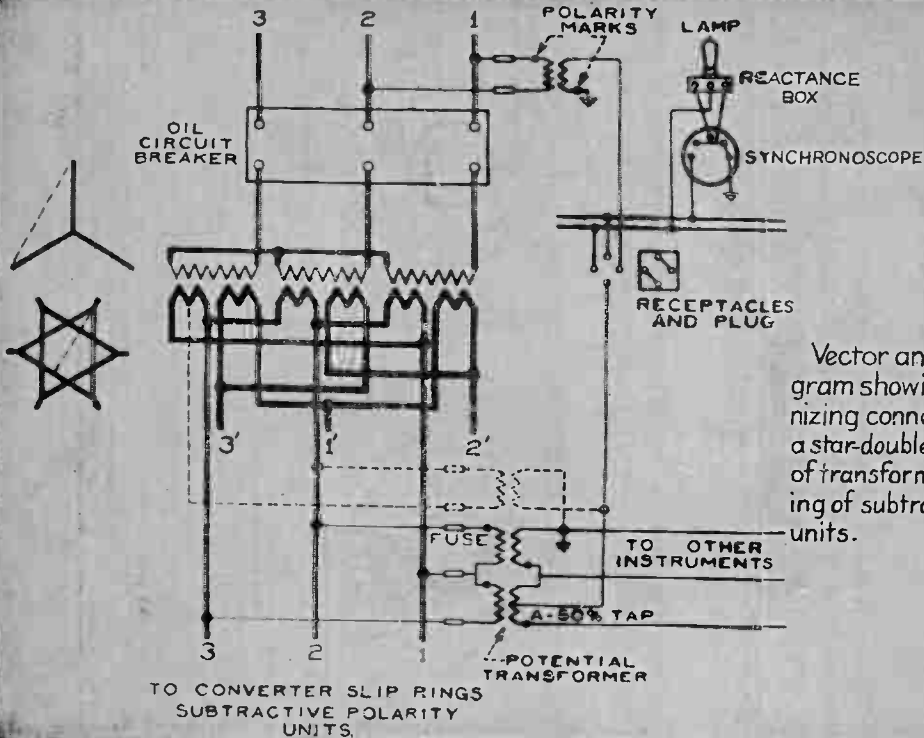
SYNCHRONIZING CONNECTION



Vector and wiring diagram showing synchronizing connections across a star-diametrical bank of transformers consisting of additive polarity units.



Vector and wiring diagram showing synchronizing connections across a delta-double delta bank of transformers consisting of subtractive polarity units.



Vector and wiring diagram showing synchronizing connections across a star-double delta bank of transformers consisting of subtractive polarity units.

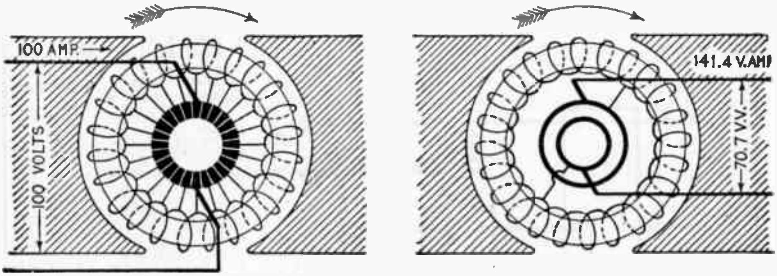
CHAPTER 13

Converters

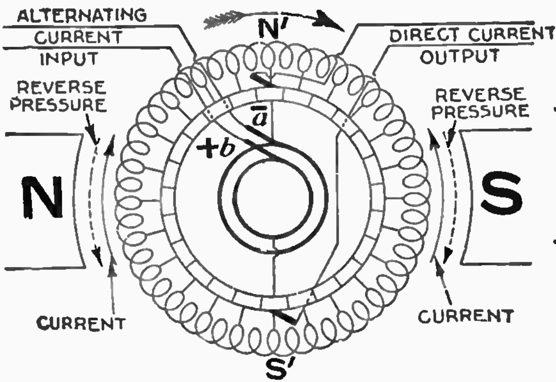
There are many instances where alternating current must be changed to direct or vice versa. Transformation from *a.c.* to *d.c.* or *d.c.* to *a.c.* may be made by means of:

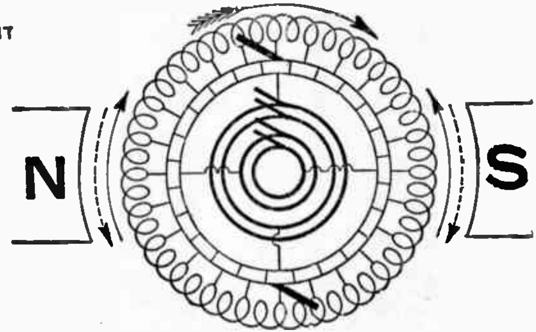
1. Rotary converters
2. Motor generator sets
3. Mercury vapor rectifiers
4. Electrolytic rectifiers.

Strictly speaking, a converter is *a revolving apparatus for converting alternating current into direct current or vice versa;* it is



FIGS. 6,577 and 6,578.—Gramme ring dynamo and alternator armatures illustrating converter operation. The current generated by the dynamo is assumed to be 100 amperes. Now, suppose, an armature similar to fig. 6,577 to be revolving in a similar field, but let its windings be connected at two diametrically opposite points to two slip rings on the axis, as in fig. 6,578. If driven by power, it will generate an alternating current. As the maximum voltage between the points that are connected to the slip rings will be 100 volts, and the virtual volts (as measured by a voltmeter) between the rings will be 70.7 (=100÷52). if the power applied in turning this armature is to be 10 kilowatts, and if the circuit be non-inductive, the output in virtual amperes will be 10,000 = 70.7 = 141.4. If the resistances of each of the armatures be negligibly small, and if there be no frictional or other losses, the power given out by the armature which serves as motor will just suffice to drive the armature which serves as generator. If both armatures be mounted on the same shaft and placed in equal fields, the combination is a ***motor dynamo.*** In actual machines the various losses are met by an increase of current to the motor. Since the armatures are identical, and as the similarly placed windings are passed through identical magnetic fields, one winding with proper connections to the slip rings and commutator will do for both. In this case only one field is needed; such a machine is called a ***converter.***





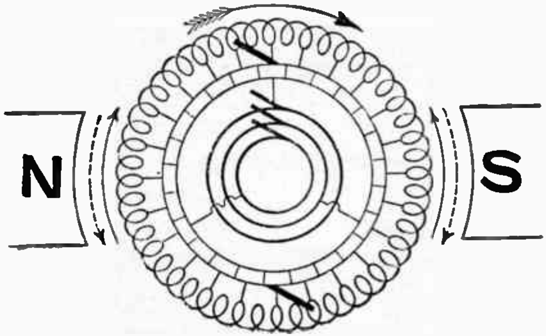


FIG. 6,579.—Diagram of ring wound single phase rotary converter. It is a combination of an asynchronous motor and a dynamo. The winding is connected to the commutators in the usual way, and divided into two halves by leads connecting segments 180° apart to collector rings. A bipolar field is shown for simplicity; in practice the field is multi-polar and energized by direct current.

FIG. 6,580.—Diagram of two phase rotary converter. This is identical with the single phase machine with the exception that another pair of collector rings are added, and connected to points on the winding at right angles to the first, giving four brushes on the alternating side for the two phase current. The pressure will be the same for each phase as in the single phase rotary. Neglecting losses the current for each phase will be equal to the direct current $\times$.707.

FIG. 6,581.—Diagram of three phase rotary converter. In this type, the winding is tapped at three points 120° distant from each other, and leads connected with the corresponding commutator segments.

usually called a rotary converter and is to be distinguished from the other methods mentioned above.

Broadly, however, a converter may be considered as *any species of apparatus for changing electrical energy from one form into another*. According to the standardization rules of the A. I. E. E., converters are classed and defined as follows:

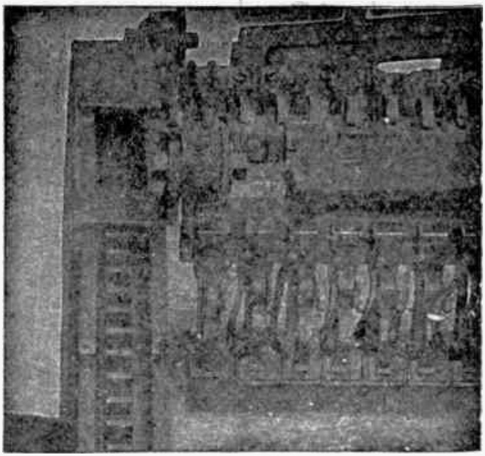
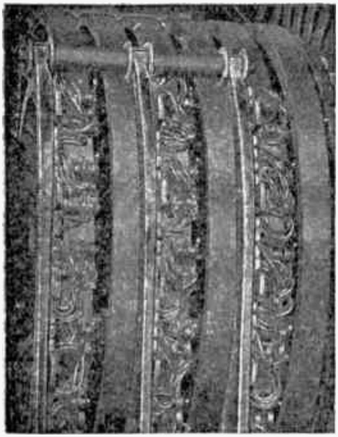


FIG. 6,582.—General Electric commutator of 1,000 *kw.* commutating pole synchronous converter for lighting service. Cover for the cooling vanes at end of commutator bars is removed.



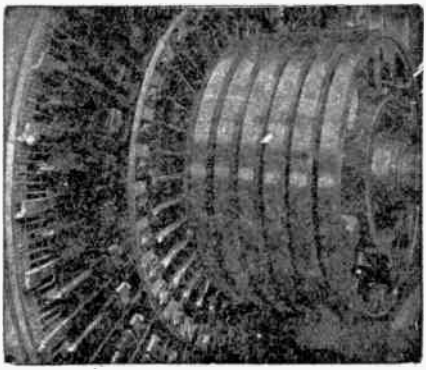
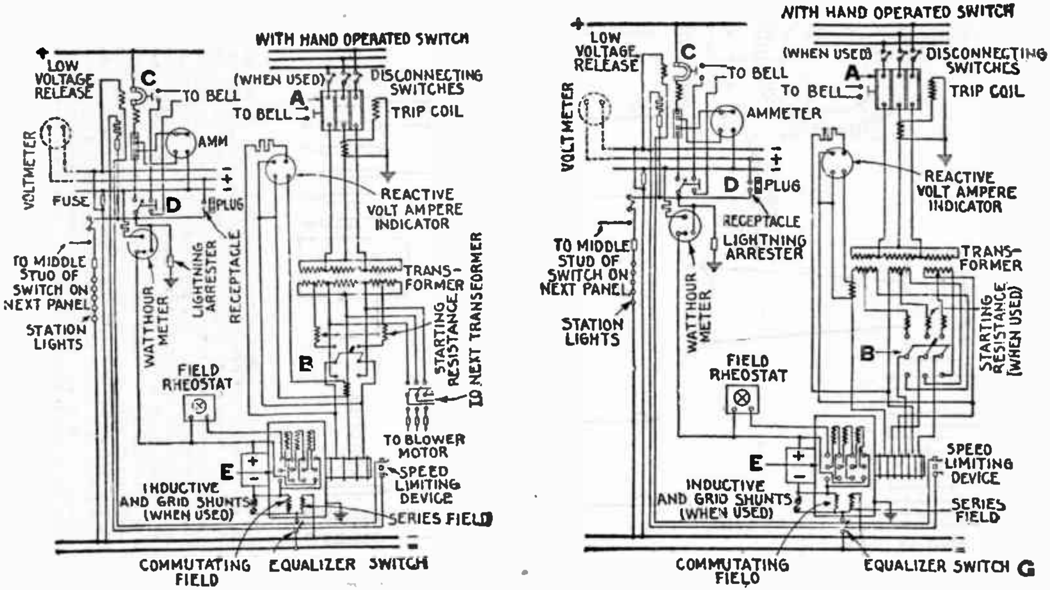
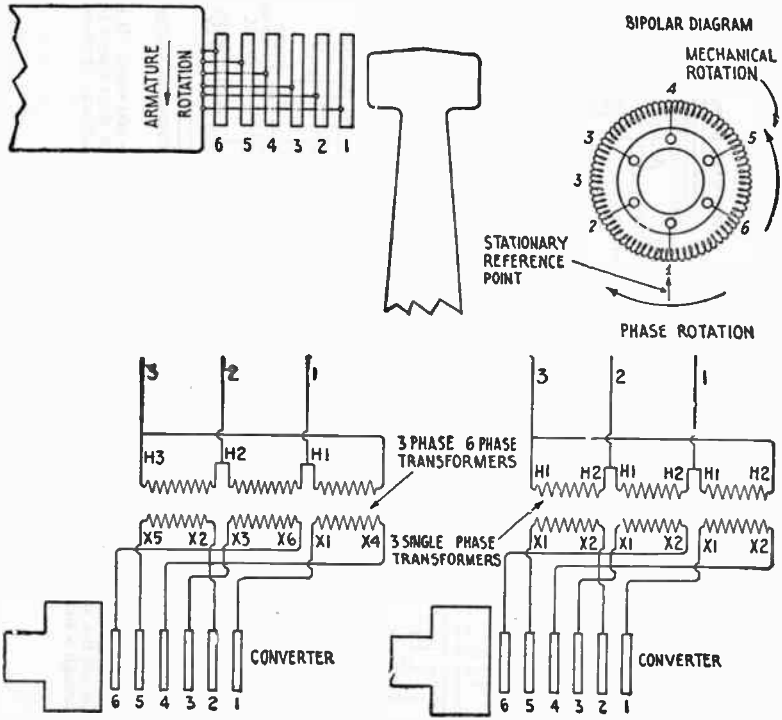


FIG. 6,583.—General Electric converter collector ring brush rigging. The brush and brush holders used on the collector rings illustrate changes in modern synchronous converter practice. The brushes are made of combined copper and graphite by a new process and have the appearance of solid copper.

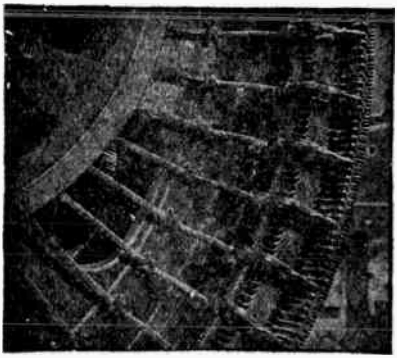
FIG. 6,584.—Detail of General Electric converter armature collector ring end.



FIGS. 6,585 and 6,586.—Converter Connections. Fig. 6,585, three phase 600 volts; fig. 6,586, six phase 600 volts. It is customary to ground converter bases. The ground connection should be heavy enough to safely carry the short circuit current in case of an armature ground. Do not run single *a.c.* leads through iron pipe—two leads opposite in phase, or three leads 120° apart in phase may be run through a single pipe.



Figs. 6,587 to 6,590—Phase rotation in synchronous converters. Figs. 6,587 and 6,588 for 6 phase machine; figs. 6,589 and 6,590 primary and secondary phase rotation in 3 phase diametrical transformers for 6 phase synchronous converter. Synchronous converters are always designed to run clockwise-viewed from the commutator end, or counter-clockwise from the collector end and the phase rotation is 1-2-3-4-5-6. The collector rings are numbered from the bearing in toward the armature as in fig. 6,587. The phase rotation on the high voltage side of the transformers is 1-2-3, as shown in fig. 6,588, which shows the corresponding low voltage connections for both 3 phase and 6 phase transformers and for 3 phase and 6 phase transformers and for three single phase transformers. In the case of 3 phase, 6 phase transformers, refer to the numbering of the leads, rather than their mechanical position, as certain forms of 3 phase transformers may have a different mechanical arrangement of low voltage leads from the one shown. When the phase rotation of the high tension supply is known, this diagram may be followed in making the primary connections; if it be not known, make the connections temporarily in the most convenient manner and try them out. In either case, the connections should be tested before any attempt is made to run the converter on full voltage from the *a.c.* end.



A direct current converter converts from a direct current to an alternating current.

A synchronous converter (commonly called a *rotary converter*) converts from an alternating current to a direct current.

A motor converter is a combination of an induction motor with a synchronous converter, the secondary of the former feeding the armature of the latter with current at some frequency other than the impressed frequency; that is, it is a synchronous converter in combination with an induction motor.

FIG. 6,591.—Equalizer connections of Westinghouse rotary converter. The armature coils are cross connected at points of equal voltage and taps are led out from the winding at suitable points to the slip rings. This construction insures a uniform armature saturation below each pole piece and eliminates one cause of sparking at the commutator.

A Frequency Converter (preferably called a *frequency changer*) converts alternating current at one frequency into alternating current of another frequency, with or without a change in the number of phases or voltages.

A Rotary Phase Converter changes alternating current of one or more phases into alternating current of a different number of phases, but of the same frequency.

Rotary Converters.—The synchronous or rotary converter consists of *a synchronous motor and a dynamo combined in one machine.*

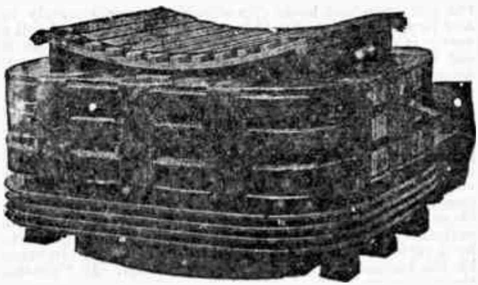
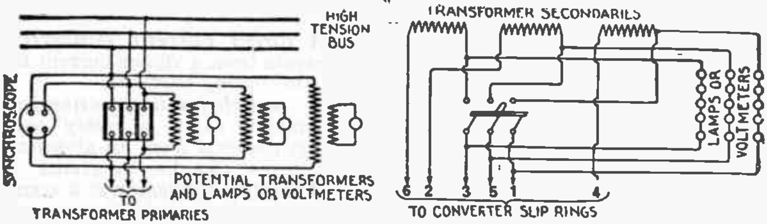
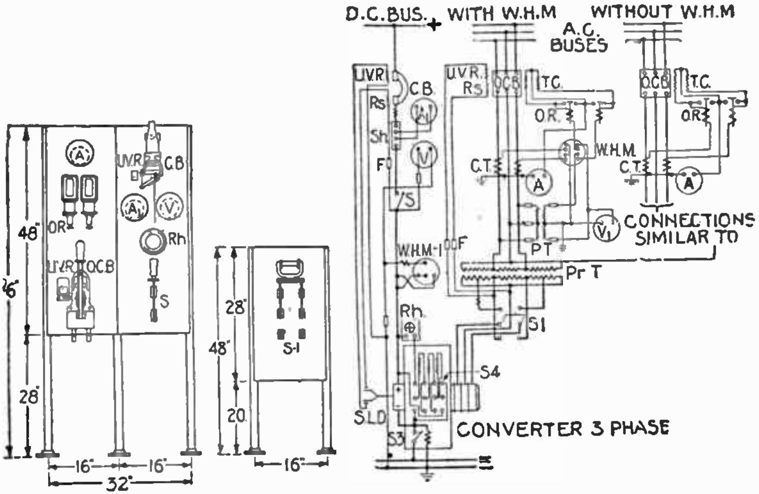


FIG. 6,592.—Westinghouse pole construction for converters. The poles are built of up sheet steel laminations held together with rivets. Projections in the inner ends of the poles form seats for the field coils and hold them in position. Copper dampers set in slots in the pole faces insure stable operation. Rotary converters for railway service are almost invariably compound wound. The series windings are formed of bare copper strap. The shunt windings are of insulated copper strap or wire. Spaces between coil turns and sections are provided for ventilation.



FIGS. 6,593 and 6,594.—"Phasing out" a synchronous converter. Fig. 6,593 on high tension side of the transformers. Raise the *a.c.* brushes and slip a sheet of varnished cambric or other insulating material between the brush holders and the rings. Close the oil circuit breakers and close the low tension starting switch on the down or running position. Make certain that the full secondary voltage appears at the brushes which bear on the diametrical rings 1-4, 2-5, and 3-6. Then open the starting switch and put the *a.c.* brushes down on the rings. The transformer secondaries will then be connected in Y, the stationary converter armature forming a low resistance neutral, compared to the resistance of the voltmeter, and the following voltage relations should exist at the switch: The voltages between blades and upper, or starting clips, should be the starting voltage, approximately ½ of the secondary voltage. The voltage between blades and lower, or running clips, should be full secondary voltage. Any deviation from these requirements indicates an interchange of starting and running leads. The voltage between each upper clip and the corresponding lower clip should be the difference between the starting voltage and full voltage, or approximately ½ secondary voltage. Any deviation from this requirement indicates an interchange of two starting or two running leads. The voltage between any two upper clips should be about 87 per cent of full secondary voltage and the voltage between any two lower clips should be twice this amount, or about 1¾ times full secondary voltage. Any deviation from this requirement indicates a reversed transformer secondary, or that the switch is connected in consecutive phases instead of alternate phases, as shown. If the voltages at the switch be properly symmetrical according to the above tests, the phase rotation must then be checked. The method of phasing out will depend upon the character of the equipment, and the available auxiliary apparatus. When the converter is arranged to start from the *a.c.* end, and a separate high tension bus fed by a single generator can be used to start the converter, a convenient method is to start the converter first on the starting taps, and then on the running taps by reducing the primary voltage. If a separate bus and generator be not available, start the machine on ½ voltage in the ordinary manner, but before throwing it to full voltage, check the voltages at the starting switch as follows: The voltage between each blade and the corresponding lower clip should be approximately ½ voltage and the voltage between any two lower clips should be about 130 per cent of full secondary voltage. When the converter is designed to start from the *d.c.* side or by an induction motor it must be phased out by means of lamps or voltmeters connected around the oil switch as in fig. 6,593 or around the low tension switches as in fig. 6,594. If possible, the synchroscope should be checked at the same time by connecting the lamps at the switch it is connected across. Any apparatus connected across the open switches should be capable of standing double line voltage. While "phasing out" converters designed to be synchronized at the oil switch, make certain that one phase is not reversed on the secondaries, since a reversed secondary phase with delta primary is equivalent to a short circuit. Such a reversal will make itself apparent by excessive current when starting with the transformers connected to the converter, so that the converter will not come to speed from the direct current end, or in the case of induction motor starting preventing the building up of the voltage. When the machine has reached approximately normal speed and voltage, correct phase rotation will be indicated by all the lamps across the oil switch growing bright at the same instant, followed by a period when they will all be dim at once. Reversed phase rotation will be indicated by the lamps growing bright in succession. In "phasing out" at the secondary switches, the indications of correct and reversed phase rotation are the same, respectively, as when "phasing out" on the high side and, in addition, the following indications are possible: If the lamps on two phases fluctuate together, and the third in a different manner, one phase is reversed but the phase rotation of the other two is correct. If the three lamp circuits become bright in a rapid succession and then pass through an interval when all are dim, a combination of reversed phase rotation, and reversed phase rotation, and reversed connections on one phase, is indicated. Usually the easiest method of correcting reversed phase rotation is to interchange two lines at the high voltage terminals of the transformers.



FIGS. 6,595 to 6,597.—General Electric three phase synchronous converter switch board and diagram of connections. *Symbols:* A, ammeter (*a.c.*); A, ammeter (*d.c.*); C.B., air circuit breaking; C.T., current transformer; F., fuse; O.C.B., oil circuit breaker; O.R., inverse time limit overload release; P.T., pressure transformer; Pr.T., power transformer; Rh., rheostat; Rs., resistance; S., switch; S_2, starting switch; S_3, equalizing switch; Sh., shunt; S. L.D., speed limit device; U.V.R., under-voltage release; T.C., trip coil; V., volt meter; V_1, volt meter (*d.c.*) (optional); W.H.M., watt hour meter (*a.c.*); W.H.M.-1, watt hour meter (*d.c.*).

NOTE.—*Operation.* In figs. 6,595 to 6,597 the machine will be started as follows: it being assumed that all switches are opened before starting and the brushes are raised from the commutator: 1. Close high tension oil circuit breaker OCB. 2. Close the starting switch SI, and let the machine come up to synchronous speed. 3. Note the *d.c.* polarity. If the polarity be right, close the field break up switch S4 in the upper position. If the polarity be wrong, throw the field switch in the lower position and hold it there until the volt meter begins to read slightly in the right direction, then close the switch in the upper positions. Hold the starting switch S1 or S2 on the one half tap until the voltage of the *d.c.* side rises to about one half normal and becomes steady. Then throw it down with a rapid movement to the running position. Let the brushes down on the commutator. Close the equalizer switch S3 (omit for a station containing only one machine). Adjust the field rheostat to give proper bus voltage. If the transformers be connected on the right high tension tap, this will draw about 20 per cent. lagging current at no load, and will give unity power factor at about three quarter load. Close the main circuit breaker CB. Try the speed limit device by hand and reclose the circuit breaker. Make certain that the *d.c.* brushes are down on the commutator. Then close the main positive switch S. Checking the position of the brushes is as much a part of

It resembles a dynamo with an unusually large commutator and an auxiliary set of collector rings. On the collector ring side, a rotary converter operates as a synchronous motor, while on the commutator side, it operates as a dynamo.

The speed depends upon the frequency of the *a.c.* and the number of poles because the input side consists of a synchronous motor.

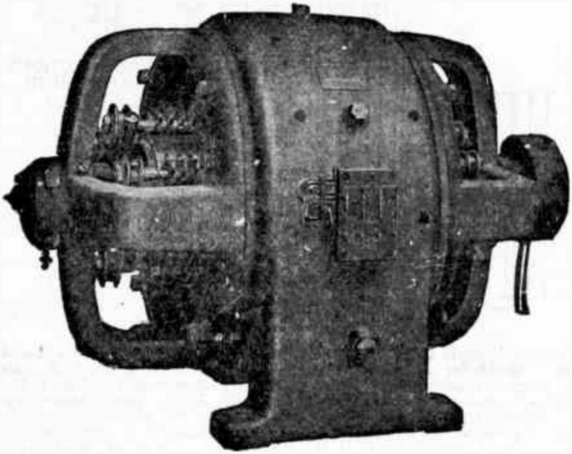


FIG. 6,598.—General Electric 1,200-250 volt shunt wound synchronous converter for industrial service.

The ratio between the impressed alternating pressure and the direct current pressure given out is theoretically constant, therefore, the direct pressure will always be as 1 to .707 for single phase converters or if the pressure of the machine used above indicate 100 volts at the direct current end, it will indicate 70.7 volts at the alternating current side of the circuit.

NOTE.—*Continued.*

the routine of starting as closing the switch, and is of even greater importance since considerable damage may result from connecting the machine to the *d.c.* bus before the brushes are lowered. Unfortunately, the pilot brushes do not act as a fuse in the circuit, but cause an arc to form between the brushes and commutator which holds until the machine is disconnected or flashes over and opens the *d.c.* and *a.c.* switches. Adjust the divisions of load between machines if more than one be in service, by means of field rheostats. If another machine in the same station be carrying load when a compound wound converter is started, the correct *d.c.* polarity may be insured by closing the equalizer switch S3 before the machine reaches synchronism. The series field will be supplied with current by the other machine sufficient to magnetize the poles in the right direction and cause the converter to drop into step with the proper polarity. It is also possible to insure correct polarity on machines which do not synchronize too rapidly by watching the swings of the *d.c.* voltmeter and closing the field switch S4 in the up position just as the volt meter begins its last swing in the right direction. The field will at once build up in the right direction and lock the converter in step with the correct polarity. The order of operation in shutting down a machine is as follows: 1. If operating in parallel with other machines drop the load off as far as possible without danger of inverting, by adjusting the field rheostats. 2. Open the air circuit breaker C.B. 3. Open the main positive switch S. 4. Open the equalizer switch S3. 5. Open the high tension oil circuit breaker O.C.B. 6. Allow the machine to come down to zero voltage, then open the field break up switch S4. Open the *a.c.* starting switch S1 or S2. Raise the brushes from the commutator.

There are two types of converter:

1. Single phase 2. Polyphase.

Usually two or three phase converters are used on account of economy of copper in the transmission line. The armature of a polyphase converter is connected similar to that of an alternator with either delta or star connections.°

In order to vary the voltage of a rotary on the *d.c.* side, pressure or voltage regulators are put in the *a.c.* circuit and may be regulated by small motors operated from the main switch board or by hand.

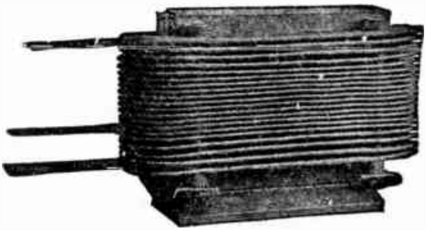
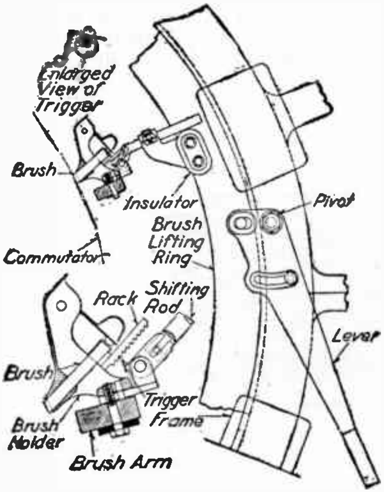


FIG. 6,599.—Commutating pole of Westinghouse commutating pole rotary converter. The commutating poles are similar in general construction to the main poles. The coils are of bare copper strap wound on edge. Ventilating spaces are provided between the pole and coil and between turns. The copper winding is bare except for a few turns at each end. Insulating bolts retain the turns in their proper position.

NOTE.—***Treatment of commutator and brushes.*** Converters are frequently shipped with the commutators freshly ground. This and the initial condition of the brush faces do not constitute a fit condition for carrying loads, and heavy loads must not be put upon a converter when first put in service. This point must be insisted upon, for if the converter be misused in this respect, its commutator may reach such a condition as to require turning, and a great deal of trouble may be experienced before proper condition is obtained. If, on the other hand, the following instructions be followed, good results are assured. When the armature is received with the commutator polished from factory testing, the converter may be loaded at once as heavily as the condition of the brush surfaces will permit with good commutation but if the commutator be not polished, the mcahine should be run light for at least 24 hours with normal brush pressure, and then an additional 24 hours at approximately half load, in order to establish a polish on the commutator surface. The desired surface will show a very high polish by reflected light and will vary in color from a light straw to a dark brown or even a blue gray, the actual color being of no consequence as long as the bars are polished uniformly from edge to edge. Use no lubricant on the commutator either during the polishing period or subsequently. Both the carbon and the graphite brushes now furnished on synchronous converters are self-lubricating, and their characteristics are seriously impaired by the use of any external lubrication. Self-lubricating carbon brushes may in some instances leave a black deposit on the commutator when first put into service. This deposit should be wiped off as rapidly as it appears by means of a piece of dry canvas or other hard, non-linting material, which should be wound around a block and held against the commutator with sufficient pressure to remove the blackening. While the converter is being run to polish the commutator and fit the brushes, the end play device should be in operation so that the commutator and the collector rings will be polished uniformly.

The advantage of unity power factor is that it prevents overheating when the rotary is delivering its full load in watts. The strength of the magnetic field greatly influences the power factor on the high tension line but does not materially affect the voltage.



Since variation of the field strength does not materially affect the voltage by adjusting the resistance in series with the magnetic circuit, the strength of the field can be changed and the power factor kept 1 or nearly 1 as different loads are thrown on and off the rotary. If the field be too strong, a leading current is produced, and if too weak, the current lags, both of which reduce the power factor and are objectionable.

It is the duty of the attendant at the substation to maintain the proper power factor. The ordinary sizes of rotaries are from 3 to 3,000 *kw.*

FIG. 6,600.—Westinghouse brush lifting device for cummutating pole rotary converter. A rack is attached to each brush as shown. Into this rack the spring hinged lifting hook of the raising device engages only when the lighting lever is shifted toward the raised position. Each brush is merely raised and lowered within its own holder so the brush position or commutation is not altered.

NOTE.—*Adjustment of end play device.* After the machine has been brought up to voltage, the end play device should start automatically into operation. If the armature will not come forward, or back from the end play device it is due to an endwise pull of the field. Test the machine by running up to full speed on the *a.c.* starting tap and pull off the power without closing the field circuit. If the machine then oscillate freely in either direction and will not oscillate when up to voltage with field closed, trouble is due to pull of field. If this field pull hold the armature over against, or near to one of the bearings so that the coil delector bumps against it when the armature oscillate, the field should be removed slightly in the opposite direction to correct it. In making this movement, take care not to disturb the air gap by shifting the field to one side or the other. Make reference marks on the feet of the field frame and on the base; move one side of the field exactly the same amount as the other, and take care to give no lateral movement. Then dowel the field in the proper position for the best operation of the end play device.

NOTE.—*Adjustment of speed limit device.* This device is adjusted at the factory (General Electric practice) to trip at 15% over speed. Check this adjustment before putting the converter into service in order to detect any change during shipment. For this overspeed test, the machine may be belted and driven by an auxiliary motor, or it may be run inverted as a *d.c.* motor and brought to the required overspeed by weakening the shunt field. In order to control the speed of compound wound converters operating as motors it will probably be found safer to disconnect or reverse the series field, or short circuit it, since the series field opposes the shunt field and tends to make the converter run away. Use an accurate speed indicator or tachometer, and check it first at the synchronous speed of the converter. Open the speed limit switch first by hand to test the circuit breaker trip coil and show that the breaker opens properly. If the speed limit device then fail to open the breaker at the required overspeed, reduce the tension on the spring by turning the nut on the adjusting screw, and conversely, if the speed limit operate at too low a speed, increase the tension on the spring. Check the final adjustment twice.

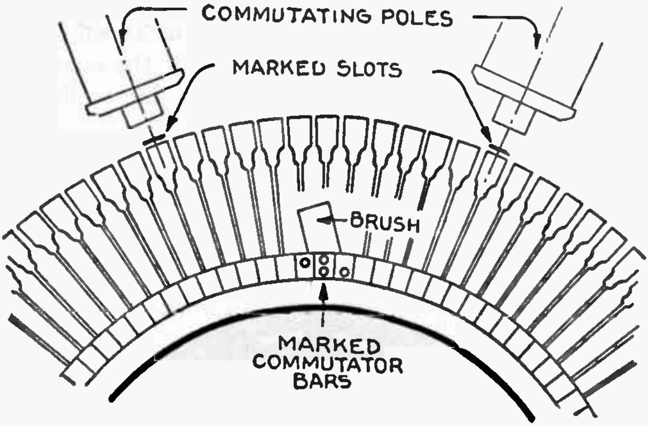


FIG. 6,601.—Detail of General Electric commutator and commutating poles. ***Commutation.*** This is affected by certain mechanical adjustments and refinements as well as by the adjustment of the commutating poles. When good commutation is not obtained after polishing the commutator, these mechanical features should be gone over thoroughly, trying the commutation after any change is made and noting the effect produced. Go over all the contacts and make certain that none are loose, particularly in the circuits. Check the *a.c.* brush pressure. It should be 3 lb. or 3¾ lb. per sq. in. per brush. Check the connections and make certain that the commutating field or any part of it is not reversed, and that one or more of the main spools are not reversed. Check the brush spacing and alignment both with paper tape, and by the commutator mica, revolving armature to two or three positions to detect errors due to variation in thickness of bars or mica. The brush spacing should always be checked with reference to the trailing side of the brush, that is, the side on which the commutator bars leave, and on which sparking usually appears. Machines of certain designs are very sensitive to brush spacing, and a variation of over 1/16 in. should be corrected. The commutator should be wrapped tightly with a long strip of paper covering its whole face and tied in place. The lapping point of this paper should then be marked, the paper should be removed, spread on a flat surface and stepped off with a large pair of dividers or similar tool into exactly equal sections, equal in number to the number of poles. The strip should then be replaced on the commutator and the studs so adjusted that the toes of the brushes on the different studs just touch these marks. ***In general,*** the more accurate the brush spacing, the more uniformly good will be the commutation. Check the mechanical neutral and try shifting the brushes each way from neutral. Very often slight shifting is advantageous. To check the neutral turn the armature over until the center lines of the two slots which are painted red are directly under the center lines of two commutating poles. The brushes of the nearest stud should be set on the center of the group of commutator bars which are stamped and painted red on the ends. Go over the brushes and see that they move freely in the holders, and that the pigtails do not interfere with any part of the rigging. Check the pressure and see that the fit is good. Look for burning or roughness of the contact surfaces. In checking the brush pressure, it will be preferable to measure the actual pressure with a spring balance, because of variation in the springs used. The correct pressure is two pounds per square inch cross section. As an example, the ¾-in. brush will have a pressure of 1⅞ lb. If a spring balance is not available, set the springs in the first notch and advance one notch for each ¼-in. wear of *d.c.* brushes, and each ½-in. wear of the *a.c.* brushes. Inspect the surface of the commutator and wipe off any blackening. If it be rough or eccentric, causing the brushes to chatter or move in the holders, it should be ground or stoned, and perhaps turned.

Compounding of Rotary Converters.—Compounding is desirable where the load is variable, such as is the case with interurban railway systems. The purpose of the compounding is to compensate automatically for the drop due to line, transformer, and converter impedance.

On account of the low power factor caused by over compounding, and the fact that sub-stations are customarily connected to the trolley at its nearest point without feeder resistance, over compounding is not recommended. An adjustable shunt to the series field is provided with each machine.

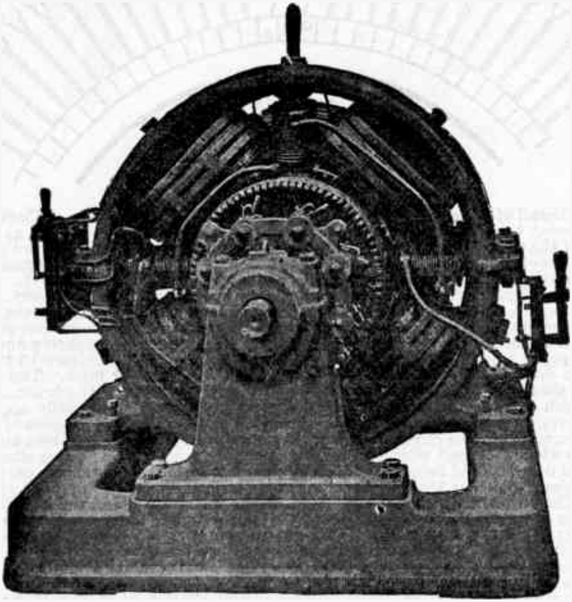
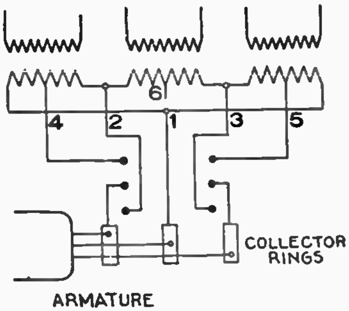
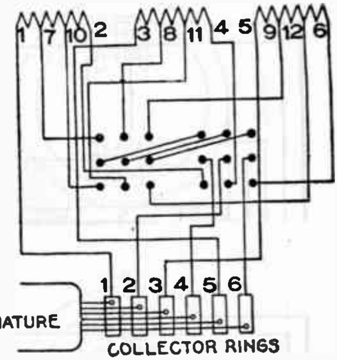


FIG. 6,602.—Westinghouse 300 *kw.*, 1,500 volt, three phase, 25 cycle, commutating pole rotary converter. The illustration shows clearly the commutating, and main poles and the relative sizes, also arrangement of the terminal connections.

NOTE.—***Adjustment of auxiliary commutating field.*** Commutating pole converters with direct connected *a.c.* boosters are provided with shunt windings on the commutating poles in addition to the customary series windings. The shunt windings are necessary in order to maintain the proper strength of commutating field under all conditions of boost and buck, since the armature reaction varies with these conditions and the series winding alone will not give the proper compensation. The auxiliary commutating field is controlled by an automatic equipment which is shipped with the converter. The installation and adjustment of this equipment is comparatively simple.

Ratio of Conversion.—The relation between the *a.c.* and *d.c.* voltages vary slightly in different machines. The ratio depends upon the number of phases and connections of the windings.

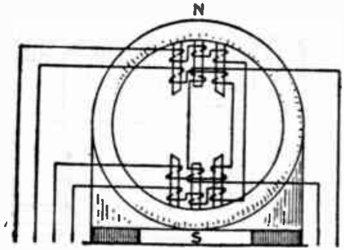


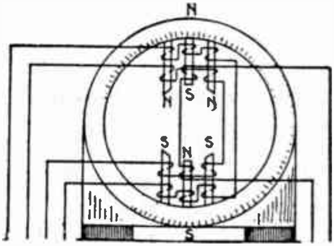


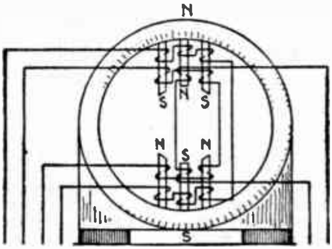
FIGS. 6,603 and 6,604.—*Alternating current starting.* Synchronous converters are generally started from the *a.c.* side like polyphase synchronous motors. The current in the armature induces a magnetic field in the pole pieces, and as the iron has hysteresis, the induced field lags behind the current producing it, thus creating a torque. It is, however, necessary to reduce the voltage at starting in order to prevent a heavy rush of current and this is done by providing taps on the transformer secondaries. Fig. 6,603 shows the arrangement of taps for starting three phase converters, leads 1, 2 and 3 being the operating terminals, and leads 1, 4 and 5 those for starting at half voltage. Lead 6 is merely for the purpose of making the three transformers duplicates. Large converters are usually connected six phase diametrical, and when started from the *a.c.* side, it is desirable to provide taps on the transformers for one-third and two-thirds voltage as shown in fig. 6,604. Leads 1 to 6, inclusive, are the operating terminals; leads 1, 3, 5, 7, 8, and 9 are for the first step, and leads 1, 3, 5, 10, 11 and 12 are for the second step. Leads 2, 4 and 6 are for the final or full voltage step. Leads 1, 3 and 5 are connected directly to the converter and the starting is done by two triple pole double throw switches as shown. When *a.c.* is used for starting, the armature winding stands in relation to the field winding, as the primary of a stationary transformer to the secondary. A large number of turns in the field spools, compared with the turns in the armature, may produce in the field winding a high induced voltage which should be kept within safe limits. This is done by breaking up the field circuit between the spools by means of a switch provided for that purpose on the frame of the machine.

NOTE.—In the *rotary converter* no lead in either sense need be given to the brushes; for the armature reactions of the motor part being, in general, opposed by those in the dynamo part, they cancel one another to a large extent. This property is common to all those motor-generators in which there is used, whether with one winding or two, a common core in a common field. The relations between speed and field are peculiar. In the case of those grouped machines, or motor-dynamos in which each armature revolves in its own field, the conditions differ from those of the converter, where there is only one field. If in either case the continuous-current side is the primary (*i.e.* motor) side, the speed of revolution will depend on the field-magnet, the weakening of which will increase the speed. The frequency of the secondary or alternating current will in that case also vary. But the ratio of the primary and secondary voltages will be independent of speed if the fields are alike, or if only one common field is used. The secondary voltage cannot be varied, while the primary voltage is kept constant, unless separate fields and separate windings be employed. If, on the other hand, the alternating-current side be used as primary, then the machine, whether motor dynamo or converter, runs as synchronous motor with a fixed speed.

Shunt wound converters are satisfactory for sub-stations in large cities and similar installations where due to the larger number of car units demanding power, the load is more nearly constant.

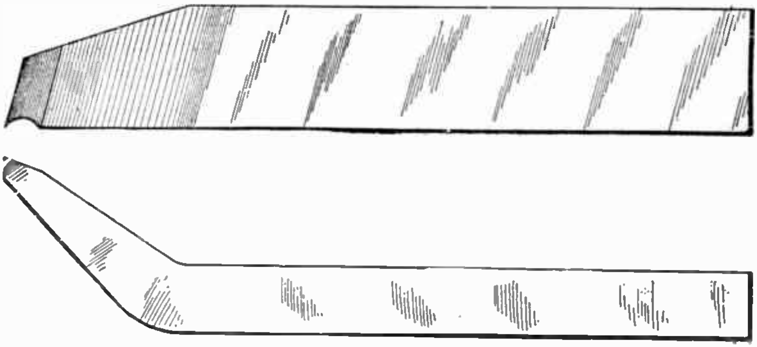






FIGS. 6,605 to 6,607.—Woodbridge split pole rotary converter. Each pole is split into three sections and provided with windings as indicated in fig. 6,605. When excited as in fig. 6,606 the commutator voltage is at its highest value; when excited as in fig. 6,607, the commutator voltage is low. The change in commutator voltage for constant collector ring voltage is in virtue of the property of rotary converters that the ratio of these two voltages is a function of the width of the pole arc.

NOTE.—*The a.c. starting method* does not require any complicated or expensive apparatus, the same switches being used for both starting and running connections. Since it is self-synchronizing, there is little possibility of confusion by the operator, as the difficulty of accurately adjusting the speed is eliminated and less time is required for the starting. After seeing that all the machine switches are open, the high tension oil switch is closed. Then the first starting switch is closed and the converter should start, running on one-half or one-third of the normal voltage as the case may be. As the speed of the machine increases, a volt meter connected across the *d.c.* side will oscillate back and forth and finally come to rest in either a positive or a reverse direction, that is, the machine may come up to synchronism with either positive or negative polarity. For this reason, it is customary to make the field switch double throw and this switch is thrown in the normal position if the volt meter indicate positive polarity. If, however, it show that the polarity of the converter is reversed, the field switch is closed in the other direction, reversing the current through the field coils. The flux set up by this reversed current in the field coils opposes and overcomes the flux induced by the *a.c.* flowing in the armature, causing the armature to drop in speed until it slips a pole, and when the pressure at the brushes is brought to zero, there is no field current and the polarity reverses. If the field switch be now opened, the converter will run in synchronism and the field switch is thrown to its original position, after which the machine is thrown successively on the two-third and the full-voltage taps. When the last switch is closed, the converter is running on full voltage and is ready for service after adjusting the shunt field rheostat to give proper voltage for the station bus bars. Three phase machines starting on one-half voltage taps with the external reactance coils in the circuit will take three-fourths to full load primary current and six phase machines starting on one third voltage taps without the reactance coils in the circuit, approximately three-fourths primary current

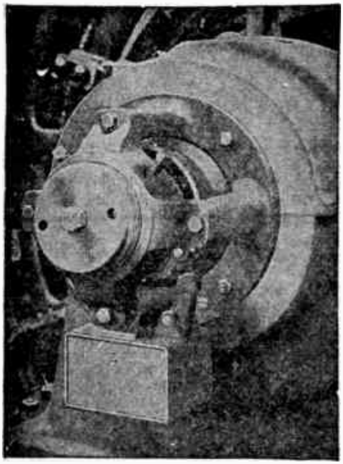


FIGS. 6,608 and 6,609.—Commutator turning tool.

NOTE.—*Commutator grinding or turning.* In many cases where a commutator is rough but is concentric, it is possible to stone it smooth with sandstone instead of turning. Whenever possible this is to be preferred, for a commutator can usually be smoothed by the removal of a few thousandths in. in this way, whereas, if it was turned, a man would probably cut away 1/16 of an inch and possibly more before completing the work. Before stoning, all traces of oil or grease must be removed from the commutator or the stone will glaze over with copper and will not cut. A piece of grindstone or medium grade scythe stone will answer the purpose; the stone should be worked from end to end of the commutator and the surface ground down evenly. This stone should span enough of the commutator's circumference to prevent its dropping into low spots and thereby exaggerating them. While stoning, the brushes should be lifted from the commutator as the grit will cut them rapidly. After stoning, the commutator should be smoothed with fine quartz (not garnet) sand paper and then polished by using the back of the paper. Before stoning or turning the commutator the clamping bolts should be tested for tightness while the machine is warm. Extreme caution should be used in tightening the bolts; in many commutators the bolts are strong enough to distort the clamping ring. After the commutator is as true as it is possible to grind it, it is necessary to polish and smooth with the finest grade of sand paper. When using the sand paper, a very little pressure should be applied and the paper should be kept moving up and down the surface of the commutator so as to prevent it developing flats. A little oil applied with the sand paper will help to give a polished surface. Sandpapering of high speed commutators should be restricted as much as possible, and should always be done with very light pressure against the commutator.

NOTE.—*End play device and speed limiting switch.* In order that the brushes may not wear grooves in the commutator and collector rings, the armature should have a slight reciprocating motion parallel to the shaft. To obtain this motion the larger machines are provided with an automatic, *magnetic* end play device. Current for its operation is obtained from the *d.c.* side of the converter. A condenser is connected across the make and break to facilitate the opening and closing of the circuit. Small machines having comparatively light armatures are equipped with a mechanical end play device. All synchronous converters are equipped with a device for automatically opening the direct current circuit in case the speed become too high. This safety device (or speed limiting switch, as it is generally called) consists of a switch which is operated by a centrifugal governor. The centrifugal weight is mounted on the shaft and revolves with it, while the switch is stationary and is mounted on the collector end pillow block. This weight is so designed that it operates at practically the same speed irrespective of the acceleration. The switch can be adjusted to operate at any predetermined speed. Under normal operating conditions, the circuit of the low voltage release coil on the line circuit breaker is closed, but should the speed of the converter increase to the predetermined setting, the switch, will open, thus opening the line circuit breaker. The current carrying parts are all stationary and so constructed that failure to operate is practically impossible when properly adjusted. It should be noted that the end play device and speed limiting switch are usually mounted at opposite ends of the shaft so that the operation of one does not in any way interfere with that of the other.

For example, a two phase rotary receiving alternating current at 426 volts will deliver direct current at 600 volts, while a three phase rotary receiving alternating current at 367 volts will deliver direct current at 600 volts.



Voltage Regulation.—Since the ratio of the *a.c.* to the *d.c.* voltage of a converter is practically constant, means must be provided to compensate for voltage variation due to changes of load in order to maintain the direct current pressure constant.

There are several methods of doing this, as by:

1. Shifting the brushes (objectionable)
2. Split pole method

FIG. 6,610.—Oscillator and speed limit device of Westinghouse commutating pole rotary converter. It automatically prevents the armature of the converter remaining in one position and thus not allowing brushes to wear grooves in both commutator and collector rings. The oscillator is a self-contained device carried at one end of the shaft. The operating parts consist of a hardened steel ball and a steel plate with a circular ball race, backed by a spring. The machine is so installed with a slight inclination toward the end carrying the oscillator, that as the armature revolves, the ball is carried upward and owing to the convergence of the steel race and shaft face, the spring is compressed. The reaction of the spring forces the armature away from its natural position and allows the ball to drop back to the lowest point of the race.

NOTE.—*In starting six phase converters,* on one-third voltage taps without the external reactance in the circuit, conditions may be found where a starting resistance must be provided to reduce the current rush. With inherent reactance transformers, however, the lower limit of starting voltage is reached and the conditions of starting will be improved. It may be found, however, in some cases of high line reactance and resistance that the voltage will drop too low for starting the machine, and if such be the case, it may be possible to start on the two-thirds voltage tap using a resistance or reactance coil to reduce the starting current. Another arrangement would also be to provide taps at 40 per cent. from one end and 30 per cent. from the other end of the transformers, so that either end could be used for starting.

NOTE.—*Two 600 volt converters* operating in parallel on the *a.c.* and in series on the *d.c.* side, giving 1,200 volts, are generally started one at a time from the *a.c.* side. When they both have been brought up to speed and corrected for the right polarity, they are connected in series; then the field is adjusted for the proper voltage and they are ready to be thrown on the direct current system.

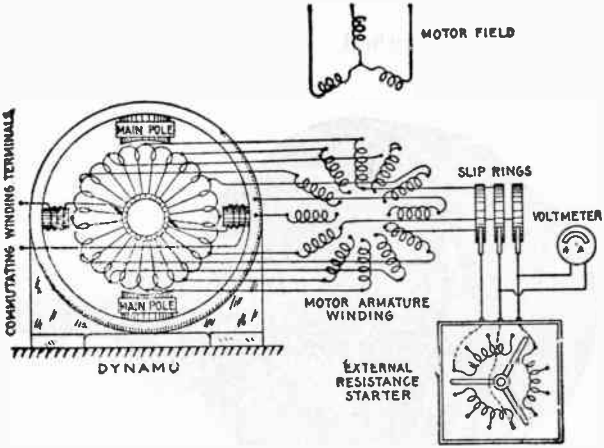


FIG. 6,611.—Diagram of "Cascade" motor generator set or motor converter, as it is called in England where it is used extensively for electric railway work. In the diagram of motor armature winding, some of the connections are omitted for simplicity. The windings are Y connected, and as they are fed by wires joined to the slip rings at the right and center, the rest of the power passes to the converter windings back to rotor winding and out to the slip rings so that part of the power enters the rotor and part through the converter.

NOTE.—***Another method of a.c. starting*** is by means of a small induction motor supported on one of the pillow blocks and with the rotor mounted on the extended synchronous converter shaft just outside the bearing. By designing the starting motor with less poles than the converter, it will enable the motor to bring the converter up to and above synchronous speed. The field switch of the converter is then closed with all the resistance cut in the field circuit. The resistance is then gradually cut out, thus increasing the iron losses of the converter and the corresponding motor torque necessary for driving it, resulting in a gradual decrease in the speed until the synchroscope indicates that the converter is in synchronism. The *a.c.* main switch is then closed and the induction motor is cut out and left to run free.

NOTE.—***D.c. starting.*** When starting from the direct current end, the collector rings of the converter are generally connected to the transformers, although this requires considerably heavier starting current than if the connections were interrupted and the *a.c.* end of the converter open circuited during starting. All the switches and breakers are assumed open on starting. Close the main *d.c.* circuit breaker. Cut the field rheostat all out. Throw in the starting switch, cutting out the resistance slowly, so that the machine is running on full voltage in one minute or less. Raise the speed to normal by means of the main field rheostat. Regulate the voltage of the *a.c.* side to the same value as the line voltage by means of the *a.c.* booster or induction regulator. Synchronize around the high tension oil switch by means of field rheostat, holding the voltage of the *a.c.* side steady. Close the high tension oil switch. Raise the *d.c.* load by means of the synchronous booster or the induction regulator, maintaining unity power factor at all loads by means of the field rheostat. The order of operations in shutting down a converter arranged to start from the *d.c.* end is as follows: Drop the load as far as possible by means of the booster or the induction regulator. Open the direct current circuit breaker. Turn the booster rheostat or the induction regulator to the maximum buck position. Open the high tension oil switch. When a converter is designed to operate on a 3-wire distribution system and the neutral for the system is obtained by connecting the middle points of the diametrical transformers, the transformer neutral must be disconnected from the main neutral bus while starting direct current, but the neutral points of the individual transformers may be left connected together. In starting this type of converter from the *a.c.* end, it is necessary not only to disconnect the transformers from the neutral bus, but to disconnect the individual transformer neutrals from each other.

3. Regulating pole method
4. Reactance method

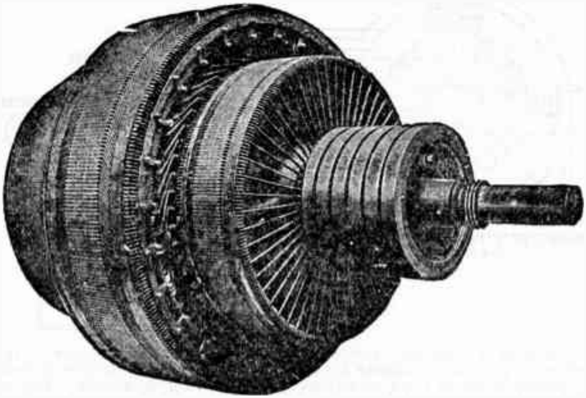


FIG. 6,612.—Armature of Westinghouse synchronous booster converter. Heavy cast yokes form the frames. They are proportioned to rigidly support the laminated steel field poles. The poles are fastened to the frame with through bolts. A lifting hook is provided on all frames.

NOTE.—*Synchronous Converters in parallel.* If several synchronous converters are to supply the same *d.c.* system, they can be connected in parallel in the same manner as shunt or compound wound generators, and they are even frequently operated in parallel with such generators and storage batteries. The different converters will divide the load according to their *d.c.* voltages, and these can be regulated by changing the applied alternating voltage. It is evidently necessary that all of the machines operating in parallel should have the same voltage regulation from no load to full load, and if a battery be also operated in parallel the voltage drop should be sufficiently large so as to cause the battery to take excessive loads. If no battery be used, it will, however, be more economical to have the machines designed for a less voltage drop. Synchronous converters operated in parallel should not be connected to the same transformer secondaries. Such a connection would form a closed local circuit in which heavy cross currents would flow, where any difference in the operating conditions of the machine occurs, as for example if the brushes of one of the machines were slightly displaced relative to the other. Compound wound converters for parallel operation should be provided with equalizer switches. For connecting a compound wound converter in parallel with one already running, the equalizer switch is closed first, so as to energize the series field from the running machine. Next, the shunt field circuit is closed and the field adjusted so that the voltage will correspond to that of the first machine and finally the main switch is closed. The load can then be transferred from the first to the second converter by weakening the shunt field of the former and strengthening that of the latter. It, for some reason, as for example, a short circuit the *a.c.* voltage should drop considerably the synchronous converters operating on the system would not drop out of step, as the direct voltage and load would be correspondingly reduced. If other dynamos or storage batteries, however, were operating in parallel on the same system, these would tend to maintain the direct voltage, and in such a case the *d.c.* would reverse and flow toward the converters running them as motors. Care should therefore in such cases be taken that the synchronous converters are provided with proper speed limiting devices and reverse current circuit breakers.

5. "Multi-tap" transformer method.

6. Synchronous regulator.

Split Pole Method.—In this arrangement each pole is split into two or three parts. One of these parts is permanently excited and it produces near its edge the fringe of field necessary for sparkless commutation.

The effect of this is the same as shifting the brushes except that no sparking results.

The other part is arranged so that its excitation may be varied, thus shifting the resultant plane of the field with respect to the direct current brushes.

Regulating Pole Method.—These poles fulfill the same functions as commutating or interpoles on motors and dynamos.

The regulating poles are used in order to vary the ratio between the alternating current collector rings and the direct current side without the use of auxiliary apparatus such as induction regulators or dial switches which involve complicated connections and many additional wires. The regulating poles are arranged with suitable connections so that the current through them can be raised, lowered, or reversed.

Reactance Method.—This consists in inserting inductance in the supply circuit and running the load current through a few turns around the field cores. This method is sometimes called *compounding*, and as it is automatic it is generally used where there is a rapidly fluctuating load.

With less inductance, the effect of the series coils on the field of the converter is quite similar to that of the compounding of the ordinary railway dynamo.

Multi-Tap Transformer Method.—This is a non-automatic method of control and, accordingly, is not desirable except where the load is fairly constant over considerable periods of time. It requires no special explanation.

Synchronous Booster Method.—This consists in combining with the converter a revolving armature alternator having the same number of poles. The winding of the booster alternator armature is connected in series with the input circuits on the converter. The field windings are either fed with current regulated by means of a motor operated field circuit rheostat, or joined in series with the commutator leads of the converter.

Converter Troubles

Commutator Heating.—Generally due to improper brush pressure, poor commutation, bearing prolonged overload, faulty condition of commutator surface. Allowable temperature is higher than can be endured by hand.

Armature Heating.—Short circuits, or improper connections, of the armature winding cause heating in a particular spot on the armature. Go over the end clips on both ends of the armature and see that they are not bent together and short circuited. Make certain that the collector taps come out at equally spaced points, and that the equalizers are symmetrically connected. In some machines the relation of the equalizers to the collector taps varies, repeating itself at regular intervals around the armature. Continued operation at heavy loads and low power factor produces excessive heating of the tap coils, and will be apparent at equally spaced points on the armature. Change the primary tap connections on the transformer so that better power factor will be obtained at the required voltage, or if possible change the primary voltage at the generating station. General heating of the whole armature is caused by unequal air gap, a grounded shunt field spool, one or more reversed spools, or a break in the field circuit. These troubles cause large circulating currents in the armature winding, and through the equalizers. The air gaps should not vary over 12 per cent. either way from the average value. Check the connections with the connection diagram, and check the polarity by separately exciting the field and holding two iron rods against adjacent pole tips all the way around. The free ends of the rods should attract each other. With a steady current flowing through the field, take the drop on each spool separately with a voltmeter. A variation of over 9 per cent. in the drop indicates a faulty spool.

Shunt Field Heating.—Faulty spools or improper connections which cause armature heating may also cause heating of the shunt field. The trouble should be located by the above outlined procedure.

Heating of Contacts.—Bolted contacts may heat if the contact surfaces be not clean, smooth and bolted together with sufficient pressure. Particular care must be taken with the contacts of connecting strips for pole piece bridges on machines which start from the alternating current end in order to prevent excessive heating during starting.

Poor Commutation.—When the *d.c.* brushes spark, the mechanical condition of the converter should first be gone over carefully. If the brushes chatter, the commutator should be stoned or ground, and if they move up and down in the holders perceptibly, it must be turned before grinding. A rough commutator may cause vibration, in the entire brush rigging, but vibration may also result from loose assembly of the rigging or poor set up of the machine, with insufficient support under the points where the weight rests on the base.

Flash Overs.—Arcing or "flashing over" at the *d.c.* brushes may be caused by excessive overloads or short circuits on the *d.c.* system, or by disturbances on the *a.c.* supply system due to lighting, switching, or accidents to other apparatus. Protection against short circuits on the *d.c.* system can be obtained by increasing the resistance of the feeder to the distribution point where the trouble is most frequent. Short feeders should be avoided, particularly in railway work. Set the main circuit breakers at about three times full load and the feeder breakers as low as possible for continuous operation. *A.c.* disturbances should be located, and reduced to a minimum. The oil switch should be adjusted to trip instantaneously so that in case of a flash over the machine will clear itself quickly, and the damage to it will be reduced as much as possible.

Sparking of A.C. Brushes.—The *a.c.* brushes should not be allowed to spark, as they wear away rapidly when sparking. Make certain that the brushes move freely in the holders, and that the pig tails are not caught on the springs or on the sides of the brush holders. See that each brush is running at the proper pressure. If the collector rings be very rough they must be ground or turned.

The synchronous booster method is particularly desirable for serving incandescent lighting systems where considerable voltage variation is required for the compensation of drop in long feeders for operation in parallel with storage batteries and for electrolytic work where extreme variations in voltage are required by changes in the resistance of the electrolytic cells.

Motor Generator Sets.—These are employed in preferance to rotary converters when it is desirable that the generating element be independent of the *a.c.* line voltage so that any degree of voltage regulation can be obtained. The following combination of motor generators are made and used to suit local conditions:

Synchronous motor..................dynamo
Induction motor....................dynamo
Direct current motor...............dynamo
Direct current motor...............alternator
Synchronous motor..................alternator
Induction motor....................alternator

An advantage of motor generator sets over converters on high frequency circuits, is that the generator can be designed with a few poles and brushes set far apart, which greatly reduces the chance of flashing over in hunting.

Frequency Changing Sets.—Sometimes it is necessary to change from, say 25 cycles on a power circuit to 60 cycles frequency for lighting. The combination for effecting such change consists of a synchronous motor and an alternator. If these machines be constructed with the proper difference in the number of pole, the desired frequency change will be obtained.

CHAPTER 14

Rectifiers

By definition, a rectifier is a device which converts alternating current into a unidirectional current by virtue of a characteristic permitting appreciable flow of current in only one direction.

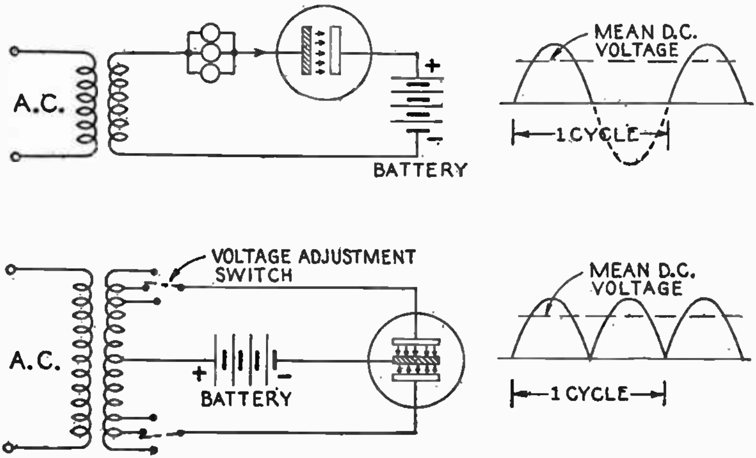
The various kinds of rectifiers may be classed as follows:

1. Mechanical.
2. Electrolytic.
3. Vibrating.
4. Oxide film.
5. Gas-filled tube.
6. Mercury arc.

Mechanical Rectifiers.—This type of rectifier consists of a form of commutating device operating in synchronism with the alternator rectifying the negative waves of the alternating current.

Electrolytic Rectifiers.—If two metals be placed in an electrolyte and then subjected to a definite difference of pressure, they will (under certain conditions) offer greater resistance to the passage of a current in one direction, than in the other direction. On account of this so called valve effect, *electrolytic rectifiers* are sometimes called "*valves*".

When an electrolytic rectifier is not in use for some time, the electrodes will lose the film; in such case they must be reformed. The loss of film may be prevented by removing the electrodes from the electrolyte and drying them. To preserve proper density of the electrolyte, water must be added from time to time to make up for evaporation. Only pure water should be used.



Figs. 6,613 and 6,614.—Diagrams illustrating half and full-wave electrolytic rectifier. (Current can pass through the device in only one direction.)

If a rectifier heat, it is an indication that it is passing alternating current, and when this condition obtains, if the electrolyte be very weak it will cause a buzzing sound. Operating a rectifier with weak electrolyte will destroy the electrodes. Excessive heating of the electrolyte indicates that the rectifier needs recharging.

Vibrator-type Rectifiers.—These are used on low voltage and very small currents. Principally, vibrating rectifiers are synchronous switching devices which reverse the circuit connections at each reversal of the alternating current.

The operating principles of a rectifier of this type is given in wiring diagram, fig. 6,615.

The transformer steps down the voltage from the *a.c.* line to the proper value for operating the magnets of the rectifier and charging the battery.

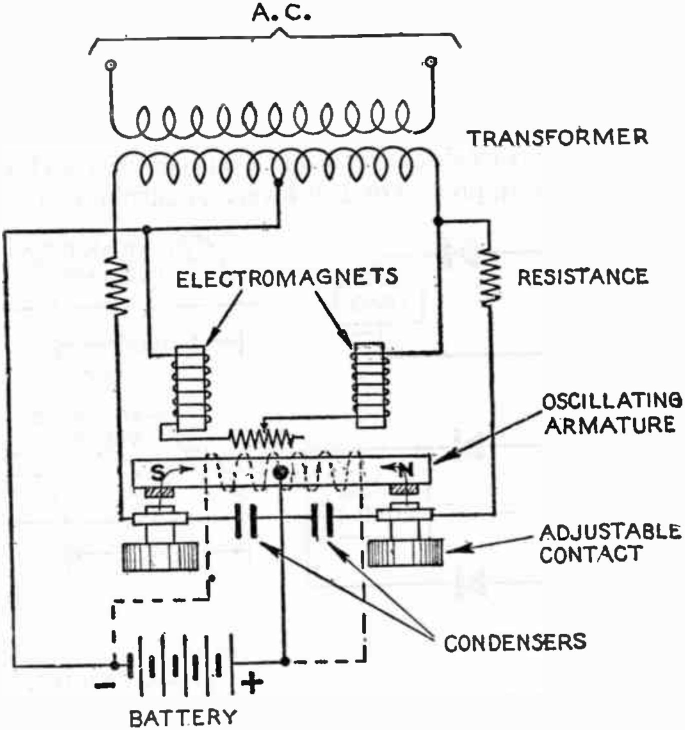


FIG. 6,615.—Wiring diagram showing arrangement of simple vibrating type rectifier. In a device of this sort the synchronous vibrations of the contacts delivers a pulsating *d.c.* current to the battery circuit.

The principal parts of the apparatus is the vibrating reed, carrying one or more contacts, thus opening or closing one or more circuits in synchronism with the energizing *a.c.* current. The reed principle can also be used as a voltage-reversing switch to invert direct current into alternating current, which although not sinusoidal, can nevertheless be transformed.

Such rectifiers and rectifier-inverters are very commonly used in automobiles and other battery operated radio receivers for supplying the high direct current voltage necessary for the plate circuits of the tubes.

Oxide Film Rectifiers.—These are also termed copper oxide rectifiers and work on the principle that the electrical resistance of a properly formed layer of copper oxide on a copper surface depends upon the polarity of the applied voltage.

One element of a copper oxide rectifier consists of a copper disc with a copper oxide layer formed on one side, and a soft metal such as lead, pressed on this layer. A current can readily

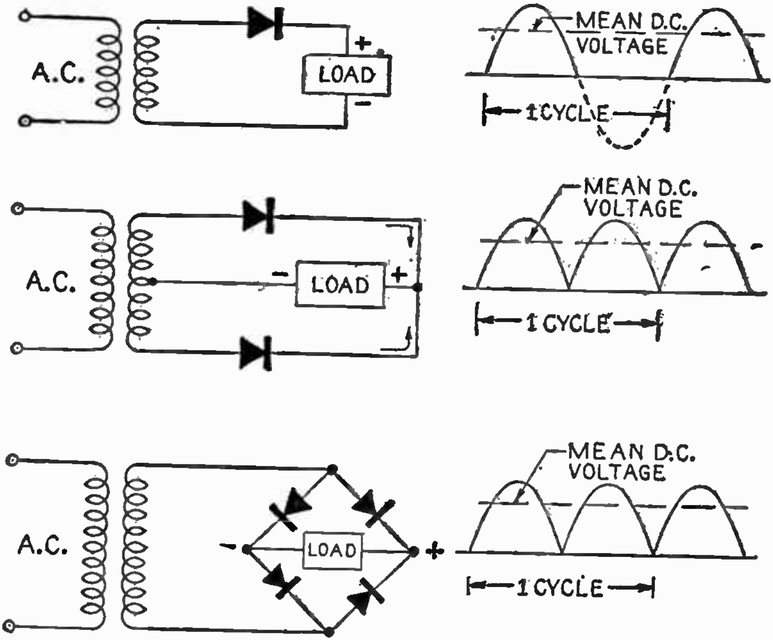


FIG. 6,616 to 6,618.—Connection methods for various types of copper oxide film rectifiers. Fig. 6,616 illustrates a single phase half-wave rectifier. Fig. 6,617 single phase full-wave, and fig. 6,618 single-phase full-wave bridge rectifier.

pass from the copper oxide to the copper disc, but a very high resistance is offered to the flow of current in the other direction. One such element can stand an alternating current voltage of approximately 11 volts.

Rectifiers of this type can be made in capacities from a fraction of an ampere to 100 amperes or more.

By connecting the various stacks in a circuit as shown in figs. 6,616 to 6,618 half or full wave rectification will be obtained. These types of rectifiers have found application in measuring devices, battery charging, or as battery substitutes for control circuits, alarm systems of all kinds, railway signaling, radio communication systems, etc.

Having no moveable parts and no electrolyte, the maintenance cost of the copper oxide rectifier is practically none, as compared with other types,

Gas-filled Tube Rectifier.—In this form of rectifier, rectification is accomplished by the ionization of an inert gas caused by a unidirectional flow of electrons from a heated electrode within the enclosed space.

This type of rectifier is used extensively for battery charging and for operation of radio sets as well as for other miscellaneous uses where only small amounts of direct current is required.

Mercury Arc Rectifiers.—A mercury arc rectifier is one which makes use of the rectifying properties of an electron-emitting cathode and non-electron-emitting anodes enclosed in a chamber containing mercury vapor.

Mercury arc rectifiers may be divided into two classes, depending upon their construction and power output as:

1. The bulb type, and
2. The power type.

The small unit or bulb type most commonly use a glass bulb in which a small pool or mercury is enclosed, and which has the required electrodes sealed into the bulb at the proper location.

Although numerous types of bulbs and their connections are found, a representative type is given in fig. 6,619.

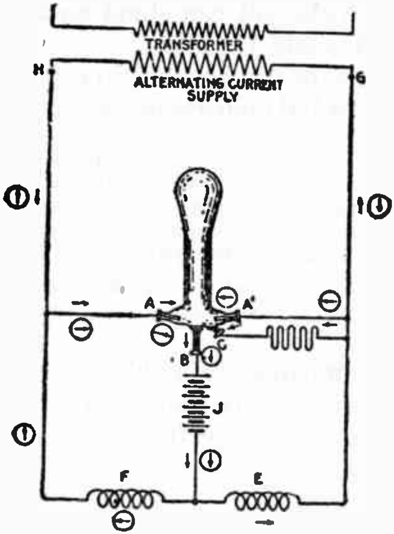


FIG. 6,619.—Schematic wiring diagram of a bulb-type mercury arc rectifier.

In the diagram **AA'** represents the graphite anodes; **B,** mercury cathode; **C,** small starting electrode; **D,** battery connection; **E** and **F,** reactance coils; **G** and **H,** transformer terminals; **J,** battery. The small starting electrode **C,** is connected to one side of the *a.c.* circuit, through resistance; and by rocking the tube, a slight arc is formed, which starts the operation of the rectifier tube. At the instant the terminal **H,** of the supply transformer is positive, the anode **A** is then positive, and the arc is free to flow between **A** and **B.** Following the direction of the arrow still further, the current passes through the battery **J,** through one-half of the main reactance coil **E,** and back to the negative terminal **G,** of the transformer. When the impressed voltage falls below a value sufficient to maintain the arc against the reverse pressure of the arc and load, the reactance **E,** which heretofore has been charging, now discharges, the discharge current being in the same direction as formerly. This serves to maintain the arc in the rectifier tube until the pressure of the supply has passed through zero, reversed, and built up such a value as to cause the anode **A,** to have a sufficiently positive value to start the arc between it and the cathode **B.**

The discharge circuit of the reactance coil **E**, is now through the arc **A'B**, instead of through its former circuit. Consequently the arc **A'B**, is now supplied with current, partly from the transformer, and partly from the reactance coil **E**. The new circuit from the transformer is indicated by the arrows enclosed in circles.

In the manufacture of rectifiers, other metals than mercury could be used, but they are not, because of the arc produced they would gradually wear away and could not be conveniently replaced. In operation the heat generated in the bulb is dissipated through the tube to the air, large tubes being submerged in a tank of oil.

The advantage of a rectifier over a motor generator set for small units is *higher efficiency and lower first cost*. A small one to two horse power motor generator outfit has an efficiency of only 40 to 50%, while mercury vapor rectifiers will have from 75 to 80% and more. The capacity of a rectifier tube is from 40 to 50 amperes. Rectifiers are specially desirable for charging storage batteries from local *a.c.* lighting circuits.

Power Rectifiers

These have the mercury and electrodes enclosed in a metal tank. They are used in various industrial plants, and in the transportation field such as on street railways, subways, interurban lines, electrified railroads, etc.

Many new applications of the mercury-arc principle to the rectification of alternating current, and the inverse operation of converting from direct to alternating current, point to a largely increased adoption of this type of apparatus because of its freedom from the limitations inherent in rotating equipment.

The mercury-arc rectifier is especially well suited to either steady load conditions, such as found in electrolytic service, or the fluctuating type of load of railway service with its high momentary overload demands. It has the very desirable characteristic of maintaining high efficiency at light loads and therefore, is particularly well adapted for use on low-load-factor loads, such as those encountered in electric-traction service. The full-load efficiency of this type of equipment is approximately the same as that of synchronous converters at 600 volts. On higher *d.c.* voltages, the efficiency of the rectifier becomes very much higher than that of the synchronous converters or motor-generator sets which would otherwise be employed.

A complete installation consists of a power transformer, an interphase transformer if used, auxiliary and insulating transformers, rectifier starting and excitation equipment, a cooling system and switchgear.

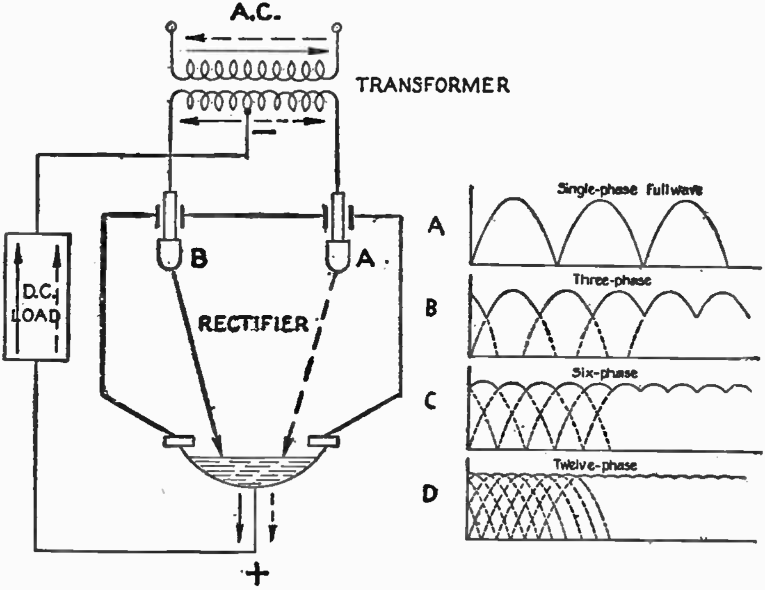
Operating Principles.—As previously noted the mercury-arc rectifier depends for its operation on the rectifying properties of a mercury cathode and non-electron-emitting anodes enclosed in a highly evacuated chamber. The current flows in the conventional sense, in one direction only, namely, from the anodes in phase sequence to the cathode, which is the electron-emitting surface. This type of rectifier is generally known as the cold-cathode type, since the cathode is a pool of cool liquid mercury. The flow of current through the rectifier is due to the movement of electrons from the arc spot of the cathode to the anodes, and to the movement of positive ions from the anode to the cathode arc spot. This exchange of ions and electrons constitutes the flow of current through the apparatus.

The commercial rectifier consists essentially of the following parts: *a highly evacuated steel chamber, an electron-emitting cathode, non-electron-emitting anodes, a mechanical arc-starting anode, excitation anodes, a water-cooling arrangement for taking up the arc losses, and a pumping system for obtaining and maintaining the high vacuum required in the vacuum chamber.*

By means of the starting and excitation equipment, the cathode arc spot is created on the surface of the liquid-mercury cathode, which causes emission of free electrons into the vacuum. These electrons will flow toward the excitation anodes because of the influence of the electrostatic field set up by the positive potential on these anodes; and current flow, in the conventional sense, is established from them to the cathode. The excitation anodes, having a positive potential and a closed circuit for the flow of current, will start operating first. After the excitation anodes have established the arc, the main power anode will start operation as soon as the power circuit breakers are closed, and current will flow, in the conventional sense, from anode to cathode, provided load is taken from the apparatus.

In the commercial power rectifier, a mercury pool is used for the cathode. because of the ease with which the excess vapor can be condensed and led back to replenish the cathode.

The principle of operation can best be illustrated by the single-phase, full-wave rectifier, a schematic diagram of which is shown in fig. 6,620. With the sinusoidal *a.c.* voltage impressed on the transformer primary, the anodes **A** and **B**, will alternately become positive each half-cycle. As each anode becomes positive, current flows from it to the cathode and back through the load to the neutral of the transformer. This produces a pulsating direct current as shown in **A**, of fig. 6,621.



Figs. 6,620 and 6,621.—Elementary wiring diagram of a single phase full-wave rectifier. Fig. 6,621 illustrates various wave forms.

In large commercial rectifiers, a multiplicity of anodes supplied with 6 or 12 phase power is used, in order to obtain a smoother *d.c.* output. The action of a 6 phase circuit is represented in fig. 6,622, where anodes and transformer windings 1 and 4, are shown by heavy lines. If there were no other windings than these in the secondary of the power transformer, the action here would be the same as in the single-phase illustration. fig. 6,620.

Each anode will fire in its turn, beginning at 1, figs. 6,622 and 6,623, and going around 2, 3, 4, etc. as its voltage becomes positive. When anode 4, opposite 1, has reached a higher positive potential than anode 3, immediately ahead of it, 4 will begin to fire, 180 electrical degrees from the point where anode 1 began to fire. In the single-phase illustration, fig. 6,620, an anode carries current slightly more than 180°. In tne 6 phase combination, the anodes fire for approximately 60 electrical degrees, if supplied from a diametrically connected six-phase transformer, fig. 6,622, instead of the 180° mentioned previously.

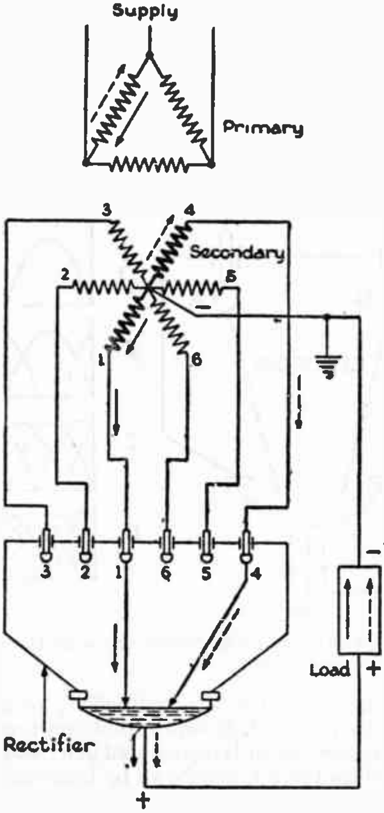


FIG. 6,622.—Schematic wiring diagram of a six-phase mercury arc rectifier.

Description of Rectifier.—The sectional view of a typical mercury arc rectifier of General Electric manufacture together with auxiliaries and schematic wiring diagram is given in figs. 6,624 and 6,626C.

With reference to fig. 6,624 this steel tank power rectifier consists of a vacuum chamber; main, starting and excitation anodes; the mercury cathode; and vacuum pumping system.

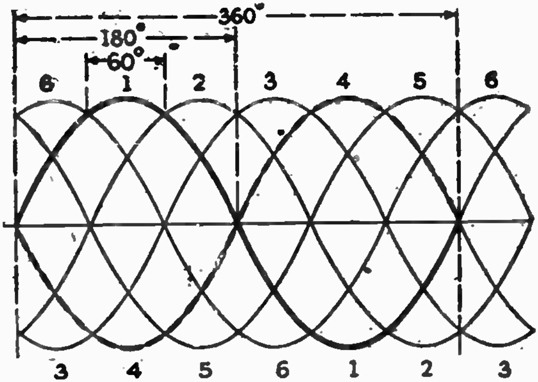


FIG. 6,623.—Illustrating anode-voltage waves for a six-phase mercury arc rectifier.

The vacuum chamber is assembled within a water jacket, and the whole unit, together with the vacuum pumping system, is supported on legs. This construction results in a compact, self-contained unit, simple to transport and install. The steel vacuum chamber is in contact with the arc; therefore, the entire structure is at approximately *d.c.* line potential. For this reason, the entire unit is supported on insulators.

The following description applies to some of the more recently designed units, which have a cylindrical vacuum tank with a sloping bottom. having an opening for the cathode at the center. A flat detachable cover is provided, in which the main, holding and starting anodes are welded permanently in place. The mercury-condensation vacuum pump is also attached to this cover.

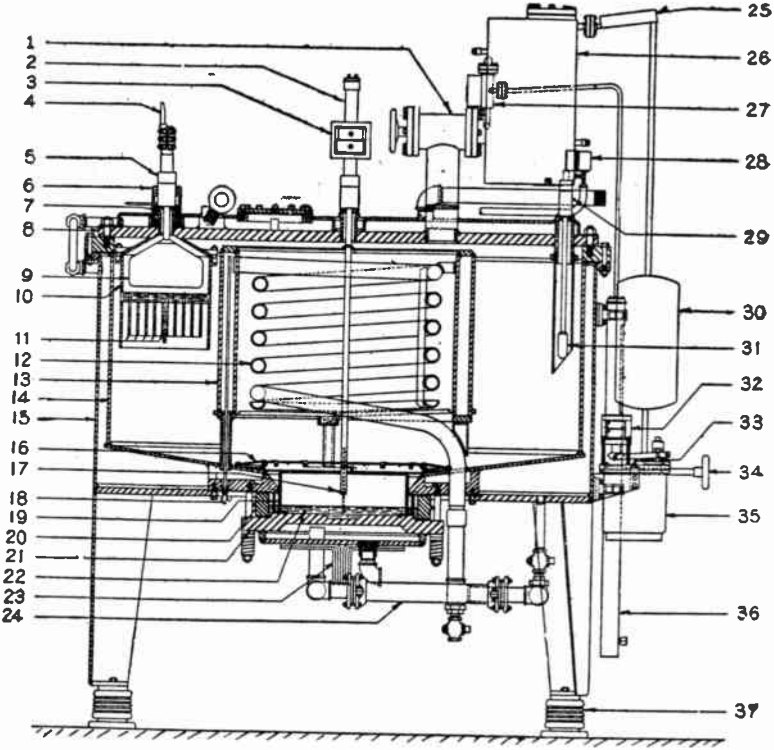


FIG. 6,624.—Sectional view of a 3,000 kw. mercury arc rectifier. In the illustration, 1 represents manual vacuum valve; 2, starting anode armature sleeve; 3, starting anode solenoid winding and yoke; 4, main anode terminal; 5, main anode insulating seal; 6, main anode heater cover; 7, main anode heater; 8, tank cover plate; 9, main anode tip; 10, baffle cylinder; 11, baffle; 12, internal cooling coil; 13, internal cooling cylinder; 14, vacuum tank; 15 water jacket; 16, mercury separator; 17, starting anode tip; 18, air vent; 19, quartz arc shield; 20, cathode insulator; 21, cathode plate; 22, cathode mercury; 23, cathode terminal; 24, cathode insulating pipe; 25, air-cooled mercury trap; 26, mercury condensation pump; 27, vacuum detector; 28, thermal relay for mercury condensation pump; 29, excitation anode insulating seal; 30, gas receiver tank; 31, excitation anode tip; 32, rotary pump valve solenoid; 33, rotary pump valve; 34, vacuum gauge operating hand wheel; 35, rotary vacuum pump; 36, vacuum gauge; 37, rectifier insulators.

The bottom and sides of the vacuum tank, the cathode and the detachable cover are surrounded by water jackets. Inside the vacuum chamber, there is a system of water-cooling surfaces.

Auxiliary Equipment

Exhaust System.—One of the most important auxiliaries of the rectifier is the exhuast system which provides a means for pumping the gas, mainly air and water vapor, from the vacuum chamber. The exhaust system consists essentially of the following parts:

1. Manually operated vacuum valve.
2. Vacuum-exhaust pipe line.
3. Mercury-condensation pump.
4. Air-cooled mercury trap.
5. Receiver tank and piping.
6. Rotary pump shut-off and relief valve.
7. Scale or dirt trap at the rotary pump.
8. Oil-sealed rotary vacuum pump which exhausts the gases into the atmosphere.

Manual Vacuum Valve.—The manual vacuum valve, fig. 6,625 is used to isolate the exhaust system. This valve is of all-steel construction, except the valve diaphragm, which is of rubber. This rubber diaphragm performs only one function, namely, to seal the rectifier from the remaining part of the exhaust system. To seal the valve-actuating stem against atmospheric pressure, a steel "accordion" is used, so that the handwheel screw will transmit enough motion to the rubber diaphragm to open and close the valve. The valve is made so that the obstruction presented to the flow of gas from the rectifier to the mercury condensation pump will be small. When the valve is closed, any part of the exhaust system can be removed without losing vacuum in the rectifier. When a part of the exhaust system has been serviced and replaced, it can be exhausted of gases before the valve is opened. In this way, any of the gases let into the exhaust system will be prevented from entering the rectifier.

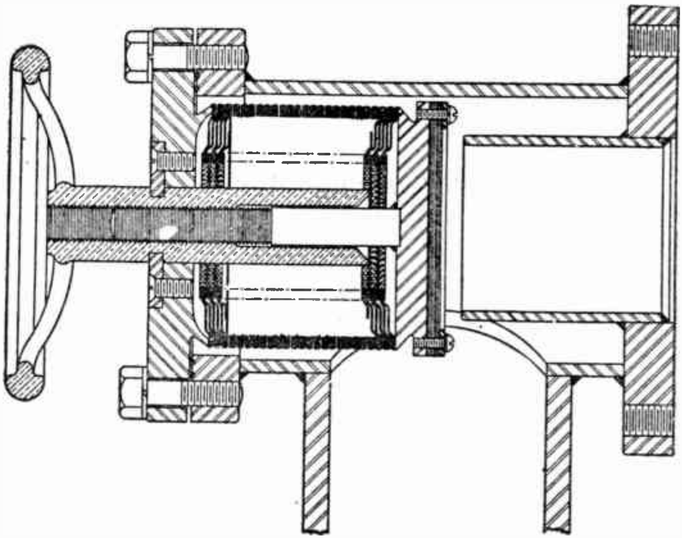


FIG. 6,625.—Sectional view of manually operated vacuum valve.

Mercury - Condensation Pump. — A mercury-condensation vacuum pump, which operates continously, is employed with every mercury-arc rectifier to maintain the vacuum. The size and speed of this pump are, to a large extent, determined by the size of the rectifier vacuum chamber. For the larger rectifiers, a three-stage pump of ample speed and capacity is used. In general, these pumps consist of a mercury boiler in which mercury is evaporated by an electric heater.

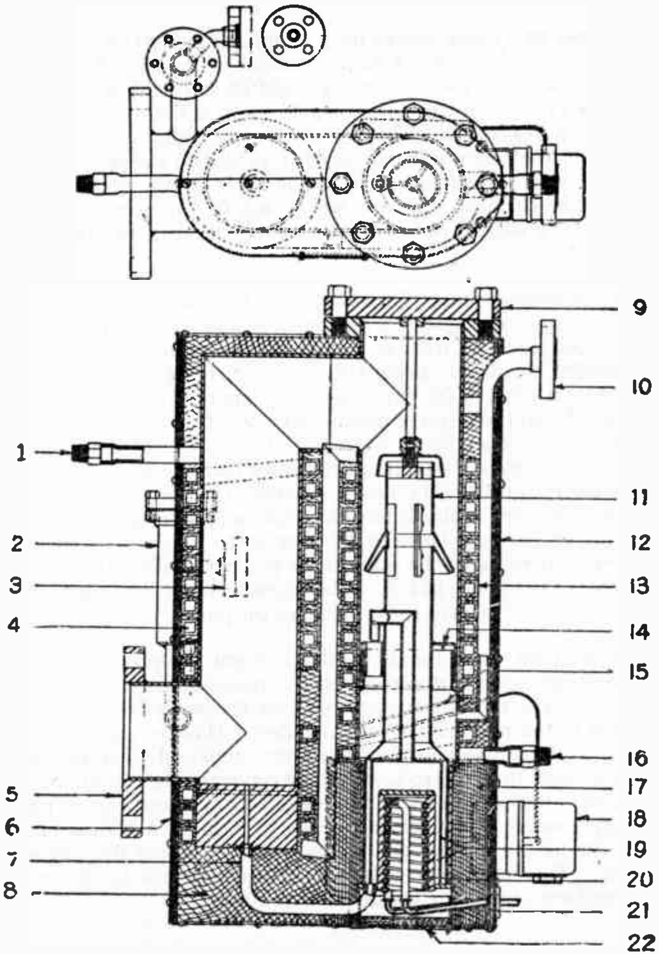


FIG. 6,626.—Sectional view of mercury condensation vacuum pump. In the illustration, 1 represents water outlet; 2, vacuum detector housing; 3, vacuum gauge connection flange; 4, exhaust pipe cooling coil; 5, exhaust pipe inlet flange (gas intake); 6, mercury return sump; 7, mercury return tube, 8, lagging; 9, service flange; 10, gas outlet flange (to mechanical pump); 11, three-stage nozzle assembly; 12, lagging jacket; 13, pump cooling coil; 14, sealing ring; 15, thermostat bulb; 16, cooling water inlet; 17, mercury boiler lagging; 18, thermostat; 19, mercury boiler; 20, heater; 21, heater leads; 22, heater cover.

The mercury vapor passes up a chimney having two or more orifices, through which the spray of mercury vapor is passed and deflected downward. Gases from the rectifier tank diffuse into this mercury vapor and are carried down with it. The outside walls of the mercury-condensation pump are water-cooled. The mercury vapor condenses on the walls of the pump, and the condensed mercury is returned to the boiler to repeat the cycle. The gases exhausted from the rectifier are cooled in the small compression chamber and are forced out of the pump. A continuous cycle of evaporation, diffusion and condensation of the mercury is thus performed.

This three-stage pump, fig. 6,626, embodies a number of unique features. The first stage takes gas at a low pressure and compresses it into the first compression chamber, from which the second nozzle takes it into the second compression chamber. From this chamber, the gas is still further compressed by a third nozzle into the third compression chamber, and thence it is forced into the receiver tank, from which the oil-sealed rotary vacuum pump exhausts the gas to the atmosphere. The mercury vapor which leaves the nozzles of the pump is condensed by the water-cooled walls of the pump and returned to the boiler. Between the second and third stages, there is a mercury shelf, or trough, which serves to seal and maintain the difference in pressure between these stages. This seal is formed by the mercury condensing on the walls of the pump and filling the trough around the inside of the pump jacket. The excess mercury here runs over a notch in the trough and returns to the boiler of the pump.

The vacuum pipe line from the vacuum chamber to the mercury-condensation pump is water cooled by means of cooling coils. Mercury vapor from the rectifier is condensed on the walls of this pipe line and returned to the rectifier vacuum chamber. However, in the larger rectifiers where large diameter pipe lines are employed, a certain amount of mercury vapor from the rectifier will be condensed in the pump. To avoid an excess of mercury in the pump boiler and to return this mercury to the vacuum chamber, a mercury return tube, *7*, in fig. 6,626, is provided between the mercury boiler and the pipe line to return the mercury to the rectifier. This insures a constant level of mercury in the boiler, and provides uniform pumping conditions at all times.

Oil-Sealed Rotary Vacuum Pump.—The rotary vacuum pump, of the oil-sealed direct driven type, fig. 6,626A, is mounted on the side of the rectifier. Because of the absence of gears, it is practically noiseless and has very little vibration.

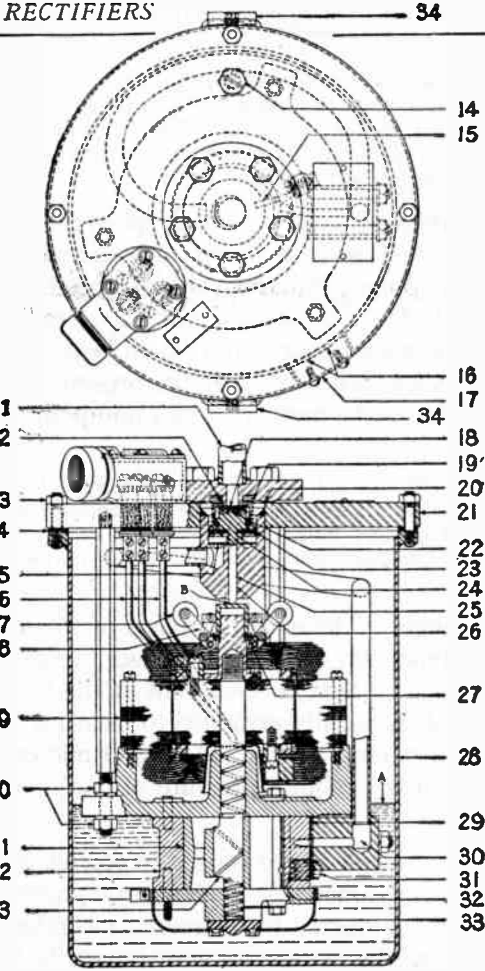


FIG. 6,626A.—Sectional view of manually operated rotary vacuum pump. In the illustration, 1 represents intake; 2, valve seat; 3, nuts; 4, gasket; 5, screen; 6, leads; 7, weights; 8, centrifugal mechanism; 9, motor; 10, adjusting nuts; 11, piston; 12, cylinder; 13, shaft; 14, oil depth gauge; 15, blade; 16, exhaust ports; 17, exhaust port shield; 18, valve diagram; 19, spring; 20, aluminum gasket; 21, cover; 22, upper valve assembly; 23, lower valve diaphragm; 24, lower valve seat; 25, plunger, 26, plunger bearing; 27, spring; 28, casing; 29, gasket; 30, pump intake; 31, exhaust valve housing; 32, exhaust valve disc; 33, screen; 34, bosses for mounting.

The pump shaft and motor are arranged in a vertical position, which facilitates inspection and maintenance. The piston of the pump does not revolve; it merely oscillates inside the cylinder, with very little relative movement of the parts. All parts are separated by oil films, providing a vacuum pumping seal and minimum wear.

Receiver Tank.—With a very high speed mercury condensation pump, a receiver tank is almost essential. Usually, the mechanical pump has comparatively low speed at low pressure. This being the case, if a quantity of gas were liberated in the rectifier, the mercury vapor pump would be so fast in removing this gas at this low pressure, that the pressure would build up on the outlet side of the mercury vapor pump until the pumping action failed.

To avoid building up high back pressures and to provide sufficient storage space, a receiver tank is used between the mechanical rotary pump and the mercury vapor pump. With this combination of mercury condensation pump, receiver tank and rotary mechanical pump, operating conditions are ideal.

Vacuum Gauge.—The essential parts of this device are the hand operated mercury displacing plunger, a stationary spacer, the glass gauge with flexibie steel joint at the top, and a gauge scale. The scale is usually arranged to measure pressures from a fraction of a micron up to 200 to 300 microns. The unit micron is a mercury column pressure of one-thousandth millimeter.

Traps.—An air-cooled trap is used to condense mercury that may escape from the mercury condensation pump on the rotary pump side, and to return it to the mercury condensation pump. Another trap, in the rotary vacuum pump, is located at the bottom end of the intake pipe to the pump, and is so arranged that it can be cleaned by removing the plug holding the gasket plug and screen in place. This trap prevents any scale, dirt or other material from entering the moving parts of the rotary pump.

Vacuum Indicator and Regulator.—This equipment is usually furnished, although in strictly manual stations, it is optional. It consists of three main parts; a vacuum detector, B, in

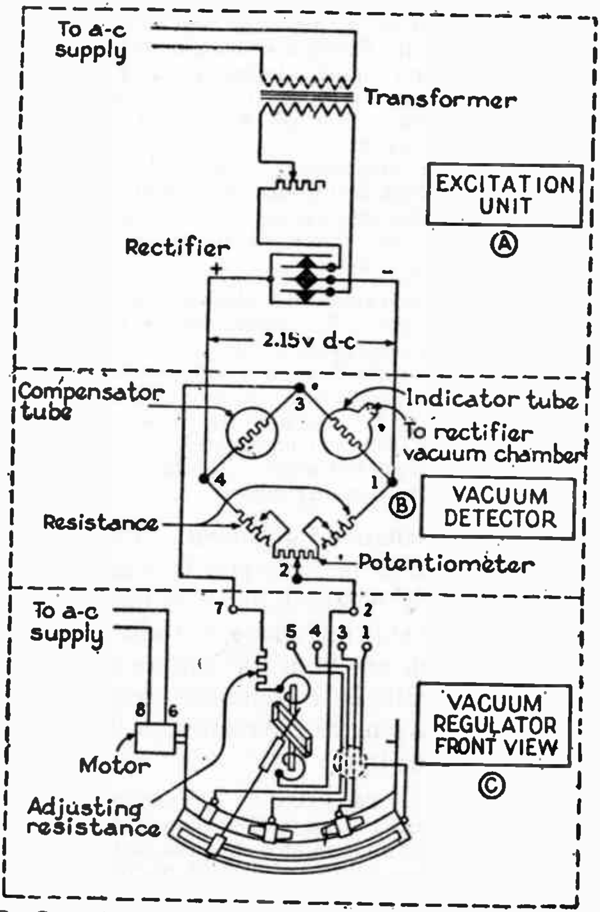


FIG. 6,626B.—Connection diagram of typical vacuum regulating equipment.

fig. 6,626B which is essentially a Wheatstone bridge; an excitation unit, A, in fig. 6,626B for this bridge; and a vacuum indicator, which is essentially the galvanometer connected across the Wheatstone bridge.

The vacuum indicator can be either of two varieties. It can be an indicator which indicates the degree of vacuum in the rectifier at all times, exactly as an ammeter or a voltmeter indicates voltage, or it can be a contact-making device, with a small motor arranged to actuate intermittent contacts so that an external circuit will be energized, depending on where the needle of the indicator is at the instant the contact is operated by the motor. With the latter arrangement, the apparatus is called a vacuum regulator, C, in fig 6,626B, and regulation, as well as indication, is obtained. This regulating arrangement is used in automatic and supervisory controlled substations, and sometimes in manual substations. The principle of operation is as follows:

The Wheatstone bridge is arranged so that one resistance arm is subject to the pressure in the rectifier. This resistor has the property of changing its resistance when the amount of gas in the tube changes. In more detail, when no gas is in the tube, the filament is hotter because of the excitation from the excitation unit. When some gas enters the tube, the filament is cooled by the gas carrying the heat from the filament to the walls of the tube. This reduction in filament temperature changes its resistance, and thus, the electrical balance of the bridge. This balance is indicated on the indicating galvanometer or vacuum regulator.

Arc-Starting and Excitation Equipment.—The starting anode is plunged into the cathode mercury pool by means of a solenoid. The solenoid is then de-energized, and a spring, compressed by the movement of the starting anode, withdraws the starting-anode tip, drawing an arc from the surface of the mercury. From this arc, the multi-phase excitation arc will pick up and continue to operate as long as the rectifier is held in readiness for load demand at the bus.

After this excitation arc has picked up, the automatic features of the circuit disconnect the starting anode and the solenoid, thus preventing their further operation. This arrangement is shown as part of fig. 6,626C. In the excitation transformer, sufficient inherent reactance is provided, so that no external resistors or reactors are required, making a very efficient combination.

Grid Excitation

Because of the diversity of applications of a rectifier having grids, the grids are excited in the manner required for the particular installation. One of the most common uses of grids is for varying the output voltage of the rectifier. An unregulated

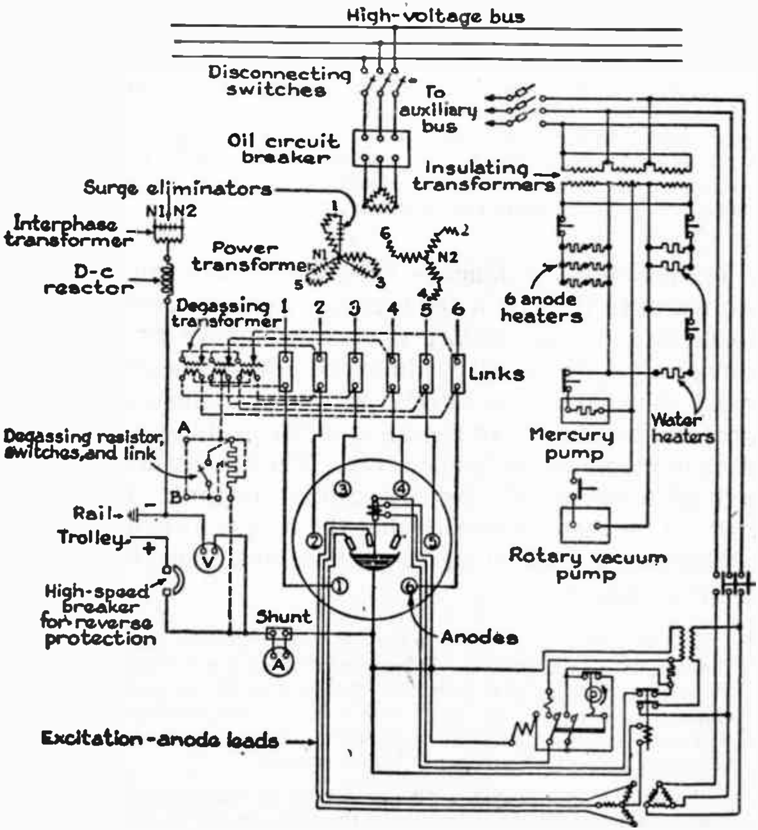


FIG. 6,626C.—Schematic diagram of mercury arc rectifier showing essential auxiliaries.

rectifier has a voltage characteristic of the shunt type, giving approximately 5% regulation from light load to full load, depending mainly on the transformer design. By means of grids, the output voltage can be reduced below the natural characteristic to provide constant voltage output, or a compounding effect, or a limit to the output current. In such cases, the natural characteristic must be selected to provide a voltage above that for which the rectifier is to be regulated.

A main anode of a rectifier equipped with grids operates or fires when it becomes positive if its associated grid is also made positive. If the grid be maintained negative, operation of the main anode is prevented. Regulation is accomplished by retarding the firing of the rectifier main anodes by changing the phase angle of the grid voltage with respect to the phase angle of the voltage applied to the main anodes.

Temperature Regulation.—With any given design of mercury arc rectifier, there is a temperature range for most efficient operation. If the rectifier is operated above or below this temperature, its capacity is impaired. Water heaters are provided to maintain the rectifier within this temperature range when the rectifier is not operating or the load losses are insufficient to maintain the temperature. The heaters are turned on and off automatically by thermostatic control. If the load losses of the rectifier be such that the temperature tends to rise beyond the best operating point, the rectifier must be cooled as described herein.

It is important at all times to prevent condensation of mercury on, or in the vicinity of, the anodes. To accomplish this, small heaters are used to maintain the anodes and their insulators at a higher temperature than all other parts of the rectifier while it is shut down or is operating on light loads. The anode losses are sufficient to maintain proper temperature distribution when any appreciable amount of load is carried.

Thermal relays, provided with each rectifier equipment either prevent operation or actuate an alarm when the temperature of the equipment is outside the operating unit.

Cooling.—Cooling of rectifiers is usually accomplished either directly by a supply water system in which the cooling water is circulated through the rectifier and wasted, or by means of a recirculating system in which the cooling water is continuously recirculated through the rectifier.

With the supply water system, water is admitted to the cooling system as required, by means of a thermostatically controlled valve, actuated in accordance with the control point temperature of the rectifier. This system does not permit treating the cooling water to prevent corrosion. Also, the available cooling water is often such that excessive corrosion is caused by its use, or an excessive amount of scale is deposited, preventing proper circulation and cooling.

The recirculating systems are provided with a pump which runs continuously, circulating the water through the cooling system. This system has the advantage of minimizing the temperature gradients throughout the rectifier, thereby providing the best possible operating conditions. It also has the decided advantage of permitting treatment of the recirculating water to prevent corrosion. A very effective but inexpensive method of treating cooling water has been developed, using a solution of sodium dichromate, an easily obtained compound, which virtually prevents corrosion.

Cooling of the liquid in the recirculating system can be accomplished in a number of ways. One of the most frequently used is a water-to-water heat exchanger through which the cooling supply water is circulated, and wasted, the quantity of water sufficient for cooling being regulated by a thermostatically operated valve. Another way is to use a fan-cooled radiator, through which the cooling water is circulated continuously. The cooling fan is operated only when required by means of a thermal relay.

Still other cooling arrangements are of course, quite possible, such as a combination of any of the previous systems or the use of a refrigerating system.

The mercury condensation vacuum pump operates most effectively at a temperature well below the operating temperature of the rectifier. Therefore, it cannot be cooled by the rectifier recirculating system. It is customary, when a recirculating system is employed for rectifier cooling, to provide the small amount of cooling water required for this pump either from the supply water or from a refrigerant-to-water heat exchanger.

Power Rectifier Substations

A rectifier substation consists briefly of the following main components which may be described as follows:

1. Incoming *a.c.* circuit equipment.
2. Step-down transformer.
3. Rectifier.
4. Rectifier control.
5. *D.c.* switchgear and control equipment.
6. Automatic control.

The incoming a.c. supply circuits.—These circuits with their accompanying high voltage *a.c.* circuit breakers, lightning arresters, protective relaying and *a.c.* equipment up to 15 kv. can be installed in metal-clad, factory-assembled units. These units reduce the time required for installation and the cost of installation and maintenance. Such equipment also provides safety for the operator.

The step-down transformer.—The step-down transformer converts from the incoming line *a.c.* voltage, 3 phase, to the proper voltage and phases to be commutated by the rectifier, and provides the required *d.c.* output. Rectifier transformers differ considerably from conventional power transformers, in that their secondary windings are arranged to produce an increased number of phases to provide the desired smoothness in the *d.c.* output of the rectifier.

The common connections of power rectifier transformers provide for 6 or 12 phase operation of the associated rectifier. Where a greater number of phases is required, it is possible to use combinations of different transformer connections to produce an over-all operation of several rectifier units which will provide the desired number of phases. Phase shifting transformers also can be used with certain of the rectifier units in a station to produce phase displacement between the various units, thus providing over-all station operation corresponding to the desired number of phases.

To illustrate, a station containing two 6 phase units can be used to operate as a 12 phase equipment when both units are in service. This would be accomplished by using Y-connected and delta-connected transformers, or a station containing three 12 phase units could be made to operate 36 phase with all units in operation by using phase-shifting transformers in series with two of the 12 phase transformers.

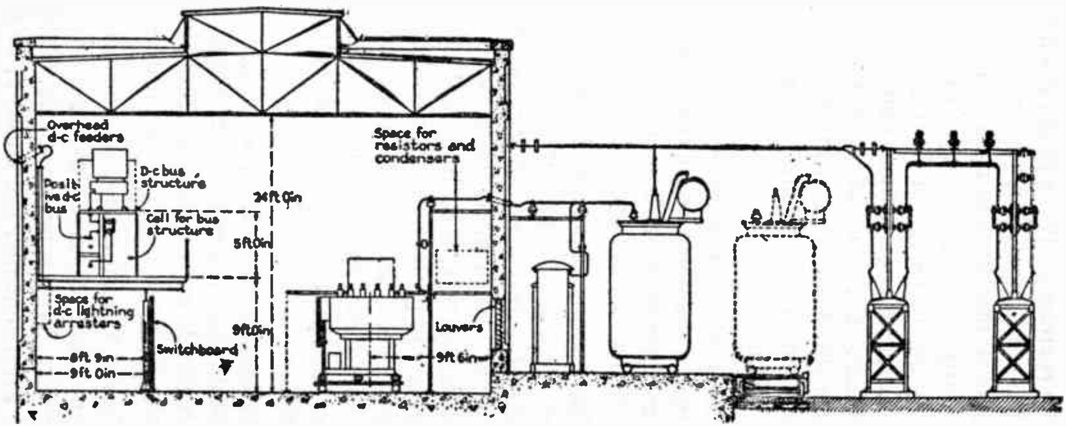


FIG. 6,626D.—Cross-sectional view of typical 3,000 volt *d.c.* rectifier sub-station layout.

The rectifier.—The rectifier itself is an important part of the station equipment, but performs a relatively simple function, in that it merely acts as a commutator for the transformer. The output characteristics of the equipment, therefore, depend largely on the design of the transformer; the only modification of characteristics which can be produced by the rectifier is to delay the firing of the anodes (phase control) in order to reduce the *d.c.* output voltage of the equipment. Continuous regulation of this nature can be provided, to give a regulated *d.c.* voltage output.

The rectifier control.—Various rectifier operations require control of one form or another, for example, temperature regulation. Such control is better accomplished by automatic relays than by an operator.

The d.c. switchgear and control.—These parts of the equipment consists of a circuit breaker which connects the rectifier to the *d.c.* bus and the *d.c.* outgoing feeder circuits. It is customary to arrange the rectifier cathode circuit breaker to trip only on reverse current, and to depend on the feeder circuit breaker for protection against short circuits and severe overloads. Very satisfactory operation results from the use of automatic *d.c.* reclosing feeders in rectifier stations to provide adequate protection for the equipment and the overhead system.

Automatic control.—This is generally employed in rectifier substations. Supervision of these automatic equipments by centralized supervisory control and telemetering provides means for co-ordinating the entire system operations.

Power Transformers.—Transformer apparatus is a very important and essential part of any power type mercury arc rectifier. With reference to fig. 6626E showing typical connection arrangements, the triple-**Y**, or forked six-phase connection

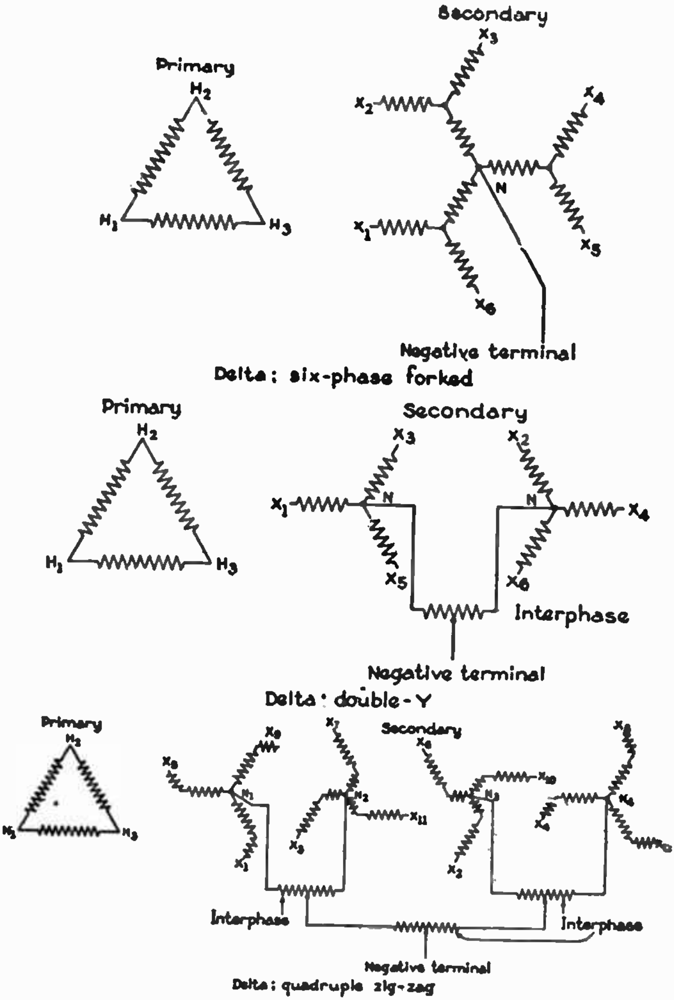


Fig. 6,626E.—Wiring diagram showing transformer connections commonly used for six and twelve anode mercury arc rectifiers. (The transformer secondary leads connect to the rectifiern aodes.)

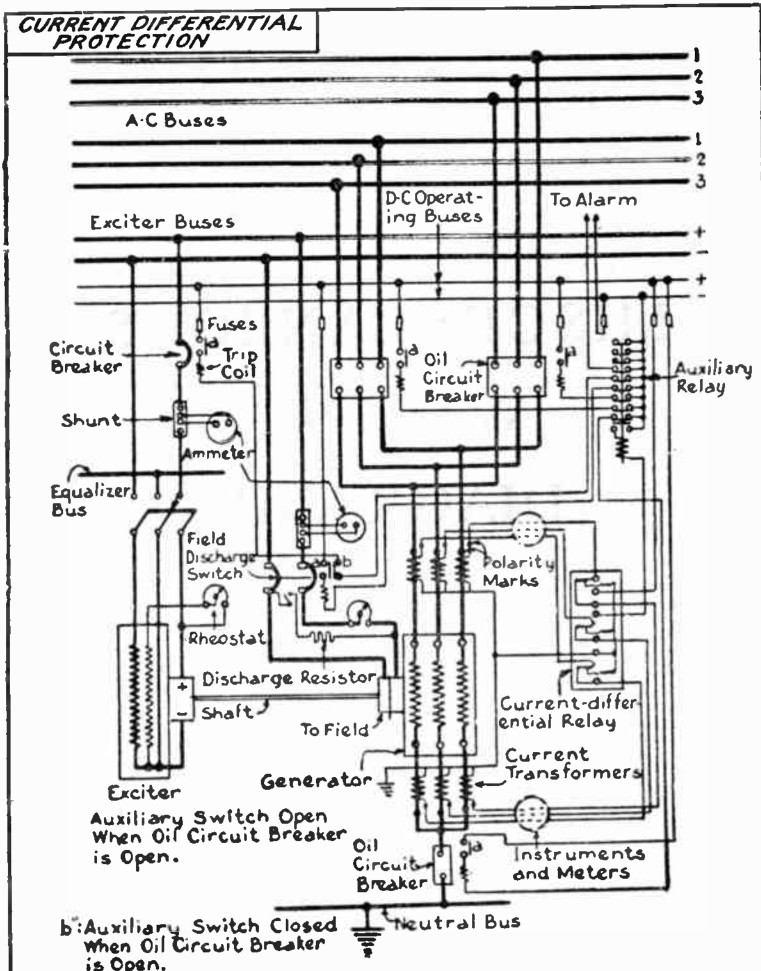
of the transformer secondary is commonly used for small installations. This connection does not require an interphase transformer. For the larger six-anode rectifiers, the double-Y connection with an interphase transformer is employed.

The secondary windings of this type of transformer are connected to form two **Y's**, reversed with respect to each other, providing a six-phase connection. The center points of the two **Y's** are joined together by the interphase transformer, which has a single winding with each end connected to the center point of one of the main transformer **Y's**.

A center tap in the interphase transformer provides the negative connection for the equipment. For twelve-anode rectifiers, the quadruple zig-zag connection of the secondary windings is used. This connection consists of four zig-zag connected **Y's**, providing a twelve-phase connection. An interphase transformer equipment, consisting of three separate transformers mounted in a single tank, is employed. Two of these windings serve to connect the center points of the main transformer **Y's** to provide two six-phase connections. The center points of these two windings are in turn, connected together through the third winding. A center connection to this winding provides the negative connection for the system.

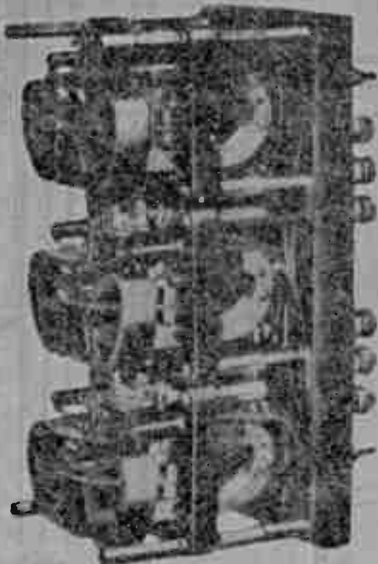
Interphase Transformers.—Interphase transformers serve to increase the firing or operating time of the rectifier anodes. If a six-phase diametrical connector be employed, each rectifier anode would fire for 60 degrees (neglecting the overlap due to the inductance of the system). With the six-phase and twelve-phase connections, described previously, employing an interphase transformer, each anode will fire for 120 degrees. Consequently, each anode will carry one-half as much current for twice the time. This decreases the duty on the rectifier anodes and provides better utilization of the transformer secondary windings.

MISCELLANEOUS WIRING DIAGRAMS



Complete diagram of connections for current differential protection of three phase "Star"-connected alternating current generator with grounded neutral and direct current exciter.

Photografic illustration of auxiliary relay and current differential relay shown on the following page.



FRONT VIEW
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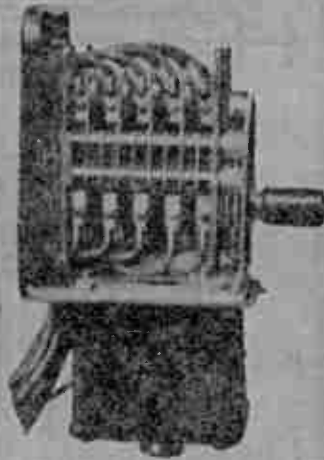
FRONT VIEW

Typical current differential Relay.
(For connection; See opposite page.)



FRONT VIEW
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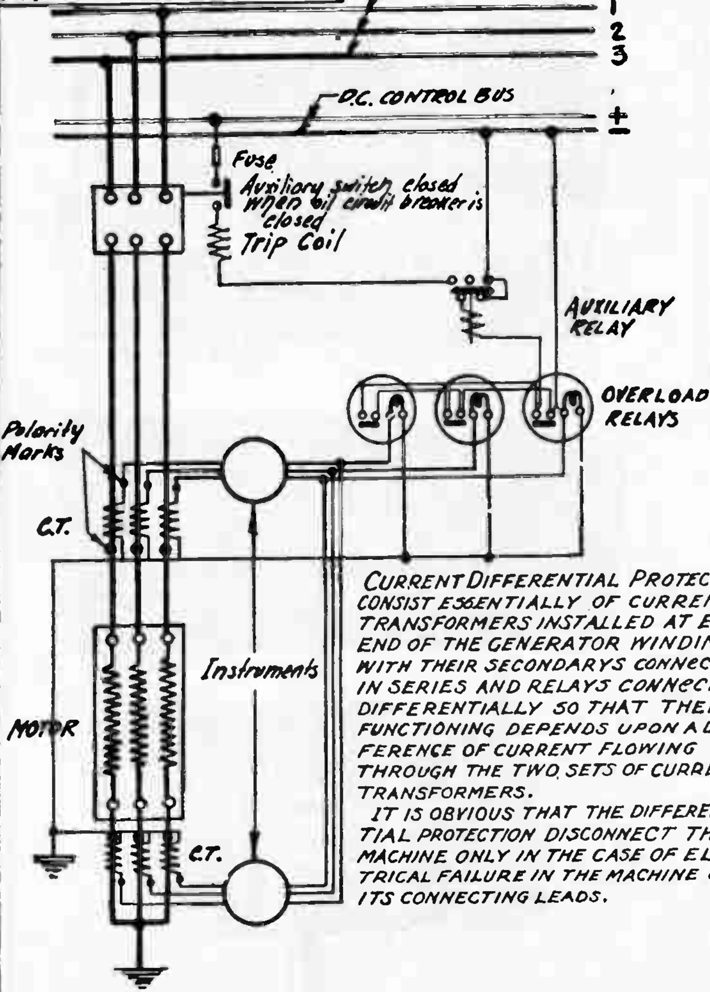
Ten circuit auxiliary relay. (For connection, See opposite page.)

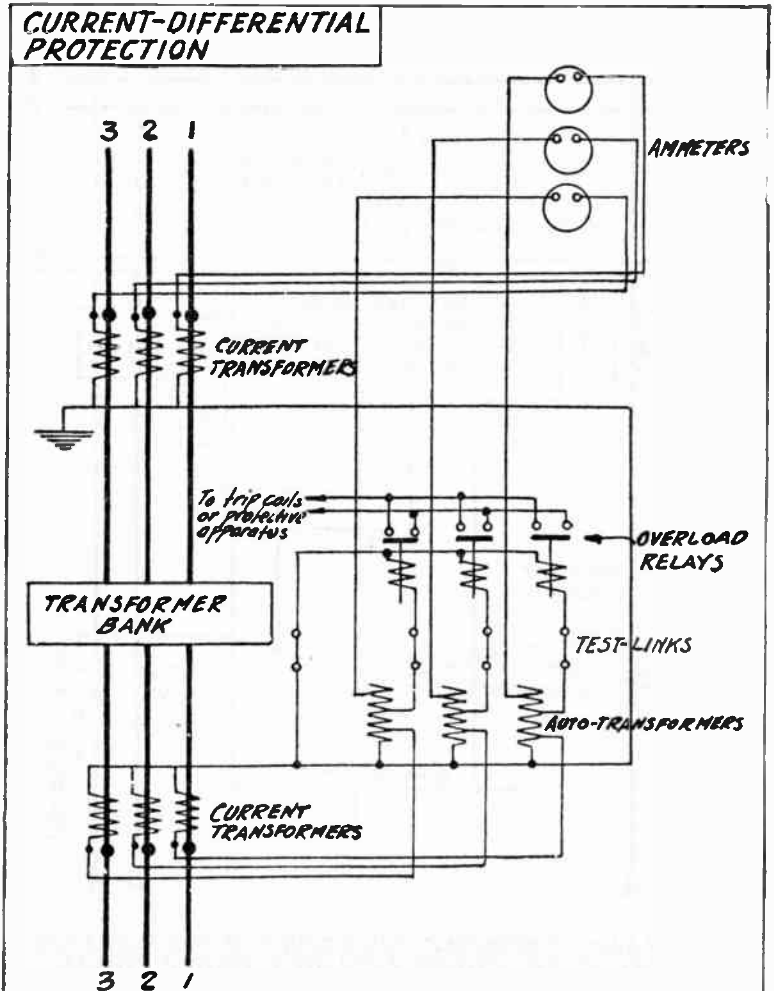
CURRENT-DIFFERENTIAL PROTECTION



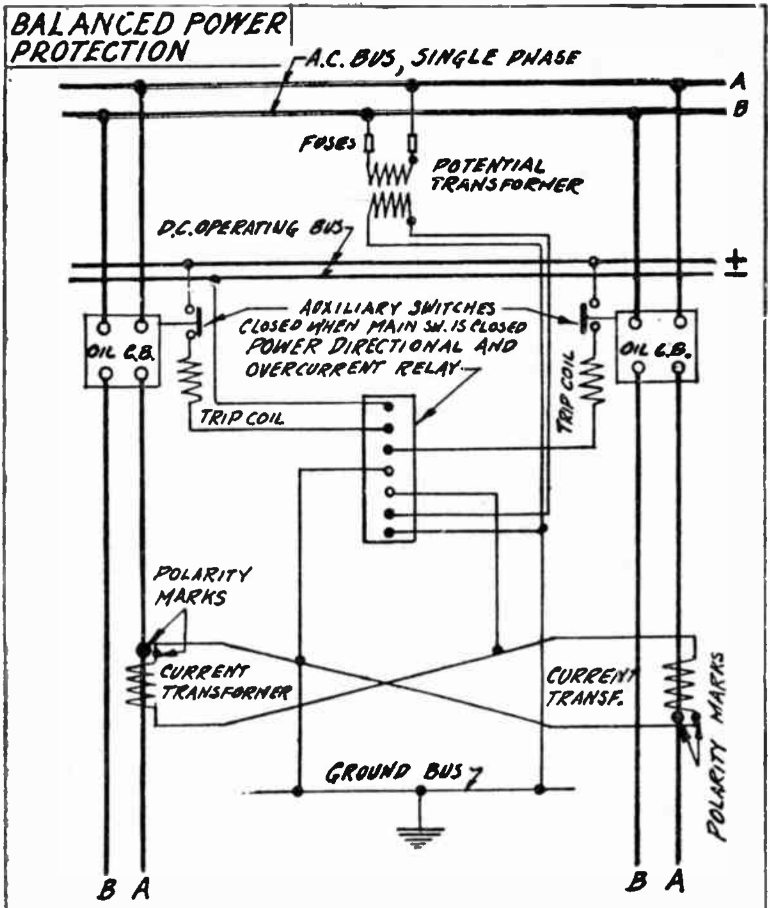
CURRENT DIFFERENTIAL PROTECTION CONSIST ESSENTIALLY OF CURRENT TRANSFORMERS INSTALLED AT EACH END OF THE GENERATOR WINDINGS WITH THEIR SECONDARYS CONNECTED IN SERIES AND RELAYS CONNECTED DIFFERENTIALLY SO THAT THEIR FUNCTIONING DEPENDS UPON A DIFFERENCE OF CURRENT FLOWING THROUGH THE TWO SETS OF CURRENT TRANSFORMERS.

IT IS OBVIOUS THAT THE DIFFERENTIAL PROTECTION DISCONNECT THE MACHINE ONLY IN THE CASE OF ELECTRICAL FAILURE IN THE MACHINE OR ITS CONNECTING LEADS.

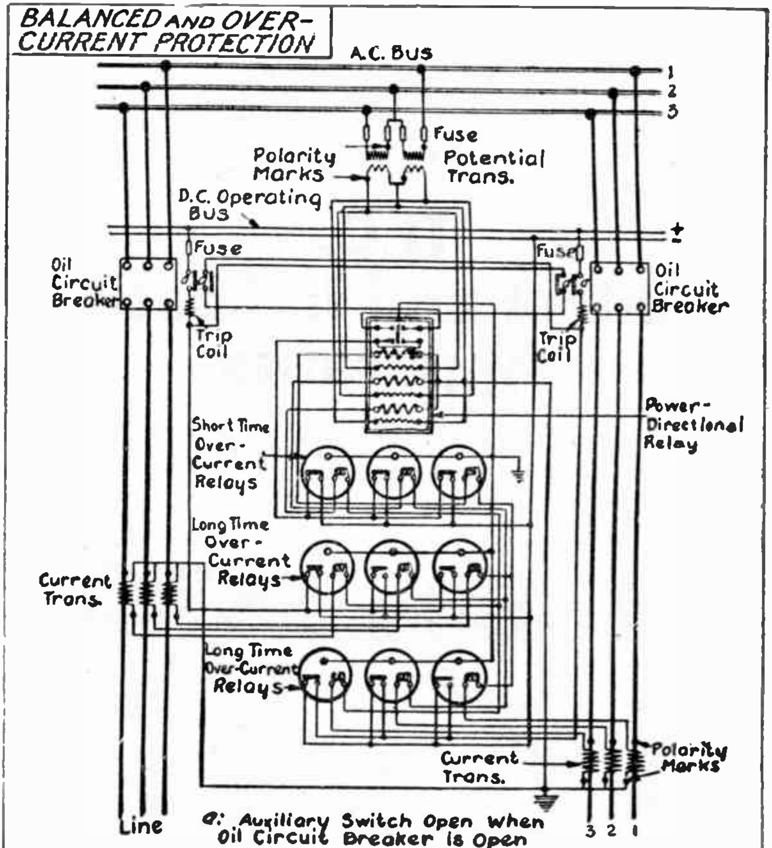
CURRENT-DIFFERENTIAL PROTECTION OF STATION AUXILIARY FEEDER USING INDUCTION TYPE OVERLOAD RELAYS.



CURRENT DIFFERENTIAL PROTECTION OVER A TRANSFORMER BANK SHOWING APPLICATION OF TEST-LINKS, FACILITATING TESTING OF RELAY COILS.



BALANCED POWER CONNECTION FOR TWO PARALLEL INCOMING, OUTGOING OR TIE LINES, SINGLE PHASE D.C. CURRENT USED FOR TRIPPING OIL CIRCUIT BREAKERS.

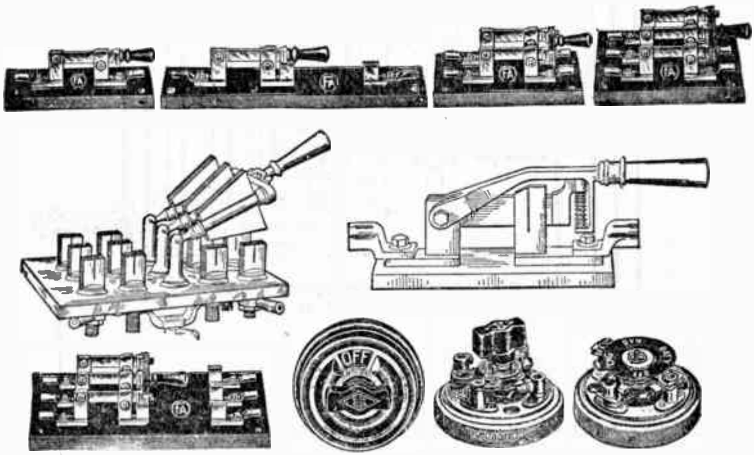


Separate balanced and overcurrent protection for two parallel Three phase incoming, outgoing or tie lines with grounded neutral.

CHAPTER 15

D.C. Control and Indicating Apparatus

For the proper control and safe operation of dynamos, motors, and other *d. c.* apparatus, numerous control and indicating devices are necessary, such as



FIGS. 6,627 to 6,636.—Various switches. Fig. 6,627 to 6,630, one two and three pole single throw knife switches; fig. 6,631, triple pole, double break, double throw knife switch for heavy current; fig. 6,632, quick break, single pole, single throw knife switch for heavy current; fig. 6,633, three pole single throw knife switch with fuse connections; figs. 6,734 and 6,635, snap switch with and without cover showing construction—the indicating dial registers "on" or "off"; fig. 6,636, gas engine snap switch.

Control Devices
- Switches
- Fuses
- Circuit Breakers
- Rheostats
- Arresters

Indicating Devices
- Galvanometers
- Ammeters
- Voltmeters
- Wattmeters

1. Control Devices

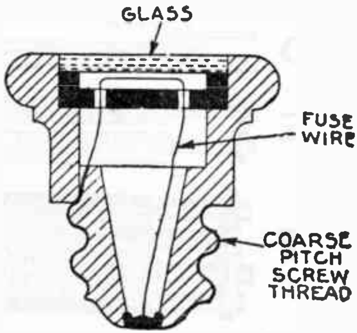
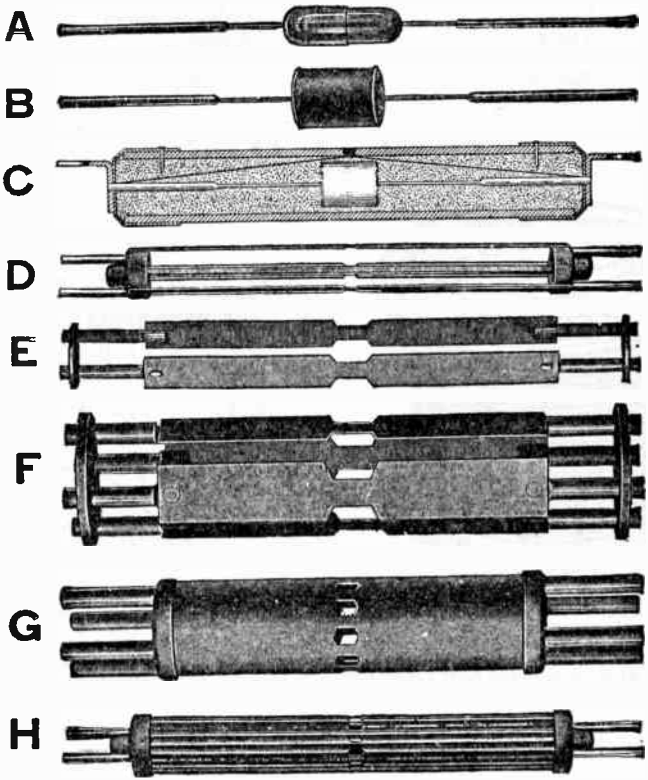


FIG. 6,637.—Spool of fuse wire usually made of an alloy of tin and lead, such as half and half solder. Bismuth is frequently added to the alloy to lower the melting point; For half and half solder the melting point is 370° Fahr. The current required to "blow" a fuse increases somewhat with the age of the fuse owing to oxidation and molecular changes. Fuses are sometimes rated according to the number of amperes to be taken normally by the circuit they are to protect. Open fuses are so unreliable that circuit breakers are preferable for large currents; when fuses are used, the enclosed type as shown in figs. 6,639 and 6,640 is usually the more desirable.

FIG. 6,638.—Cross section through plug fuse. With this type of fuse it is impossible to place any except the correct size of plug in the socket.

FIGS. 6,639 and 6,640.—D and W enclosed or cartridge fuse showing blow indication. When the fuse blows, it is indicated by the appearance of a black spot within the circle on the lable as in fig. 6,040 Fuses should be placed wherever the size of wire changes or wherever there is a branch of smaller size wire connected, unless the next fuse on the main or larger wire is small enough to protect the branch or small wire, but more lights may be added on the large wire, making it necessary to put in a larger one. Experiments have shown that for large fuses, a multiple fuse is more sensitive than a single one. A one hundred ampere fuse may be made by taking four wires of twenty-five amperes capacity.



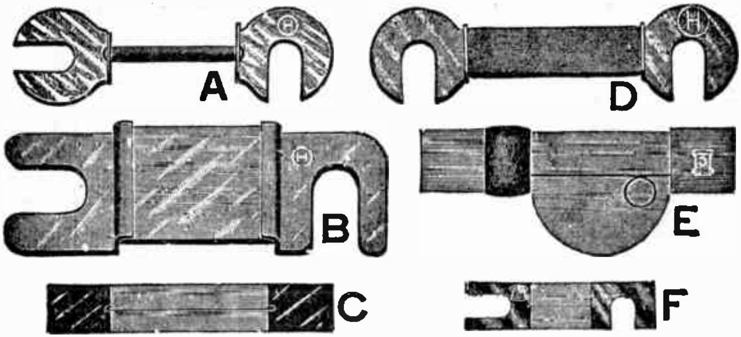
FIGS. 6,641 to 6,648.—Interior construction of D. & W. fuses. ***In the manufacture*** of these fuses, four types of fuse link are used according to capacity of fuse, and classified as: 1, air drum link; 2, flat link; 3, multiple link; 4, cylinder link In the air drum link, figs. **A** and **B**, a capsule provides an air space about the center of the link, the rate of heat conduction through the confined air being very slow, the temperature of that portion of the link rises rapidly with increasing current, rendering the blowing point practically constant; fig. **C**, shows a section through the complete fuse. In the flat link, fig. **D**, the section is reduced in the center, cutting down as far as possible the volume of metal to be fused. Figs. **E** to **G**, show various forms of multiple link construction. By subdividing the metal, increased radiating surface is obtained which permits a reduction in the volume of fusible metal necessary, and the metal vapor formed when the fuse blows on heavy over load is more readily dissipated. Figs. **F** and **G**, show two forms of the cylinder link, the plain cylinder fig. **F**, being used for low voltage and large current, and fig. **G**, for certain high tension service. The corrugated cylinder presents more surface to the fuse filling than the plain type and secures a maximum radiating surface with resulting minimum volume of metal for a given current.

Switches.—A switch is *a device by means of which an electric circuit may be opened or closed*, turning on and off the current. There are numerous kinds of switches.

A ***single pole switch*** controls only one of the two wires of a circuit; a ***double pole switch*** controls both.

A ***two pole switch*** breaks the circuit with less *arcing* than a single pole switch. Switches are said to be *single* or ***double break***, according as each pole or blade is constructed to give one or two breaks, thus a two pole double break switch breaks the circuit in four places simultaneously, rendering it capable of stopping a heavy current without undue arcing.

In the quick break switch the contact pieces are snapped apart by a spring to reduce the duration of the arc as much as possible.

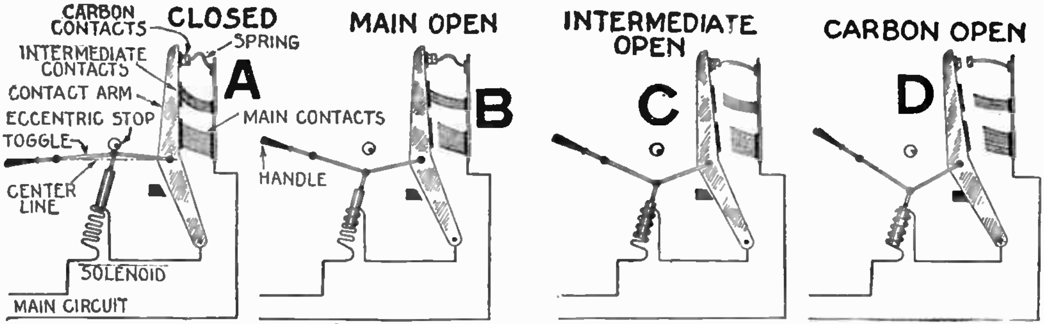


Figs. 6,649 to 6,654.—Various open fuses. Fig. 6,649, fuse for main and branch blocks; fig. 6,650, standard railway fuse; fig. 6,651, Edison main style; fig. 6,652, sneak current fuse; fig. 6,653, W. U. pattern; fig. 6,654, Bell telephone style; When an open fuse "blows as a result of overloading, the rupture is accompanied by a flash, and by spattering of the fused material. With large currents this phenomenon is a source of danger, and the use of enclosed fuses is accordingly recommended whenever the rating of the fuse exceeds 25 amperes.

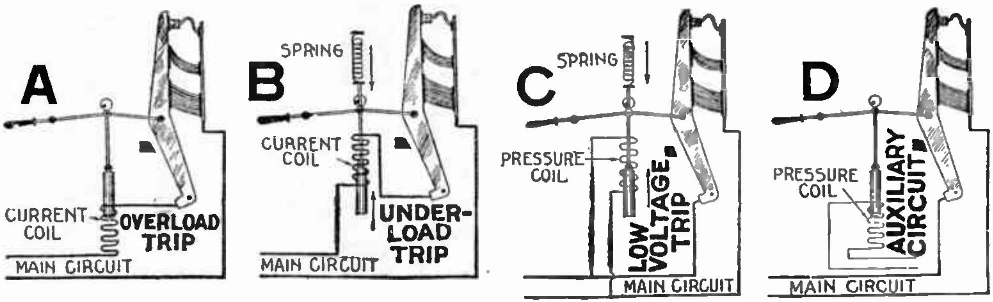
A switch whose contact pieces consist of a pivoted blade and fixed jaws is called a ***knife switch***, and ***it should be placed so that gravity tends to open it.***

A ***double throw switch*** controls two circuits and is used when it is desired to open one circuit and quickly close another, for instance, in ignition, the engine is started on the battery circuit and then the double throw switch is thrown over to the magneto side. Evidently both circuits cannot be closed at the same time which is a desirable feature.

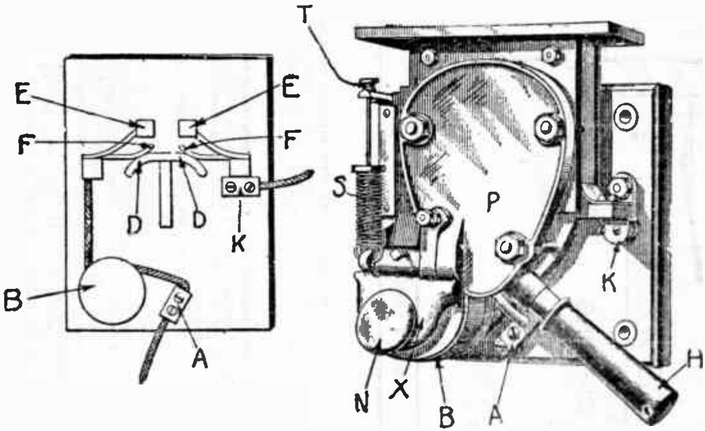
Fuses.—By definition, a fuse is simply a strip of fusible metal



FIGS. 6,655 to 6,658.—Elementary diagrams illustrating the operation of a carbon circuit breaker of the overload type, showing the progressive opening of such device. Fig. 6,655, closed position; fig. 6,656, main contacts open; fig. 6,657, intermediate contacts open; fig. 6,658, carbon contacts open, circuit broken.



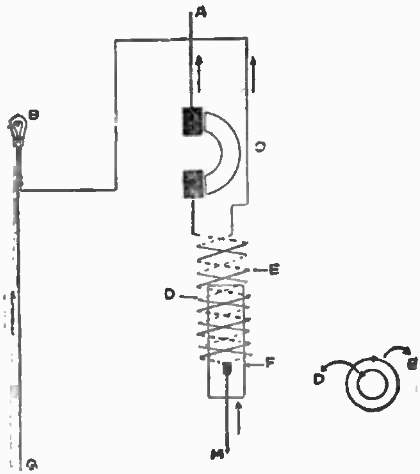
FIGS. 6,659 to 6,662. —Elementary diagrams illustrating the various methods of electromagnetic control for circuit breakers. Fig. 6,659, overload trip; fig. 6,660. underload trip; fig. 6,661, low voltage trip; fig. 6,662, control from auxiliary circuit by means of a "relay."



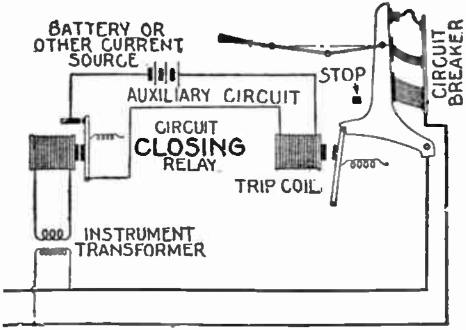
FIGS. 6,663 and 6,664.—*Magnetic blow out circuit breaker.* Its operation is based on the principle that *a conductor carrying a current in a magnetic field will tend to move in a direction at right angles to the field.* ***In operation,*** A and K, are the terminals, D,D, is a contact that is forced up against F,F, when the breaker is set. The current then takes the path A–B–F–D,D–F–K. ***When the breaker trips,*** the contact piece D,D, flies down and the tendency is for an arc to form between F,F; the magnetic field blows the arc upwards, and whatever burning takes place is on the contacts E,E, which are so constructed that they may be readily renewed. ***To trip the breaker by hand,*** the knob N, is pressed.

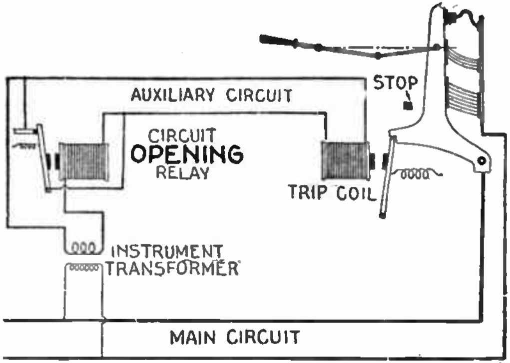
often consisting of lead with a small percentage of tin connected in series in the circuit.

If the temperature exceed a predetermined limit by an abnormal increase of current, the fuse will melt or "blow," thus opening and protecting the current. All circuits



FIGS. 6,665 and 6,666—Reverse current circuit breaker: fig. 6,666, view looking at end of coils of cut out, showing direction of current. A, to + bus bar; B, resistance lamp; C, brush of cut out D, shunt coil; E, series coil; F, core that trips cut out; G, to − bus bar; H, to + pole of dynamo





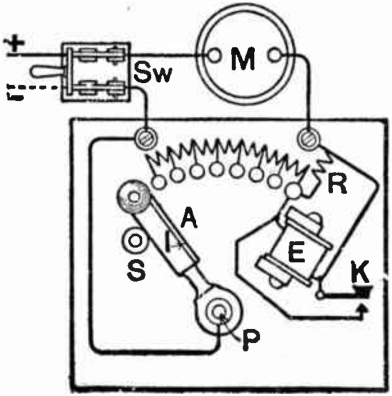
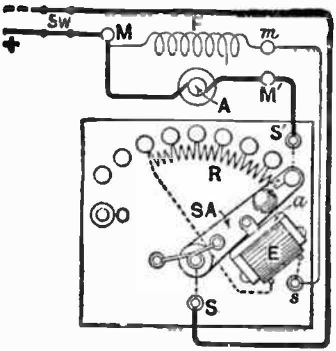


FIG. 6,667.—Diagram illustrating the operation of a ***circuit closing relay.*** When the predetermined abnormal condition is reached in the main circuit, the relay closes the auxiliary circuit, thus energizing the trip coil and opening the breaker.

FIG. 6,668.—Diagram illustrating the operation of a ***circuit opening relay.*** When the relay contacts are in the normal closed position, as shown, the coil is short circuited. When the predetermined abnormal condition is reached in the main circuit, the relay contacts are opened with a quick break, sending the current through the trip coil momentarily, and opening the breaker.

FIG. 6,669.—Starter with no voltage release for a series motor. A helical spring coiled around the lever pivot P, and acting on the lever A, tends to keep it in the off position against the stop S. This lever carries a soft iron armature I, which is held by the poles of the electro-magnet E, when, in starting the motor, the arm has been gradually forced over as far as it will go. Should anything happen to interrupt the current while the motor M, is running, E, will lose its magnetism and A, will be released, and will fly over to the off position. E, is usually shunted by a small resistance R, so that only a portion of the main current flows through it. This device constitutes the ***no voltage release,*** and ensures that all the resistance is in circuit every time the motor is started.



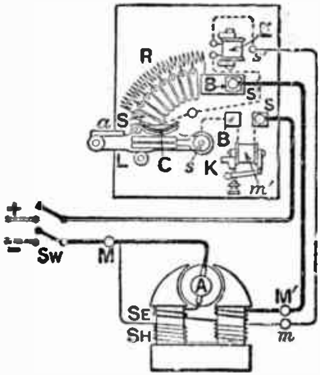


FIG. 6,670.—Starter with no voltage release for a shunt motor. The terminals of the motor are at M, M', *m*, and those of the starter at S, S', *s*. The lever SA, is shown in the "on" position. The current enters the motor at the terminal M, and there divides, part going through the field coil F, and the main current through the motor armature A. The armature current enters the starter at the terminal S', and traversing the lever SA, leaves by the terminal S. The field current enters the starter at the terminal *s*, traverses the coil of the magnet E. (which holds up the armature *a*, linked to the lever) and thence completes its journey through the whole of the resistance R, and through the lever SA, to the terminal S. When the supply is cut off by opening Sw, or should the field circuit be accidentally broken, the magnet E, will release *a*, and the lever, which will thereupon fly to the "off" stop O. It should be noticed that when SA, is off, A and F, form a closed circuit with the resistance R and magnet E. The inductance of F, has consequently no chance of causing destructive sparking when the current is shut off. *In starting* the motor, Sw is first closed, and then, as the lever is slowly moved, the resistance R, which at first is all in circuit with A, is gradually transferred from A to F. The resistance of R, is too small to affect appreciably the current in F, which necessarily consists of a comparatively large number of turns of fine wire. The arrangement is adopted to render the breaking of the shunt circuit unnecessary.

FIG. 6,671.—Starter with no voltage release and overload release connected to a compound motor. With a shunt motor, the only difference in the diagram would be that the series winding SE, would be absent, and the armature A, would then be connected straight across between the main terminals M and M'. When switch Sw. is closed, the current will enter the starter at its terminal S, and pass through the magnet coil *m'*. of the overload release to the switch lever L, which is shown in the off position. As soon as L. is moved up to make contact with the first contact S, the current divides; part going through the resistance R, and the terminals S' and M', to the series coil SE (if a compound motor), and armature A; and part through the no voltage magnet E, to the shunt winding SH. As the lever L, is moved up toward E, the effect is to take R, out of the armature circuit and put it into the shunt circuit. When the iron armature *a*, fixed on the switch lever, comes against the poles of E, the laminated copper brush C, bears against the blocks B, B, and so affords a better path for the current than through the spindle *s*. Should the supply voltage fail, either temporarily or permanently, E. will release *a*, and L. will fly off under the tension of a helical spring coiled round *s*. If there should be an overload on the motor, tending to pull it up and cause an excess of current to flow through the armature; this excess current, passing through *m'*, will make it attract its armature, so bringing two contacts together at K, which will short circuit E, and allow the switch to fly off. The connections between E and *m'*, are not shown in the figure. When only the normal current is flowing, the attraction between *m'* and its armature is not sufficient to pull the latter up. The actual forms and arrangement of parts on the starters are well shown in some of the figures.

subject to abnormal increase of current which might overheat the system should be protected by fuses.

Circuit Breakers.—A circuit breaker is a switch which is opened automatically when the current or the pressure exceeds or falls below a certain limit, or which can be tripped by hand.

The automatic operation depends on properly arranged electromagnets. Circuit breakers are made to operate on overload or underload, and a reverse current, the latter type being sometimes called a discriminating cut out.

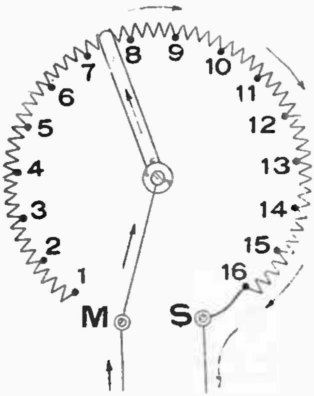


FIG. 6,672.—Diagram of plain rheostat. The rheostat is connected in series in the circuit that it is to control. *In operation,* when the lever is on contact 1, the current is opposed by all the resistance of the rheostat so that the flow is very small. As the lever is moved over contacts 1, 2, 3, etc., the coils are successively cut out, thus diminishing the resistance, and when contact 16 is reached all the resistance is short circuited allowing the full current to flow. M and S are the terminals.

FIGS. 6,673 to 6.675.—General Electric *magnetic blow out arrester* for use on railways. *It consists of an adjustable spark gap in series with a resistance. Part of the resistance* is in shunt with a blow out coil, between the poles of which is the spark gap. *In operation,* when the lightning pressure comes on the line, it causes the spark gap to break down and a discharge occurs through the gap and the resistance rod to ground. Part of the current shunts through the blow out coil producing a strong magnetic field across the spark gap. The magnetic field blows out the discharge arc and restores normal conditions.

Rheostats.—By definition, a rheostat is *a variable resistance box.*

It contains a number of resistance elements joined in series so arranged that they may be progressively cut out of the circuit by the movement of a lever over a number of contacts connecting different forms of the resistance.

A rheostat is connected in series in a circuit, and when designed to be used in starting motors it is frequently called a starting box or "starter."

For motor control a rheostat should be provided with an overload release and a no-voltage release.

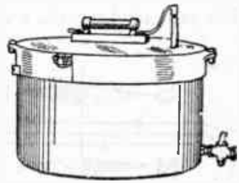


FIG. 6,676.—Westinghouse ***electrolytic station lightning arrester*** for direct current up to 1,500 volts consists of a tank of oil in which are placed, on properly insulated supports, a nest of cup shaped aluminum trays. The spaces between the trays are filled with electrolyte, a sufficient quantity for one charge being furnished with each arrester. The top tray is connected with the line through a 60 ampere fuse, and the bottom tray is connected to the tank which is thoroughly grounded by means of a lug. The fuse is of the enclosed type and mounted on the cover of the arrester. ***A small charging current*** flows through the trays continuously and keeps the films on the trays built up, so that no charging is required. This charging current is not, however of sufficient value to raise the temperature appreciably. The immersed area of each tray is 100 square inches. The shape and the arrangement of the trays is such that any gases generated by the discharge can pass out readily without disturbing the electrolyte between the trays.

Lightning Arresters.—These devices *provide paths by which lightning disturbances or other static discharges may pass to the earth.*

In general, their construction comprises an assembly of air gaps, resistances, inductances and arc suppression devices. A lightening arrester must prevent excessive pressure differences between line and ground, and between conductor turns in the electrical apparatus.

An *air gap* is frequently used to form the necessary high resistance which must

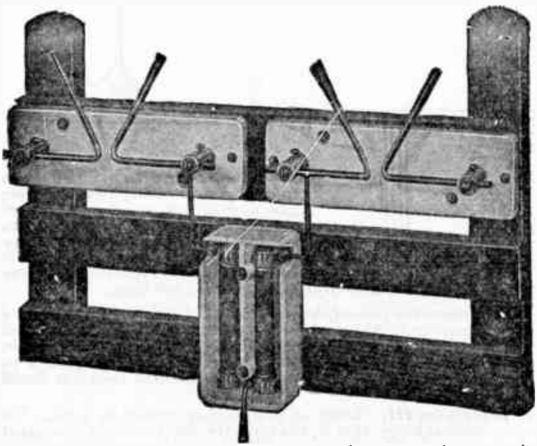
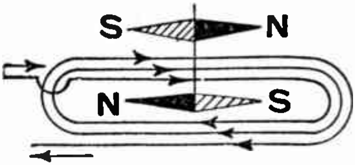


FIG. 6,677.—General Electric horn type ***air gap*** arrester, mounted for 15 light series arc circuit. The horn type arrester consists of a horn gap wit h series resistance between each line and ground.

which must be interposed between the ground and the conductor. The resistance is such that any voltage very much in excess of the maximum normal will cause a discharge to ground, whereas at other times the conductor is ungrounded because of the air gap. This forms the principle of air gap arresters. There may be one gap or many in series, and the gap may be in air or in vacuum. Other methods are: electrolytic, magnetic blow out, choke coils, static interruptors, etc.



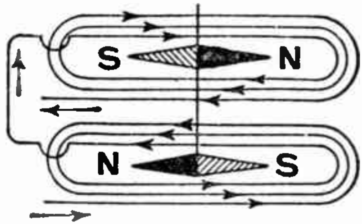
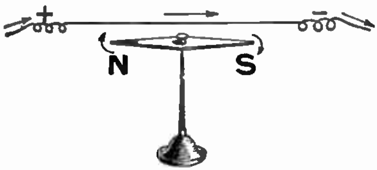
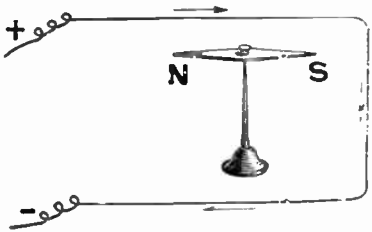


FIG. 6,678.—Connections of single coil astatic needles. The coil surrounds the lower needle and the direction of the current between the two needles tends to turn them the same way.

FIG. 6,679.—Connections of double coil astatic needles. *With this arrangement*, the direction of current in both coils will tend to turn the system in the same direction, making the needles more sensitive than with a single coil in fig. 6,678.





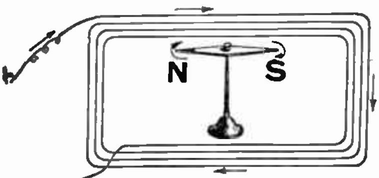


FIG. 6,680.—*Galvanometer principles I* Effect of neighboring current upon a magnetic needle: The north pole of the needle will turn toward the east, for by Ampere's rule, *if a man could swim in the conductor with the current, and turn to face the needle, then the north pole of the needle will be deflected toward his left hand.*

FIG. 6,681.—*Galvanometer principles II.* Effect of neighboring current in a loop. In accordance with Ampere's rule, the *upper* wire causes the N pole of the needle to turn to the left, while if a man imagine himself swimming in the lower wire in the direction of the current, and facing the needle (that is, swimming on his back), the N pole of the needle will turn to his left—that is to the east. The effect of the loop then has double the effect of the single wire in fig. 6,680.

FIG. 6,682.—*Galvanometer principles III.* Effect of neighboring current in a coil. The coil, as shown, is equivalent to several loops, that is, the force tending to deflect the needle is equal to that of a single loop multiplied by the number of turns. Hence, by using a coil with a large number of turns, a galvanometer may be made very sensitive so that the needle will be perceptibly deflected by very feeble currents



FIG. 6,683.—Breguet upright galvanometer with glass shade.

FIG. 6,684.—Bunnell horizontal galvanometer. It has two coils, one of which is of zero resistance and one of fifty ohms resistance adapting it to a variety of test.

FIG. 6,685.—Bunnell galvanometer for measurements of instruments, lines, batteries, wires and any object from 1/100 to 10,000 ohms or more.

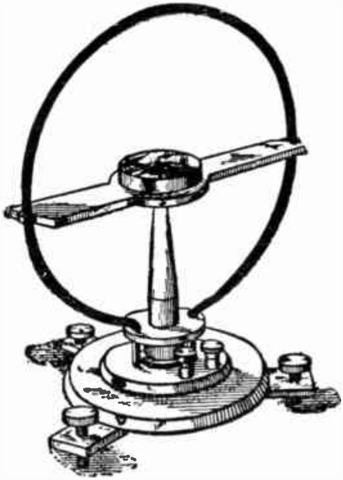
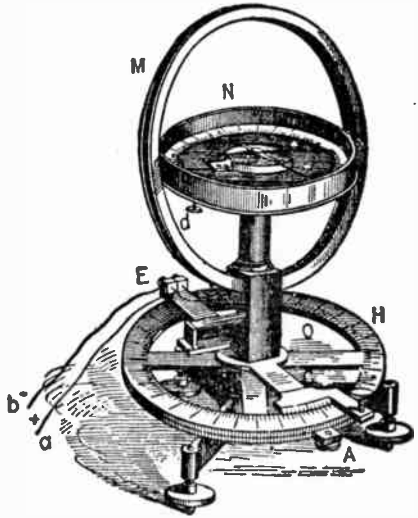



FIG. 6,686.—*Tangent* galvanometer. ***It consists of*** a short magnetic needle suspended at the center of a coil of large diameter and small cross section. If the instrument be so placed that, when there is no current in the coil, the suspended magnet lies in the plane of the coil, that is, if the plane of the coil be set in the magnetic meridian, then *the current passing through the coil is proportional to the tangent of the angle by which the magnet is deflected from the plane of the coil*, or zero position—hence the name: "tangent galvanometer."

FIG. 6,687.—*Sine* galvanometer. ***The parts are:*** M, coil; N, graduated dial of magnetic needle H, graduated dial by which the amount of rotation necessary to bring the needle to zero is measured; E, terminals of the coil; O upright standard carrying coil and graduated dial of magnetic needle; C, base with levelling screws. ***In operation***, the coil is moved so as to follow the needle until it is parallel with the coil. Under these circumstances, the strength ***of the deflecting current*** *is proportional to sine of angle of deflection.*

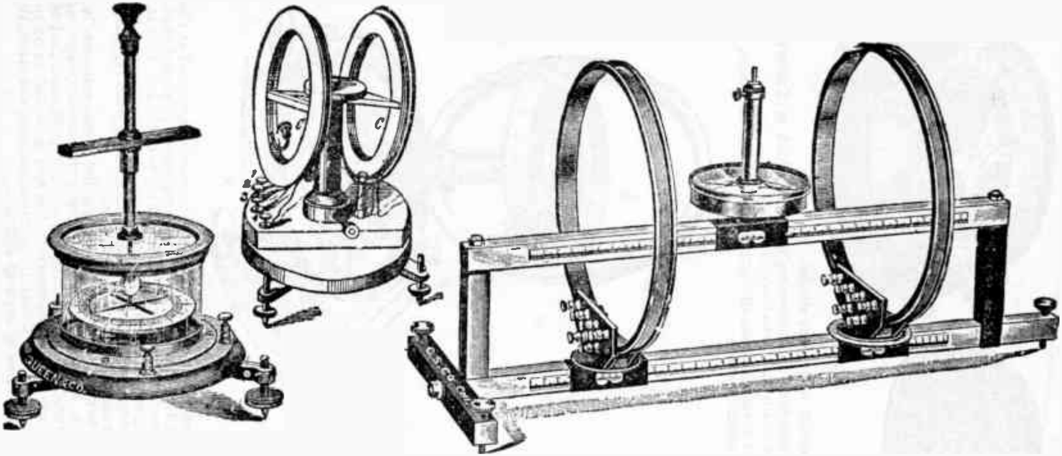
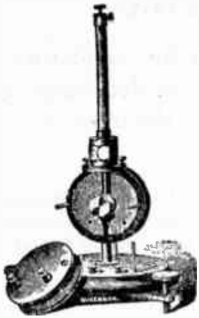


FIG. 6,688.—Queen reflecting static galvanometer. It is mounted on a mahogany base with levelling screws. A plain mirror is attached above the upper needle. The entire combination of mirror and needles is suspended by unspun silk from the interior of a brass tube, which also carries a weak controlling magnet. A dial 4 inches in diameter and graduated in degrees, enables the deflections of the needle to be accurately read. The mirror can be used with a reading telescope and scale, or by means of a lantern, the image of a slit may be reflected from the mirror to a screen. Resistance, .5 to 1,000 ohms.

FIG. 6,689.—*Differential* galvanometer. ***It consists of*** a magnetic needle suspended between two coils of equal resistance so wound as to tend to deflect the needle in opposite directions. ***In operation,*** the needle *shows no deflection when two equal currents are sent through the coils in opposite directions.* Its special use is for comparing two currents.

FIG. 6,690.—Central Scientific Co. universal tangent galvanometer. This instrument may be used as a tangent, Gaugain, Helmholtz-Gaugain, sine, cosine, Wiedemann or detector galvanometer. The coils, which slide on a beam parallel to the one carrying the needle box, are wound on brass rings 12 inches in diameter. On each ring are wound two coils of 48 turns each, connected to separate binding posts, and double wound so as to be of equal resistance. The coils and needle box are each provided with an indicator for reading their position on the scale. The needle box is swivelled and removable and one coil may be rotated about its vertical axis and its position read on a disc graduated in degrees. Currents may be measured ranging from .000002 ampere to 100 amperes.



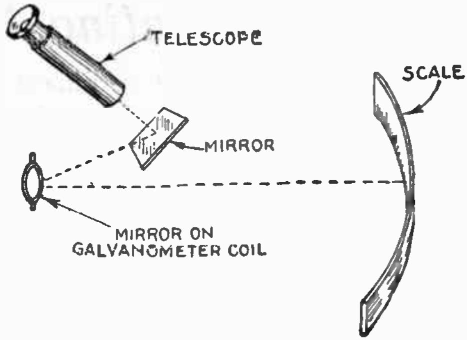
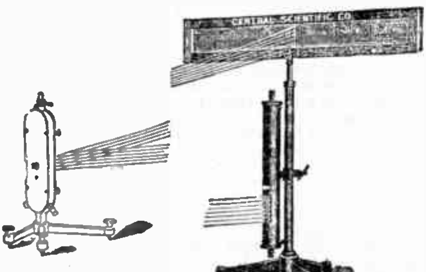
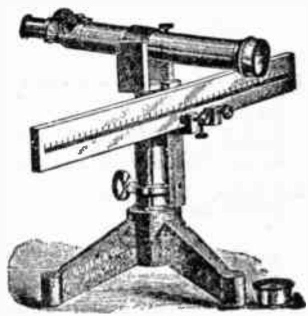


FIG. 6,691.—Queen *dead beat* and *ballistic* galvanometer *In construction,* the magnetic system is given considerable weight, so arranged as to give the reading without useless swings of the needle. This is obtained by hanging a bell magnet with its mirror by a long cocoon fibre, the eddy currents induced in the copper bringing the system quickly to rest. *Used for* measuring momentary currents, for instance, the discharge of a condenser.

FIG. 6,692.—Telescope method of reading galvanometer deflections by reflections of scale reading in mirror.





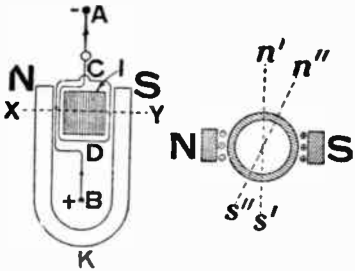
FIGS. 6,693 and 6,694.—Galvanometer lamp and scale for individual use. *The scale* is etched on a ground glass strip 6 centimeters wide by 60 centimeters long with long centimeter divisions and short millimeter divisions the entire length, reading both ways from zero in the center. It is mounted in an adjustable wooden frame. A straight filament lamp(110 volts) is enclosed in a metal hood japanned black to cut out all reflected light.

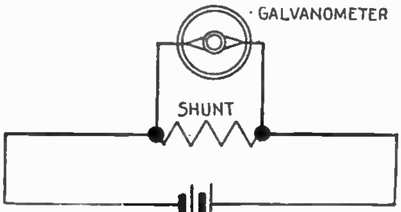
FIG. 6,695.—Queen reading telescope. This arrangement is utilized to measure the deflections of a galvanometer having suspended mirror moving system. *It consists of* a reading telescope mounted as illustrated with a millimeter scale, having a length of 50 centimeters. In use, the image of the scale is seen in the galvanometer mirror through the telescope. The eye piece of the telescope has a cross hair which acts as a reference line so that by noting the particular division on the scale when the galvanometer is at rest, the amount of deflection can be readily observed when the galvanometer is deflected.

2. Indicating Devices

Galvanometers.—These instruments are for indicating the presence of an electric current in a circuit, and determining its direction, strength and pressure, by measuring the electromagnetic effect of the current.

Its principle is that a magnetic needle is deflected when influenced by an electromagnetic field, and a simple galvanometer consists essentially of a magnetic needle suspended within a coil of wire and free to swing over





FIGS. 6,696 and 6,697.—Diagrams of *D'Arsonval* galvanometer. ***In construction***, the coil is wound upon a copper form, and suspended between a permanent magnet by fine wires to the points A and B. The magnet has its poles at N and S There is a soft iron cylinder fixed between the poles in order to intensify the magnetic field across the air gaps in which the coil moves. *n's'*, position of coil when no current is flowing; *n''s''*, position when current is flowing. This galvanometer is adapted to general use.

FIG. 6,698.—Diagram showing method of connecting galvanometer shunt. *The shunt greatly increases the range of measurement.*

the face of a graduated dial. The action of the current was discovered by *Oersted*. Galvanometers may be divided into two general classes, as those having: 1, a movable magnet and stationary coil, and 2, stationary magnet and movable coil; either type may have a short or long coil. The principle forms of galvanometer are: 1, astatic; 2, tangent; 3, sine; 4, differential; 5, ballistic; 6, D'Arsonval.

Ammeters and Voltmeters.—An ammeter or ampere meter is simply a commercial form of galvanometer so constructed that the deflection of the needle indicates directly the strength of current *in amperes*.

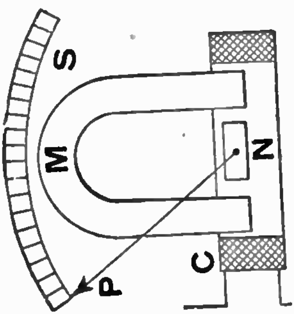


FIG. 6,699.—*Moving iron* type instrument. The essential parts are: N, soft iron needle; C, coil; M, permanent magnet; P, pointer; S, scale. *Current passing through the coil acts on the needle, causing it to turn against the restraining force due to the influence of the permanent magnet.*

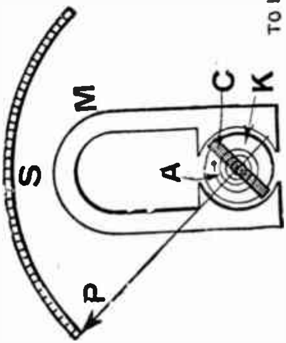


FIG. 6,700.—*Moving coil* type instrument. The essential parts are: A, spiral spring; C, coil; K, soft iron core; M, permanent magnet; P, pointer; S, scale. *Current passing through the coil causes the moving system to turn against the restraining force due to the influence of the permanent magnet.*

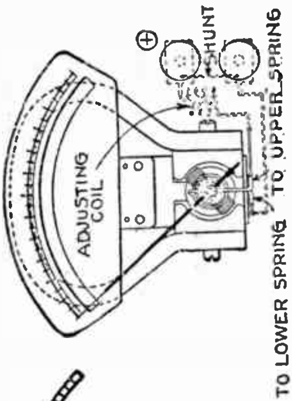


FIG. 6,701.—Western Ammeter showing shunt enclosed within the instrument. The reading is ***dead beat*** which means *without useless vibrations of the needle.*

A good ammeter should have a very low resistance so that very little of the energy of the current will be absorbed; the needle should be dead beat, and sufficiently sensitive to respond to minute variations of current.

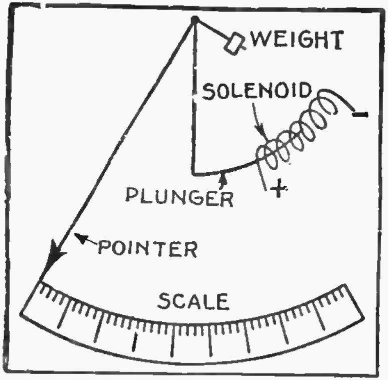
According to the principle of operation, ammeters and volt-meters are classified as:

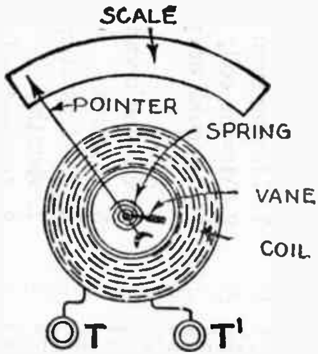
1. Moving iron;
2. Moving coil;
3. Solenoid or plunger;
4. Magnetic vane;
5. Hot wire;
6. Electrostatic;
7. Astatic;
8. Inclined coil;
9. Fixed and movable coil.

Ammeters are connected in series in the circuit, or in shunt; according as they are designed to receive all or only a fraction of the current.

A voltmeter has a high resistance coil instead of one of low resistance, so that very little current will pass through it.

If a high resistance be connected in series with a sensitive ammeter that will measure very small currents, then the current





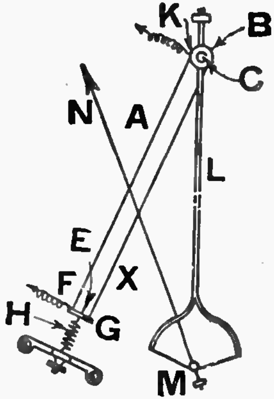


FIG. 6,702.—Plunger type instrument. *In principle, the current to be measured passes through the solenoid, producing a magnetic effect on the soft iron plunger which tends to draw it into the coil, and thus cause the pointer to move over the graduated scale.* The instrument, because of the residual magnetism of the air is less reliable than the usual types. ***Adapted*** to large currents.

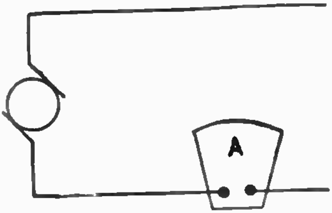
FIG. 6,703.—Magnetic vane instrument. ***In principle,*** a soft iron vane, *eccentrically pivoted within a coil carrying the current to be measured, is attracted toward the position where it will conduct the greatest number of magnetic lines of force against the restraining force of a spring or equivalent.* T and T¹ are the terminals.

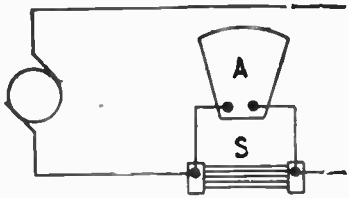
FIG. 6,704.—Diagram showing principle and construction of the Whitney ***hot wire*** instruments. The action of instruments of this type *depends on the heating of a wire by the passage of a current causing the wire to lengthen.* This elongation is magnified by suitable mechanism and transmitted to the pointer of the instrument. AX, wire; B, pulley; C, shaft; E, plate; F and G, ends of wire; H, spring; M, pulley; N, pointer.

passing through the circuit is directly proportional to the pressure or voltage at its terminals and the instrument may be calibrated to read volts. A voltmeter is connected ***in parallel*** in the circuit.

Wattmeters.—These instruments are designed to measure directly the products of the amperes and volts in a circuit and give its readings in watts. In the *dynamometer* type there are two coils, or sets of coils, one of which is fixed and the other movable.

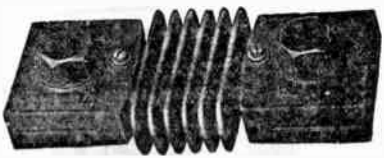
The movable coil is connected in the current circuit, and the fixed coil in the pressure circuit, or the reverse. The *induction* type is used on alternating current circuits. In this type, electromagnets are arranged near a vane in which eddy currents





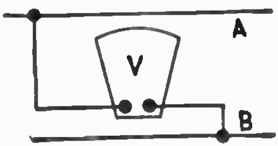
FIGS. 6,705 and 6,706.—Connections for series and shunt ammeters. When the construction is such that all the current passes through the instrument, it is connected as in fig. 6,705 but where the instrument is designed to take only a fraction of the current, it is connected across a shunt, as in fig. 6.706, a definite proportion of the current passing through the instrument and the remainder through the shunt.

1,000 Ampere Type B Shunt



400 Ampere Type D Shunt

FIGS. 6,707 and 6,708.—Westinghouse ammeter shunts. These shunts are used where heavy currents are to be measured. The shunt is connected in series with the bus bar or circuit to be measured, and its terminals are connected by means of small leads to the ammeter or other instrument.



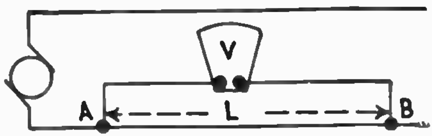
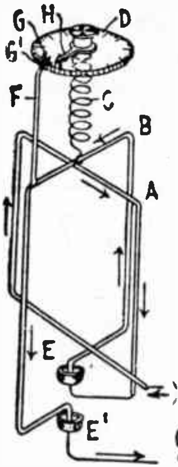


FIG. 6,709.—Voltmeter connection for measuring the pressure in an electric circuit. The voltmeter is connected *in parallel* in the circuit at the point where the voltage is to be measured.

FIG. 6,710.—Voltmeter connection for measuring the "drop" or fall in voltage in a certain length of wire, as for instance, the length between the points A and B. The voltmeter is *shunted* between the two points whose pressure difference is to be measured.



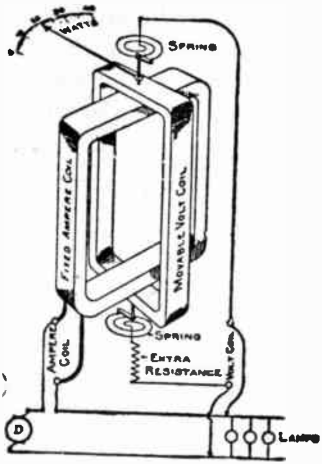
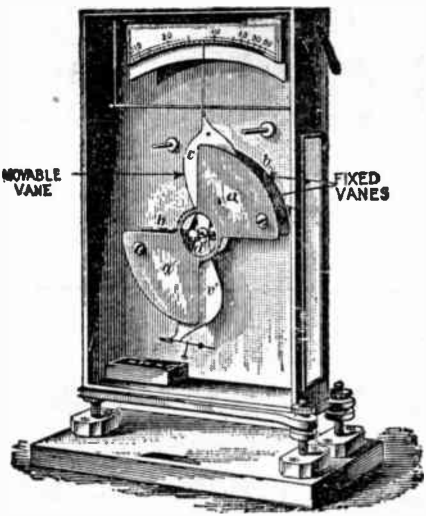


FIG. 6,711.—Diagram of Siemens' electro-dynamometer. *It consists of* two coils on a common axis, but set in planes at right angles to each other in such a way that a torque is produced between the two coils which measures the product of their currents. This torque is balanced by twisting a spiral spring through a measured angle of such degree that the coils shall resume their original relative positions. If used for measuring *current*, the coils are connected in series, and the reading is then proportional to the square of the current. If used as a *wattmeter*, one coil carries the main current and the other a small current, which is proportional to the pressure. The reading is then proportional to the power in the circuit.

FIG. 6,712.—Diagram showing connections of Siemens' electro-dynamometer as arranged to read watts.



are caused to flow which react on the magnetic field, and the record made is proportional to the force of the reaction. A *recording* wattmeter is one that will register the watt-hours expended during an interval of time.

FIG. 6,713—Kelvin *electrostatic* voltmeter for high pressures up to 200,000 volts. *In principle, the vanes which act as condensers take charges proportional to the pressure difference between them, resulting in a certain attraction which lends to rotate the movable disc against the restraining force of gravity.* In the figure *aa* and *b* are two fixed vanes and *c* a movable vane, carrying a pointer and having a proper weight at its lower end.

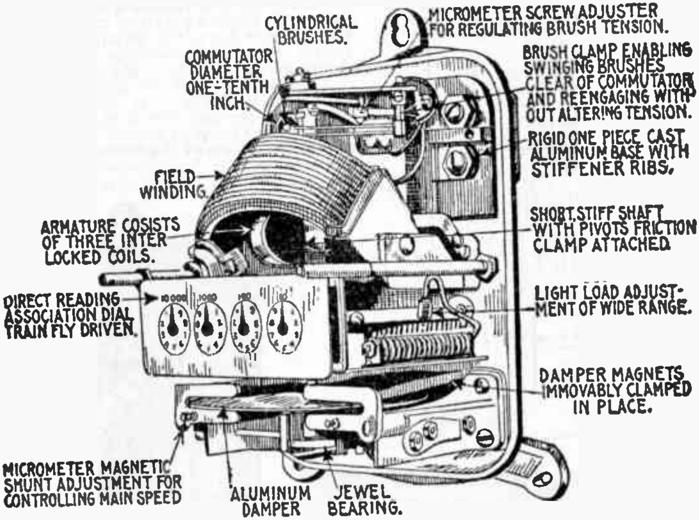


FIG. 6,714.—Interior view of Columbia watt hour meter showing construction, principal parts, and connections. The armature winding consists of three coils approximately circular in shape. The coils are form wound, interlocked with one another and with the light impregnated fibre disc which serves as a spacer for them. The aluminum damper disc has the conventional anti-creep provision in the shape of the three small soft iron plugs, mounted close to the central staff. The commutator has three segments and is made of chemically pure silver. Each brush is formed of a length of phosphor bronze wire bent like a hair pin and secured at its "U" end to a brass sleeve, which in turn is secured to an insulated stud by a set screw. An extension on the sleeve carries a micrometer screw brush adjustment.

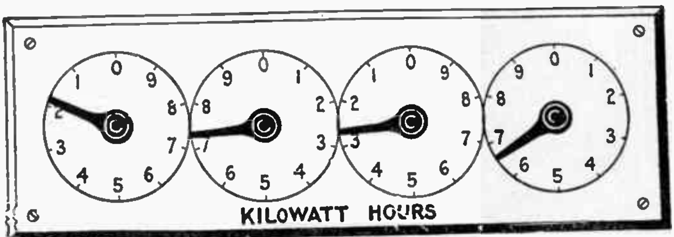


FIG. 6,715.—Watt hour meter recording dials. *To read the meter:* Begin at the left and set down for each dial the *lower* figure next to each hand, not necessarily the figure nearer the hand. In the above example the statement is 1,726 kilowatt hours or 1,726,000 watt hours. Subtract the previous statement to arrive at registration for a given period. Some meters are subject to a multiplying constant so stated on their face, and the registration of such meters must be multiplied by the constant as shown. to determine the actual consumption of electrical energy.

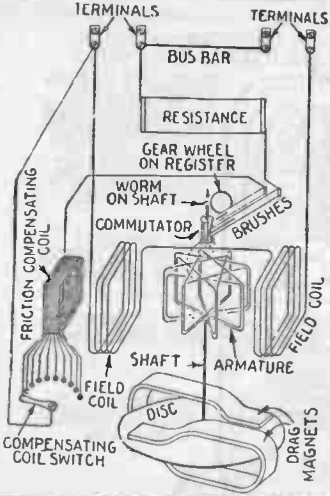


FIG. 6,716.—Diagram showing internal connections of the Duncan watt hour meter. Its operation depends upon the principle of the well known electro-dynamometer, in which the electro-magnetic action between the currents in the field coils and an armature produces motion in the latter. It also embodies the other two necessary watt hour meter elements required for the speed control and registration of the revolutions of the armature, these being embodied in the drag magnet and disc, and the meter register respectively.

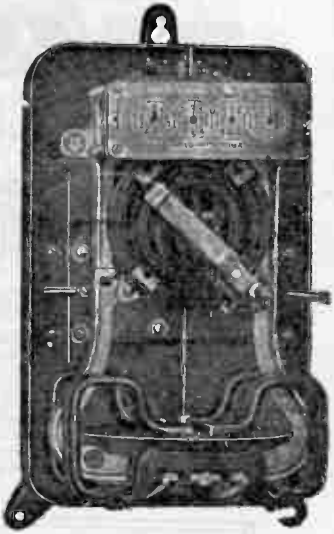


FIG. 654.—Interior view of Thompson watt hour meter (type C-6). Capacity: 5 to 600 amperes, two wire, and 5 to 300 amperes, three wire; 100 to 250 volts. The meter is supported by three lugs, the upper one of which is keyholed, and the lower right hand one slotted. This permits rapid and accurate levelling as the top screw can be inserted and the meter hung thereon approximately level.

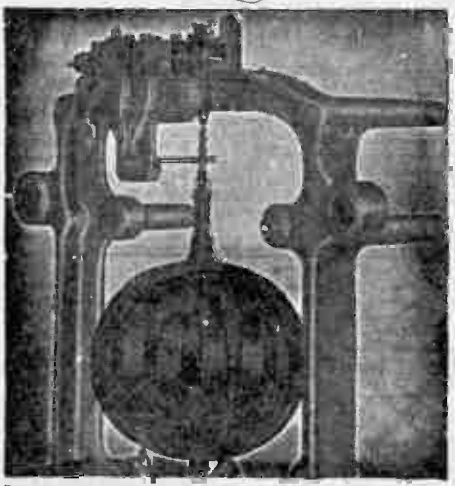
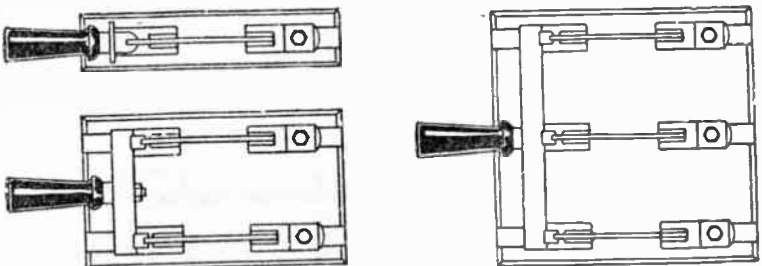


FIG. 656.—Interior of Thompson watt hour meter (type C-6) showing armature, small commutator and gravity brushes. A spherical armature moving within circular field coils is the construction adopted in this meter. The armature is wound on a very thin paper shell, stiff enough to withstand the strain due to winding and subsequent handling. The wire composing the armature is of the smallest gauge consistent with mechanical strength. Ribbon wire is employed for the field coils, thus economizing space and further carrying out the idea of concentration

CHAPTER 16

A.C. Control and Indicating Apparatus

Various devices are required for the proper control of the alternating current, such as,



FIGS. 6,718 to 6,720.—Various single throw switches. Fig. 6,718, single pole; fig. 6,719, double pole; fig. 6,720, three pole. *A single pole switch should only be used for very light duty.*

1. Switching devices;
   a. Ordinary switches; *b.* Oil break switches:
   c. Remote control switches.

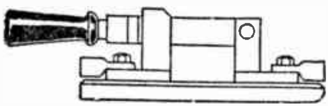
2. Current or pressure limiting devices;
   a. Fuses; *b.* Reactances; *c.* Circuit breakers: *d.* Relays.

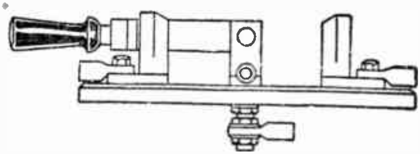
3. Lightning protection devices;

   a. Air gap arresters;
   b. Multi-gap arresters;
   c. Horn gap arresters;
   d. Electrolytic arresters;
   e. Vacuum tube arresters;
   f. Choke coils;
   g. "Static" interrupters.

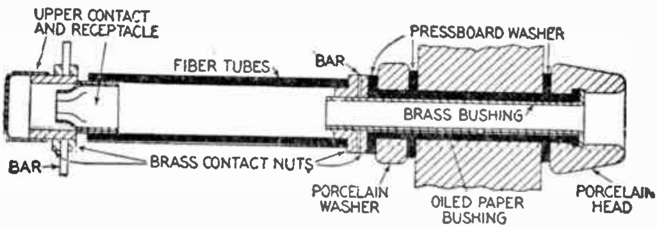
4. Regulating devices;

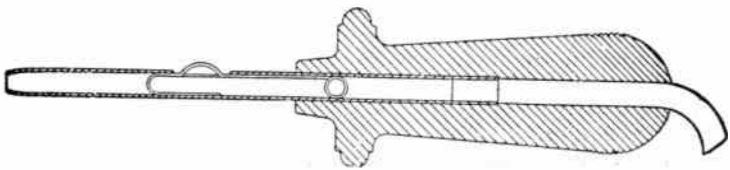
   a. Induction voltage regulators;
   b. Variable ratio transformer regulators {drum type; dial type;
   c. Compensation shunts;
   d. Pole type regulators;
   e. Small feeder voltage regulators;
   f. Automatic voltage regulators;
   g. Line drop compensators;
   h. Starting compensators;
   i. Star delta switches;
   h. Synchronous condensers.





FIGS. 6 721 and 6,722.—Various single pole switches. Fig. 6,721, single throw; fig. 6,722 double throw.





FIGS. 6,723 and 6,724.—Enclosed arc bus transfer plug switch The current is supplied in a tube enclosed at one end, thereby confining the arc and limiting the supply of air.

5. Indicating devices:

   a. Moving iron instruments {plunger type; inclined coil type; magnetic vane type;

   b. Hot wire instruments;

   c. Induction instruments {shielded pole type; repulsion type;

   d. Dynamometers;

   e. Instrument transformers;

   f. Watthour meters {commutator type; induction type, Faraday disc type;

   g. Frequency indicators {synchronous motor type; resonance type; induction type;

   h. Synchronism indicator {lamp type; voltmeter type; resonance type; rotating field type;

   i. Power factor indicators {wattmeter type; rotating field type;

   j. Ground detectors;

   k. Earth leakage cut outs;

   l. Oscillographs.

Switching Devices

A switch is *a piece of apparatus for making, breaking, or changing the connections in an electric circuit.*

Since the electric current cannot be stopped instantly when the circuit in which it is flowing, is broken, an arc is formed as the switch contacts separate; this tends to burn the contacts, and to short circuit, the severity of such action depending on the voltage and the proximity of the switch terminals. Accordingly, in switch design, provision must be made to counteract these tendencies. Thus,

1. The contacts should separate along their entire length, rather than at a point;

2. The terminals should be far enough apart and properly protected to prevent short circuiting of the arcs;

3. The break should be quick:

4. The gap should be surrounded by the proper medium (air or oil) to meet the requirements of the electrical conditions.

A great variety of switches have been introduced to suit the different requirements. Knife switches are used for low pressure service, the multiple break form being used where it is desired to reduce the arcing distance. Knife switches should open downward so gravity will keep them open.

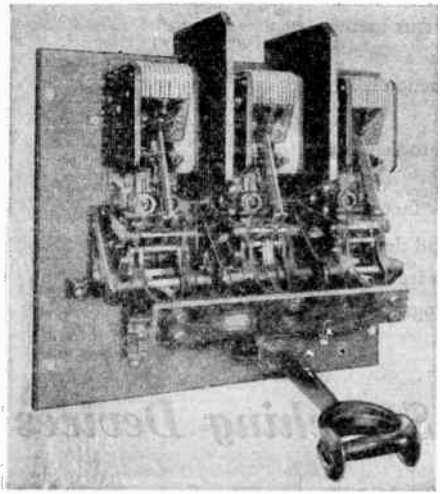


FIG. 6,725.—Typical manually operated air circuit breaker having a current rating of 2,000 *amp.* and above. One of the best methods to test breakers of this type for perfect contact alignment is to close the contacts on a piece of thin tissue paper and a piece of thin carbon paper, with the carbon next to the tissue. When the breaker is closed and opened, it is a simple matter to determine the amount of impression made on the paper. Good impressions will show 75% or more of the length of each bar on the contacts.—*Courtesy General Electric Co.*

Forms of Break.—On high pressure circuits there are several types of switch, they are classified *with respect to the break*, that is to say, according as the break takes place.

1. In open air;
2. In an enclosed air space;
3. Aided by a metal fuse;
4. In oil.

If the break take place in open air, a relatively long gap is required to extinguish the arc. The enclosed air break switch is more compact. The opening arm of a metal fuse break switch draws the fuse through a tube thus opening the circuit without much disturbance. In a horn gap switch, the arc formed on breaking the circuit, as it travels toward the extremities of the horns, becomes attenuated and is finally ruptured.

An oil switch is one in which the break occurs under oil; it is used almost universally on high pressure *a.c.* circuits.

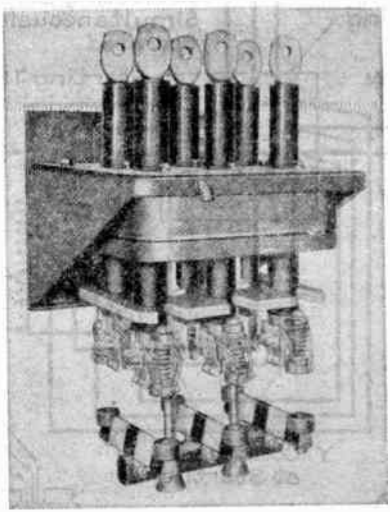


FIG. 6,726.—Illustrating a 600-*amp.*, 5,000-volt oil circuit breaker with tank removed, showing butt-type spring-pressure contacts and wedge and finger type silver to silver main contacts. Periodic checks should include tightening of nuts, checking spring pressure, pigtails and contact wipe.—*Courtesy General Electric Co.*

Remote Control.—It is desirable in the case of switches on high pressure circuits (1100 volts and over) to locate the parts which carry the high pressure current *at some distance from the switchboard in order that they may be operated with safety.*

They may be operated either by hand or by power, large switches being usually operated by means of remote control.

Selection of Control Wire Size.—Although in most contactor and relay operations a 20% voltage drop is allowed, it is important that control wires be so selected that this maximum drop under all conditions not be exceeded.

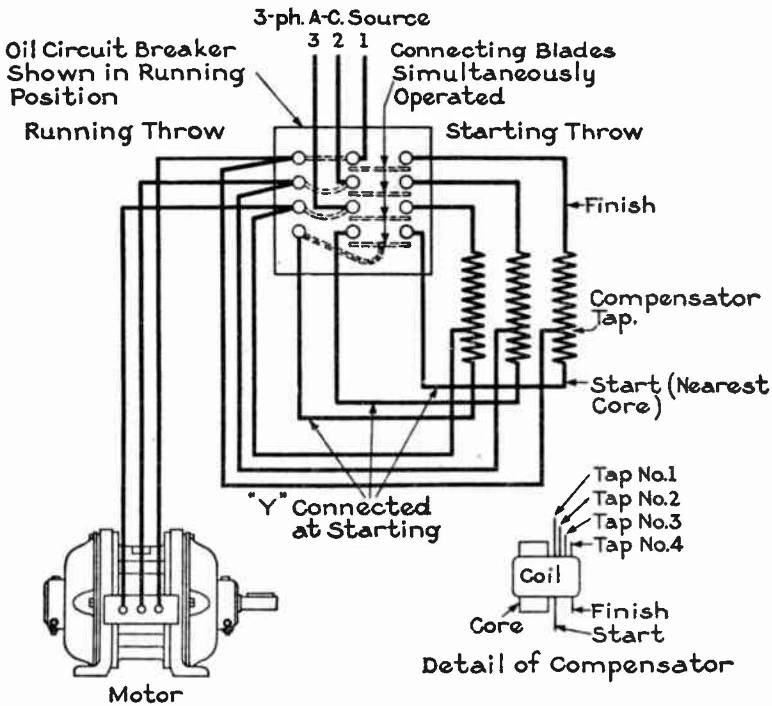


FIG. 6,727.—Wiring diagram showing connection of 4 pole, double throw oil circuit breaker with autotransformer suitable for operation of squirrel cage induction motors. *Operation* The system of connections are such that the motor terminals are permanently connected to the starting taps on the autotransformer. With both throws of the breaker open, the autotransformer and motor are entirely disconnected from the source of power and the Y of the autotransformer is open. When the starting side of the breaker is closed, the Y on the autotransformer is closed and the autotransformer is connected to the source of power. When the starting side is open and the running side is closed, the motor is connected directly to the source of power, with voltage still applied on the starting side of the autotransformer. No current, however, flows in the autotransformer since the Y is open.

Therefore, in remote operations of controls, it is often desirable to know the allowable length and size of a conductor that can be used between the remote operating point and the controller. These calculations differ for alternating and direct current circuits, in addition to being affected by capacity, as well as inductance from adjacent conductors. Under ordinary circumstances, however, these factors need not be considered unless the control line is of considerable length.

Direct current contactors and relays are generally designed to pick up at 80% coil voltage when hot. This means that if 100% control circuit voltage is available, theoretically a 20% voltage drop can be tolerated in the conductor in series with the coil, and the device will still operate. To allow a factor of safety, because of varying operating conditions, a 10% drop in the control wire is a safer value to use. On this basis, using Ohm's law, we obtain:

$$R = \frac{0.1 \times E}{I}$$

Where R = conductor resistance in ohms.

I = pick-up current of contactor or relay coil in amperes.

E = normal operating voltage of contactor or relay coil in volts.

On alternating current contactors and relays, however, the inrush current required to close the magnet is much higher than the normal current after the magnet has closed. Therefore, the formula previously shown cannot be used. In numerous applications it is found that the resistance in series with the coil can be as much as 25% of the total ohmic resistance of the coil.

If the resistance of the coil be not known, it can readily be obtained by energizing the coil on direct current, and by measuring the voltage across the coil and the current flowing through it.

Then the unknown coil resistance is:

$$R = \frac{E}{I}$$

This resistance cannot be measured by an application of alternating current.

Now any wire table can conveniently be used to determine the minimum size of copper wire after the ohmic resistance has been obtained by either of the two methods previously given.

In many applications it will be found that this minimum size is impractical from the standpoint of mechanical strength.

In such cases, a wire should be selected large enough to fulfill in addition to electrical requirements, mechanical requirements as well. This latter requirement is an important consideration especially when it be required that the wire be strung out of doors on poles where it is often subjected to the strain of wind, sleet or snow.

Current and Pressure Limiting Devices

The importance or current and pressure limiting devices is to *protect circuits from overheating due to abnormal current.*

Fuses.—A fuse is "an electrical safety valve," or *wire or strip of metal in a cut out, which may be fused by an excessive current.*

For large currents, circuit breakers should be used in place of fuses.

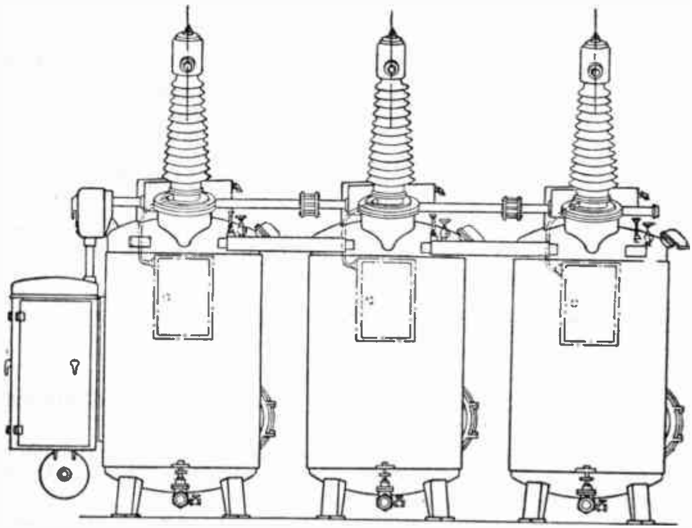


FIG. 6,728.—General Electric Series FK—439, 230 *kv.* 800 *amp.* high speed oil circuit breaker. The oil circuit breaker operating mechanism is designed for high speed operation (3-cycle interrupting, 20-cycle reclosing, 60-cycle system). The breaker incorporates a multi-break interrupter (not shown) consisting of parallel resistors which provides positive control of over-voltages that accompany interruption of line charging currents. It consists essentially of a helix of michrome wire wound on a grooved board that is molded to the shape of the interrupting cylinder. The pneumatic operating mechanism (shown at left in the illustration) is equipped with a compressor unit which automatically provides the breaker with sufficient air pressure operation when required.

Circuit Breakers.—By definition, a circuit breaker is *a device, which **automatically** opens the circuit in event of abnormal conditions, in the circuit.*

The arc may be broken: 1, by magnetic blow out, 2, by thermal break, or 3, by carbon break. In the carbon break the arc is progressively broken through: 1, main contacts, 2, intermediate contacts, and 3, carbon contacts.

Automatic Control of Circuit Breakers.—This is secured *by the use of solenoids or trip coils.* These coils may be wound in series or in shunt with the main circuit, or in shunt with an auxiliary circuit.

The automatic controls arising from these connections give various kinds of protection to the circuit and are known as

1. Overload trip;
2. Underload trip;
3. Low voltage trip;
4. Auxiliary circuit trip.

NOTE.—Oil switches are often used on systems with generator capacity of many thousand kilowatts. It is therefore, essential that the switches shall be able to break not only their normal current, but also greatly increased current that would flow if a short circuit or partial short circuit occur.

Protective Relays for A.C. Systems

Protective relays are used to protect circuits from abnormal conditions of voltage or current which would be undesirable or dangerous to the circuit and associated equipment.

Purpose of Protection.—Relay protection is applied to an electrical system for the purpose of minimizing the interruptions of service and the damage to apparatus which result from abnormal conditions in the system.

In applying relays to a system the primary considerations are as follows:

1. To maintain service under all conditions.
2. To disconnect only the line or apparatus in which a fault has developed.
3. To disconnect the faulty portion from the remainder of the system as soon as possible in order to prevent trouble due to fall of voltage in the healthy part of the system.
4. To prevent injurious heating due to short circuits or heavy overcurrents.

Great care must be exercised therefore, in the selection of relays so as to obtain the proper sequence and selectivity of operation.

Power System Components.—In general, a power system may be said to consist of some, or all of the following: *Alternating current generators, exciters, auxiliary transformers, auxiliary feeders, main transformers, outgoing lines, incoming lines, tie lines, miscellaneous circuits, including direct-current machines and control, signal and auxiliary circuits.*

Relay Selection.—The selection and application of relays for any circuit cannot properly be made unless the selection is based on the nature and characteristics of the entire system of which the circuit under consideration forms a part.

Only by harmonizing all the characteristics of each item of the system can the best results from the relay be obtained. This is particularly true on the interconnected system. The proper functioning of a system depends upon the proper selection and application of its protective relays, which work in conjunction with the other protective apparatus installed.

Relay Classification

Relays may be classified according to their type, as for example *plunger*, *induction*, etc. according to their contacts, as *circuit opening*, *circuit closing*, etc. or according to their function, such as operating on *current*, operating on *voltage*, etc. The last mentioned method of classification seems to be the best one and is the method used in this chapter. There are alternating current relays operating on current voltage, change of phase relation, power and frequency. There are direct current relays operating on current, voltage and power. There are temperature relays operating on replica of temperature.

In addition to the protective relays divided into the classifications given previously there are: *auxiliary relays*, *control relays* and *signal relays*.

Relays Operating on Current.—These may be sub-divided into overcurrent undercurrent and current differential relays.

Relays Operating on Voltage.—These like the current relays are sub-divided into overvoltage, undervoltage, voltage-differential and voltage-directional relays.

Relays Operating on Power.—Power relays are divided into overpower, underpower and power directional relays.

Relays Operating on Temperature.—Temperature relays may be subdivided into three general classes as follows: Those operating on change of electrical resistance, those operating on the action of a thermostatic couple and those operating on volatilization of a liquid.

Relay Requirements

Advantages in Using Relays.—Where the volt ampere load of the relay is less than that of the trip coil, relays may be used primarily for the purpose of reducing the volt-amperes imposed upon the current transformers by normally short-circuiting the breaker trip coils.

Where the trip coils are located at the breaker remote from the switchboard, relays may be used to advantage mounted on the switchboard where they are readily accessible and where adjustments can be easily made. Relays are inherently more accurate than trip coils, and may be obtained to operate upon the occurrence of almost any form of disorder whereas trip coils are usually limited to plain overcurrent, instantaneous or time.

Relays may also be used primarily for the purpose of reducing the burden imposed on oil circuit breakers. In the case of necessary system time gradings, this decreased burden on the oil circuit breakers may be taken advantage of since the selection and application of oil circuit breakers for a system depends in many cases upon the time settings of the protective relays.

The greatest duty imposed on an oil circuit breaker is its frequent instantaneous opening when short circuits occur in the circuit controller. This is apparent from the fact that in most cases the maximum short circuit current is reached instantaneously with the occurrence of the short circuit and rapidly reduces to some lower sustained value.

The use of relays, therefore, by delaying the parting of the breaker contacts makes it possible to use a breaker of smaller interrupting capacity than would otherwise be possible, and may also permit the increasing of the generating capacity of the system without requiring the installation of new oil circuit breakers of higher interrupting capacity.

Requisites of a Relay.—Until suitable operating conditions occur a relay should remain in its normal (in operating or "dormant") position with the contacts definitely open (in the case of a circuit closing relay) or definitely closed (in a circuit opening relay).

When the suitable operating conditions occur, the relay should complete its travel instantaneously or in a prescribed inverse or definite time, closing (or opening) the prescribed number of contacts, and holding the contacts in the operated position until the required performance outside the relay has been completed. Some relays then reset automatically, others remain in the operated position until they are reset either manually by means of a resetting device or electrically by means of a resetting winding. Usually when the resetting is automatic it is instantaneous but a few relays are required to introduce a time interval in the resetting.

All relays should operate consistently when the operating conditions are repeated. The operation of alternating current relays should not be seriously affected by slight variations in frequency and wave form. The correct operation and resetting of direct current relays should not be prevented by residual magnetism in the iron of the relay. Neither alternating nor direct current relays should be affected seriously by stray magnetic fields of ordinary strength.

The foregoing are general statements, applicable to practically all relays, but to greater or less degree, depending upon the construction and operating principle of the relay. Individual relays have certain detailed features of operation, according to the purpose of the design. Thus, an induction overcurrent relay has a time current curve that repeats itself with great accuracy; the time is strongly inverse at small overcurrents and slightly inverse at large currents.

Relay Applications

In the following examples on application of relays previously described it is not intended to cover all kinds and types of applications permissible with the use of these relays. Conditions attending individual installations often vary, so each application of the proper type of relay must be given due consideration and study.

A.C. Generator Protection.—It is of the utmost importance that generators be kept in service, and it is therefore, the general practice to omit overcurrent protection from such circuits. Experience has shown, however, that no part of a system is free from the possibility of injury. The arrangements described in the following paragraphs serve to protect the generator by disconnecting it from the buses and removing its excitation before serious injury results. The generator circuit breaker is non-automatic as regards overcurrents or short circuits in the external system.

This assures that troubles external to the generator windings shall not disconnect the generator, which would, thereby, interrupt service in the whole system. This is in line with the purpose, as previously stated, for which protective relays are designed, that is, to maintain service over the greatest possible portion of the system under all conditions, and to disconnect only that part containing the fault.

The large capacity and cost of modern units has made it necessary, however, to consider means of quickly and effectively protecting the generators in times of fault or short circuit in their internal windings.

Current Differential Protection.—Generally this consists of current transformers installed at each end of the generator windings, with their secondaries connected in series and relays connected differentially so that their functioning depends upon a difference of current flowing through the two sets of current transformers. Current transformers and relay connection for various types of differential protection are indicated in figs. 6,729 and 6,730. In a relay protection scheme of this type separate transformers should be provided for the meters and instruments.

Protection is afforded against grounds occurring in the generator windings and against internal short circuits between turns and the same phase. If the neutral of the system is not grounded, however, protection against grounds in the generator windings is afforded only upon the occurrence of a second ground on another phase of the system.

Generators and Transformers Operated as a Unit.—When a generator and a transformer are operated as a unit with no breaker between the generator and the transformer separate relays should be used for protection against generator and transformer faults.

Power Directional Protection.—It is possible that a great amount of damage can be done to steam turbines, due to overheating when driven for an appreciable length of time by an alternator on the system. The heating depends on the amount of steam available for cooling the rotor and blades and in cases where the steam supply is entirely cut off, considerable damage may be done to the turbine before this condition is noticed.

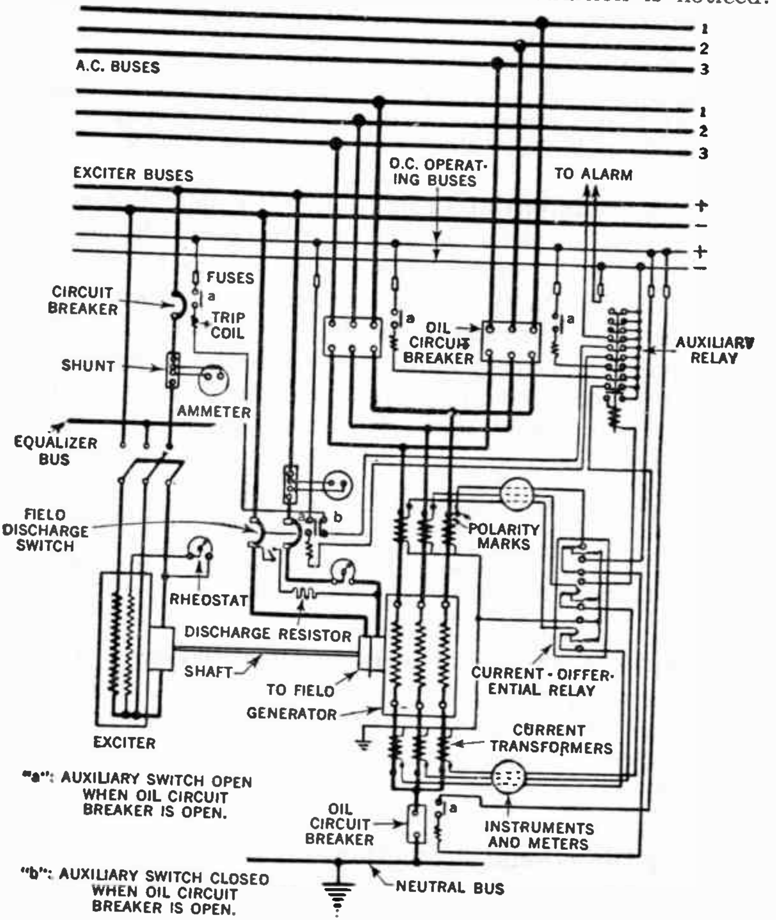


FIG. 6,729.—Wiring diagram showing current differential protection of three-phase Y connected grounded neutral alternating current generator with direct connected exciter. In the diagram, **a** indicates auxiliary switch open when oil circuit breaker is open, **b** auxiliary switch closed when oil circuit breaker is open.

For protection against this or any other condition where it is desirable to prevent the alternator from running light on the system a relay system as shown in fig. 6,731 may be used.

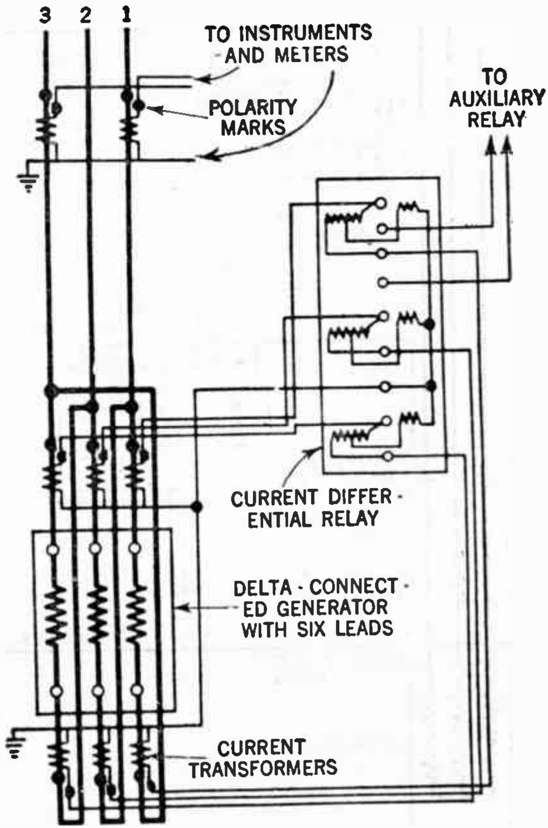


FIG. 6,730.—Illustrating connections for differential protection of three-phase delta connected alternating current generator (Relay connections only illustrated).

As observed from the diagram, the power directional relay is connected directly to control a definite time relay and is not connected through the contacts of overcurrent relay as is the usual case when protecting against line faults. This arrangement permits the power-directional relay to begin

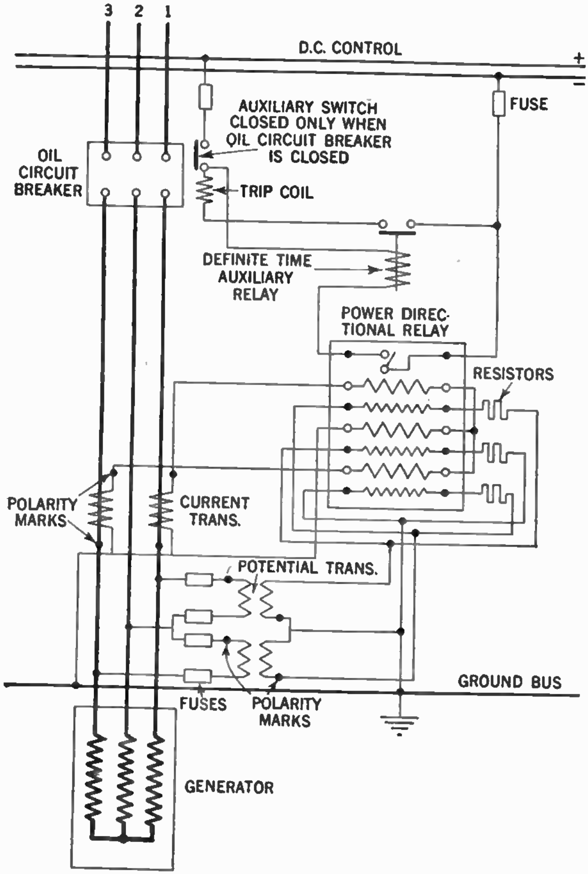


FIG. 6,731.—Wiring diagram showing protection against alternator running light as synchronous motor in case of loss of prime mover power.

to operate the definite time auxiliary relay at very low reversal of power. The use of the definite time relay prevents faulty operation of the equipment occasioned by possible momentary reverse energy surges at synchronizing or temporary phase displacement.

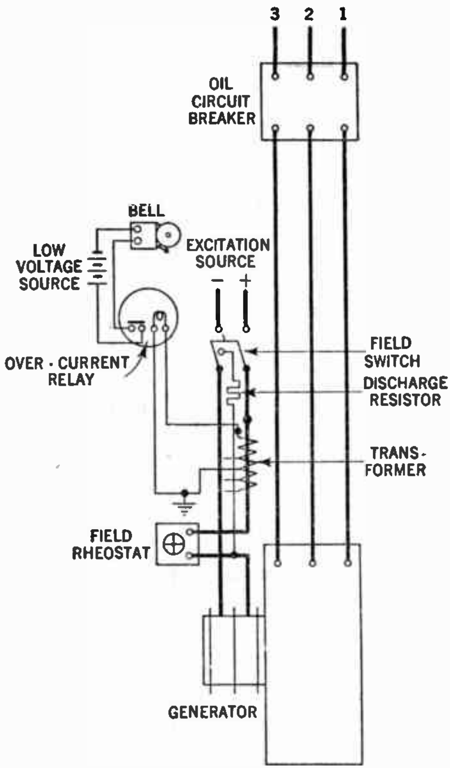


FIG. 6,732.—Protection of alternating current turbo-generator field structure against overheating due to unbalanced or single phase load in armature.

Protection Against Unbalanced Load.—A single phase or unbalanced load on a turbo-alternator induces a double frequency current in the field winding and other parts of the rotor structure.

In case of sufficient unbalance the heat generated by these induced currents added to the heat generated by the field current may be so great as to cause damage. As a protection against this a sensitive overcurrent relay, operating in conjunction with a transformer connected in the field circuit, can be used. See fig. 6,732.

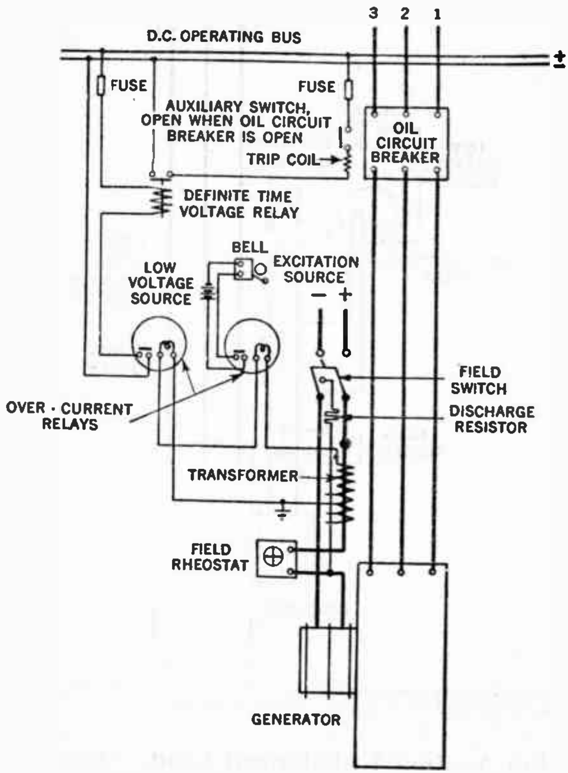


FIG. 6,733.—Protection of alternating current turbo-generator field structure against overheating due to unbalanced or single phase load in armature. The circuit includes two relays, one to sound alarm and the other to trip the oil circuit breaker.

The transformer used for this service has a secondary winding equipped with taps for the relay connections, and it is so designed that the direct current normally flowing will not cause saturation of the core. Only the

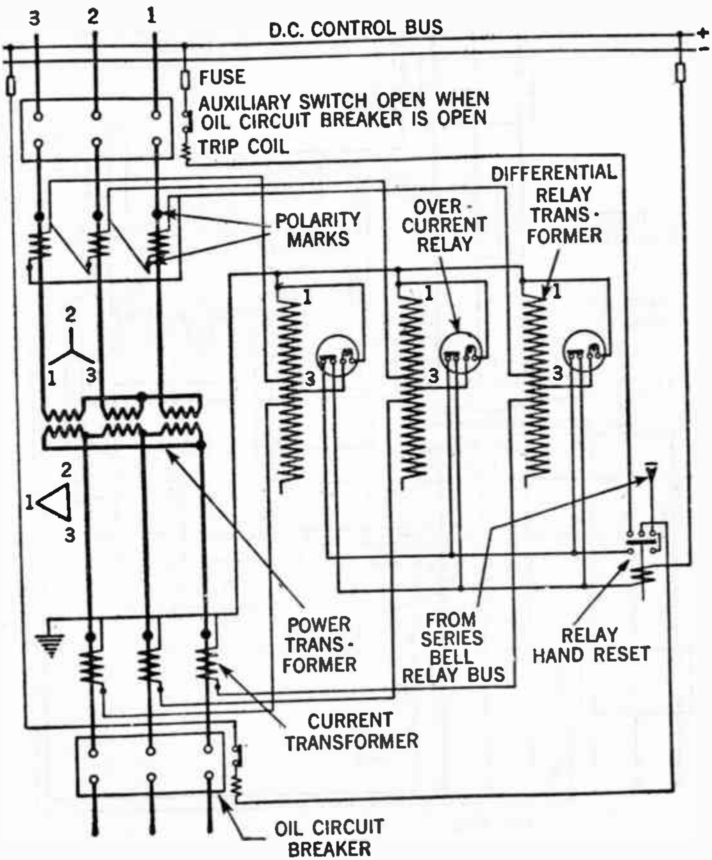


FIG. 6,734.—Illustrating method for differential protection of power transformers. Differential protective equipment is used with power transformers, especially when two or more are operated in parallel, to obtain automatic and simultaneous tripping of the breakers on both the high and low voltage sides of the transformers on internal troubles only, where the breakers are non-automatic or through short circuit or overcurrent.

double frequency current will be transformed and if of sufficient magnitude, will operate the relay. In fig. 6,732 the relay causes a signal bell to ring.

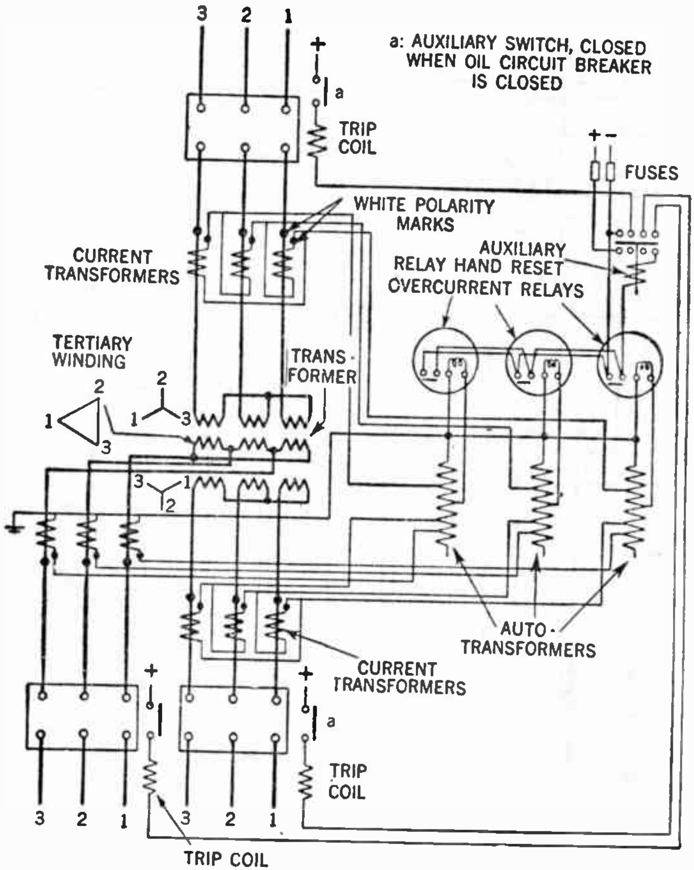


FIG. 6,735.—Differential protection of power transformer bank having a tertiary winding. The hand-reset auxiliary relay has one circuit opening contact and a number of circuit-closing contacts. The operating coil is connected in series with the circuit opening contact to release the holding coil of the overcurrent relays, and the circuit closing contacts trip the breakers. The use of the hand-reset auxiliary relay eliminates the need for additional auxiliary switches on the breakers, as would be required if self-resetting auxiliary relays were used to release the holding coils of the over-current relays.

In fig. 6,733 two relays are shown, one with a lower current coil and the other with a higher; the lower current relay operates a warning signal, while the higher current relay trips the generator circuit breaker, through an auxiliary definite-time relay, if the unbalanced conditions persist long enough to overcome the time features of the relay combination.

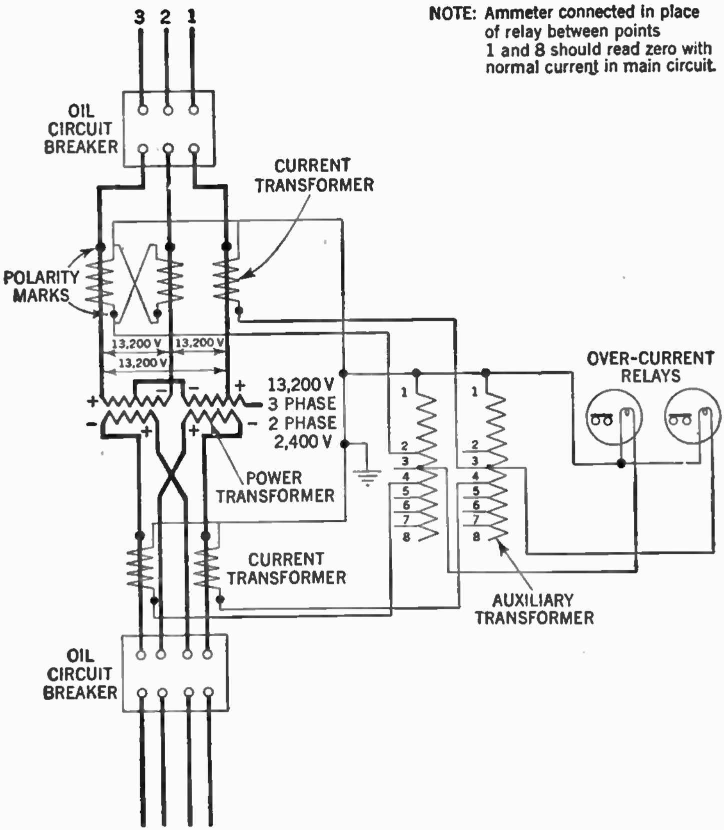


FIG. 6,736.—Method of differential protection of power transformers connected to furnish a quarter phase voltage on the secondary.

Transformer Protection

Transformer protection may vary widely depending upon the size of the unit, how it is connected in the circuit, its importance as a unit part of the system and its voltage rating.

Small distribution transformers are usually protected by fuses, while large units in feeder circuits may be equipped with various types of protective equipment varying from long-time over-current to high-speed differential protection. Figs. 6,734 to 6,736 serves to illustrate typical transformer protective schemes.

Feeder Protection

Protection for outgoing, incoming and tie lines are here grouped together because in a great many respects the problems of protective relay equipments for them are similar. An incoming line is usually at the opposite end of an outgoing line. A tie line is one having a source of power at each end, so that such a line can be considered as a combination outgoing and incoming line at each end.

Outgoing lines may be divided roughly into four classes, as follows:

1. Radial feeders.
2. Parallel lines.
3. Loop feeders.
4. Networks.

Radial Feeders.—Radial feeders are lines which branch out from a single source of supply, either a generating station or a

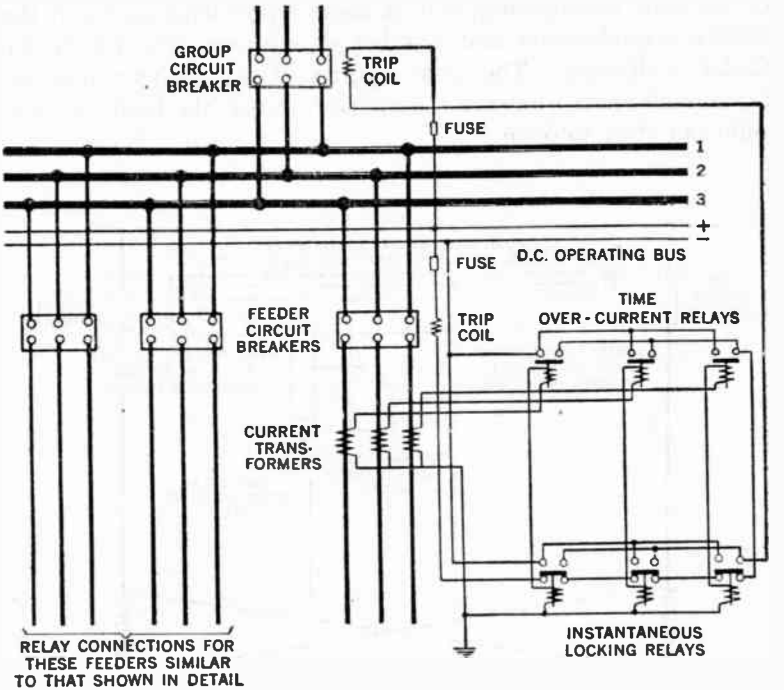


FIG. 6,737.—Wiring diagram showing group breaker connections with locking relays to protect feeder breakers on excessive current (group breaker only tripped). Sometimes economy in oil circuit breakers can be effected by grouping a number of feeders together controlled by one heavy duty breaker, each separate feeder equipped with a light duty breaker. The feeder breaker will have sufficient interrupting capacity satisfactorily to open the circuit upon the occasion of overcurrent but not sufficient interrupting capacity to clear a short circuit or excessive overcurrent. In such cases a locking relay is used to lock the feeder breaker in. Each feeder is equipped with a complement of time overcurrent relays adjusted to function to trip the feeder breaker on simple overcurrent, and a set of instantaneous locking relays with high current coils, adjusted not to function as long as the primary current does not exceed the capacity of the feeder breaker but to function instantaneously in case the current exceeds this value. The functioning of the locking relay opens the tripping circuit of the feeder breaker (thus locking the feeder breaker closed) and closes the tripping circuit of the heavy duty group breaker. It will be noted that all of the circuit opening contacts are in series and the circuit closing in parallel, which condition is necessary for satisfactory operation in case of trouble in any phase.

sub-station. Overcurrent relays are used to protect radial lines and are set with time delay varying from instantaneous up to the maximum allowable at the source of supply. The accuracy of the time settings required of these relays depends upon the service requirements and number of sections into which the feeder is divided. The time settings of the relays should be far enough apart to insure the breaker nearest the faulty section sufficient time to open.

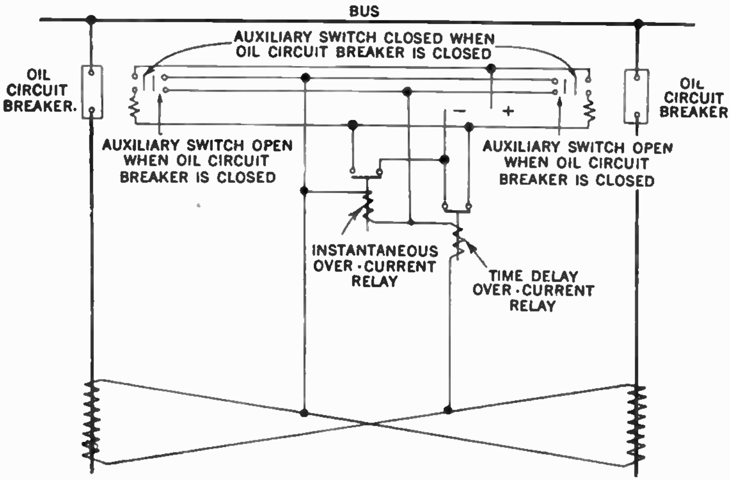


FIG. 6,738.—Balanced protection of two parallel lines with time overcurrent protection for single line operation.

Parallel Lines.—Parallel lines are those in which two or more lines are operated between two stations either or both of which may be generating stations or substations. Balanced protection may be divided into two classes, namely: *Non-discriminating* and *discriminating*. The *non-discriminating* scheme of protection is applicable only where the loss of both lines for a short time is not extremely important since both lines are opened at the same time when a fault occurs.

The bus is not affected by this operation and the only steps necessary to restore service are to determine the good line and to

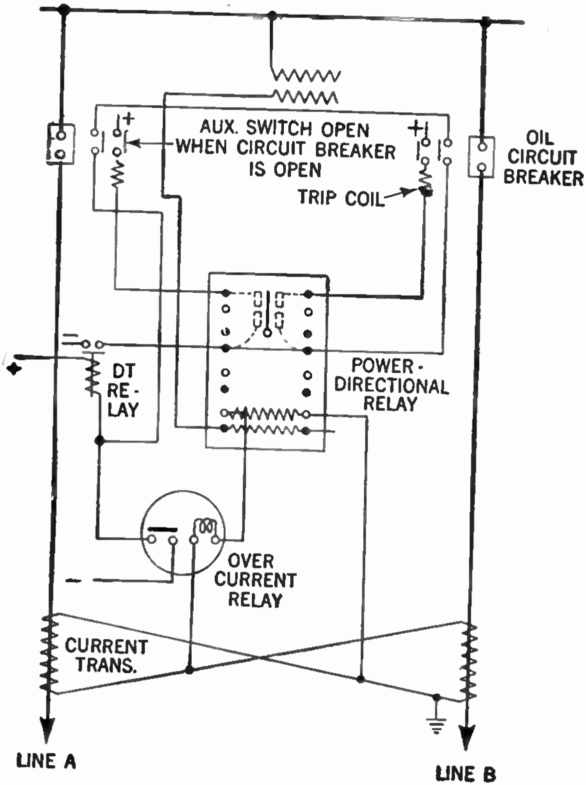


FIG. 6,739.—Balanced power protection for two parallel incoming or outgoing lines, with provision for definite time action with one line of service.

replace it without its mate. The inconvenience is greatly compensated for due to the fact that no potential connections are necessary. This kind of protection will, of course, not be used where continuity of service is imperative. Fig. 6,738 shows a typical method of protection in a non-discriminating system.

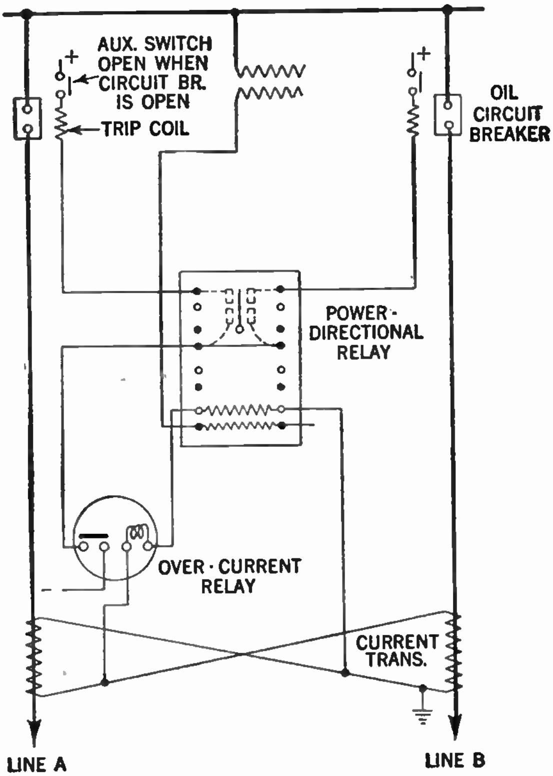


FIG. 6,740.—Balanced power protection for two parallel incoming lines.

Discriminating balanced protection for parallel lines is accomplished in two ways: (1) By means of *power-directional* relays, and (2) by means of *percentage current differential* relays. Figs. 6,739 to 6,741 shows different applications of the power directional relay for different system conditions. Balanced current protection by use of percentage differential relays is shown in fig. 6,742 the relay used may be a plunger or induction type.

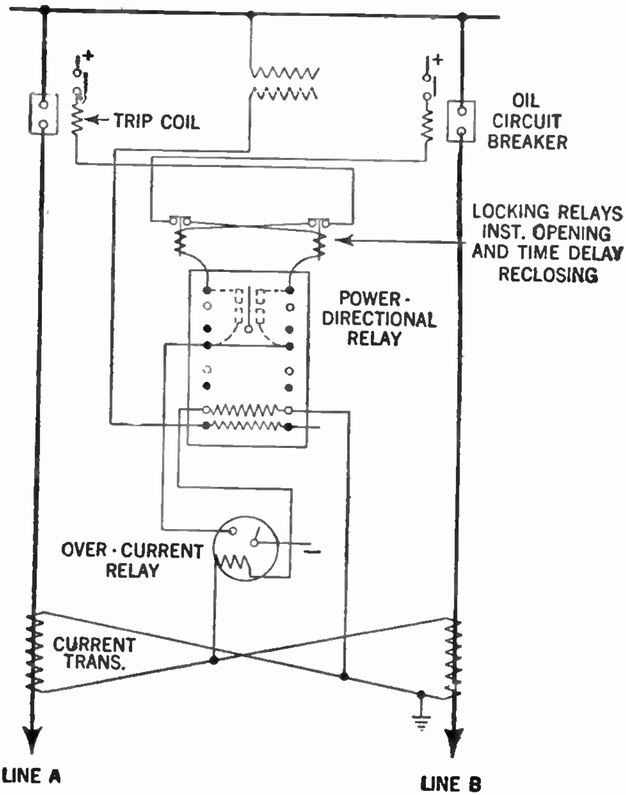


FIG. 6,741.—Time delay balanced power protection for two parallel lines.

With reference to the diagram when the difference between the currents in the two lines becomes sufficiently great to cause the relay to function, the contact mechanism will be operated on the side to trip the breaker carrying the heavier current. So long as a balanced condition exists and

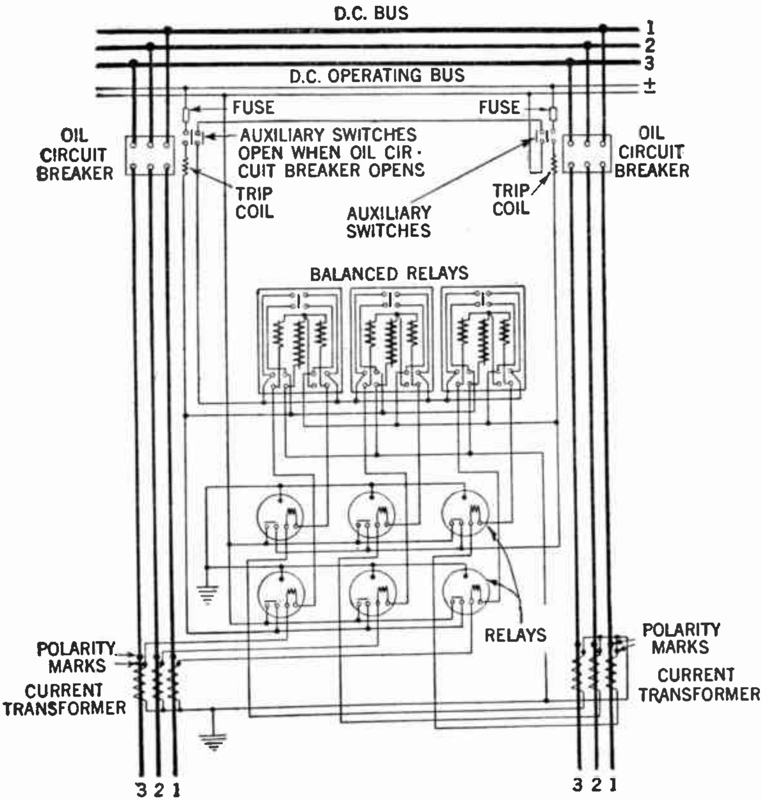


FIG. 6,742.—Showing connections for mechanically balanced current differential relays applied to two-parallel lines. *Operation:* When the difference between the currents in the two lines becomes sufficiently great to cause the relay to function, the contact mechanism will be operated on the side to trip the breaker carrying the heavier current. So long as a balanced condition exist and there is no appreciable difference in the reactance of the two lines, the relay will not trip either breaker if differential current is less than that required to unbalance the relay, no matter how high the current be in the two lines.

there is no appreciable difference in the reactance of the two lines, the relay will not trip either breaker if differential current is less than that required to unbalance the relay, no matter how high the current may be in the two lines.

Loop Feeders.—Loop feeders (or ring feeders as they are sometimes termed) are circuits which consists of one or more lines starting out from a generating station, feeding a number of substations and then returning to the original source or to another tied to it. Protective schemes applicable to feeder of this type are as follows: (1) *Overcurrent time and directional scheme*, and (2) *pilot wire schemes*.

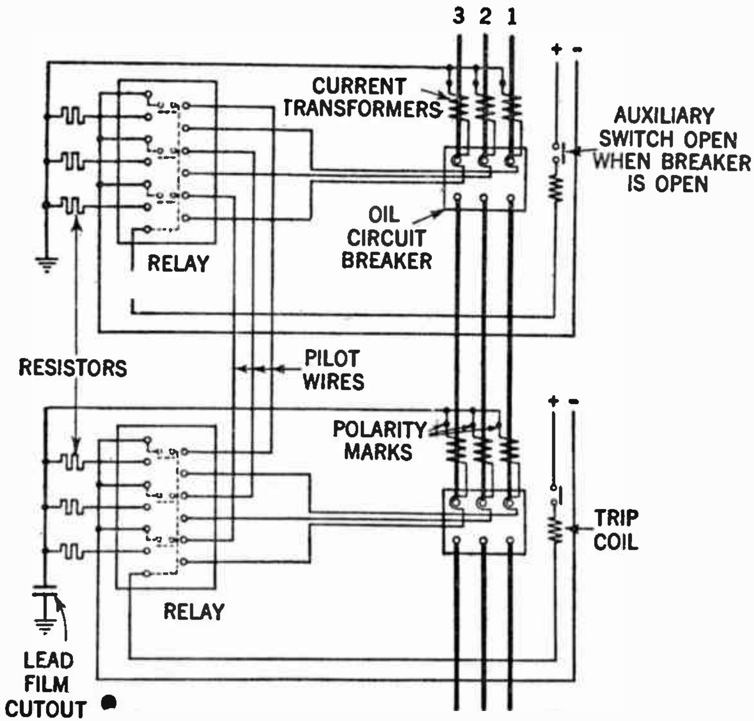


FIG. 6,743.—Connection of pilot-wire protection of line using differential relays.

In the overcurrent time protective system, the overcurrent relays are adjusted for definite time operation and arranged to function progressively. These overcurrent relays will protect against excessive current flow in the normal direction.

Since it is not practical to make more than four or five selective time settings, therefore, when the number of stations on a line is too great to permit sufficient spacing between the time settings of the overcurrent relays for selective operation, pilot-wire protection between two or more stations may be used.

The basis of pilot-wire protection is that equal currents will flow at both ends of a line if no fault exists in that line, while unequal currents will flow if any kind of fault is present. The requirements of a pilot-wire scheme are that it shall function to trip the breakers at both ends of the protected line in the event of a fault in that line, and that it shall not trip the breaker at either end for faults in other parts of the system, even though the fault current should pass through the pilot wire protected section.

This is accomplished by balancing the currents at both ends of the line so that only the fault current controls the functioning of the relay contacts. The connections of two stations by pilot wires has the effect of making these two stations a unit in the loop, thereby reducing the number of time spacings by one. Practically instantaneous protection is provided against faults in the line between the two stations so connected, but for faults in other parts of the loop the pilot wire relays are non-operative.

Any number of lines in the loop may be protected by this system, each one adding a station to the loop without any change in the number of time settings required for those lines protected by time overcurrent or power-directional protection. When only one or two lines in a loop are to be provided with pilot-wire protection and the remainder with time protection, it is better to place the pilot-wire sections near the center of the loop. Fig. 6,743 illustrates the application of pilot-wire protection.

Motor Protection

Induction Motors.—Overcurrent or overload protection with circuit-opening time relays are commonly employed for all types of induction motors except when the motor is part of a motor-generator set and drives a generator of more than 300 volts, in which case instantaneous relays are commonly used.

When squirrel cage induction motors are started by means of autotransformers with starting and running oil circuit breakers, the overcurrent protection is applied only to the running breaker and no protection is provided during the starting period. Small motors are usually protected against overheating by overload type fuses or thermal elements in contactors.

Undervoltage protection is employed in some locations particularly where across the line starting is not permissible and where unexpected starts would be hazardous. Time-delay fixtures are desirable if undervoltage trips are used.

Synchronous Motors.—As far as overcurrent and overload protection is concerned the protection of synchronous motors is the same as that for induction motors. In the case of synchronous motors, however, steps are often taken to provide some protection against leaving the field circuit closed after a motor has been shut down and to protect the motor against failure of excitation.

In the first case the field may be overheated and damaged due to lack of ventilation by windage. In the second case the amortisseur winding provided for starting may become overheated or even burned out due to the motors attempt to carry load as an induction motor. Synchronous motors having a direct current generator on the same shaft of a generator set are automatically relieved of excitation when the motors are shut down, and on the other hand will have a comparatively certain source of excitation until shut down.

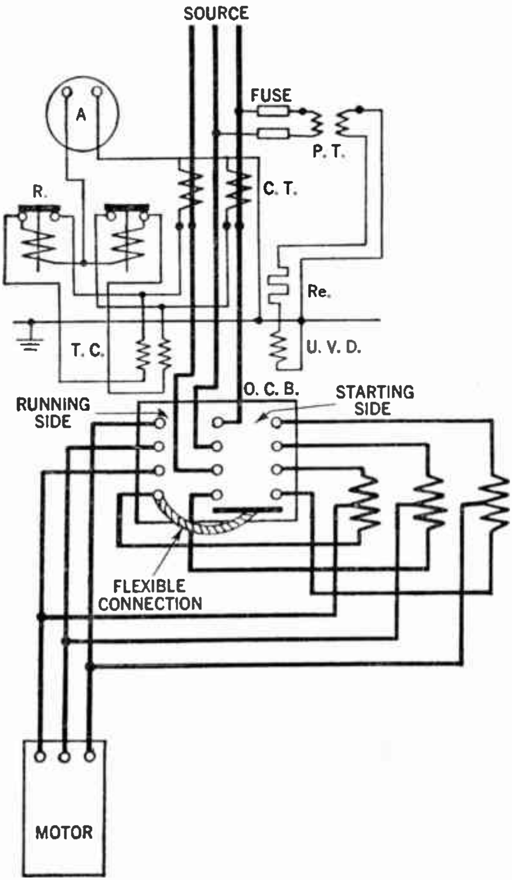


FIG. 6,744.—Wiring diagram showing overcurrent protection of squirrel cage induction motors, using double-throw starting oil circuit breaker. In the diagram **A**, indicates ammeter; **C.T.** current transformers; **O.C.B.** oil circuit breaker; **P.T.** potential transformer; **R**, inverse time overcurrent relay; **Re** resistor; **TC**, overcurrent trip coil; **U.V.D.** under-voltage device.

To give similar protection to a synchronous motor having an independent source of excitation protective field equipment as indicated in fig. 6,745 is commonly used. This is suitable for synchronous motors started with their field closed through the discharge resistor.

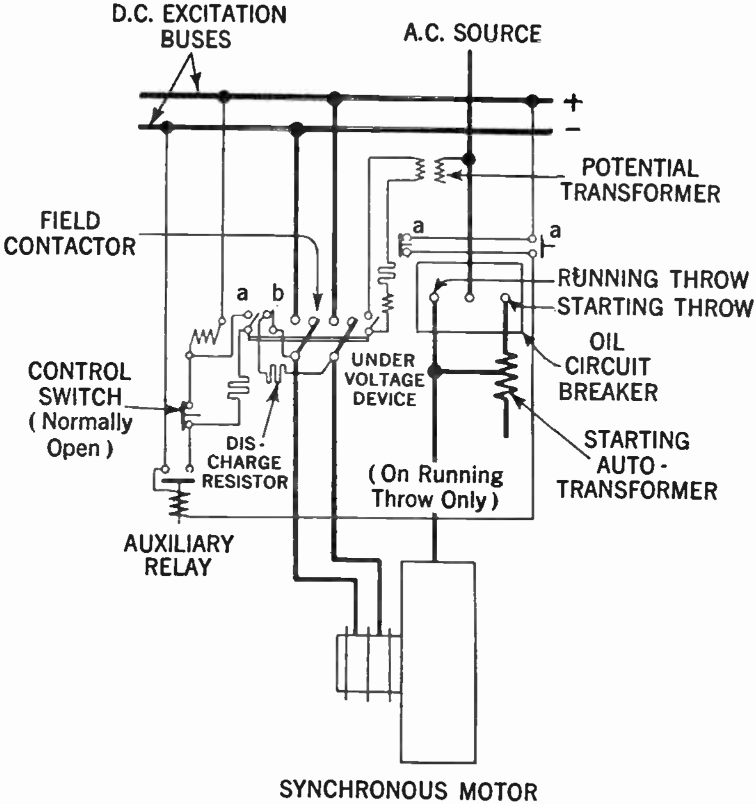


FIG. 6,745.—Protective field control for synchronous motor with excitation from independent source. Motor started with field circuit closed through discharge resistor. In the diagram **a**, indicates auxiliary switch open when oil circuit breaker is open; **b**, indicates auxiliary switch closed when oil circuit breaker is open.

Motors which require open field starting will in most cases be taken care of by adding an auxiliary switch of sufficient insulation and contact opening to withstand the high voltage induced in the field during starting, to the starting throw of the oil circuit breaker. This is illustrated in fig. 6,746. The auxiliary switch should be so adjusted as to open before the breaker closes, thus avoiding the interrupting of any current.

The wiring scheme shown in figs. 6,745 and 6,746 make use of a magnetic contactor for the field discharge switch. The coil of the contactor is operated from the excitation source. The contactor is closed by a push button switch and is sealed through a resistor and the contacts of a plunger type instantaneous closing and time opening relay.

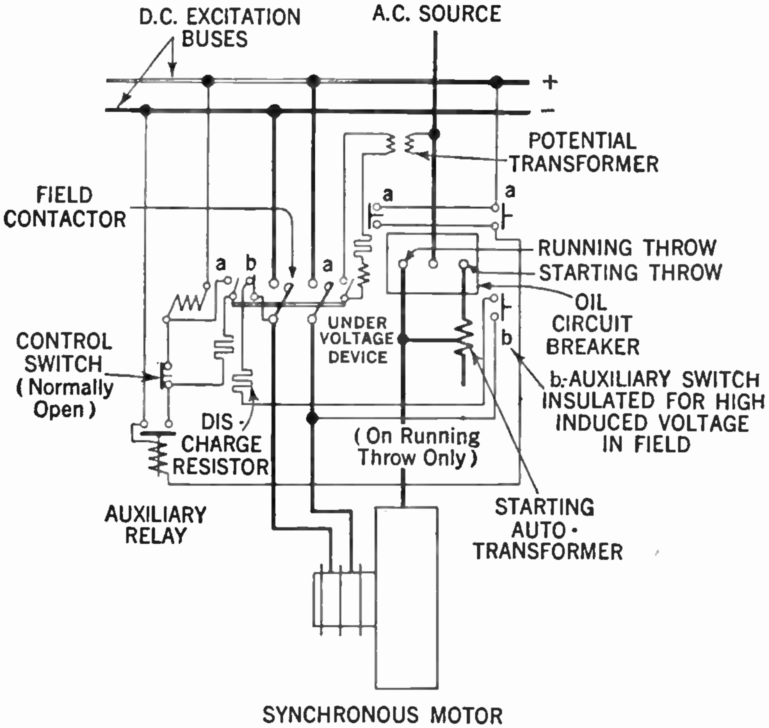


FIG. 6,746.—Protective field control for synchronous motor with excitation from independent source. Motor started with field open-circuited. In the diagram a, indicates auxiliary switch open when oil circuit breaker is open; b, indicates auxiliary switch closed when oil circuit breaker is open.

Lightning Protective Devices

These are ordinarily called lightning arresters. Although lightning arresters may differ in construction, their primary purpose is to provide a path to ground to discharge electric surges resulting from lightning strokes, or other disturbances which would otherwise result in transmission interruption or damage to lines and equipment.

*By definition a lightning arrester is a device which has the property of reducing the voltage of a surge applied to its terminals, is capable of interrupting follow * current if present, and restores itself to its original operating conditions.*

Principal Types.—Depending upon their construction and employment, lightning arresters are generally classified as: (1) Thyrite. (2) Oxide film. (3) Pellet. (4) Expulsion protector. (5) Gap.

Thyrite Lightning Arrester.—This type of lightning arrester fig. 6,760, is manufactured by the General Electric Co. and employs discs of a homogenous, nonporous, inorganic, ceramic compound which changes from an insulator to an excellent conductor when the voltage increases above a certain predetermined value. In series with the Thyrite discs is a gap unit consisting of several gaps in series, each shunted and shielded by Thyrite resistors producing a controlled and uniform distribution.

The discs and gaps are sealed in a porcelain container with metallic top and bottom. The units are assembled one or more in a stack to obtain proper voltage rating. This arrester is used on voltages up to 242 *kv.*

* NOTE.—The follow current is generated current which flows through the arrester following the passage of the surge current.

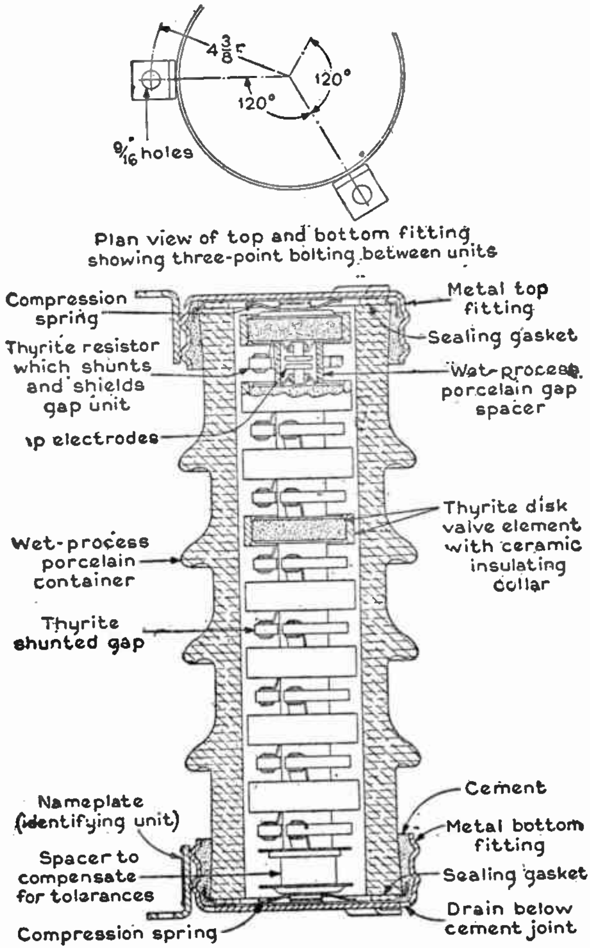


Fig. 6,760.—Cross-sectional view of a Thyrite high-voltage distribution arrester showing assembly details.

Oxide Film Lightning Arrester.—The oxide film lightning arrester, fig. 6,761, consists of a number of cells with a gap in series between the line and ground. The cells are held together under slight pressure and are arranged in sections or stacks according to voltage and kind of circuit.

The cells are disc shaped about 8 inches in diameter and ½ inch thick. Each cell is made of two circular brass plates fitted firmly to an annular piece of porcelain. Lead peroxide which

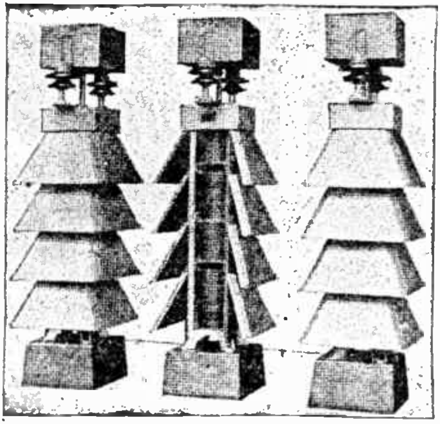


FIG. 6,761.—Illustrating a three phase, oxide film lightning arrester for outdoor service. Shields of middle leg removed for inspection. This construction is typical of outdoor three phase oxide film lightning arresters.

has a very low resistance completely fills the space between the metal plates. The inside of the metal plates is covered with a varnish film which is an insulator.

When excessive voltage spark over the gap, it is impressed on the cells and breaks down the insulating coating of the metal plates. The break down occurs as a form of a small puncture on the film coating. As. soon as the films give away, a discharge current flows through the cells to ground, thus relieving the lightning pressure.

The oxide film lightning arrester is manufactured for outdoor and indoor service and is also used in large transmission systems up to 220 *kv.* The pellet type is designed for outdoor service, for potential up to 73 *kv.*

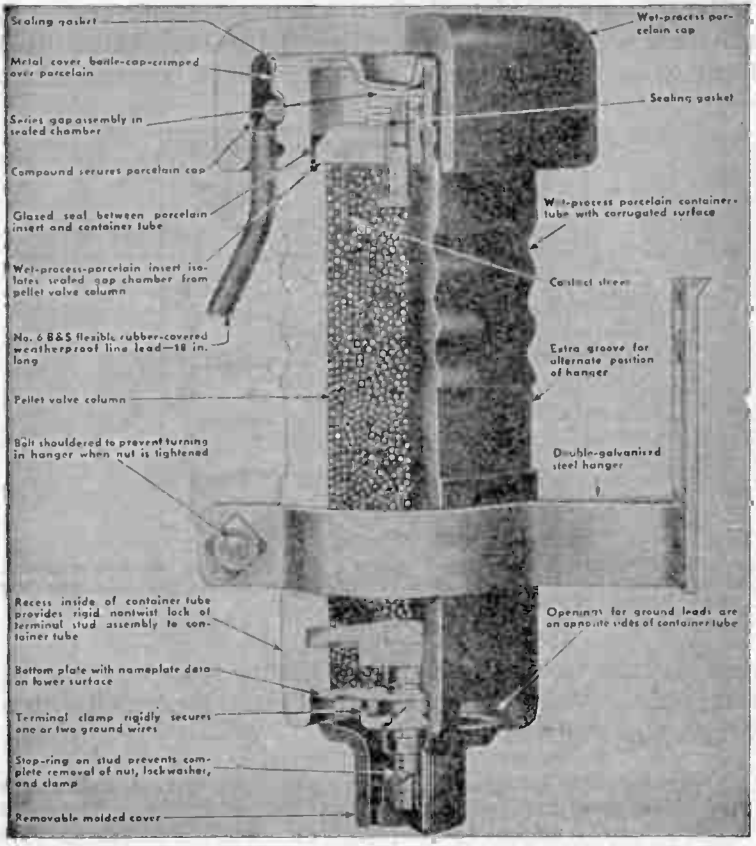


FIG. 6,762.—Typical 3 Kv. pellet lightning arrester showing construction details.

Pellet Type Lightning Arrester.—The pellet type is a modication of the oxide film lightning arrester. The lead peroxide is here formed into small pellets which are coated with litharge powder, which forms the film similar to the varnish film on the cell type of arrester.

The litharge coated pellets are placed in good contact with the conductors, fig. 6,762. This arrester is used on voltages between 300–73,000 volts.

The principles of operation of the pellet type is very similar to the oxide film arrester. When excessive voltage occurs, the contact surface of the pellets is punctured by the discharge, but the sealing action instantly reforms the film and the contact surface of the pellets in the path of the discharge and the arrester is ready for subsequent service.

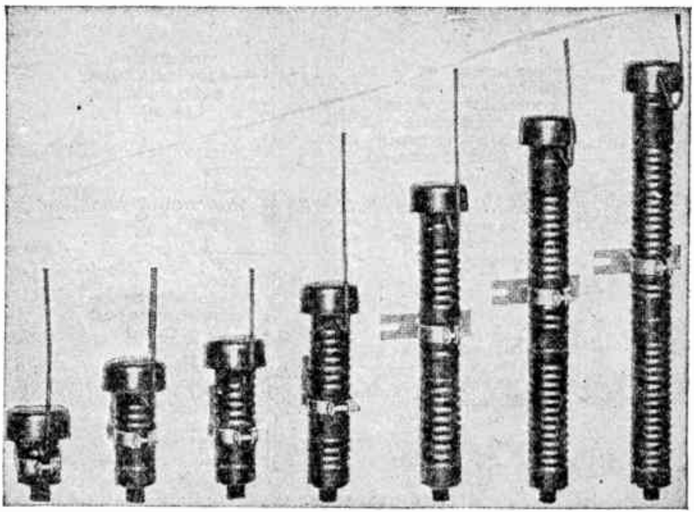


Fig. 6,763.—Showing a complete line of pellet type lightning arresters ranging from 1,000 to 15,000 volt rating.

Expulsion Type Arresters.—The expulsion type of lightning arrester, fig. 6,764 consists principally of a gap in a tube, which on breakdown generates a gas within the tube and extinguishes the arc. As there is an upper and a lower limit of current which such a gap can interrupt, the gap rating must be selected with due regard to the maximum and minimum short circuit currents possible on the line. The tube is connected in series with an external gap. They find their use for line protection, and for station protection where a better form of protection cannot be justified.

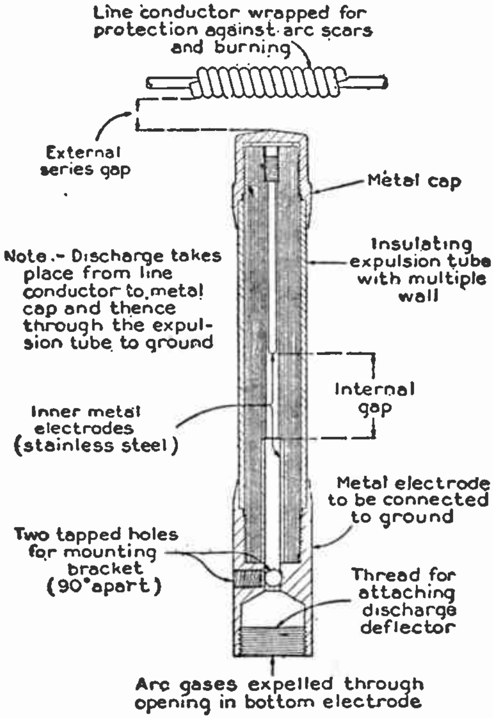


FIG. 6,764.—Showing construction principles of an expulsion protector tube lightning arrester.

Gap Arresters.—Although sometimes used, this form of arrester is now largely replaced by previously mentioned types. The multi-gap arrester consists essentially of a number of cylinders spaced with a small air gap between them and placed between the line to be protected, and the ground.

In *operation*, the multi-gap arrester discharges at a much lower voltage than would a single gap having a length equal to the sum of the small gaps.

The horn gap arrester consists essentially of two horn shaped terminals forming an air gap of variable length, one horn being connected to the line to be protected and the other to the ground usually through a series resistance.

In *operation*, the arc, due to the line current which follows a discharge, rises between the diverging horns and becoming more and more attenuated is finally extinguished.

It is used as an emergency arrester on some overhead lines, to operate only when a shut down is unavoidable.

Lightning Arrester Maintenance.—To obtain the most effective protection, the following maintenance pointers should be observed:

(a) Obtain a reliable low-resistance arrester ground. Inter-connect all apparatus grounds, arrester grounds, overhead ground wires, cable sheaths, machine frames, etc., using short direct ground connections.

(b) When the arrester is installed, make sure that it will not be subjected to power voltages higher than its designated maximum voltage rating. The application of higher power voltages than recommended may result in destruction of the arrester or thermal damage which may subsequently prevent proper valve resealing after discharge.

(c) Do not use arrester above its designated altitude limit as this has effect similar to excess power voltage. Use special arrester, or if arresters have external series gap, use special external gap setting. Use special clearances at higher than designated altitude.

(d) To prevent external flashover, maintain required clearances to grounded hardware, line conductors, vegetation, etc. Also, in contaminated atmospheres, clean exposed insulation surfaces periodically the same as other station or line insulation.

(e) Check concrete or other foundation for base-mounted arresters to assure that undue settling has not occurred which would place mechanical strain on arrester.

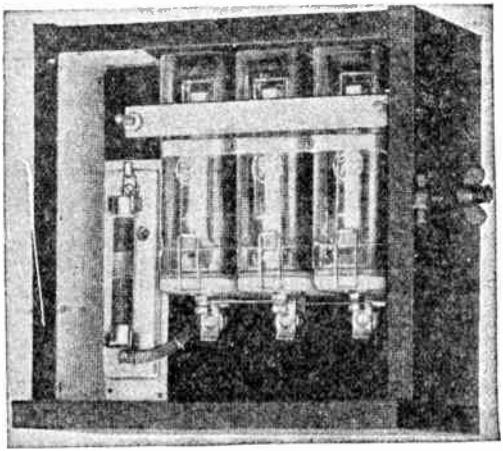
(f) Be sure all electrical connections are clean and tight, and make good electrical contact. Check for damaged porcelain and for loose bolts on assembly or mounting hardware. In general, inspection should be made annually or more frequently, depending upon local conditions.

(g) Do not use wrenches which enable excess leverage on bolts and nuts.

(h) Where external series air gaps are used, maintain gap setting to recommended value.

(i) Any electrical test may cause unnecessary damage as well as needless waste of time and money. Before making any test, obtain manufacturer's recommendations.

(j) Before handling an arrester, always disconnect it from the power line.



FIGS. 6,765 to 6,767.—Showing a direct current aluminum cell lightning arrester, with a maximum rated voltage of 750 volts. The aluminum-cell type arrester is manufactured for *d.c.* voltages of from 0 to 3,900 volts.

Regulating Devices

Regulation of Alternators.—Practically all the methods employed for regulating the voltage of dynamos and *d.c.* circuits, are applicable to alternators and *a.c.* circuits.

For example, in order that they shall automatically maintain a constant or rising voltage with increase of load, alternators are provided with composite winding similar to the compound winding of dynamos, but since the *a.c.* cannot be used directly for exciting the field magnets, an accessory apparatus is required to rectify it or change it into *d.c.* before it is used for that purpose.

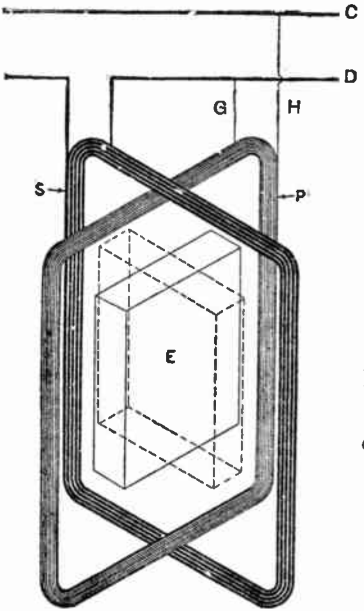


FIG. 6,768.—Diagram *illustrating the principle of induction voltage regulators. The primary coil* P, *consisting of many turns of fine wire*, is connected across the main conductors C and D, coming from the alternator. *The secondary coil* S, *consisting of a few turns of heavy wire*, is connected in series with the conductor D. The laminated iron core E, mounted within the coils, is capable of being turned into the position shown by the dotted lines. When the core is in plane of P, the magnetic lines of force produced in it by the primary coil, induces a pressure in the secondary coil which aids the voltage; when turned to the position indicated by the dotted lines, the direction of the magnetic lines of force are reversed with respect to the secondary coil and an opposing pressure will be produced therein. Thus, by turning the core, the pressure difference between the line wires G and H, can be varied so as to be higher or lower than that of the main conductors C and D. Regulators operating on this principle may be used for *theatre dimmers*, as controllers for series lighting, and also to adjust the voltage or the branches of unbalanced three wire single phase and polyphase systems.

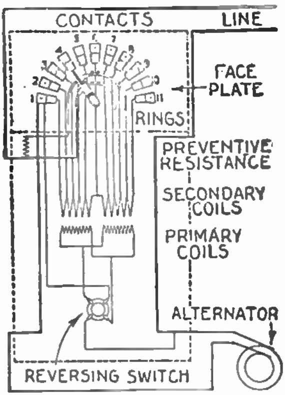
It is a fact, however, that composite wound alternators do not regulate properly for inductive as well as non-inductive loads.

In order to overcome this defect compensated field alternators have been designed which automatically adjust the voltage for all variations of load and lag.

A. C. Feeder Regulation.—With slight modification, the various methods of feeder regulation employed with *d.c.*, may be applied to *a.c.* distribution circuits.

For instance, if a non-inductive resistance be introduced in any electric circuit, the consequent drop in voltage will be equal to the current multiplied by the resistance. Therefore, feeder regulation by means of rheostats is practically the same in the case of *a.c.* as in that of *d.c.* In the case of the former, however, the effect of self-induction may also be utilized to produce a drop in voltage. In practice, this is accomplished by the use of self-induction coils which are commonly known as reactance coils.

Application of Induction Type Regulators.—In supplying lighting systems, where the load and consequently the pressure drop in the line increases or decreases, *it becomes necessary to raise or lower the voltage of an a.c., in order to regulate the voltage delivered at the distant ends of the system.*



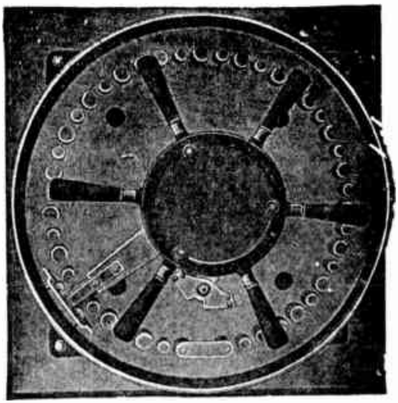


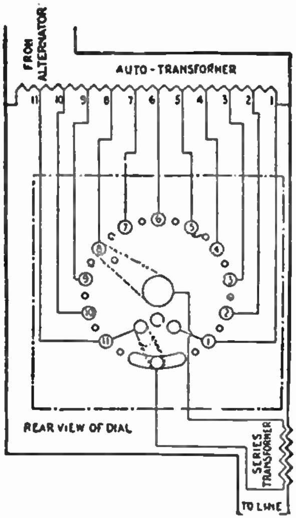
Fig. 6,769.—Diagram showing connections of Stillwell regulator.

Fig. 6,770.—Dial of Westinghouse dial type variable ratio voltage regulator.

This is usually accomplished by means of *a.c. regulators or induction regulators*. A devise of this kind is essentially a transformer, the primary of which is excited by being connected directly across the circuit, while the secondary is in series with the circuit as shown in fig. 6,768. By this method the circuit receives the voltage generated in the secondary.

There are two kinds of pressure regulator: **1**, induction regulator, and **2**, variable ratio transformer.

Induction Voltage Regulator.—It consists of a *primary*



winding or exciting coil, and a secondary winding which carries the entire load current.

The primary is wound for the full transmission voltage, and is connected across the line, while the secondary is connected in series with the line.

In operation, when the primary coil is turned to various positions, the magnetic flux sent through the secondary coil varies in value, thereby causing corresponding variation in the secondary voltage, the character of which depends upon the value and direction of the flux.

Induction regulators are operated by hand or automatically by means of a small motor controlled by voltage regulating relays. Two relays are used because a primary relay of sufficient accuracy could not be made powerful enough to carry the relatively large current required for operating the motor.

FIG. 6,771.—Diagram of connections for Westinghouse ***11 point dial, series transformer and auto-transformer.*** The auto-transformer has a number of taps connected across the line, the series transformer is placed in series with one side of the line, and connected to a dial, as shown.

Variable Ratio Transformer Voltage Regulators.—The principle of operation of this class of regulator is virtually the same as that of the induction type regulator; that is, both consist of regulating transformers, but *in* ***the variable ratio method*** *the primary or series coil is divided into a number of sections which may be successively cut in or out of the circuit to be regulated*, instead of varying the flux through the entire coil, as in the induction type.

There are two mechanical forms of variable ratio regulator: 1, drum type, and 2. dial type.

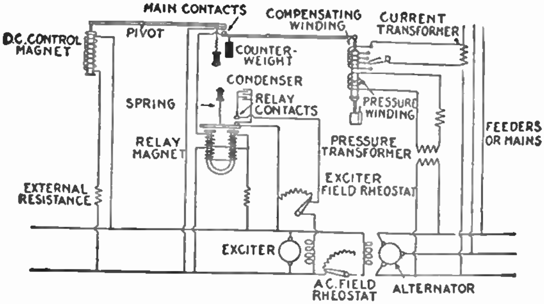
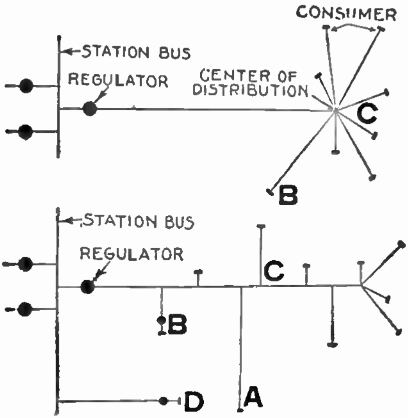
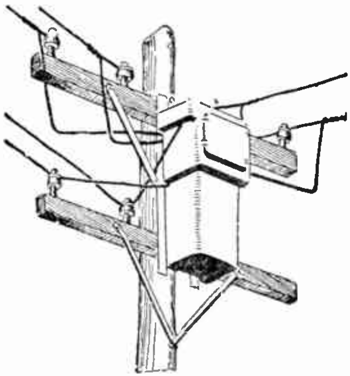


Fig. 6,772.—Diagram of General Electric automatic voltage regulator connections with alternator and exciter.





Figs. 6,773 and 6,774.—Systems of distribution illustrating use of ***small feeder*** or ***pole type voltage regulators.*** The drop is generally negligible except on long lines as, consumer B, fig. 6,773. In order to obtain perfect regulation at B, it would be necessary to install a separate regulator in that line, this regulator to be installed either at the center C, or preferably at B. In a great many cases the power distribution is not as ideal as indicated in fig 6,773, but rather as shown in fig. 6,774, that is, the consumers are connected all along the feeder. In this case there is no definite center of distribution, and the automatic regulator installed in the station can be adjusted to give only approximately constant voltage at an imaginary center of distribution C; that is, the voltage cannot be held constant at any definite point during changes of load distribution. The majority of the consumers may, however, obtain sufficiently good voltage, while a few may have reason for criticism. To overcome this difficulty it is necessary either to increase the copper in the feeder or else to install small automatic regulators.

Fig. 6,775.—General Electric pole type regulator in service as installed on top of pole.

Small Feeder Voltage Regulators.—In some generating stations the voltage is maintained constant at the bus bars and the line drop compensated by automatically operated regulators connected in the main feeders.

It is possible in this way to obtain constant voltage at all loads at the various distribution centers; that is, at those points on the feeders where the lines of the majority of consumers are connected as shown in fig. 6,774.

It is evident, however, that, while the voltage at the center of distribution can be maintained constant, no account can be taken ot the drop in the lines between this center and the consumers. This drop is, however, generally negligible.

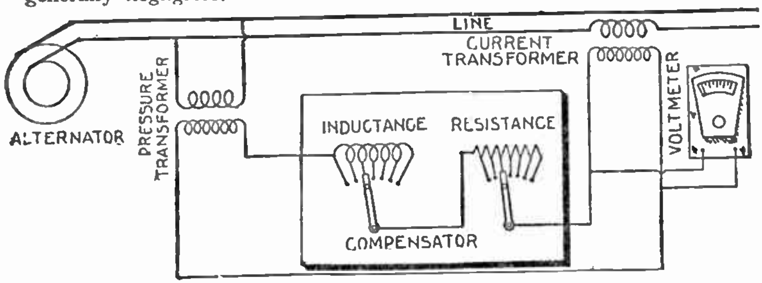


FIG. 6,775.—Diagram showing ***essential parts and connections for a line drop compensator.*** *The compensator corrects the voltmeter indication at the supply end of a feeder for the ohmic and inductive drop in pressure between that point and the point of consumption*, so that the reading of the station voltmeter corresponds with the actual voltage at the point of consumption, independent of the power factor and current. ***It is especially useful*** for adjusting pressure regulators.

Automatic Voltage Regulators for Alternators.—The accurate regulation of voltage on any *a.c.* system is of importance. The desired voltage may be maintained constant at the alternator terminals by rapidly opening and closing a shunt circuit across the exciter field rheostat.

Line Drop Compensators.—In order that the actual voltage at a distant point on a distribution system may be read at the station *some provision must be made to* **compensate** *for the line drop*, that is, for the difference in voltage between the alternator and the center of distribution.

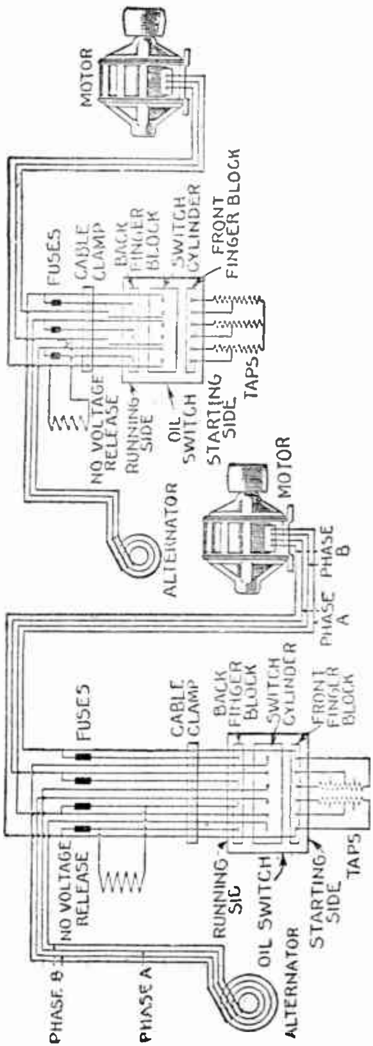


FIG. 6,776.—Diagram of connections of General Electric two phase starting compensator with no voltage release and fuses.

FIG. 6,777.—Diagram of connections of General Electric three phase starting compensator with low voltage release and fuses.

In order to do this a device known as a "line drop compensator" is placed in the volt meter circuit as shown in fig. 6,775.

The elements of the compensator are a variable resistance and a variable inductance. In manipulation, if the amount of inductance and resistance be properly adjusted, there will be produced a local circuit corresponding exactly in all its characteristics to the main circuit. Hence, any change in the main circuit produces a corresponding change in the local circuit, and causes the volt meter to always indicate the pressure at the end of the line or center of distribution or at any point for which the adjustment is made.

Starting Compensators.—These are used for starting induction motors and consist of *inductive windings (one for each phase) with a number of taps connecting with switch contacts* as shown in figs. 6,776 and 6,777.

A starting compensator is similar to a rheostat except that inductive windings are used in place of the resistance grids. Starting compensators are not necessary for small motors up to, say, 7 horse power.

Star Delta Switches.—These are starting switches, designed for use *with small three phase squirrel cage motors having their windings so arranged that they may be connected in star for starting and in delta for running.*

In starting the motor, the drum lever is thrown in the starting direction which connects the field windings of the motor **in star.** When the motor has accelerated and has come partially up to speed, the starting lever is quickly thrown to the running position in which position the field windings are connected **in delta.** The effect of connecting the field winding in star at starting is to reduce the voltage applied to each phase winding, while in the running position each phase of the field winding has full line voltage impressed upon it.

Synchronous Condensers.—A synchronous motor when sufficiently excited will produce a leading current, that is, when over excited it acts like a great condenser, and *when thus operated on circuits containing induction motors and similar apparatus for the purpose of improving the power factor it is called a synchronous condenser.*

The relation of power factor to the size and efficiency of prime movers, generators, conductors, etc., and the value of synchronous condensers for improving the power factor is generally recognized.

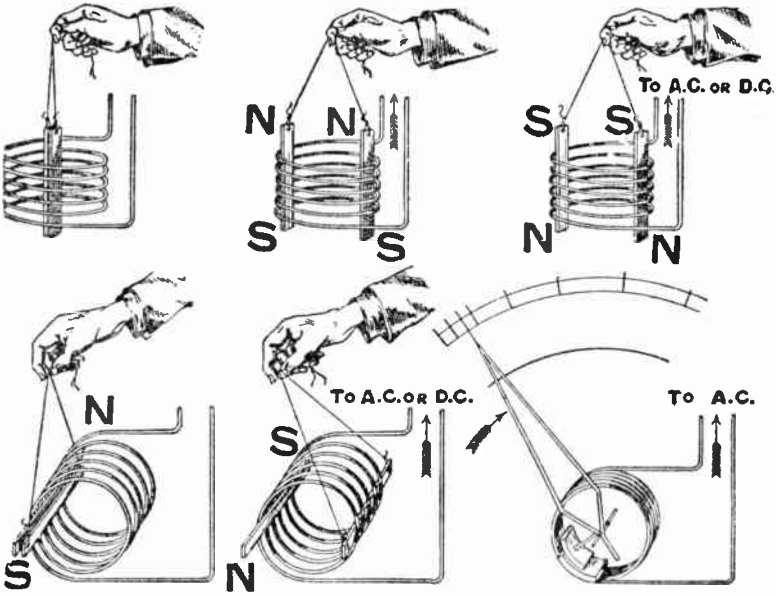
Indicating Devices

In the measurement of *a.c.*, it is not the average, or maximum value of the current wave that defines the current commercially, but the *square root of the mean square value*, because this gives the equivalent heating effect referred to direct current and it is the value that *a.c.* ammeters and voltmeters indicate.

There are several types of instrument for measuring *a.c.*, and they may be classified as

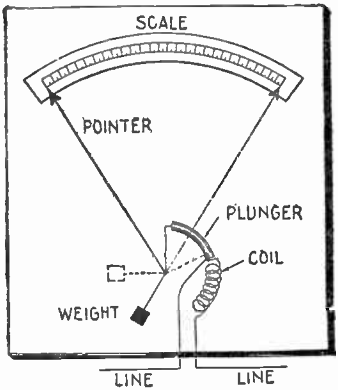
1. Electromagnetic (moving iron)
   - *a.* Plunger;
   - *b.* Inclined coil;
   - *c.* Magnetic vane.
2. Moving coil
3. Hot wire
   - *a.* Shielded pole;
   - *b.* Rotary field.
4. Induction

Electromagnetic or Moving Iron Instruments.—This



FIGS. 6,778 to 6,783.—Principle of moving iron repulsion instruments. If direct current be sent through the two small pieces of iron suspended vertically within a solenoid by thread as in fig. 6,778, they will become magnetized and since they are in the same magnetic field both will be affected the same, and will repel each other as in fig. 6,779. If the current be sent through the solenoid in the opposite direction the result will be the same. Next if the coil be laid on its side and the two pieces of iron be placed within it horizontally as in fig. 6,781, one fixed and the other free to move and a current be passed through the solenoids the two pieces of iron will repel each other. If an *a. c.* be used instead of *d. c.* and it reverses with sufficient frequency, the polarity of the two pieces of iron will reverse in step with the current and they will repel each other as before. Hence on employing this principle in instrument construction two curved pieces of iron are used, one fixed and the other pivoted so that it will rotate when electrically repelled from the fixed iron as in fig. 6,783. A pointer attached to the movable iron moves over a graduated scale.

type of instrument depends for its action upon *the pull of flux in endeavoring to reduce the reluctance of its path.*



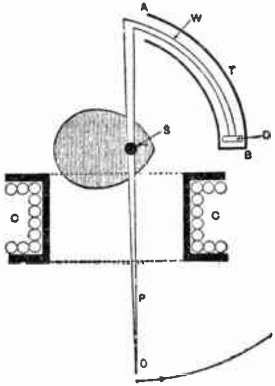
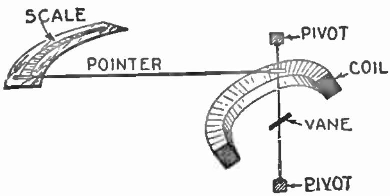


FIG. 6,784.—Plunger form of electromagnetic or moving iron type of ammeter. The plunger is so suspended that the magnetic pull due to the current flowing through the coil is balanced by gravity. For *a.c.* the plunger is laminated.

FIG. 6,785.—One form of ***plunger instrument*** as made by Siemens. *It has gravity control, is dead beat, and is shielded from external magnetic influence.* ***The moving system consists of*** a thin soft iron pear shaped plate pivoted on a horizontal spindle S, running in jewelled centers. To this spindle S, is also attached a light pointer P, and a light wire W, bent as shown, and carrying a light piston D, which works in a curved air tube T. This tube T, is closed at the end B, but is fully open at the other end A, and constitutes the air damping device for making the instrument dead beat.



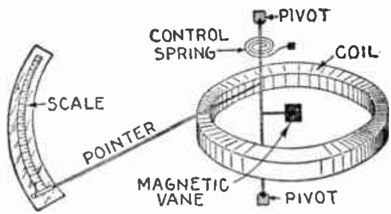
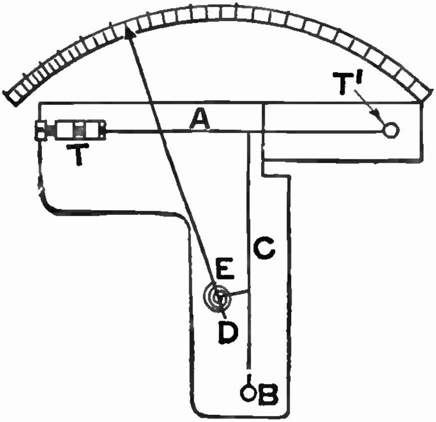


FIG. 6,786.—Inclined coil form of electromagnetic or moving iron instrument. ***In operation,*** when a current is passed through the coil, the iron tends to take up a position with its longest sides parallel to the lines of force, which results in the shaft being rotated and the pointer moved on the dial, the amount of movement depending upon the strength of the current in the coil.

FIG. 6,787.—Magnetic vane form of electromagnetic or moving iron instrument. ***In principle, a piece of soft iron placed in a magnetic field and free to move, will move into such position as to conduct the maximum number of lines of force.*** ***In operation,*** the vane will move against the restraining force of a spring so that the distance between it and the inner edge of the coil will be as small as possible.

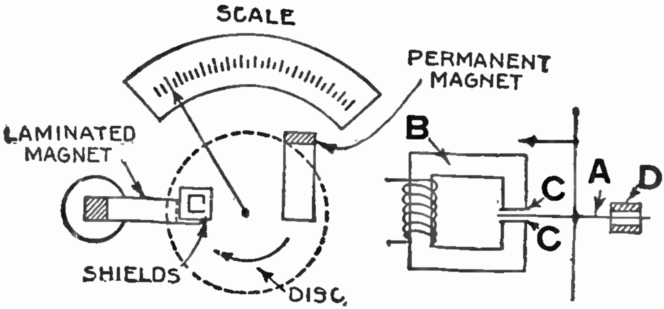
This pull is proportional to the product of the flux and the current, and so long as no part of the magnetic circuit becomes saturated, the flux is proportional to the current, hence the pull is proportional to the square of the current to be measured.



Hot Wire Instruments.—In principle, these depend for their operation on *the expansion and contraction of a fine wire carrying either the current to be measured or a definite proportion of that current.*

The expansion or contraction of the wire is caused by temperature changes, which in turn are due to the heating effect of the current flowing

FIG. 6,788.—Hot wire instrument. A, is the active wire carrying the current to be measured and stretched between the terminals T and T'. It is pulled taut at its middle point by another wire C (fastened at B), which carries no current, and is, in its turn, kept tight by a thread passing round the pulley D, attached to the pointer spindle, the whole system being kept in tension by the spring E.

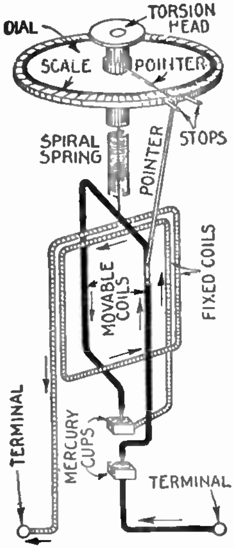


FIGS. 6,789 and 6,790.—Plan and elevation of shielded pole type of induction instrument *It consists of* a disc A, or sometimes a drum and a laminated magnet B. Covering some two-thirds of the pole faces are two copper plates or shields C, and a permanent magnet D. *In operation,* eddy currents are induced in the two copper plates or shields C, which attract those in the disc, producing in consequence a torque in the direction shown by the arrow, against the opposing action of a spring. Magnet D, damps the oscillations.

through the wire. These variations are magnified by suitable multiplying gear.

Induction Instruments.—These were invented by Ferraris, and are sometimes called after him.

They are for alternating current only. The shielded pole type is shown in figs 6,789 and 6,790. In the rotary field type, the parts are arranged similar to those of wattmeters, the necessary split phase being produced



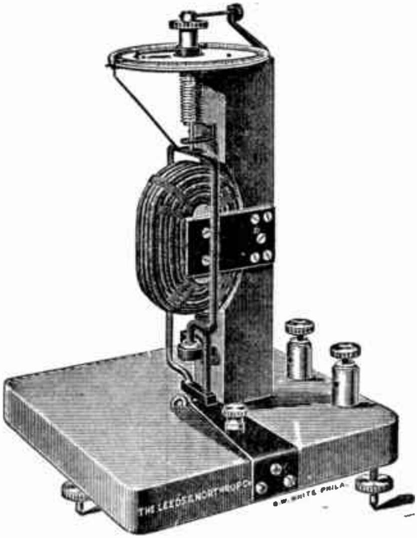
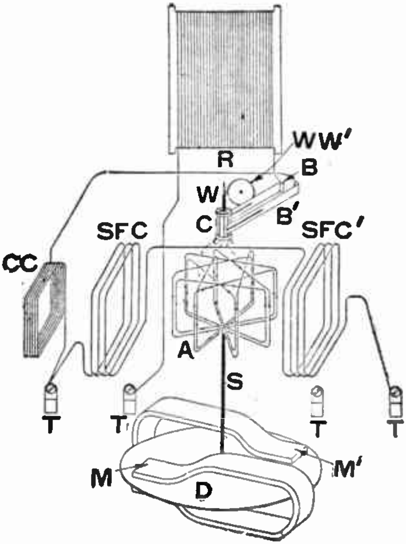


FIG. 6,791.—Diagram of Siemens' dynamometer. *It consists of* two coils on a common axis but set in planes at right angles to each other in such a way that a torque is produced between the two coils which measures the product of their currents. This torque is measured by twisting a spiral spring through a measured angle of such degree that the coils shall resume their original relative positions. *When constructed as a voltmeter,* both coils are wound with a large number of turns of fine wire, making the instrument sensitive to small currents. Then by connecting a high resistance in series with the instrument, it can be connected across the terminals of a circuit whose voltage is to be measured. *When constructed as a wattmeter,* one coil is wound so as to carry the main current and the other made with many turns of fine wire of high resistance suitable for connecting across the circuit.

FIG. 6,792.—Leeds and Northrup *electro-dynamometer. It is a reliable instrument for the measurement of alternating currents of commercial frequencies.*



by dividing the current into two circuits, one inductive and the other non-inductive.

Dynamometers.—These are used to measure volts, amperes, or watts, and their operation depends on *the reaction between two coils when the current to be measured is passed through them.*

One of the coils is fixed and the other movable. The ends of the movable coil dip into

FIG. 6,793.—Internal connections of Thompson recording commutator type watt hour meter. *The parts are:* A, armature; BB', brushes; C, commutator; CC, friction compensation coil; D, disc; MM', drag magnets; R, resistance; S, shaft; SFC, SFC', series field coils; T, terminals; W, worm; WW', worm wheel.

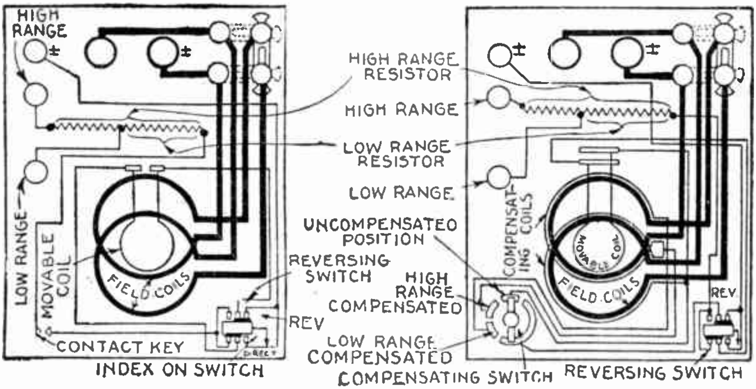
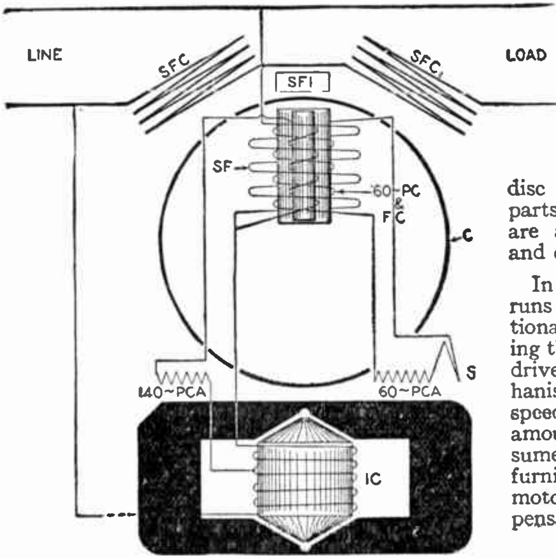


FIG. 6,794.—Internal connections of Weston 30 watt meter. When the links are in the position indicated by full lines the sections of the field are connected in series and the instrument is ready for use on the low current range. When the links are in the position indicated by dotted lines the sections of the field are connected in multiple and the instrument is ready for use on the high current range.

FIG. 6,795.—Internal connections of Weston low power factor watt meter.

mercury cups, which act as pivots and electrical contacts, making connection with one end of the fixed coil and one terminal of the instrument.

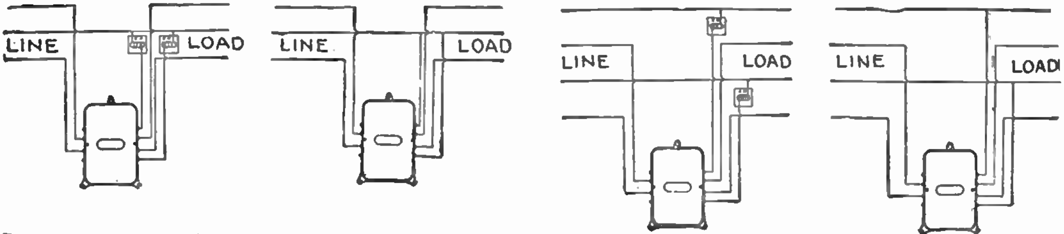
Watt Hour Meters.—A watt hour meter is a watt meter that will register the watt hours expended during an interval of time. *Watt hour meters are often erroneously called* ***recording*** *or* ***integrating*** *watt meters.*



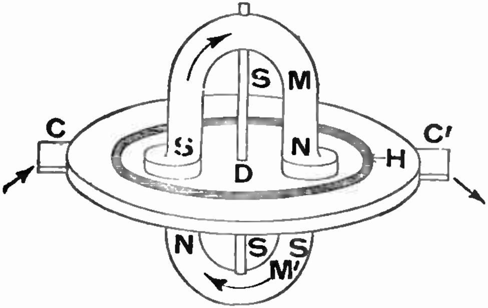
There are several types of the electromoter form of watt hour meter, which may be classified as: 1, commutator type; 2, induction type; 3, Faraday disc type. The essential parts of a watt hour meter are a motor, generator, and counting mechanism.

In operation, the motor runs at a speed proportional to the energy passing through the circuit, it drives the counting mechanism at the proper speed to indicate the amount of energy consumed. The generator furnishes the load for the motor. The meter is compensated, to correct the

FIG. 6,796 —Diagram of Fort Wayne, induction watt hour meter. ***It is designed*** to register the energy of alternating current circuits regardless of the power factor, ***and embodies the usual induction motor, eddy current generator and registering mechanism.*** The electrical arrangement of the meter consists of ***a current circuit*** composed of two coils connected in series with each other and in series with the line to be measured, and ***a pressure circuit*** consisting of a reactance coil and a pressure coil connected in series with each other and across the line to be measured. In addition, the pressure circuit contains a light load coil wound over a laminated sheet steel member, adjustably arranged in the core of the pressure coil and connected across a small number of turns of the reactance coil so as to give a field substantially in phase with the impressed pressure. The light load winding is further provided with a series adjustable resistance furnished for the purpose of regulating the current flowing in the light load winding, thereby providing a means of lagging the meter on high frequencies, such as 125 or 140 cycle circuits. The pressure circuit also comprises a lag coil wound over the upper limb of the core of the pressure circuit and provided with an adjustable resistance for obtaining a field component in quadrature with the shunt field.



Figs. 6,797 to 6,800.—Connections of Fort Wayne multi-phase watt hour meters (type k_3—forms MAB and MAK), for 100-625 volt circuits, 5-150 amperes. Fig. 6,797 two and three phase, three wire circuit, 25-36 cycles; fig 6,798 two and three phase, 3 wire circuit, 36 cycles and above; fig. 6,799 two phase 4 wire circuit, 25-36 cycles; fig. 6,800 two phase, 4 wire circuit, 36 cycles and above.



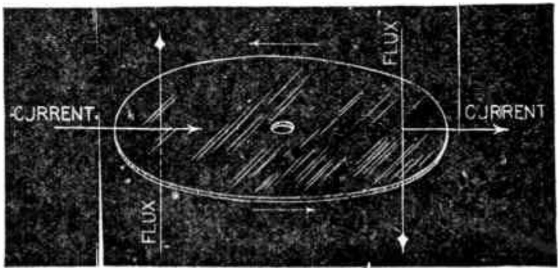
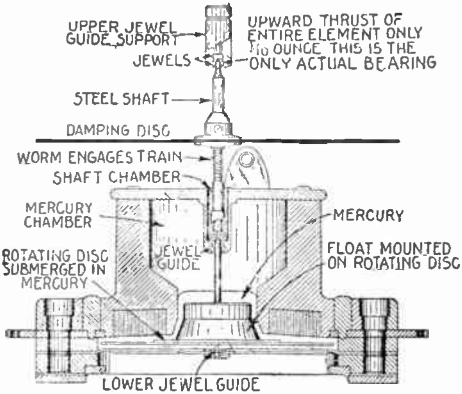


Fig. 6,801.—Faraday disc, or mercury motor ampere hour meter; view showing electric and magnetic circuits. The electric current enters the contact C, passes through the comparatively high resistance mercury H, to the edge of the low resistance copper disc D, across the disc to the mercury H, and out of contact C′. The magnetic flux cuts across the disc on each side from N, to S, making a complete circuit through M and M′. When connected to an eddy current damper or generator which requires a driving force directly proportional to the speed of rotation, the mercury motor generator becomes a meter.

Fig. 6,802.—Diagram showing relative direction of current, magnetic flux, and motion of disc in Faraday disc, or mercury motor ampere hour meter. According to the laws of electromagnetic induction, *if a current carrying conductor cut a magnetic field of flux at right angles, a force is exerted upon the conductor, tending to push it at right angles to both the current and the flux.*

error due to friction, by exacting an adjustable auxiliary field from the shunt or pressure circuit. The induction type of watt hour meter is the equivalent of a squirrel cage induction motor.

The moving element is a rotating disc which acts like the squirrel cage armature of an induction motor, developing the motive torque for the meter; it revolves through an air gap in which a rotating field is produced.



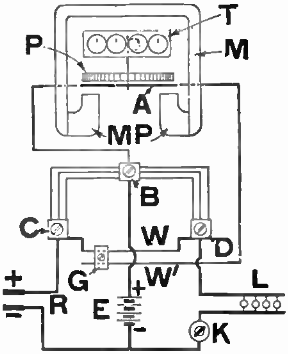
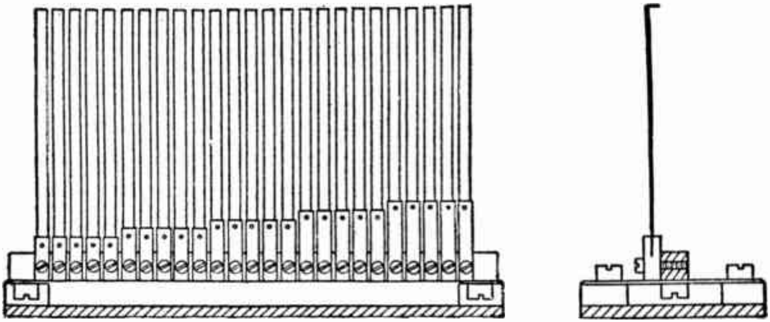
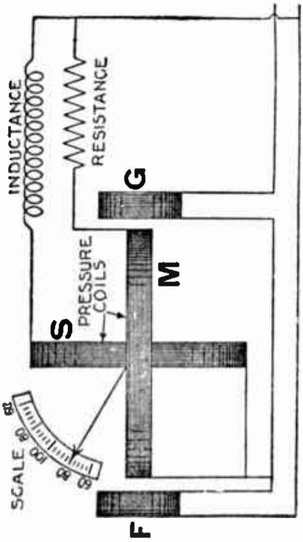


Fig. 6,803.—Sectional view of Faraday disc or mercury motor ampere hour meter as made by Sangamo Electric Co The illustration does not show the magnets and indicating mechanism.

Fig. 6,804.—Circuit diagram of Sangamo ***differential shunt type ampere hour meter for use in battery charging.***



Figs. 6,805 and 6,806.—Frahm resonance type frequency meter reeds. Owing to the principle employed in the meter it is evident that the indications are independent of the voltage. change of wave form, and external magnetic fields.



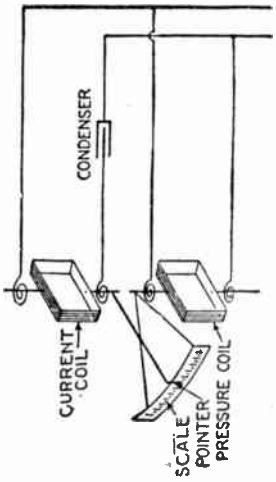


FIG. 6,807.—Langsdorf and Gegole induction type frequency meter. ***Its operation*** is based on the fact that if an alternating pressure of E, volts be impressed on a condenser of capacity C, in farads, the current in amperes will be equal to $2\pi\nu EC$, provided the pressure be constant. For a discussion of this meter, see *Electrical Review*, vol. LVIII, page 114.

FIG. 6,808.—Single phase, disc or rotating field type power factor meter. ***In construction***, the coils are placed about a common axis, along which is pivoted an iron disc or vane. The magnetizing coils FG, are in series with the load. ***In operation***, if the load be very inductive, the coil M, experiences very little torque and the system will set itself as shown in the figure. As the load becomes less inductive, the torque on S, decreases and on M, increases so that the system takes up a particular position for every angle of lag or lead.

There is also a retarding disc in which eddy currents are induced in rotating through a constant field produced by permanent magnets.

The retarding disc may be the same disc used for the moving element, in which case the meter field acts on one edge while the permanent magnet field acts on the edge diametrically opposite. This arrangement simplifies the number of parts and saves space and weight of moving element.

The Faraday disc type, or mercury motor ampere horn meter consists essentially *of a copper disc floated in mercury between the poles of a magnet and provided with leads to and from the mercury at diametrically opposite points.*

Frequency Indicators.—A frequency indicator or meter is an instrument used ***to determine*** *the frequency, or number of cycles per second of an alternating current.*

There are several forms of frequency indicator, whose

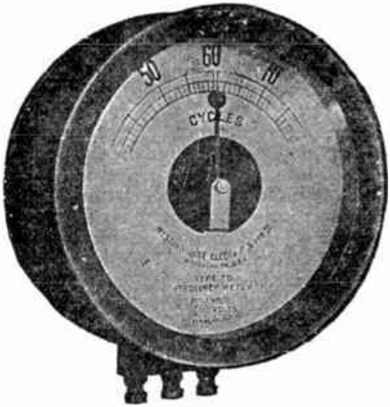


FIG. 6,809.—Westinghouse induction type frequency meter. The normal frequency is usually at the top of the scale to facilitate reading. The damping disc moves in a magnetic field, thus damping by the method of eddy currents. The standard meters are designed for circuits of 100 volts nominal and can be used for voltages up to 125 volts. For higher voltages, transformers with nominal 100 volt secondary should be used.

principle of operation differs, and according to which, they may be classed as: 1, synchronous type; 2, resonance type; and 3, induction type.

In the synchronous type *a small synchronous motor is connected in the circuit of the current whose frequency is to be measured.*

After determining the revolutions per minute by using a revolution counter, the frequency is easily calculated as follows:

frequency = (revolutions per second × number of pole) ÷ 2.

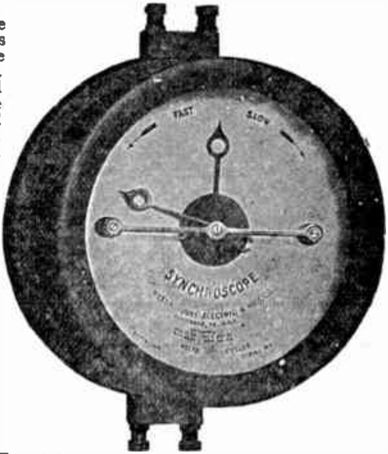


FIG. 6,810.—Westinghouse rotary type of synchroscope or synchronism indicator. The indication is by means of a pointer which assumes at every instant a position corresponding to the phase angle between the pressures of the bus bars and the incoming machine, and therefore rotates when the incoming machine is not in synchronism. The direction of rotation indicates whether the machine be fast or slow, and the speed of rotation depends on the difference in frequency. The pointer is continuously visible, during both the dark and light periods of the synchronizing lamps.

The resonance type consists of *a pendulum, or reed, of given length, which responds to periodic forces having the same natural period as itself.*

The instrument comprises a number of reeds of different lengths, mounted in a row, and all simultaneously subjected to the oscillatory attraction of an electro-magnet excited by the supply current that is being measured. The reed, which has the same natural time period as the current will vibrate, while the others will remain practically at rest.

This type is desirable for laboratory use.

The induction type consists of *two voltmeter electro-magnets acting in opposition on a disc attached to the pointer shaft.*

One of the magnets is in series with an inductance, and the other with a resistance, so that any change in the frequency will unbalance the forces acting on the shaft and cause the pointer to assume a new position, when the forces are again balanced. The aluminum disc is so arranged that when the shaft turns in one direction, the torque of the magnet tending to rotate it decreases, while the torque of the other magnet increases. The pointer therefore comes to rest where the torques of the two magnets are equal, the pointer indicating the frequency on the scale.

Synchronism Indicators.—These devices, sometimes called synchroscopes, or synchronizers *indicate the exact difference in phase angle at every instant,* and the difference in frequency, between an incoming machine and the system to which it is to be connected, so that the coupling switch can be closed at the proper

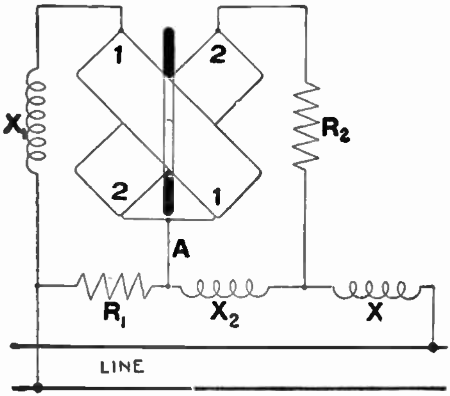


FIG. 6,811.—Diagram of Weston induction type frequency meter connections. The coils are connected in series across the line, with a reactor in series with one and a resistor in series with the other. A resistor is connected in parallel with one coil and the reactor, and a reactor is connected in parallel with the other coil and the resistor; then the whole combination is connected in series with a reactor, the purpose of which is to damp out the higher harmonics. The circuits, as shown, form a Wheatstone bridge, which is balanced at normal frequency. An increase in frequency will increase the reactance of the reactors and thus upset the balance of the bridge, allowing more current through one coil and less through the other.

instant. There are several types of synchronizer, such as: 1, lamp or volt meter type; 2, resonance or vibrating reed type, and 3, rotating field type.

The simplest arrangement consists of *a lamp or preferably* *a voltmeter connected across one pole of a two pole switch connecting the incoming machine to the bus bars, the other pole of the switch being already closed.*

If the machines be out of step, the lamps will fluctuate in brightness, or the voltmeter pointer will oscillate, the pulsation becoming less and less as the incoming machine approaches synchronous speed. Synchronism is shown by the lamp remaining out, or the voltmeter at zero.

The resonance type works on the same principle *as the resonance type of frequency meter already described.*

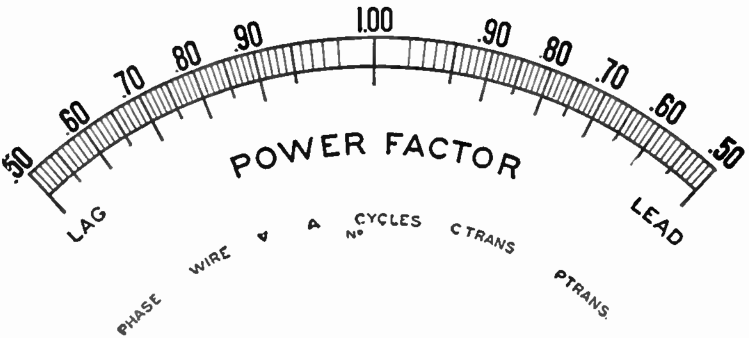
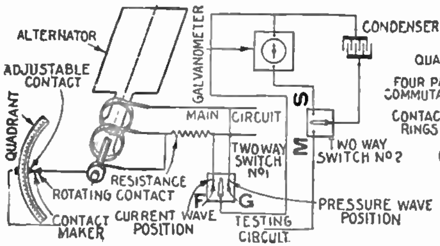


FIG. 6,812.—Weston power factor instrument scale. Range from .50 lagging to .5 leading. The scale divisions are open and very nearly uniform, except near unity power factor, where the instrument is extremely sensitive. A change in time phase angle of 5 degrees at unity power factor will produce a deflection of the pointer of .35 in.

The operation of the rotating field type depends on the production of a rotating field by the currents of the metered circuits in angularly placed coils, one for each phase in the case of a polyphase indicator. In this field is provided a movable iron vane or armature, magnetized by a stationary coil whose current is in phase with the voltage of one phase of the circuit. As the iron vane is attracted or repelled by the rotating field, it takes up a position where the zero of the rotating field occurs at the same instant as the zero of its own field.

In the single phase meter the positions of voltage and current coils are interchanged and the rotating field is produced by means of a split phase winding, connected to the voltage circuit.

Power Factor Indicators.—Meters of this class indicate the



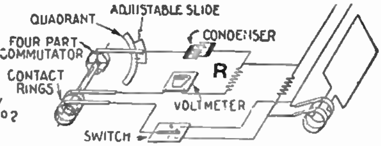
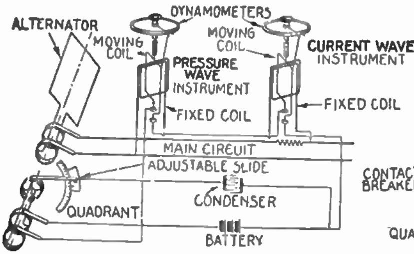


Fig. 6,813.—*Joubert's step by step method* of wave form measurement. For current wave measurement switch No. 1 is placed on contact F, and for pressure wave measurement on contact G, switch No. 2 is now turned to M, and the drop across the resistance (assuming switch No. 1 to be turned to contact F) measured by charging the condenser, and then discharging it through the galvanometer by turning the switch to S. This is repeated for a number of positions of the contact maker, noting each time the galvanometer reading and position of the contact maker. By plotting the positions of contact maker as abscissæ, and the galvanometer readings as ordinates, the curve through them will represent the wave form. The apparatus is calibrated by passing a known constant current through the resistance.

Fig. 6,814.—*Four part commutator method* of wave form measurement. The contact device consists of two slip rings and a four part commutator. One slip ring is connected to one terminal of the source, the other to the volt meter, and the commutator to the condenser. By adjusting R, when a known direct current pressure is impressed across the terminals, the volt meter can be rendered direct reading.



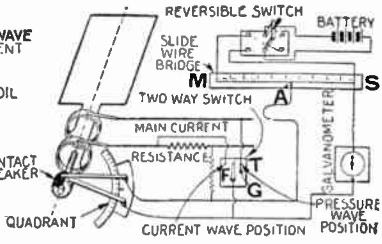


Fig. 6,815.—*Modified four part commutator method* of wave form measurement (Duncan's modification). By this method one contact maker can be used for any number of waves having the same frequency. Electro-dynamometers are used and the connections are made as here shown. The moving coils are connected in series to the contact maker, and the fixed coils are connected to the various sources to be investigated, then the deflection will be steady and by calibration with direct current can be made to read directly in volts.

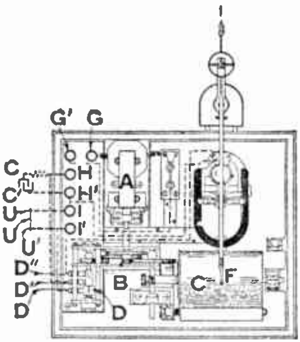
Fig. 6,816.—*Ballistic galvanometer method* of wave form measurement. *The test may be made* by placing the contact breaker in successive positions and taking galvanometer readings, the switch being turned to F in measuring the current wave, and to G in measuring the pressure wave. M S is the slide wire bridge and A the contact slider. If belt drive be used, and pulleys be of same size, paste a thin strip of paper around the face of one of the pulleys thus altering the velocity ratio of the drive slightly from unity.

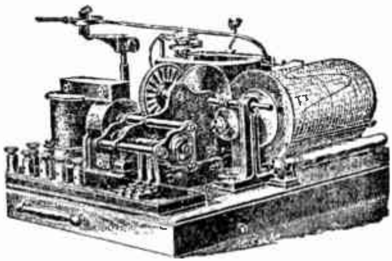
phase relationship between pressure and current, and are therefore sometimes called *phase indicators*.

There are two types: 1, watt meter type; and 2, disc, or rotating field type.

In the wattmeter type, the phase relation between the pressure and the current fluxes is such that on a non-inductive load the torque is zero.

For instance, in a dynamometer wattmeter, the pressure circuit is made highly inductive and the instrument then indicates *volts* × *amperes* × *sin* ϕ instead of *volts* × *amperes* × *cos* ϕ, that is to say, it will





Figs. 6,817 and 6,818.—Hospitalier ondograph. Fig. 6,317, mechanism and connections; fig. 6,818 exterior view. The instrument represents a development of Joubert's step by step method of wave form measurement. **The principle** on which its action is based consists in *automatically charging a condenser from each 100th wave, and discharging it through a recording galvanometer, each successive charge of the condenser being automatically taken from a point a little farther along the wave.* ***In construction***, a synchronous motor A, is so connected by gears B, to a commutator D, that for n revolutions of the motor, the commutator makes $n-1$ revolutions. The commutator automatically charges condenser *cc*; from the line and discharges it through a galvanometer E, which indicates instantaneous current valves. HH' are meter terminal connected to condenser *cc'*, through a resistance; II', are connections to service to be measured. ***In operation***, a long pivoted pointer carrying a pen and actuated by electro-magnets, records on a revolving drum a wave form representing the alternating current, pressure or current wave.

indicate the wattless component of the power. A dynamometer of this type is sometimes called an idle current wattmeter.

The disc, or rotating field type, consists of two pressure coils placed at right angles to each other, one being connected through a resistance, and the other through an inductance so as to "split" the phase and get the equivalent of a rotating magnetic field.

Ground Detectors.—Instruments of this name are used for detecting (and sometimes measuring) the leakage to earth through the insulation of a line or network and are sometimes called *ground or earth indicators, or leakage detectors.*

For low tension systems ***moving coil*** (*for alternating current*) or ***moving iron*** instruments (*for direct current*) are the most used, while for high tension systems electrostatic voltmeters are to be preferred.

Wave Form Indicators.—The various methods of wave form

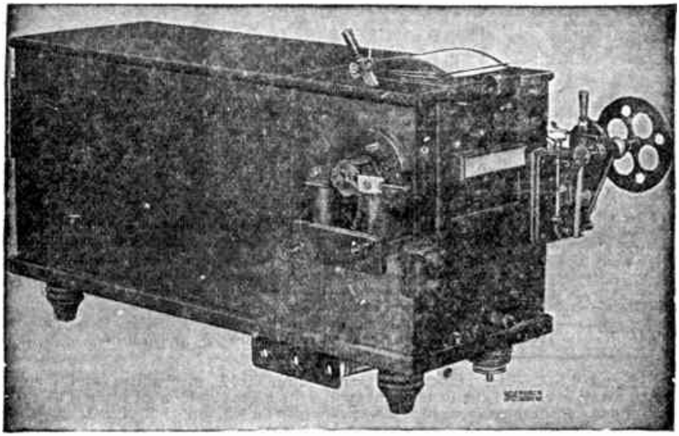
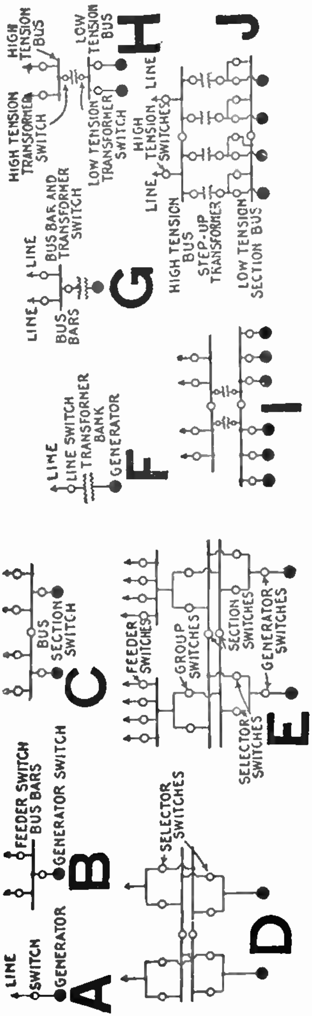


FIG. 6,819.—General Electric moving coil osillograph. *the moving element consists of single loops of flat wire carrying a small mirror and held in tension by small spiral springs.* The current passing down one side and up the other, forces one side forward and the other backward, thus causing the mirror to vibrate on a vertical axis. The vibrator elements fit into chambers between the poles of electro-magnets, and are adjustable. so as to move the beam from the mirror, both vertically and horizontally. A sensitized photographic film is wrapped around a drum and held by spring clamps. The drum, with film, is placed in a case and a cap then placed over the end, making the case light, when the index is either up or down. The loading is done in a dark room. A driving dog is screwed into the drum shaft and which, when the drum and case are in place revolves the film past a slot.

measurement may be classed as: 1, step by step; and 2, constantly recording, the latter being the more convenient method.

Switchboard Connection Principles.—The interconnection



FIGS. 6,820 to 6,829.—Diagrams illustrating principles of switchboard connections. Diagram **A**, simplest form generator feeding directly into line. **B**, generator supplying two or more feeders through single set of bus bars requiring switch for each feeder and single generator switch. **C**, two generators and addition of bus section switch **D**, several generators supplying two independent circuits. **E**, standard connection for city street railway. **F**, simplest system with transformers. **G**, system with several lines. **H**, several generators connected to low tension bus bars through generator switches. **I**, system with many feeders supplied by several small generators. **J**, system with generator transformer unit.

of generators, transformers, lines, bus bars, and switches with their relays, in modern switchboard practice is shown by the diagrams, figs. 6,820 to 6,829.

The figures being lettered A, to J, for simplicity, the generators are indicated by black discs, and the switches by open circles, while each heavy line represents a set of bus bars consisting of two or more bus bars according to the system of distribution. It will be understood, also, in this connection, that the number of pole of the switches and the type of switch will depend upon the particular system of distribution employed.

Switchboard Panels.—The term "panel" means *the slab of marble or slate upon which is mounted the switches, and the indicating and controlling devices.*

There are usually several panels comprising switchboards of moderate or large size, these panels being classified according to the division of the system that they control, as for instance: 1, generator panel; 2, feeder panel; 3, regulator panel; etc.

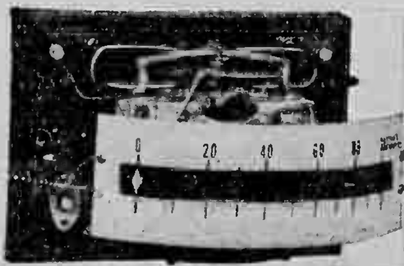
In the care of a dynamo, the generator panel would have mounted upon it a reverse current circuit breaker, an ammeter, a double pole main switch (or perhaps a single pole switch, since the circuit breaker could also be used as a switch) a double pole socket into which a plug could be inserted to make connection with a voltmeter mounted on a swinging bracket at the end of the board; a rheostat handle, the spindle of which operates the shunt rheostat of the machine, the rheostat being placed either directly behind the spindle, if of small size, or lower down with chain drive from the hand wheel spindle, if of larger size, a field discharge switch and resistance, a lamp near the top of the panel for illuminating purposes, a fuse for the voltmeter socket, and, if desired, a watthour meter.

The indicating and control apparatus for a feeder circuit is assembled on a panel called the feeder panel.

The most common equipment in the case of a direct current feeder panel comprises an ammeter, a double pole switch, and double pole fuses or instead of the fuses, a circuit breaker on one or both poles; in the case of a traction feeder a choke coil and a lightning arrester are often added.

METERS AND CONNECTIONS

WATTMETER



SINGLE PHASE WATT METER

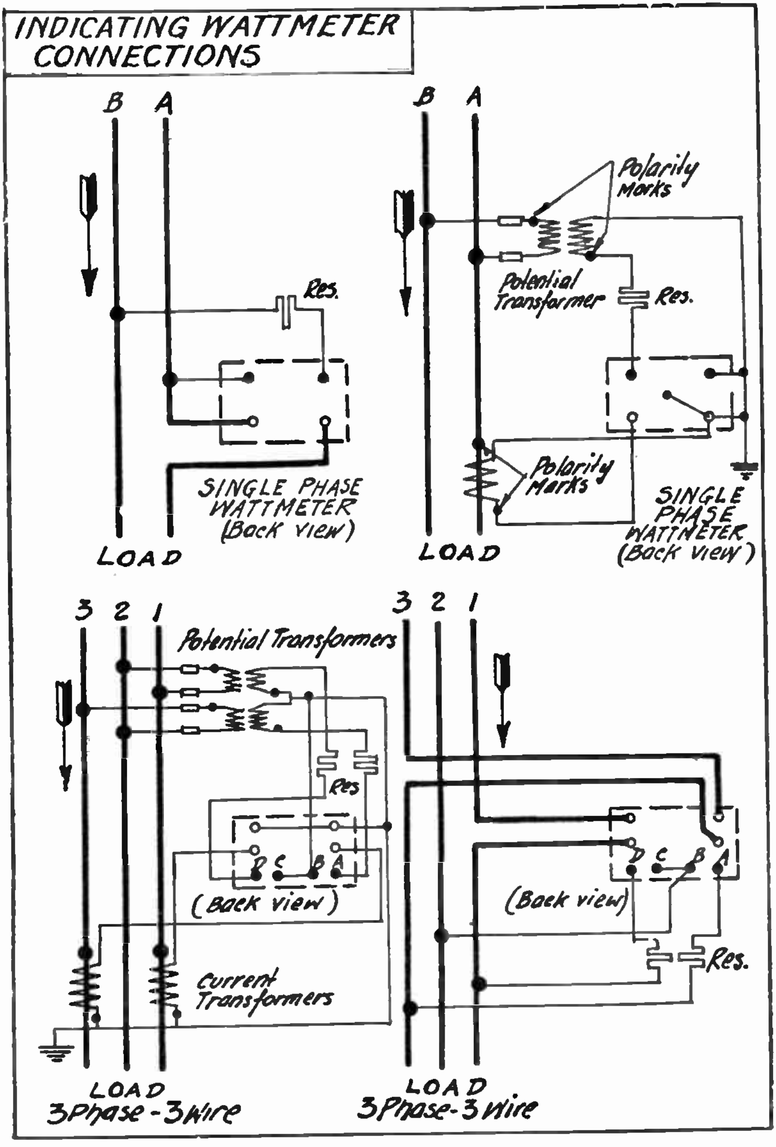
Single phase wattmeters are usually made for current capacities up to and including 200 amp., and for potentials up to and including 650 volts for use without transformers; and when current and potentials are in excess of the above figure, transformers are required.

Polyphase indicating wattmeters are designed for use on balanced or unbalanced two-phase, three or four wire, and three-phase three wire systems, regardless of the conditions of the load.

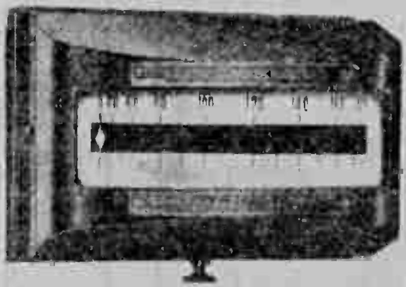
Polyphase wattmeters are usually made for current capacities up to and including 60 amp., and for potentials up to and including 650 volts, and when current and potential are in excess of the above figure, transformers are required.

For example of connection diagram,

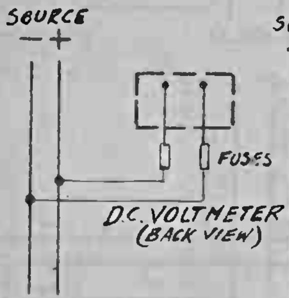
See following page.


INDICATING WATTMETER CONNECTIONS
B A
Res.
SINGLE PHASE WATTMETER (Back view)
LOAD
B A
Polarity Marks
Potential Transformer
Res.
Polarity Marks
SINGLE PHASE WATTMETER (Back view)
LOAD
3 2 1
Potential Transformers
Res
D C B A
(Back view)
Current Transformers
LOAD
3 Phase - 3 Wire
3 2 1
D C B A
(Back view)
Res.
LOAD
3 Phase - 3 Wire

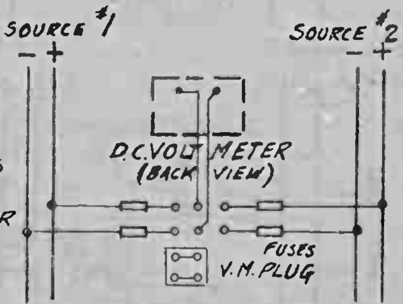
VOLTMETER AND CONNECTIONS



THOMSON VOLTMETER



DIRECT CONNECTED
D.C. VOLTMETER

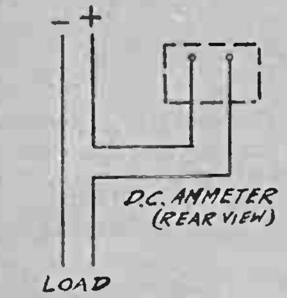


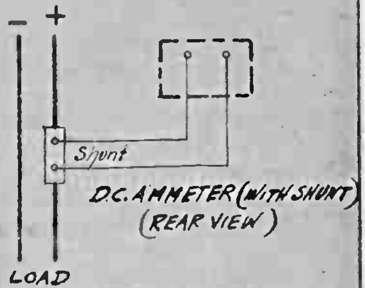
TYPICAL CONNECTION
WHEN MEASURING VOLTAGE
BETWEEN 2 D.C. SOURCES

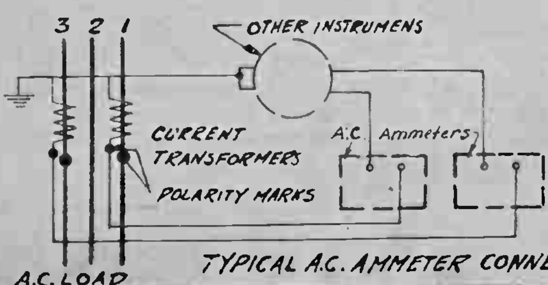
When connecting A.C. voltmeters check voltage and frequency of source to be measured with that of the meter. And when used with potential transformers connect the primarys across the source which potential is to be measured, and secondary to voltmeter.
Note: Secondary voltage of potential must be suitable for the instrument with which they are to be used.

AMMETER AND CONNECTIONS

D.C. AMMETER

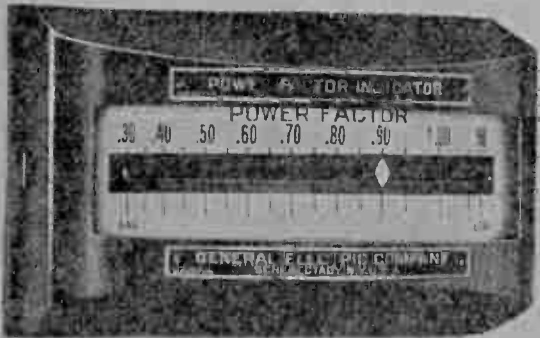






TYPICAL A.C. AMMETER CONNECTIONS

POWER FACTOR INDICATOR



POWER FACTOR INDICATOR

Power-factor meters are designed to show the power-factors, lagging or leading, at which various lines are operating; and they are adapted for balancing systems only.

Usually, instruments having capacities up to and including 20 Amperes can be operated without current transformers, when used on potentials up to 650 volts or less.

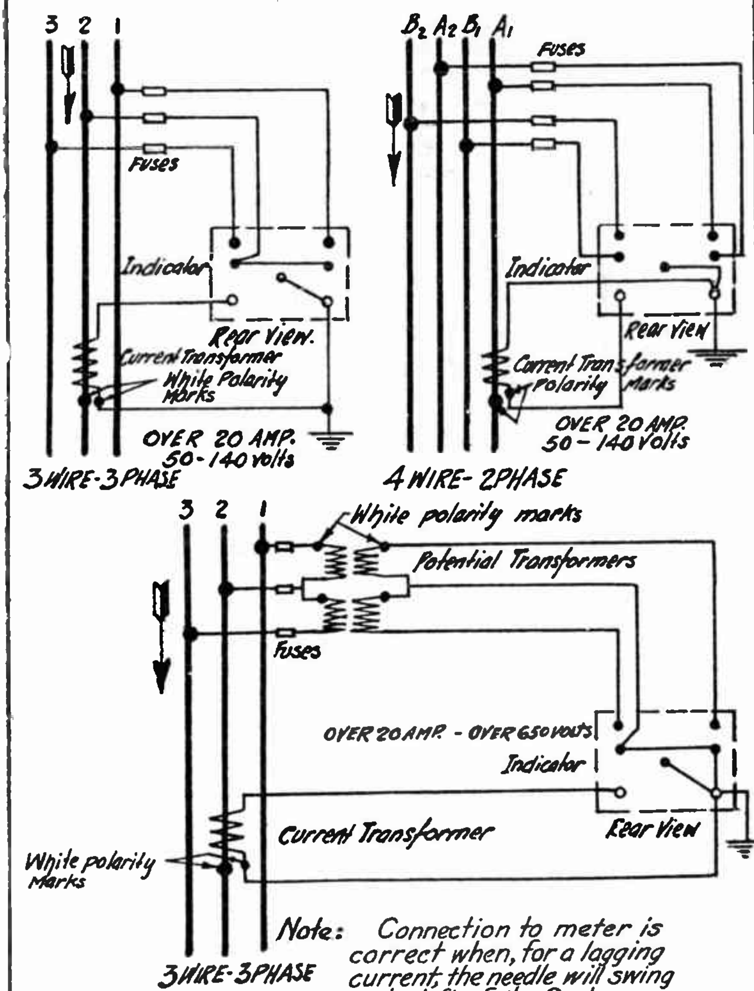
But all instruments for use on circuits over 650 volts, or having capacities exceeding 20 Amp., require one current transformer for each instrument.

Instruments used on circuits where the potential exceeds 650 volts, require two potential transformers for each instrument.

When the circuit voltage exceeds 140 volts, external resistances are used; and should be connected to instruments according to manufacturers diagram.

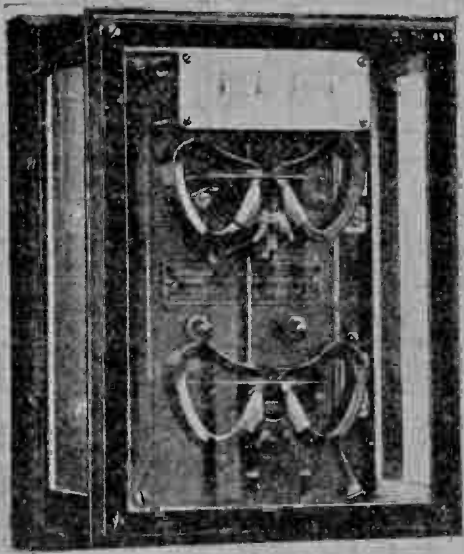
For example of connection diagrams see the following page.

POWER FACTOR INDICATOR CONNECTIONS



Note: Connection to meter is correct when, for a lagging current, the needle will swing to the left of the Scale.

POLYPHASE WATTHOUR METER



CONNECTIONS:

When connecting the meter, direction of currents should be carefully noticed, and when used with instrument-Transformers study polarity markings carefully, as most transformers of recent manufacture have such markings painted on or near one primary and one secondary terminal.

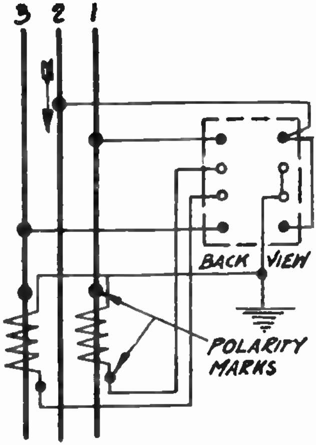
These markings give the polarity or direction of current, and facilitates the proper connection and correct direction of meter elements.

A line entering a marked terminal of the Primary may be considered as coming out of the marked terminal of the Secondary.

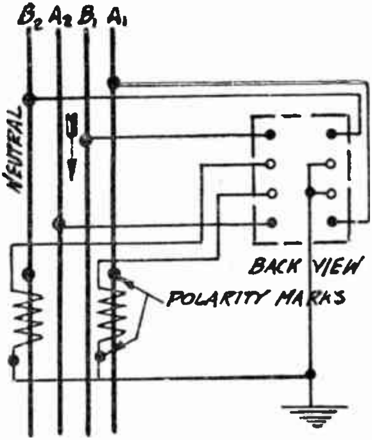
When properly connected the moving element of the meter will always rotate at right.

SEE CONNECTION DIAGRAMS, ON THE FOLLOWING PAGE.

POLYPHASE WATTHOUR METER CONNECTIONS



3 WIRE, 3 PHASE CIRCUIT

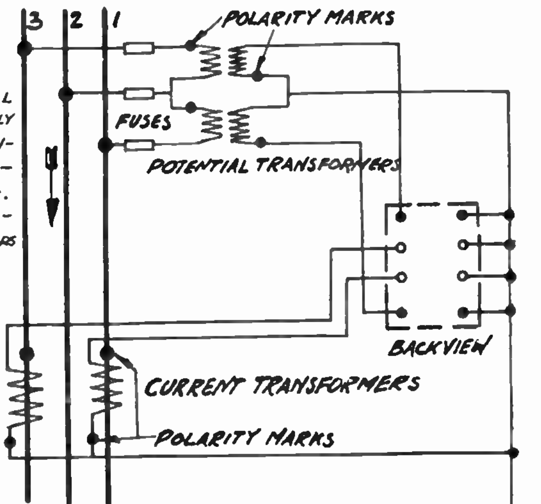


4 WIRE, 2 PHASE CIRCUIT

=NOTE=

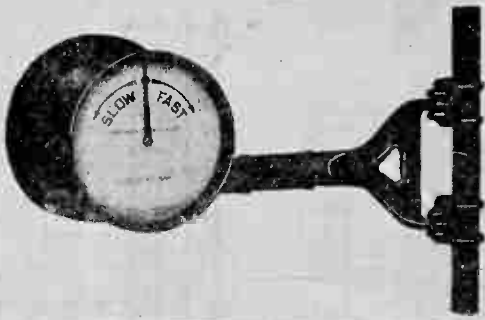
THE METER WILL REGISTER CORRECTLY WHEN LOAD IS CONNECTED IN DIRECTION OF ARROWS.

FOR OTHER APPLICATIONS: SEE MAKERS DIAGRAM.



3 WIRE, 3 PHASE CIRCUIT

GENERAL METHOD OF SYNCHRONIZING



— SYNCHRONISM INDICATOR —

PARALLEL OPERATION OF SYNCHRONOUS GENERATORS

Before Generator #2 can be connected in parallel with Generator #1, the following conditions must be obtained:

(1) Both machines must have the same frequency and wave form.
(2) Their terminal voltages must be equal.
(3) Their sequence of Maximum potential values must be the same.

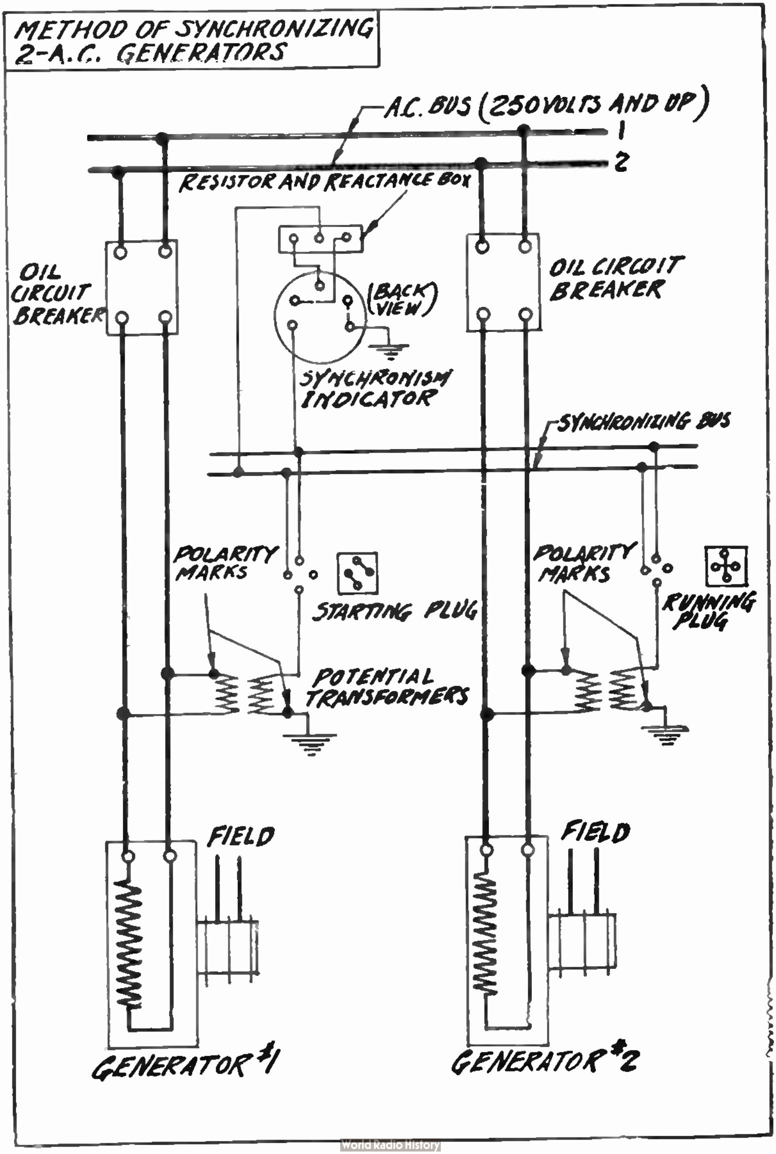
When synchronizing proceed as follows:

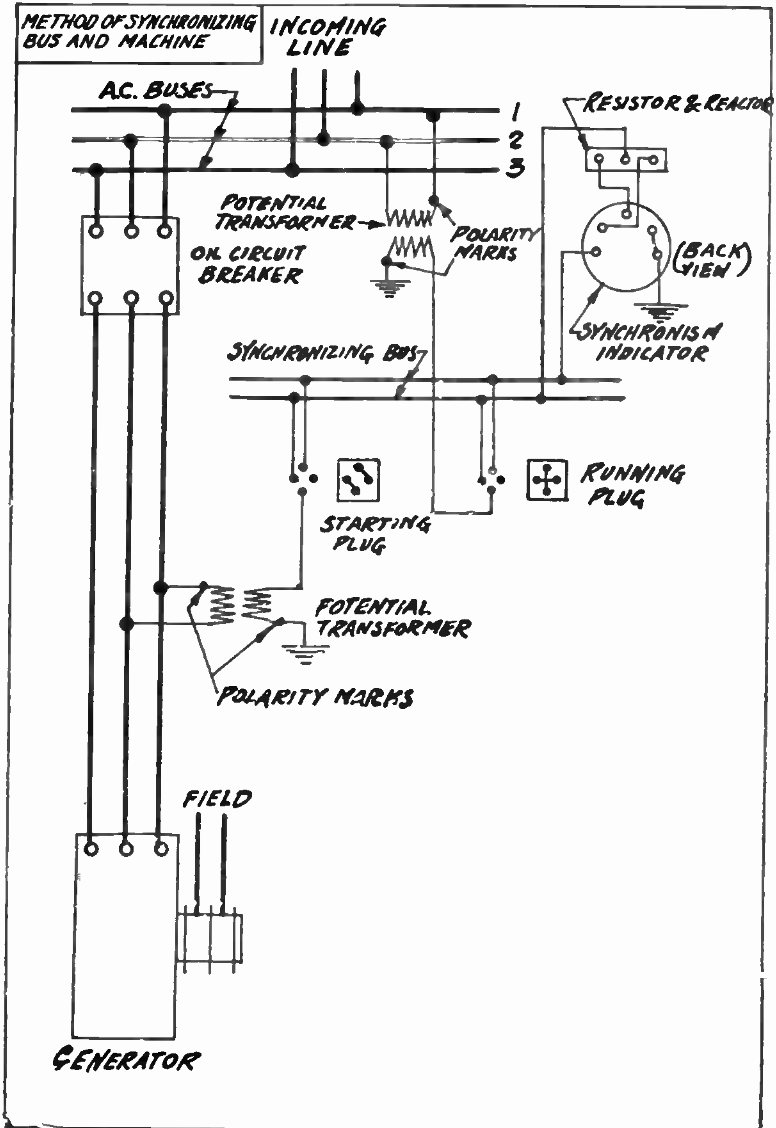
I. LAMP SYNCHRONIZING : Machine #1 is running and supplying the load and its oil circuit breaker is closed, the running plug is inserted. Bring machine #2 up to voltage by slowly increasing the speed of its prime mover, as the speed of mach. #2 increases insert the starting plug, when now the machines are running at nearly the same speed, the synchronizing lamps light up then go out, light up again etc. If the machines are in steps with lamps out or lamps in, (Depending on if light or dark lamp connections are used) wait until they go out for a few seconds then close the oil circuit breaker on machine #2 and the machines are now in parallel.

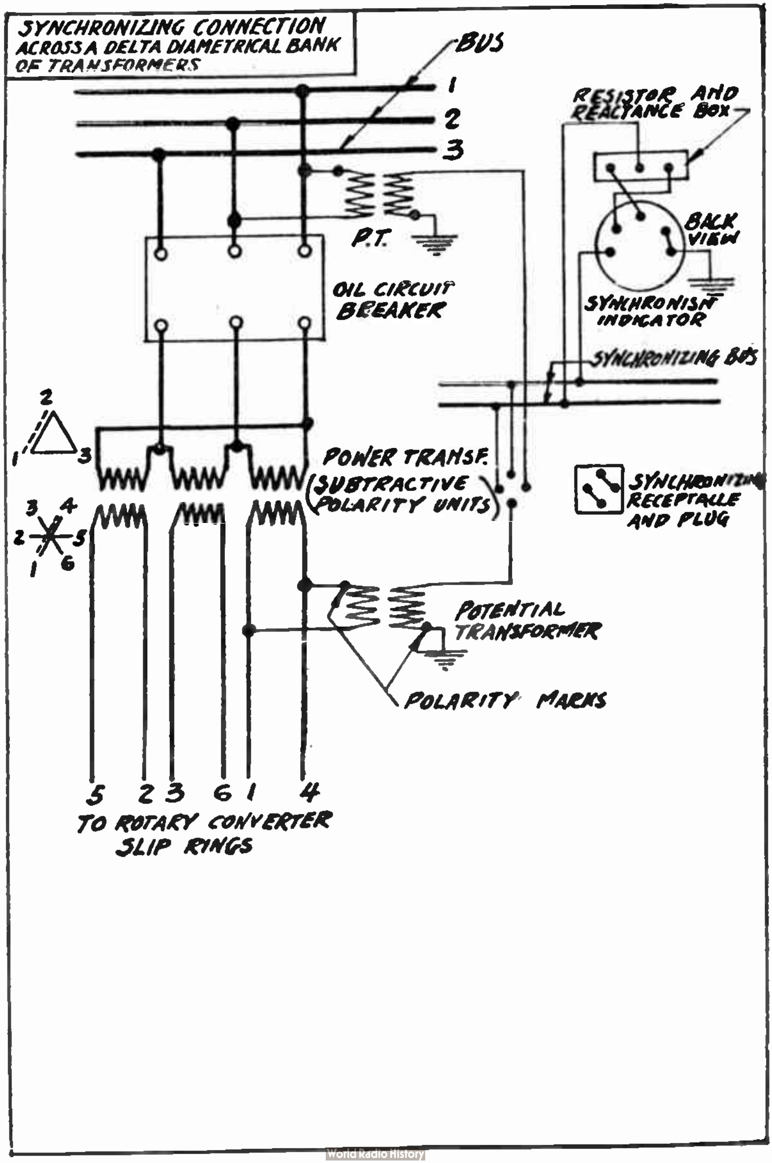
II. INDICATOR SYNCHRONIZING

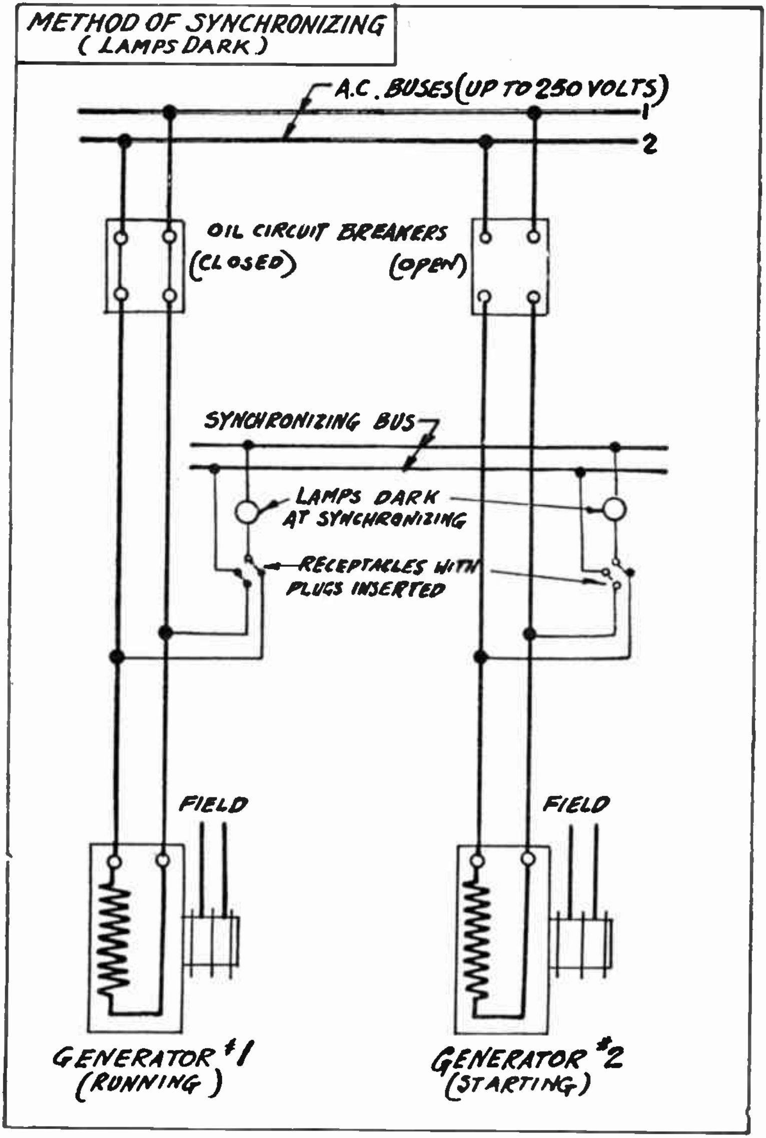
Proceed same as before: The rotary motion of the pointer on the indicator indicates whether the Generator to be synchronized is running to slow or to fast. When the pointer remains stationary in the vertical position the two machines are in synchronism and the oil circuit breaker can be closed.

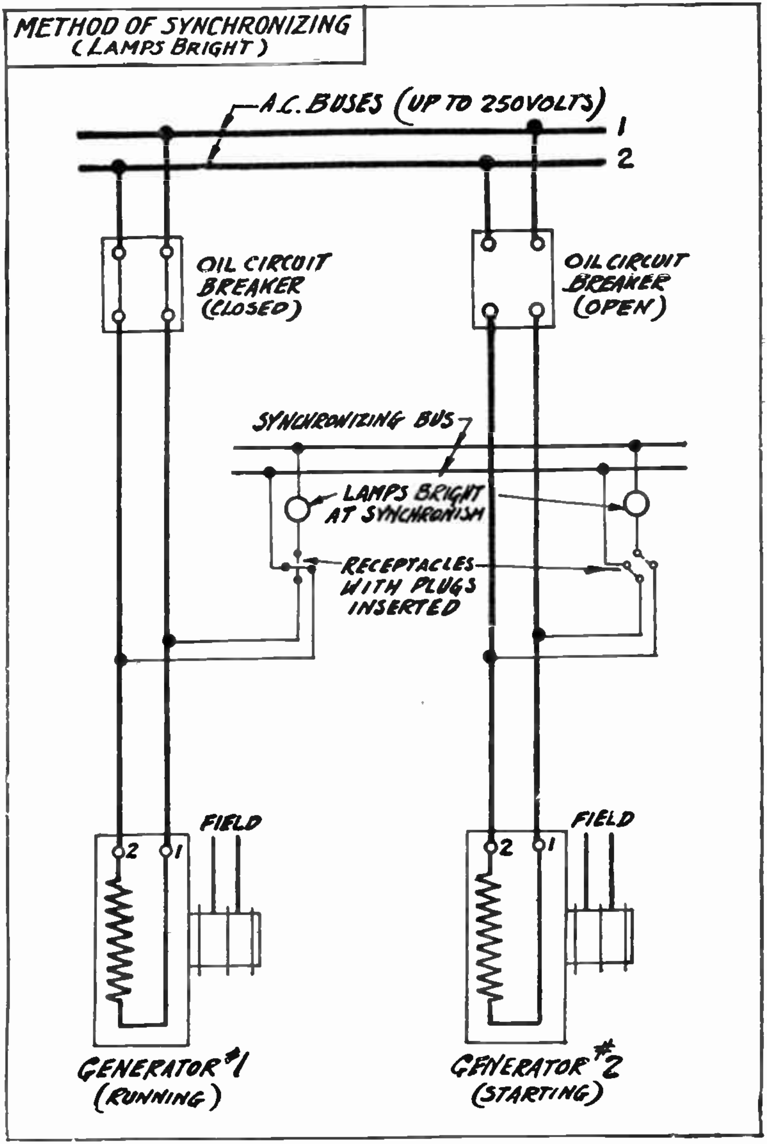
After paralleling the two machines adjust the mechanical power input and the generated e.m.f. until each machine supplies its share of the total load, and the power factor of each machine is the same and equal to that of the total load.

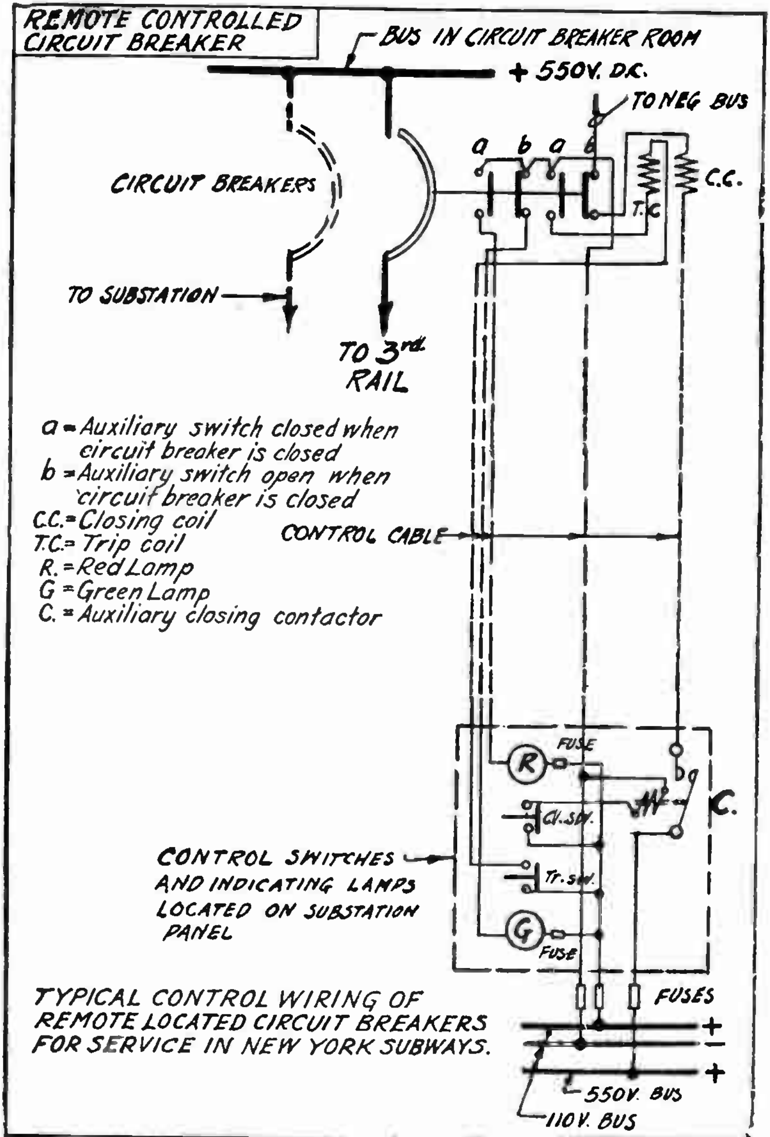

METHOD OF SYNCHRONIZING
2-A.C. GENERATORS
A.C. BUS (250 VOLTS AND UP)
1
2
RESISTOR AND REACTANCE BOX
OIL CIRCUIT BREAKER
OIL CIRCUIT BREAKER
(BACK VIEW)
SYNCHRONISM INDICATOR
SYNCHRONIZING BUS
POLARITY MARKS
STARTING PLUG
POLARITY MARKS
RUNNING PLUG
POTENTIAL TRANSFORMERS
FIELD
FIELD
GENERATOR #1
GENERATOR #2


METHOD OF SYNCHRONIZING BUS AND MACHINE
INCOMING LINE
A.C. BUSES
1
2
3
RESISTOR & REACTOR
POTENTIAL TRANSFORMER
POLARITY MARKS
OIL CIRCUIT BREAKER
(BACK VIEW)
SYNCHRONISM INDICATOR
SYNCHRONIZING BUS
RUNNING PLUG
STARTING PLUG
POTENTIAL TRANSFORMER
POLARITY MARKS
FIELD
GENERATOR


SYNCHRONIZING CONNECTION
ACROSS A DELTA DIAMETRICAL BANK
OF TRANSFORMERS
BUS
1
2
3
RESISTOR AND
REACTANCE BOX
BACK
VIEW
P.T.
OIL CIRCUIT
BREAKER
SYNCHRONISM
INDICATOR
SYNCHRONIZING BUS
POWER TRANSF.
(SUBTRACTIVE
POLARITY UNITS)
SYNCHRONIZING
RECEPTACLE
AND PLUG
POTENTIAL
TRANSFORMER
POLARITY MARKS
5 2 3 6 1 4
TO ROTARY CONVERTER
SLIP RINGS

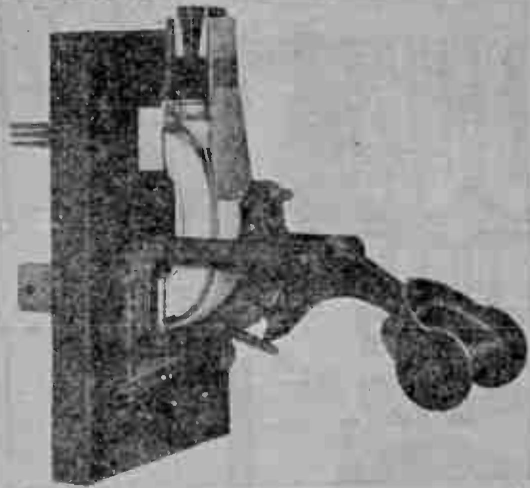

METHOD OF SYNCHRONIZING
(LAMPS DARK)
A.C. BUSES (UP TO 250 VOLTS)
1
2
OIL CIRCUIT BREAKERS
(CLOSED)
(OPEN)
SYNCHRONIZING BUS
LAMPS DARK
AT SYNCHRONIZING
RECEPTACLES WITH
PLUGS INSERTED
FIELD
FIELD
GENERATOR #1
(RUNNING)
GENERATOR #2
(STARTING)

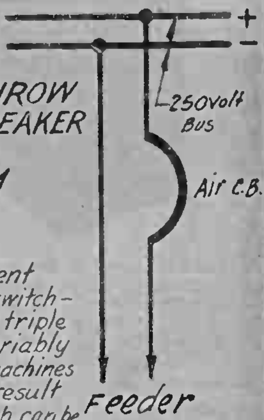

METHOD OF SYNCHRONIZING
(LAMPS BRIGHT)
A.C. BUSES (UP TO 250 VOLTS)
1
2
OIL CIRCUIT BREAKER (CLOSED)
OIL CIRCUIT BREAKER (OPEN)
SYNCHRONIZING BUS
LAMPS BRIGHT AT SYNCHRONISM
RECEPTACLES WITH PLUGS INSERTED
FIELD
2
1
FIELD
2
1
GENERATOR #1
(RUNNING)
GENERATOR #2
(STARTING)



TYPICAL CONTROL WIRING OF REMOTE LOCATED CIRCUIT BREAKERS FOR SERVICE IN NEW YORK SUBWAYS.

AIR CIRCUIT BREAKER



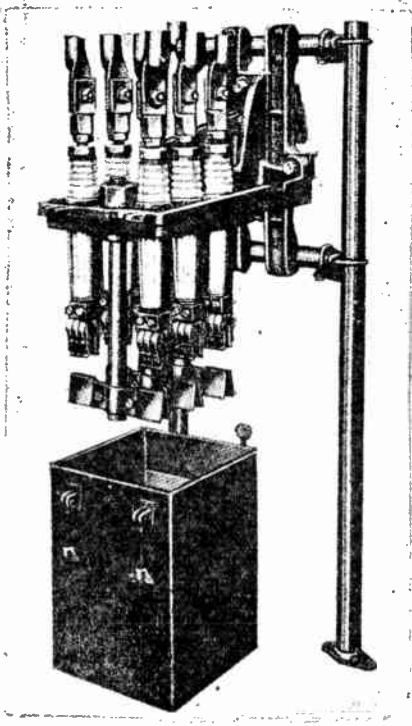


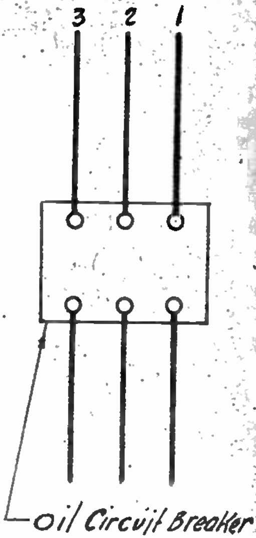
SINGLE POLE SINGLE THROW
OVERLOAD AIR CIRCUIT BREAKER
WITH
WIRING DIAGRAM
250 V. 2000 AMP.

Air circuit breakers are used as current interrupting devices for all direct current switch-boards. They are made in single, double, and triple pole combinations. They are used almost invariably as automatic devices to prevent damage to machines or other electrical apparatus which might result from abnormal conditions in the circuit, which can be short-circuit or over-current, reverse current, under-voltage, unbalanced voltage in three wire systems, phase reversal etc. To obtain some form of protection it is necessary to use a relay in connection with the breaker.

For instruction pertaining to size, operation, installation and maintenance, inquire electrical manufacturer.

OIL CIRCUIT BREAKER





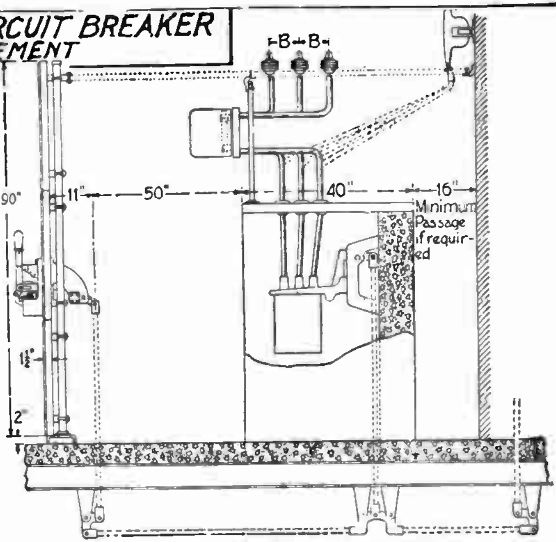
METHOD OF MOUNTING OIL CIRCUIT BREAKERS

There are four standard methods of mounting Oil Circuit Breakers: (1) On back of panel. (2) On panel frame. (3) On framework remote from panel. (4) In cells.

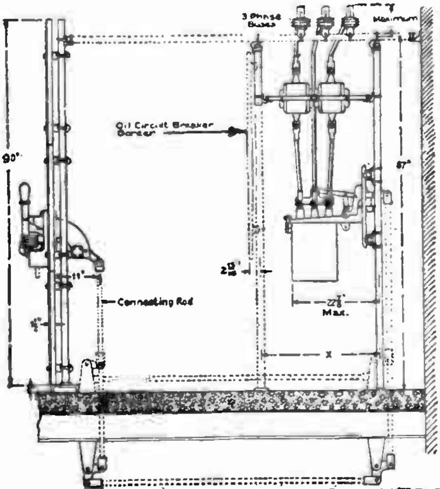
1. Back of panel mounting are used for small plant switchboard for circuits up to and including 2500 volts and up to 800 Amp. in capacity.
2. On panel frame up to and including 2500 volts and for any breakers above 800 amperes in capacity, but is not recommended when the greater number of breakers is 800 Amperes or above in capacity.
3. On framework remote from panel for circuits above 2500 volts and up to 6600 volts, and for double-throw breakers except in occasional cases where connections can be made satisfactorily on back of panel, or on panel frame. For large tank type breakers up to and including 73000 volts.
4. In cells for circuits above 6600 volts.

For various methods of oil circuit Breaker mounting, see the following pages.

OIL CIRCUIT BREAKER ARRANGEMENT



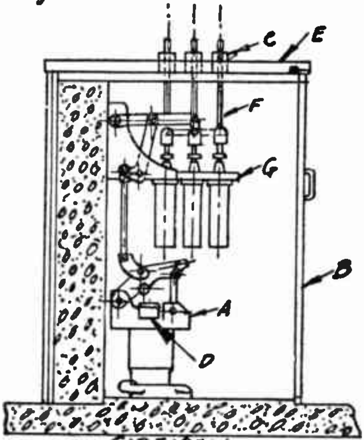
MANUALLY OPERATED, REMOTE CONTROLLED BREAKER IN CELL.



MANUALLY OPERATED, REMOTE CONTROLLED BREAKER ON FRAMEWORK.

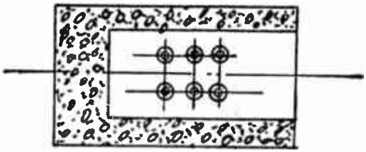
OIL CIRCUIT BREAKER ARRANGEMENT

C = Porcelain bushing
D = Auxiliary switch
E = Soapstone barrier
F = Connectors
G = Oil Circuit Breaker
A = Solenoid
B = Sliding Door



SIDE VIEW

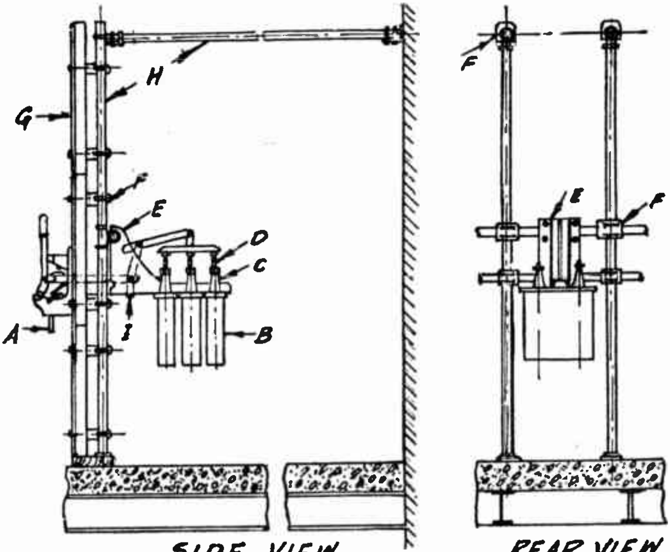
OIL CIRCUIT BREAKER MOUNTED IN CELL HOUSING (SOLENOID OPERATED)



TOP VIEW

Note: For wiring of remote controlled solenoid operated circuit breaker see diagram of typical A.C. feeder panel

OIL CIRCUIT BREAKER ARRANGEMENT

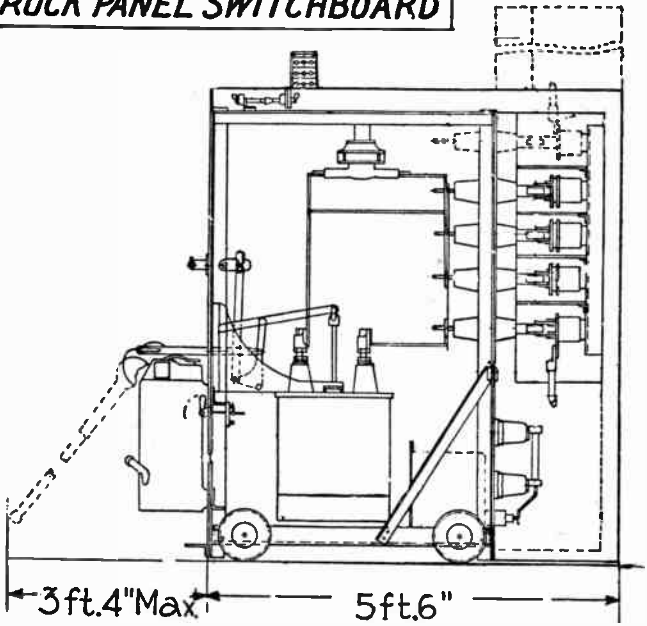


SIDE VIEW REAR VIEW

OIL CIRCUIT BREAKER MOUNTED ON PANEL FRAME (MANUALLY OPERATED)

A = Trip coil calibrating tube
B = Oil tank
C = Insulator
D = Contact stud
E = Frame
F = Standard fitting
G = Panel
H = Pipe
I = Links

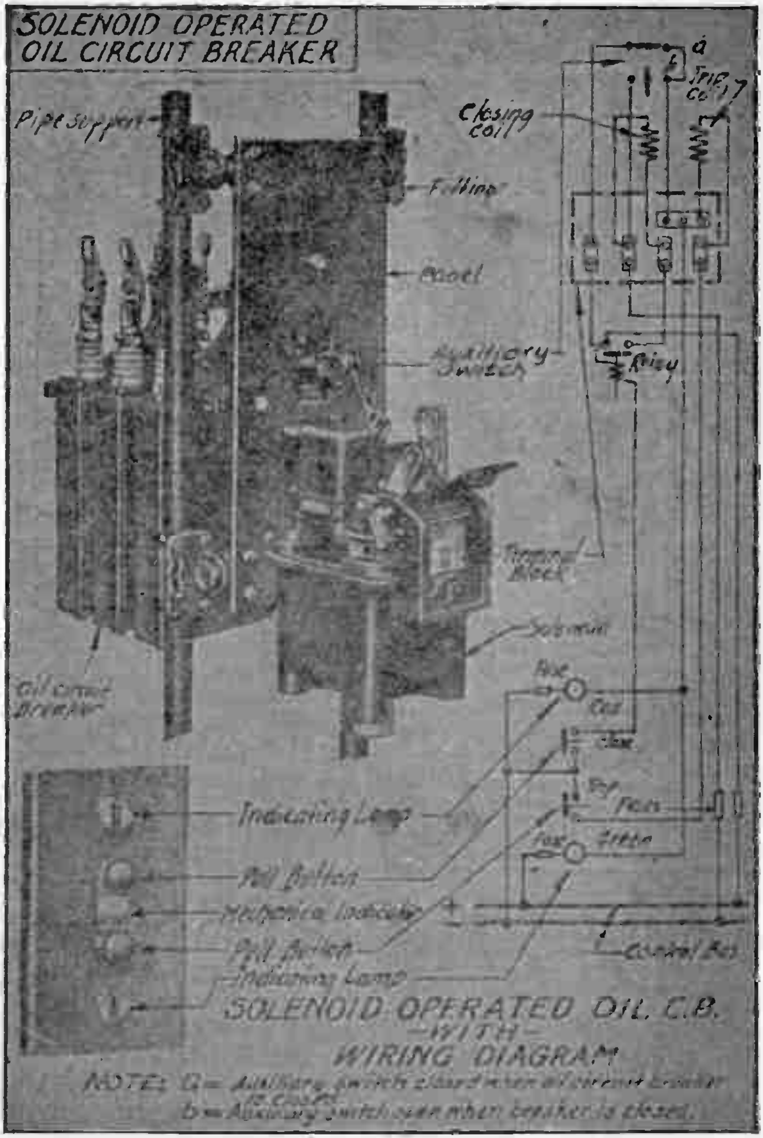
TRUCK PANEL SWITCHBOARD



MOTOR OPERATED OIL CIRCUIT BREAKER MOUNTED ON SAFETY ENCLOSED REMOVABLE TRUCK TYPE PANEL (General Electric Co., Mfg.)
An aisle space of at least 7'-6" must be left in front of panel.

The typical truck type panel, as the term is generally applied, consists of two elements; the truck or removable element, and the housing or stationary element. The former carries the oil circuit breaker, instrument transformers, breaker operating mechanism instrument and meters, and movable disconnecting devices. The housing carries the bus bars, stationary disconnecting devices, cables, and the tracks for the removable element.

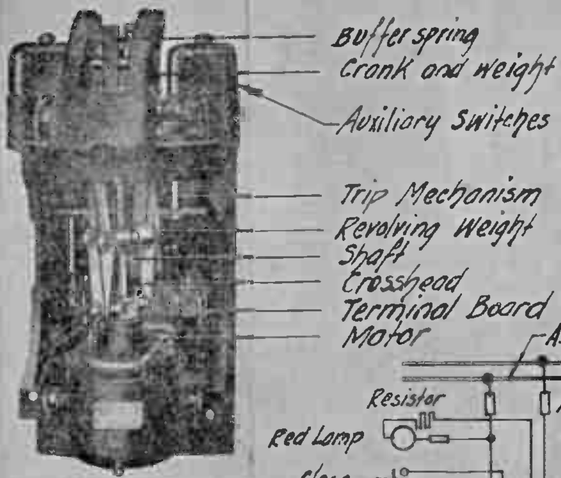
The principal features of this type switchboard are: Reliability and continuity of service, (in case of inspection or repairs a truck can be withdrawn and a spare put in its place) safety to the employees, facility of installation and maintenance, and economy in operation.



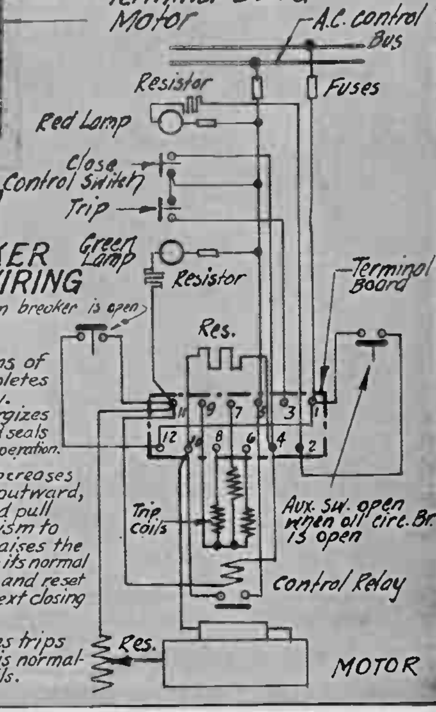
SOLENOID OPERATED OIL C.B.
—WITH—
WIRING DIAGRAM

NOTE: a = Auxiliary switch closed when oil circuit breaker is closed.
b = Auxiliary switch open when breaker is closed.

MOTOR MECHANISM FOR OIL CIRCUIT BREAKER



MOTOR MECHANISM FOR OIL CIRCUIT BREAKER OPERATION WITH WIRING DIAGRAM.



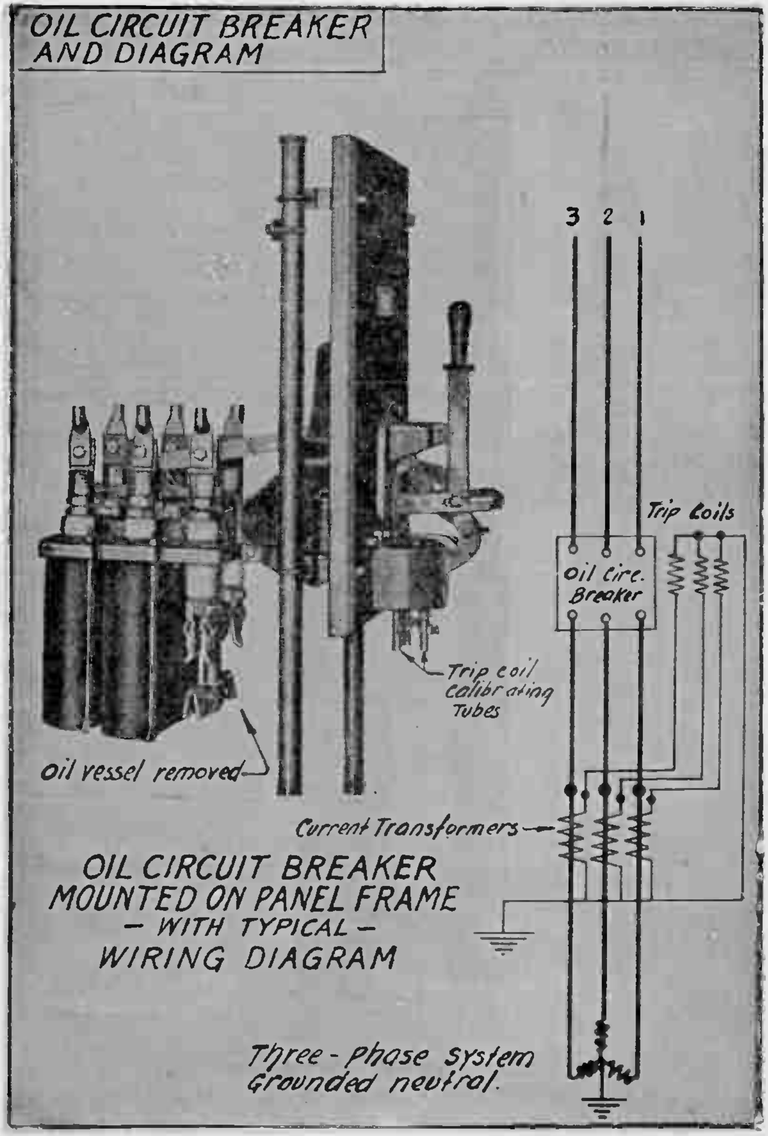
— OPERATION —

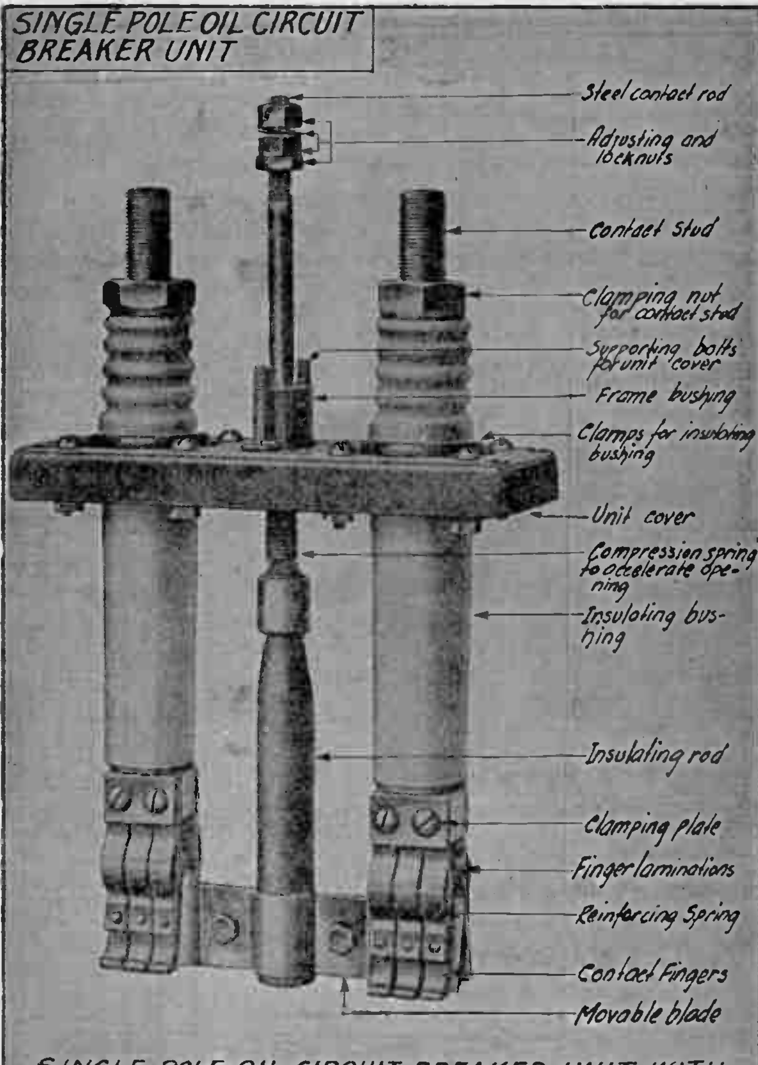
The breaker is closed by means of a pull button switch which completes the circuit of the control relay.

The control relay in turn energizes the motor of the mechanism, and seals itself to insure complete closing operation.

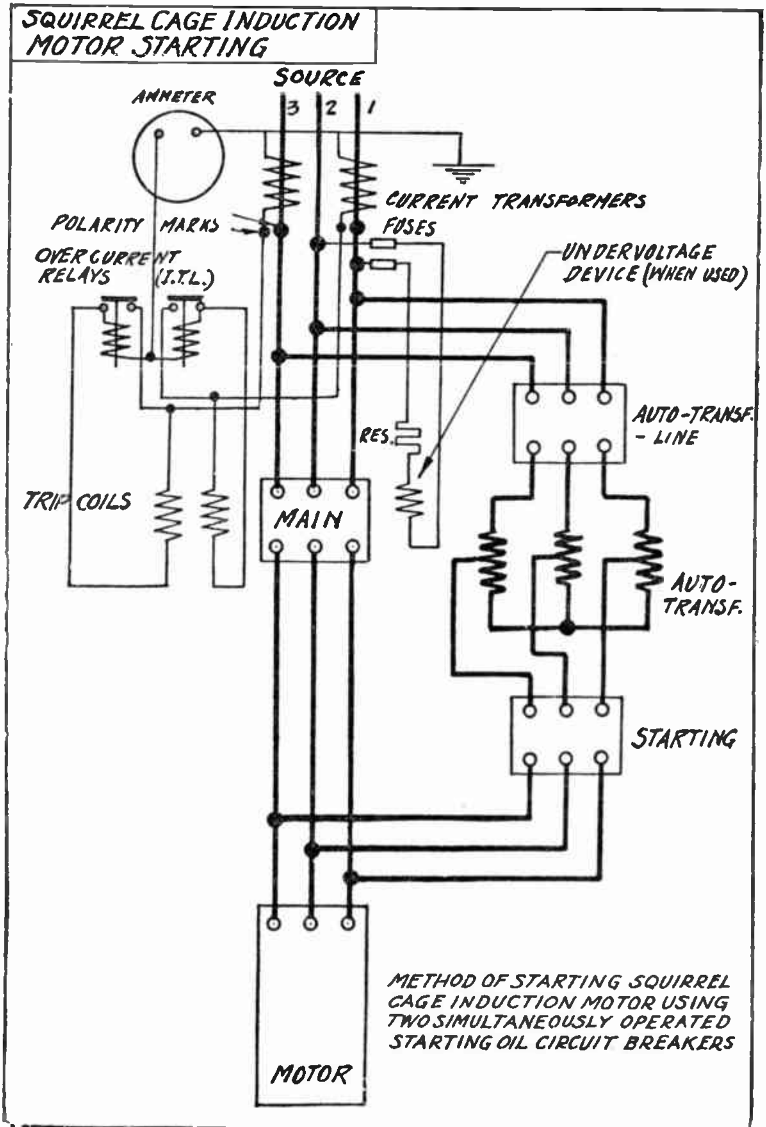
As the motor of the mechanism increases in speed the flyweights move outward, away from the driving shaft, and pull downward the toggle mechanism to close the breaker. This action raises the counterweight, which returns to its normal position after the breaker opens and reset the toggle mechanism for the next closing operation.

The circuit breaker at all times trips free from the mechanism, and is normal-ly tripped by overload trip coils.

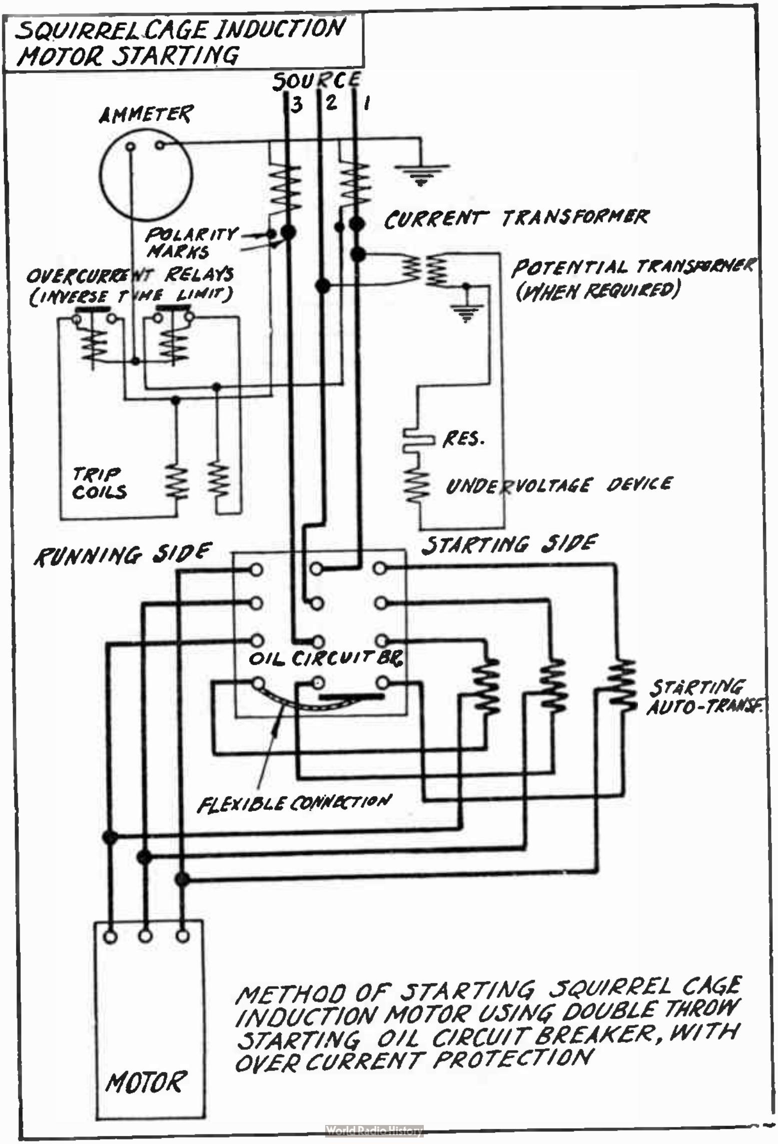

OIL CIRCUIT BREAKER
AND DIAGRAM
3 2 1
Trip Coils
Oil Circ.
Breaker
Trip coil
Calibrating
Tubes
Oil vessel removed
Current Transformers
OIL CIRCUIT BREAKER
MOUNTED ON PANEL FRAME
– WITH TYPICAL –
WIRING DIAGRAM
Three-Phase System
Grounded neutral.



SINGLE POLE OIL CIRCUIT BREAKER UNIT WITH OIL VESSEL REMOVED (General Electric Mfg.)



SQUIRREL CAGE INDUCTION MOTOR STARTING
SOURCE
AMMETER
3
2
1
CURRENT TRANSFORMERS
POLARITY MARKS
FUSES
OVERCURRENT RELAYS (I.T.L.)
UNDERVOLTAGE DEVICE (WHEN USED)
AUTO-TRANSF. - LINE
RES.
TRIP COILS
MAIN
AUTO-TRANSF.
STARTING
METHOD OF STARTING SQUIRREL CAGE INDUCTION MOTOR USING TWO SIMULTANEOUSLY OPERATED STARTING OIL CIRCUIT BREAKERS
MOTOR

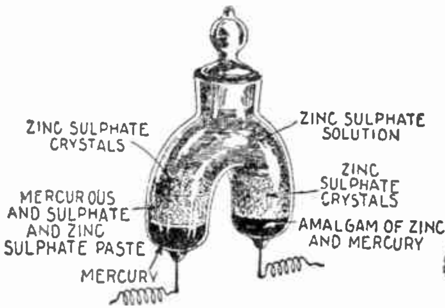

SQUIRREL CAGE INDUCTION MOTOR STARTING
SOURCE
3
2
1
AMMETER
CURRENT TRANSFORMER
POLARITY MARKS
OVERCURRENT RELAYS (INVERSE TIME LIMIT)
POTENTIAL TRANSFORMER (WHEN REQUIRED)
RES.
TRIP COILS
UNDERVOLTAGE DEVICE
RUNNING SIDE
STARTING SIDE
OIL CIRCUIT BR.
STARTING AUTO-TRANSF.
FLEXIBLE CONNECTION
MOTOR
METHOD OF STARTING SQUIRREL CAGE INDUCTION MOTOR USING DOUBLE THROW STARTING OIL CIRCUIT BREAKER, WITH OVER CURRENT PROTECTION

CHAPTER 17

Tests

Most tests are made with a galvanometer and other devices such as switches, resistance sets, etc.

Pressure Measurement.—*The* **total** *pressure of a circuit is*



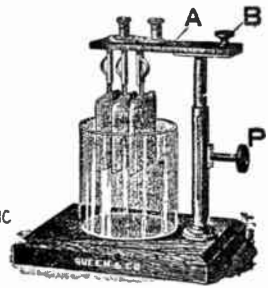


FIG. 6,830.—Clark cell, or standard for the ***International volt.*** The pressure is 1.434 volts at 15° C., decreasing .00115 volt for each increase of 1° C.

FIG. 6,831.—Queen weight voltameter for determining the strength of current by the weight of metal deposited in a given time. ***To calculate,*** the strength of an unknown current which has passed through a weight voltameter, *divide the gain in weight by the number of seconds the current flows through the instrument and by the weight deposited by one ampere in one second.* That is, current strength in amperes = gain in weight ÷ (time in seconds × .0003286).

independent of resistance or current, hence in measuring pressure with an ordinary voltmeter, since the measurement is made on *closed circuit*, the reading gives **less** *than the total pressure.*

The error is very slight because the resistance of the voltmeter is very high and the current so small that the loss of pressure in the battery can be neglected.

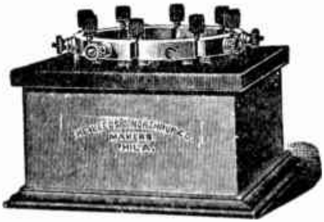
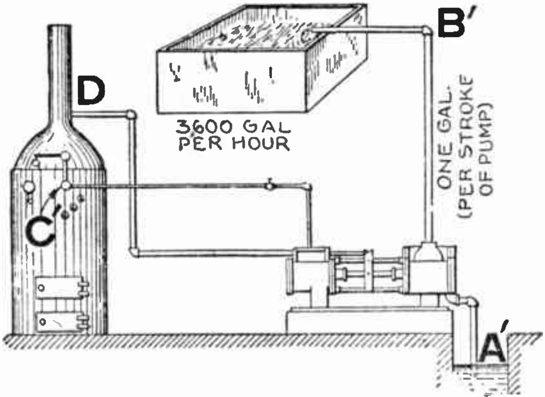


FIG. 6,832.—Standard resistance box: 100,000 ohms, in four units of 10,000, 20,000, 30,000, and 40,000 ohms. An "infinity" plug separates each coil from the ones adjacent. Segments are elevated from the hard rubber top by special washers in order to increase insulation. Binding posts are so arranged as not to be in the way when plugs are used.



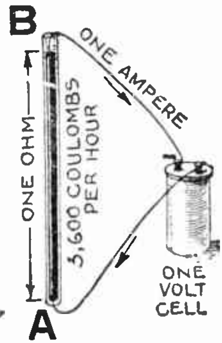
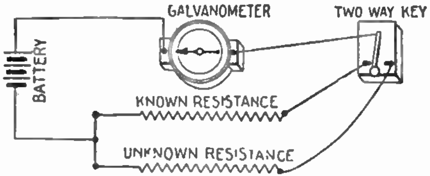


FIG. 6,833.—Diagram of steam pump showing hydraulic analogy illustrating the difference between amperes and coulombs. If the current strength in fig. 6,834 be one ampere, the quantity of electricity passing any point in the circuit per hour is $1 \times 60 \times 60 = 3{,}600$ coulombs. The *rate* of current flow of one ampere here illustrated may be compared to the rate of discharge of a pump as in fig. 6,833. Assuming the pump to be of such size that it discharges a gallon per stroke and is making 60 strokes per minute, the quantity of water discharged per hour (coulombs in fig. 6,834) is $1 \times 60 \times 60 = 3{,}600$ gallons. Following the analogy further (in fig. 6,834), the pressure of one volt is required to force the electricity through the resistance of one ohm between the terminals A and B. In fig. 6,833, the boiler must furnish steam pressure on the pump piston to overcome the friction (resistance) offered by the pipe and raise the water from the lower level A′ to the higher level B′. The difference of pressure between A and B in the electric circuit corresponds to the difference of pressure between A′ and B′. The cell furnishes the energy to move the current by maintaining a difference of pressure at its terminals C and D; similarly, the boiler furnishes energy to raise the water by maintaining a difference of pressure between the steam pipe C and exhaust pipe D′.

FIG. 6,834—The **International ohm.** By definition, *the resistance of 14.452 grammes of mercury in the form of a column of uniform cross section 106.3 centimeters in length, at a temperature of 0° C.* This is approximately equivalent to a column 106.3 *cm.* long, having a uniform cross section of 1 sq. mm. In the figure the resistance of the external circuit and the standard one volt cell is assumed to be zero.



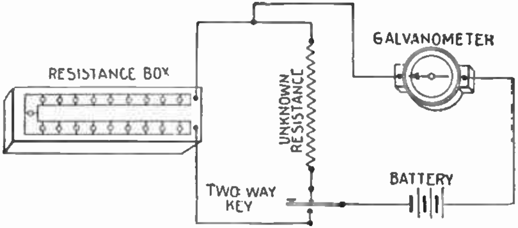
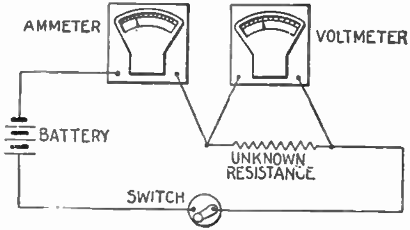


FIG. 6,835.—***Direct deflection method*** of testing resistances; a useful and simple method which may be used in numerous tests. Galvanometer readings are taken through the known, and unknown resistances, and the current being proportional to the deflections, the value of the unknown resistance is easily calculated.

FIG. 6,836.—***Substitution method*** of testing resistances. ***In testing,*** first note deflection with unknown resistance in circuit, then press key so that the current will pass through the resistance box, and adjust the resistance in the box so that the deflection of the galvanometer is about the same as with the unknown. Now switch from one circuit to the other, changing the resistance in the box until equal deflections are obtained. When this obtains, the resistance in the box is the same as the resistance being tested.



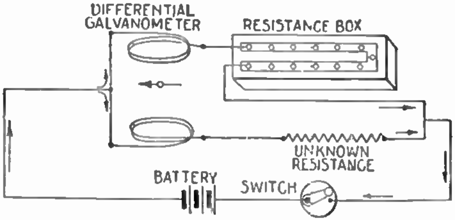
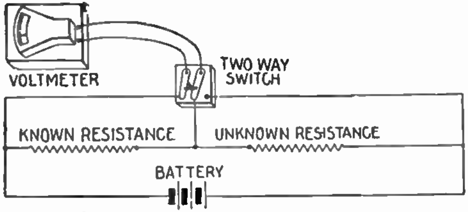


FIG. 6,837.—***Fall of potential method*** of testing resistances; a convenient method for testing at stations, requiring only the usual instruments to be found at a station. The resistance of the voltmeter must be very high.

FIG. 6,838.—***Differential galvanometer method*** of testing resistances. ***In making the test,*** the resistance box is adjusted till the galvanometer needle shows no deflection. When this condition obtains, the resistance in circuit in the resistance box is equal to the unknown resistance, hence, a reading of the box gives the value of the unknown resistance



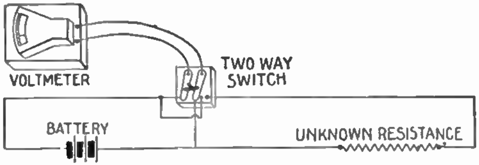
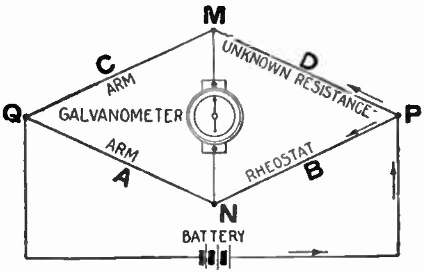


FIG. 6,839.—***Drop method*** of testing resistances. The apparatus is connected as shown and readings taken with voltmeter across known and unknown resistance. The unknown resistance is then easily calculated.

FIG. 6,840.—***Voltmeter method*** of testing resistances. Knowing the resistance of the voltmeter, turn switch to the left and from reading calculate resistance corresponding to one division of the scale. Turn switch to right and multiply reading by resistance required for deflection of one division. This gives resistance of voltmeter and unknown resistance; subtracting from this the resistance of voltmeter gives value of the unknown resistance.



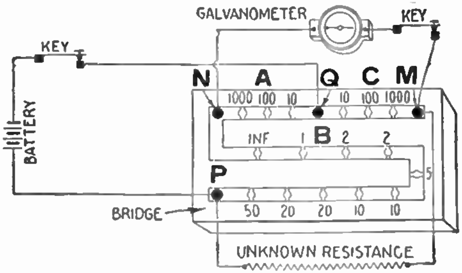
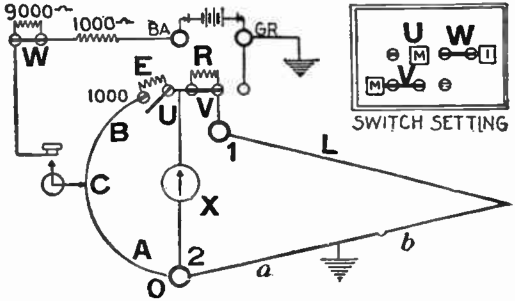


FIG. 6,841.—Diagram showing principle of ***Christie*** or ***so-called*** Wheatstone's bridge. A,B,C. and D, are the four members which constitute the bridge. The current from the battery divides at P, part traversing DC, and part transversing BA. The galvanometer, connected to M and N, will indicate when the currents are equal in the two branches by giving *no* deflection. This is then a *zero* or *nil method* of testing. The resistances and keys required in testing are arranged in fig. 6,842. In the actual instrument, the members A,B,C, and D are known by the names given in the figure.

FIG. 6,842.—Diagram showing usual arrangement of resistances in arms of Wheatstone's bridge. ***In practice***, the bridge is seldom or never made in the lozenge shape of the diagram, fig. 6,841, this diagram being given merely for clearness. The resistance box of fig. 6,842 is, in itself, a complete "bridge," the appropriate connections being made by screws at various points. The letters in the above diagram correspond with those in fig. 6,841 and the three figures should be carefully compared.

Current Measurement.—The unit of current, called the *ampere*, is defined as *the unvarying current which, when passed through a solution of nitrate of silver in water* (15 *per cent. by weight of the nitrate*) *deposits silver at the rate of* .001118 *gramme per second.*

This chemical decomposition is measured by an electrolytic cell called a *voltameter.*



FIGS. 6,843 and 6,844—Murray loop method of fault location with leeds and Northrup fault finder, *Case 1.*—When there are two wires having equal resistance, in one of which there is a fault. Connect and set switches as shown; join the good wire to post 1 and the faulty wire to post 2. The resistance of E, is equal to that of AB. From the symmetry of the arrangement, it is evident that, if the fault were exactly at the junction between the good and bad wires, the contact point C, would rest for a balance at 1,000 on the scale, or at 500 if the fault were half-way along the bad wire; hence, at whatever point it comes to rest, the reading divided by 1,000 and multiplied by the length of the bad wire is the distance from the instrument to the fault.

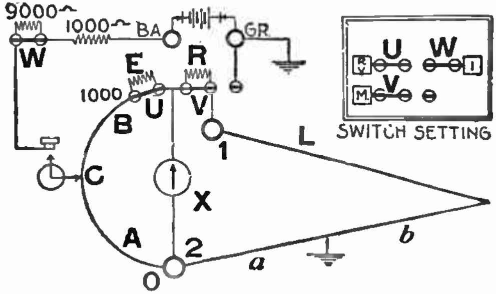
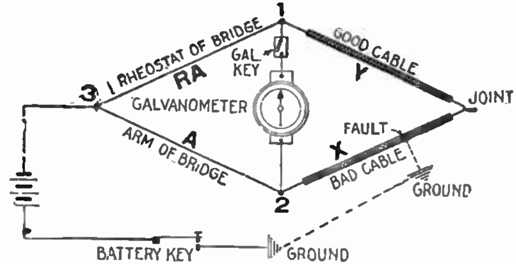


FIG. 6,845 and 6,846.—Murray loop method of fault location with Leeds and Northrup fault finder: *Case 2.*—Where the good and bad wires are unequal. The figure shows the connections. It is the ordinary Murray loop and it is evident that the resistance *v*, to the fault will be obtained from the formula *a*—(A ÷ 1,000) X *r*, where *r*, is the resistance of the loop, and A, is the reading of the contact C, on its scale. The distance *d*, to the fault is obtained from the formula *d*=A*r* ÷ (1,000 X M) where M is the resistance per mile of the faulty wire



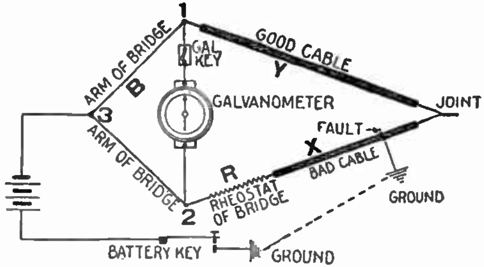
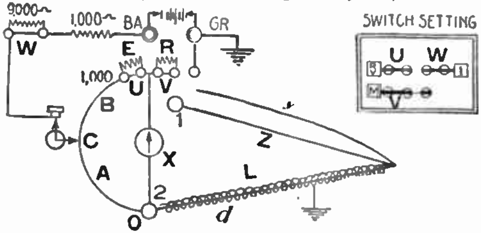
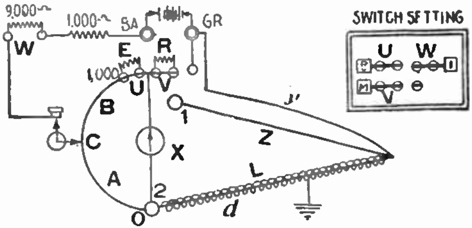


Fig. 6,847.—The Murray loop test. The apparatus is connected as in the figure. The rheostat of the bridge is used in place of the second arm to permit large adjustment. X and Y, are the resistances of the cable between the fault and the points 1 and 2 respectively.

Fig. 6,848.—The Varley loop test. The diagram shows the various connections. X and Y, are the resistances of the cable between the fault and the points 1 and 2 respectively. L, is the resistance of the good and bad cable or X + Y.





Figs. 6,849 and 6,850.—Special loop test with Leeds and Northrup fault finder. For the first measurement connect the faulty wire to 2, either of the good wires, as Z, to 1, the post Gr, to ground, and short circuit the coils R and E, by closing switches U and V, as in the figures. Balance in the usual way and call the dial reading A. For the second measurement, connect the post Gr, (disconnected from ground), to the other good wire y as shown in figs. 6,851 and 6,852, and get another balance; call this reading A′. The distance d, to the fault is determined from the simple formula $d = AL \div A'$ where L, is the length of the cable or faulty wire.

Figs. 3,851 and 6,852.—Special loop test as made with the Leeds and Northrup fault finder. Diagram showing connections for the second measurement. The special loop test may be used to advantage where the length of the cable or faulty wire only is known, and where there are two other wires which may be used to complete the loop. To use an outside battery, connect one pole to Ba, and ground the other. The pressure of this battery must never exceed 110 volts; if it be over 25 volts, see that switch W, is open.

Resistance Measurement.—Ohm's law shows that the strength of the current falls off in proportion as the resistance in the circuit increases.

This gives a basis for measuring resistance. There are various methods by which an unknown resistance may be measured, as by the: 1, direct deflection method; 2, method of substitution; 3, fall of potential method; 4, differential galvanometer method; 5, drop method; 6, voltmeter method; 7, wheatstone bridge method.

Christie Bridge.—For accurate measurements of resistance this method is almost universally used.

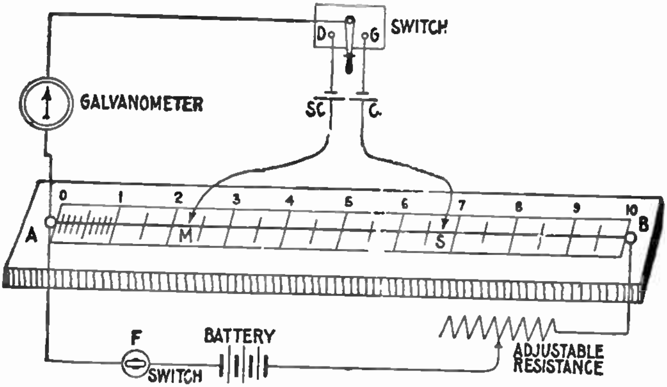


FIG. 6,853.—Diagram of potentiometer showing method of measuring the voltage of a cell. The potentiometer is simply a high resistance wire of uniform diameter stretched between two binding posts, A and B, in such a way that contact can be made at its ends and along its length. Necessary circuits are plainly shown in the figure; Sc, is a *standard cell* and C, the cell to be tested. M, and S are sliding contacts, connecting with the "slide wire."

The so-called "Wheatstone" bridge was invented by Christie, and improperly credited to Wheatstone, who simply applied Christie's invention to the measurement of resistances.

Loop Test.—This is a method of *locating a fault in a telegraph or telephone circuit when there is a good wire running parallel with the defective one.*

In the process, the good and bad wires are joined at their distant ends and one terminal of the battery is connected to a Wheatstone bridge, while the other terminal is grounded. There are different ways of making loop tests as by: 1, Murray loop; 2, Varley loop; 3, Special loop.

Commercial Testing

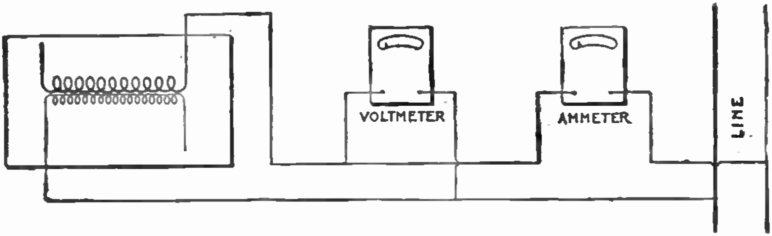


FIG. 6,854.—Transformer insulation resistance test. The insulation, besides being able to resist puncture, due to increased voltage, must also have sufficient resistance to prevent any appreciable amount of current flowing between primary and secondary coils. It is, therefore, sometimes important that the insulation resistance between primary and secondary be measured. This can be done, as here shown. Great care should be taken to have all wires thoroughly insulated from the ground, and to have an ammeter placed as near as possible to the terminals of the transformer under test, in order that current leaking from one side of the line to the other, external to the transformer, may not be measured. Great care is required in making this measurement, in order to obtain consistent results.

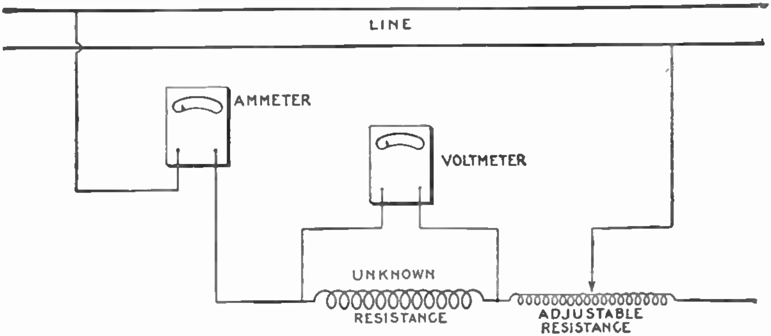


FIG. 6,855.—Resistance measurement by "drop" method. The circuit whose resistance is to be measured, is connected in series with an ammeter and an adjustable resistance to vary the flow of current. A voltmeter is connected directly across the terminals of the resistance to be measured, as shown in the figure. According to Ohm's law $I = E \div R$, from which, $R = E \div I$. If then the current flowing in the circuit through the unknown resistance be measured, and also the drop or difference of pressure, the resistance can be calculated by above formula. In order to secure accurate determination of the resistance such value of current must be used as will give large deflections of the needle on the instruments employed. A number of independent readings should be taken with some variation of the current and necessarily a corresponding variation in voltage. The resistance should then be figured from each set of readings and the average of all readings taken for the correct resistance.

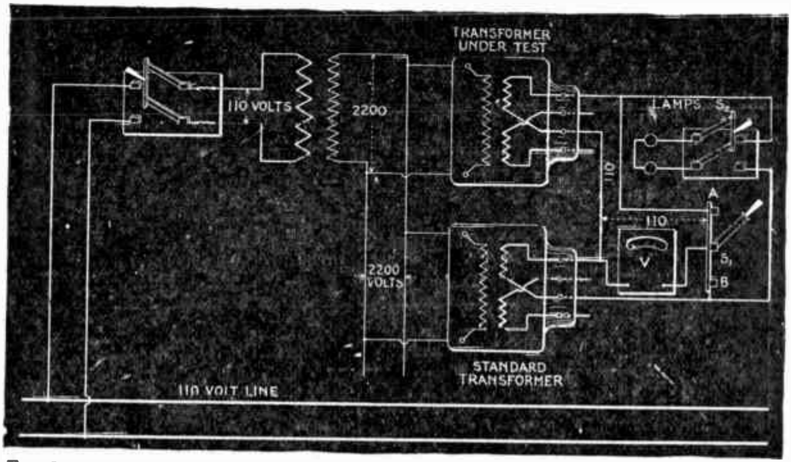


FIG. 6,856.—Transformer winding or ratio test. The object of this test is to check the ratio between the primary and the secondary windings. For this purpose a transformer of known ratio is used as a standard. Connect the transformer under test with a standard transformer as shown. Leave switch S_2, open. With the single pole double throw switch in position, S_1B, the voltmeter is thrown across the terminals of the standard transformer. With the switch in position S_1A, the voltmeter is thrown across the terminals of the transformer under test. The voltmeter should be read with the switch in each position. If the winding ratio be the same as that of the standard transformer, the two voltmeter readings will be identical.

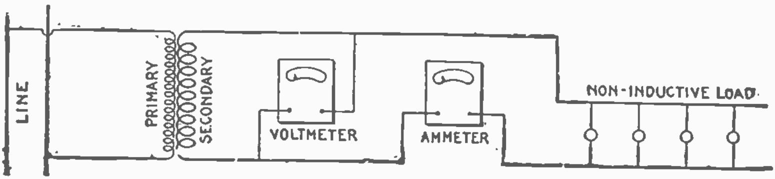


FIG. 6,857.—Temperature test of transformer with non-inductive load. The figure shows the simplest way of making the test. Connect the primary of the transformer to the line as shown, and carry normal secondary load by means of a bank of lamps or other suitable resistance, until full load secondary current is shown by the ammeter in the secondary circuit. The transformer should then be allowed to run at its rated load for the desired interval of time, temperature readings being made of the oil in its hottest part, and also of the surrounding air. Where temperatures of the coil rather than temperatures of the oil are desired, it is necessary to use the resistance method. This is obtained by first carefully measuring the resistance of both primary and secondary coils at the temperature of the room, and then, after the transformer has been under heat test for the desired time, disconnect it from the circuit and again measure the resistance of primary and secondary. For proper method of calculating the temperature rise from resistance measurements, the reader is referred to the standardization rules of the A. I. E. E. In making resistance measurements of large transformers by the drop method care should be taken to allow both ammeter and voltmeter indications to settle down to steady values before readings are taken. This may require several minutes. Each time the current is changed it is necessary in order to obtain check values on resistance measurements, to wait until the current is again settled to its permanent value before taking readings.

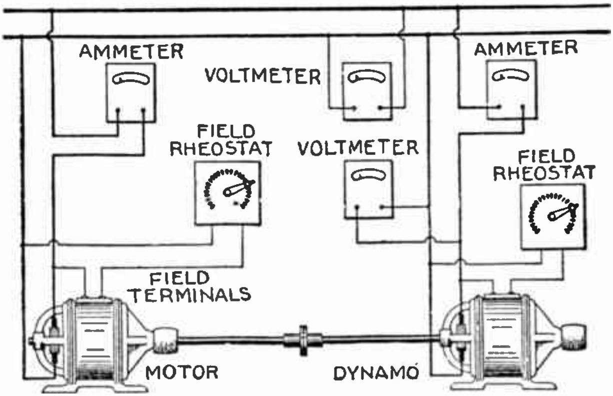


FIG. 6,858.—Temperature test of direct current motor or dynamo; loading back method. The motor is started in the usual way, with the dynamo belted to it, the circuit of the dynamo being open. The field of the dynamo is then adjusted so that the dynamo voltage is equal to that of the line. The dynamo is then connected to the circuit and its field resistance varied until it carries normal full load current. Under these conditions, if the motor and dynamo be of the same size and type, the motor will carry slightly in excess of full load, the difference being approximately twice the losses of the machines. Under these conditions the total power drawn from the line is equal to twice the loss of either machine. Temperature readings are taken as in other temperature tests.

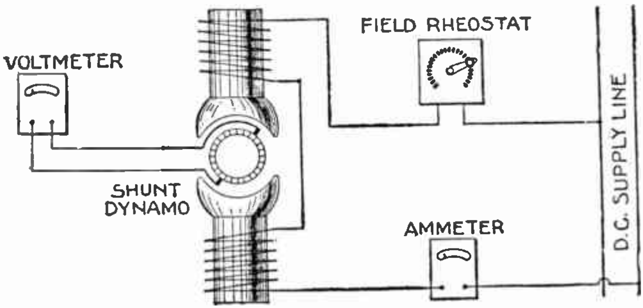


FIG. 6,859.—Direct motor or dynamo magnetization test. The object of this test is to determine the variation of armature voltage without load, with the current flowing through the field circuit. The armature should be driven at normal speed. The adjustment resistance in the field circuit is varied and the voltage across the armature measured. The curve obtained by plotting these two figures is usually called magnetization curve of the dynamo. It is usual to start with the higher resistance in the field circuit so that very small current flows, gradually increasing this current by cutting out the field resistance. When the highest no load voltage required is reached, the field current is then diminished, and what is called the descending (as opposed to the ascending) magnetization curves are obtained. The difference in the two curves is due to the lag of the magnetization behind the magnetizing current, and is caused by the hysteresis of the iron of the armature core.

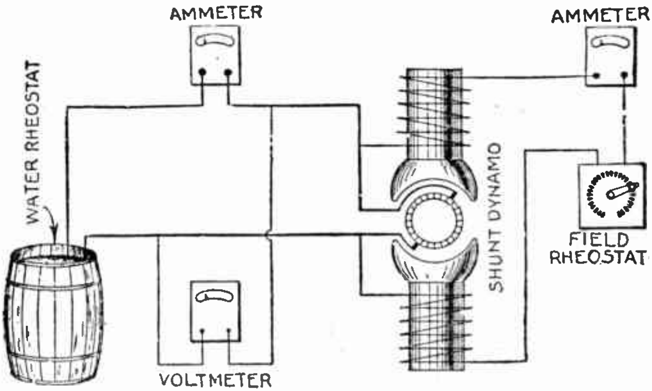


FIG. 6,860.—Shunt dynamo, external characteristic test. The shunt field is so adjusted that the machine gives normal voltage when the external circuit is open. The field current is then maintained constant and the external current varied by varying the resistance in the circuit. By plotting voltage along the vertical, against the corresponding amperes represented along the horizontal, the external characteristic is obtained.

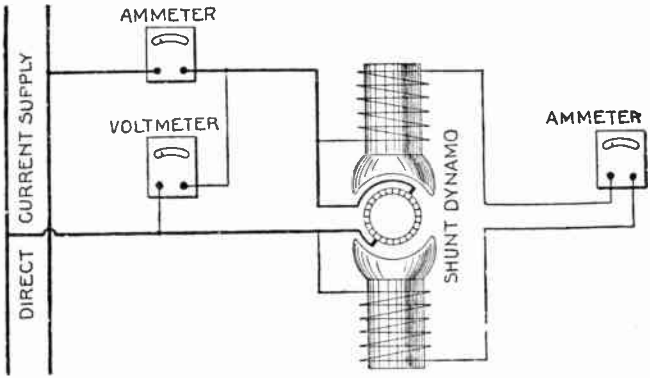


FIG. 6,861.—Load and speed test of direct current shunt motor. *The object* of this test is to maintain the voltage applied to the motor constant, and to vary the load by means of a brake and find the corresponding variation in speed of the machine and the current drawn from the circuit If the motor be a constant speed motor, the field resistance is maintained constant. The above indicates the method of connecting instruments for the test alone; for starting the machine the ordinary starting box should, of course, be inserted.

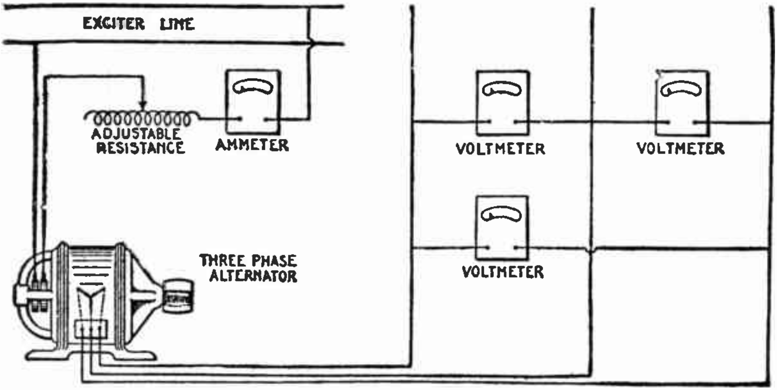


FIG. 6,862.—Alternator excitation or magnetization curve test. The object of this test is to determine the change of the armature voltage due to the variation of the field current when the external circuit is kept open. As here shown, the field circuit is connected with an ammeter and an adjustable resistance in series with a direct current source of supply. The adjustable resistance is varied, and readings of the voltmeter across the armature, and of the ammeter, are recorded. The speed of the generator must be kept constant, preferably at the speed which is given on the name plate. The excitation or magnetization curve of the machine is obtained by plotting the current and the voltage.

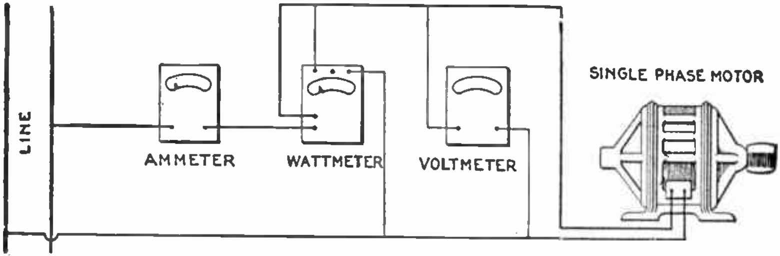


FIG. 6,863.—Single phase motor test. In this method of measuring the input of a single phase motor of any type, the ammeter, voltmeter and wattmeter are connected as shown in the illustration. The ammeter measures the current flowing through the motor, the voltmeter, the pressure across the terminals of the motor, and the wattmeter the total power which flows through the motor circuit. With the connections as shown, the wattmeter would also measure the slight losses in the voltmeter and the pressure of coil of the wattmeter, but for motors of ¼ H.P. and larger, this loss is so small that it may be neglected. The power factor may be calculated by dividing the true watts as indicated by the wattmeter, by the product of the volts and amperes.

NOTE.—In motor testing, by the methods illustrated in the accompanying cuts, it is assumed that the motor is loaded in the ordinary way by belting or direct connecting the motor to some form of load, and that the object is to determine whether the motor is over or under loaded, and approximately what per cent. of full load it is carrying. All commercial motors have name plates, giving the rating of the motor and the full load current in amperes. Hence the per cent. of load carried can be determined approximately by measuring the current input and the voltage.

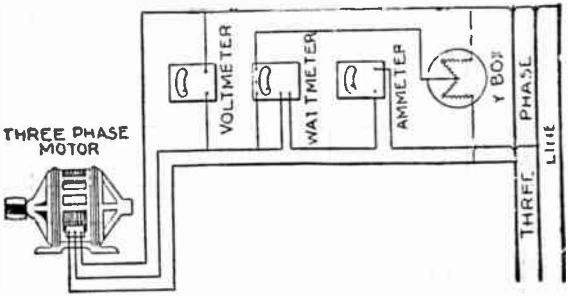


FIG. 6,864.—Three phase motor, one watt meter and Y box method. This method is of service only, provided the voltages of the three phases are the same. A slight variation of the voltage of the different phases may cause a very large error in the readings of the wattmeter, and inasmuch as the voltage of all commercial three phase circuits is more or less unbalanced, this method is not to be recommended for motor testing. With balanced voltage in all three phases, the power is that indicated by the wattmeter, multiplied by three. Power factor may be calculated as before.

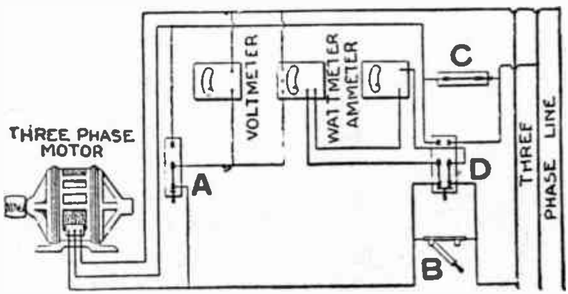


FIG. 6,865.—Three phase motor test; one watt meter method .This method is equivalent to the two watt meter method with the following difference. A single volt meter (as shown above) with a switch, A, can be used to connect the volt meter across either one of the two phases. Three switches, B, C, and D, are employed for changing the connection of the ammeter and watt meter in either one of the two lines. With the switches B and D, in the position shown, the ammeter and watt meter series coils are connected in the left hand line. The switch C, must be closed under these conditions in order to have the middle line closed. Another reading should then be taken before any change of load has occurred, with switch A, thrown to the right, switch B, closed, switch D, thrown to the right and switch C, opened. The ammeter and the current coil of the watt meter will then be connected to the middle line of the motor. In order to prevent any interruption of the circuit, the switches B, D and C, should be operated in the order given above. With very light load on the motor the watt meter will probably give a negative deflection in one phase or the other, and it will be necessary to reverse its connections before taking the readings. For this purpose a double pole, double throw switch is sometimes inserted in the circuit of the pressure coil of the watt meter so that the indications can be reversed without disturbing any of the connections. It is suggested, before undertaking this test, that the instructions for test by two watt meter and by the polyphase watt meter methods be read.

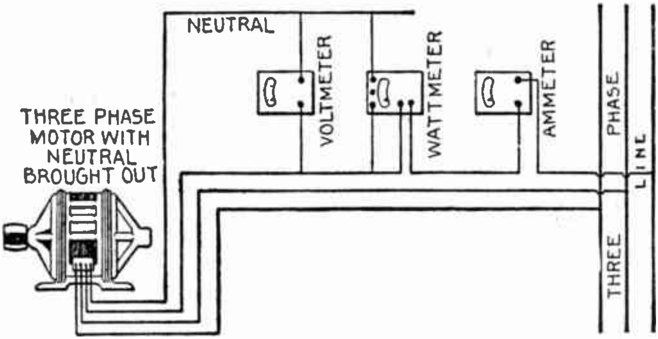


FIG. 6,866.—Test of three phase motor with neutral brought out; single watt meter method. Some star connected motors have the connection brought out from the neutral of the winding. In this case the circuit may be connected, as here shown. The volt meter now measures voltage between the neutral and one of the lines, and the watt meter the power in one of the three phases of the motor. Therefore, the total power taken by the motor will be three times the watt meter readings. By this method, just as accurate results can be obtained as with the two watt meter method. The power factor will be the indicated watts divided by the product of the indicated amperes and volts.

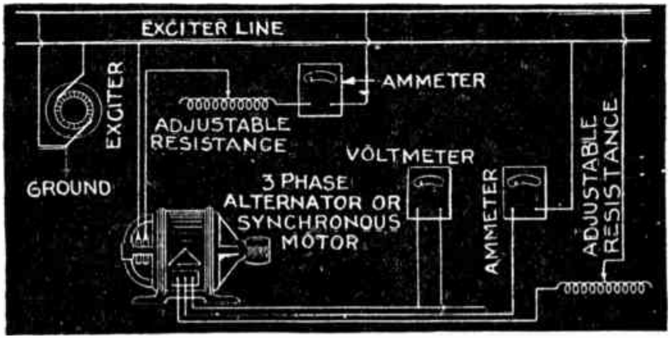


FIG. 6,867.—Three phase alternator or synchronous motor temperature test. Supply the field with normal field current. The armature is connected in open delta as illustrated, and full load current sent through it from an external source of direct current, care being taken to ground one terminal of the dynamo so as to avoid danger of shock due to the voltage on the armature winding. The field is then driven at synchronous speed. If the armature be designed to be connected star for 2,300 volts, the voltage generated in each leg of the delta will be 1,330 volts, and unless one leg of the dynamo were grounded, the tester might receive a severe shock by coming in contact with the direct current circuit. The insulation of the dynamo would also be subjected to abnormal strain unless one terminal were grounded. By the above method the field is subjected to its full copper loss and the armature to full copper loss and core loss. Temperature readings are taken as per standardization rules of the A. I. E. E. This method may also be used with satisfactory results on large three phase motors of the wound rotor type. If the alternator pressure be above 600 volts, a pressure transformer should be used in connection with the voltmeter.

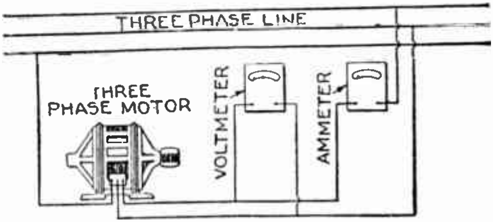


FIG. 6,868.—Three phase motor test; voltmeter and ammeter method. If it be desired to determine the approximate load on a three phase motor, this may be done by means of the connections as shown in the figure, and the current through one of the three lines and the voltage across the phase measured. If the voltage be approximately the rated voltage of the motor and the amperes the rated current of the motor (as noted on the name plate) it may be assumed that the motor is carrying approximately full load. If, on the other hand, the amperes show much in excess of full load rating, the motor is carrying an overload. The heat generated in the copper varies as the square of the current. That generated in the iron varies anywhere from the 1.6 power, to the square. This method is very convenient if a wattmeter be not available, although, it is, of course, of no value for the determination of the efficiency or power factor of the apparatus. This method gives fairly accurate results, providing the load on the three phases of the motor be fairly well balanced. If there be much difference, however, in the voltage of the three phases, the ammeter should be switched from one circuit to another, and the current measured in each phase. If the motor be very lightly loaded and the voltage of the different phases vary by 2 or 3 per cent., the current in the three legs of the circuit will vary 20 to 30 per cent.

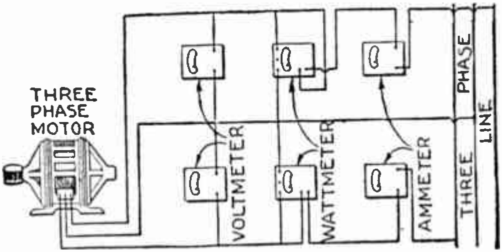


FIG. 6,869.—Three phase motor test by the two wattmeter method. If an accurate test of a three phase motor be required, it is necessary to use the method here indicated. Assume the motor to be loaded with a brake so that its output can be determined. This method gives correct results even with considerable unbalancing in the voltages of the three phases. With the connections as shown, the sum of the two wattmeter readings gives the total power in the circuit. Neither meter by itself measures the power in any one of the three phases. In fact, with light load one of the meters will probably give a negative reading, and it will then be necessary to either reverse its current or pressure leads in order that the deflection may be noted. In such cases the algebraic sums of the two readings must be taken. In other words, if one read plus 500 watts and the other minus 300 watts, the total power in the circuit will be 500 minus 300, or 200 watts. As the load comes on, the readings of the instrument which gave the negative deflection will decrease until the reading drops to zero, and it will then be necessary to again reverse the pressure leads on this wattmeter. Thereafter the readings of both instruments will be positive, and the numerical sum of the two should be taken as the measurement of the load. If one set of the instruments be removed from the circuit, the reading of the remaining wattmeter will have no meaning. As stated above, it will not indicate the power under these conditions in any one phase of the circuit. The power factor is obtained by dividing the actual watts input by the product of the average of the voltmeter readings × the average of the ampere readings × 1.73.

CHAPTER 18

Wires and Wire Calculations

To acquaint the reader with the terminology employed in this and subsequent chapters, the following definition of terms most commonly used are given:

Appliance.—Appliances are current consuming equipment, fixed or portable for example, heating, cooking and small motor operated equipment.

Branch Circuit.—That portion of a wiring system extending beyond the final overcurrent device protecting the circuit. A device not approved for branch circuit protection, such as a thermal cutout or motor overload protective device, is not considered as the overcurrent device protecting the circuit.

Branch Circuits (Appliance).—Appliance branch circuits are circuits supplying energy either to permanently wired appliances or attachment plug receptacles, that is, appliance or convenience outlets or to a combination of permanently wired appliances and additional attachment plug outlets on the same circuit; such circuits to have no permanently connected lighting fixtures.

Branch Circuits (Combination Lighting and Appliance).—Combination lighting and appliance branch circuits are circuits supplying energy to both lighting outlets and appliance outlets.

Branch Circuits (Lighting).—Lighting branch circuits are circuits supplying energy to lighting outlets only.

Branch Circuits (Motor).—A motor branch circuit is a branch circuit supplying energy only to motors.

Cabinet.—A cabinet is an enclosure designed either for surface or flush mounting and provided with a frame, mat or trim in which swinging doors are hung.

Conduit Box.—A conduit box is a metal box adapted for connection to conduit for the purpose of facilitating wiring, making connections, mounting devices, etc.

Distribution Center.—A distribution center is a point at which is located equipment consisting generally of automatic overload protective devices connected to buses, the principal functions of which are the subdivision of supply and the control and protection of feeders, sub-feeders or branch circuits or any combination of feeders, sub-feeders or branch circuits.

Distribution Center (Branch Circuit).—A branch circuit distribution center at which branch circuits are supplied.

Distribution Center (Feeder).—A feeder distribution center is a distribution center at which feeders or sub-feeders are supplied.

Distribution Center (Main).—A main distribution center is a distribution center supplied directly by mains.

Feeder.—A feeder or feeder circuit is a conductor or group of conductors of a wiring system between the service equipment or the generator switchboard of an isolated plant, and the branch circuit overcurrent device.

A feeder or feeder circuit in an interior wiring system, is a set of conductors extending from the original source of energy in the installation to a distributing center and having no other circuits connected to it between the source and the center.

Sub-Feeder.—A sub-feeder is an extension of a feeder, or of another sub-feeder, from one distribution center to another and having no other circuit connected to it between the two distribution centers.

Junction Box.—A junction box is a metal box with a blank cover which serves the purpose of joining different runs of conduit, tubing wireway or raceway, and provides space for the connection and branching of the enclosed conductors.

Knockout.—A knockout is a portion of the wall of a box or cabinet so fashioned that it may be removed readily by the blow of a hammer at the time of installation in order to provide a hole, usually circular in shape for the entrance of wires or the attachment of conduit, cable, etc.

Mains.—A main is any supply circuit to which other consuming circuits, sub-mains or branches, are connected through automatic cutouts (fuses or circuit breakers) at different locations along its length. An energy consuming device is never connected directly to a main, a cutout is always being interposed between the device and the main.

Mains (Interior Wiring).—Mains are the conductors extending from the service switch, generator bus or converter bus to the main distribution center.

Service Conductors.—That portion of the supply conductors which extends from the street main or duct or from transformers to the service equipment of the premises supplied. For overhead conductors this includes the conductors from the last line pole to the service equipment.

Service Equipment.—The necessary equipment, usually consisting of circuit breaker or switch and fuses and their accessories located near the point of entrance of supply conductors to a building and intended to constitute the main control and means of cutoff for the supply to that building.

Service (Master).—A master service is a service supplying the service equipment which supplies a group of buildings under one management.

Pull Box.—A pull box is a metal box with a blank cover which is inserted in a run of conduit, raceway or tubing to facilitate pulling in the conductors, or which is installed at the termination of one or more runs of conduit, raceway tubing or wireway for the purpose of distributing the conductors.

Direct Current Wiring

By direct current wiring we generally mean a system of wiring in which the current flowing in the wires is supplied by means of *direct current generators*, *rectifiers* or *batteries*.

Direct current although occasionally found as a source of power and light in industrial plants is not used to any large extent except for electric railroad operation where the third rail system of power distribution is being used. Other locations where direct current has found employment is in metal refinery and electroplating processes and also in certain industries where close regulation of motor speed is required.

The possibility of obtaining a wide range of speed adjustment and maintenance of nearly constant speed relations makes the direct current motor useful particularly in reversing steel mill drives and other locations where close speed regulation is necessary.

Wiring Systems.—There are two wiring systems in general use for direct current work. They are:

1. Two wire, and
2. Three wire systems.

The source of electrical supply may be a central or an isolated plant. The greater part of interior wiring is done on the two-wire system, the three-wire system being used primarily for feeders and mains.

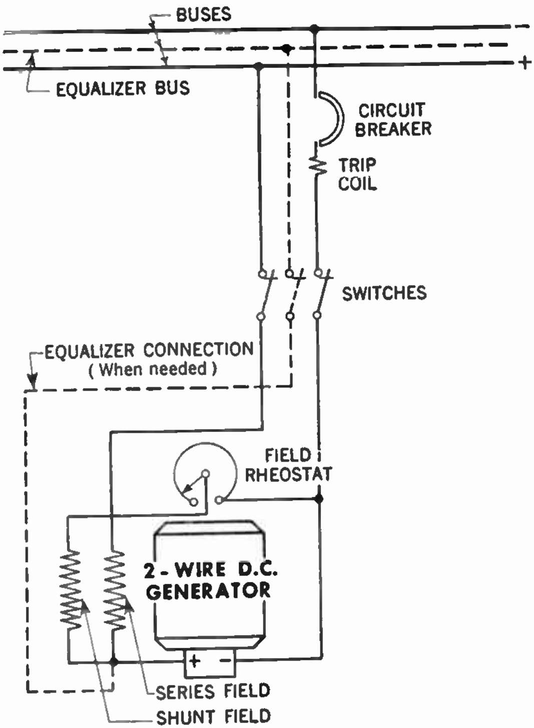


FIG. 6,870.—Typical connection diagram of two-wire direct current generator protected by a single pole circuit breaker.

Direct current three-wire systems usually employ a three-wire generator with an external balance coil, although instead of one balance coil two such coils are sometimes used. In a system of this type the center tapped balance coil or coils act as a neutral and is therefore usually referred to as the *neutral* or *third* wire.

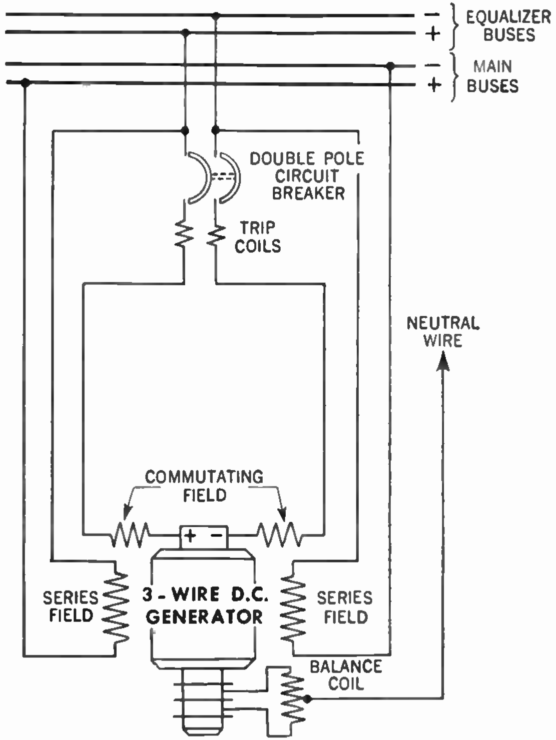


FIG. 6,871.—Typical connection diagram for three-wire generator having one balance coil and a double-pole, double-coil circuit breaker.

With the direct current three wire system, the neutral wire is generally made of the same size as either of the two outer wires. The reason for having the three wires of the system of the same size is because if one of the outer fuses should burn out, one side of the system would be loaded while the other wire would have no current flowing. Where a grounded neutral has the same area or cross section as either of the outer wires, the fuse is generally omitted.

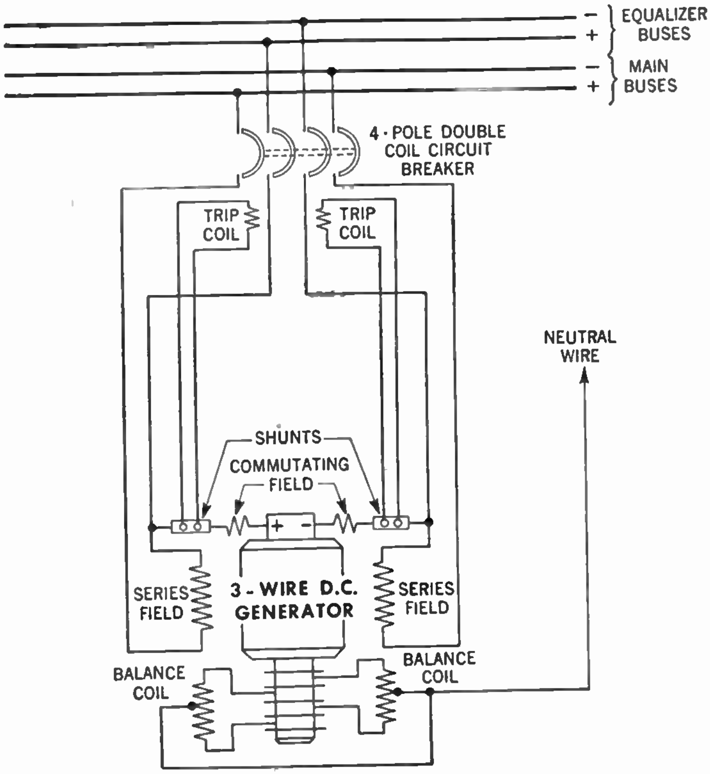


FIG. 6,872.—Typical connection diagram for three-wire generator having two balance coils and a four-pole two-coil circuit breaker.

When designing a three-wire distribution system some effort should be made to arrange the load so that the unbalanced current be kept at a minimum, and in any event not to exceed 25% of the full load current flowing in the outer wires. Motors unless very small, are generally connected across the outer wires, and will therefore receive approximately twice the voltage of the lamps, which are connected across one of the outer wires and the neutral.

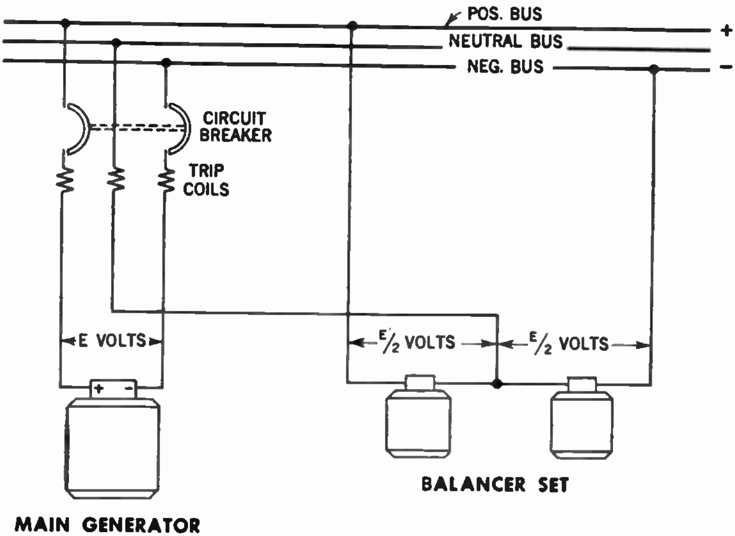


FIG. 6,873.—Typical connection diagram of balancer set operated in connection with a two-wire generator to supply a three-wire direct current system. On a balanced load both machines constituting the balancer set run *light* as motors, but with an unbalanced load one machine runs as a motor, thus driving the other machine which runs as a generator, since they are both mechanically as well as electrically connected. According to *Code requirements*, two wire generators used in conjunction with balancer sets to obtain neutrals for three-wire systems shall be equipped with overcurrent devices which will disconnect the three-wire system in the case of excessive unbalancing of voltages.

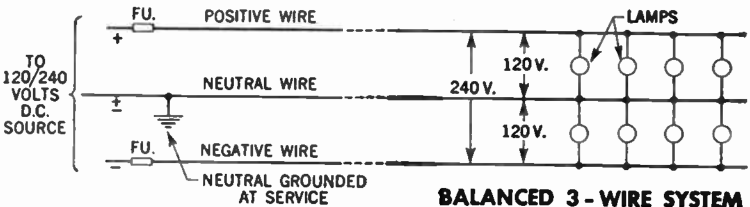


FIG. 6,874.—Three-wire direct current system of distribution. When the same number of lamps of equal size be connected in the manner shown, there will be no current flow in the neutral wire.

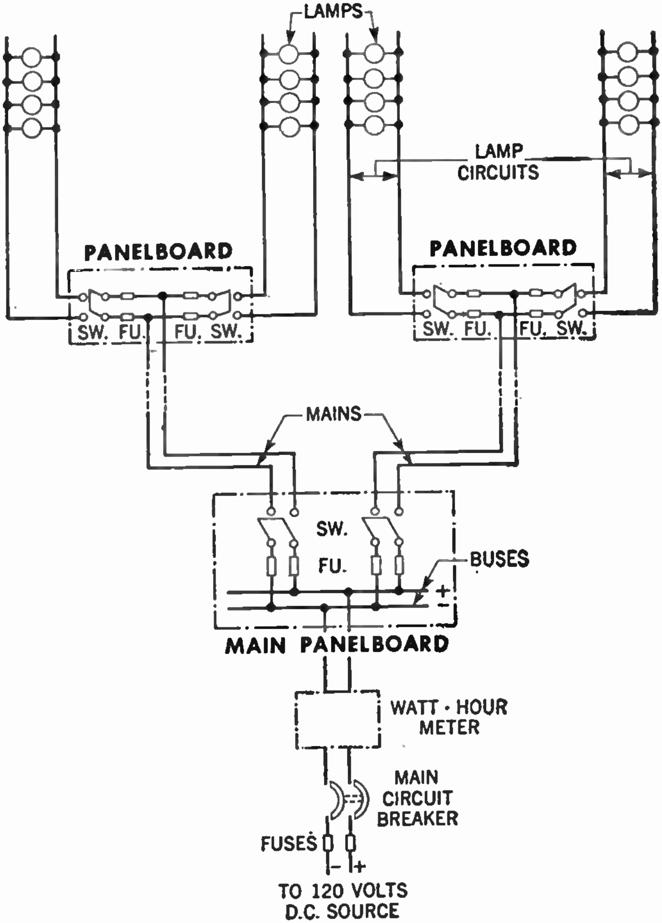


FIG. 6,875.—Showing general scheme of wiring for two-wire system.

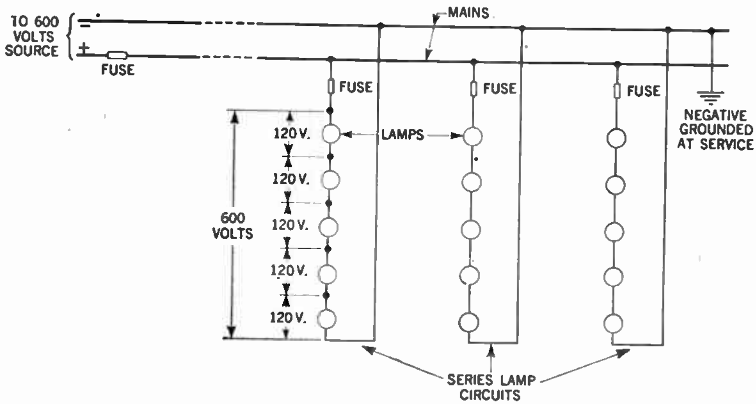


FIG. 6,876.—Series lamp system of distribution. A system of this type is used for lighting chiefly in certain railroad operations where the lamps are connected directly between the third rail and negative conductor. The difference in pressure between any two points in the circuit is equal to the lamp voltage, (about 120 volts) multiplied by the number of lamps in the circuit. The obvious disadvantage in using a system of distribution of this sort is that if one filament burns out the whole circuit will fail (since all lamps are connected in series) in addition if the circuit becomes grounded between any one of the lamps, the lamps will receive an excessive voltage usually ending in failure of the filament or filaments.

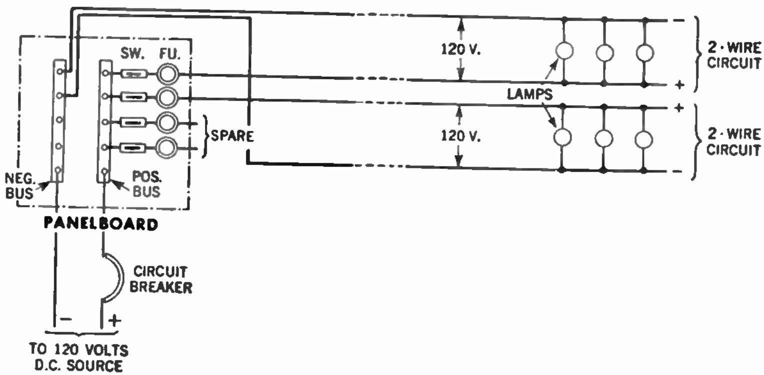


FIG. 6,877.—Showing typical lamp connection to a distribution panel supplied from a two-wire direct current source.

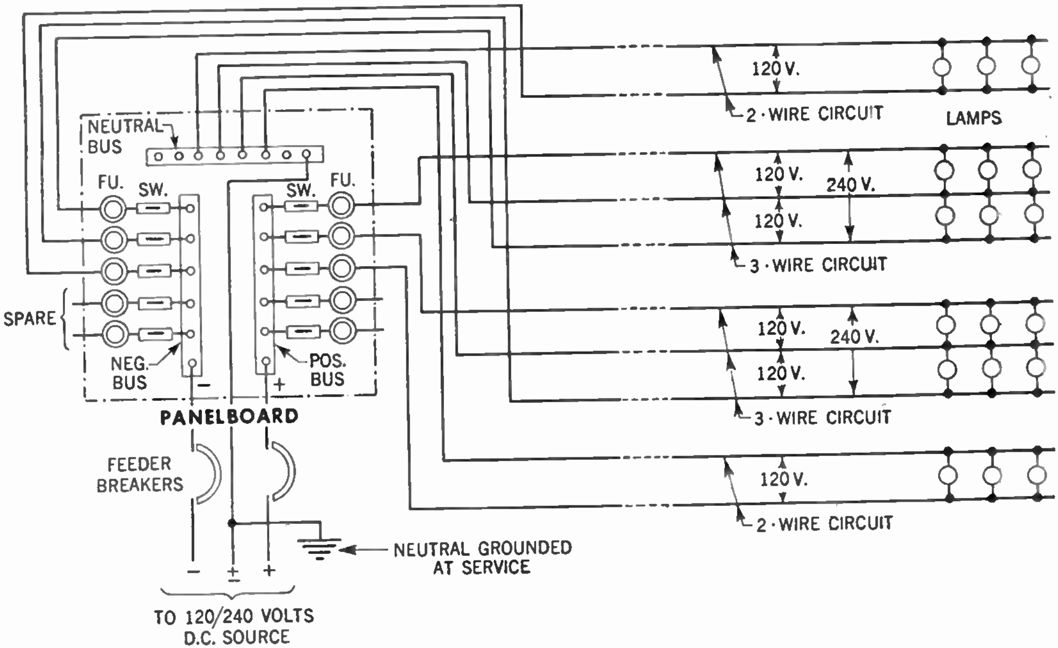


FIG. 6,878.—Showing typical lamp connection to a distribution panel, supplied from a three-wire direct current source. In a three-wire distribution system of this type, the load should be balanced as closely as possible between the two outer wires and the neutral.

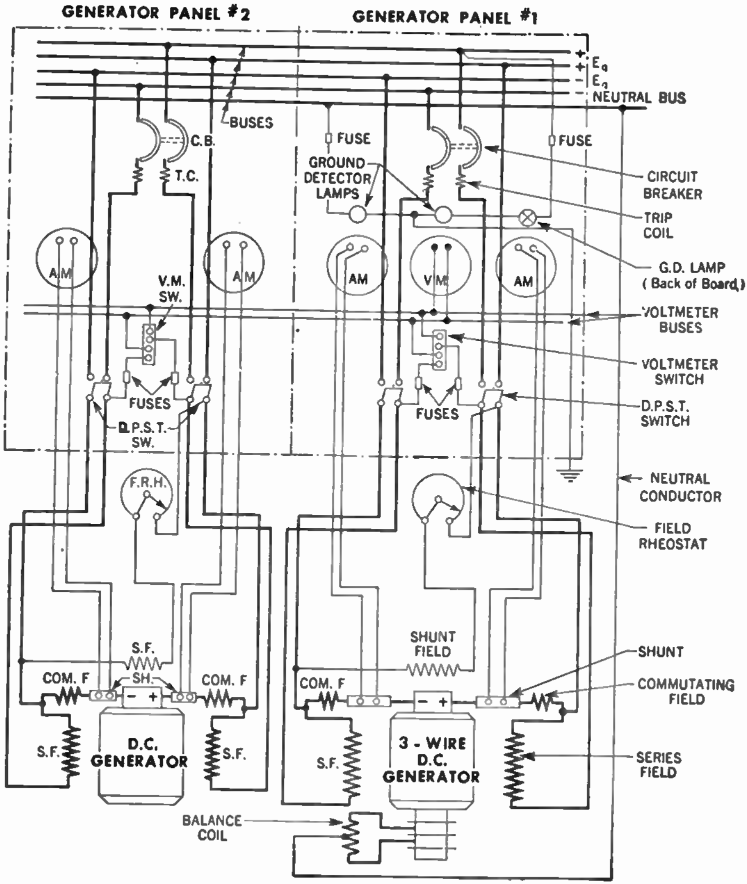


FIG. 6,879.—Showing typical switchboard wiring for parallel operation of two direct current generators. According to Code requirements, three-wire direct current generators, whether compound or shunt wound, shall be equipped with overcurrent devices, one in each armature lead, and so connected as to be actuated by the entire current from the armature. Such overcurrent devices shall consist either of a double-pole, double-coil circuit breaker, or of a four-pole circuit breaker connected in the main and equalizer leads and tripped by two overcurrent devices, one in each armature lead. Such protective devices shall be so interlocked that no one pole can be opened without simultaneously disconnecting both leads of the armature from the system.

Load Center.—The load center of a circuit is that point at which it can be assumed that the total load is concentrated. Thus the load center of a group of equally spaced motors or lamps each of the same size will be at the middle of that group as shown in fig. 6,880.

To determine the load center of a group of appliances of unequal size and spacing proceed as follows:

1. Multiply the current taken by each appliance by its distance to the point of distribution or mains.

2. Add all the products thus found and divide this sum by the total current of the circuit.

A typical example showing the method used for determination of the load center of a circuit is shown in fig. 6,881.

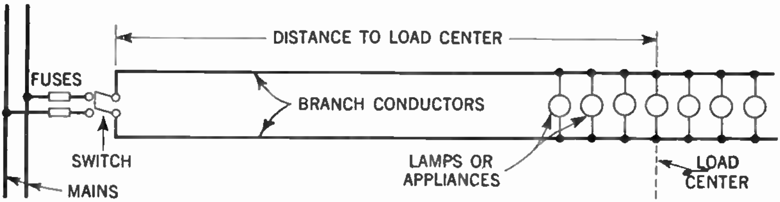


FIG. 6,880.—Showing load center of equally spaced lamps or appliances all of which have the same capacity or current demand.

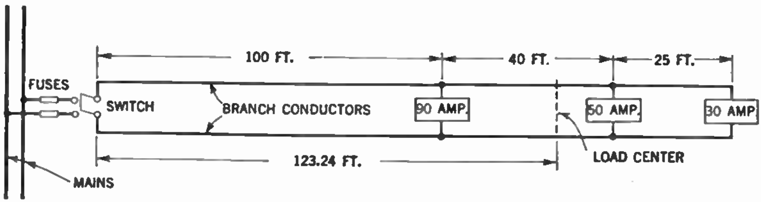


FIG. 6,881.—Illustrating method of calculating load center distance of a circuit having unequal loads unsymmetrically spaced. With reference to text calculation for the above circuit is as follows: Number of ampere feet for the complete load $=100\times90+140\times50+165\times30=$ 20,950. The total amperage of the circuit $=90+50+30$ or 170. The distance in feet from the switch terminal $=20{,}950/170$ or 123.24 feet.

Conductor Economy.—In interior and exterior wiring installations it is often necessary to increase the conductor size beyond that which is required by the *National Electrical Code* because of economical considerations. Obviously any conductor selected for a particular installation must fulfill the requirements of mechanical strength and carrying capacity and the voltage drop must not exceed practical limits.

In most cases one of the foregoing requirements will determine the size of the conductor. It may be well, however, also to consider the power loss (I^2R) which calculation may indicate that it will be desirable to use a larger conductor than contemplated because of the cost of the power wasted due to the excessive resistance in the conductor.

It has been laid down as a general rule, that for the transmission of any given amount of energy, the most economical conductor is one having such a resistance that the value of the energy wasted in heat annually is equal to the interest per annum on the original outlay upon the conductor. This rule is known *Kelvin's Law.* This law is also frequently stated as follows: *The most economical cross-section of a conductor is that for which the annual cost of energy wasted is equal to the interest on that portion of the capital outlay, which can be considered proportional to the weight of copper used.*

Stated mathematically the cross-section of the most economical conductor is:

$$A = 593I \sqrt{\frac{c_1 x h}{c \times p}} \qquad \text{circular mils} \qquad (1)$$

Where I = current in amperes for (h) hours per year.

c_1 = cost of electrical energy in dollars per KWH.

c = cost of wire in dollars per pound.

p = annual percent interest on capital invested in line wires, including depreciation and taxes.

Wiring Calculation.—Because of its favorable electrical and mechanical characteristics *copper* is nearly always used as a conductor for both exterior and interior wiring. Every conductor offers a certain amount of resistance to the flow of current and this resistance varies directly as the length of the conductor, and inversely as its cross-sectional area.

Therefore, if a length of a conductor be known and its cross-sectional area as well as the conductivity of the material, its resistance may easily be calculated. Accordingly, the resistance of any conductor is equal to its *length in feet* multiplied by its *resistance per mil foot*, thus:

$$\text{Resistance in ohms} = \frac{\text{Length in feet} \times \text{Resistance per mil foot.}}{\text{Circular mils}}$$

$$\text{or briefly, Ohms} = \frac{\text{Feet} \times 10.8^*}{\text{Circular mils}} \qquad (2)$$

If letters be used, we obtain the customary formula for a two wire circuit:

$$R = \frac{L \times 21.6}{A} \qquad (3)$$

Where R = resistance in ohms.
L = Length one way or the single distance of the circuit in feet.
A = cross-sectional area of conductor in circular mils.

---

*NOTE 1.—The resistance of a circular mil foot of commercial copper (a wire one foot in length having a cross-sectional area of one circular mil) is usually quoted at from 10.6 to 11 ohms per mil foot at normal temperatures. For practical wiring calculations 10.8 ohms per mil foot is sufficiently accurate to give an acceptable result.

NOTE 2.—In countries where the meter system is being used, the resistance value for commercial copper is quoted as 0.0175 ohm per meter, when the cross-sectional area of the conductor is one square millimeter. The formula for resistance in ohms of a single conductor then becomes:

$$R = \frac{\text{Length in meters} \times 0.0175}{\text{Area in square millimeters}}$$

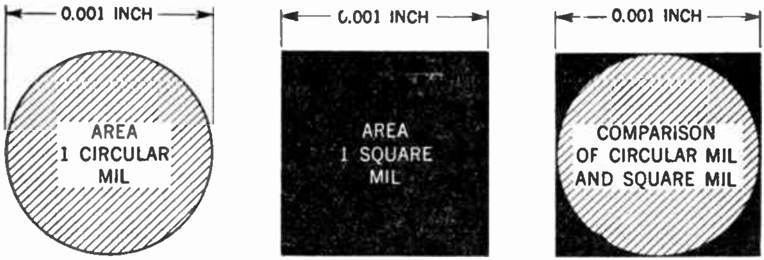
For a complete circuit, we obtain:

$$R = \frac{2 \times \text{Length in meters} \times 0.0175}{\text{Area in square millimeters}}$$

Effect of Resistance.—The effect of resistance to an electric current is to cause a drop in voltage, and the energy lost in overcoming this resistance appears in the form of heat. Now, according to Ohm's law,

$$\text{Volts} = \text{Amperes} \times \text{Ohms} \qquad (4)$$

With the assistance of the foregoing expression the voltage drop in any direct current circuit may readily be obtained. Thus, for example, if the circuit carries a current of 200-*amp.* and the total resistance be say 0.035 ohm, the voltage drop$=200\times0.035$ or 7 volts.



FIGS. 6,882 to 6,884.—Showing greatly enlarged views of circular mil and square mil. Fig. 6,884 indicates relative size of the two units.

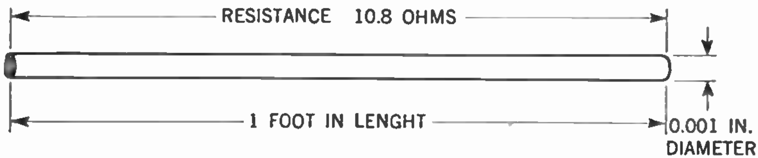


FIG. 6,885.—Illustrating dimensions and approximate resistance of one circular mil-foot of copper.

By substituting in (4) the value for the resistance in ohms as obtained in (2) we have

$$\text{Volts} = \frac{\text{Amperes} \times \text{Feet} \times 10.8}{\text{Circular mils}} \qquad (5)$$

If the customary symbols be used, we may write,

$$E = \frac{I \times L \times 10.8}{A} \tag{6}$$

Where E is the voltage drop, I the current in amperes and A the cross-section of the conductor in circular mils.

In the foregoing formula therefore E means that the volts lost, or drop between the beginning and the end of a circuit is equal to the current flowing through the circuit multiplied by the product of the conductors' length in feet, multiplied by the resistance of one mil foot of wire, divided by the area of the conductor in circular mils.

Since the length of the circuit is given as the "run" or distance one way, that is, one half the total length of wire in the circuit, formula (6) must be multiplied by 2 to get the total drop, therefore we may write:

$$E = \frac{I \times L \times 2 \times 10.8}{A} = \frac{I \times L \times 21.6}{A} \tag{7}$$

If equation (7) be solved with respect to the wire size in circular mils, we have

$$A = \frac{I \times L \times 21.6}{E} \tag{8}$$

Similarly $I = \dfrac{E \times A}{21.6 \times L}$ (9)

and $L = \dfrac{E \times A}{21.6 \times I}$ (10)

Where it is desired to have a working formula for N lamps each of which requires I amperes, we obtain

$$A = \frac{21.6N \times I \times L}{E} \tag{11}$$

If on the other hand, it is desired to find the number of lamps which a given size of wire will supply with a given voltage drop, another formula may be written as follows,

$$N = \frac{A \times E}{21.6 \times L \times I} \tag{12}$$

It should be remembered that all of the foregoing formulas apply to direct current heating appliance and lamp circuits only. In the case of calculations for direct current motors, the formulas should include provision for overload current and efficiency of motor as determined by the *National Electrical Code.*

Power Loss Calculation.—If it be assumed that 10.8 ohm is the resistance of a circular mil foot of copper wire, the power loss in watts in any electrical copper conductor may be found thus:

$$P = \frac{10.8 \times I^2 \times L}{A} \tag{13}$$

Where P is the power loss in the conductor in watts

I is the current in amperes flowing in the conductor.

L is the length of the conductor in feet (one way).

A is the area of the conductor in circular mils.

For a two wire direct current circuit, we have:

$$P = \frac{21.6 \times I^2 \times L}{A} \tag{14}$$

Where the resistance of circuit is given, the power loss in watts may be obtained from the expression:

$$\text{Power loss in watts} = I^2R \tag{15}$$

Direct Current Motor Circuit Calculation.—With respect to direct current motors, the Code requires each motor to have a name plate with the name of the manufacturer, capacity in volts, current in amperes, horsepower ratings and the normal speed in revolutions per minute, etc. In calculating for such motors it is only necessary to take the efficiency of the motor and the overload into consideration to arrive at an acceptable value for the required wire size.

The formula for the size of wire in circular mils necessary for a direct current motor rated in horsepower will therefore be as follows:

$$A = \frac{HP \times 746 \times L \times 21.6 \times 1.25}{E \times E_t \times \text{efficiency}} \tag{16}$$

Where HP is the rating in horsepower of the motor; L, distance in feet to the motor; E, voltage drop; E_t terminal voltage. The overload factor is here taken as 1.25 since branch circuit conductors supplying an individual motor must have a carrying capacity not less than 125 percent of the motor's full load current rating. For long runs, it may be necessary in order to avoid excessive voltage drop to use conductors of sizes larger than obtained by the foregoing formula.

Calculations of direct current circuits may be made directly from the foregoing formulas, although in practice, voltage drop tables and curves are usually resorted to in designing of conductor sizes. The following examples will serve to illustrate calculation procedures.

***Example.**—A copper transmission line* 1.5 *miles in length is used to transmit* 10 *kilowatts from a* 600 *volt generating station. The voltage drop in the line is not to exceed* 10% *of the generating station voltage.*

Calculate

(*a*) Line current.

(*b*) Resistance of the line.

(*c*) Cross-section of wire.

Solution.—(*a*) Line current $I_L = \dfrac{10{,}000}{600} = 16.67$ amp. *Ans.*

Voltage drop $= 600 \times 0.1 = 60$ volts.

(*b*) Resistance of the line $= \dfrac{60}{16.67} = 3.6$ ohms. *Ans.*

Substituting the foregoing values in formula (3) we obtain

$$3.6 = \frac{5{,}280 \times 2 \times 1.5 \times 10.8}{A} \text{ or}$$

$$(c)\ A = \frac{5{,}280 \times 3 \times 10.8}{3.6} = 47{,}520 \text{ C.M.} \quad \textit{Ans.}$$

The nearest size of wire having an area equal to or greater than this is a No. 3 wire and this should be used. (See table page 540-9).

Example.—*A certain wiring scheme requires a circuit 50 feet in length which is to be made up of a No. 10 wire. The current is 35 amperes. Calculate the voltage drop in the circuit.*

Solution.—Substituting the values in formula (7) we obtain:

$$E = \frac{35 \times 50 \times 21.6}{10{,}380} = 3.6 \text{ volts.} \quad \textit{Ans.}$$

Example.—*What size wire should be used on a 250-volt circuit to transmit a current of 200 amperes a distance of 350 feet to a center of distribution, with a loss not to exceed 3% under full load?*

Solution.—Substituting the given values in formula (8) we obtain,

$$A = \frac{200 \times 350 \times 21.6}{0.03 \times 250} = 201{,}600 \text{ C.M.} \quad \textit{Ans.}$$

The nearest size conductor having an area equal to or larger than this is a 0000 conductor.

Example.—*A two-wire circuit is to carry a load of 50 amperes a distance of 300 feet with a permissible voltage drop of 2.5 volts. What size of conductor must be used?*

Solution.—Substituting our values in formula (8) we obtain,

$$A = \frac{50 \times 300 \times 21.6}{2.5} = 129{,}600 \text{ C.M.} \quad \textit{Ans.}$$

The nearest size conductor having an area equal to or larger than this is a 00. A.W.G. which should be used.

Example.—*It is desired to connect* 80, 50-*watt incandescent lamps on a* 110 *volt circuit. The distance from the mains to the center of the lamp group is* 200 *feet. What size wire is required if a maximum voltage drop of two volts be permitted?*

Solution.—Since each lamp takes 50 watts, the current flow is $50 \times {}^{80}/_{110}$ or 36.36 amperes. Substituting the given values in formula (8) the size of wire is found to be:

$$A = \frac{21.6 \times 36.36 \times 200}{2} = 78{,}538 \text{ C.M.} \quad \textit{Ans.}$$

The nearest size of wire having an area equal to or greater than this is a No. 1, and this should be used.

Example.—*A combined lamp and heating appliance load requires* 70 *kilowatts. The distance between the load center and the distributor panel is* 250 *feet. The voltage at the distribution panel is* 230 *volt and it is desired to keep the voltage drop within* 2%. *What size conductor is required?*

Solution.—The current flow is 70,000/230 or 304.3 amperes. Applying formula (8) the size of the conductor is found to be

$$A = \frac{304.3 \times 250 \times 21.6}{0.02 \times 230} = 357{,}550 \text{ C.M.} \quad \textit{Ans.}$$

The nearest size of conductor having an area equal to or greater than this is a 400,000 circular mil cable.

Example.—*A* 20 *kilowatt balanced lighting load is to be supplied by a three-wire* 115/230 *volts generator. The length of the run between the generator switchboard mains and the lighting load center is* 250 *feet. What size of conductor should be used if maximum voltage drop permitted is* 2%?

Solution.—On a balanced three-wire system the current in each of the outer conductors would be 20,000/230 or 87 amperes. The permissible voltage drop is 0.02×230 or 4.6 volts. Substituting our values in formula (8) the conductor size is found to be

$$A = \frac{87 \times 250 \times 21.6}{4.6} = 102{,}130 \text{ C.M.} \quad \textit{Ans.}$$

The nearest size conductor having the required area is No. 1/0, since No. 1 conductor has an area of only 83,690 circular mils.

Example.—*It is required to calculate the voltage drops on an unbalanced direct current three-wire circuit having the following data: Length of circuit* 750 *feet; Positive and negative conductor each No.* 000 *A.W.G. Neutral conductor No.* 1 *A.W.G. The positive and negative conductor carries* 125 *and* 100 *amperes respectively.*

Solution.—With reference to table giving properties of copper conductors (page 540-9) we obtain the resistance of 1,000 feet of No. 000 = 0.0642 ohm and that of No. 1 = 0.129 ohm per 1,000 feet.

The respective voltage drops are calculated as follows:

$$E = IR = 125 \times 0.0642 \times 0.75 = 6.02 \text{ volts}$$
(drop on positive conductor).

$$E = IR = 100 \times 0.0642 \times 0.75 = 4.82 \text{ volts}$$
(drop on negative conductor).

$$E = IR = (125 - 100)\ 0.129 \times 0.75 = 2.42 \text{ volts}$$
(drop on neutral conductor).

In a voltage drop calculation of this type the voltage drop in the neutral conductor is added to the drop on the side having the larger current and subtracted from the side having the smaller current, thus making the total voltage drop 6.02 + 2.42 = 8.44 volts on the "heavy" side, and 4.82 — 2.42 = 2.40 volts on the "lighter" side. *Ans.*

Example.—*Calculate the conductor size required to connect a direct current motor rated at 50 amperes, when the supply voltage is 230, the circuit length is 50 feet and the voltage drop 4 volts.*

Solution.—By applying formula (8) we obtain

$$A = \frac{50 \times 50 \times \overline{21.6}}{4} = 13{,}500 \text{ C.M.} \quad \textit{Ans.}$$

Since a No. 10 conductor contains only 10,380 circular mils the next larger size or a No. 8 conductor should be used.

Example.—*What is the approximate number of amperes drawn by a 30 horsepower direct current motor having an efficiency of 90% when connected to a 230 volts source?*

Solution.—The current drawn by the motor is

$$I = \frac{\text{Horsepower} \times 746}{\text{Impressed voltage} \times \text{Efficiency}} = \frac{30 \times 746}{230 \times 0.9} = 108 \text{ amperes.}$$

Example.—*A 25-h.p. 230-volt d.c. motor is to be supplied with power from a switchboard bus located at a distance of 75 feet from the motor. The line drop is not to exceed 5% of the receiver voltage, when the motor is delivering full load at 86% efficiency.*

Calculate

(*a*) *Cross-section area of feeder in C.M.*

(*b*) *Kilowatts supplied to switchboard.*

Solution.—The current drawn by the motor is

$$I = \frac{25 \times 746}{230 \times 0.86} = 94.3 \text{ amperes.}$$

The voltage drop in the conductors

$$E = 0.05 \times 230 = 11.5 \text{ volts.}$$

(*a*) Cross-sectional area of conductors

$$A = \frac{94.3 \times 75 \times 21.6}{11.5} = 13{,}300 \text{ C.M.} \quad \textit{Ans.}$$

(*b*) Power supplied at switchboard

$$Ps = \frac{94.3 \times 241.5}{1{,}000} = 22.77 \text{ kilowatts.} \quad \textit{Ans.}$$

Example.—*Determine the power loss in a circuit 80 feet in length consisting of No. 1 conductors when the current density is 75 amperes.*

Solution.—Applying formula (14) the power loss is,

$$P = \frac{21.6 \times 75^2 \times 80}{83{,}690} = 116 \text{ watts}$$

Example.—*What size wire should be used for a 20 horsepower 220-volt motor having an efficiency of 90% when the length of the circuit is 80 feet and the drop 2 volts?*

Solution.—Applying formula (16) with proper constants, we obtain,

$$A = \frac{20 \times 746 \times 80 \times 21.6 \times 1.25}{220 \times 2 \times 0.9} = 81{,}400 \text{ C.M.}$$

The nearest standard size conductor is a No. 1 A.W.G. which has an area of 83,690 circular mils.

Example.—*What is the proper size of wire for a 10-h.p., 220-volt motor having an efficiency of 90% when the length of the circuit is 200 feet and the maximum allowable voltage drop is 2%?*

Solution.—Substituting the given values in formula (16) we obtain,

$$A = \frac{10 \times 746 \times 200 \times 21.6 \times 1.25}{220 \times 4.4 \times 0.9} = 46{,}240 \text{ C.M.}$$

The nearest size conductor having an area equal to or larger than this is a No. 3 conductor and this should be used.

Alternating Current Wiring

Alternating current wiring differs from that of direct current mainly in certain effects which must be considered and which do not enter into direct current calculations. They are:

1. Inductance { Self-inductance / Mutual-inductance.
2. Capacity.
3. Skin effect.
4. Frequency.
5. Power factor.

For interior wiring where incandescent lamps are fed by an alternating current, none of the foregoing factors needs consideration, since mutual inductance, capacity and skin effect are so small as to be almost negligible. Therefore, in lamp wiring the previously given formulas may be applied to alternating current as well.

Self-Inductance.—Self-inductance is the property of an electric circuit which determines, for a given rate of current change in the circuit, the electromotive force induced in the same circuit.

Mutual Inductance.—Mutual inductance is the common property of two associated electric circuits which determines for a given rate of current change in one of the circuits, the electromotive force induced in the other.

Capacity.—In a system of more than two conductors a voltage difference between them corresponds to the presence of a quantity of electricity in each. All alternating current circuits have a certain capacity because each conductor acts like the plate of a condenser, and the insulating medium acts as a dielectric. The capacity between two or more conductors depends upon the insulation of each

Skin Effect.—Skin effect is the phenomenon of non-uniform current distribution over the cross-section of a conductor caused by the variation of the current in the conductor itself. The tendency of an alternating current to confine itself to the outer portions of the conductor has the effect of increasing its ohmic resistance.

If the conductor be large, or the frequency high, the central portion of the conductor carries little if any current, hence the resistance of a conductor is greater for alternating current than for direct current.

Frequency.—The frequency of an alternating current in ordinary light and power circuits depends upon the construction of the generator (number of poles) and the revolutions per minute (speed of the machine). In the United States the commercial frequency is usually 60 cycles per second, although certain power systems are designed for 25 and 50 c.p.s. The number of cycles per second has a direct effect upon the inductance of the circuit.

Power Factor.—The power factor is the *ratio* of *active power* to *apparent power*. Where the load consists of incandescent lamps only, the power factor is unity or one hundred per cent. In all alternating current circuits having an inductive load, such as fluorescent lamps and motors, allowance must be made for the power factor because of the inductive characteristic of this type of load.

Voltage Drop (Lighting Load Only).—The maximum voltage drop to the lamp in a well designed lighting system, should *not exceed three per cent.* Many designs limit the drop to two per cent or less. If, on the other hand, the illumination is not used for work, and if economy demands it, voltage drops of five per cent or more, may have to be allowed.

The fluctuations at the service and the additional lowering of the service voltage due to regulation of the service transformers (where employed) by any connected motor loads to the same transformers must also be taken into account when deciding the maximum value of the permissible voltage drop.

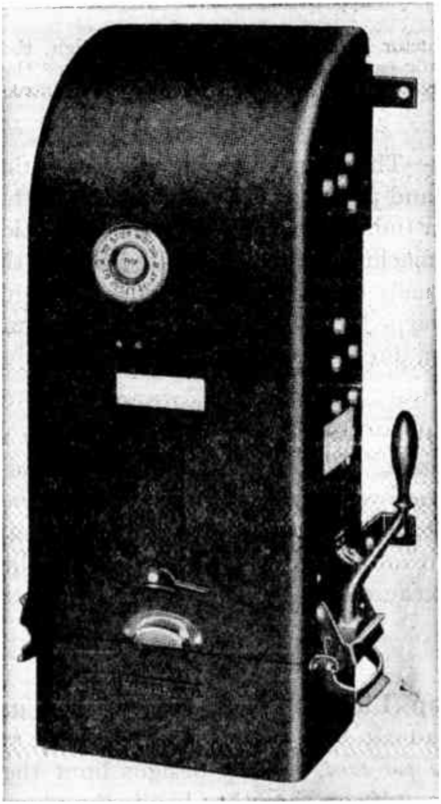


FIG. 6,886.—General Electric *a.c.* reduced voltage autotransformer type starter for squirrel cage induction motors. This compensator consists principally of an autotransformer, a manually operated set of contacts, and a temperature overload relay.

Voltage Drop (A.C. Motors Only).—For feeders serving power loads only it is necessary to consider the behavior of the alternating current motor at reduced voltages. Roughly, the full-load current of an induction motor varies inversely with the

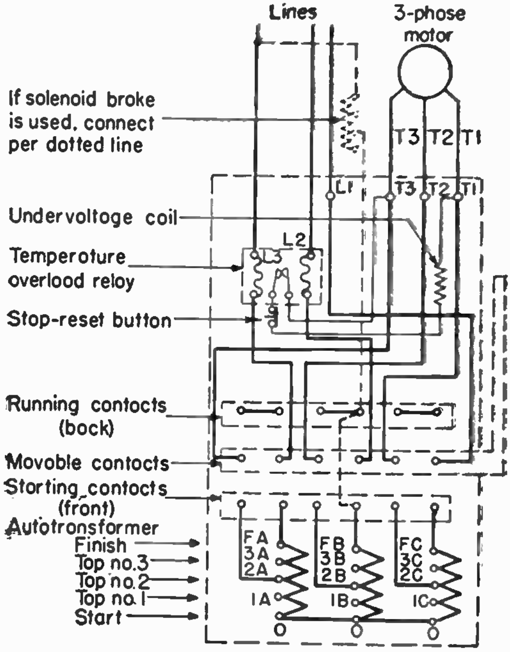


FIG. 6,887.—Wiring diagram of General Electric *a.c.* reduced voltage autotransformer type starter for squirrel cage induction motors. ***Operation:*** With reference to fig. 6,886, when the operating handle is pushed away from the operator, the autotransformer is connected to the power source, and at the same time, the motor which is being controlled is connected to the taps of the autotransformer. These taps apply a certain percentage of the line voltage to the motor. After the motor speed has reached a normal value, the operator pulls back the handle to the running position, which connects the motor to full line voltage. The handle is held in the running position by an under-voltage tripcoil. If the overload relay trips out, if the line voltage fails momentarily, or if the cover is removed, the under-voltage coil is de-energized and this allows the handle to return to the off position. To restart the motor, the overload relay must be reset by pushing a reset button on the outside of the case. Then the operating handle is thrown first to the starting then to the running position to start the motor.

voltage; both the starting torque and the pull-out torque vary directly with the square of the voltage; the slip at a given load varies about inversely with the square of the voltage.

The reduction of terminal voltage at the motor has very little effect on the speed; it increases the current (and thereby the calculated voltage drop also) and considerably reduces the starting and pull-out torques. Where these torques are not of prime importance, as with fan and pump drives, the values of voltage

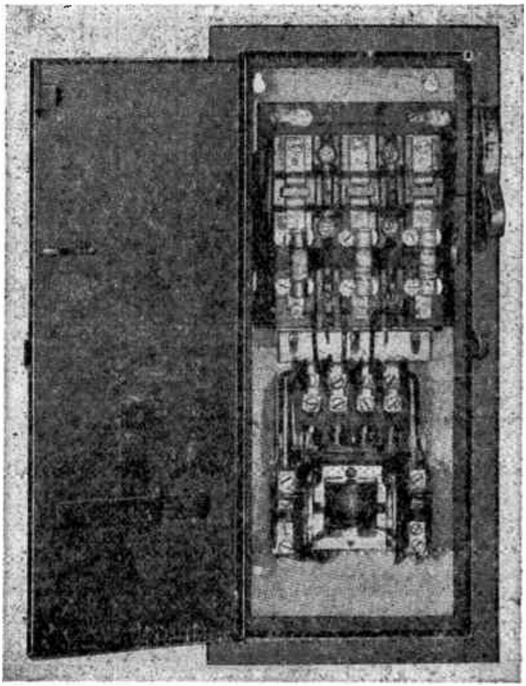


FIG. 6,888.—Combination *a.c.* magnetic motor starter with cover open. The cover of the starter is so interlocked with the safety switch handle that the cover cannot be opened when the safety switch is in the *on* position, nor can the safety switch be closed when the cover is open. This arrangement provides protection for the motor maintenance man or operator.—*Courtesy General Electric Co.*

drop within certain limits is mostly subject to economic consideration.

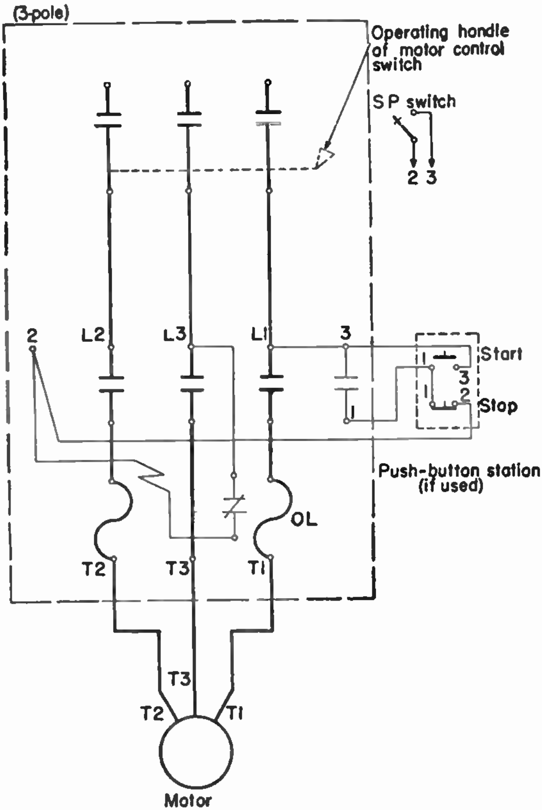


FIG. 6,889.—Wiring diagram for *a.c.* magnetic motor starter shown in fig. 6,888. This starter in addition to the two-element temperature overload relay incorporates facilities for remote control operation by means of a push button station when desired. ***Operation:*** Assuming the *start-stop* push button be used with the starter, pushing the *start* button closes the starting contactor, and thus connects the motor to the line. The motor is disconnected from the line by pushing the *stop* button. The action of the contactor is controlled by means of an operating coil incorporated in the motor starter. Directly across-the-line starters of this type are usually limited in sizes to about 25 *h.p.* in the lower voltage ranges (110 to 220 volts) because of undesirable line-voltage fluctuations encountered.—*Courtesy General Electric Co.*

A voltage drop of five per cent or less based on full-load motor current and power factor represents good conservative practice, but a voltage drop of as much as ten per cent will still result in satisfactory operation provided it includes the voltage drop at the service resulting from fluctuations of the supply voltage. This practice agrees with that of manufacturers in general, who guarantee satisfactory operation of motors at ten per cent above or ten per cent below the nominal voltage.

In order to determine the size of wire necessary for an alternating current motor rated in horsepower it is necessary to know the efficiency of the motor and the power factor. Where the power factor cannot be accurately determined an assumed average value of 80 to 85% will generally produce an acceptable result. The efficiency of motors generally depend upon their horsepower ratings and may vary from 70 to 95%, the latter value being reached for very large motors only.

Wire Calculations.—In wiring layout for incandescent lamp circuits operating on alternating current, the calculation of wire sizes will be the same as for direct current. With alternating current motors and other appliances having an inductive load, however, it is necessary to know the efficiency of the motor and the power factor.

The product of the power factor and the actual efficiency of the motor gives the apparent efficiency and this last quantity determines the size of the starting apparatus, wire, etc., necessary to properly operate the motor.

For correct functioning of any motor it is important to observe that the *voltage of the source* conform with that of the motor name plate rating (within the limits usually given for voltage drop). In addition the name plate gives information as to whether the machine is to be employed for alternating or direct current; if alternating, for what frequency and how many phases, the maximum current for continuous operation, winding connections, torques, etc. A service factor (sometimes called overload factor) is also given which allows the motor to be overloaded a slight amount.

In laying out the wiring for a motor which requires a heavy starting current, allowance should be made for this momentary current increase, otherwise the terminal voltage may drop below the point where the motor will not start.

To appreciate the value of the starting current for various types of motors the fusing practice according to the *National Electrical Code* recommendations, require that:

1. Squirrel-cage motors should be fused at not more than 300 per cent of rated motor current.

2. High-reactance motors rated at not more than 30 amperes should be fused at not more than 250 per cent of rated motor current, or, if rated at more than 30 amperes, should be fused at not more than 200 per cent of rated motor current.

3. Wound-rotor motors should be fused at not more than 150 per cent of rated motor current.

The size of wire for any alternating circuit may be determined by slightly modifying the formula used in direct current work, which as derived on page 373, is:

$$\text{circular mils} = \frac{\text{amperes} \times \text{feet} \times 21.6}{\text{drop}} \tag{1}$$

It is sometimes however convenient to make the calculation in terms of watts. Formula (1) may be modified for such calculation.

In modifying the formula, the "drop" should be expressed in percentage instead of actual volts lost, that is, instead of the difference in pressure between the beginning and the end of the circuit.

In any circuit the loss in percentage, or

$$\% \text{ loss} = \frac{\text{drop}}{\text{impressed pressure}} \times 100$$

from which

$$\text{drop} = \frac{\% \text{ loss} \times \text{impressed pressure}}{100} \qquad (2)$$

Substituting equation (2) in equation (1)

$$\text{circular mils} = \frac{\text{amperes} \times \text{feet} \times 21.6}{\dfrac{\% \text{ loss} \times \text{imp. pressure}}{100}}$$

$$= \frac{\text{amperes} \times \text{feet} \times 2{,}160}{\% \text{ loss} \times \text{imp. pressure}} \qquad (3)$$

Equation (3) is modified for calculation in terms of watts as follows: The power in watts is equal to the *applied voltage* multiplied by the current, that is to say, the power is equal to the *volts at the consumer's end of the circuit* multiplied by the current, or simply

$$\text{watts} = \text{volts} \times \text{amperes}$$

from which

$$\text{amperes} = \frac{\text{watts}}{\text{volts}} \qquad (4)$$

$$\text{circular mils} = \frac{\dfrac{\text{watts}}{\text{volts}} \times \text{feet} \times 2{,}160}{\% \text{ loss} \times \text{volts}}$$

$$= \frac{\text{watts} \times \text{feet} \times 2{,}160}{\% \text{ loss} \times \text{volts}^2} \qquad (5)$$

This formula (5) applies to a direct current two wire circuit, and to adapt it to any alternating current circuit it is only necessary to use the letter M instead of the number 2,160. thus

$$\textbf{circular mils} = \frac{\textbf{watts} \times \textbf{feet} \times \textbf{M}}{\textbf{\% loss} \times \textbf{volts}^2} \qquad \textbf{(6)}$$

in which M is a coefficient which has various values according to the kind of circuit and value of the power factor. These values are given in the following table:

VALUES OF M

SYSTEM	POWER FACTOR									
	1.00	.98	.95	.90	.85	.80	.75	.70	.65	.60
Single phase	2,160	2,249	2,400	2,660	3,000	3,380	3,840	4,400	5,112	6,000
Two phase (4 wire)	1,080	1,125	1,200	1,330	1,500	1,690	1,920	2,200	2,556	3,000
Three phase (3 wire)	1,080	1,125	1,200	1,330	1,500	1,690	1,920	2,200	2,556	3,000

It must be evident that when 2,160 is taken as the value of M, formula (6) applies to a two wire direct current circuit and also to a single phase *a.c.* circuit when the power factor is unity.

In the table, the value of M, for any particular power factor is found by dividing 2,160 by the square of that power factor for single phase and twice the square of the power factor for two phase and three phase.

NOTE.—The above table is calculated as follows: For ***single phase*** M = 2,160 ÷ power factor^2 × 100; for ***two phase*** four wire, or three phase three wire, M = ½ (2,160 ÷ power factor^2) 100. Thus the value of M for a single phase line with power factor .95 = 2,160 ÷ .95^2 × 100 = 2,400.

For ordinary calculations however, it is customary to use tables which take into account such factors as wire spacing, power factor, frequency, etc. Accordingly in order to determine the voltage drop of an alternating current circuit, the following formula may be used:

$$\text{Voltage drop} = \frac{\% \text{ Loss } \times E}{100} \times S \qquad (7)$$

VALUE OF "S" FOR 60 CYCLES

Size of wire B. & S. gauge	Area in circular mils.	.98 power factor					.90 power factor					.80 power factor					.70 power factor				
		Spacing of conductors					Spacing of conductors					Spacing of conductors					Spacing of conductors				
		1"	3"	6"	12"	24"	1"	3"	6"	12"	24"	1"	3"	6"	12"	24"	1"	3"	8"	12"	24"
500,000	500,000	1.21	1.45	1.61	1.77	1.92	1.32	1.80	2.11	2.44	2.75	1.27	1.89	2.25	2.64	3.03	1.14	1.72	2.12	2.53	2.92
300,000	300,000	1.15	1.29	1.38	1.48	1.57	1.19	1.47	1.66	1.84	2.02	1.11	1.46	1.68	1.90	2.12	1.00	1.33	1.56	1.78	2.01
0,000	211,600	1.12	1.22	1.28	1.34	1.41	1.13	1.33	1.45	1.58	1.63	1.03	1.27	1.43	1.58	1.75	1.00	1.14	1.29	1.45	1.69
000	167,800	1.09	1.18	1.22	1.28	1.29	1.08	1.23	1.33	1.44	1.53	1.00	1.16	1.28	1.41	.153	1.00	1.02	1.15	1.28	1.50
00	133,100	1.07	1.14	1.16	1.21	1.25	1.03	1.16	1.24	1.32	1.40	1.00	1.07	1.17	1.27	1.36	1.00	1.00	1.03	1.13	1.21
0	105,500	1.05	1.10	1.14	1.17	1.20	1.00	1.09	1.16	1.22	1.28	1.00	1.00	1.07	1.15	1.22	1.00	1.00	1.00	1.01	1.09
1	83,690	1.04	1.08	1.10	1.13	1.15	1.00	1.05	1.09	1.14	1.19	1.00	1.00	1.00	1.05	1.11	1.00	1.00	1.00	1.00	1.00
2	66,370	1.02	1.05	1.08	1.10	1.12	1.00	1.00	1.04	1.08	1.12	1.00	1.00	1.00	1.00	1.02	1.00	1.00	1.00	1.00	1.00
3	52,630	1.02	1.04	1.06	1.07	1.09	1.00	1.00	1.00	1.03	1.06	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
4 5	41,740 33,100	1.00	1.02	1.03	1.04	1.07	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6 7	26,250 20,820	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
8 9 10	16,510 13,090 10,380	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Where the % loss is a percentage of the applied power, that is, the power delivered to the motor or apparatus and not a percentage of the power at the *a.c.* generator; E, is the voltage at the consumers end of the circuit. The coefficient S, has various values as given in the accompanying table. These values are substantially true for transmission lines having a length of up to 20 miles and for voltages up to 25,000. On longer lines, due to the capacity effect the voltage drop will be somewhat inaccurate.

Current Calculation.—As previously stated, the effect of power factor less than unity, is an increase in current, and consequently a conductor of somewhat larger capacity is required for a lower power factor.

For single phase alternating current, the current flowing at the motor terminal, is:

$$I = \frac{\text{HP} \times 746}{E \times \text{Power factor} \times \text{Efficiency}} \quad (8)$$

Similarly for a two phase motor

$$I = \frac{\text{HP} \times 746}{2\,E \times \text{Power factor} \times \text{Efficiency}} \quad (9)$$

and for a three phase motor, the current

$$I = \frac{\text{HP} \times 746}{1.73 \times E \times \text{Power factor} \times \text{Efficiency}} \quad (10)$$

Motor Horsepower.—Motor horsepowers may conveniently be calculated from instrument readings when desired. The formulas are as follows:

D.C. Motors.

$$\text{HP} = \frac{\text{Volts} \times \text{Amperes} \times \text{Efficiency}}{746} \quad (11)$$

Single phase A.C. Motors

$$\text{HP} = \frac{\text{Volts} \times \text{Amperes} \times \text{Efficiency} \times \text{Power Factor}}{746} \quad (12)$$

Two phase A.C. Motors

$$HP = \frac{\text{Volts} \times \text{Amperes} \times \text{Efficiency} \times \text{Power Factor} \times 2}{746} \quad (13)$$

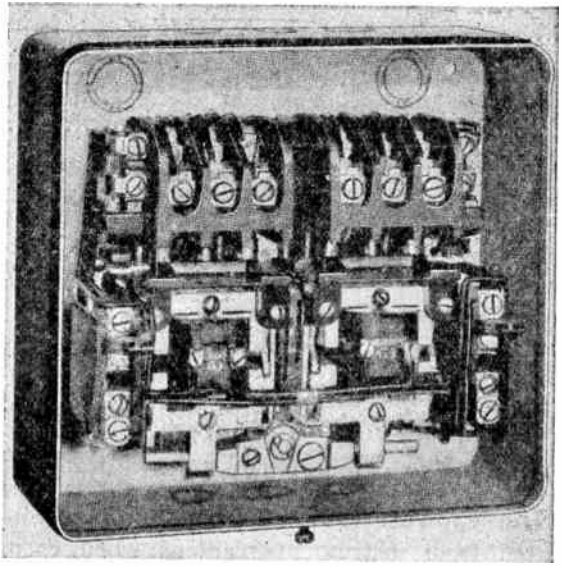


FIG. 6,890.—Illustrating typical *a.c.* magnetic reversing motor starter with front cover removed. This starter consists essentially of two magnetic contactors (one of which is being used for operating the motor in the reverse direction), one temperature overload relay, and a three-button push button station, or their equivalent to control the starter.—*Courtesy General Electric Co.*

Three phase A.C. Motors

$$HP = \frac{\text{Volts} \times \text{Amperes} \times \text{Efficiency} \times \text{Power Factor} \times 1.73}{746} \quad (14)$$

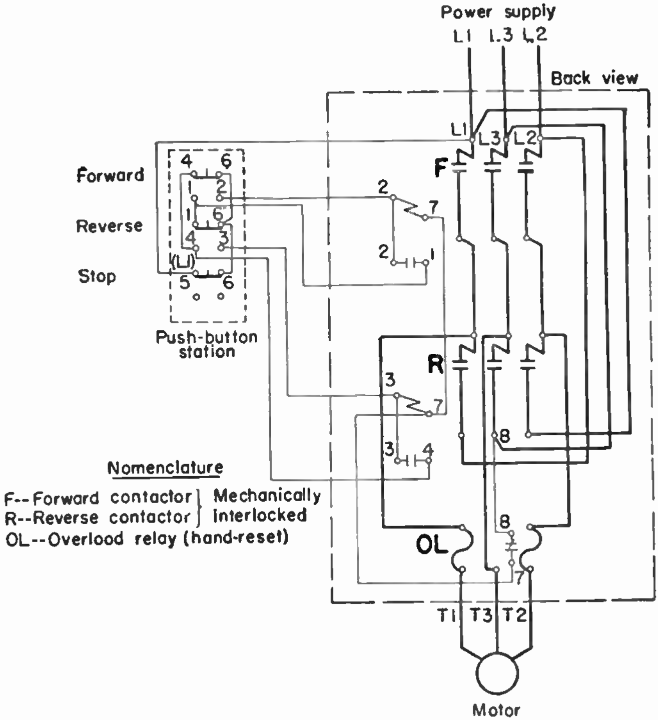


FIG. 6,891.—Wiring diagram for *a.c.* magnetic reversing motor starter shown in fig. 6,890. ***Operation:*** When the *forward* button is depressed contactor F closes and applies power to the motor. A holding circuit for the coil of F is established around the foreward push button by auxiliary interlock **F**. The motor continues to run until shut down by depressing the *stop* button, by tripping of the overload relay, or by power failure. Following an overload condition which causes relay **OL**, to trip, it is necessary to reset the relay contact by hand before the motor can be restarted. Operation of the motor in the reverse direction is obtained by the *reverse* button. The back, or normally closed contacts of the directional push-button units are used for electric interlocking and prevent the coils of contactors **F** and **R** being energized at the same time. With this arrangement it is also possible to reverse the motor direct from the *forward* and *reverse* button, without first operating the stop button.—*Courtesy General Electric Co.*

Example.*—What size wire must be used on a single phase circuit* 2,000 *ft. in length to supply* 3 *kw. at* 220 *volts with a loss of* 4%, *the power factor being* 90%?

Solution.—Inserting values in formula (6) we obtain:

$$\text{Circular mils} = \frac{3{,}000 \times 2{,}000 \times 2{,}660}{4 \times 220^2} = 82{,}438$$

With reference to wire table (page 540-9) the nearest larger wire size is No. 1 A.W.G. which has an area of 83,690 cir. mils, and this should be used.

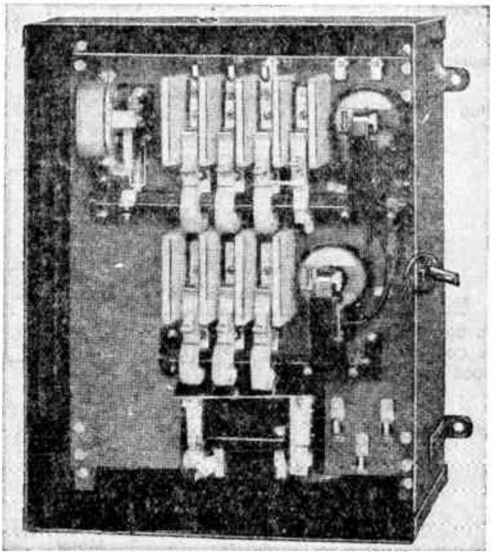


FIG. 6,892.—Typical automatic primary resistor motor starter with front cover removed.—*Courtesy General Electric Co.*

Example.—*A* 50 *h.p.* 60 *cycle single phase* 440 *volt induction motor, having a full load efficiency of* 92% *and a power factor of* 80% *is to be operated at a distance of* 1,000 *feet from the alternator. The wires are to be spaced* 6 *in. apart and the voltage drop is* 5%.

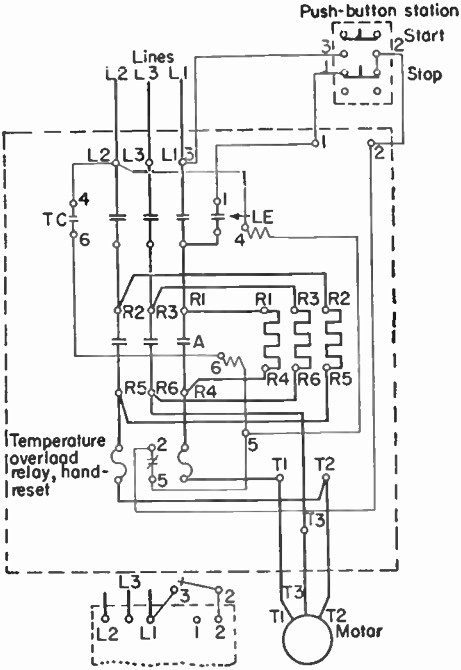
Calculate.—(*a*) Electrical horsepower; (*b*) Watts; (*c*) Apparent load; (*d*) Line current; (*e*) Size of wires; (*f*) Voltage drop; (*g*) Voltage at the alternator.

Solution.—

$$(a)\ \text{Electrical horsepower} = \frac{\text{Brake horsepower}}{\text{Efficiency}} = \frac{50}{0.92} = 54.3 \quad \textit{Ans.}$$

(*b*) $\text{Watts} = 54.3 \times 746 = 40{,}508$ *Ans.*

(*c*) Apparent load $= \dfrac{\text{Watts}}{\text{Power factor}} = \dfrac{40{,}508}{0.8} = 50{,}635$ *Ans.*



If SP master switch is used in place of push-button station, connect as shown

FIG. 6,893.—Wiring diagram of automatic primary resistor motor starter shown in fig. 6,892. A motor starter of this type applies approximately 80% of line voltage to the motor for starting, thus limiting the inrush current to approximately 80% of the full-voltage locked-rotor value and producing a starting torque of approximately 64% of the full voltage locked-rotor value. ***Operation:*** When the start button is depressed the line contactor closes its contacts connecting the motor to the line through the series line resistors **R**, at reduced voltage. The transfer from reduced voltage to full voltage is made by means of definite time interlock **TC** mechanically actuated by the closing of the line contactor. After a predetermined time contacts **TC** operates which in turn energizes the coil of the accelerating contactor which in closing short-circuits the series line resistors without interrupting the circuit.—*Courtesy General Electric Co.*

(*d*) Line current $= \dfrac{\text{Apparent load}}{\text{Volts}} = \dfrac{50{,}635}{440} = 115$ *Ans.*

(*e*) Size of wires. Cir. Mils =

$$\frac{\text{Watts} \times \text{Feet} \times \text{M}}{\%\ \text{Loss} \times \text{Volts}^2} = \frac{40{,}508 \times 1{,}000 \times 3{,}380}{5 \times 440 \times 440} = 141{,}443 \quad \textit{Ans.}$$

From table (page 540-9) nearest size larger wire is 3/0 A.W.G. which should be used.

(*f*) Voltage drop $= \dfrac{\%\ \text{Loss} \times E}{100} \times S = \dfrac{5 \times 440 \times 1.28}{100} = 28.16$ *Ans.*

(*g*) Voltage at alternator = volts at motor + drop = 440 + 28.16 = 468.16 *Ans.*

Example.—*A circuit supplying current at 440 volts, 60 cycles, with 5% voltage loss and a power factor of 80% is composed of No. 2 wires spaced one foot apart. What is the drop in the line?*

Solution.—Substituting the given values in formula (7) and the value of *S*, as obtained from the table, we obtain:

$$\text{Voltage drop} = \frac{5 \times 440 \times 1}{100} = 22 \text{ volts.} \quad \textit{Ans.}$$

Example.—*A single phase 50 horsepower 440 volt motor has a full load efficiency of 90% and a power factor of 80%. How much current will the motor draw from the line?*

Solution.—Applying formula (8) a substitution of values gives:

$$I = \frac{50 \times 746}{440 \times 0.9 \times 0.8} = 117.7 \textit{ amp.} \quad \textit{Ans.}$$

Example.—*A 10 kw. 220 volt single phase motor and light load has a combined power factor and efficiency of 85 and 80% respectively. What is the current?*

Solution.—With reference to formula (8) page 391, we have:

$$I = \frac{10{,}000}{220 \times 0.85 \times 0.8} = 67 \textit{ amp.} \text{ (nearly)} \quad \textit{Ans.}$$

Example.—*A 25 h.p. three phase induction motor has a full load efficiency of 85% and a power factor of 80%. How much current will the motor draw from the 220 volt line?*

Solution.—By substituting our values in formula (10) we obtain:

$$I = \frac{25 \times 746}{1.73 \times 220 \times 0.8 \times 0.85} = 72 \textit{ amp.} \text{ (approximately)} \quad \textit{Ans.}$$

Example.—*A 440 volt, three phase induction motor draws 40 amp. from the line. Calculate the motor output in horsepower when the efficiency of the motor and power factor are 85 and 80% respectively.*

Solution.—A substitution of values in formula (14) gives:

$$\text{Horsepower} = \frac{440 \times 40 \times 0.85 \times 0.80 \times 1.73}{746} = 27.8 \quad \textit{Ans.}$$

Example.—*An industrial load of 450 kilowatts is operated at a power factor of 65%. What will be the rating of a synchronous condenser (over-excited synchronous motor without load) to raise the power factor to 90%?*

Solution.—Since the voltage is constant, the kilowatts and quadrature kilovolt-amperes are proportional to the energy quadrature currents respectively. In our particular problem the apparent power component is:

$$\textit{Kva.} = \frac{450}{0.65} = 692$$

The reactive power component is:

$$\sqrt{692^2 - 450^2} = 525 \textit{ kva.}$$

With the power factor raised to 90% the reactive power will be:

$$\frac{450}{0.9} = 500 \textit{ kva.}$$

which will have a wattless or apparent power component of

$$\sqrt{500^2 - 450^2} = 218 \textit{ kva.}$$

It is obvious that the synchronous condenser must supply the difference between 525 and 218 *kva.* or 307 *kva.* A 300 *kva.* synchronous condenser would therefore meet the foregoing requirements. *Ans.*

Example.—*A direct current motor takes 720.8 amperes at 115 volts and has an efficiency of 90%. How many horsepower does it deliver?*

Solution.—

$$\text{Input to motor} = 720.8 \times 115 = 82{,}892 \text{ watts}$$

$$\text{Output of motor} = 82{,}892 \times 0.9 = 74{,}603 \text{ watts}$$

Horsepower (at motor pulley)

$$= \frac{74{,}603}{746} = 100 \textit{ h.p.} \text{ (approximately).} \quad \textit{Ans.}$$

Example.—*A 25 h.p. engine drives a d.c. generator. If the generator has an efficiency of 84% how many (a) kilowatt and (b) horsepower does it deliver?*

Solution.—

(a) Kilowatt delivered

$$= 0.84 \times 25 \times 0.746 = 15\tfrac{2}{3}\ k.w.\quad Ans.$$

(b) Horsepower delivered

$$= 0.84 \times 25 = 21.0\ h.p.\quad Ans.$$

CHAPTER 19

Inside Wiring

The different methods of interior wiring may be conveniently grouped into the following general classes:

1. Open or exposed wiring;
2. Wires run in mouldings;
3. Concealed knob and tube wiring;
4. Armored (B.X.) cable wiring;
5. Flexible conduit wiring;
6. Rigid conduit wiring.

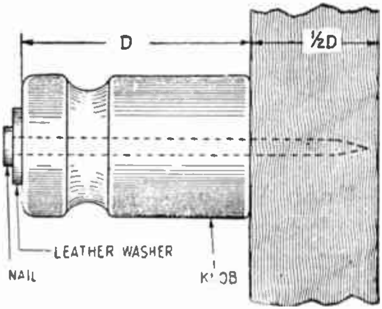


FIG. 6,933.—Correct knob fastening. Unless the member to which knob is fastened be deep enough to permit a nail penetrating to a depth of one half the height of the knob as here shown, use wood screws or nails. On stone or tile walls, special bolts should be used.

1. Open or Exposed Wiring

This method of wiring possesses the advantages of being cheap, durable and accessible.

It is used a gerat deal in factories, mills and buildings where the unsightly appearance of the wires exposed on the walls or ceilings is of no consequence.

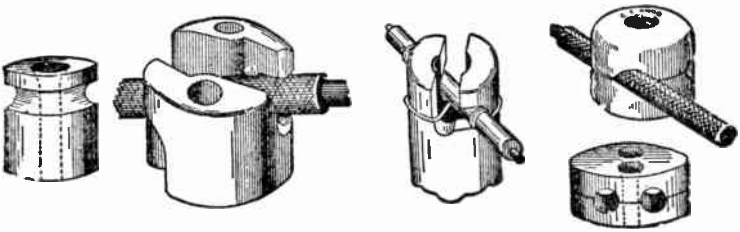
The kinds of wire used is either *rubber covered* or slow burning weather proof wire.

Rubber insulation should always be used where the wire is in a damp place, such as a cellar, and either weather proof or rubber insulation may be used to protect it against corrosive vapors.

For wiring in bakeries, mills, heat treating rooms, boiler rooms and all other warm rooms, slow burning asbestos covered wire is required.

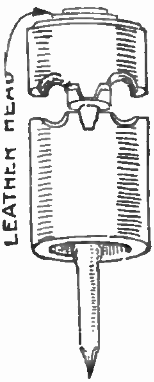
There are two methods of open or exposed wiring; known as

1. Knob wiring; 2. Cleat wiring.



Figs. 6.934 to 6.938.—Various porcelain knobs.

Knob Wiring.—This is the simplest and cheapest method. It is forbidden in some cities, except for temporary decorative work.



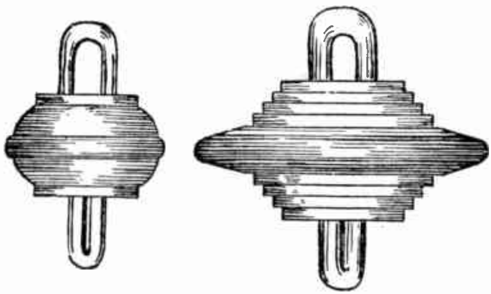
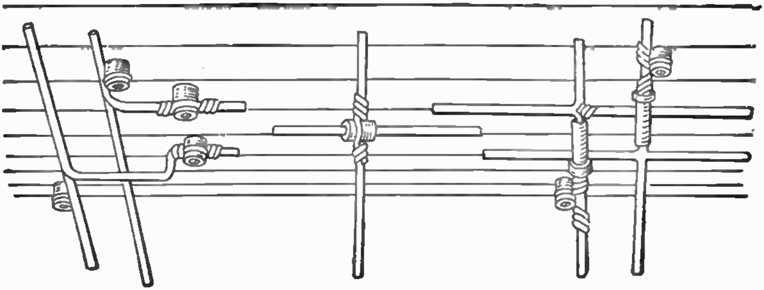


Fig. 6,939.—Knob complete with nail and leather head. The leather head is pinched over on the side so that nail cannot fall out.

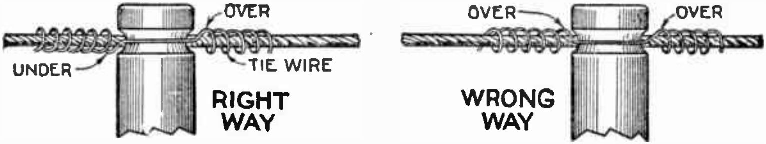
Figs. 6.940 and 6.941.—Strain insulators as used on ends of wire when run on mill timbers.

The knobs should be placed every 4½ ft. and the wires not less than 5 inches apart.

Knobs are secured by means of wood screws or nails, when nails are used, leather washers called leather heads are slipped over the nail so that the head of the knob will not be broken when the head of the nail is hit by a hammer.



FIGS. 6,942 to 6,944.—Crossing of wires. Where wires cross each other, tubes should be used except in case of large stiff wires as in fig. 6,942; here one wire may be bent down and carried under the other; fig. 6,943, short bushing strung on the wire—this method is usually unsatisfactory, especially where a large number of wires cross each other; fig. 6,944, wires crossing each other through tubes. Flexible tubing, such as circular loom may be used in crossing wires in dry locations. Insulators should always be provided where wires cross to support the wires, thus preventing the upper wires sagging and touching those below.



FIGS. 6,945 and 6,946.—Right and wrong methods of tying wires to grooved knobs, called *tying in*. In fig. 6,945. one end of the tie wire passes over the wire, the other passes under. Pliers must be used so that the wires will be firmly secured. In tying in the wires, the first and last knob should be tied in and the intermediate knobs tied in last. Where the wires are of a large size a block and tackle should be used, care being taken not to pull too tight as this will stretch the wire. The tie wires should be of solid wire and of the same size as the wire to be secured, one wire is passed underneath the wire and the other wire is passed over so that it is secured at both ends. Pliers should be used as tie wire cannot be properly secured by hand.

In crossing over pipes or wires, porcelain tubes should be used. When it is impossible to use porcelain tubes flexible loom can be used. Where the wires are run over, sweating, or dripping water, pipes, the loom or tubes should be placed on top of the pipe to prevent the water eating into the insulation. The ends of the tubes or loom should be taped to prevent them working loose and moving away from their original positions.

When passing through walls and partitions, the wires should be protected by tubes; where this is impossible loom can be used.

Knobs must not be run down side walls any farther than 7 ft. from the floor at this point they should be boxed in, or run in loom a continuous piece of loom into a conduit.

Knob wires can be run on rafters provided they are in blind attics or in places out of reach. Knob wires should not be run on cellar joists, unless protected from each side by guard strips.

In buildings of mill construction, where the wires are not less than number 8,

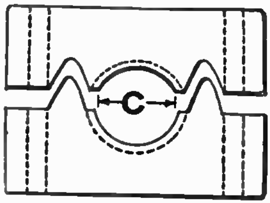
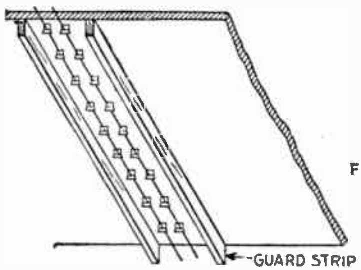


FIG. 6,947.—Common two wire cleat for wire sizes No. 14 to No. 10.

FIG. 6,948.—B. & D. one wire cleat for wires No. 8 to No. 0.



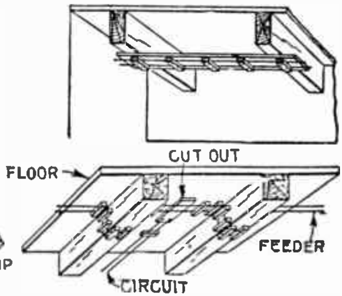


FIG. 6,949.—Method of protecting exposed wiring on low ceilings by two guard strips.

FIGS. 6,950 and 6,951.—Cleat wiring methods. Fig. 6,950, cleat work across beams, the cleats are carried by boards attached to the beams; fig. 6.951, method of carrying wires on cleats around beams.

B. & S. gauge, the wires may be run from timber to timber if they be spaced six inches apart. Where wires are run in this manner, they should be dead-ended by strain insulators or by using double knobs. Heavy wires such as used in mills or for outside work can be supported ("tied in") on grooved knobs.

Cleat Wiring.—This method of wiring cannot be used in theatres, public buildings or garages that contain more than two cars.

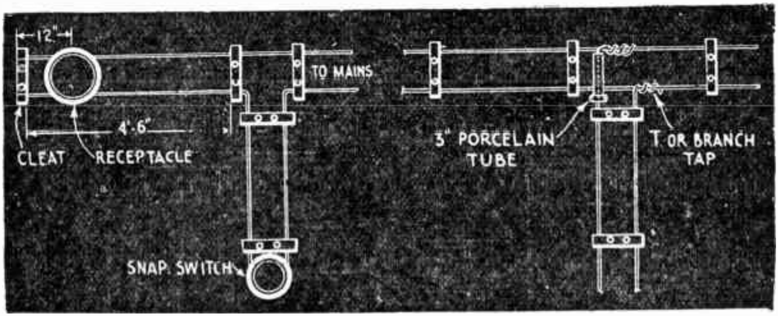
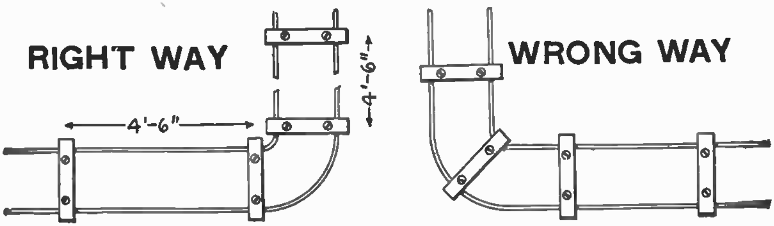


FIG. 6,952.—Cleat wiring for snap switch to operate receptacle. On long runs such as in factories, the wires should be deadened to a cleat located not less than one ft. from the last light, receptacle or drop.

FIG. 6,953.—Cleat wiring method of making a tap for branch circuit. Tubes always should be used, the tube being placed over the wire so that it rests upon the main wire, a cleat should then be installed so that the tube cannot slip away leaving the wires unprotected.



FIGS. 6,954 and 6,955.—Right and wrong methods of making a turn with cleats. In fig. 6,955, an additional cleat is used adding unnecessary expense.

Before making a cleat installation, the local inspection bureau should be consulted, as cleats are fast becoming outlawed in many states.

Cleats.—They are constructed of porcelain, the tops and bottoms being alike and inter-changeable. They may be obtained with grooves for two or three wires. Cleats are best secured to wooden surfaces by wood screws, but for quick and rough work nails protected by leather washers called nail heads or leather heads may be used.

For securing cleats to wood 2 inches number 8 flat or round head screws should be used, where nails are to be used the ten penny 10D size should be used. For metal ceiling work, toggle bolts similar to those used for metal moulding should be used, except in places where the metal overlaps each other wood screws may be secured to the wooden furring strips. For plastered ceilings constructed with wooden lath 2½ in. No. 8 wood screws should be used. Where the ceiling is constructed with metal lath, the only means of securing the cleats are with commercial toggle bolts. On concrete ceilings, holes drilled and filled with wooden plugs are good cleat

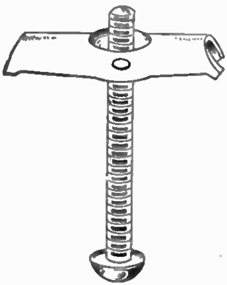


FIG. 6,956.—Toggle bolt for securing cleat to metal ceilings, or ceilings on which plaster is laid on metal lath. A hole is first punched in the ceiling with a 20 penny nail or a brad awl. the bolt is then inserted through the cleats and is shoved up into the ceiling.

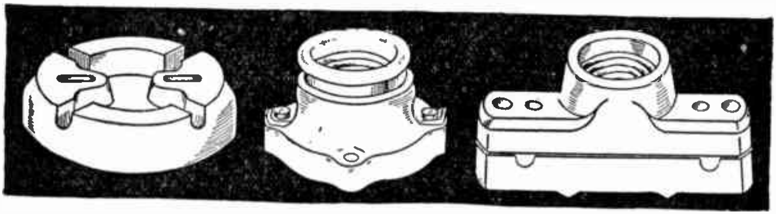


FIG. 6,957.—Snap switch sub-base as used under snap switches for cleat wiring.
FIGS. 6,958 and 6,959.—Exposed and concealed contact cleat receptacles. The concealed contacts are more desirable, as the live wires are protected.

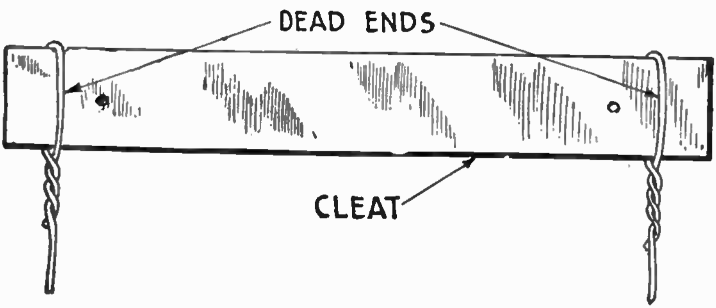
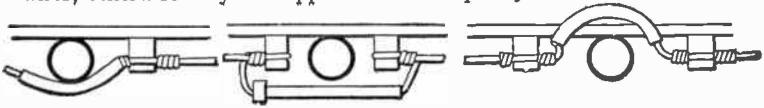


FIG. 6,960.—Method of *dead ending* wires on cleats. The line is simply secured by the cleats the ends are wound around the wires on the cleats. Four or five turns will do.

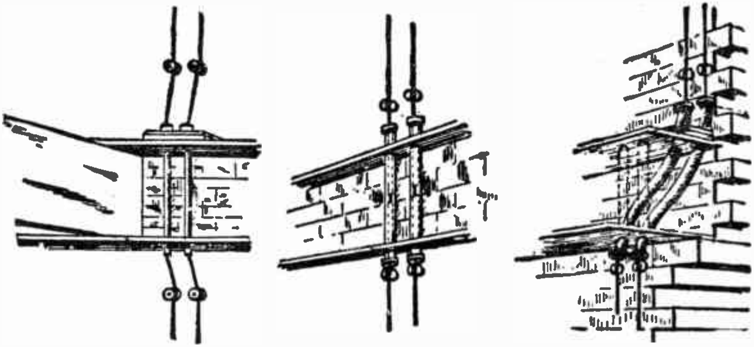
supports, lead shields may be used but wood plugs are quicker and more secure.

Spacing of Cleats.—They should be spaced not over 4½ ft. apart, the wire at all times being taut and insulated from the surface wired over. In practice it will be found that it is impossible to maintain the standard spacing of 4½ ft., so therefore in order to make the job appear neat and workmanlike the cleats should be installed so that their spacing is symmetrical.

Running the Wires.—The kinks should first be removed from the wires, otherwise they will appear slack and poorly installed. This is best



FIGS. 6,961 to 6,963.—Wiring across pipes. The wires should preferably run over rather than under the pipes. Fig. 6,961 shows crossing with circular loom, and fig. 6,962, one in which a tube is used. Both of these methods are satisfactory in the case of gas pipes, but for steam pipes or water pipes which are liable to leak or sweat and drip moisture, the crossing should be above as shown in fig. 6,963. On side walls where vertical wires run across horizontal water pipes, the latter should be enclosed and the moisture deflected to one side.



FIGS. 6,964 to 6,966.—Wiring through floors. *The bushing must be continuous.* Porcelain tubes may be used as in fig. 6,964, or short bushings may be arranged on iron pipes as in fig. 6,965. Fig. 6,966 shows method employed in case of offset in the wall. Sometimes the floor can be taken up and an iron conduit, properly bent, put in place, the wires being reinforced with flexible tubing. Another method is to attach the wires to insulators; in this case the floor must not be put down until the wiring has been examined by the inspector.

done by running the handle of a hammer over the wire. The wires are then secured to the first and last cleats of the run and drawn up as tight as possible. This is only accomplished by pulling the wires by hand; never use pliers as this method causes the wire to kink and break. The cleats should be screwed down as firm as possible so that the wire will not slip through. If nails be used on long runs for securing the cleats, it is advisable to use screws on the first and last cleats, as nails have a tendency to work loose. The intermediate cleats are then installed so that the spacing is symmetrical.

Cross Overs.—When crossing over wires, metal beams, protruding pipes, the wires should be protected by porcelain tubes. Where it is impossible to install tubes, loom can be used. Always place tubes or loom over instead of under dripping pipes so that the moisture will not ground the wires.

Side Wall Protection.—On side walls the cleats should not be run down any further than 7 ft. from the floor line. At this point they must be protected from mechanical injury by installing them in wood moulding or in conduit, or by boxing in.

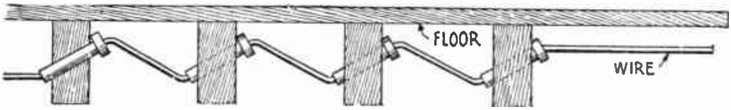
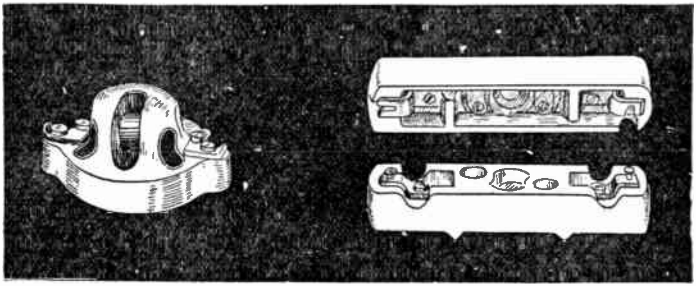


FIG. 6,967.—Exposed wiring passing through beams, showing the usual objectionable method of boring the holes at an angle as practiced by workmen not equipped with the proper boring tool. Insist on the holes being bored parallel to the floor. When the holes are bored at the middle of the beam, that is, through the neutral axis, the beam is not perceptibly weakened by the cut. Porcelain tubes are used where the wire passes through the beams.



FIGS. 6,968 to 6,970.—Open and concealed contact drop cord rosettes for cleat wiring. The open type is the most economical to use as it is in one piece but the covered or concealed is the safer.

Passing Through Floors.—The same methods are employed as in knob wiring, as shown in figs. 6,964 to 6,966. The same kind of protection applies to passing through partitions and large beams. Loom must never be used unless it be actually impossible to use tubes.

Cleats in Cellars.—Cleats must never be attached to cellar joist unless protected by a guard strip 2 ins. high on each side, or they may be mounted on a running board of pine not less than 4 in. × ⅞ in. Before using running board or guard strip it should first be ascertained whether it is possible to run the wires on cellar beams. These generally run through the center of the cellar

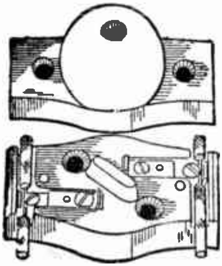


FIG. 6,971.—Receptacle suitable for use with open wiring, the requirement being that the contact ears should not be exposed.

Practical Points Relating to Exposed Wiring

1. In interior wiring no wires smaller than No. 14 B. & S. gauge should be used, except as allowed by the underwriters, and no more than 660 watts should be allowed to a circuit.

2. Tie wires should have an insulation equal to that of the conductors which they secure.

3. In all cases, whether the wires be run on knobs, split insulators, or cleats, the wires should be supported at intervals of at least 4½ feet, and if exposed to mechanical injury, the supporters should be placed at closer intervals.

4. Wires run on bare ceilings of low basements, especially where they are liable to injury, should be protected by two wooden guard strips as shown in fig. 6,951. The protective strips should be at least ⅞ inch in thickness and slightly higher than the knobs, insulators, or cleats. Wires should not be run closer than 6 inches apart and 2 inches from the surface wired over. Wires run near water tanks must be rubber covered so as to render them moisture proof.

5. Cleats should be used for the wiring of stores, offices, or buildings having flat ceilings, provided the wiring is installed in dry locations.

6. When the installation is exposed to dampness or acid fumes such as those developed in stables, bakeries, etc., the wires should run on knobs or split insulators, and should be rubber covered.

7. When wires are run at right angles to beams which are more than 4½ feet apart, a running board should be used and the wires cleated to it as shown in fig. 6,949. It is desirable, however, to avoid the use of running boards, whenever possible by running the wires parallel with the beams, thus reducing the cost of insulation.

8. In factories or other buildings of open mill construction, mains of No. 8 B. & S. gauge or larger wire, where they are not exposed to injury, may be placed about 6 inches apart and run from timber to timber, not breaking around, and may be supported at each timber only

9. The best location for feeders is on the walls. In dry buildings the fire and weather proof wire can be used with safety: but covered wire must be used on buildings subject to any form of dampness. In all cases where feeders are run on the walls, they should be protected from mechanical

injury by boxing at least 6 feet high on each floor. If floor switches be used they may be mounted on the front of the boxing. In such cases, the holes in the boxing through which the wires pass to the switches, should be provided with porcelain bushings.

10. The rosettes, receptacles, sockets, snap switches, etc., used in connection with exposed wiring should conform in all respects to the standards specified by the Underwriters.

2. *Wiring Run in Mouldings*

(Raceway Systems)

Surface metal raceway may be used in dry locations. It *shall not be used* (1) where concealed, except that the back and sides of multi-outlet assembly may be surrounded by the building finish, and metal raceways approved for the purpose may be used for under-plaster extensions; (2) where subject to severe mechanical injury unless approved for the purpose; (3) where the voltage is 300 volts or more between conductors unless the metal has a thickness of not less than 0.040 inches; (4) where subject to corrosive vapors; (5) in hoistways; (6) in storage battery rooms; nor (7) in any hazardous location.

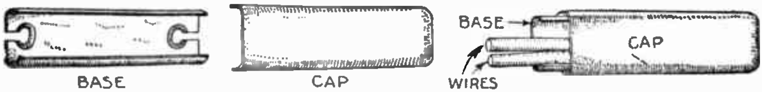
Size of Conductors.—No conductor larger than No. 6 shall be installed in a surface metal raceway.

Numbers of Conductors in Raceway.—The number of conductors installed in any raceway shall not be greater than the number for which the raceway is approved, and in no case shall more than 10 conductors be installed as permitted for signal and control systems.

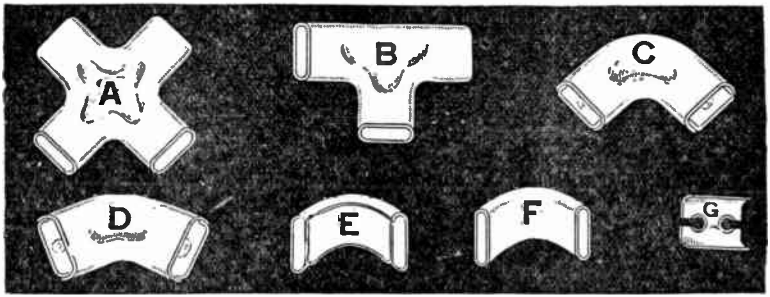
Extensions Through Walls and Floors.—Except in multi-oulet assemblies raceways may be extended through dry walls, dry partitions and dry floors, if in unbroken lengths where passing through.

Multi-Outlet Assembly.—Multi-outlet assembly and all fittings used in connection with the assembly, shall be approved for the purpose.

Metal Moulding.—This kind of casing for wires, also known as *raceways*, consists of a base and capping or cover made of steel. It is $31/32''$ wide and $7/16''$ high, shipped in lengths of $8' 4''$, with twelve lengths per unit package.



FIGS. 6,997 to 6,999.—Metal moulding. An approved form consists, as shown, of two pieces: base (fig. 6,997), and cap (fig. 6,998), so formed as to snap together, the cap snapping over the base as in fig. 6,999. The entire moulding should be galvanized or coated with a rust preventive. When the base is held in place by screws or bolts from the inside, depressions must be provided so that the heads of the screws will be flush with the surface of the moulding.



FIGS. 7,000 to 7,006.—National metal moulding fittings. Fig. **A**, cross; fig. **B**, tee; fig. **C**, 90° flat elbow; fig. **D**, 45° flat elbow; fig. **E**, external elbow; fig. **F**, internal elbow; fig. **G**, fitting coupling.

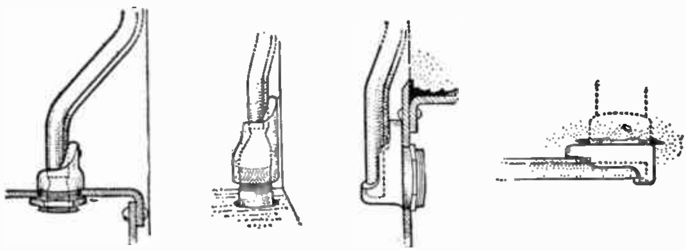
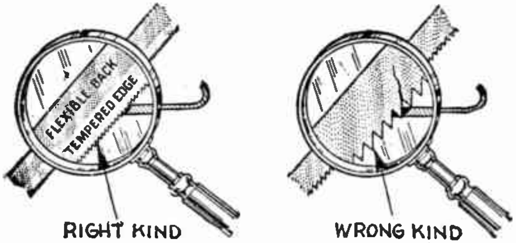


FIG. 7,007 to 7,010.—Various outlet connectors for attaching molding to conduit outlet boxes.

Code Requirements.—Metal moulding is permitted in circuits requiring not more than 1,320 watts with not over 300 volts. Splices are not allowed; use approved junction boxes or outlet plates. Four No. 14 wires with approved rubber insulating covering may be installed in the moulding. All sections must be secured together both mechanically and electrically, and must be grounded. Moulding can be used on plastered walls, side walls with proper protection; must not be used in cellars, damp places, hot rooms, or for outside work.



FIGS. 7,011 and 7,012.—Right and wrong kind of hack saw blade for cutting metal molding showing effect of using a coarse tooth blade. A blade with fine teeth as in fig. 7,011 will *ride* the molding and prevent stalling or catching.

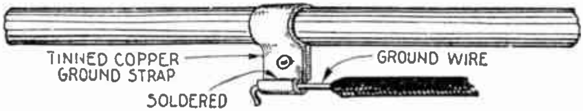
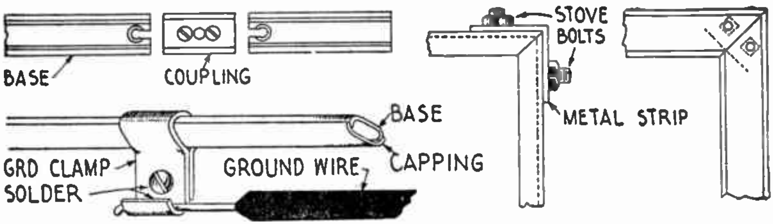
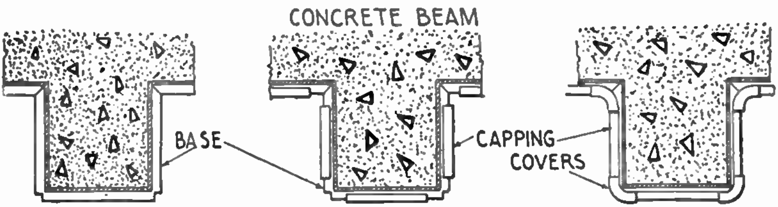


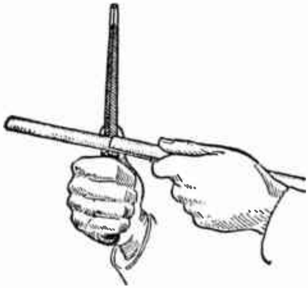
FIG. 7,013.—Metal molding ground clamp.



FIGS. 7014 to 7,019.—Method of bonding and grounding metal moulding.



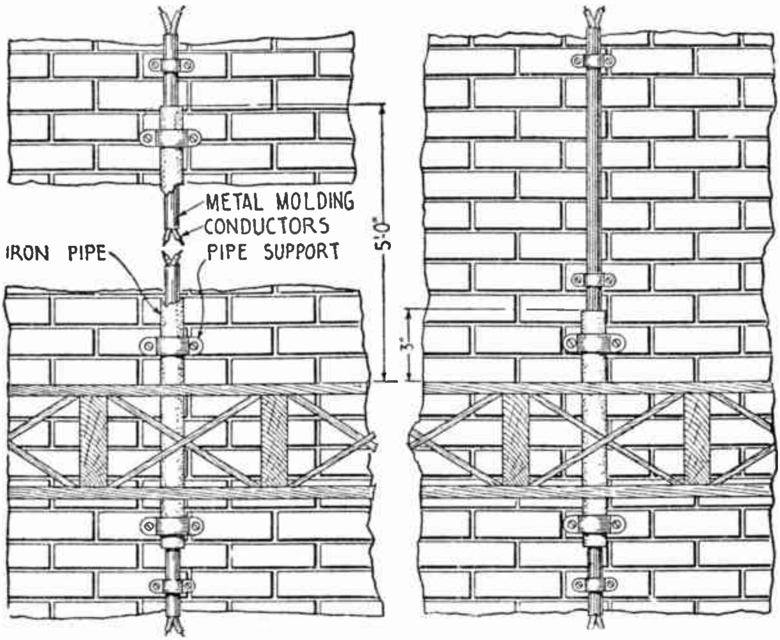
FIGS. 7,020 to 7,022.—Method of running metal moulding around beams.



Where metal moulding passes through floors it should be encased in a pipe to prevent scrub water entering and to afford additional mechanical protection. On side walls, the continuous length of iron pipe should, where the moulding might be exposed to mechanical injury, extend a distance of at least 5 feet above the floor and downward from floor to a few inches below ceiling.

Installation of Metal Moulding.—There are two methods of

FIG. 7,023.—Method of cutting metal moulding with three cornered file. *In cutting,* use a small piece of capping for a straight edge, as shown; mark the base or capping deeply and break it off, being very careful to mark the moulding deeply on both sides.



FIGS. 7,024 and 7,025.—Methods of protecting metal moulding in passing through a floor. Fig. 7,024, protection against mechanical injury; fig. 7,025, protection in exposed locations.

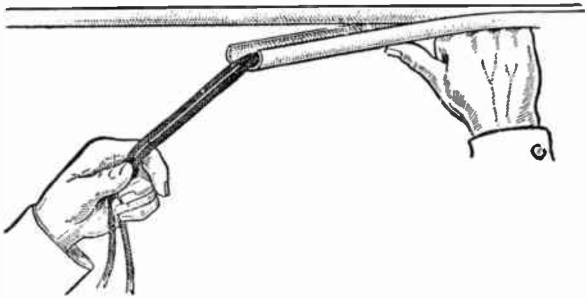
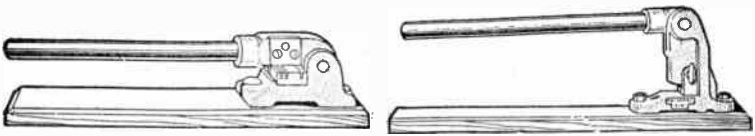
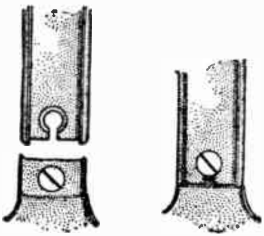
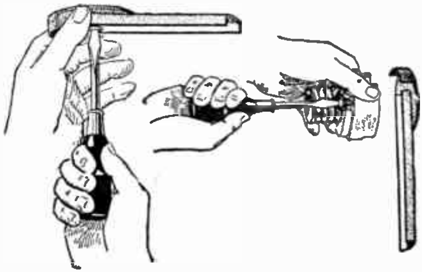


FIG. 7,026.—Method of installing wire in metal molding: first put up all base plates of fittings and then lay wire into each length of capping as it is snapped on, as shown.



FIGS. 7,027 and 7,028.—Shear and punch for cutting and punching metal molding.





FIGS. 7,029 to 7,031.—Coupling and connecting ends of metal molding, showing screws and screw holes.

FIGS. 7,032 and 7,033.—Method of installing metal molding device at the end of a run.

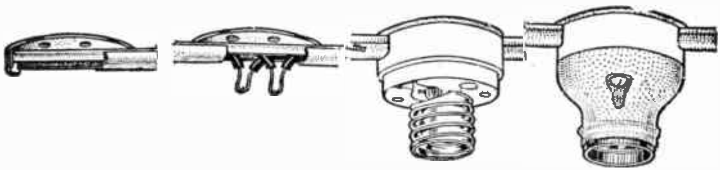
A B C D E F

FIGS. 7,034 to 7,039.—Methods of supporting National metal molding. Fig. A, on wood surfaces use a No. 8 flat head wood screw; fig. B, on lath and plaster use a 1¼ in. No. 8 flat head wood screw; fig. C, on metal ceilings use oone toggle bolts 2 ins. long; fig. D, on plastered ceilings of metal lath, use flat toggle bolt; fig. E, on tile use flat toggle or cone toggle bolt; fig. F, on concrete use lead shields.

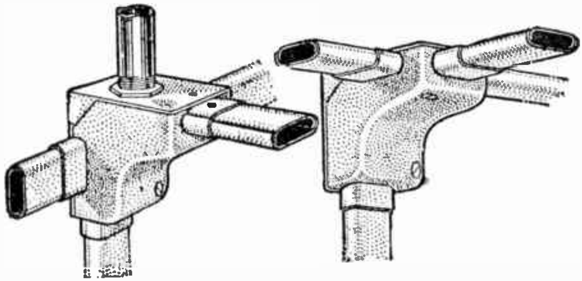
cutting the moulding—by hack saw or by a special shear.

If a hack saw be used, select only a fine toothed flexible back saw with tempered edges; coarse toothed blades crack and break on moulding.

When cutting moulding with a hack saw it is not necessary to cut all the way into moulding, but only just nick the moulding so, if it be given a slight up and down motion it will break apart. Files also may be used, the three cornered being the best. Holes must be punched in the base for



FIGS. 7,040 to 7,043.—Method of wiring receptacles for use on metal molding.

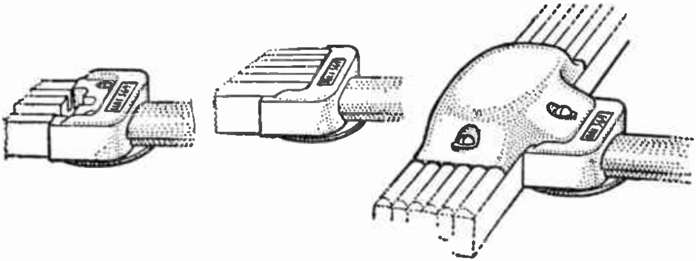


FIGS. 7,044 and 7,045.—Metal moulding branching fittings. Fig. 7,044 shows the moulding running up the sidewall, branching both ways close up in the corner on the sidewall, running out onto the ceiling and a tap passing up through to the floor above in ½ inch conduit. Fig. 7,045 shows the moulding running up the sidewall, branching both ways close up in the corner on the ceiling and running out onto the ceiling.

FIGS. 7,046 to 7,048.—Base, cover, and canopy for fixture outlets; note knock out holes in base for picking up concealed wiring.

screws, this can be made with a special punch or may be drilled by a twist drill in a brace or breast drill.

Bending.—The base and capping must be assembled and bent as one piece of moulding. The moulding is quite soft and is easily bent over the knee or the edge of a table; Hickeys may be obtained for this purpose.



Figs. 7,049 to 7,051.—Moulding adapters for connecting metal moulding to wooden moulding.

Figs. 7,052 to 7,058.—Various wiremold fittings. Fig. 7,052, 90° flat elbow; fig. 7,053, 45° flat elbow; fig. 7,054, external elbow; fig. 7,055, corner box; fig. 7,056, external elbow; fig. 7,057, tee; fig. 7,058, cross.

After moulding is snapped together and bent, it should be separated by means of a screw driver pried under the end and pull down, do not separate by pulling apart by hand as this bends capping and base out of shape.

Installing.—The base is first put in place after which the wires are laid in the capping and snapped in place by slightly rapping capping with a light hammer. If capping persist in springing away on the ends, bend over edges with hammer so that they will fit base snugly.

Avoid crossing the wires in the capping as this causes capping to bulge and short circuit. The moulding is coupled together by means of special couplings.

In running around beams the base only is bent by cutting a 90° V with a hack saw at the bend. Both internal and external bends may be made

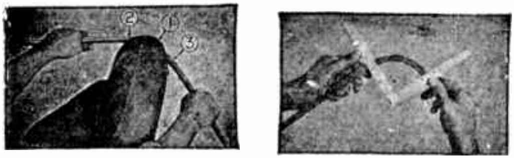
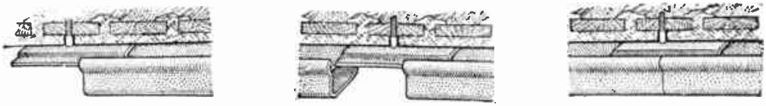
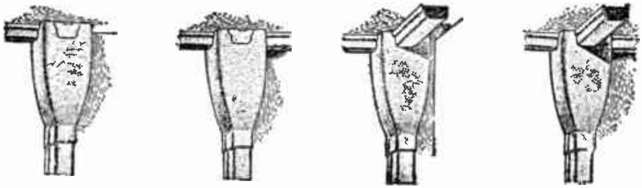


FIG. 7,064.—Wiremold ground clamp.

FIGS. 7,059 to 7,063.—Knee method of bending wiremold. Fig. 7,059 shows a wireman starting offset at what will be the center of the finished bend; figs. 7,060 to 7,062 show the points selected for progressive "bites"; fig. 7,063, finished bend. On internal bends the capping will sometimes tend to spread if bent too fast but can be easily drawn into place again by tapping with the handle of a hammer or a heavy screw driver. Wiremold can also be easily offset to pass from side wall to the baseboard or to break around similar shallow obstructions, and through the exercise of a little care and the use of a bench vise can be offset edgewise to a limited extent when occasion demands.

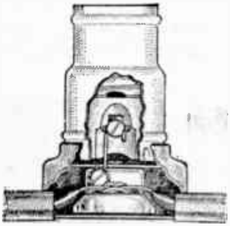


FIGS. 7,065 to 7,067.—Method of coupling wiremold by use of coupling fitting



FIGS. 7,068 to 7,071.—Various wiremold corner boxes.

by means of these notches. The capping is then laid in place after which the corners are covered over with special elbow covers.



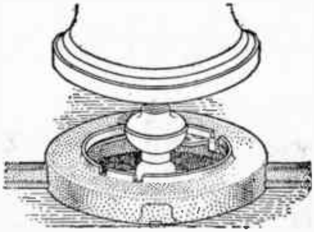
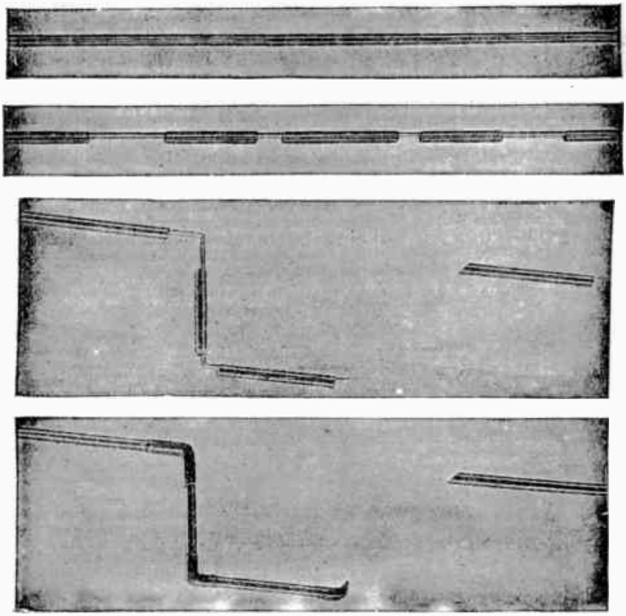


Fig. 7,072.—Method of joining receptacle to wiremold.

Fig. 7,073.—Round fixture outlet base for wiremold.

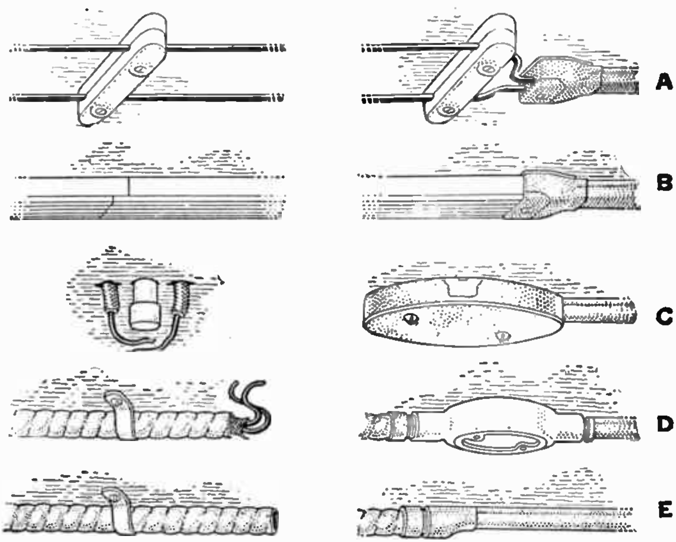


Figs. 7,074 to 7,077.—Method of passing around beams with wiremold. Mark off the face and depth of beams on a length and slot the capping only on these centers. Take out two $1\frac{5}{8}$ in. sections of capping where wiremold is to break around the bottom of the beam, and two 4 in. sections where it breaks from the ceiling, as in fig. 7,075. Bend base to form around beam as in fig. 7,076 and fish in wires. Snap on external and internal elbows as in fig. 7,077

All fittings are connected to the moulding by means of a set screw which clamps down the moulding.

"Wiremold" Metal Moulding.—This is a form of metal moulding raceway that is quickly installed.

It is smaller than the usual type of metal moulding and only two No. 14 wires can be inserted in it. It is in reality a form of conduit, only it is not air or water proof.

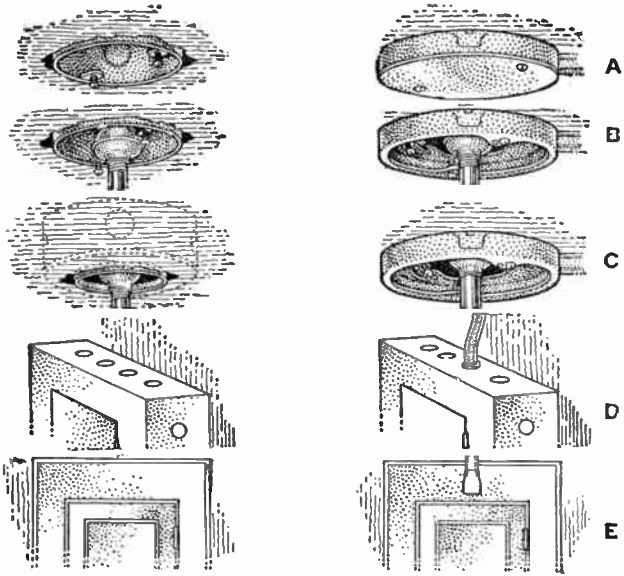


Figs. 7,078 to 7,087.—Methods of tapping various wiring systems with wiremold. A, cleatwork; B, wooden molding; C, concealed knob and tube; D, armored cable; E, metallic flexible conduit.

The wires are fished or pushed through the raceway. There is no base or capping, they being permanently assembled at the factory.

Code Requirements.—Wiremold is permitted on circuits of not over 300 volts or 1,320 watts. It must be grounded to a water pipe. No splices are allowed inside of wiremold, use junction boxes. It must not be concealed or installed in damp or very hot places, such as bakeries.

Installation of Wiremold.—Use a fine tooth hacksaw for



FIGS. 7,088 to 7,097.—Method of tapping various fittings with wiremold. A, concealed conduit box no fixture; B, concealed conduit box with fixture; C, concealed conduit box having open cover ¾ in. deep; D, metal surface type switch and cut out cabinet; E, metal concealed type switch and cut out cabinet.

cutting. The ends of wiremold must be brushed to prevent the rough edges cutting into the wire.

In coupling lengths of wiremold, a coupling fitting is used which serves also as a support; it is first fastened to the ceiling or wall before making the joint.

Wiremold can be easily bent without the use of any special tools or hickey and with a little practice can be worked down to a 3 in. or a 3½ in. radius without trouble, particularly on internal bends. It is also easily worked in passing around beams, etc.

2. *Concealed Knob and Tube Wiring*

This is one of the cheapest forms of house wiring in use today, but it is fast becoming outlawed in many cities by municipal rules.

The objections being that it is subject to mechanical injury, is liable to interference from rats, mice, etc., and as the wires are liable to sag against beams, laths, etc., or likely to be covered with shavings, a fire could easily result in case of an overheated wire or short circuit.

The advantages are cheapness, especially in wiring completed buildings and the absence of any wires or mouldings on the walls. Knob and tube wiring consists in running the wires concealed between the floor beams and studs of a building, knobs being used to support the wires when run parallel to the beams or studs, and porcelain tubes, when run at right angles through the beams or studs as shown in fig. 7,098.

Code Requirements.—Wires with rubber covered insulation must be used, and rigidly supported on non-combustible, non-absorptive insula-

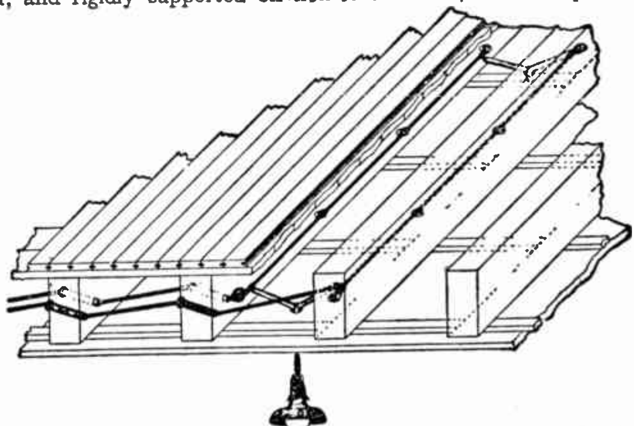


FIG. 7,098.—Concealed knob and tube wiring. The wires are carried on porcelain knobs attached to the beams. If run perpendicular to the beams, holes are bored in the latter and porcelain tubes with a shoulder at one end, inserted in the holes through which the wires pass. The knobs should support the wires at least one inch from the surface over which they run, and should not be spaced further than 4½ feet apart. The use of split knobs does away with the necessity of using tie wires. The conductors must be at least 5 inches apart and it is better to support them on separate beams when possible. Each wire must be encased in a piece of flexible tube at all switches, outlets, etc., and this piece of tubing should be sufficiently long to extend from the last insulator and project at least one inch beyond the outlet.

tors which separate the wire at least one inch from the surface wired over. Wires must be 5 ins. apart, taut, and separated from contact with the walls of floor timber and partitions through which they pass by insulating tubes of glass or porcelain. Maximum spacing for rigid supports of horizontal wires 4½ ft.

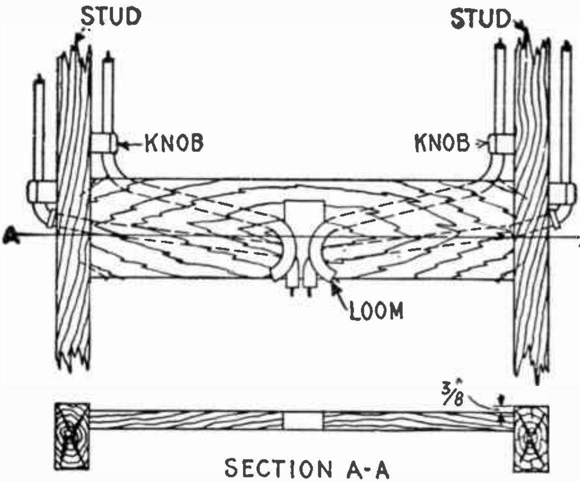
Installation of Knob and Tube Wiring.—Usually nothing need be disturbed on the first floor as the various outlets can be reached from the basement and from the second floor.

In boring holes in floor beams for the porcelain tubes they should be bored at the center of the beam to prevent nails being driven into the tubes and cutting the wires. A competent workman will have a special boring machine so that the holes can be bored parallel to the floor instead of at an angle as is done with the ordinary brace and bit. This latter method is very objectionable and should not be tolerated on first class

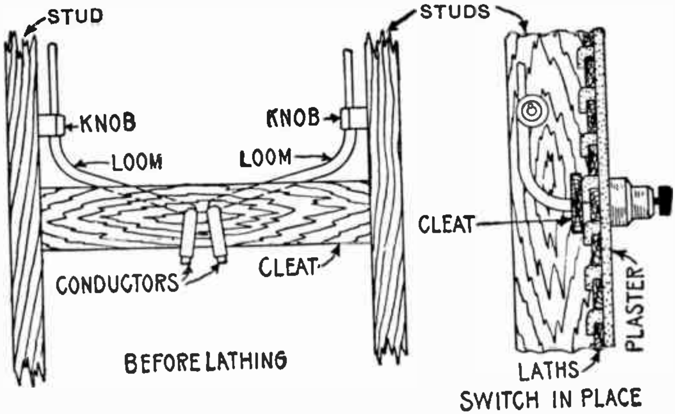
Fig. 7,099.—Porcelain tube as used in knob and tube wiring. The standard tube as used in house wiring comes in all lengths and is 5/16 in. in diameter.

work. In wiring, say the first floor, a strip of flooring is removed from the floor above so as to expose the beams. Then two holes are bored through each of the beams spaced 5 ins. apart, the porcelain tubes inserted in the holes and the wires threaded through these tubes, the outlets made, as later described, and the strip of flooring replaced. Where it is impossible to insert a tube, loom may be used.

When passing through floors with wires, an additional tube must be placed over the wire so that the wire will be encased and protected at least 4 ins. from above the floor so that the wires will be protected from falling plaster and other objects. When passing through portions that contain brick, tile or concrete fire stops, the wires should be encased in loom and should then be encased in a metal pipe, the loom being in one continuous piece and extending from knob to knob.



Figs. 7,100 and 7,101.—Elevation and sectional view showing arrangement of switch outlet in concealed knob and tube wiring.



Figs. 7,102 and 7,103.—Arrangement of surface switch in concealed knob and tube wiring. For a surface snap switch outlet, an iron box is not necessary, but a ⅞ in. cleat must be installed to hold the tubing in place and to provide a proper support for the screws that hold the switch. In wiring old buildings where supporting cleats were not provided back of the plaster, a ¾ in. wooden block or plate should be installed on the surface, to which the switch can be attached.;

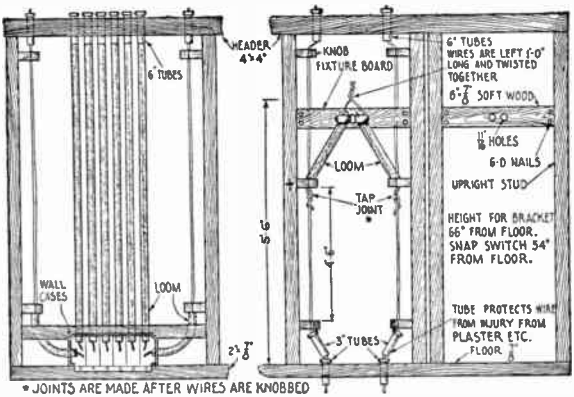
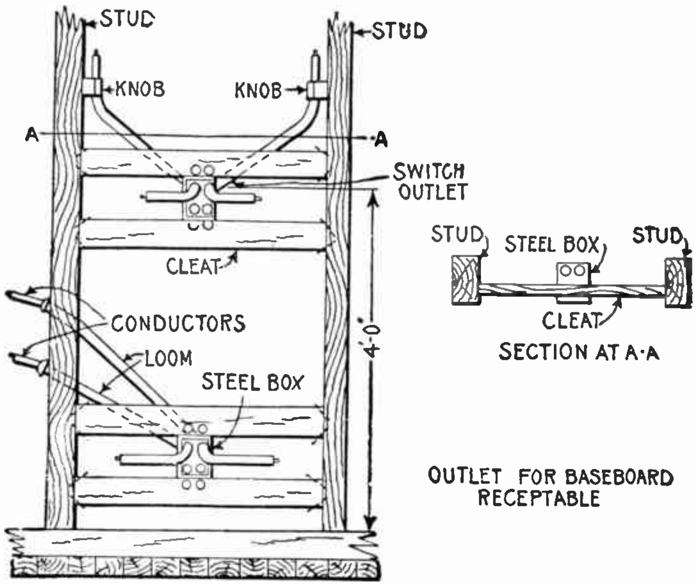


Fig. 7,104.—Method of installing wires where spacing of 5 ins. cannot be made. *All wires spaced less than 5 ins., must be encased in loom.* The loom must be continuous and in one piece from the tube to the wall case where at this point it must be secured by a clamp to the box. As shown, there is room for wires on the side of the studs; these wires need not be encased in loom.

Fig. 7,105.—Method of avoiding cross stud by locating wall cases a little above center of partition.

Never attempt to pull wires taut with the claw of a hammer or with a pair of pliers as these methods cause the wire to become kinked which in turn break the wires causing open circuits and endless trouble. Wires should be pulled taut by hand and the knobs should be nailed down sesurely. Sagging wires are considered violations and are not allowed by inspectors. Knobs with two grooves should be used as they save time and money when making taps for side lights or base plugs.

Joints.—All joints should be well taped and soldered. In houses under construction where there are no windows, it is suggested as a time saver, that all joints should be covered with soldering paste to prevent them being coated with a film of acid that comes from factory smoke and fumes, as it will be found that solder will not stick to joints unless protected in this manner. A gasoline torch of one pint capacity should be used for soldering joints as in this mode of wiring there are numerous joints and much time will be saved if all the joints are soldered and then taped, as



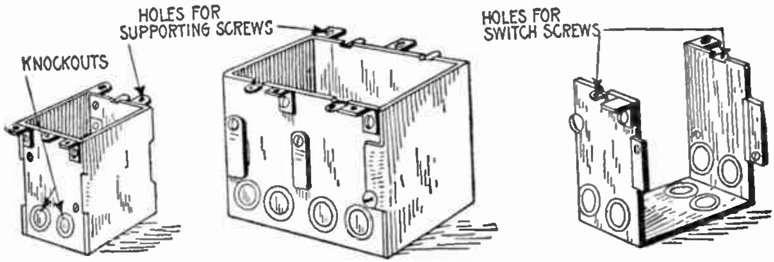
FIGS. 7,106 and 7,107.—Arrangement of switch and receptacle outlets in knob and tube wiring. *In wiring for switches,* flexible tubing must be used on the conductor ends from the last porcelain support, as shown, the same as on conductor ends for other outlets. A pressed steel switch box should be used to encase each flush switch mechanism, even though it already be encased in porcelain. A ⅞ in. wood cleat or cleats are arranged to support the switch box. These wooden cleats should not be set out flush with the outer edges of the sheets, but should be set about ⅜ in. back as shown to allow a space in which the plaster can "grip."

if the wiremen go to a joint and solder it and then tape it, he will lose much time and will waste gasoline.

Wall Cases.—These are metal boxes for supporting and encasing flush switches and receptacles, switches and receptacles should not be installed without these as they are a great protection against starting fires from sparking switches.

Wall cases in sections are called gangs, thus a wall case for two switches would be called a two gang box.

When installing bare receptacles, a board ⅞ in. thick should be cut out the same size as the wall case—the ears of the wall case should be adjusted so that the front edge of the wall case will extend out ⅞ in., the wall case should then be screwed to the board (not nailed) and the board is then nailed against the upright studs, so that the front surface of the box will be 1¾ ins. from the edge of the studs. This will bring the wall case



FIGS. 7,108 to 7,110.—Switch boxes for concealed knob and tube wiring. These are for flush switches and are formed from sheet steel. A single switch box can be expanded for any number of switches, by using the proper number of spacers. Single and double switch boxes can be supplied already assembled and are used where feasible, because it is cheaper to buy them this way than to assemble them. Holes partially punched, which can be knocked out with a hammer blow, are provided in the sides and back through which the flexible conduit wire protection can be extended.

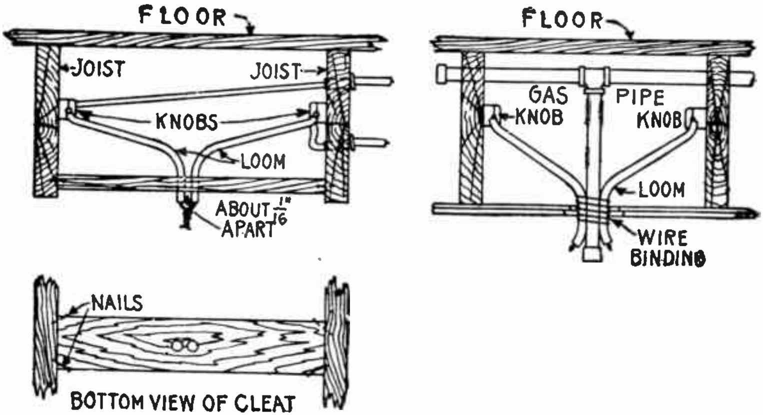
or box just flush with the finished base or mop board. Thicknesses of base boards are about ⅞ in., but this should be ascertained before installing the wall case. The above directions are based on base boards having a thickness of ⅞ in. A good rule to remember is that lath and plaster take up ⅞ in. Wires entering wall case should be encased in loom, which should in turn be secured to the box by clamps.

After wires are brought into a wall case they should be twisted and marked so that they will easily be identified when the switches are to be installed. Switches and receptacles are never installed in wall cases until after all the plastering has been done. All wall cases should be stuffed with newspaper or rags so that they will not be filled with plaster and should have a stick extend at least 4 ins. out of them so that they will not be plastered over, the stick serving as a mob mark.

Wall cases should be installed so that the front edge of the box extends ¾ in. from the edge of the studs. Wall cases should be supported on strips of wood which are not less than ⅞ in. thick. Laths will not do. The strips should be placed so that they are flush with the front edge of the studs.

Fixture Supports.—A good method of installing a fixture support is to take a piece of wood ⅞ in. thick by 6 ins. wide and nail flush with the lower edge of the beams; this is for straight electric fixtures.

In case of a combination gas and electric fixture no board is required. The looms should be secured to the gas pipe so that they will not slip down, the wires at all outlets should be twisted together so that they will not be lost singly.



FIGS. 7,111 to 7,113.—Methods of making fixture outlets in concealed knob and tube wiring. A cleat consisting of a piece of board at least ⅞ in. thick, should be nailed between the joists or studs into which the wood screws supporting the electrolier can be secured. Holes are then bored through the cleat, through which the flexible tubing can pass. With a combination gas and electric fixture as shown in fig. 7,112, no cleat is necessary, because the gas pipe supports the fixture. The flexible tubing should be wired to the gas pipe, to prevent displacement by artisans who have occasion to work around the outlet.

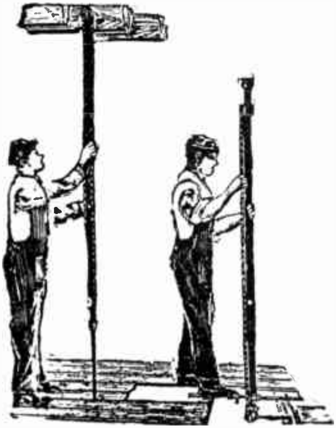
In some cities municipal laws require the use of outlet boxes for loom at all outlets in knob and tube work, although not shown in the drawings, they are not required by the *Code* but they only recommend their use.

Location of Outlets.—The standard height for side wall outlets are 66 ins. from the floor. Flush switch outlets should be installed at a standard height of 54 ins. from the floor to the center of the switch box.

Wall receptacles, such as used for electric irons, etc., should be installed at the same height as switch outlets.

Base plug outlets should be installed in the center of the base board, not lower than 2 ins. from the floor.

Points on Wiring Houses Under Construction.—The plans and specifications of the house should first be gone over very carefully.



For one family houses it is suggested that a separate circuit be made for each floor, the cellar light being taken off at the first floor circuit, attic light being taken from second floor circuit.

Cellar light sometimes can be tapped off of base receptacles or vice versa.

Always arrange the circuits so that they will drop down over the meter or distribution panel.

FIG. 7,114.—Boring machine for boring porcelain tube holes in knob and tube work. It will bore a hole parallel with the floor (avoiding slanting tubes) and in less time than with a brace.

FIG. 7,115.—Electrician's bit designed for rough usage. *It has* a coarse worm and sharp cutter so that it will pull itself into the wood without much effort. Ordinary fine worm carpenter's bits are not suitable as they easily clog in the hole.

Always try to place base plugs under switches as this saves wire and labor. Group as many switches as possible at one point, this also saves labor and material.

The holes should be bored with a ***boring machine.*** If this be not possible it is suggested that the wireman have the apprentice bore the holes. All holes should be bored before wiring is begun.

For 2 in. joists, 3 in. tubes should be used; for 3 in. joists 4 in. tubes should be used.

Tubes should be inserted as the holes are bored; this saves time in going back to the same place to insert tubes.

A time saver is to have the wireman wear an apron that is similar to those worn by carpenters with two compartments, one for tubes, the other for knobs.

Always make joints as branch circuits or taps are made; this saves time. Also cover joint with soldering paste as soon as made.

In general on knob and tube work there are many details that should be borne in mind mainly that time must be saved; this is only accomplished by having a system about your work such as outlined above. Never go back to an outlet; always finish the work at one particular spot, going back and forth is costly.

Always locate centers of rooms for outlets and install outlet boards for fixtures supports before wiring, install wall cases, receptacles, etc. Soldering should not be attempted until all the joints and all wires have been run.

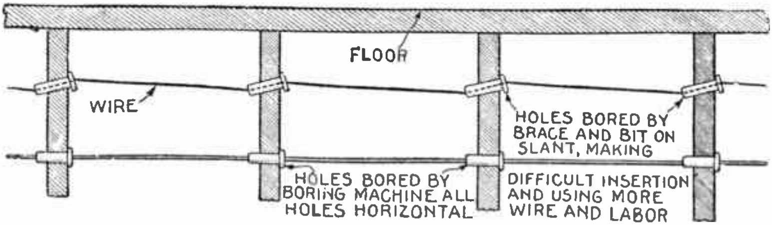


FIG. 7,116.—Comparison of porcelain tube holes as bored with brace and bit and with boring machine. The use of a brace and bit is not only a waste of time but makes an objectionable job.

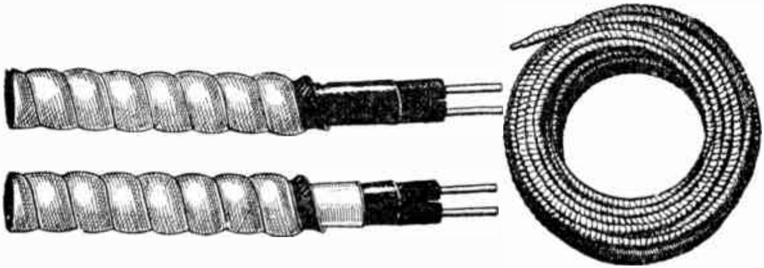
As a final reminder neatness counts, tight wires and neat joints insure a good installation. Always trace out all circuits before house is considered as finished.

5. Armored (B.X.) Cable Wiring

Armored cable, hereafter called by its trade name, B.X. Cable, consists of a duplex or two wire cable covered by a specially wound steel casing. B.X. cable is manufactured in long lengths (coils of 250 ft. and less) and may be obtained with either 2 or 3 conductors, also with a lead covering for outside and underground wiring.

B.X. cable is flexible and the conductors are well protected from mechanical injury. While this form of wiring has not the advantage of the conduit system—namely, that the wires can be withdrawn and new wires inserted without disturbing the building in any way whatever—yet it has many of the advantages of the flexible steel conduit, and it has some additional advantages of its own. For example, in a builidng already erected, this cable can be fished between the floors and in the partition walls, where it would be impossible to install either rigid conduit or flexible steel conduit without disturbing the floors or walls to an extent that would be objectionable.

B.X. cable is less expensive than the rigid conduit or the flexible steel conduit, but more expensive than cleat wiring or knob and tube wiring, and is strongly recommended in preference to the latter.



FIGS. 7,117 and 7,118.—Greenfield flexible armored (B. X.) cable and length of cable coiled.

FIG. 7,119.—Greenfield flexible armored cable, lead covered conductors (B.X.L.) for use in wet places.

Code Requirements.—Must be continuous from outlet to outlet. Must be equipped at every outlet with an approved outlet box or plate. Must have metal armor grounded. Must have approved terminal fittings when entering junction boxes. Armor must not be injured in bending; minimum bend, 1½ ins. inner radius.

Installing B.X. Cable.—In order to properly remove the metal casing or armor, a fine toothed hack saw should be used.

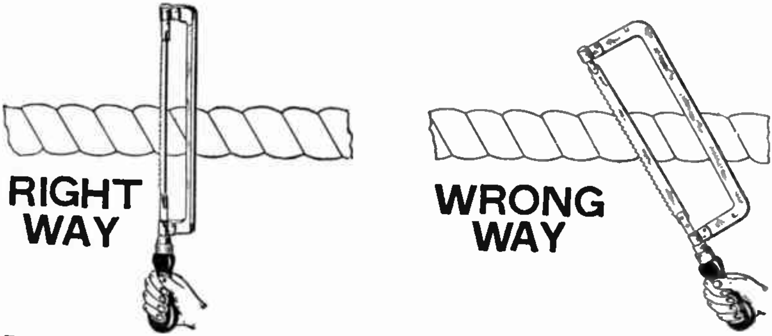
The armor is cut diagonally across. The cut should not entirely cut through the sheath, but should be deep enough so that it will break if given a slight inward bend. Do not cut too deep as this may sever the wires or puncture the insulation.

After armor sheath has been removed, the outer protecting braid must be removed from the duplex conductors. This is best done by making a slit one inch below the sheath about one inch long, and then by pulling on the outer braid it will readily come off without much effort.

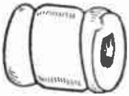
Before the cable is installed it should be examined at each end to see whether any parts of the sheath punctures the insulation.

This is very important as grounds and short circuits are often thus accidentally made.

In installing on concealed work, the cable is drawn through a hole in every joist and beam that it passes through, notching out or cutting grooves in joists is not permitted. Care should be taken that the cable should be installed so that no nails will puncture the armor when the floor is laid



FIGS. 7,120 and 7,121.—Right and wrong way to cut B.X. cable with a hack saw.



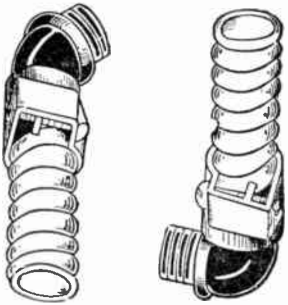


FIG. 7,122—Cable connector for securing B.X. cable to outlet boxes, etc.

FIG. 7,123.—Bushing for B.X. cable. Where the cable enters wall cases, they should be securely clamped to the box and be equipped with a bushing.

FIGS. 7,124 and 7.125.—45° and 90° elbows for making sharp turns from outlet box with B.X. cable.

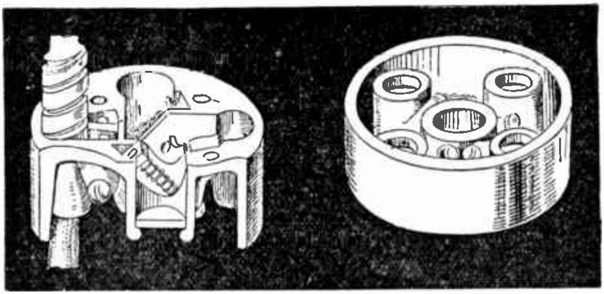
back as nails will cause short circuits and grounds, which are very difficult to find.

It is not necessary to draw the cable through the joists in blind attics; the cable may be laid on top of the joists.

By blind attics it is meant where the cable would not be disturbed by walking around.

No junction boxes are permitted to be concealed under floors or walls. Make all splices at fixture or switch outlets, if junction boxes be necessary they should be installed in a clothes closet or pantry or in open accessible attics.

Where the B.X. cable enters an outlet box, plate, or cabinet the cable should be securely fastened to it by B.X. connectors; also, it is important



FIGS. 7,126 and 7,127.—*Dead ground* cable boxes. For straight electric work male boxes should be used, these come already with a threaded fixture stud. A female or combination box is used where the electric fixture is attached to a gas pipe.

that these connectors be screwed up as tightly as possible, as it is essential that the entire installation be one straight metallic system.

When running B.X. through floors, it also must be protected by a piece of pipe which should extend at least 4 inches above and below the floor.

B.X. should be supported by straps or clamps which should be spaced about every 18 ins.

B.X. can be run on top of cellar joists without any running board. It is advisable to strap the cable at every other joist.

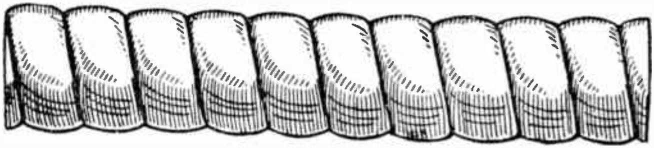
On exposed work the cable should be secured by straps, nails being prohibited.

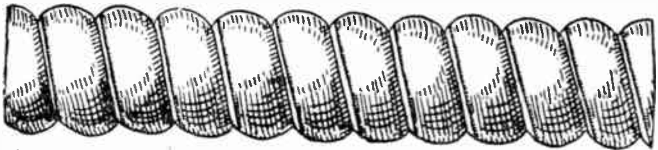
B.X. cable must never be run in damp cellars, or exposed to the weather or laid in concrete. in which the concrete is poured, unless it is lead covered

(B.X.L.). B.X. cable however may be run against brick walls or may be laid in plastered walls and ceilings provided however that they are dry. Never bend B.X. cable in any manner whereby the sheath may become injured, as this may cause a ground: *minimum inner radius* 1½ ins.

Where it crosses water, a steam or water pipe, for ordinary common 2 or 3 wire B.X., ¾ pipe will easily slide over. The sleeve should also be screwed so that it will not slide away. This can be best done by strapping both ends of the sleeve to the cable.

When wiring for 3 way switches 3 wire cable should be used, as it is more economical to use one 3-wire cable instead of two 2-wire cables. By following the general outline for concealed house wiring, little trouble will be experienced in installing a good job.





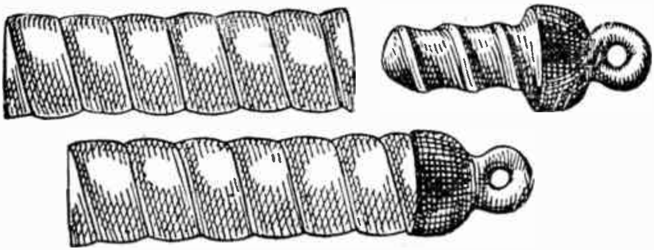
FIGS. 7,128 and 7,129.—Greenfield flexible steel conduit; fig. 7,128 single strip type; fig. 7,129 double strip type. The former (fig. 7,128) is formed with a single strip of galvanized steel, interlocked and gasketed in such a manner as to be suitable for concrete construction. The double strip type (fig. 7,129) is constructed of a concave and convex steel strip, spirally wound upon each other in such a manner as to interlock their concave surfaces. Thus the convex surfaces of the two strips form respectively the outer and inner surfaces of the conduit. This construction insures a smooth interior surface, thus reducing the possibility of friction in the drawing in of conductors. A gasket is provided between the inner and outer strips rendering the conduit moisture proof. This form of flexible conduit is especially adapted to use where the wiring is installed after completion of building, because it is very flexible.

5. Flexible Conduit Wiring

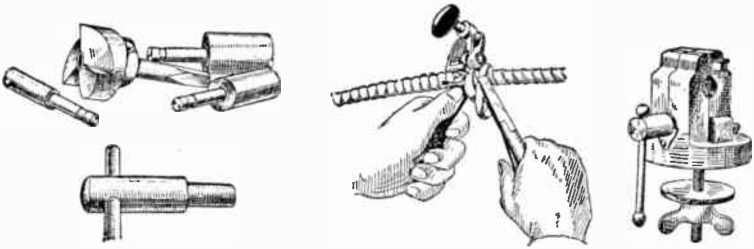
Flexible conduit is a continuous flexible steel tube composed of convex and concave metal strips, wound spirally upon each other in such a way as to interlock their concave surfaces.

It possesses considerable strength and can be obtained in long lengths (50 to 200 feet); elbow fittings are not required as the conduit may be bent to almost any radius. The fissures of the conduit provide some ventilation; this is an advantage in some places and a disadvantage in others.

Flexible conduits are used to advantage in many cases where rigid conduits would not be desirable. It is especially adapted to completed buildings where it is desired to install the wiring by "fishing" without greatly disturbing



FIGS. 7,130 to 7,132.—Greenfield flexible steel conduit and fish plug, showing method of insertion. Fish plugs are made for ⅜ inch, ½ inch, and ½ inch conduit and are useful in drawing in the conduit in finished buildings where it is desired to fish it under doors or in partitions. After the conduit has been cut off square in the special vise, the fish plug may be screwed into the tube and the fish wire or drawing in line should then be attached to the eyelet on the end of the plug.



FIGS. 7,133 to 7,137.—Greenfield flexible conduit tools. Special tools are necessary for installing this type of conduit. Fig 7,133, bushing; fig. 7,134, reamer; fig. 7,135, bushing tool; fig. 7,136, cable armor cutter; fig. 7,137, vise for holding conduit. To remove cable armors, clamp the conductor firmly in the armor cutter and with a pair of cutting pliers back the armor off, one strip at a time, to the point of contact with the cutting edge of the tool. The vise for holding conduit takes all sizes. The conduit can be cut with an ordinary hack saw. To protect the insulation against any possible injury while the wire is being drawn in, a soft metal bushing should be inserted in the end of the tube and secured permanently thereto by means of the bushing tool. The bushing provided for this purpose has an outside thread, which permits its being screwed into the end of the tube and then expanded by the use of the tool. The tool should always be used after the bushing has been screwed into the pipe, then the bushing tool should be inserted.

the walls, floors, or ceilings. It should not be used in damp places because of the fissures.

In installing flexible conduit, it is "fished" under floors, in partitions between the floor and ceiling, by making pockets in the floors, walls or ceilings, say every 15 or 20 feet, and fishing through first a stiff metal wire called a "snake," and then attaching the conduit to same and pulling the conduit in place from pocket to pocket.

On vertical runs, a chain or weighted string is used which is dropped from the outlet to the floor and its lower end located by sound of the chain end or weight striking the floor.

Black Enameled and Galvanized Rigid Conduit

Size	Conduit				
	Diameters		Thickness	Wt Per Foot	Threads Per Inch
	External	Internal			
¼	540	364	.085	425	18
⅜	675	493	091	568	18
½	.840	622	109	852	14
¾	1 050	824	113	1 134	14
1	1 315	1 049	133	1 684	11½
1¼	1 660	1 380	140	2 281	11½
1½	1 900	1 610	145	2 731	11½
2	2 375	2 067	154	3 678	11½
2½	2 875	2 469	203	5 819	8
3	3 500	3 068	216	7 616	8
3½	4 000	3 548	226	9 202	8
4	4 500	4 026	.237	10 889	8
4½	5 000	4 506	.247	12 642	8
5	5 563	5 047	258	14 810	8
6	6 625	6 065	280	19 155	8

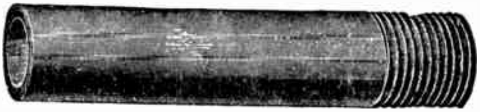


FIG. 7,138.—Rigid conduit. The dimensions of the various sizes are given in the table at the left, from which it will be seen that the dimensions and threads are the same as for standard (so called) wrought iron pipe.

6. *Rigid Conduit Wiring*

Rigid conduit, commonly called pipe (but different from ordinary pipe used for other purposes) comes in lengths of 10 ft. or less, and must never be used in sizes smaller than one-half inch pipe or nominal size.

There are two kinds of rigid conduit, the unlined and the lined. Unlined conduit consists of an iron or steel pipe, similar in size, thickness, and in every other way to gas pipe, except that special precautions are taken to free it inside from scale or any irregularities; it is then coated inside with enamel, outside it is sometimes enameled and sometimes galvanized.

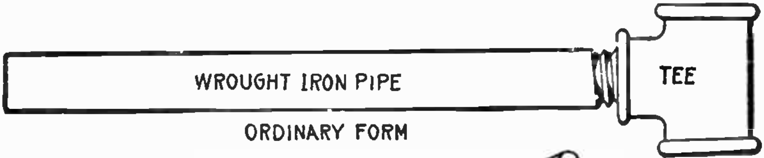
Lined conduit usually consists of a plain iron pipe lined with a tube of paper which has been treated with an asphaltic or similar compound.

this paper tube is cemented or fastened to the inside of the iron pipe so that it forms practically an integral part of the same.

As compared with lined conduit, unlined conduit is cheaper, because having no lining, a smaller size of conduit can be used for any given size of conductor; it is also cheaper to install, as it can be bent, threaded, and cut more readily than the lined conduit. Wires may be more easily inserted and withdrawn as the inside is smoother than that of the lined conduit.

A disadvantage of unlined conduit is that the *Code* requires the use of double braided conductors instead of single braided which are allowed for lined conduits.

The installation of wires in conduits not only affords protection from



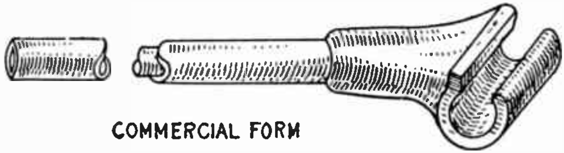


FIG. 7,139.—Ordinary form of hickey or conduit bender. It consists of a piece of one inch steam pipe about three feet long with a one-inch cast iron tee screwed onto one end of the pipe. This device is used as follows: the conduit to be bent is placed on the floor and the tee slipped over it. The workman then places one foot on the conduit close to the tee, and pulls the handle of the bender towards him. As the bending progresses, the workman should take care to continually move the bender away from himself, to prevent the buckling of the conduit.

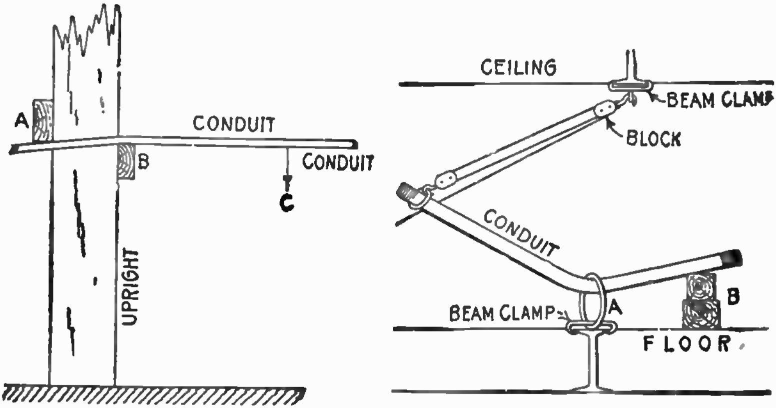
FIG. 7,140.—Commercial form of hickey or conduit bender.

mechanical injury, but also reduces the liability of a short circuit or ground on the wires producing an arc which would set fire to the surrounding material; the conduit being of sufficient thickness to blow a fuse before the arc can burn through the conduit.

Code Requirements.—Rigid conduit must be continuous from outlet to outlet or to junction bores, and must properly enter and be secured to all fittings, and the entire system be mechanically secured in position. In case of service connections and main wires, this involves running each conduit continuously into a main cut out cabinet or gutter surrounding the panel board as the case may be. Conduits must be equipped at every outlet with an approved outlet box or plate. Outlet plates must not be used where it is practicable to install outlet boxes. The outlet box or plate must be so installed that it will be flush with the finished surface, and if this surface be broken, it shall be repaired so that it will not show any gaps or open spaces around the edge of the outlet box or plate.

In buildings already constructed where the conditions are such that neither outlet box nor plate can be installed, these appliances may be omitted by special permission, providing the conduit ends are bushed and secured. It is suggested that outlet boxes and fittings having conductive coatings be used in order to secure better electrical contact at all points throughout the conduit system.

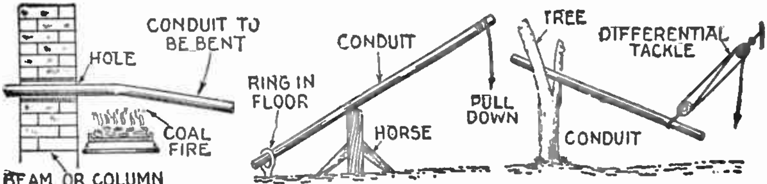
Metal conduits where they enter junction boxes, and at all other outlets, etc., must be provided with *approved* bushings or fastening plates, fitted so as to protect wire from abrasion, except when such protection is obtained by the use of *approved* nipples, properly fitted in boxes or devices.



FIGS. 7,141 and 7,142.—Methods of bending large conduits. A substantial support is necessary which may consist, as in fig. 7,141, of two pieces of 2×4 studding A and B, securely fastened to an upright. The conduit is placed under the block A and over the block B, and then bent by a downward pressure exerted at C, the conduit in the meantime being gradually advanced in the direction C, to give a curve of the required radius. The method shown in fig. 7,142, may be used wherever a ring A, can be attached to a beam or girder by means of clamps or otherwise to serve as a support. In this case the conduit is slipped through the ring and placed on the top of blocking B. The bending is accomplished by means of a block and tackle rigged to an overhead beam as shown. Where ring supports cannot be arranged, the application of frame bending methods give the most satisfactory results.

Conduits must have the metal of the conduit permanently and effectually grounded. Conduits and gas pipes must be securely fastened in metal outlet boxes so as to secure good electrical connections. If conduit, couplings, outlet boxes or fittings having protective coating of insulating material, such as enamel, be used, such coating must be thoroughly removed from threads of both couplings and conduit and from surfaces of boxes and fittings where the conduit is secured in order to obtain requisite good connection.

Where boxes used for centers of distribution do not afford good electrical connection, the conduits must be joined around them by suitable bond wires. Where sections of metal conduit are installed without being fastened to the metal structure of buildings or grounded metal piping, they must be bonded together and joined to a permanent and efficient ground connection. Junction boxes must always be installed in such a manner as to be accessible. All elbows or bends must be so made that the conduit or lining of same will not be injured. The radius of the curve of the inner edge of any elbow must not be less than 3½ ins. Must have not more than the equivalent of four quarter bends from outlet to outlet, the bends at the outlets not being counted.



FIGS. 7,143 to 7,145.—Methods of bending large conduits. Fig. 7,143, by heating. Large conduit such as sizes above 3" may be bent if they be first filled with dry sand to prevent kinking and heated until cherry red over a coal fire, then bending as shown. In fig. 7,144, the conduit is inserted into a ring secured to the floor and bent over a horse by pulling down on the end. The pipe will not kink as the wooden horse is softer than the pipe. Another method, as shown in fig. 7,145, consists of inserting the conduit in the V of a tree and bending by attaching block and tackle, worked by team of horses, or preferably by a differential tackle as shown.

FIG. 7.146 —Rittenhouse conduit bender.

Installing Rigid Conduit.—Cutting should be done with a hack saw unless the pipe be thoroughly reamed to remove the burr.

The presence af a burr with its sharp edges might cut into the insulation of the wire and cause short circuits or grounds.

Bends.—The best method of bending small size conduit is by the use of a bending tool called a *hickey*, of which there are various types. A cheap and serviceable hickey can be made out of a 1 in. tee screwed on to a piece of 1 in. water pipe about 36 ins. long.

In place of a hickey, a vise, or the conduit may be bent by drilling a hole in a large upright or horizontal beam. Some wiremen bend ½ in.

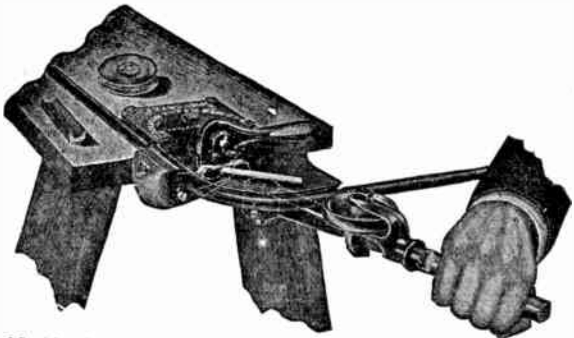
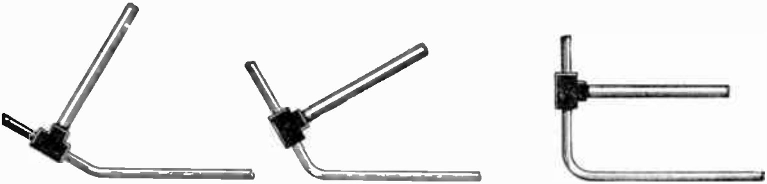


FIG. 7,147.—Machine for making quarter bends. This type of a tool should be used on large jobs where a number of bends the same size is desired.



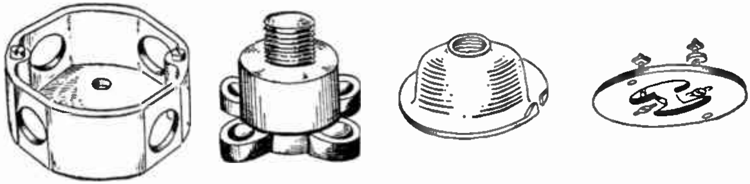
FIGS. 7,148 to 7,150.—Correct method of making a quarter bend with a hickey. The pipe should be marked at the place where the bend is to be made, grasp pipe with hickey and raise pipe from floor a few inches, shift hickey and bend conduit a little more; keep shifting hickey until the proper bend is made. Unless hickey be shifted, the pipe will be kinked, thus making it difficult to pull the wires through the pipe; kinked bends will not pass inspection. *To make an offset:* Stand hickey on floor in an upright position with the bending part up, insert pipe into opening and pull down on the pipe, using the length of the pipe as a leverage, having made the bend as far as desired, turn the bend up and repeat as above.

conduit over the knee, small offsets and saddles for particular work should be bent with a hickey.

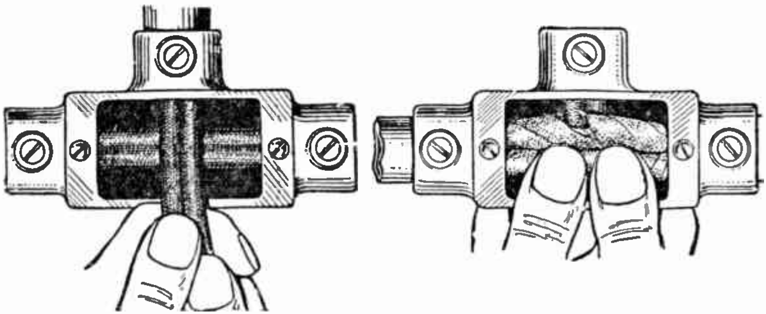
Other methods consist in utilizing trolley tracks, crutches of a tree, spaces between cast iron sewer pipes and catch basins, street man hole covers, machinery, etc.

Always make sure that the bends are true, otherwise the offset will have a crook or bow in it.

For small and close work use a hickey, but for rough work use a hole in a wall, etc.



FIGS. 7,151 to 7,154.—Conduit fittings. Fig. 7,151, round style outlet box; fig. 7,152, insulated fixture stud for use in outlet boxes (note insulated studs are used instead of insulating joints); fig. 7,153, outlet box cone; fig. 7,154, spider cones for snap switches and receptacles to fit round boxes.



FIGS. 7,155 and 7,156.—Conduit tee fitting. Fig. 7,155 shows method of pushing wires through conduits from tee fitting, and fig. 7,156, how a splice or branch tap appears from the fitting—note method of tapping.

Instead of bending the conduit standard elbows or bend fittings may be used. These have female threads at each end into which the threaded ends of the conduit is screwed.

These are very valuable for the larger sizes above 1 in., but for smaller sizes ½ to 1 in., it is best that the conduit itself should be bent.

Water and gas pipe fittings are not permitted to be used in electrical and conduit work as they are not constructed to receive electric wires.

Threading.—To successfully cut threads, the dies should be sharp and *plenty of lubricant should be used*, otherwise the dies are overheated, lose their temper and soon become dull with resulting poor thread and much physical effort required to cut the threads. Do not expect to obtain perfect threads unless the dies be ground to the correct cutting angle—as usually manufactured this angle is not correct.

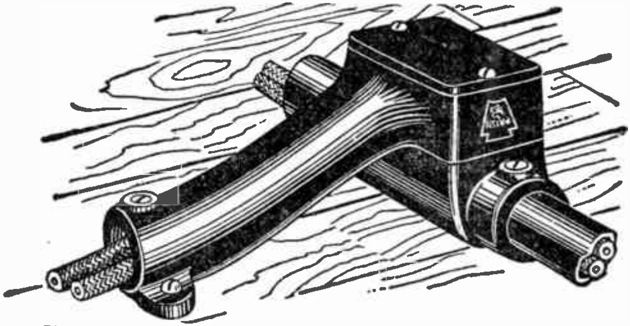


FIG. 7,157.—Fitting for tapping a branch circuit from an existing conduit installation.

In joining conduit lengths, ***running threads are used for the same purpose as the thread on unions in steam fitting.***

The proper method for making a running thread is to cut a thread on the conduit the same length as the length of the coupling; the thread should be made loose so that the coupling will turn easily. A lock-nut is placed in back of the coupling to lock coupling in place.

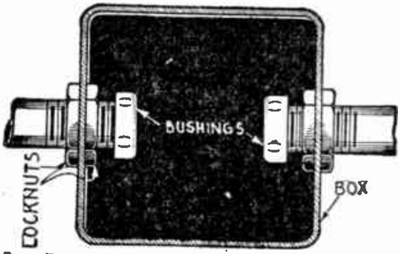


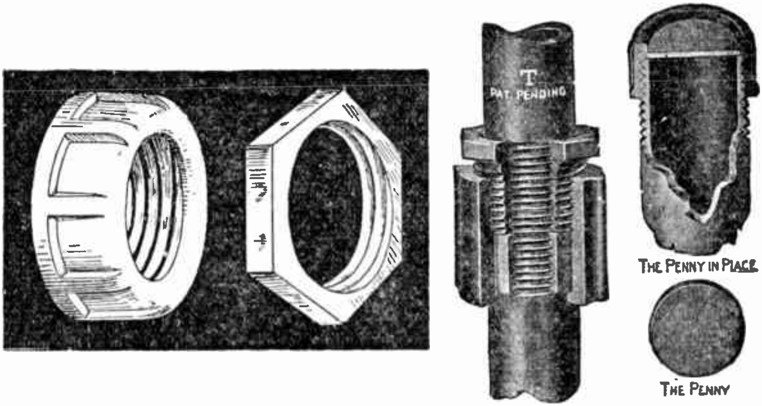
FIG. 7,158.—Method of securing conduit to outlet or junction boxes. *Two locknuts and a bushing must be used* as shown.

In cutting, do not lubricate by the spasmodic flooding with oil, as this immediately runs off and does little good. Instead of oil provide a small can of lard and apply to pipe end with a brush. Evidently as the die advances, the heat of cutting progressively melts the lard, thus giving a continuous supply of lubricant with no waste. Only right hand threads are used for electrical work.*

In this joining together lengths of conduit butt the ends of conduit together and run coupling over pipe to be coupled, after running the coupling up as far as it will go, lock the coupling with the lock nut so that a good tight joint will be made.

Running threads should not be made on pipe for underground purposes, unless joints are tight and painted with lead and conductors in conduit are lead covered.

Outlets.—All conduits should be secured to all outlet boxes by means of two lock nuts and a bushing, the lock nuts to prevent shifting of the



FIGS. 7,159 to 7,163.—Conduit fittings. Fig. 7,159, lock nut; fig. 7,160, bushing; fig. 7,161 Erickson's coupling or running thread union; figs. 7,162 and fig. 7,163, penny plug to prevent foreign objects falling into conduit.

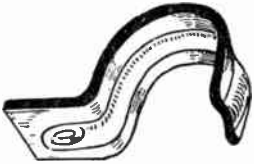
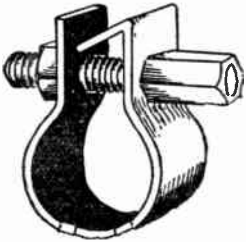
pipe, and the bushing to protect wire from abrasion. The lock nuts must be made up as tightly as possible to make the conduit system one.

The ends of all conduits where they terminate such as on meter loops, motors, and apparatus must be equipped with a porcelain or other insulated bushed fitting. Plain iron bushings are not to be used only on conduits protecting ground wires.

Where it is desired to install a number of conductors in one large conduit and distribute them from a central point, *junction boxes* should be used. These should be used on long conduit runs as *pull boxes* to facilitate installing the wires in the conduit.

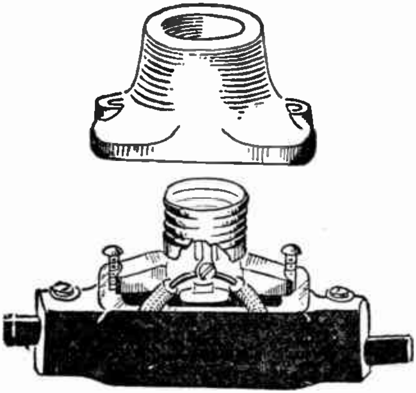
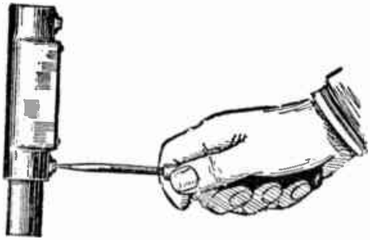
Laying Conduit.—For concealed work in houses, a strip of the flooring is removed and the joists are all notched out by making saw cuts and setting in the conduits so that the conduit is flush with the top of the joists. Pan cake boxes are used so that all wires enter at the back of each box.

In laying conduit in concrete, it should be bent at each end and brought into the back of the outlet boxes and secured by locknuts and bushings. Pancake of flush boxes should be used. The pipe is looped from outlet making all joints at outlets.

Figs. 7,164 and 7,165.—Conduit clamps. Fig. 7,164, old style requiring two screws; fig 7,165 new style, single screw.

Fig. 7,166.—Conduit ground clamp.

Figs. 7,167 and 7,168.—Receptacle wired to a conduit fitting and receptacle cover. Note method of securing wires to terminal screws.

Fig. 7,169.—Method of locking fitting to conduit by screws.

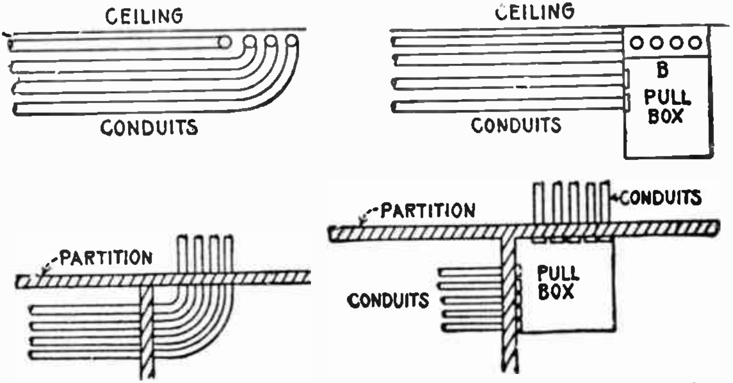
Lofts and factory buildings of beam construction offer much difficulty in installing conduits. Bending the conduit to pass around beams requires a lot of labor, causes difficulty in pulling in the wires, and presents an unsightly appearance. These objections may be overcome by the use of fittings called *pipe taplets* which can be obtained in various types. In this method short lengths of scrap pipe may be utilized; all the pipe may be cut to measure on the bench and installed in sections.

The wires are easily pushed through and extra extensions may be made from these fittings.

Methods of Securing Conduits.—On wood or plaster ceilings conduit should be secured by means of straps. These may be obtained in various forms and may be fastened either by nails or screws.

On metal ceilings toggle bolts should be used, the same on ceilings of metal lath. On concrete ceilings wooden plugs or lead shields should be inserted into holes dulled by means of brick drills.

Conduits may be secured to iron beams or girders by means of specially constructed beam clamps.



FIGS. 7,170 to 7,173.—Pull boxes and their use in conduit work. A pull box is a convenient device used for the purpose of avoiding the disadvantages of having too many bends in one continuous line of conduit; too many bends will give trouble when the conductors are drawn in. Pull boxes are also useful in places where the arrangement of the conduit is such that trouble would be experienced in bending it to a fit, and also in the case of conduits which are first run on a side wall and then have to be carried across the ceiling at right angles to the wall. Fig. 7,170 shows an example of objectionable bends, and fig. 7,171, the method of overcoming the difficulty by the use of a pull box. It is evident that it would be impossible to make some of these bends so as to permit the drawing in of the conductors. This difficulty is overcome, as shown, by placing a pull box on the wall, with its top close to the ceiling. A board B, having the proper size holes for the conduits is fastened to the front of the box and close to the ceiling. After the conductors have been drawn into the conduits along the wall as far as the pull box, they can be readily pulled away from the box through the holes in the board into the corresponding conduit on the ceiling. Fig. 7,173, shows the use of a pull box in a case where it is necessary to run conduit through partitions at right angles to each other.

Grounding of Conduits.—Ground connections should be made either by ground clamps or by special methods in which ground clamps are not used. In installing ground clamps at least one clamp is used on the conduit and one on the pipe which affords the ground. A ground wire is arranged between the two and soldered in the lug of each. More than one ground is desirable. At all combination outlets, ground the outlet box to the gas pipe. Ground wires should be large enough to give ample mechanical strength, No. 10 copper wire being the smallest that should be used.

Pulling Wires in Conduit.—The wires should be free from all kinks and bends and should be straightened out and laid parallel as they enter the conduit, and wherever possible they should be pushed in by hand.

Never push wires up in vertical conduits as this is double work, pushing against gravity; always push down whenever possible.

Never apply oil or grease to wires so that they will slide easy, this rots the insulation. Powdered talcum or soap stone should be used especially in the hot weather when the insulation is sticking.

If wires can not be pushed by hand they shold be pulled or snaked in by attaching them to snake wires.

Do not attempt to pull wires into runs of conduit that have extra long lengths as it is much easier to insert a pull box at certain points in the run to relieve excess labor in pulling ir wires.

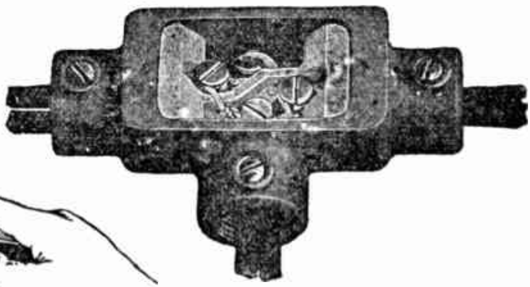


FIG. 7,175.—Special branch or tee conduit fitting which requires no splicing of wires.

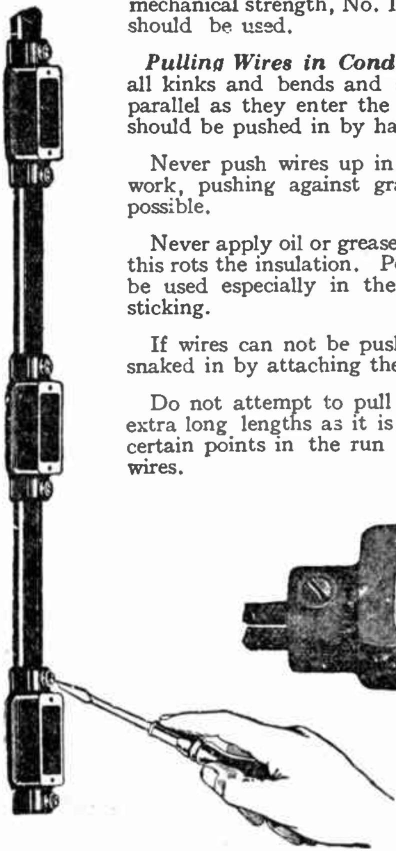


FIG. 7,174.—Method of making a border of lights with conduit fittings. Set screws permit aligning fittings in place

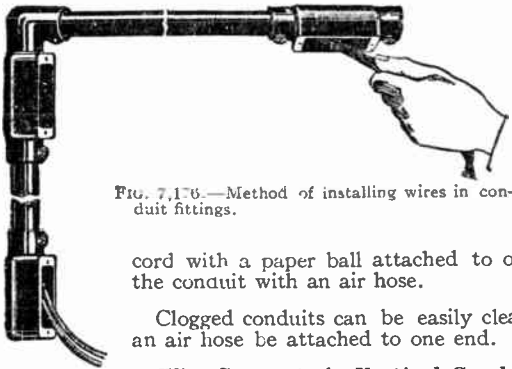


FIG. 7,176.—Method of installing wires in conduit fittings.

The obsolete method of hooking snakes pushed in from each end of the conduits, requires a lot of labor, which may be avoided by the use of pull boxes properly placed.

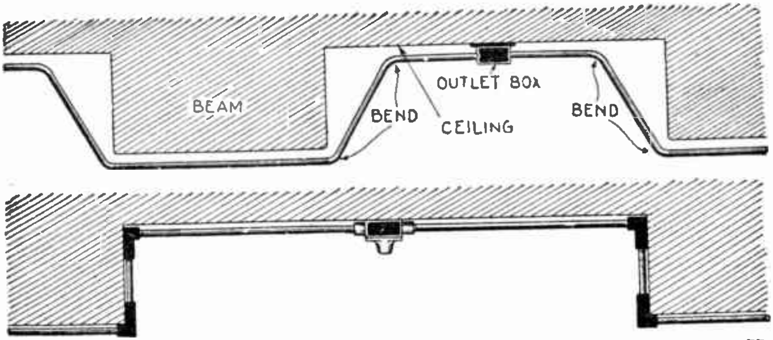
In pulling wires in long conduits, much time can be saved if a cord with a paper ball attached to one end is blown through the conduit with an air hose.

Clogged conduits can be easily cleaned of foreign objects if an air hose be attached to one end.

Wire Supports in Vertical Conduits.—All wires in vertical conduits are required to be supported as follows:

No. 14 to 0 inclusive every 100 feet. No. 00 to 0000 inclusive every 80 feet. Above 0000 to 350,000 C. M. inclusive every 60 feet. Above 350,000 C. M. to 500,000 C. M. inclusive every 50 feet. Above 500,000 C. M. to 750,000 C. M. inclusive every 40 feet. Above 750,000 C. M. every 35 feet.

In supporting wires approved clamping devices are used or insulating wedges are inserted in the end of the conduits. On long vertical runs



FIGS. 7,177 and 7,178.—Two methods of passing around ceiling beam with conduit. Fig. 7,177, bending method—laborious and presents unsightly appearance. Fig. 7,178, using fittings instead of bending the conduit. An easy and neat way and one which permits using scrap or short lengths of conduit.

junction boxes may be inserted at the required intervals in which the insulating supports are installed.

Practical Points Relating to Inside Conduit Wiring.—The following instructions apply to the installation of wiring in both rigid and flexible conduit:

1. All conduits should be made continuous from one junction or outlet box to another, or to the various fixtures. A conduit installation is made a complete system by the use of outlets, outlet boxes, switch or junction boxes, and panel boxes with doors and locks, which serve to thoroughly protect the circuit at all points.

2. In the installation of interior conduit wiring, the tubes are usually

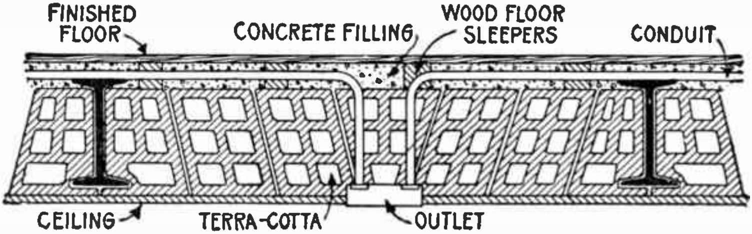


FIG. 7,197.—Method of installing conduits in fire proof buildings. *The installation* of the conduit includes the placing of all outlet boxes, and when this has been completed, the lathing or plastering work is executed, and after that is finished, the wire is pulled into the tubes, and the receptacles, switches, etc., put in position. The work of pulling in the wires may be greatly facilitated by the use of *pull boxes* as shown in figs. 7,171 and 7,173.

put in place as soon as the partitions of the buildings have been constructed. In non-fire proof buildings, the tubes are usually supported from the underside of the floor beams, but in fire proof buildings they are placed on top of the floor beams and under the floor as in fig. 7,197.

3. When conduit is used in damp places, lead encased wires should be used, and the wires drawn in very carefully so as to prevent any injury to the casings.

4. For wiring installations in buildings constructed entirely of reinforced concrete, the preliminary work should be laid out during the progress of the building operations so as to avoid, as much as possible, the necessity of drilling holes in the finished concrete work.

5. For concealed wiring, the location of all the outlets should be marked by sheet iron tubes large enough to hold the conduits. These tubes should be properly plugged, and set in the false work before the concrete is poured

in. In a similar manner, threaded pieces of conduit of the proper size, should be placed in the false work for risers.

6. For exposed wiring on concrete walls and ceilings, suitable cast iron supports should be set in the moulds at regular intervals. When liberally used, these supports will also serve as good supports for other pipes.

7. Where a conduit line terminates on the outside of a building some suitable fitting such as a pipe cap should be used, as shown in fig. 7,180, to prevent the entrance of moisture into the conduit system.

8. Where it is desirable or necessary to continue open wiring from conduits, or where the character of the wiring makes it necessary to bring the wires over from the conduit, as in an arc lamp, neat and safe work can be done by use of a suitable form of *condulet* as shown in fig. 7,181.

9. Where a conduit line terminates in a switch or panel box. the lining or casing of the panels should be of iron, and the conduit firmly secured to

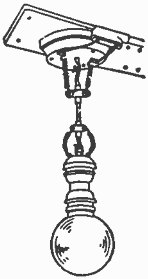
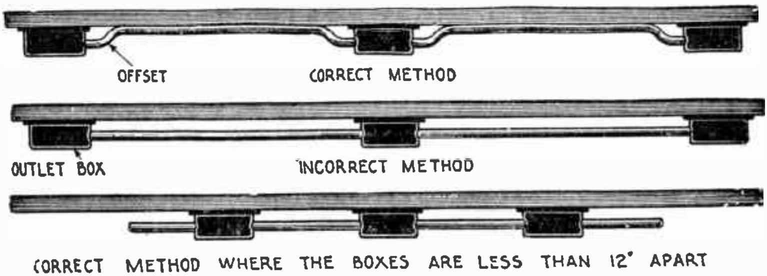


FIG. 7,180.—Service entrance to interior conduit system; showing method of preventing moisture reaching the interior of the conduit system.

FIG. 7,181.—Outlet to arc lamp from conduit by use of condulet. The wires are brought out from the conduit system at a distance of 2½ inches apart. Conduits are made in a great variety of design with interchangeable porcelain covers which render them adaptable to almost all cases requiring the installation of outlet boxes.



FIGS. 7,182 to 7,184.—*Right* and *wrong* methods of installing conduit to outlet boxes. When the conduit hole is in the center of the box, a much neater job is made if the conduit be bent at each outlet where the pipe enters the box. On borders or decorative work where the outlets are close to each other, as in fig. 7,184, short pieces of pipe need not be bent, because of the considerable labor required in making a multiplicity of bends. Fig. 7,183 show incorrect method where boxes are over 12 ins. apart.

it so as to make good electrical contact. Vertical lines of conduit should be fastened to the wall or other supports in such a manner as to prevent the weight of the conduit coming on the panel box, and each length of conduit installed should be fastened so as to bear only its own weight. The best method of fastening conduit to brick walls is by the use of expansion bolts and screws. In the case of fire brick ceilings or other plastered walls, toggle bolts should be used. When conduits are run on wooden or iron beams, various kinds of pipe hanger may be employed.

10. There are numerous devices on the market for bending conduit for the making of elbows, offsets, etc., but the majority possess the disadvantage that the conduit must be taken to them to be bent. In the case of the smaller sizes, this difficulty is avoided by the use of some form of conduit bender such as shown in figs. 7,139 and 7,140.

11. In all cases, the interior diameter of the conduit installed should be amply sufficient to permit of the wires being drawn in easily, thus providing a substantial raceway for the conductors. The practice of pulling wires through conduit by means of a block and tackle is very objectionable. It is evident that if the wires be pulled in by the application of much force the insulation is very liable to become damaged; furthermore, much difficulty will be experienced in pulling them out again, especially in warm places where the heat tends to soften the lining of the conduit, and also the rubber covering of the wire. Powdered soapstone put in the pipe while the wires are being drawn in will lessen the friction and permit the wire to go in more readily.

VARIOUS LAMP CONTROL SCHEMES

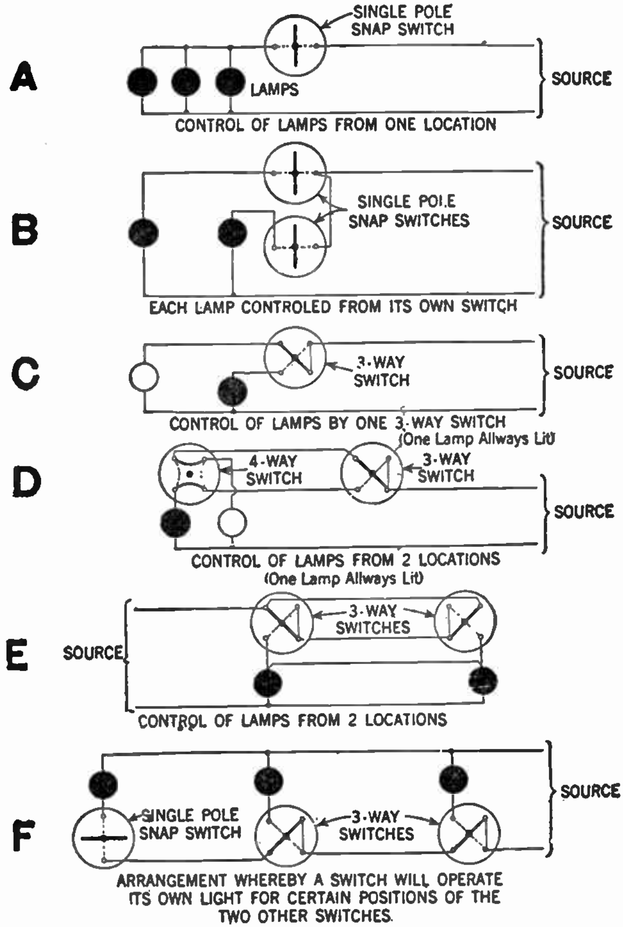


FIG. 7,185.—In the lamp control diagrams represented above **A**, illustrates the connection when one single pole snap switch is used. **B**, shows how two lights (or two groups of lights) can be controlled individually from a set of two single pole switches. **C** to **E**, illustrates a series of special types of lamp control used in, for example, test circuits, or in any location where a particular control scheme be desired.

LAMP CONTROL FROM 2-LOCATIONS

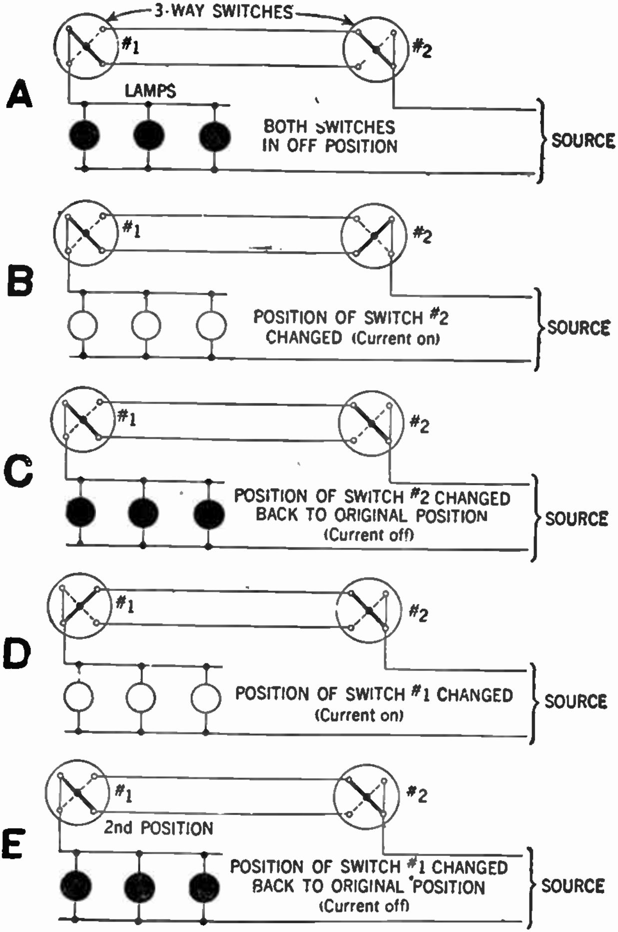


FIG. 7,186.—A convenient and often used method for control of a lamp or a group of lamps from two points by means of 3-way switches is shown in the diagrams. The lamps may be extinguished or lighted from either switch regardless of the position of the other. When both switches are in the position shown at **A**, the lamps are extinguished, and can be illuminated by the operation of switch No. 1 or 2. If as shown in diagram at **B**, No. 2 switch is operated, the lamps will be illuminated and can now be extinguished from either switch. A typical sequence of operation is shown diagramatically in **A** to **E**.

CONTROL OF LAMPS FROM MORE THAN ONE LOCATION BY MEANS OF 3 AND 4-WAY SWITCHES

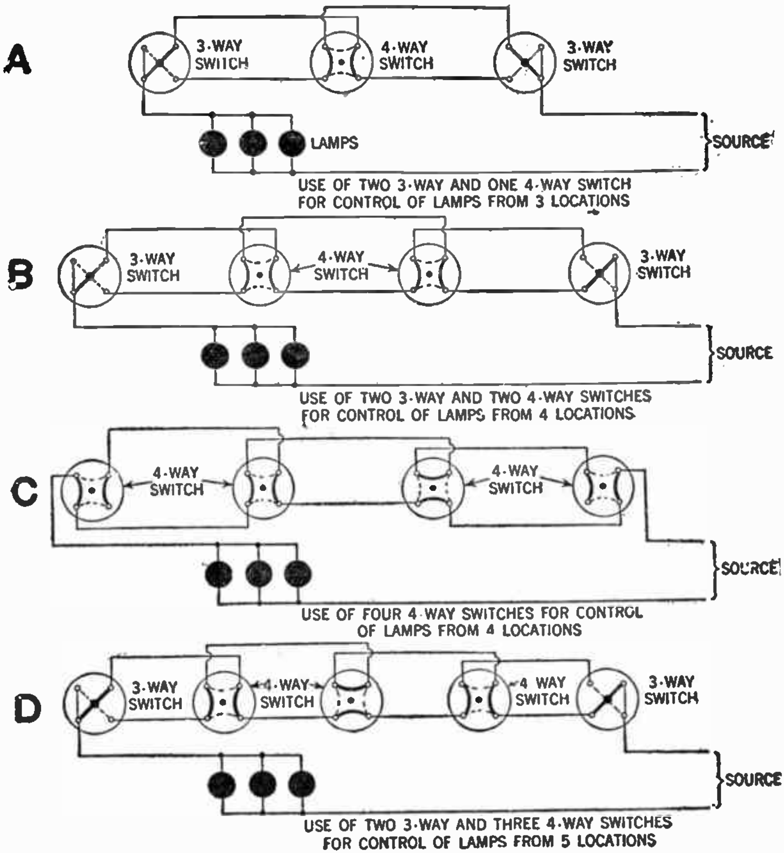


FIG. 7,187.—The series of connection diagrams shown in **A** to **D**, illustrate the conventional methods of lamp control when using 3- and 4-way switches. With reference to **A**, it is obvious that for any additional point of control desired, a 4-way switch connected the same as the middle switch must be used. See diagrams **B** to **D**.

LAMP CONTROL FROM 2-CIRCUIT ELECTROLIER SWITCH

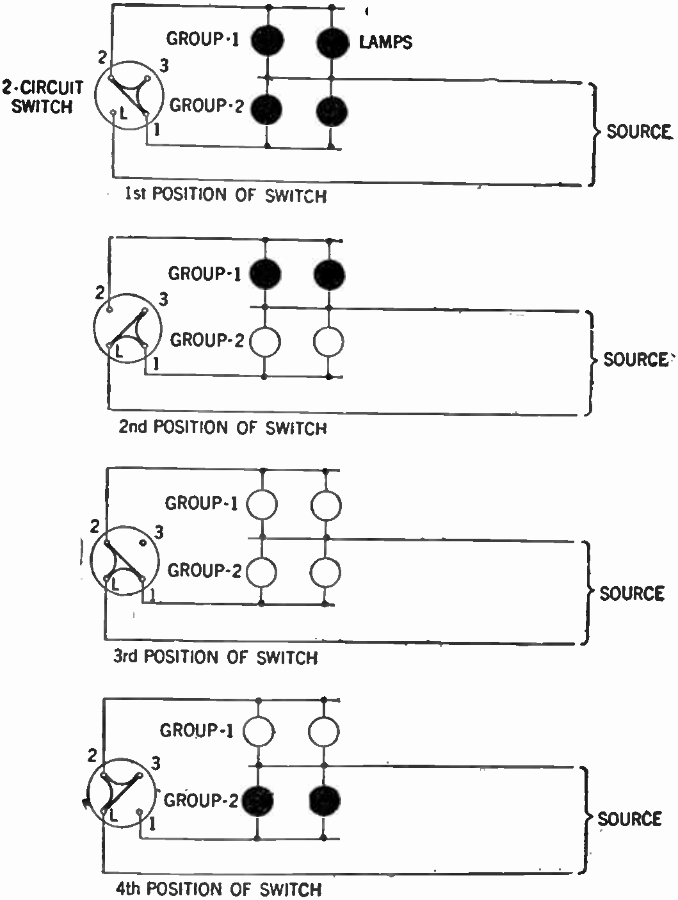


FIG. 7,188.—Showing sequence of operation for control of two groups of lamps from typical two-circuit electrolier switch. As shown in the diagram the two groups of lamps are extinguished in the first position of the switch. When operating the switch to second position, group No. 2 will be illuminated. In the third position the maximum amount of brightness is obtained as both groups of lamps are illuminated, and finally in the fourth position, group No. 1 only is lit. This switch may not be considered as standard—it is only one of several arrangements.

LAMP CONTROL FROM 3-CIRCUIT ELECTROLIER SWITCH

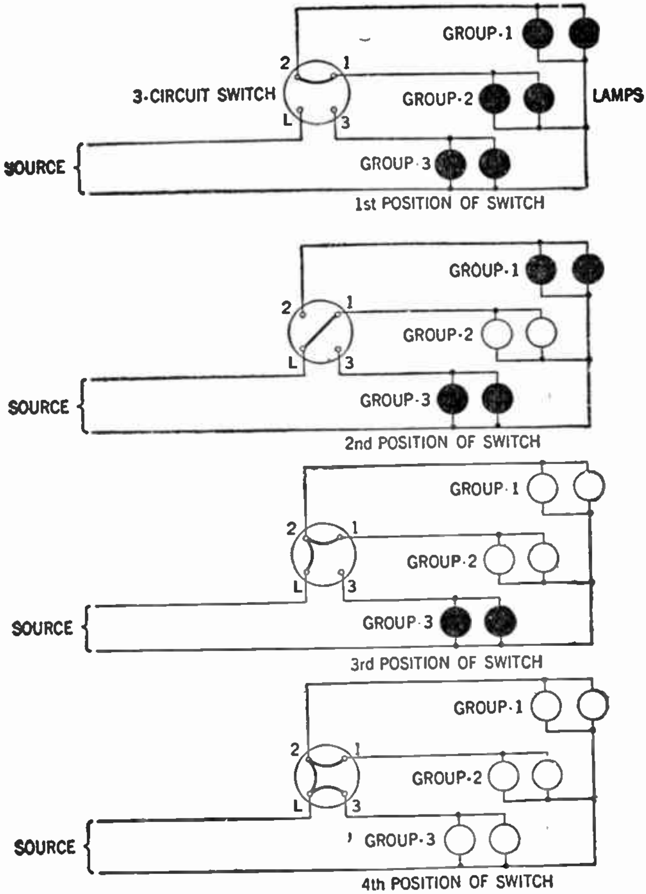


FIG. 7,189.—A 3-circuit electrolier switch from which three groups of amps are controlled is shown above. The sequence of operation is depicted diagramatically and is principally the same as shown in the previous 2-circuit switch. In the 4th position maximum illumination is obtained, with all lamps lighted. The switch shown is typical only among a great variety of switches manufactured for electrolier or dome lamp control. The current carrying capacity of the switch as well as potential of the source to be connected should be considered for each individual application.

LAMP CONTROL FROM 2-LOCATIONS

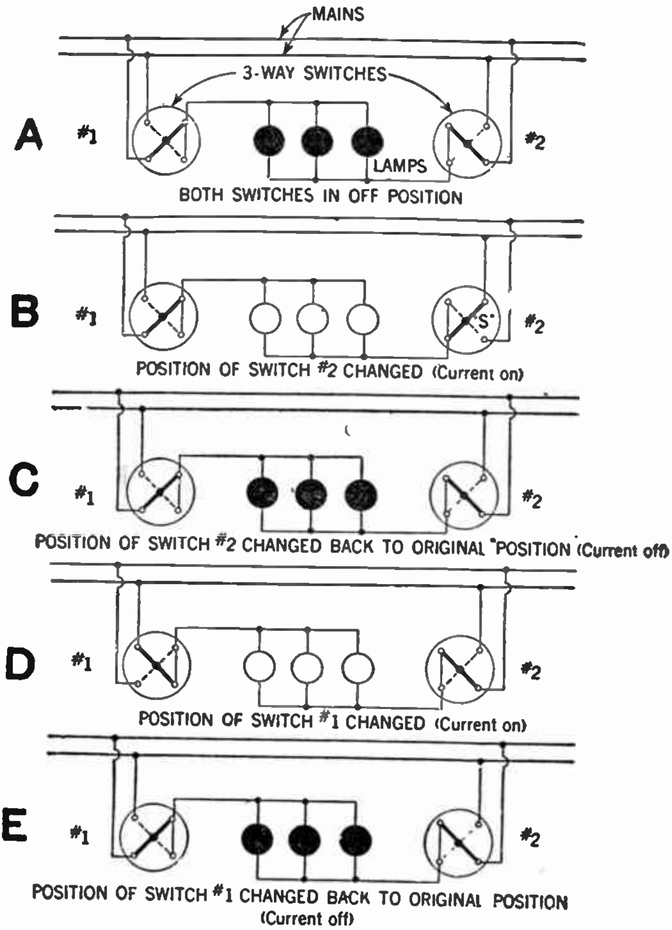


FIG. 7,190.—This connection provides an economical means of lamp control from two locations. Although *not permissible* under the *National Electric Code*, it is shown only as an electrically possible circuit. As a in previous connection shown, both switches are in off position at A, the lamps extinguished, and can be lit by operating either switch. If switch No. 2, at B, is operated to position "S" the lamps will be illuminated, and can be extinguished again from any one of the two switches. A to E, inclusive, shows the lamps lighted or extinguished depending on position of switch No. 1, relative to the position of switch No. 2.

STAIR-WAY LAMP CONTROL WIRING

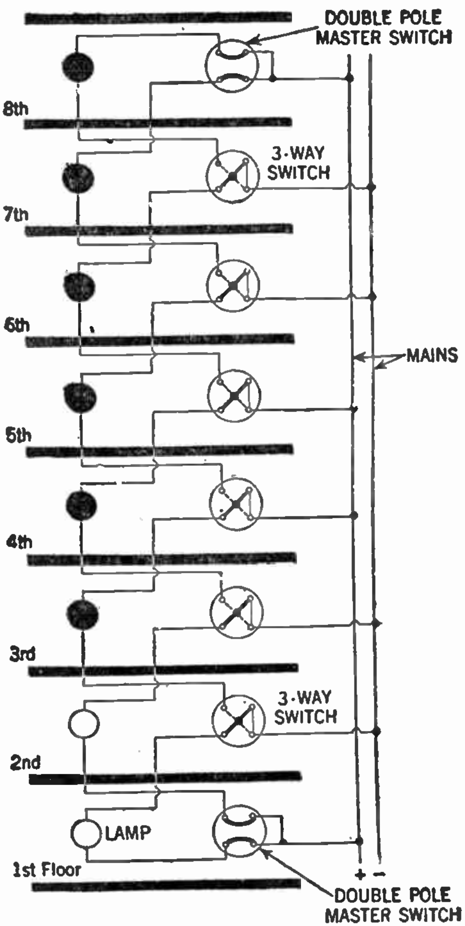


FIG. 7,190A.—Typical stair-way lamp control wiring. As shown in circuit diagram, the switches used in this type of light control consist of two double pole switches, inter-connected on the first and last floor, and one 3-way switch for each floor. The sequence of operation is as follows: Closing switch on the first floor lights lamp on first and second floor. Turning the switch on the second floor extinguishes the light on the first floor and lights the lamp on the third floor, etc. This operation is continued until the top floor is reached, in other words the switch on each floor should be turned in passing.

CHAPTER 20

Wiring Finished Buildings

The wiring of finished houses is not as easy as it may appear, as there are no two houses built alike, and there are no two wiremen who would wire the same house in the same manner.

Then there are numerous setbacks that make it difficult to proceed with the work quickly, such as parquet floors, double floors, clogged partitions and other obstructions which are outlined so that if the instructions are carefully followed no difficulty will be experienced.

By laying out the job and drawing a rough sketch much labor and material will be saved.

In many cases the only instructions given the electrician who does the wiring is simply a plan showing the location and number of lights, from which he must figure out how to install them using the least amount of

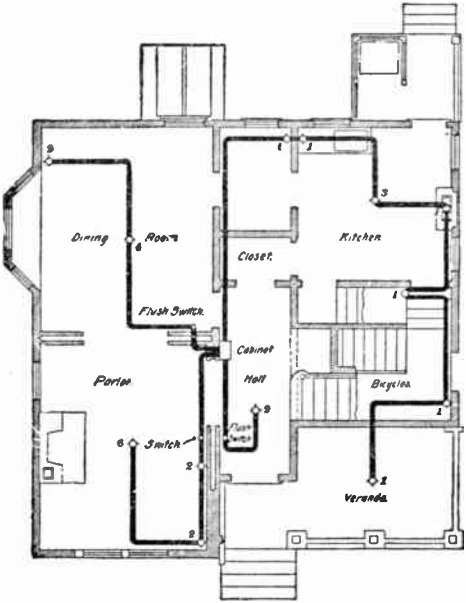


FIG. 7,191.—Plan showing one floor of a dwelling house wired with conduits. The numbers on the various outlets indicate the number of lamps supplied. The wiring is carried out on the loop system, and it will be noticed that no branches are taken off between outlets. Four circuits are used in order that there may not be more than ten lamps on any one circuit.

material and labor consistent with a good installation that will pass inspection.

It should be ascertained how many sockets are to be attached to each outlet, as the code allows only 660 watts to each 2 wire circuits on 40 watts per socket, base plugs are counted as sockets.

After having laid out the number of lights per circuit and the number of circuits. the center of distribution should then be found—if a large house having over 4 circuits, it is advisable to install a panel board that will feed the various circuits, this panel should be installed at a central point.

Panel boards in loft buildings or in any building requiring 8 to 10 circuits to a floor should be distributed one to a floor.

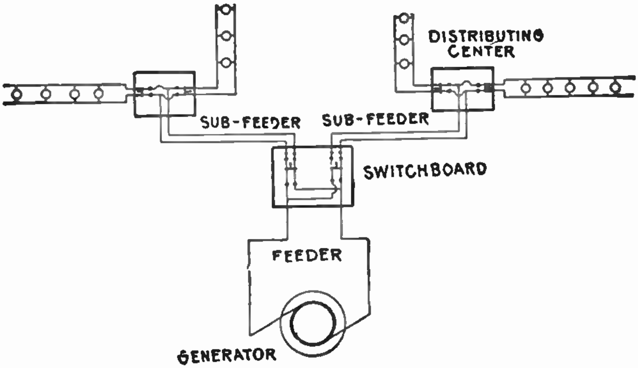


FIG. 7,192.—Two wire parallel system as used with isolated plant.

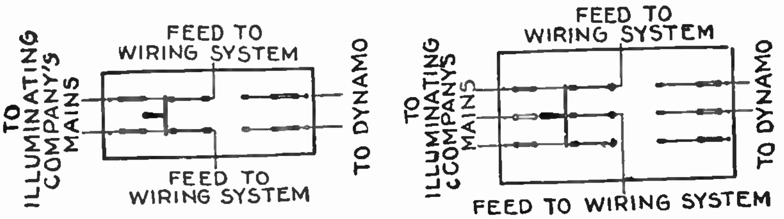


FIG. 7,193.—Double throw switch for use in isolated plants when auxiliary power is used from the central station is case of breakdown.

FIG. 7,194.—Double throw three pole switch for use in isolated plants where auxiliary power is brought in through three wire system. The side of the switch controlling the current is bridged as shown.

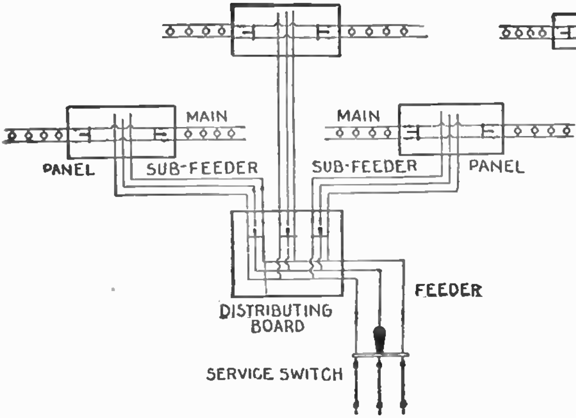
In a building covering a large area it is often advisable to install two panels or centers to a floor, with two sets of feeders. It is advisable to keep circuit lengths down to 100 feet or less, and the judicious laying out of circuit centers will save many feet of wiring.

The distributing centers or cut out cabinets should be installed near a partition that is so located as to make the running of risers easy, and should be on an inside wall to guard against dampness.

If only one distributing point be used, it should be either in the cellar or attic and risers run to the different floors.

In private houses it is sometimes advisable to install only one panel for the entire house. This is good practice for a three story house not requiring over twelve circuits.

In some cases it is not advisable to install a panel, but to bring the wires



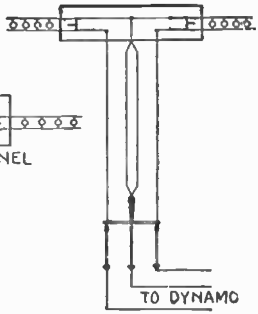


FIG. 7,195.—Three wire convertible, or three wire two wire system; used to advantage where power is supplied from an outside source and brought in through the three wire system. The only difference between the three wire convertible, and the straight three wire system is that the center, or neutral, wire of the mains and feeders should have a current capacity equal to the other two. *The reason* for this is that it allows the system to be readily changed over to a two wire system for use in connection with a private plant. It sometimes happens that after using power from the local electric illuminating company for some time, conditions arise which make it expedient for the owners to install a private electric plant. If a straight three wire system had been originally installed, the mains and the feeders when used on a two wire system would not be heavy enough by 25 per cent., as the neutral wire of a straight three wire system is the same in size as one of the two outer wires, and theoretically carries one-half the current or less.

FIG. 7,196.—Diagram showing reinforcement of neutral wire necessary to change regular three wire system to two wire system. The capacity of the neutral wire must equal that of the sum of the two other wires.

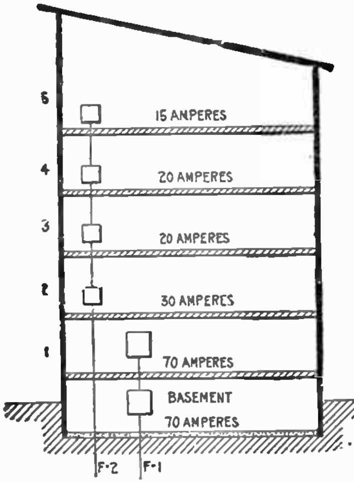
down to the cellar, to the meter board where fuse blocks for the various circuits are installed on the meter board.

Feeders and Mains.—Making a feeder layout for a large building, a good method is to draw an elevation of the building as in fig. 7,197, and note on each floor the current requirements.

The best plan is to furnish a feeder for every floor, especially in large installations. In smaller installations one or two feeders are sometimes all that are required.

Feeders for motors should be independent of lighting feeders. In calculating sizes, feeders requiring over 2 inch pipe should not be used. It is better to subdivide them, especially if there be many bends or offsets, since two inch pipe is about the limiting size for economical handling.

Feeders should radiate from a distributing panel, having a proper sized switch and fuse for each feeder.



If the system of wiring be such that auxiliary power is taken from a local lighting company, it is a good plan to have each circuit corntolled by a double throw switch so that in case of overload, any circuit can be fed from the illuminating company's mains as in fig. 7,193.

It is advisable to install feeders and mains in conduit even though the circuit wires be run otherwise. Since the former carry the main supply of current it is important to have them well protected as they usually run up side walls.

The underwriters make numerous restrictions against open or moulding work on brick walls and require good protection, and this is an additional reason for piping the mains and feeders.

FIG. 7,197.—Diagram showing current required on each floor of building. A sketch of this kind is useful in laying out the feeder system. In the building here shown it will be seen that the basement and first floor require the most power. In such a case a feeder is run for these floors, and a sub-feeder from the basement to the first floor. It is not worth while to reduce the size of the sub-feeder unless the amount of current used on the sub-feeder be a small percentage of that used in the feeder. Another reason is that in changing the size of a wire, the underwriters require a fuse to be inserted. This makes it necessary to install a larger panel with larger trim, etc., and the consequent expense easily offsets any gain made by installing a smaller wire.

In laying out the branch circuits, it is not good practice to use up the underwriters' circuit allowance of 660 watts.

If a circuit be wired with the full allowance of lamps, no additions could be made without violating the *Code* requirements.

Locating Outlets.—If concealed wiring is to be installed, the outlets should be marked on the ceilings and walls with a pencil cross at the spot, marking also the location of switches, etc.

If a ceiling outlet is to be placed at the center of the ceiling, it is first located on the floor and then transferred to the ceiling by means of a plumb bob.

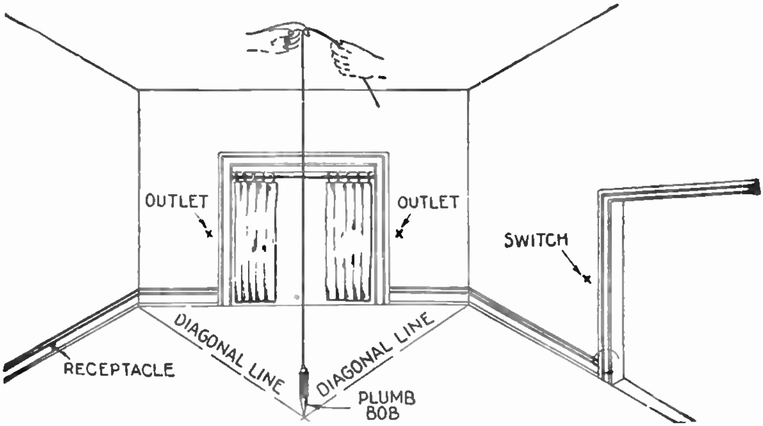
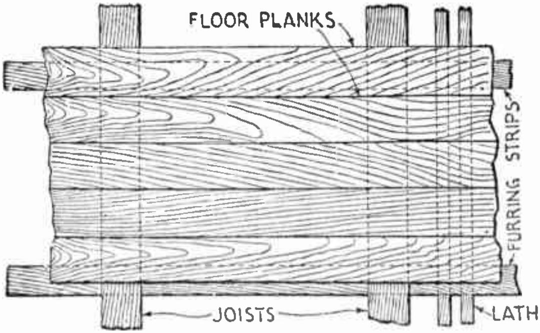


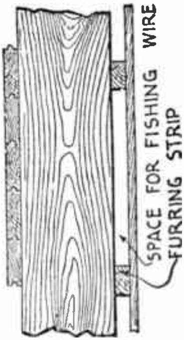
FIG. 7,198.—Marking for outlets and method of locating ceiling outlet on floor and transferring it to the ceiling with plumb bob.

Furring Strips.—After locating the outlets a small portion of flooring is removed to find out whether or not there are seventh-eighths inch furring strips between the joists and the ceiling plaster.

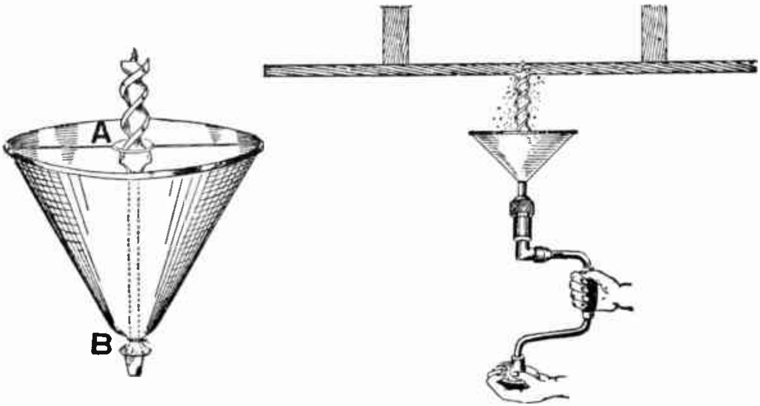
If house have hot air registers set in the floors, they may be lifted up, instead of taking up flooring. If it be found that there are furring strips, much labor will be saved, as the wires may then be fished from outlet to outlet and little flooring need be removed. All houses however are not so built, so in case there be no furring strips it will be necessary to take up the floor and bore a hole in each joist or beam.

Cutting the Outlets.—After locating the centers for the outlets, the plaster must be cut out so that the outlet box will set in.





FIGS. 7,199 and 7,208.—Floor and joists with *furring strips* showing space between lath and joist introduced by the furring strips permitting wires to be fished without taking up flooring and boring joists.



FIGS. 7,201 and 7,202.—Cone dirt catcher for bit and application in boring ceiling outlets. *It consists of* a suitable size cone, made of stiff cardboard and provided with a guide A to hold it central with the bit. Attached to the lower end is a cloth tube B, which is fastened with a string to the shank, Fig. 7,202 shows the cone in use.

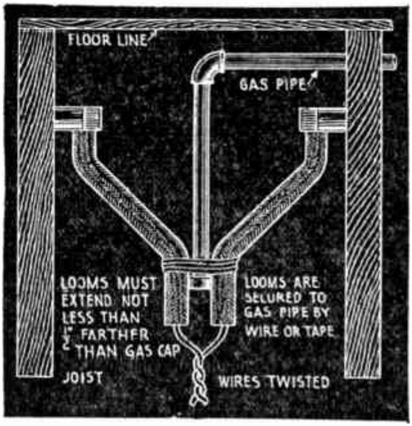


FIG. 7,203.—Method of making a ceiling outlet for a combination gas and electric fixture.

For this purpose a special tool has been designed, this plaster drill is constructed so that it may be fitted over a gas pipe, the cutters are adjustable so that any size hole may be cut. A bell shaped cup catches any dirt that may be removed so that a neat and clean job is made, if drill of this type is used. But if a plaster drill be not obtained, the outlet box should be traced over with a pencil and the plaster should be chiseled around this mark with a ¼ inch blade screw driver.

Outlet Boxes.—After the plaster has been removed, the outlet box should be set in, so that it will fit snugly. The *Code* requires that the lower edge of all outlet boxes should not be set back in plaster any farther than ¼ inch.

The box should be fitted to the hole in the plaster, and the lath should then be marked and notched out with a jack knife to allow the cable to properly pass through into the box. Securing outlet boxes to laths is not allowed as this is not considered as a support, and in time loosens up the plaster.

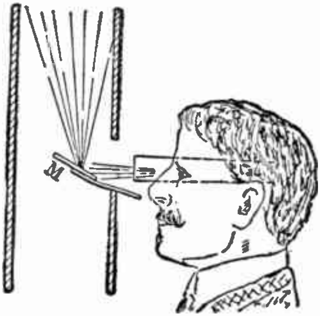


FIG. 7,204.—Device for examining partition interiors. A pocket flash lamp and a little mirror are the only apparatus required to inspect the interior of a wall or partition which would ordinarily be inaccessible. For fishing wires, retrieving cable and inspecting finished work, the lamp and mirror will be found most useful.

The only places where a board is not required is where an outlet happens to be located on a beam, joist or stud. Side lights can be located on upright studs which are the best supports to be obtained, but it is not always possible to locate outlets on joists, and still have the outlet in the center, for this reason outlet boards should be installed. These should be very carefully installed so as not to mar the ceiling.

Where the outlet is to be made to existing gas pipe outlets combination boxes should be used. No board is required, except that the box be securely fastened to the gas pipe.

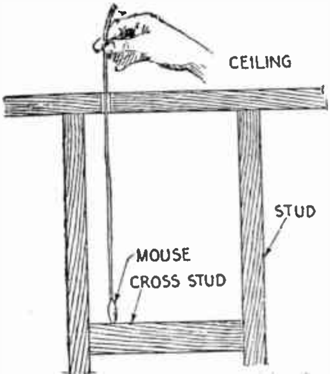
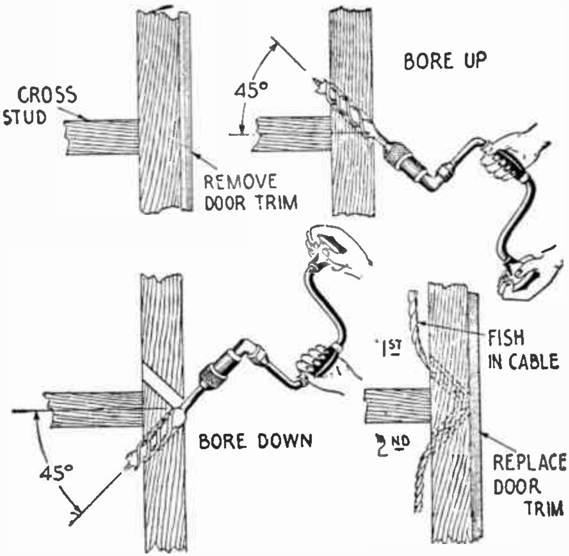


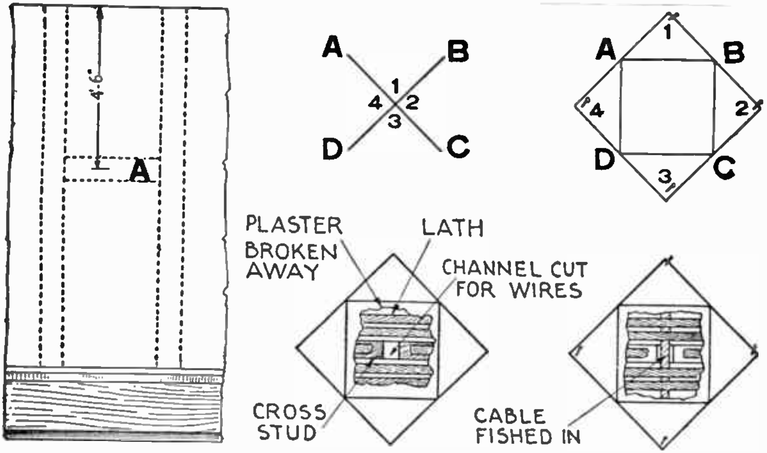
FIG. 7,205.—Exploring in partition for cross stud.

The *Code* requires that the box; should fit snugly around the plaster, where the plaster is broken, it should be mended with plaster of paris.

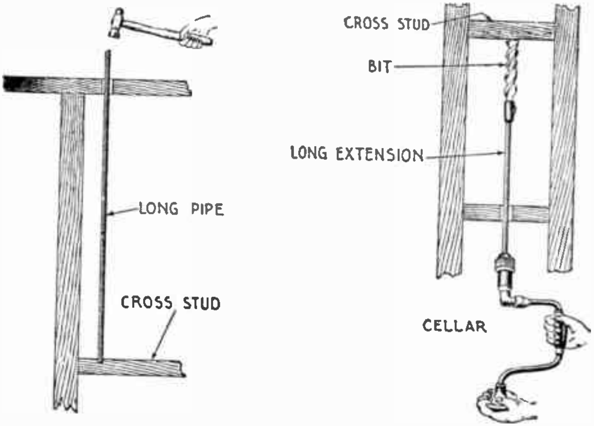
Obstructions in Partitions.— In the older houses constructed when builders had some regard for strength, partitions were reinforced with cross studs so that it is impossible to get by them.



FIGS. 7,206 to 7,209 —Method of passing by cross stud in partition when wires are run next to a d



Figs. 7,210 to 7,214.—Method of passing by cross stud in partitition when plaster must be cut. Locate cross stud as in fig. 7,210, 4½ ft. below ceiling. With a sharp knife cut wall paper along two diagonals AC, and BD. Thoroughly moisten paper with a sponge. Peel back the ends 1, 2, 3, 4, to the position shown in fig. 7,212 and fasten with pins. Cut out the plaster in the square thus opened up and cut a channel in the cross stud as in fig. 7,213 Fish in the cable as in fig. 7,214, replaster and fold back wall paper, pasting it to cover the square just plastered.



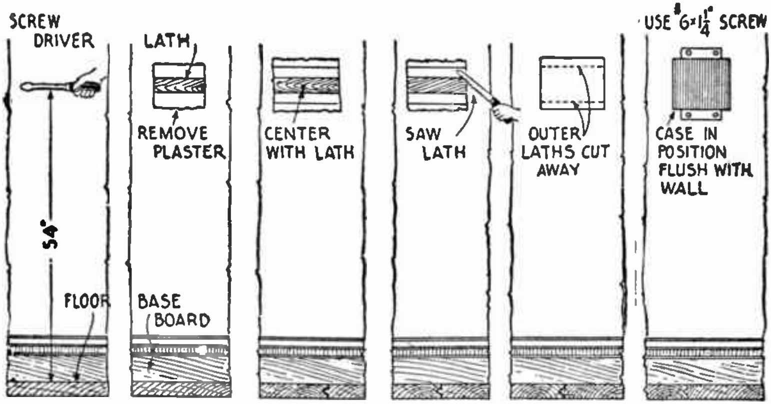
Figs. 7,215 and 7,216.—Two methods of passing by cross stud in partition: *1*, by inserting from above a long pipe and breaking stud by hammering; *2*, by boring up from cellar with brace and bit having a long extension.

When a cross stud is encountered, the switch outlet may be located above the stud, the standard height being 54 inches above the floor.

Before attempting to drop down a partition it should first be ascertained whether or not a cross stud or concrete, mineral wool, brick or rubbish filling, is in the partition. A hole is drilled in the top header of the partition and a string with a lead weight lowered if the weight reach the floor (this can be ascertained by sound) the partition is clear.

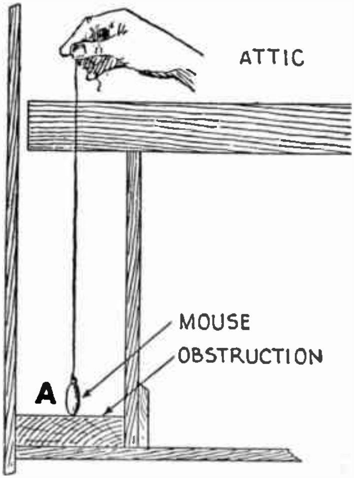
Cutting Out Wall Case or Switch Outlets.—This is a difficult operation and must be performed carefully.

After having first ascertained that it is possible to drop down the partition, 54 inches is measured up from the floor, the plaster is punctured



FIGS. 7,217 to 7,222.—Method of cutting out wall case outlet as described in the accompanying text.

with a screw driver, if the screw driver go between the lath, another hole should be punctured, and so on until the plaster has been broken away and shows a whole lath; now take the wall case and center the lath with the center of the wall case, with a pencil, run over the outer edges of the wall cases. Now with a hammer and screwdriver, carefully chisel out the plaster on the pencil lines. After the plaster has been removed, with a fine key hole saw, carefully cut away the center whole lath, after this has been cut away, the other lath should be trimmed with a sharp jack knife so that the box fits snugly. The ears of the box should be adjusted so that the box fits just flush with the finished plaster. Now screw box to lath with 1¼ inch No. 6 wood screws, any larger than these will crack the lath.



Dropping Wires Down Outer Walls.—First a hole should be bored in the header and the mouse lowered until it reaches the cellar, or hits an obstruction.

Usually obstructions are encountered as fire stops are placed at each floor to prevent the enclosed space acting as a flue in case of fire. These stops usually consist of 2 × 4 strips or brick. To reach them the baseboard must be removed. This is easily pried off with a floor chisel, sometimes it is necessary to set in the nails with a nail set. If walls be of brick, the entire distance from attic to cellar may be fished with a steel fish or snake wire, as the laths are attached to a ⅞ strip which is nailed to the brick.

Fig. 7,223.—Exploring between inner and outer walls with mouse. At A, an obstruction is encountered. This must be cut or bored to permit wires to pass. It may be reached by removing the base board, or may be bored from above with a multi-extension bit.

Fishing.—This is a method of running wires through walls, floors and ducts by the aid of another wire called a *snake* or fish wire attached to the conductors, threaded and drawn through in advance

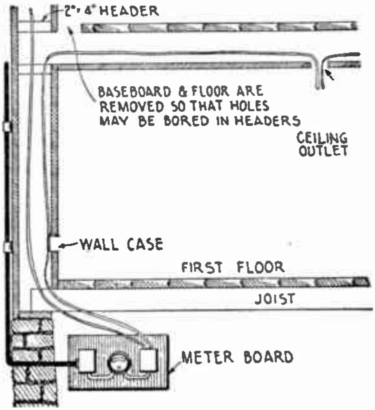
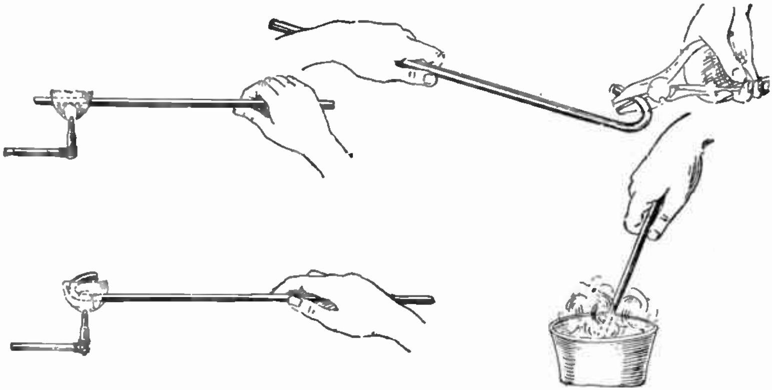


Fig. 7,224.—Method of dropping down a partition that has headers, also showing method of bringing circuits down to meter.

Snake or fish wires are made of the best steel and tempered in oil. All snakes should have a hook bent at each end, and to do this the wire must first be annealed.

The proper method of annealing is to hold the end of the snake in the flame of a torch until it becomes cherry red, then bend into shape, heat again to cherry red color and quickly insert the heated end in a pail of water; this hardens the wire, so that the hook will not pull apart.

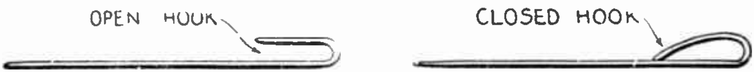


FIGS. 7,225 to 7,228.—Method of making a snake. Hold wire in flame till cherry red (fig 7,225) bend to shape (fig. 7,226); heat again (fig. 7,227), and submerge end in cold water while cherry red (fig. 7,228).

Snake wire may be obtained in various shapes but the type best adapted for house work is ⅛ inch wide, $\frac{1}{16}$ inch thick.

The proper way to attach the wires to be pulled into the snake is to just loop them through the hook of the snake and fold them over with pliers.

If wires are to be pulled through a long run, they should be taped.



FIGS. 7,229 and 7,230.—Open and closed snake hooks. *The open hook* is used in hooking one snake to another. *The closed hook* is used for fishing.

In fishing in a house constructed with furring shifts between the joists and ceilings there will be plenty of room to draw through the loom or cable.

Furring strips in old houses having single floors will be found to run parallel with the floor boards.

After having cut the outlet as just described, a steel wire or snake is inserted into the hole so that it may be pushed into the space made by the furring strip, having inserted the end of the snake, it is gently pushed as far as desired; if the snake encounter an obstruction, it may be caught against a piece of plaster or become twisted.

With a little practice a snake may be fished over 50 ft. with ease, having reached the outlet, another snake or piece of wire is pushed up into the hole at the outlet and the snake is *hooked*, and then gently drawn through the outlet; the wires are then attached and pulled through. If a man be at each end considerable labor will be saved.

FIG. 7,231.—Method of taping end of snake.

FIG. 7,232.—Method of attaching wires to snake for pulling.

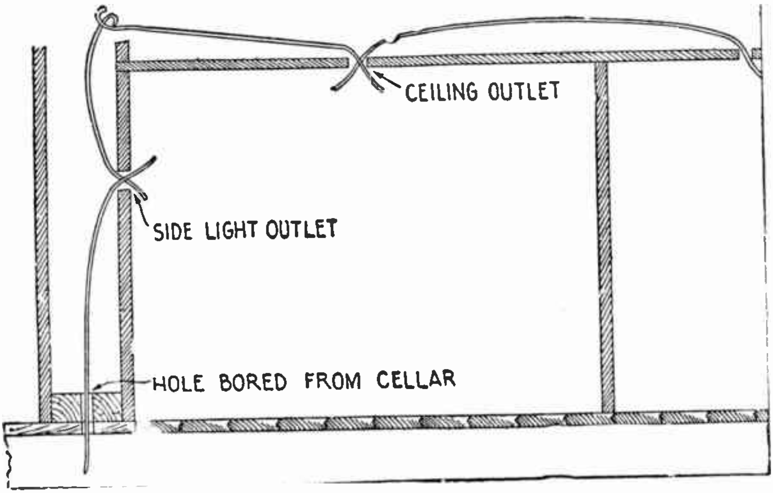


FIG. 7,233.—Fishing from outlet to outlet.

When pulling through the wires it is also necessary that some one be at each end so that one will feed the wires in and the other will pull them out.

The wires should be gently pulled so no damage will be done to the plastered ceiling.

If, in pulling the snake, the wires get stuck, the snake and the wires should be pulled back and forth as most likely the wires are caught against a plaster clinker. This operation will break off these clinkers.

Sometimes a whole house may be fished without taking up any floors,

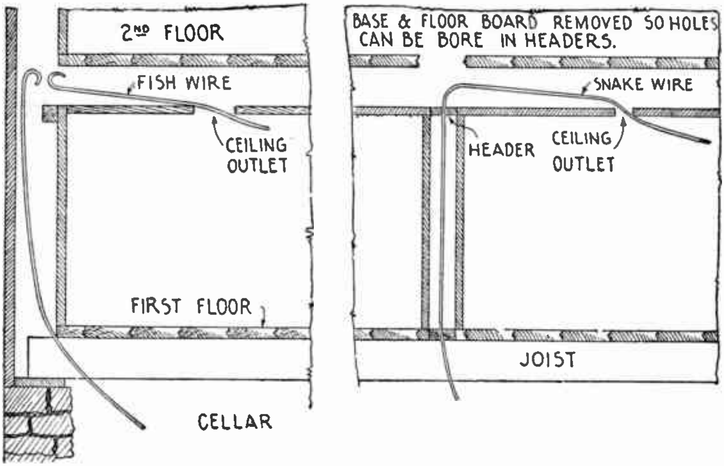


FIG. 7,234.—Method of fishing in wires without removing floors or base board. The fish or snake wire is pushed up from cellar and hooked as shown. This method is only possible when there are no headers.

FIG. 7,235.—Method of fishing in wires through headers.

but it may be necessary to take off base boards and flooring to drop down to the meter board or switch outlets.

Sometimes it is necessary to use two snakes on long runs and hook them underneath the ceiling.

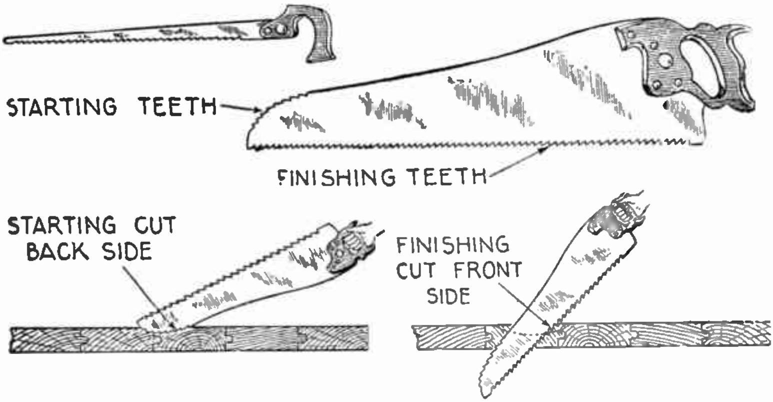
In this case the ends of the snakes should be connected to a bell and battery so the bell will ring when the ends touch each other.

Taking Up Floor.—Various kinds of flooring are to be encountered in wiring houses.

In those built previous to 1875 the floor boards are as wide as 10 to 12" and are smoothed edged, unlike the present day type of board which has a tongue and groove. This type of flooring is very simple to take up.

If when cutting the outlets, a small hole be bored through the ceiling and the bit pushed up till it comes in contact with the flooring of the room above, and this flooring be also bored, it will show where to take up the flooring to install the wires when they run parallel with the joists. When the wires must run perpendicular to the beams all the flooring must be taken up so that the holes can be bored in the joists through which the wires must pass.

Floor planks are properly removed by driving the nails down with a nail set and lifting up the board. If double floors be encountered, it will



FIGS. 7,236 and 7,237.—Floor saws. Fig. 7,236 ordinary compass saw. It should be about 8 to 12 ins. long, very thin blade and tapered to ¼ in. at the end; fig. 7,237, special double edge saw for finished floors.

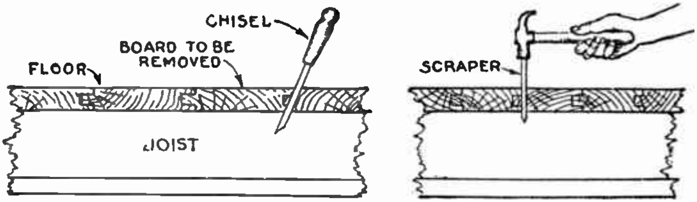
FIGS. 7,238 and 7,239.—Method of working the double dge saw. Fig. 7,238, starting the cut with back edge; fig. 7,239 finishing cut with front edge.

be found very difficult as double floors are constructed of hard wood such as oak, or maple, and must be handled with extreme care and patience. For this type of floor, the tongue is split by inserting a carpenter's floor scraping blade, which is a sheet of steel about $4\times6\times\frac{1}{64}$". These can be purchased at any hardware store at a small sum.

The scraper should be hammered down so that the tonque is split, both sides of the board should be split, so that no difficulty will be experienced when lifting up the board.

After both sides of the board that is to be removed has been treated as above, a floor chisel should be inserted where the ends of the board meet with another and the board gently raised.

In raising the board, it is better to take more time and proceed



Figs. 7,240 and 7,241.—Two methods of cutting tongue of floor planks. Fig. 7,240, with chisel at angle—this cuts off tongue and also lower lip of adjacent plank; fig. 7,241, with scraper making a vertical cut.

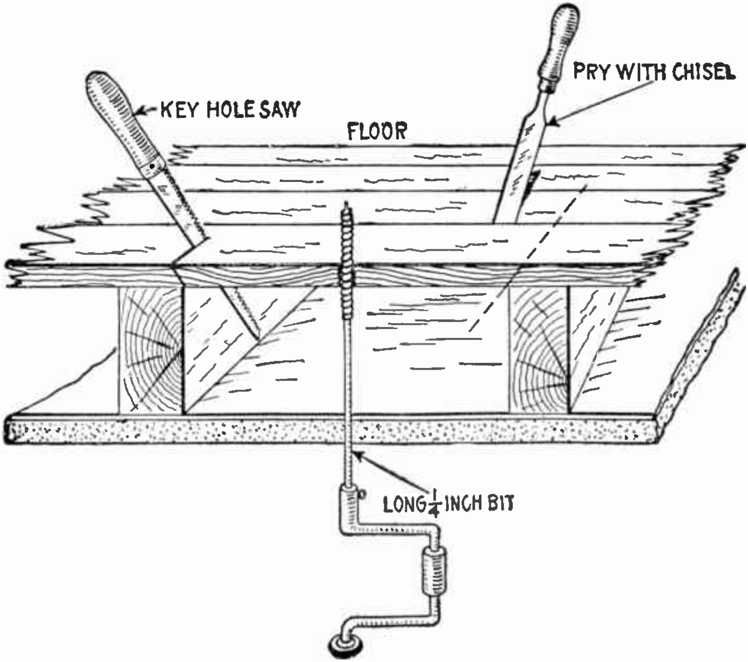


Fig. 7,242.—Sectional view showing method of cutting a pocket or opening in floor for the insertion of wires.

cautiously, as the finest floors may easily be ruined by having one board split, chipped or marred.

After the boards have been removed, they should be numbered or marked so that they will go back in place without any confusion. They should be placed away in a safe place until ready to lay back the floor.

Holes for wires should be bored in the center of the joists so that when laying back the flooring, the nails will not penetrate the metal sheath and short circuit or ground the wires.

Cutting Pockets.—The center of each pocket is indicated

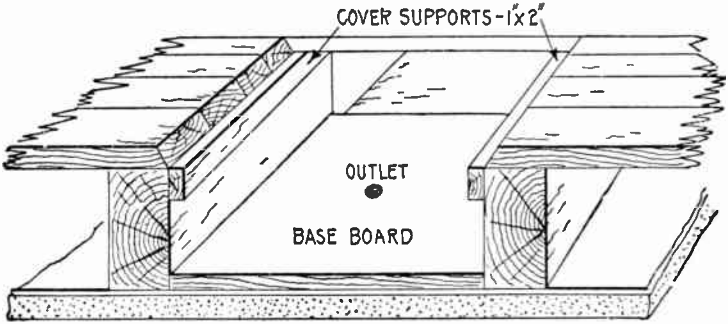


FIG. 7,243.—View of outlet pocket showing base board, and cover supports in position.

by the small hole which was bored in through the flooring when cutting the ceiling outlets.

In opening a pocket ¼ in. holes are bored to insert a keyhole saw through the joint between two boards at each end of the pocket, and as near the beams as possible, then the board is cut at an angle as indicated in fig. 7,242.

Next saw the tongue of the matched board on each side of the pick and pry up the boards with a chisel as shown. Having taken up the boards, nail a cleat on the side of each joist as in fig. 7,243 so that when the floor is laid back there will be a good support.

A baseboard is next installed as in fig. 7,243 to give a secure hold for the screws used in fastening the fixtures. Two holes are then bored diagonally with a 11/16 inch bit inserting the bit in the small hole bored in the ceiling as in fig. 7,242. The outlet wires are then tied around the knobs and the upper ends being bared and tapped on to the main wire. A piece of loom is slipped on each outlet wire after which it is thrust through the outlet as in fig. 7,244.

Replacing Floors and Trim.—In replacing floors, small finishing nails should be used; these are inconspicuous and will not split the wood when being driven.

When replacing base boards and other finished trim that has been pried

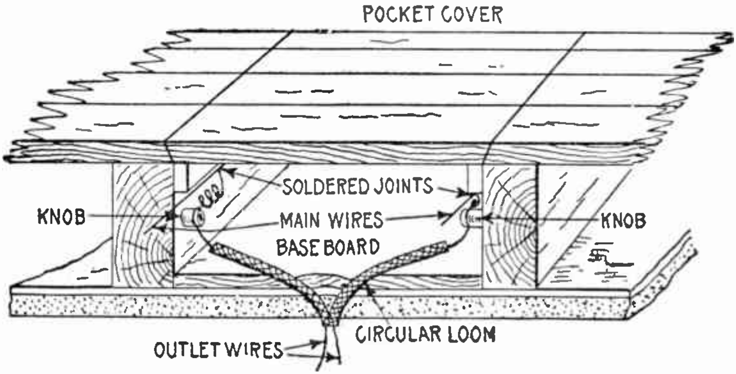


FIG. 7,244.—View of completed pocket and ceiling outlet showing method of bringing out the wires.

off do not attempt to drive back the nails, but cut them off with cutting pliers, as driving the nails back will knock off large chips from the trim.

After the nails have been cut off, the head of the nail should be set in with a nail set and a new nail driven in the same hole.

Hard wood floors and trim should be gone over with floor wax to remove all scratches and mars.

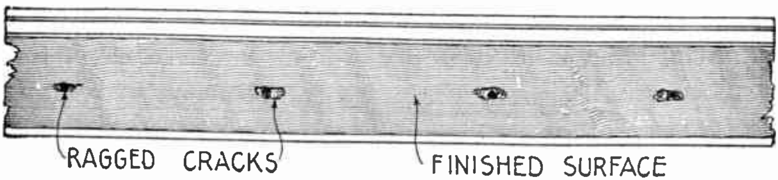


FIG. 7,245.—Appearance of a varnished base board after nails are driven out. The proper way is to leave nails in the board, cutting them off close with cutting pliers.

Installing Flush Switches and Receptacles in Wall Cases. —Care should be taken that the switch fits flush with the edge of the plaster.

In order for the switch to fit flush, the case should fit flush, otherwise it will be necessary to insert small washers under the switch ears.

Switch plates will not fit properly unless the switch be flush; if the switch be not flush, the plate will buckle and bend in the center.

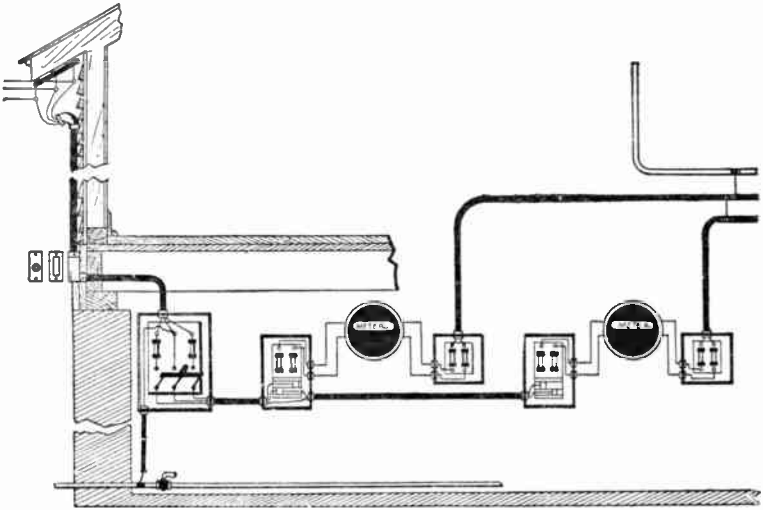


FIG. 7,246.—Two family house meter board arrangement as used throughout Connecticut: note method of service pipe and meter loop arrangement.

Perfect fitting switch plates give an artistic and workmanlike appearance to any installation.

Meter Boards.—A meter board should be constructed of seven-eighths inch soft wood (pine) of sufficient size to accommodate the meter and cut-out boxes.

Secure the board against the foundation wall of the building. Paint board two coats of black asphaltum or other insulating paint.

Do not nail boards to foundation wall unless there be an air space back of it. The use of 2×4 studs makes a secure board.

For one single meter, a board 24×18 is amply large with room to spare for future additions.

The main switch is mounted on the left side of the board.

All modern meters feed the left for mains, and feed out to the right for house cut outs.

Do not place a meter board any higher than 7 ft., or lower than 4½ ft.

Service Connections.—This includes the wiring from the street supply to the meter board

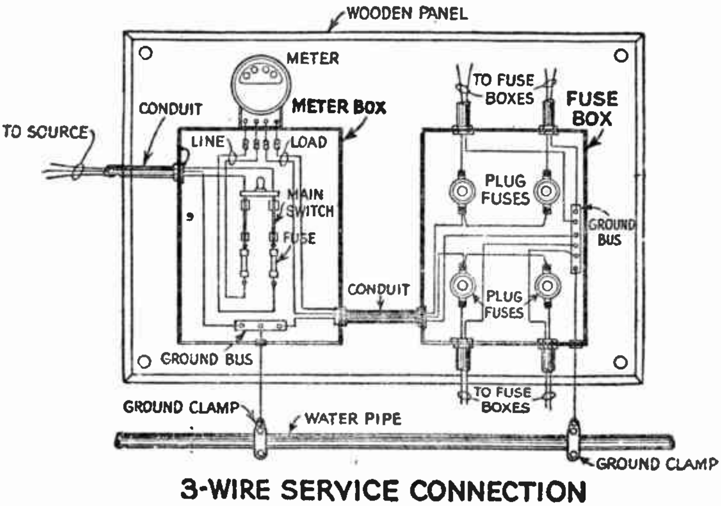
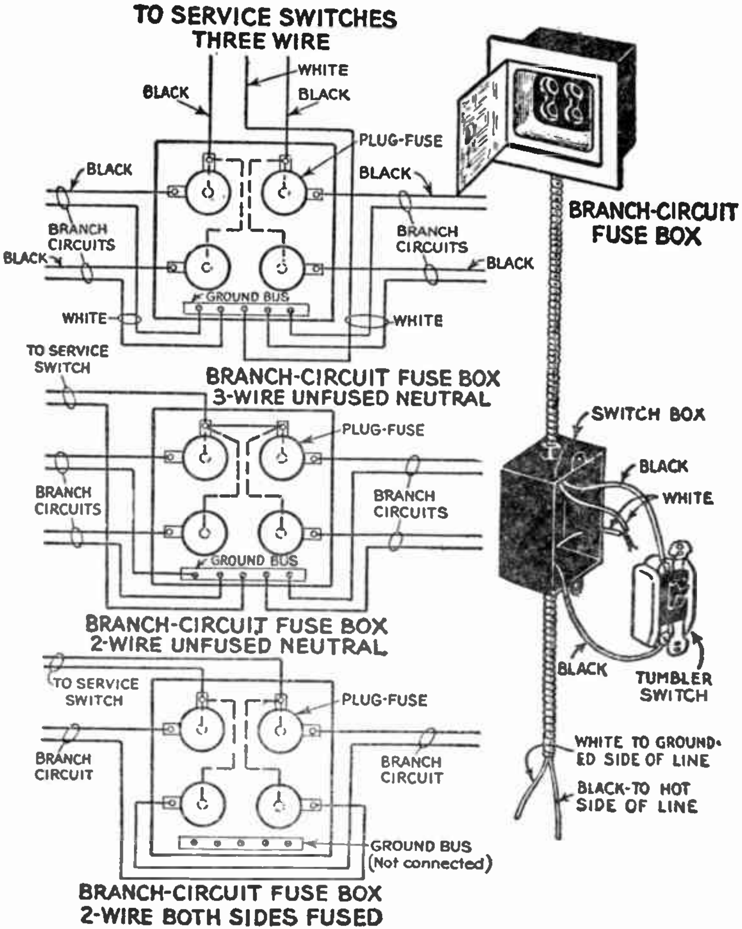


FIG. 7,247.—Illustrating wiring arrangement of a three-wire service installation, for a single family dwelling.



FIGS. 7,248 to 7,259.—Wiring diagram of various branch circuit fuse boxes. In the past it has been the practice to locate all circuit protective disconnects in one location. This location all too frequently was in the basement or other equally inconvenient space. It is becoming more and more common to place these control centers near the load centers. In residence wiring the kitchen, laundry and utility rooms have the greatest portion of the electrical load. For this reason, it is desirable to locate at least one of the control centers in such area. This will result in the branch circuits being short in length, because of their proximity to the various lighting and appliance outlets.

The wires outside should be run only in galvanized conduit, although the black enamelled form is approved.

The service pipe should be run up the side of the building where directed by the local lighting company.

The top of the service cap must be equipped with a service cap or pipe cap; this cap must have a non-combustible, non-absorbtive bushing where the wires pass through.

Where the conduit enters the building the right angle turn may be made by using an approved pipe fitting, or by a goose neck bend.

The *Code* requires that all wires, where they enter a building be protected by a fusible switch and cut out.

In case it be impossible to place this at point of entrance, a cut out can be placed there and sub-mains run to the meter board.

All switches and cut outs must be mounted in iron boxes with a hinged cover deep enough to cover the switch and cut out and large enough so that a switch can be opened or closed in the box. Also wide enough to allow a space around the switch or cut out.

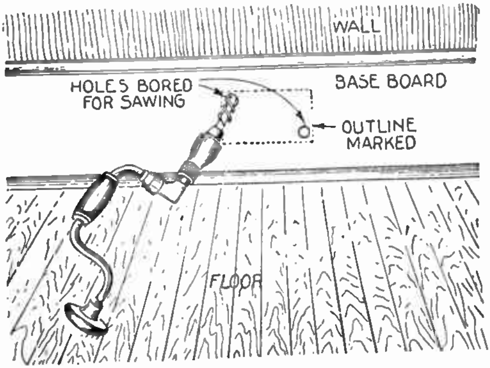


FIG. 7,260.—Installing switch box in base board. 1, mark outline of box on base board; 2, bore two holes as shown to start saw; 3, saw to outline; 4, clear opening to bring box flush; 5, install box in opening after removing suitable knock outs.

Switches for Lighting Installations.—Plug fuse switches are only approved for use on voltages up to 125 volts and to stand a load of 30 amperes.

In the case of a fair size residence a 30 ampere switch of the plug type could probably be used (note types of switches are optional with local central stations).

In the case of a large installation having a load exceeding 30 amperes, cartridge fuse switches and cut outs must be used.

These are designed for pressures up to 600 volts.

Cut out boxes usually have ½ in. knock outs; if a larger size conduit be used, these knock outs must be enlarged by reaming unless boxes with larger size knockouts be obtained. The conduit is secured to the box by two locknuts and a bushing.

Wires leaving the cut out box should pass through porcelain insulators or bushings.

The box should be secured to the board by means of ¾" wood screws.

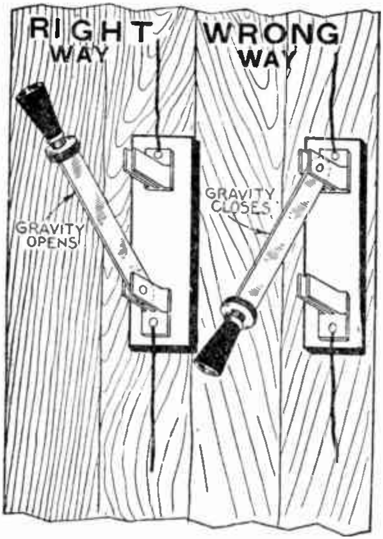


FIG. 7,261.—*Right* and *wrong* way of installing knife switches. They should always be installed so that gravity tends to open them, otherwise when the hinges become worn, the switch might close.

The switch or cut out should be secured in the box by means of holes drilled or punched through the box, wood screws passing through the cut out box and screwed into the wood meter board will securely hold any cutout or switch.

Installation of Knife Switches.—When installed in a vertical position, the switch should be so placed that gravity will tend to open it.

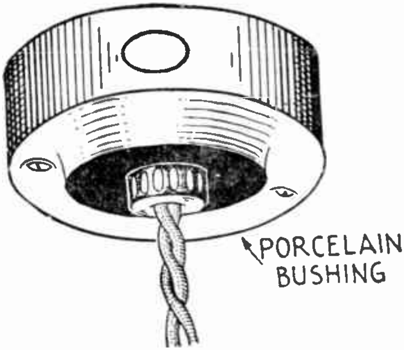
Where a three wire switch is used, the middle or neutral fuse clip must be made solid, so that no fuse may be installed in the center clip (this is for lighting installations on a single phase, or a *d.c.* system).

Drop Cords.—According to the *Code*, only reinforced cord not smaller than No. 18 can be used for drop cord purposes and must be used without adjusters.

Only $\frac{3}{8}$ sockets may be used equipped with a porcelain bushing, or sockets with pendant caps, or all porcelain sockets must be used.

Hard rubber or composition bushings are not allowed.

Where the wires enter a socket, rosette, or an outlet box, they should be relieved of any strain by making an Underwriter's knot so that the weight of the socket, shade and lamp will not be on the joint



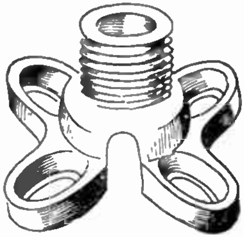


FIG. 7,262.—Drop cord fixture leaving conduct outlet box cover. A porcelain bushing must be used with all metal covers.

FIG. 7,263.—Fixture stud for supporting fixtures to outlet boxes.

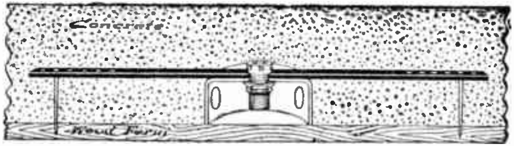
Square or granny knots are not approved, sockets may be obtained with strain relief devices attached.

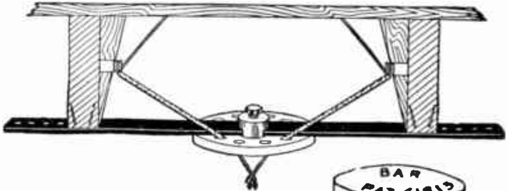
Stripping Drop Cord.—With a sharp knife cut around the outer braid just deep enough to cut the braid and re-enforced rubber covering. Then cut a slit parallel with the cord just deep enough to cut only the outer braid. Remove outer braid and with each hand pull on each wire and re-enforced rubber braid will fall away. About 2 ins. is sufficient for sockets, and rosettes; 6 ins. to be allowed where the cord is to be spliced to other wires such as in outlet boxes, etc.

Uses of Drop Cord.—For inside of residences, re-enforced cotton cord

FIG. 7,264.—Austin straight bar hanger and stud. The stud is slotted allowing free movement along the bar, yet may be easily tightened by the locknut in any selected place, making it possible to set box at desired spot although conduit may bear a little off length.

FIG. 7,265.—Austin universal box cleat used chiefly for side wall construction can also be used on ceiling work. By nailing across the front of joists a flush position for the box is obtained.

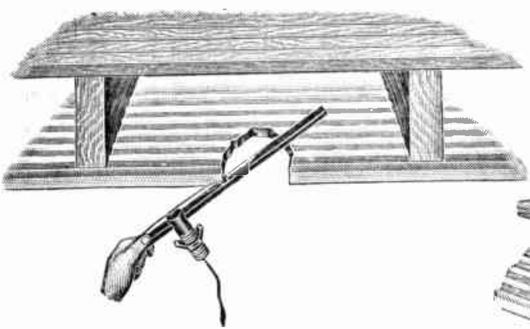


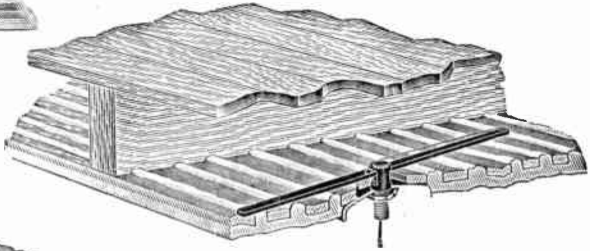


FIGS. 7,266 to 7,269.—Application of Austin straight bar hanger and view of stud and lock nut. All four knock outs are accessible in standard outlet boxes; especially suited to loom box, all eight knock outs can be used.

can be used with a light outer braid. For factories, the heavy type should be used. For cellars, the slicked or weatherproof type should be used. For bakeries or places where they are subjected to a large heat or where the cord is attached to heating appliances, regular asbestos heating cord must be used.

For auto garages, extra heavy marine deck cable should used, or the same encased in a specially wound metalic sheath.





FIGS. 7,270 and 7,271.—Austin "Economy" old work hanger. *Application:* The plaster is opened only large enough to permit the stud to pass through. The stud is then slipped to the end of the bar as shown and the assembly slipped through the hole. When the box is in a horizontal position, the wire leader is drawn through the stud. This slides the bar into position and centers the stud on the bar. The outlet box is fastened to the stud with a lock-nut and secured tightly in place.

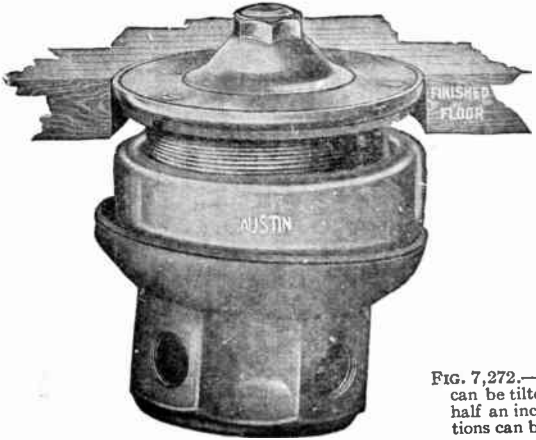


FIG. 7,273.—Adapting ring.

FIG. 7,272.—Austin adjustable floor outlet box. It is water tight. The cover can be tilted half an inch in any direction and raised or lowered more than half an inch. All adjustments are made on the inside. Electrical connections can be made in the box without breaking joints at the floor flange.

For show windows B. X. drop cord must be used.

Clusters of more than one light must not be attached to drop cords.

Drop cords may be extended from their outlets to another position by means of ceiling buttons.

Fixture Wiring.—Chain fixtures must be wired with flexible cord preferably single conductors so that each one may be laced through each link of the fixture chain.

Chain fixtures are suitable for show windows.

One-eighth inch trade size sockets should be used so that loops may be screwed into the socket caps.

Chain fixtures that are attached to concealed knob and tube wiring or wooden moulding may be attached with fixture crow feet or tripods.

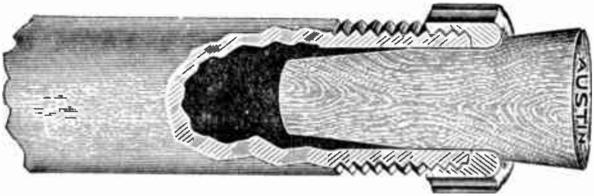


FIG. 7,274.—Austin conduit plugs for corking conduit systems during construction to keep out dirt, plaster, concrete, etc. These plugs are especially needed in poured concrete work.

If the ceiling be of metal or plaster containing metal lath, a fibre or rubber canopy insulator must be used.

Brackets or side wall fixtures must be wired with No. 18 fixture (solid wire) or larger.

The ends of all pipes and bodies being reamed so that the burrs will not cut into the insulation.

Pendants or fixtures that are constructed of tubing must be wired with solid fixture wire.

Combination fixtures that are attached to gas pipes must be equipped with insulating joints so that the fixture will be perfectly insulated and free from grounds, likewise must all fixtures that are attached to metal outlet boxes of B. X. and conduit wiring or knob and tube wiring where the fixture is to be secured to a gas pipe.

Fusing of House Circuits.—For lighting circuits no fuse larger than 10 amperes may be used except with special permission from the local inspector or where all the lights are controlled by one switch; also no lighting circuit should have a load in access of 660 watts except in factories where all the lights are connected with porcelain sockets and a wire not smaller than a No. 14 is used, but in houses the 660 watt rule must prevail.

Thus on a 110 volt system it is best to figure 7 amperes per circuit.

For each circuit a cut out must be provided. These cut outs must be

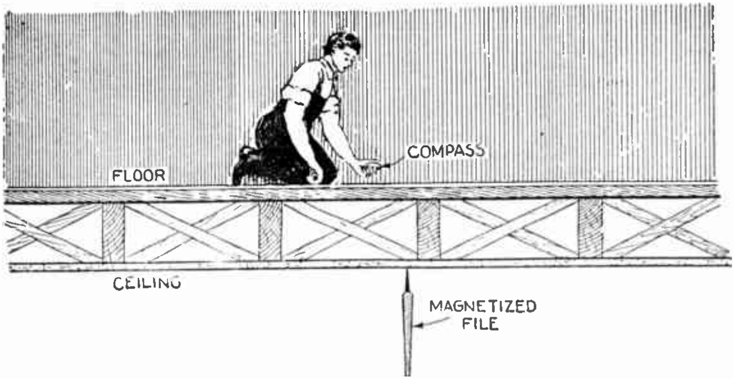


FIG. 7,275.—Method of locating outlet with a compass. A strongly magnetized file is placed at the point selected for outlet, then by exploring on the floor above with a compass, the needle will be agitated when moved directly over the file.

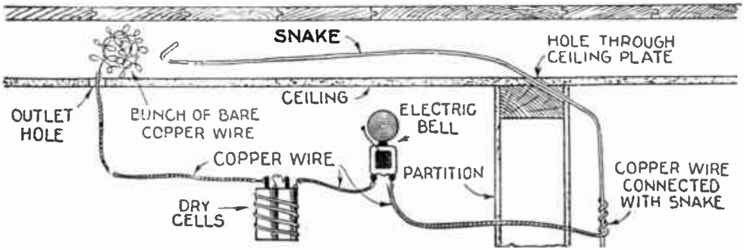
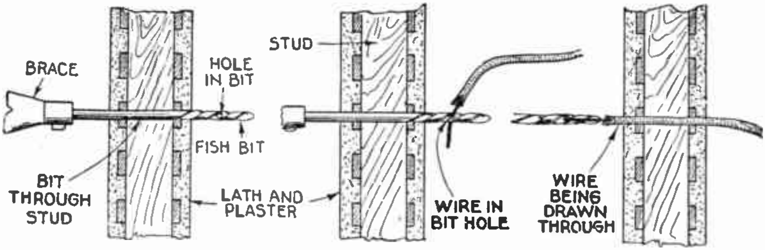


FIG. 7,276.—Method of fishing with snake and electric bell.

installed in metal cabinet or boxes and preferably mounted directly on the meter board. Cut out boxes should not be mounted any higher than 7 ft. from the floor and no lower than 4½ ft.

If the cut outs be grouped in one box, all over 4 circuits must have a box with a gutter around it unless a box be made so that the wires enter opposite the cut out terminals.

The use of water or gas pipe fittings on services are prohibited.



FIGS. 7,277 to 7,279.—Method of using steel fish bit. After boring through as in fig. 7,277, thread end of wire through hole in bit (fig. 7,278), and withdraw bit bringing with it the wire that is to be passed through the bored hole as in fig. 7,279.

Main switches should be fused in accordance with the carrying capacity of the wires to which they are connected, according to the following:

Fusing Table

Load (amperes).....	1	3	6	10	15	20	25	30
Fuse (amperes).....	3	6	10	15	20	25	30	35

Types of Fuses.—Plug fuses are largely used for loads up to 30 amperes at pressures up to 125 volts.

Cartridge fuses are used up to 1,000 amperes and up to 100,000 volts. Drop cord rosettes used in mills are fused with fuse wire or links which screw under the terminals on the rosette. The largest size fuse wire permissible is 3 amp. size.

FIG. 7,280.—Method of exploring between floor and ceiling with flash lamp and mirror.

Small transformers for wireless work, bell ringing, etc., should be fused with the minimum size fuse permissible, which is 3 amperes.

Three and Four Way Switches.—These are used for controlling one or more lights from two or more points.

Wiring diagrams for different types of switches are shown in the accompanying cuts. Three way switches are always installed with hall lights. Three wire cable should always be used, as, if one wire be used in a cable, it will heat up due to the inductive effect of the grounded cable. This is an important matter and should not be overlooked.

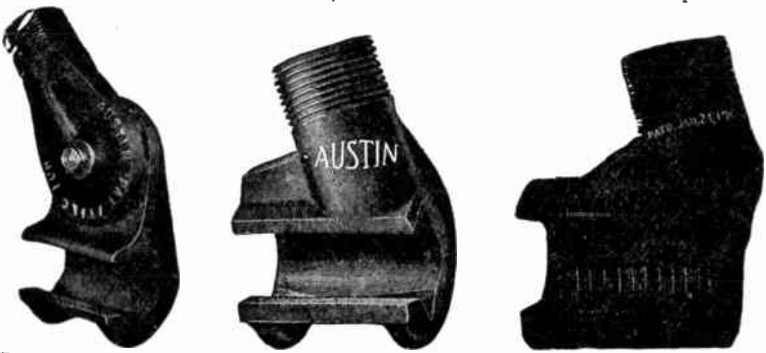
Three way switches are similar to 3 point return call bell push buttons.

FIG. 7,281.—Austin tempered steel fish tape. *It is made* of flat tempered spring wire. The flat shape lends to its flexibility which is necessary for long runs of conduit having several bends. The tempering prevents the tape curling after long use. *It comes* in lengths, multiples of 25 feet.

One side of the circuit is in contact all the time, the mechanism of the switches serving also as a reversing switch. The two wires connected between each switch are called the travelers.

Four way switches are used where more than two 3 way switches are required, 4 way switches operate the same as 3 ways, but are connected differently, the 4 ways being placed in the traveler wires; any number of 4 way switches may be installed with a set of 3 way switches.

In connecting up 4 ways care should be taken that one wire of the travelers is reversed to the switch, otherwise the switches will not operate.



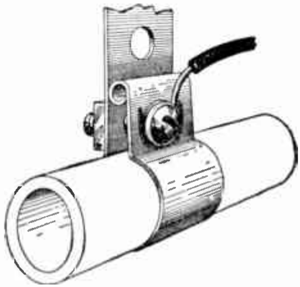
FIGS. 7,282 to 7,284.—Austin Hickeys. Fig. 7,282, adjustable: fig. 7.283. "bull dog" non-skid: fig. 7.284. Lakin for short bend in awkward positions.

Wiping Joints.—Large splices can best be soldered if the solder be first roughly applied with a good gasoline torch. Then a moleskin or canvas joint wiping pad is quickly run around the joint so that it will be smooth. By melting a little paraffin wax on the joint, it will appear smooth and shiny.

Surplus solder should be removed, when soldering large joints, a metal drip pan to catch the dripping should be placed underneath the joints so that the drippings can be caught and melted over again.

Taping.—The *Code* states that the same form of insulation must be placed on joints as removed. Thus if rubber covered wire be used, rubber tape must be put over the joint and this covered with friction tape. In taping at least three layers of each kind of insulation must be wound tightly over the splice.

Always hold the hand over a splice that has been taped so the heat of the hand will vulcanize the tape.



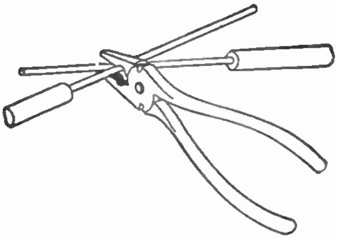
FIGS. 7,285 and 7,286.—Austin adjustable ground clamps, made in three sizes being adjustable in various ranges from three-eighths to three inch pipe.

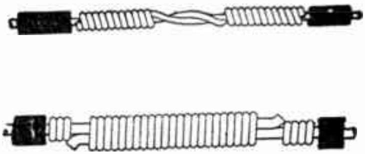
On large size cables and wires, after the wires have been taped it is suggested that all joints should be painted over with two coats of insulating paint or black asphaltum especially where the joints are exposed to the weather.

Wire and Cable Splicing.—In splicing a cable the insulation must first be removed. To do this a sharp knife is necessary, as it is impossible to hold an edge on a knife it is suggested that a knife having extra hard steel be used so that it will hold its edge longer than the inferior type, old files, ground down to an edge and fitted with a suitable handle, make very excellent knives.

Removing Insulation.—First, mark off the desired amount of insulation that is to be removed and with a sharp knife cut all around the insulation just deep enough so that it barely touches the metal of the wire, then hold the joint of the knife parallel with the wire and cut a long gash into the insulation as deep as the blade will enter. With a pair of pliers pull off the insulation and it will be found that the insulation will come off easily leaving the wire clean and bare. If the insulation be removed as with solid wire, it will be found that the insulation will stick to the wire and will be very difficult to remove. Note flexible re-enforced drop cord insulation should be removed in the same fashion as stranded wire.

The insulation of stranded cable should be removed in the same fashion





Figs. 7,287 to 7,289.—*Splicing.* Figs. 7,287 and 7,288, making a wire splice, and the twist completed; fig. 7,289, a wrapped joint on large wire. The joint should be carefully tinned and soldered in order to give good electrical contact and to avoid corrosion along the contact surface. Where wires are too large to be twisted together, the ends are given a short bend and the two wires wrapped firmly together with a smaller bare copper wire, after which the joint is thoroughly tinned and soldered, preferably by pouring hot solder over the joint. The joint is then insulated by wrapping it with two layers of pure rubber, and three layers of tape, sufficient to make the insulation thickness equal to that of the wire, after which the whole joint should be painted with water proof paint.

as stranded wire. Use a hack saw to cut around the wire and a large hunting knife or razor to cut the insulation.

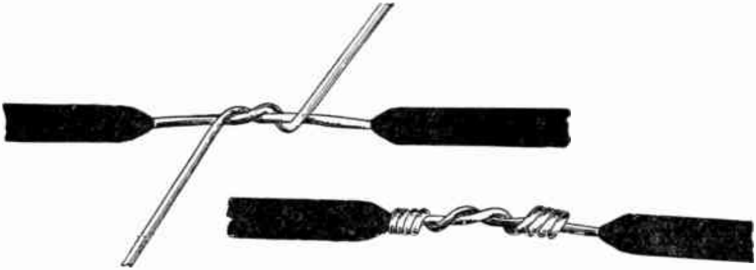
Splicing.—The Western Union type of joint is used for making running splices such as are used for continuing a run of wire Figs. 7,290 and 7,291, show the method of making the joint, and fig. 7,292, a tee or branch tap joint.

Pig Tail Splice.—This splice is used for making splices in junction boxes, fixture outlets, and all other places where a number of wires terminate.

The insulation is removed on all the wires, the same amount of insulation being removed from each wire so that the wires all come out evenly skinned. Bunch them all together and with a long pair of pliers twist them all together either to the right or left, keep twisting them until they are all tight, with the cutting edge of the pliers, trim off the ends so that there are no sharp points.

Soldering.—Small size solid and stranded wires can be soldered with the heat of alcohol torch although a gasoline torch gives better results.

In order that the solder will properly stick, it is essential that the wire



FIGS. 7,290 and 7,291.—Western Union joint. *In splicing* ends of the wire both being properly cleaned, are twisted together in opposite directions, as in fig. 7,290, then take one end and wind it around 4 or 5 times around the bare surface of the other wire, treat the other end in the same manner, use pliers in pulling the wire around the turns, otherwise they will not be tight, be sure that the ends of the splice terminate at the insulation, do not make the joints too long or too short, 4 or 5 times on each end, as in fig. 7,291, is sufficient.

FIG. 7,292.—Tee or branch tap joint. This joint is used in junction boxes. The splice is made the same as the running butt splice only all the wires are wound around the same wire. *In splicing,* the wire to be tapped is skinned so that just enough insulation is removed so that the proper number of turns may be wound around it. Hold the new wire that is to be tapped parallel with the wire that is already installed, and with a pair of pliers wind the wire around 4 or 5 times and clinch end of wire so it will not protrude.

should be thoroughly cleaned. Having cleaned the wires they should be coated with a thin film of a non-corroding soldering paste: this is to further remove the dirt and oxidization that is on the wire; unless soldering paste be used, the solder will not stick to the joint, apply the heat and do not apply the solder until the soldering paste on the joint begins to bubble, then apply a little solder until the solder runs, turn the wire all around so that the solder runs all around the joint. Allow joint to cool.

Joints also may be dipped in a pot of solder, provided they are covered with paste before dipping.

Remember that the metal to be soldered must be as hot as the solder and vice versa.

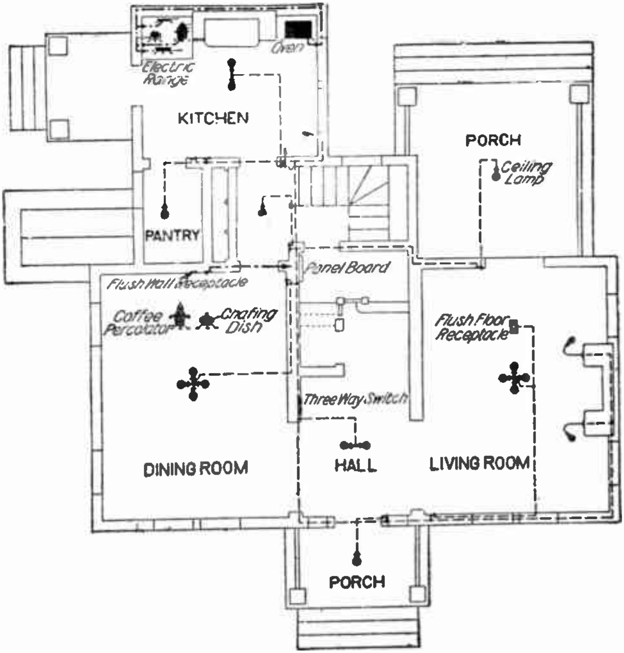
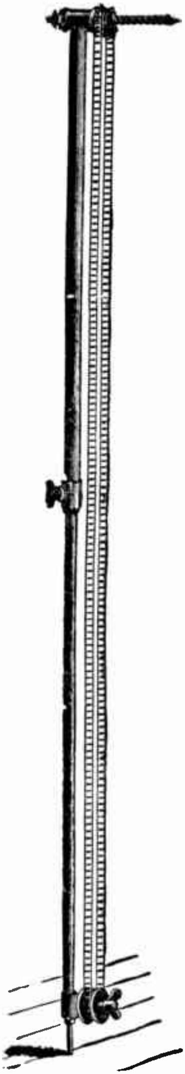


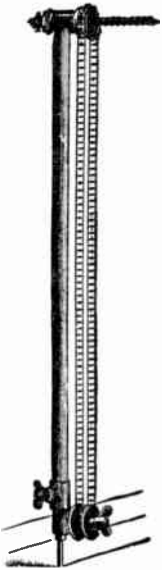
FIG. 7,293.—Wiring for heat appliances; plan of first floor. The location of the outlets is of importance. Usually a flush receptacle in the base board meets the requirements. Where several heating circuits are used it is essential that an appliance taking a large current be not placed on the regular lighting circuit. To guard against this possibility, special receptacles should be installed, constructed for plugs which will not fit any other receptacle.

NOTES

NOTE.—Sewer catch basin covers and street manhole covers may be used as a bending device, the pipe being inserted through the holes in the covers, and weight born down on pipe.

NOTE.—*To prevent terminal lugs becoming dirty* and covered with solder they should be covered with laundry soap before applying heat of torch.





FIGS. 7,294 and 7,295.—Henderson's boring machine fig. 7,294, extended; fig. 7,295, telescoped. This machine is for boring holes through joists from the floor. It has ball bearings and universal bit holder and is built to telescope to 4½ feet and extend 2 feet.

NOTE.—*A handy angle soldering copper* may be made from an ordinary soldering copper by cutting a 90° V notch at about the middle of the copper and bending over 90°.

NOTE.—*Metal tubing* may be easily broken apart if a notch be filed all around the outer surface with a 3 cornered file.

NOTE.—*An old umbrella* inverted and hung on a gas fixture will prevent dirt and plaster falling on the floor while cutting out around gas pipes.

NOTE.—*To prevent ceilings and walls becoming scorched* while soldering with a torch, a sheet of asbestos board should be held around and above joint to be soldered, sheet substituted.

NOTE.—By cutting off the head of a ten penny nail and inserting nail in a brace, it may be used as a wood drill through any kind of soft wood; try it.

NOTE.—*Broken screws or bolts* may be removed if a slot be cut into the screw with a hack saw, use the thumb nail as a guide for the saw, after a deep slot is cut, insert screw driver into slot and remove broken screws.

NOTE.—*Locking screws that work loose* such as on fans, and motors may be locked in place if chisel marks be made opposite the slots.

NOTE.—*Mica washers* may be obtained from old burnt out fuse plugs, for repairing electric irons and appliances.

NOTE.—*When short a lock nut* rather than go back to the shop, cut a lock nut from a coupling with a hack saw.

NOTE.—*Porcelain tubes* may be cut off if they be scratched with a file and heated in a flame, a sharp blow at joint of scratch, when cooled will break off part not desired.

NOTE.—*Pulling in wires* in fixture arms after first having tried to push wires in. If found difficult, drop a piece of pull chain, such as used on pull chain sockets, this will easily slide through any bend, attach wires to end and pull through.

NOTE.—Splits in hard wood floors and trim may easily be repaired by using common pins in the same manner as nails.

NOTE.—Plaster of Paris may be prevented hardening by mixing a little lime with the plaster. Plaster surfaces may be smoothed off with a brush soaked in water.

NOTE.—Stillson wrench jaws that do not grip can be made like new by filing out the jaws with a three cornered file.

NOTE.—A *brick drill* may be easily made from any piece of scrap water pipe by cutting a number of knotches on the end; use a hack saw and a three cornered file.

NOTE.—*Wood bits* may be sharpened with a fine manicuring file, never file the outer surface of a bit as it makes the cutters smaller and will be more difficult to turn bit through hole, as twist of bit is larger.

NOTE.—Vinegar (white) may be used as a substitute soldering flux, so may bicarbonate of soda or borax.

NOTE.—*Stripped threads* on screws or bolts may be replaced by filling in worn and stripped threads with hard solder and rethreading.

NOTE.—*Driving a nail in brick walls.* If it do not hold, another nail should be driven diagonally across the nail so that it will cross and bind the nail, this method is very effective and secure.

NOTE.—*A 20 penny nail* makes a good substitute for a prick punch for punching holes in cut out boxes. Nails also may be used as nail sets.

NOTE.—*A good meter board* paint may be made from dissolving lamp black in gasoline. This also makes a good motor paint.

NOTE.—*Cutting line shafting.* To cut off a section of line shafting, a hack saw should be held on the place to be cut and the shaft should be run by power. this will cut off the shaft smoothly and quickly.

NOTE.—Old broom sticks cut up into pieces 4 inches long are good plugs for concrete walls to fasten outlet boxes and pipe, etc.

NOTE.—*Knife sharpener.* A common porcelain tube may be used for the frequent sharpening of a knife blade dulled by scraping insulation and wires.

CHAPTER 21

Outside Wiring

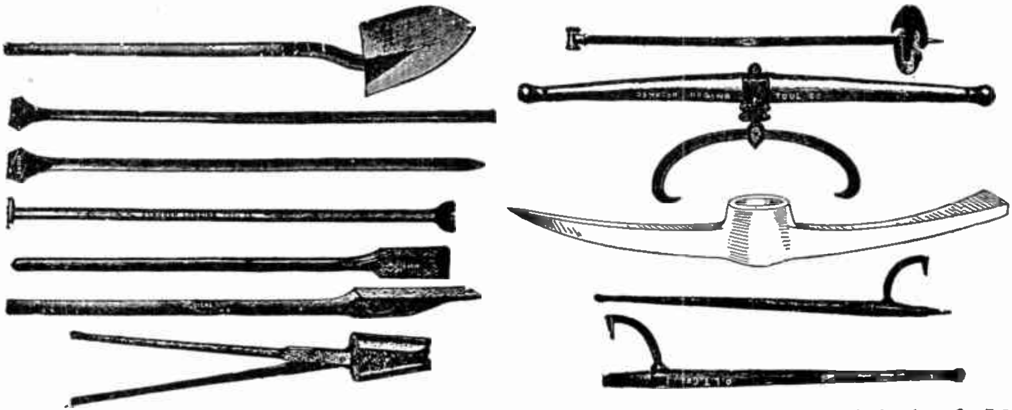
Materials for Outside Conductors.—Copper wire is now considered to be the most suitable material not only for the transmission of current for electric light and power purposes, but also for telegraph and telephone lines, in place of the iron wire formerly employed.

Tensile Strength of Copper Wire

Size of wire B. & S. gauge	Tensile strength, lbs.	Size of wire B. & S. gauge	Tensile strength, lbs.
0000	9971	9	617
000	7907	10	489
00	6271	11	388
0	4973	12	307
1	3943	13	244
2	3127	14	193
3	2480	15	153
4	1967	16	133
5	1559	17	97
6	1237	18	77
7	980	19	61
8	778	20	48

Hard drawn copper wire is used in outside construction, because its tensile strength ranges from 60,000 to 70,000 pounds or about twice that of soft copper. This is desirable to withstand the stresses to which the wire is subjected which, in the case of long spans, are considerable

Pole Lines.—Various species of northern pine, cedar and cypress, because of their size and straightness, are suitable for large poles.



FIGS. 7,295 to 7,306.—Pole construction tools. Fig. 7,295, long handled digging shovel; fig. 7,296, digging bar, fig. 7,297, crow and digging bar; fig. 7,298, tamping and digging bar; 7,299, wood handle tamping bar; fig. 7,300, slick digging tool; fig. 7,301, post hole auger; fig. 7,302, carrying hook; fig. 7,303, tamping pick; fig. 7,304, split wooden handle post hole auger fig. 7,305, cant hook; fig. 7,306, socket peavey.

The preservation of wooden poles is important. Decay of the pole occurs especially at or near the soil line. There are several preservation processes, such as creosoting, burnettizing, kyanizing, carbolizing, and vulcanizing. The application of pitch and tar oftentimes results in more harm than good.

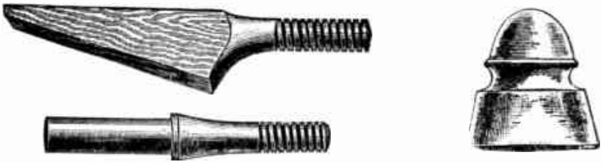
Methods of Setting Wooden Poles.—Where poles have to be planted in low, swampy ground, or where the climatic conditions are such that timber decays rapidly it has been found advantageous to place the poles in concrete settings.

This method is often used in the Southern States, square poles being placed in settings about 7′ deep and 3½′

square. In very soft ground the employment of a concrete setting is sometimes impracticable. In such cases piles are driven deep into the soil, and the pole bolted to the part of the pile extending above the ground.

Reinforced Concrete Poles.—Untreated wooden poles must be replaced by new poles about every six years whereas reinforced concrete poles will last indefinitely.

One form of reinforced concrete pole consists of a skeleton frame work



FIGS. 7,307 to 7,309.—Glass insulator and insulator pin and bracket. The insulator here shown is of the pony double petticoat type. Insulator pins are used with cross arms, brackets are attached direct to the pole.

of four corrugated iron rods covered with ordinary concrete. The pole is octagonal in shape, 30 feet long, and provided with mortises for cross arms, the latter being fastened in place by means of iron bolts. It is stated that they are less expensive than pine poles, and that each pole can be manufactured at the point on the line at which it is to be installed or planted.

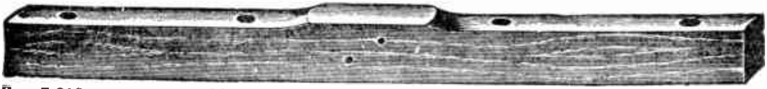


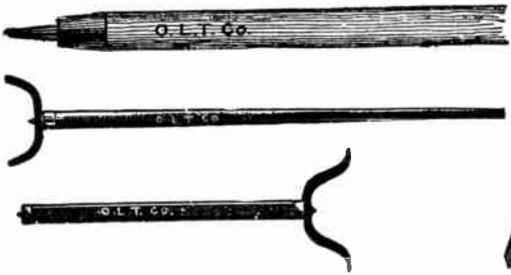
FIG. 7,310.—Cross arm which carries the insulator pins. The standard cross arm is 3¼×4¼ inches, double painted, and bored for 1½ inch pins and two ½ inch bolt holes. Telephone arms are 2¾×3¾ inch, bored for 1¼ inch pins and two ½ inch bolts.

Cross Arms.—These are usually attached to the poles before they are erected.

They are commonly made from yellow pine wood, generally 3¼×4¼ inches, and are freely coated with good mineral paint as a preservative. Attachment is made to the pole by cutting a *gain* one inch deep and of sufficient breadth to allow the longest side of the cross arm to fit accurately. It is then secured in place by a lag screw, with a square head, so that it may be driven into place with a wrench. The cross arm is further secured to the pole by galvanized ¼×1¼ flat iron braces.

The cross arms are bored with holes for the insertion of the insulator pins, which are made of locust wood and threaded at the upper end to receive the glass insulator.

The cross arm is made of such a length as to accommodate the number of pins to be inserted. An arm for two pins is made three feet long, according to the standard usually followed, with holes for the pins at center points three inches from either end and a space of 28 inches between them in the center.



FIGS. 7,311 to 7,314.—Pole line construction tools. Fig. 7,311, pike pole; fig. 7,312, raising fork; fig. 7,313, mule pole support; fig. 7,314, jenny pole support.

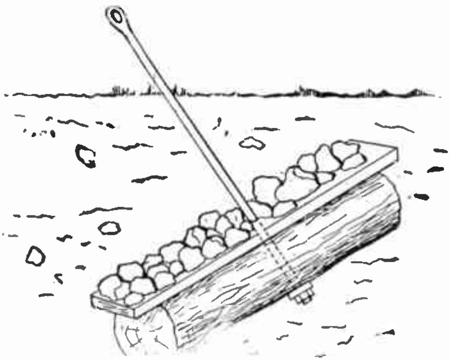


FIG. 7,315.—Guy anchor log in position.

FIG. 7,316.—Stombaugh guy anchor. It is made of cast iron and can be screwed into the ground like an auger

Light and power wires must not be strung on the same cross arm with telegraph or telephone wires.

Spacing the Poles.—This is governed by the weight of the lines the poles must carry, the heavier the lines, the greater the number of poles.

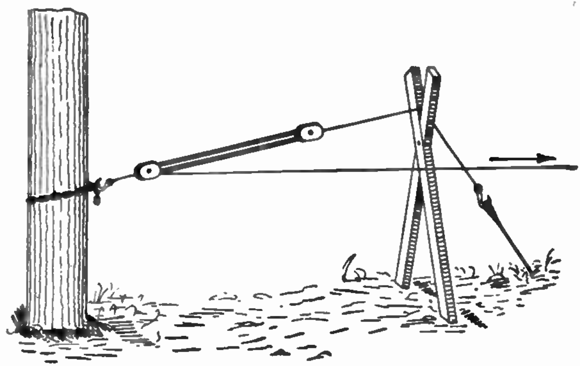


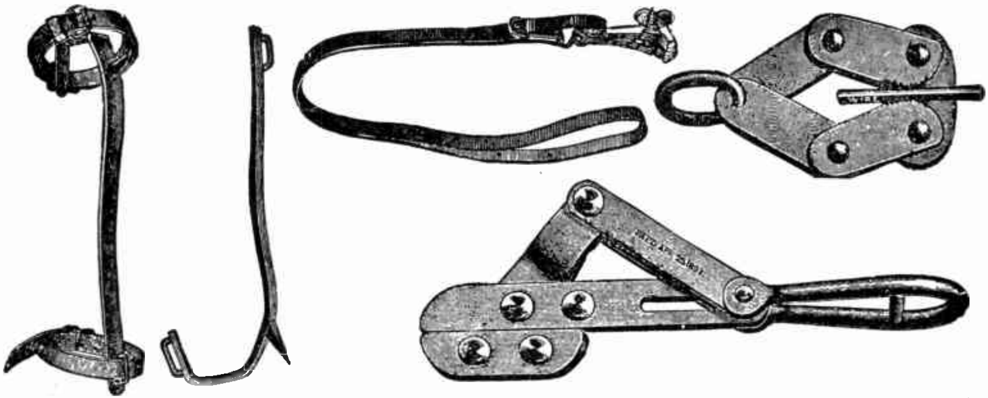
FIG. 7,317.—Method of pulling an anchor into place before the guy wire is fastened to the top of the pole, thus obviating the liability of pulling the pole out of plumb.

The spacing of poles also depends on their liability to injury from storms and wind in any given locality, and the nature of the service. Poles for a telephone line may be spaced twenty to fifty to the mile—that is, from about 260 to 100 feet apart.

Erecting the Poles.—The holes must be dug to as nearly the required depth as possible.

Holes for poles are dug very little wider than their diameter at the butt, and the depth is usually computed according to the nature of the soil and the weight of the proposed line. Excavation, while sometimes accomplished with patent post hole augers, or even dynamite, is usually done with a long handled digging shovel, and the earth removed with a spoon shovel.

The poles are rolled or carried on hooks to the holes. In erecting, a piece of timber is inserted in the hole as a slide to prevent crumbling of the earth as the pole is slid into place. The end is raised by hand sufficiently to allow the "dead man," or pole hoist, to be placed beneath, and

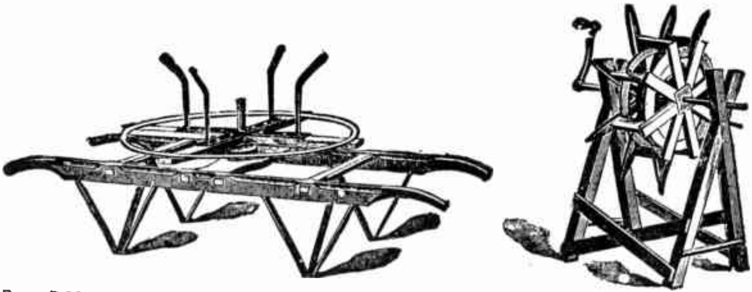


FIGS. 7,318 to 7,322.—Lineman's tools. Figs. 7,318 and 7,319. Eastern pole climbers, with and without strap for attaching to legs; fig. 7,320, portable vise with strap for pulling up the slack in splicing; figs. 7,321, one form of "come along." The wire is inserted between jaws and is held fast when tension is applied to the ring; fig. 7,322, an improved form of "come along" or wire stretcher. The jaws which grip the wire are smooth and remain parallel in closing, thus the wire is not scratched or indented, as with circular jaws having teeth.

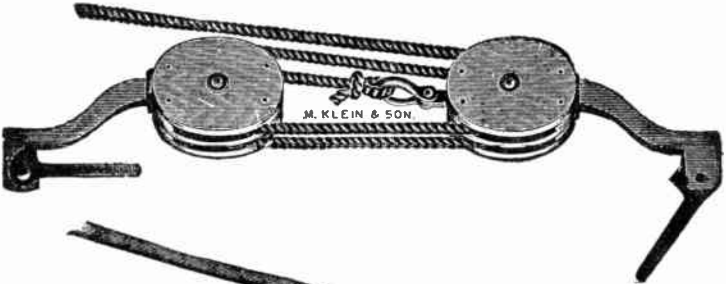
this is moved along regularly as the pole is lifted with pike poles, until it slides into place through the force of gravity.

Guys for Poles.—These are attached near the top and secured either to the base of the next pole, to a suitable guy stub or post, or to a guy anchor, which is buried about eight feet in the earth and held down by stones and concrete.

Wiring the Line.—In stringing the lines, either one or the full number of wires may be put up at the same time.



FIGS. 7,323 and 7,324.—Pay out reels. Fig. 7,323, type used for telephone or telegraph work; fig. 7,324, type used for electric light work.



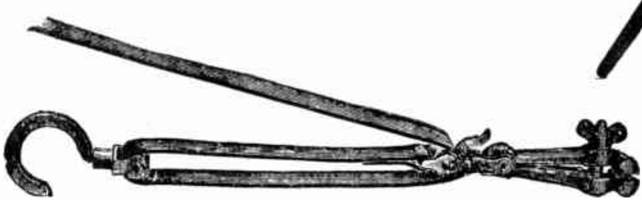


FIG. 7,325.—Lineman's block and fall with "come alongs" for stretching wire and holding same when making splices.

FIG. 7,326.—Wireman's "come along" with hook and tackle.

Trolley wires.—National Electrical Code.

12-*i*.—Must not be smaller than No. O. B. & S. gauge copper or No. 4 B. & S. gauge silicon bronze, and must readily stand the strain put upon them when in use.

12-*j*.—Must have a double insulation from the ground. In wooden pole construction the pole will be considered as one insulation.

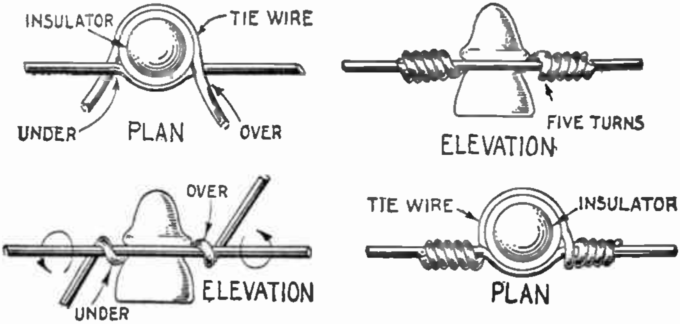
12-*k*.—Must be capable of being disconnected at the power plant or of being divided into sections, so that in case of fire on the railway route, the current may be shut off from the particular section and not interfere with the work of the firemen. This rule also applies to feeders.

12-*l*.—Must be safely protected against accidental contact where crossed by other conductors.

Where guard wires are used they must be insulated from the ground and electrically disconnected in sections of not more than 300 feet in length.

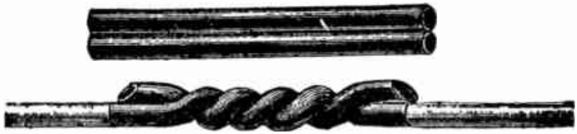
When one line only is to be strung, the operation consists simply in reeling the wire and running it off from a hand reel. At each pole the wire is drawn up to its place, pulled out to the desired tension, and attached to the insulator.

In the operation of stringing a number of lines at once, the method is different. The reels are placed at the beginning of a section, each wire

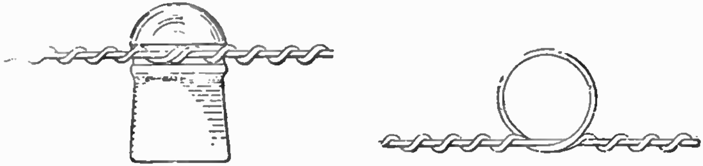


FIGS. 7,327 to 7,330.—Methods of tying in wires to insulators. A separate wire is used for *tying in* the wire to the insulator. This is called a tie wire it should be about 18 to 24 ins. long, must be of hard drawn wire, and of the same size wire as the line wire. The wire is twisted around the main wire, as in fig. 7,327, but it is more difficult to make the tie in than it appears. A tight tie in can not be made by hand, pliers must be used. First the tie wire is looped around the insulator, one end of the wire over and the other end under the main wire, as in fig. 7,327, separately each end is wound around the line wire with pliers, five turns or more, so that the strain will be both ways.

FIG. 7,331.—American wire joint. This is a simple method of connecting the ends of the sections of wire by tightly twisting the ends around each other for a few turns; it is *the standard Western Union* wire joint.

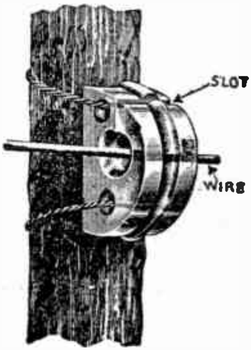


FIGS. 7,332 and 7,333.—McIntire sleeve and sleeve joint. An approved method of making the joints of telephone lines is by the use of some form of sleeve, such as is shown in fig. 7,332. *This consists of* two copper tubes of the required length, and of sufficient inside diameter, to admit the ends of the wires to be joined, fitting tightly. The tubes are then gripped with a tool, shown in fig. 7,336, and twisted around one another, so that the wires are securely joined and locked, as shown in fig. 7,332.



FIGS. 7,334 and 7,335.—Approved method of attaching wire to an insulator; elevation and plan of insulator and tie. The line wire is first laid in the groove of the insulator, after which a short piece of the same size of wire is passed entirely around to hold it in place, then it is twisted to the line at either side with pliers.

FIG. 7,336.—McIntire's twisting clamp for wires 00 to 16 B. & S. gauge.



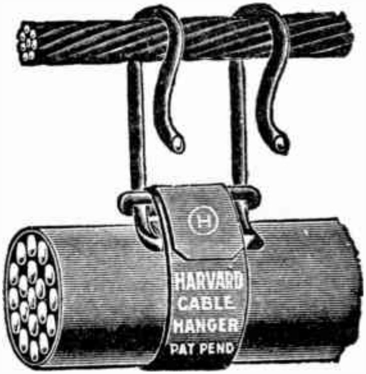


FIG. 7,337.—Tree insulator for temporary or repair work. *It is made* of a single piece of glass, and is provided with a slot which the wire cannot leave accidentally. The back of the device is concave and provided with ribs which prevent sliding. It can be readily slipped over wires already in place, is available for electric light circuit, and will take wires up to ½ inch, in diameter.

FIGS. 7,338.—Overhead cable construction. *In some cases,* particularly on short lines exposed to inductive disturbances from power and other electrical circuits, it is usual to string the cables on poles such as usually carry the bare conducting wires. It is not necessary, however, to insulate the cable in any way; consequently it is merely hung to a supporting wire rope or cable, called the "messenger wire." being attached either with some form of hanger or by loops of tarred marline. The marline is sometimes wound over the cable and messenger wire from a bobbin, but frequently it is merely wound on by hand.

being inserted and secured through a separate hole in a board, which is perforated to correspond with the spacing of the insulators on the cross arms. A rope is then attached to this running board, which is drawn by a team of horses through the stretch to be wired, being lifted over each pole top in turn. When a certain length has thus been drawn out, the wires are drawn to the required tension between each pair of poles and secured to the insulators.

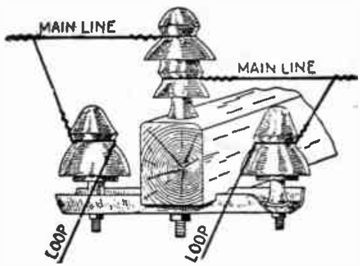
In applying tenting to the wires in stringing, some sag must be allowed. A general rule is to make the tension on a wire equal to ⅓ of its breaking load. The sag usually allowed is given in the following table:

Sag Table

Span in Feet	Temperature Fahr.		
	30°	60°	80°
	Sag in Inches		
75	1¼	2½	3⅛
100	3	4¼	5½
130	5⅛	7	8⅝
150	6¾	9	11¼

In drawing out the wire, it is customary to use a wire clamp, or "come along." This tool is attached to a block and tackle, or drawn in by hand, and, as soon as the proper force has been applied, the wire is held, while the lineman secures is to the insulator.

Another contrivance for this purpose is the pole ratchet, by which the wire is drawn tight and held until attached to the pole.



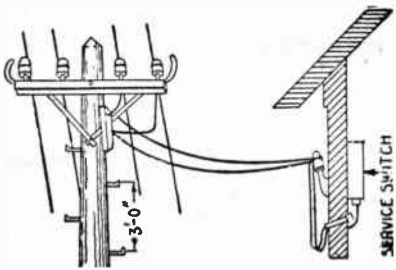


FIG. 7,339.—Method of making a series "loop" service connection.

FIG. 7,340.—Parallel service connection. Service wires tapped to the main wires, are run to inslators on an auxiliary cross arm, thence to insulators on the side of the building, and through the drain tube to the service switch.

The methods of attaching wires to insulators, splicing, etc., are shown in the accompanying cuts.

Transpositions.—Due to rapid current changes in telephone and telegraph lines, transpositions are necessary to avoid inductive disturbances.

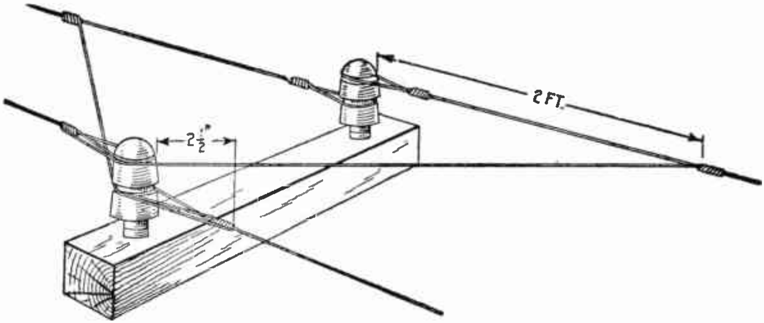


FIG. 7,341.—Method of making a "transposition." This is usually done by means of *transposition insulators*, which are either double insulators, one being screwed to the pin above the other, or else such caps as are shown in fig. 7,344. Such insulators are intended to act as circuit breakers, the particular wire to be transposed being cut and "dead ended", or tied around, on both the upper and lower grooves of the cap. The free end of each length is then passed back and around the insulator and twisted, or sleeve jointed to the other limb of its own circuit.

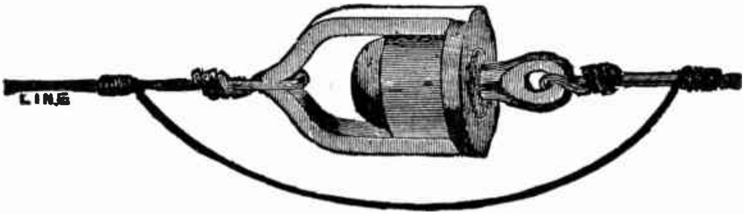


FIG. 7,342.—Clark's "antihum"; a device designed to prevent the humming of telegraph wires,

For short lines and pole systems with only a few wires it is not necessary to transpose very frequently. On longer lines it has been found amply sufficient to transpose once every quarter mile; that is to say to change the relative position of the wires of the different circuits at posts situated about that distance apart. This does not mean, however, that each pair of wires is transposed so often, but that on ordinary sized systems, the transposition of some one circuit is amply sufficient to secure balanced relations and effectually counteract the effects of cross induction. It is a matter which must be carefully calculated and planned in each particular instance in order to secure the best advantages.

Insulators.—Glass and porcelain are employed almost universally for supporting overhead wires.

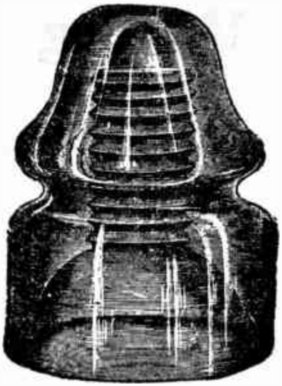


FIG. 7,343.–Telegraph and telephone line glass insulator.

FIG. 7,344.—Type of insulator used in making a transposition.

Insulators made of these materials are superior to those made of other material such as hard rubber, or various compounds of vegetable or mineral matter, with the exception perhaps of mica insulators used on the feeders of electric railway lines.

CHAPTER 22

Underground Wiring

In large cities, the best method of running wires for all varieties of electrical power transmission is to place them underground.

The expense of installing an underground system is very great in comparison with that of overhead construction, but the cost of maintenance is much less and the liability of interruption of service greatly reduced.

The various underground systems may be divided into three classes:

1. Lead encased cables laid directly in the ground;
2. Solid or built in systems;
3. Drawing in systems.

Where cables are laid directly in the ground, the metallic covering, consisting usually of a lead tube, which is placed over the insulation is depended upon for mechanical protection.

Such cables are largely used for short private lines and the first cost is less than that of the others, but in case of repairs it has to be dug up.

In the drawing in systems, the cables are drawn in after the conduits are built.

The conduit of the drawing in system may consist of various forms of pipe or troughs of iron, earthenware, concrete, wood or fibre, while those of the solid or built in systems are composed of either iron tubes or concrete trenches.

Vitrified Clay Pipe.—Various forms of vitrified clay conduit appear to possess the qualifications, desirable in underground construction, to a higher degree than any other type.

They are made in both single and multiple duct, the single type being about 3½ inches in diameter, or 3½ inches square, and 18 inches long. Multiple conduit is made in two, three, four, six and more sections, ranging from 2 to 3 feet in length.

Single conduit is best suited where there is great crowding of gas, water and other pipes, as the conduit can be divided into several layers so as to cross over or under such pipes.

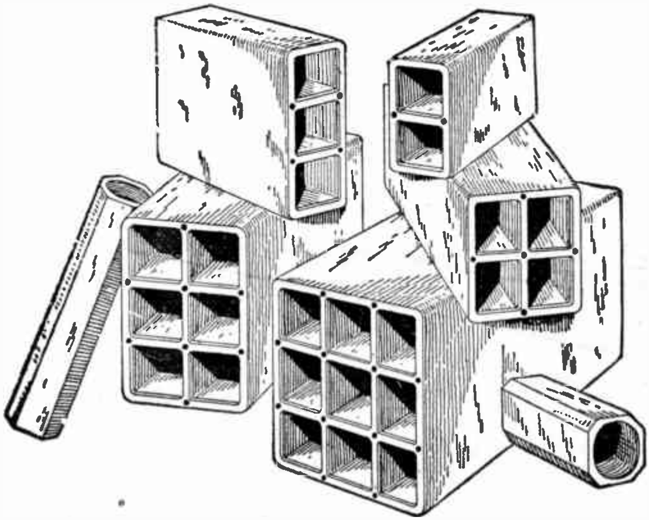


FIG. 7,345.—A few forms of vitrified clay pipe conduits; view showing single and multiplex types. The dimensions of each duct are about 3½ X3½. The lengths vary from two to three feet.

The multi-duct conduit can be laid somewhat cheaper, especially in lines of about two to four ducts; it is best suited to districts free from sub-surface obstructions.

In laying conduit, a trench is dug, usually sufficiently wide to allow the placing of three inches of concrete on each side of the ducts, and sufficiently deep to hold at least thirty inches of concrete on top of the upper layer of concrete forming the conduit, and to allow for three inches of concrete in the bottom. The trench is graded from some point near the middle of the block to the manhole at each intersection, or from one manhole to the next manhole, at a gradient not less than 2 inches to 100 feet.

The tiles of the several ducts are placed close together, and the joints plastered and filled with cement mortar consisting of one part of Portland cement to one part of sand. When the conduit is being laid, a wooden mandrel about four or five feet long, three inches in diameter, and carrying a leather or rubber washer from three to eight inches larger at one end is drawn through each duct so as to draw out any particles of foreign matter or cement which may have become lodged in the joints, and also to insure good alignment of the tiles.

Single duct conduits are usually laid by brick layers. This fact accounts for the somewhat greater cost of the single over the multiple conduit which

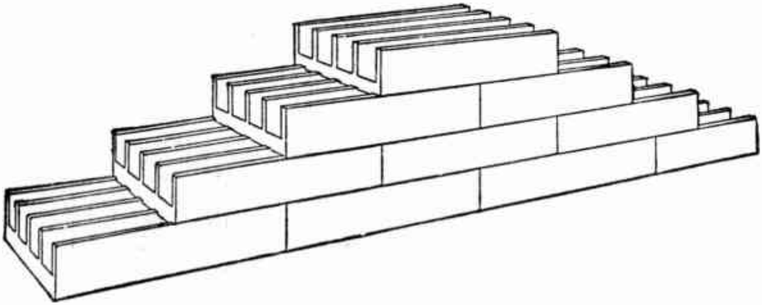


FIG. 7,346.—Vitrified clay or earthenware trough conduit; this type of conduit consists of troughs either simple or with partitions, the latter type being shown in the figure.

is usually laid by ordinary laborers. One good brick layer and helper, however, will lay from 200 to 300 feet of single duct conduit per hour.

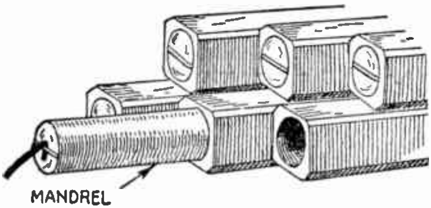
Vitrified Clay or Earthenware Trough Conduit.—It consists of troughs either simple or with partitions as shown in fig. 7,346.

They are usually made in tiles 3 or 4 inches square for each compartment, with walls about one inch thick. The length of the tiles ranges from two to four feet. Each of the two foot form duct troughs weighs about 85 pounds. When laid complete, the top trough is covered with a sheet of mild steel, about No. 22 gauge, made to fit over the sides so as as to hold it in position, and then covered over with concrete.

In laying multiple duct earthenware conduit, the ducts or sections are centered by means of dowel pins inserted in the holes at each joint, which is then wrapped with a six inch strip of asphalted burlap, or damp cheese cloth, and coated with cement mortar as shown in fig. 7,348. Economy of space and labor constitutes the principal advantages derived from the use of multiple duct conduit.

Concrete Duct Conduits.—These are usually constructed by placing collapsible mandrels of wood or metal in a trench where the ducts are desired and then filling the trench with concrete.

After the concrete has solidified, the mandrels are taken out in pieces, leaving continuous longitudinal holes which serve as ducts. Some builders



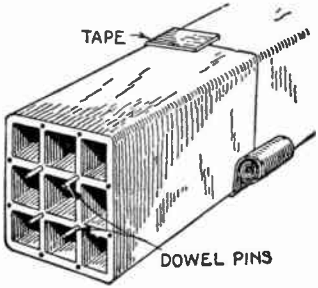


FIG. 7,347.—Method of laying single duct vitrified clay conduit. The tiles of the several ducts are placed close together as shown in the figure, and the joints plastered and filled with cement mortar consisting of one part Portland cement and one part sand.

FIG. 7,348.—Method of laying multiple duct vitrified clay conduit. The section are centered by the dowel pins shown in the cut.

produce a similar result by placing tubes of sheet iron or zinc in the concrete as it is being filled into the trench. These tubes have just enough strength to withstand the pressure to which they are subjected, and are, therefore, very thin and liable to be quickly destroyed by corrosion, but the ducts formed by them will always remain unimpaired in the hardened mass of concrete.

Wooden Duct Conduits.—In this type of conduit, the ducts are formed of wooden pipe, troughing, or boxes, and constitute the simplest and cheapest form of conduit.

A pipe conduit consists of pieces of wood about 4½ inches square, and three to six feet long, with a round hole about three inches in diameter bored through them longitudinally. As shown by fig. 7,349 a cylindrical projection is turned on one end of each section, which, when the conduit is laid fits into a corresponding recess in one end of the next section. The sections are usually laid in tiers, those of one tier breaking joint with those of the tiers above or below.

The trough conduit consists of ducts about 3 inches square made of horizontal boards and vertical partitions, usually of yellow pine about one inch in thickness. This form of conduit can be laid in lengths of 10 and 12 ft., or it can be built along continuously. The life of wooden

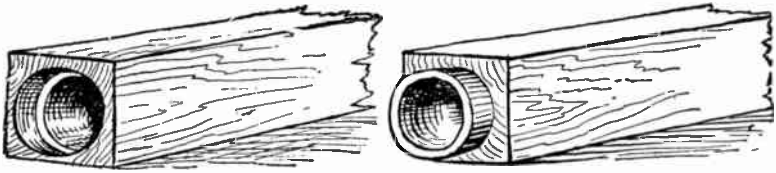
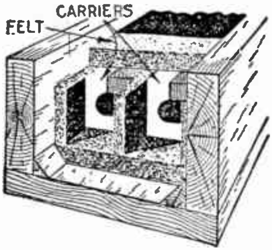


FIG. 7,349.—Wooden pipe type of conduit. *It consists of* pieces of wood about 4½ inches square, and three to six feet long, with a wide hole about three inches in diameter, bored through them longitudinally.



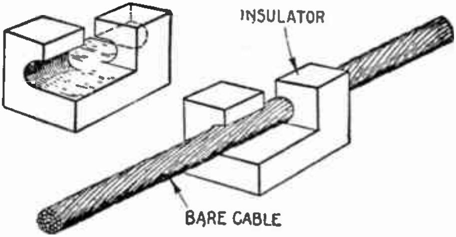


FIG. 7,350.—Perspective view of wooden built-in conduit. *It consists of* an outer rectangular casing of wood which is lined inside with impregnated felt

FIGS. 7,351 and 7,352.—Porcelain bridgework or carriers for supporting underground conductors.

conduit may be increased by the application of sterilizing processes. Wooden conduit is best adapted for temporary installations.

Wooden Built-in Conduits.—The chief advantage of these are high insulating quality, the capability of using bare wire and rods for underground conductors, and reduced cost.

In construction, a wooden trough is laid in a trench about 18 inches deep. Porcelain carriers are placed in the trough at intervals of 4 to 5 feet, to act as bridgework for supporting the conductors. This bridgework is placed on and is surrounded by impregnated felt or similar material, and the spaces between the carriers, after the conductors have been placed in position on them is filled with voltax, which hardens rapidly and forms a solid insulating material throughout the conduit.

Wrought Iron or Steel Pipe Conduits.—These are formed of pipes similar to gas or steam pipes, with screw or other connections.

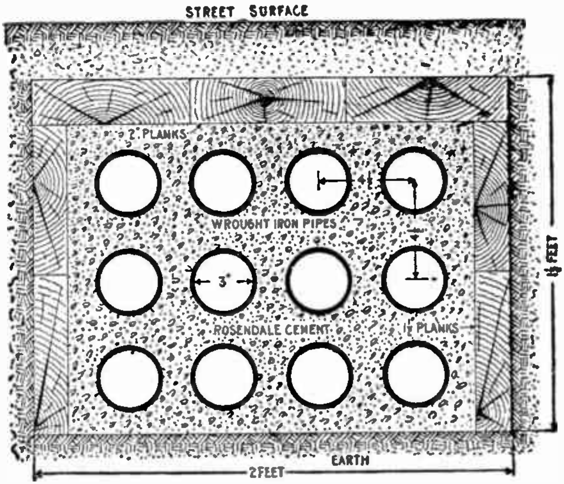


FIG. 7,353.—Cross section of wrought iron pipe conduit laid in hydraulic cement.

They are laid either simply in the earth, or in hydraulic cement, and are the strongest and one of the most satisfactory forms of underground conduit. In construction, a trench, the width of which will depend upon the number of pipes to be laid, is first dug in the ground, and after its bottom has been carefully leveled, is braced with side planking and filled to the depth of two to four inches with a layer of good concrete, consisting of two parts of Rosendale cement, three parts of sand, and five parts of broken stone capable of passing through a one and one-half inch mesh. This concrete is well secured in place and forms the bed for the lowermost layer or tier of pipes.

Ordinary wrought iron pipe is employed, in 20 foot lengths about three to four inches in diameter, depending upon the size and number of cables they are intended to carry. After the last tier of pipes have been put in place, and a layer of concrete from two to four inches placed over it, a layer of two inch yellow pine planking is laid over the whole.

The principal object of the top covering is to protect the conduit against the tools of workmen making later excavations.

Practical experience shows that workmen will dig through concrete without stopping to investigate as to the character of the obstruction, but under similar circumstances, will invariably turn away from wood.

In best construction the pipes are lined with a layer of cement ⅝ in. thick and containing no sand.

Cast Iron Pipe and Trough Conduit.—Cast iron pipe for

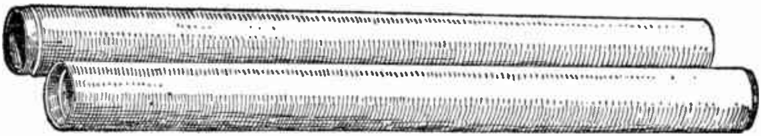


FIG. 7,354.—Fibre conduit. It consists of pipes made of wood pulp, having about the same thickness as cast iron pipe. Slip joint conduit for electrical subways is three inches inside diameter. The socket joints keep the lengths centered and make it easier to lay than a mere butt joint. It is laid in cement like iron pipe.

underground conduits is similar to ordinary wrought iron pipe, except that it is thicker.

The additional thickness is necessary to make the strength equal to that of wrought iron; it is therefore heavier to handle and more expensive.

The trough conduit consists of shallow troughs of cast iron in six foot lengths, laid directly in the earth so as to form a system of continuous troughing in which the conductors are placed and then covered over by cast iron covers which are bolted to the trough.

The advantages are that the cables can be laid directly in place, thus eliminating any chance of injury during the process of drawing in, and second, the cables are easily accessible at any point by simply removing one or two of the sectional cast iron covers, thus permitting of their being readily inspected and repaired.

Fibre Conduits.—This form of conduit consists of pipes made of wood pulp impregnated with a bituminous preservative and insulating compound.

These pipes are laid in concrete in a manner similar to iron pipe. Fibre conduits are made in sizes ranging from 1 inch to 4 inches in diameter and from 2½ to 5 feet in length, with walls ranging from ¼ to ½ inch in thickness.

In laying the socket joint type of fibre conduit, after the trench has been dug to the required width and depth, depending upon the number of pipes to be placed in a tier and the number of tiers, a bed of concrete about 3 inches deep is placed on the bottom and a line drawn on one side for the alignment of the first line of pipes. The other lines of pipe or ducts are laid parallel to the first line, and are separated from it and from each other by means of ¼ inch or ½ inch wooden or iron pegs.

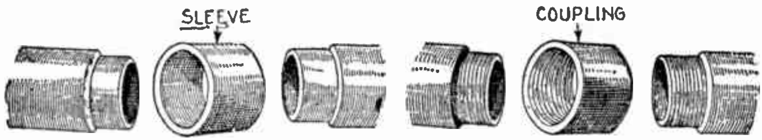


FIG. 7,355.—Sleeve joint type of fibre. Both the socket type and the sleeve type are easily aligned without the use of a mandrel.

FIG. 7,356.—Screw joint type of fibre conduit. *This method* of connection will form a tight line and is suitable for running under the lawns of private houses and parks, under the streets of towns and villages, and in other places where the cost of building electric subways is prohibitive.

The pipes are well grouted and covered with a layer of concrete to the depth of ¼ or ½ inch, and the next tier laid in place in the same manner.

When the final tier of pipes has been installed, it is covered with a layer of concrete about 2 to 3 inches deep.

When necessary to cut a length of pipe to break joints or to enter a manhole, the remaining part of the length may be utilized by using a fibre conduit sleeve having an inside diameter ½ inch greater than the pipe being used on the system.

Edison Tube System.—This arrangement consists of a series of iron tubes or pipes containing one or more copper conductors which are placed therein before each complete section or pipe leaves the factory, so that they only need to be joined together to form a continuous line of underground conduit with conductors in place.

Underground Cables.—Electric light and power cables for use in conduit may be divided into two classes: *moisture proof*, and *non-moisture proof*, according to the character of the insulator.

In the moisture proof cables, the insulation consists of some form of rubber, or of bitumen, and a metal sheath or covering, usually of lead, is provided to protect the cable from mechanical or chemical injuries. The non-moisture proof cables are insulated with paper impregnated with oil, wax, or resinous compounds.

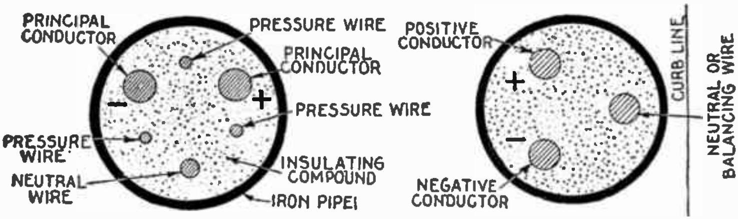


FIG. 7,357.—Cross section of Edison "feeder" tube. This runs from the power station to the centers of distribution, and contains two principal conductors and a smaller conductor to serve as a neutral wire and also three insulated cables of seven strands of No. 19 B. W. G. wire each. These cables form independent circuits and enable the voltages at the distant end of the feeder to be read at the central station. For this reason they are commonly called pressure wires.

FIG. 7,358.—Cross section of Edison "main" tube. A number of these tubes, which radiate from the center of distribution and loop the ends of the feeders together, have three conductors of the same size. These tubes are placed in the ground so as to bring the positive and negative conductors on one side of the center of the tube, and the neutral conductor on the other side. The mains are always laid with the neutral conductor adjacent to the curb line and for convenience, this side of the tube is commonly called the *inside*. The feeders are always laid with the positive conductor on the right hand side.

Metal Sheaths on Underground Cables.—Metal sheaths are used on rubber covered cables to protect the insulating compounds from the deteriorating effects of electrolysis and various kinds of acids and gases which, under present methods of construction, are ever present in the underground conduits.

It is a fact, however, that the lead sheath on a low tension cable, which is used as one side of a grounded circuit, has been, in some cases the cause of, instead of, cure for electrolysis. The proper cure lies in the omission of the sheath altogether, but as this is not practical except in the case of very large conductors, the best thing that can be done is to interrupt the continuity of the sheath by some form of insulating joint.

Pot Heads.—The upper end of a lateral cable is equipped with a discharge bell, which is commonly called a pot head.

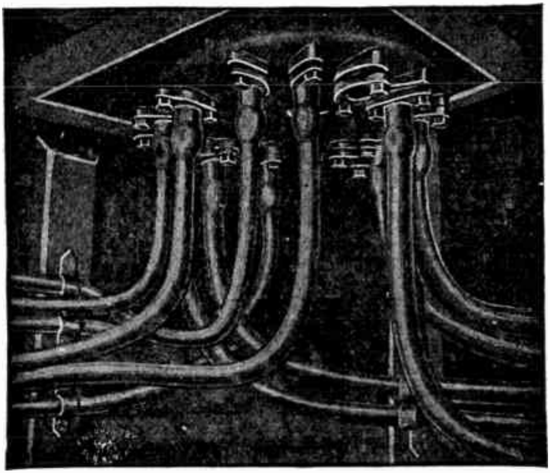


FIG. 7,359.—Bottom of General Electric manhole junction box; view from manhole interior. The cables enter the bottom of the box as shown through composition nozzles to which the lead sheathes are united by a wiped solder connection, forming a permanent water and gas tight joint. Stuffing boxes are sometimes substituted, doing away with the wiped joint, rendering the boxes suitable for use with unleaded or braided cables. The normal position of the distributing cables is in the upper ducts so that they may be brought to the junction box without crossing other lines. The entrance nozzles and seats are so arranged that all terminals are soldered to cables outside of box and any cable may be removed without disturbing any soldered joint. The wiped joints unite electrically the lead sheathes of all cables entering the box and by connecting a single earth bond to the shell of the box all cable sheathes are solidly grounded. Incombustible shields prevent the arc from a blown fuse making a ground connection to the shell or inner cover.

The purpose of a pot head is to hermetically seal the end of the cable and bring the conductors out in such a manner as to permit of their being conveniently connected to the primary service boxes.

Pot heads are usually made in three parts, the base being of cast brass, having a diameter depending upon the size of the conductors, with a hole in the lower end threaded within in such a manner as to make a tight fit on the cable.

In connecting the head to a cable, after the cable has been bent in to the proper position, the brass base is slipped down over it with the larger end up, and then screwed down on the lead sheath. The threads cut down into the lead sheath to a distance of about ½ inch along the sheath, thus making an air tight connection without necessitating the making of a wiped joint.

The separate conductors are now bared of their insulation for a distance of about two inches, and then spliced to heavy rubber covered braided wire of sufficient length to reach the primary service boxes. The joints connecting these rubber covered wires and the cable conductors are spliced in the same manner as straight splices, the paper sleeves used being of sufficient diameter to be backed out of the way over the rubber insulation.

When the splice is completed, a brass shell threaded at one end to fit a female thread in the upper end of the brass base, is slipped over the end of the rubber covered wire and screwed into the base. A hood of sheet copper having the form of a quarter section of a ball is slipped over the top of the frame and its lower edge tracked in position below the horizontal shelf. This hood makes the pot head water, snow, and insect proof

CHAPTER 23

Power Wiring

Wiring of Motors (Code Provisions).—All motor wiring should be performed according to the requirements of the *National Electrical Code* in addition to existing *local Codes* and requirements in force at the place of installation.

Since the detailed requirements of the Code with respect to motor circuits are too numerous to be fully enumerated only the basic general rules for motors are abstracted here.

Fig. 7,360 represents a schematic diagram of a motor circuit together with feeder and branch circuit equipment all lettered for proper identification.

(Note A) ***Feeder Overcurrent Protection.***—A feeder which supplies motors shall be provided with overcurrent protection which shall not be greater than the largest rating or setting of the branch circuit protective device for any motor of the group (based on tables 26 and 27, pages 540-16 and 540-17) plus the sum of the full load currents of the other motors of the group.

(Note B) ***Feeder Conductors.***—Conductors supplying two or more motors shall have a current carrying capacity of not less than 125% of the full load current rating of the highest rated motor in the group, plus the sum of the full-load currents of the remaining motors supplied by the feeder.

(Note C) ***Motor Branch Circuit Conductors.***—Branch circuit conductors supplying an individual motor shall have a current carrying capacity of not less than 125% of the motor full load current rating. If the circuit supplies two or more motors, computation of the conductor size should be made in the same manner as that given for feeder conductors.

(Note D) ***Motor Branch Circuit Overcurrent Protection.***—The motor branch circuit overcurrent device shall be capable of carrying the starting current of the motor. The Code specifies the maximum permissible size as a percentage of the full load circuit of the motor, depending upon its type, starting method and locked rotor current. These maximum values are given in table 20, pages 540-10 to 540-13.

Note E) *Disconnecting Means.*—The disconnecting means for each motor and controller shall consist of an indicating type disconnecting switch or circuit breaker, having a current carrying capacity of not less than 115% of the motor name plate current rating, and arranged so as to disconnect the ungrounded conductors.

For motors less than 50 *h.p.* the switch is generally rated in horsepower whereas motors rated at more than 50 *h.p.* have their disconnecting means rated also in amperes.

The disconnecting means serving a group of motors may be a single disconnecting switch when driving a single machine or piece of apparatus, or protected by one set of overcurrent devices, or in a single room within sight of the disconnecting means.

(*Note F*) *Motor Running Overcurrent Device.*—Continuous duty motors rated at more than one horsepower shall have a running overcurrent protection not greater than 125% of the full load rating of the motor. The motor running overcurrent device may be shunted out during starting period of the motor, provided the device by which the overcurrent protection is shunted out or cut out cannot be left in the starting position, and the motor shall be considered as protected during the starting period if fuses or time delay circuit breakers rated or set at not over 400% of the full load current of the motor, are so located in the circuit as to be operative during the starting period of the motor.

(*Note G*) *Motor Controller.*—A controller shall be provided for each motor or group of motors as in paragraph (E) above.

Each controller shall normally be in sight of the motor and shall be capable of starting and stopping the motor which it controls, and for an alternating current motor shall be capable of interrupting the stalled rotor current of the motor. Controllers generally are rated in horsepower.

(*Note H*) *Secondary Circuit Conductors.*—Conductors connecting the secondary of a wound rotor alternating current motor to its controller shall have a current carrying capacity which is not less than 125% of the full load secondary current of the motor if for continuous duty. The capacity of the conductors between controller and resistor shall not be less than 110% of full load secondary current for continuous duty motors.

Motor Circuits

The following general groupings or types of circuit layouts should be followed in wiring of motors, in order that the installation will conform with the requirements of the *Code*.

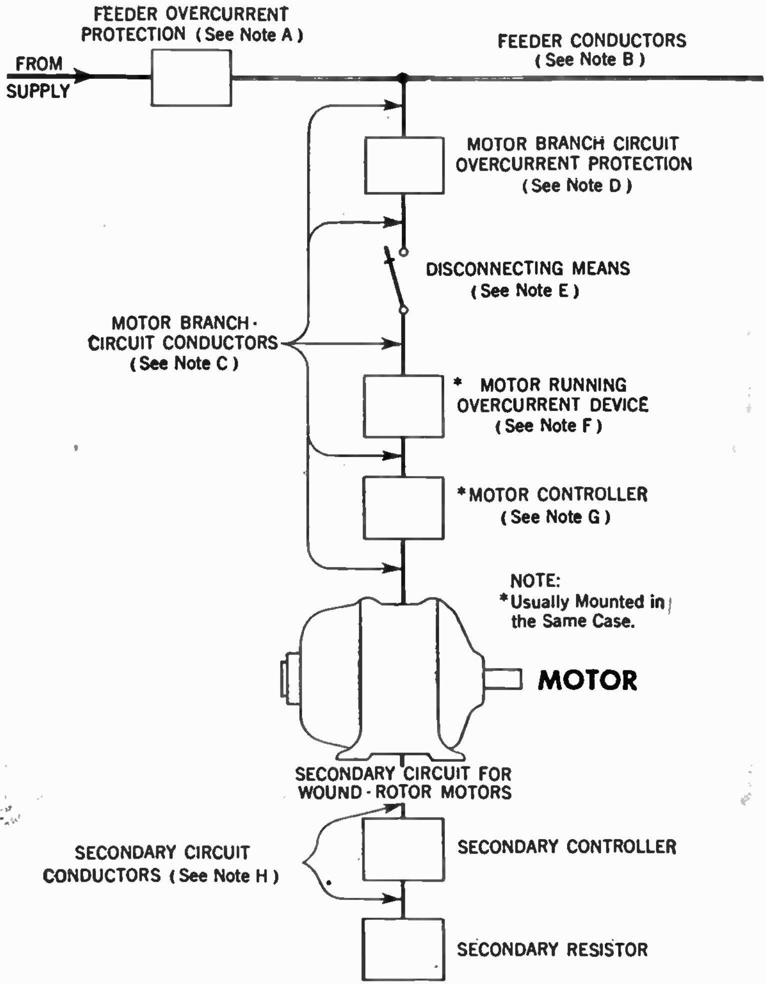


FIG. 7,360.—Schematic diagram showing typical motor feeder and branch circuits. For notes see text.

In general there are five different types of motor wiring as follows:

Type 1.—A separate branch circuit to each motor from a power panel-board or distribution center as illustrated in fig. 7,361.

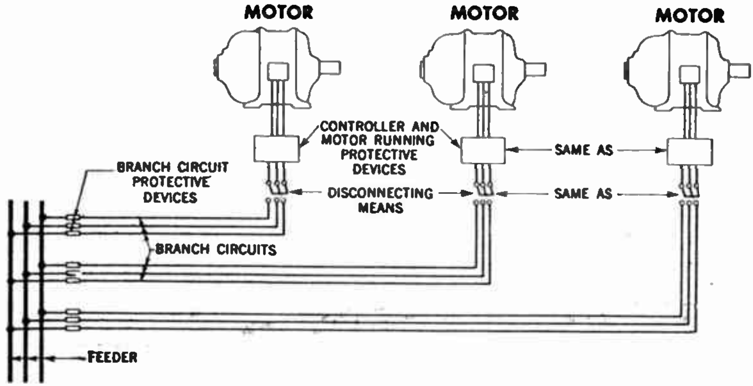


FIG. 7,361.—Showing general layout for *type 1* wiring. A wiring layout of this type is very common and may be used for almost any condition.

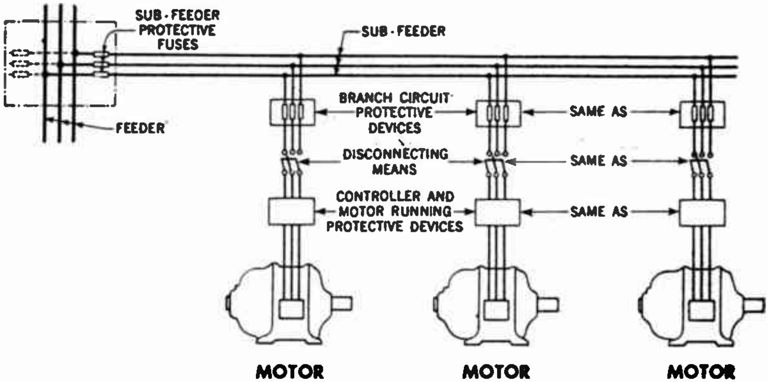


FIG. 7,362.—General layout for *type 2* wiring. A wiring layout of this type is used chiefly in industrial plants where a large number of motors are used to drive individual machines.

Type 2.—A feeder or subfeeder may supply all motors with branch circuits tapped to the subfeeder at convenient points as illustrated in fig. 7,362. This wiring method is similar to that shown in fig. 7,361, except that the branch circuit overcurrent protective devices are mounted individually at the points where taps are made to the subfeeder instead of at the branch circuit distribution center.

Type 3.—A feeder or subfeeder may supply all motors with branch circuits tapped to the subfeeder at convenient points as illustrated in fig. 7,363. This wiring method is similar to that shown in fig. 7,362, except

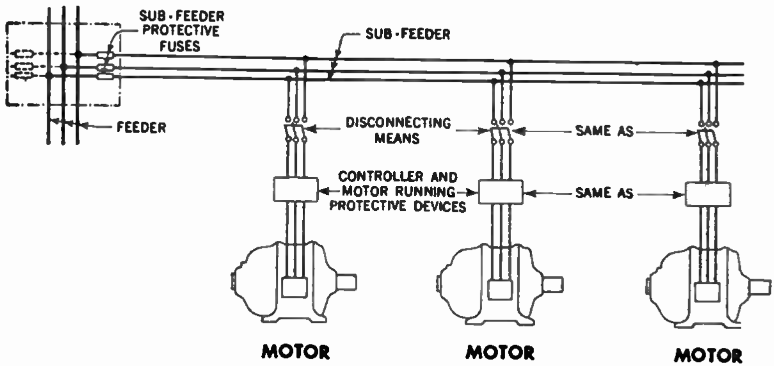


FIG. 7,363.—Showing layout for *type 3* wiring.

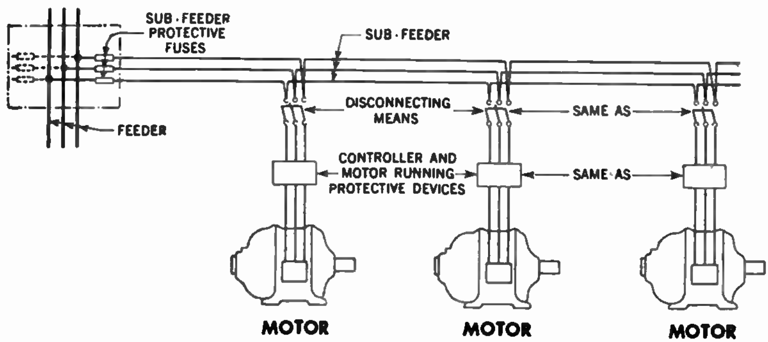


FIG. 7,364.—Layout for *type 4* wiring. This wiring method differs from that shown in fig. 7,363, mainly in that a subfeeder is connected directly to the disconnecting means to each motor. A wiring scheme of this type will show a saving in cost over either of the foregoing wiring layouts, if the subfeeder can be brought directly to each controller.

that no overcurrent devices are provided to protect the subfeeder taps. In this case the motor branch circuits are considered as originating at the controller.

Type 4.—A feeder or subfeeder may be carried directly to the disconnecting means or controller for each motor as illustrated in fig. 7,364. In all other respects this wiring method is similar to that shown in fig. 7,363.

Type 5.—A group of small motors each having a full load rated current not exceeding 6-*amp*. each may be used on a motor branch circuit protected at not more than 15-*amp*. at 125 volts or 10-*amp*. at 250 volts, or with lamps and other appliances on the 15, 20 and 25-*amp*. branch circuits, as illustrated in figs. 7,365 and 7,366. Motors connected in these circuits are required to be provided with running overcurrent protective devices in special cases.

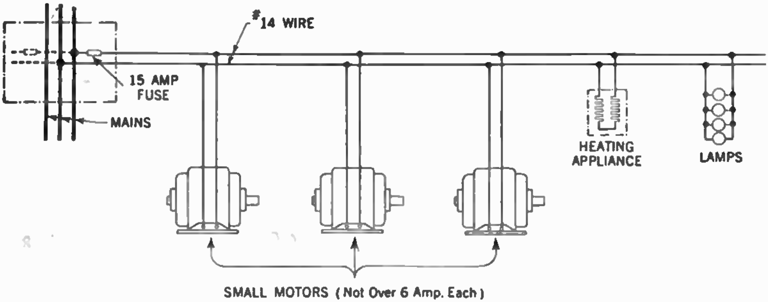


FIG. 7,365.—Layout for *type 5* wiring. In this wiring scheme a 15-*amp*. branch circuit is supplying small motors and other loads.

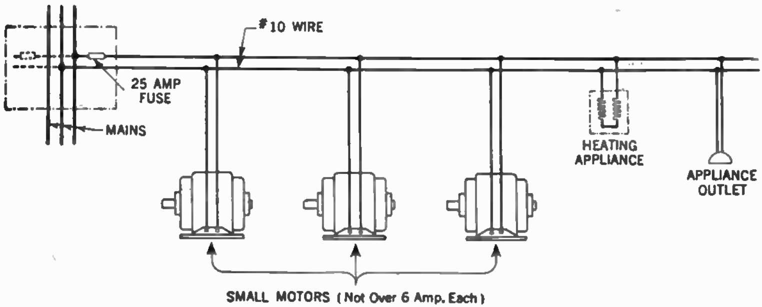


FIG. 7,366.—Layout for *type 5* wiring. Here a 25-*amp*. branch circuit supplies small motors and other loads.

Branch Circuits.—By definition a branch circuit is that portion of the wiring system extending beyond the final overcurrent device protecting the circuit. The essential parts of a typical motor branch circuit as previously described consists of: (a) *the branch circuit conductors*; (b) *the branch circuit overcurrent devices*, and (e) *the motor running protective devices.* These parts of a motor circuit are shown in fig. 7,367.

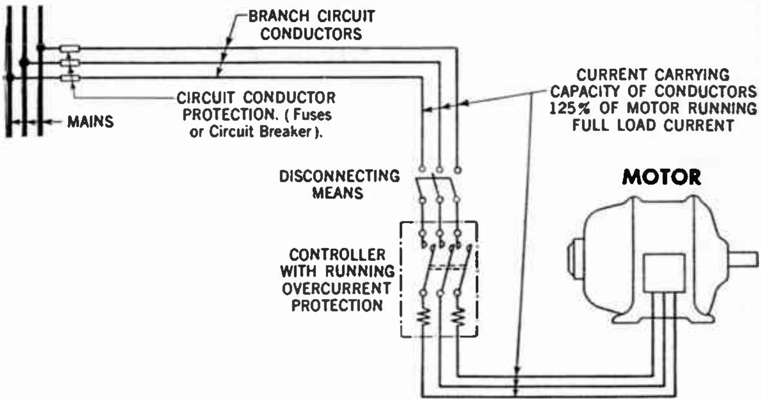


FIG. 7,367.—Showing essential component parts of typical branch circuit motor wiring.

Size of Conductors for Motor Circuits

Branch circuit conductors supplying an individual motor shall have a current carrying capacity of not less than 125 percent of the motor full load current rating; provided that conductors for motors used for short time, intermittent, periodic or varying duty, may have a current capacity of not less than the percentage of the motor name plate current rating as shown in the following table, unless the authority enforcing the *Code* grants special permission for conductors of smaller size.

As noted in the table, the necessary carrying capacity of conductors depend upon the class of service and upon the rating of the motor. A motor having a 15-minute rating for example, is designed to deliver its rated horsepower during periods of approximately 15 minutes each, with cooling intervals between the operating period. For long runs, it may be necessary in order to avoid excessive voltage drop, to use conductors of larger sizes than that found by reference to tables.

Classification of Service	Percentages of Name Plate Current Rating			
	5 Minute Rating	15 Minute Rating	30 & 60 Minute Rating	Continuous Rating
Short-Time Duty Operating valves, raising or lowering rolls	110	120	150	...
Intermittent Duty Freight and passenger elevators, shop cranes, tool heads, pumps, drawbridges, turntables, etc.	85	85	90	140
Periodic Duty Hoists, rolls, ore and coal-handling machines	85	90	95	140
Varying Duty	110	120	150	200
	or lower at the discretion of the authorities enforcing the regulations.			

Wound Rotor Motors.—Conductors connecting the secondary of a wound rotor *a.c.* motor to its controller shall have a current carrying capacity, which is not less than 125 per cent of the full load secondary current of the motor if for continuous duty. For other than continuous duty, these conductors shall have a carrying capacity in per cent of full load secondary current not less than that specified in the foregoing table.

Where the secondary resistor is separate from the controller, the carrying capacity of the conductors between controller and resistor shall be not less than that given in the following table.

Resistor Duty Classification	Carrying capacity of wire in per cent of full load secondary current
Light starting duty	35
Heavy starting duty	45
Extra heavy starting duty	55
Light intermittent duty	65
Medium intermittent duty	75
Heavy intermittent duty	85
Continuous duty	110

The full load secondary current of wound rotor type motors shall be obtained from the manufacturers name plate.

Starters or combined starters and speed regulating devices as used in the secondary circuits of wound rotor induction motors usually consist of a dial type or drum controller with accompanying resistor units which in the case of the dial type controller is a part of the controller itself, whereas drum controllers have separately mounted resistors which are connected to the controller proper according to the manufacturers diagram.

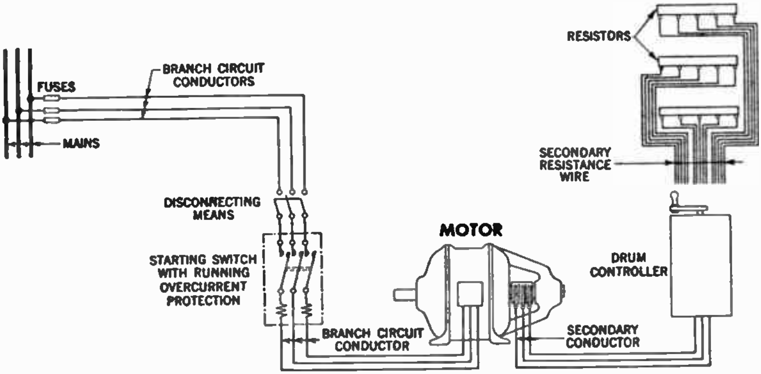


FIG. 7,368.—Wiring diagram of typical wound rotor motor with drum controller. Speed regulation drum controllers may be of either the motor reversing or non-reversing type. Secondary resistors for wound rotor motors are as a rule designed for star connection.

Conductors Supplying Two or More Motors.—Conductors supplying two or more motors shall have a current carrying capacity of not less than 125% of the full load current rating of the highest rated motor in the group, plus the sum of the full load current ratings of the remainder of the motors in the group. (See example, page 540-3.)

Motor Overcurrent Protection

The following provisions specify overcurrent devices intended to protect the motors, the motor control apparatus and the branch circuit conductors against excessive heating due to motor overloads. *Continuous duty motors* shall be protected against overload as follows:

Motors of More than One Horsepower.—For a motor rated more than one horsepower, this protection shall be secured by the use of one of the following means:

1. A separate overcurrent device which is responsive to motor current. This device shall be rated or set at not more than 125% of the motor full load current rating for an open type motor marked to have a temperature rise not over 40C, and at not more than 115% for all other types of motors.

2. A protective device integral with the motor which is responsive to motor current or to both motor current and temperature. This device must be approved for use with the motor which it protects on the basis that it will interrupt current to the motor when the motor is operated in an ambient temperature of 40C and with overcurrent of the percentage values given in paragraph 1. If the motor current interrupting device is separate from the motor and its control circuit is operated by a protective device integral with the motor, it must be so arranged that the opening of the control circuit will result in interruption of current to the motor.

Motors of Less than One Horsepower.—Motors of one horsepower or less which are manually started, and which are within sight from the starter location, shall be considered as protected against overcurrent by the overcurrent device protecting the conductors of the branch circuit. This branch circuit overcurrent device shall not be larger than that specified in table 20, page 540-10, except that any such motor may be used at 125 volts or less on a branch circuit protected at 20 *amp*. Any such motor which is out of sight* from the starter location shall be protected as specified in the following paragraphs for automatically started motors.

Any motor of *one horsepower or less* which is started *automatically* shall be protected against overcurrent by use of one of the following means:

1. A separate overcurrent device which is responsive to motor current. This device shall be rated or set at not more than 125% of the motor full load current rating for an open type motor marked to have a temperature rise not over 40C, and at not more than 115% for all other types of motors.

*NOTE.—A distance of more than 50 feet is considered equivalent to being out of sight.

2. A protective device integral with the motor which is responsive to motor current or to both motor current and temperature. This device must be approved for use with the motor which it protects on the basis that it will prevent dangerous overheating of the motor due to overload or failure to start. If the motor current interrupting device is separate from the motor and its control circuit is operated by a protective device integral with the motor, it must be so arranged that the opening of the control circuit will result in interruption of current to the motor,

3. If part of an approved assembly which does not normally subject the motor to overloads and which is also equipped with other safety controls (such as the safety combustion controls of a domestic oil burner) which protect the motor against damage due to stalled rotor current. Where such protective equipment is used it shall be indicated on the name plate of the assembly where it will be visible after installation.

4. If the impedance of the motor windings is sufficient to prevent overheating due to failure to start, the motor may be protected as previously stated, for motors of less than one horsepower manually started.

Many alternating current motors of less than 1/20-*h.p.*, such as clock motors, series motors, etc. and also some larger motors such as torque motors, come within this classification. It does not include split phase motors having automatic switches to disconnect the starting windings.

The secondary circuits of wound rotor (slip ring) alternating current motors, including conductors, controllers, resistors, etc., shall be considered as protected against overcurrent by the motor running overcurrent device.

Intermittent and Similar Duty Motors.—A motor used for a condition of service which is inherently short time, intermittent, periodic or varying duty is considered as protected against overcurrent by the branch circuit overcurrent device, provided the overcurrent protection does not exceed that specified in tables 26 and 27 pages 540-16 and 540-17.

Any motor is considered to be for continuous duty unless the nature of the apparatus which it drives is such that the motor cannot operate continuously with load under any conditions of use.

Size of Protective Devices.—Where the values specified for motor running overcurrent protection do not correspond to the standard sizes or ratings of fuses, non-adjustable circuit breakers, thermal cutouts, thermal relays, the heating elements of thermal trip motor switches, or possible settings of adjustable circuit breakers adequate to carry the load, the next higher size, rating or setting may be used, but not exceeding 140 per cent of the motor full load current rating. If not shunted during the starting period of the motor, the protective device shall have sufficient time delay to permit the motor to start and accelerate its load.

Shunting During Starting Period.—If the motor is manually started, the running overcurrent protection may be shunted or cut out of circuit during the starting period of the motor (as shown in fig. 7,369), provided the device by which the overcurrent protection is shunted or cut out cannot be left in the starting position, and the motor shall be considered as protected against overcurrent during the starting period if fuses or time delay circuit breakers rated or set at not over 400 per cent of the full load current of the motor, are so located in the circuit as to be operative during the starting period of the motor. The motor running overcurrent protection shall not be shunted or cut out during the starting period if the motor is automatically started.

Fuses.—If fuses are used for motor running protection a fuse shall be inserted in each ungrounded conductor.

Devices Other Than Fuses.—If devices other than fuses are used for motor running protection, the following table shall govern the minimum allowable number and location of overcurrent units such as trip coils, relays or thermal cutouts.

Kind of Motor	Supply System	Number and location of overcurrent units, such as trip coils, relays or thermal cut-outs
1-phase *a.c.* or *d.c.*	2-wire, 1-phase *a.c.* or *d.c.*, ungrounded	1 in either conductor
1-phase *a.c.* or *d.c.*	2-wire, 1-phase *a.c.* or *d.c.*, one conductor grounded	1 in ungrounded conductor
1-phase *a.c.* or *d.c.*	3-wire, 1-phase *a.c.* or *d.c.*, grounded-neutral	1 in either ungrounded conductor
2-phase *a.c.*	3-wire, 2-phase *a.c.*, ungrounded	2, one in each phase
2-phase *a.c.*	3-wire, 2-phase *a.c.*, one conductor grounded	2 in ungrounded conductors
2-phase *a.c.*	4-wire, 2-phase *a.c.*, grounded or ungrounded	2, one per phase in ungrounded conductors
2-phase *a.c.*	5-wire, 2-phase *a.c.*, grounded neutral or ungrounded	2, one per phase in any ungrounded phase wire
3-phase *a.c.*	3-wire, 3-phase *a.c.*, ungrounded	2 in any 2 conductors
3-phase *a.c.*	3-wire, 3-phase *a.c.*, one conductor grounded	2 in ungrounded conductors
3-phase *a.c.*	3-wire, 3-phase *a.c.*, grounded-neutral	2 in any 2 conductors
3-phase *a.c.*	4-wire, 3-phase *a.c.*, grounded-neutral or ungrounded	2 in any 2 conductors, except the neutral

Number of Conductors Disconnected by Overcurrent Device.—Motor running protective overcurrent devices, other than fuses or thermal cutouts shall simultaneously disconnect a sufficient number of ungrounded conductors, to interrupt current flow to the motor.

It is recommended that all ungrounded conductors be opened if devices accomplishing this are available.

Motor Controller as Running Protection.—A motor controller may also serve as the running overcurrent device if the number of overcurrent units complies with the table shown on page 525 and if these overcurrent units are operative in both the starting and running position in the case of a direct current motor and in the running position in the case of an alternating current motor.

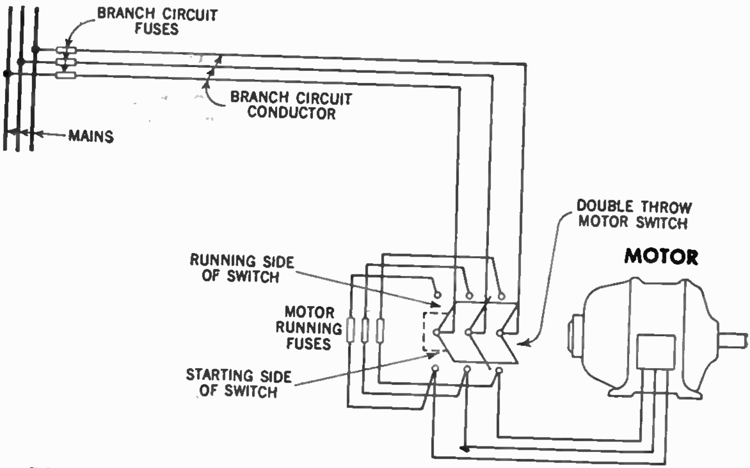


FIG. 7,369.—Wiring diagram showing across the line method of motor starting. The double throw switch is thrown in the lower position at starting, thus shunting out the running fuses. After the motor has attained its normal running speed the switch is thrown in the upper position. The switch must be so constructed that it cannot be left in the starting (or lower) position.

Thermal Cutouts and Relays.—Thermal cutouts, thermal relays and other devices for motor running protection which are not capable of opening short circuits, shall be protected by fuses or circuit breakers of not over four times the rating of the motor for which they are designed, unless approved for group installation, and marked to indicate the maximum size of fuse by which they must be protected.

Motor running overcurrent devices other than fuses shall have a rating of at least 115 per cent of the full load current rating of the motor.

Automatic Restarting.—A motor running protective device which can restart a motor automatically after overcurrent tripping shall not be nstalled unless approved for use with the motor which it protects. A motor which can restart automatically after shut-down shall not be installed so that its automatic restarting can result in injury to persons.

Motor Branch Circuit Overcurrent Protection

The following provisions specify overcurrent devices intended to protect the motor branch circuit conductors, the motor control apparatus, and the motors against overcurrent due to short circuits or grounds.

Ratings or Setting for Individual Motors.—The motor branch circuit overcurrent device shall be capable of carrying the starting current of the motor. Overcurrent protection shall be considered as being obtained when this overcurrent device has a rating or setting not exceeding the values given in tables 26 or 27 pages 540-16 and 540-17 provided that where the overcurrent protection specified in the tables are not sufficient for the starting current of the motor, it may be increased but shall in no case exceed 400 per cent of the motor full load current. Fuse ratings calculated on this basis are given in columns 7, 8, 9 and 10, table 20, page 540-10 to 540-13.

Several Motors on One Branch Circuit.—Two or more motors may be connected to the same branch circuit under the following conditions:

a. Two or more motors each not exceeding 1 horsepower in rating and each having a full load rated current not exceeding 6 amperes, may be used on a branch circuit protected at not more than 20 amperes at 125 volts or less, or 15 amperes at 600 volts or less. Individual running overcurrent protection is unnecessary for such motors unless required by the provisions of pages 522 and 523.

b. Two or more motors of any ratings each having individual running overcurrent protection, may be connected to one branch circuit provided all of the following conditions are complied with:

1. Each motor running overcurrent device must be approved for group installation.

2. Each motor controller device must be approved for group installation.

3. The branch circuit must be protected by fuses having a rating equal to that specified on page 527 for the largest motor connected to the branch circuit plus an amount equal to the sum of the full load current ratings of all other motors connected to the circuit.

4. The branch circuit fuses must not be larger than allowed by specifications covering the thermal cutout or relay protecting the smallest motor of the group.

5. The conductors of any tap supplying a single motor need not have individual branch circuit protection, provided they comply with either of the following: (1) No conductor to the motor shall have a current carrying capacity less than that of the branch circuit conductors, or (2) no conductor to the motor shall have a current carrying capacity less than one third that of the branch circuit conductors, with a minimum in accordance with table on page 520, the conductors to the motor running protective device being not more than 25 feet long and being protected from mechanical injury.

Combined Overcurrent Protection.—Motor branch circuit overcurrent protection and motor running overcurrent protection may be combined in a single overcurrent device if the rating or sett ng of the device provides the running overcurrent protection specified on pages 522 and 523.

Fuses.—If fuses are used for motor branch circuit overcurrent protection a fuse shall be placed in each ungrounded conductor.

Capacity of Fuseholder.—If fuses are used for motor branch circuit overcurrent protection, the fuseholders shall not be of a smaller size than required to accommodate the fuses specified by table 20, page 540-10, except that where the authority enforcing this code is satisfied that the conditions of maintenance and supervision provide that appropriate fuses for the starting characteristics of the motor will be continually available, fuseholders of smaller size than specified by table 20, may be used.

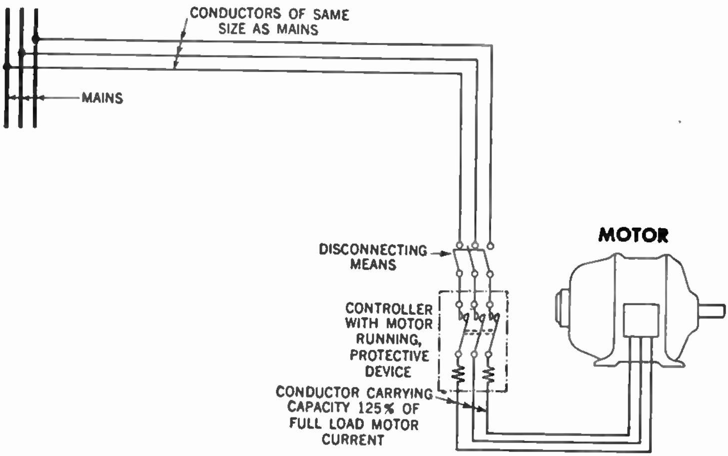


FIG. 7,370.—Motor wiring diagram where the branch circuit conductors are of the same size as the mains. In this case branch circuit protective devices may be omitted.

Rating of Circuit Breaker.—Circuit breakers for motor branch circuit protection shall have a continuous current rating of not less than 115 per cent of the full load current rating of the motors.

Feeder Taps in Inaccessible Location.—If the location of a tap to the feeder conductors is not accessible, the motor branch circuit overcurrent device may be placed where it will be accessible, provided the conductors between the tap and the overcurrent device have the same overcurrent capacity as the feeder; or provided they have a current carrying capacity of at least 1/3 of the feeder and are not more than 25 feet long and are protected from mechanical injury.

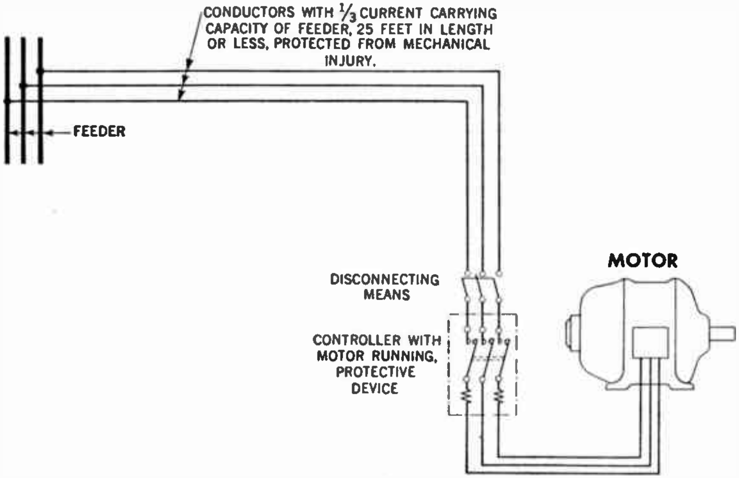


FIG. 7,371.—Wiring diagram of motor circuit where the conductors to motor controller have one-third the current carrying capacity of the feeder. In this case branch circuit protective devices may be omitted.

Selection or Setting of Protective Device.—If the values for branch circuit protective devices given in table 26, page 540-16, or table 27, page 540-17, do not correspond to the standard sizes or ratings of fuses, non-adjustable circuit breakers, or thermal devices, or possible settings of adjustable circuit breakers adequate to carry the load, the next higher size, rating or setting may be used.

A distance of more than 50 feet is considered equivalent to being out of sight.

Motor Feeder Overcurrent Protection

The following provision specify overcurrent devices intended to protect feeder conductors supplying motors against overcurrent due to short circuits or grounds.

Rating or Setting; Motor Load.—A feeder which supplies motors shall be provided with overcurrent protection which shall not be greater than the largest rating or setting of the branch circuit protective device, for any motor of the group, plus the sum of the full load currents of the other motors of the group.

If two or more motors of equal horsepower rating are the largest in the group, one of these motors shall be considered the largest for the foregoing calculations.

If two or more motors of a group must be started simultaneously, it may be necessary to install larger feeder conductors and correspondingly larger ratings or settings of feeder overcurrent protection.

Ratings or Settings; Power and Light Loads.—If a feeder supplies a motor load and in addition a lighting or a lighting and appliance load, the feeder overcurrent protective device may have a rating or setting sufficient to carry the lighting or the lighting and appliance load as determined in accordance with tables 26 and 27, pages 540-16 and 540-17.

*Motor Controllers**

The following provisions are intended to require suitable controllers for all motors.

*NOTE.—As used in this chapter the term *controller* includes any switch or device which is normally used to start and stop the motor.

Suitability.—Each controller shall be capable of starting and stopping the motor which it controls and for an alternating current motor shall be capable of interrupting the stalled rotor current of the motor.

Rating.—The controller shall have a horsepower rating, which shall not be lower than the horsepower rating of the motor except as follows:

a. For a stationary motor rated at 1/8 horsepower or less that is normally left running and is so constructed that it cannot be damaged by overload or failure to start, such as clock motors and the like, the branch circuit overcurrent device may serve as controller.

b. For a stationary motor rated at 2 horsepower or less, and 300 volts or less, the controller may be a general use switch having an ampere rating at least twice the full load current rating of the motor.

c. For a portable motor rated at 1/4 horsepower or less, the controller may be an attachment plug and receptacle.

d. A branch circuit type circuit breaker, rated in amperes only, may be used as a controller. When this circuit breaker is also used for overcurrent protection, it shall conform to the appropriate provision of this chapter governing overcurrent protection.

Opening of Conductors.—Except when the controller serves also as a disconnecting switch, the controller need not open all conductors to the motors.

In grounded conductors one pole of the controller may be placed in a permanently grounded conductor provided the controller is so designed that the pole in the grounded conductor cannot be opened without simultaneously opening all conductors of the circuit.

In Sight of Motor.—A motor and its driven machinery shall be within sight of the point from which the motor is controlled, unless one of the following conditions is complied with:

a. The controller and its disconnecting means is capable of being locked in the open position.

b. A normally operable switch, which will prevent the starting of the motor, is placed within sight of the motor location. This switch may be placed in the remote control circuit of a remote control type of switch.

c. Special permission is given by the authority enforcing the *National Electrical Code.*

Number of Motors Served by Each Controller.—Each motor shall be provided with an individual controller, except that for motors of 600 volts or less a single controller may serve as a group of motors under any one of the following conditions:

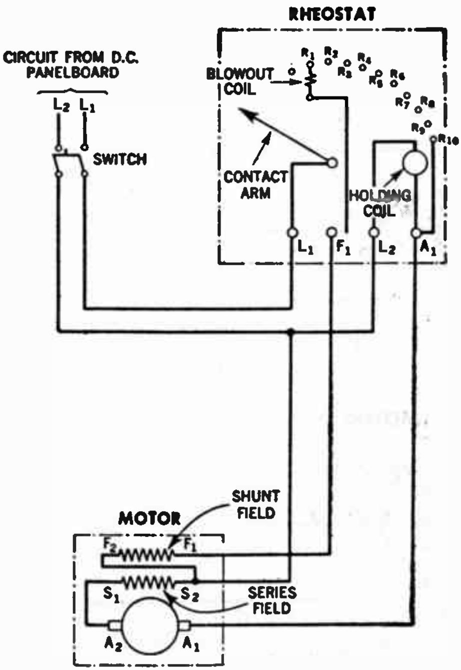


Fig. 7,372.—Wiring diagram of starting rheostat for compound wound direct current motor. For shunt wound motors the series field coil is omitted.

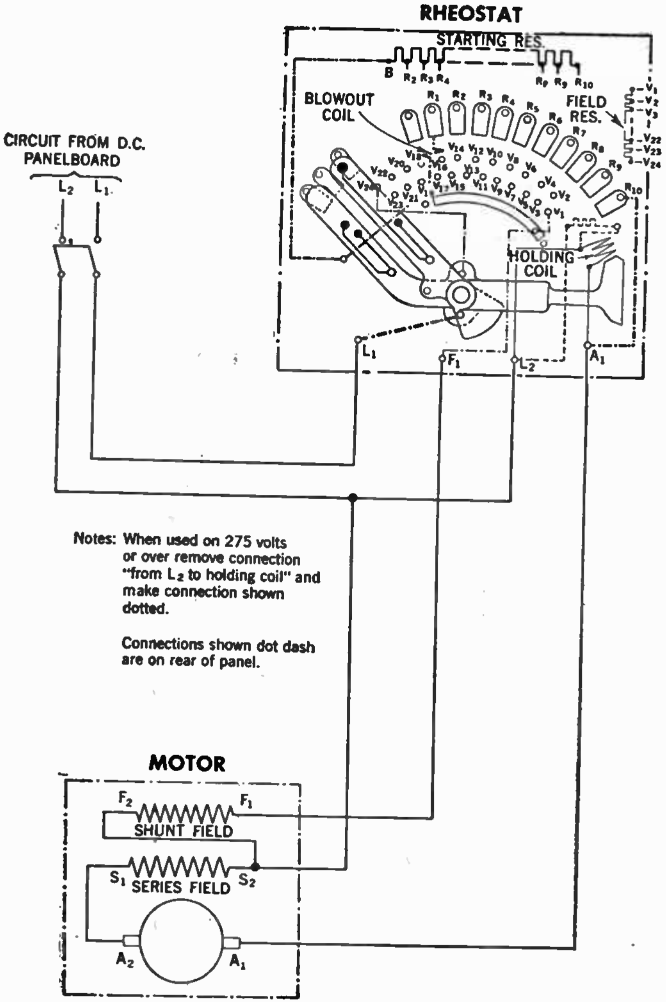


FIG. 7,373.—Typical wiring diagram for *starting and speed regulating duty by field control only.* Diagram is for direct current compound wound motors. For shunt wound motors the series field coil is omitted.

a. If a number of motors drive several parts of a single machine or piece of apparatus such as metal or woodworking machines, cranes, hoists and similar apparatus.

b. If a group of motors are under the protection of one overcurrent device.

c. If a group of motors is located in a single room within sight of the controller.

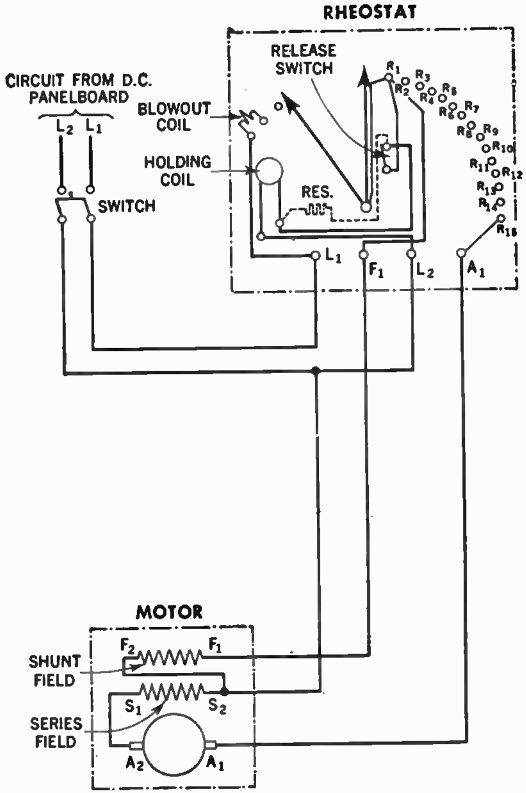


FIG. 7,374.—Typical wiring diagram for *starting and speed regulation*; regulating duty 50% speed reduction by armature control. Diagram is for direct current compound wound motors. For shunt wound motors the series field is omitted.

Adjustable Speed Motors.—Adjustable speed motors, if controlled by means of field regulations, shall be so equipped and connected that they cannot be started under weakened field, unless the motor is designed for such starting.

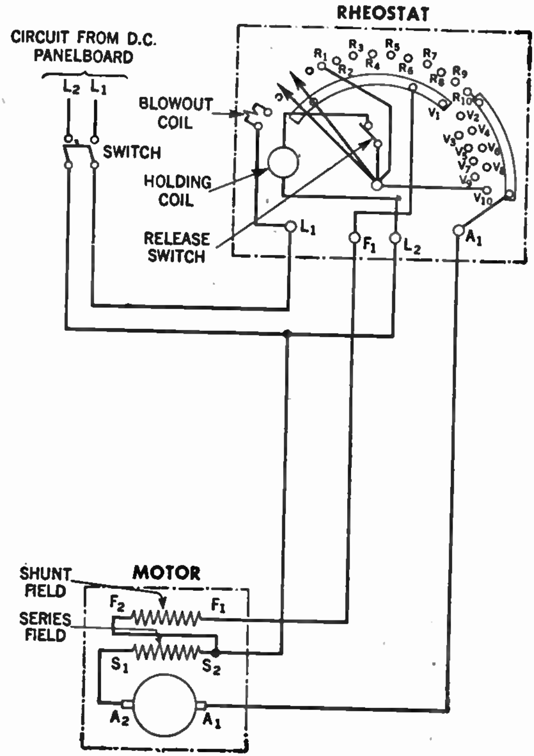


FIG. 7,375.—Typical wiring diagram for starting and speed regulation; regulating duty 50% speed reduction by armature control and 25% speed increase by field control. Diagram is for direct current compound wound motors. For shunt motors the series field is omitted.

Speed Limitation.—Machines of the following types shall be provided with speed limiting devices, unless the inherent characteristics of the machines, the system, or the load and the mechanical connections thereto, are such as to safely limit the speed, or unless the machine is always under manual control of a qualified operator.

a. Separately excited direct current motors.

b. Series wound motors.

c. Motor-generators and converters which can be driven at excessive speed from the direct current such as by a reversal of current or decrease in load.

Fuseholder Rating.—The rating of a combination fuseholder and switch used as a motor controller shall be such that the fuse holder will accommodate the size of the fuse specified in table 20, page 540-10 for motor running protection.

Disconnecting Means

The following provisions specify disconnecting means for motors and controllers capable of disconnecting them from the circuit. (See diagram fig. 7,360.)

Type.—The disconnecting means shall be a motor circuit switch, rated in horsepower or a circuit breaker except as permitted in the following paragraphs. Every switch in the motor branch circuit within sight of the controller location shall comply with these requirements. A distance of more than 50 feet is considered equivalent to being out of sight.

a. For stationary motors of ⅛ horsepower or less the branch circuit overcurrent device may serve as a disconnecting means.

b. For stationary motors rated at 2 horsepower or less and 300 volts or less, the disconnecting means may be a general use switch having an ampere rating at least twice the full load current rating of the motor.

c. For stationary motors rated at more than 50 horsepower, the disconnecting means may be a motor circuit switch also rated in amperes, a general use switch, or an isolating switch.

It is recommended that isolating switches for motors exceeding 50 horsepower, not capable of interrupting stalled rotor current be plainly marked *Do not open under load.*

d. For portable motors an attachment plug and receptacle may serve as the disconnecting means.

Carrying Capacity.—The disconnecting means shall have a carrying capacity of at least 115 per cent of the name plate current rating of the motor.

Grounded Conductors.—One pole of the disconnecting means may be placed in a permanently grounded conductor if the disconnecting means is so designed that the pole in the grounded conductor cannot be opened without simultaneously disconnecting all conductors of the circuit.

To Be Indicating.—The disconnecting means shall plainly indicate whether it is in the open or closed position.

To Disconnect Both Motor and Controller.—The disconnecting means shall disconnect both the motor and controller from all ungrounded supply conductors. The disconnecting means shall be in the same enclosure with the controller.

Switch or Circuit Breaker as Both Controller and Disconnecting Means.—A switch or circuit breaker complying with the foregoing provisions may serve as both controller and disconnecting means if it opens all ungrounded conductors to the motor, is protected by an overcurrent device (which may be a set of fuses) which opens all ungrounded conductors to the switch or circuit breaker, and is one of the following types:

a. An air brake switch, operable directly by applying the hand to a lever or handle.

b. A circuit breaker operable directly by applying the hand to a lever or handle.

c. An oil switch used on a circuit whose rating does not exceed 600 volts or 100 amperes, or on a circuit exceeding this capacity if under expert supervision and by special permission.

The oil switch or circuit breaker specified above may be both power and manually operable. If power operable, provision should be made to lock it in the open position.

The overcurrent device protecting the controller may be a part of the controller assembly or may be separate.

A compensator type of controller is not included above and will require a separate disconnecting means.

Service Switch as Disconnecting Means.—If an installation consist of a single motor, the service switch may serve as the disconnecting means, provided it conforms with the foregoing requirements of this chapter, and is within sight of the controller.

In Sight of Controller.—The disconnecting means shall be located within sight of the controller or be arranged to be locked in open position.

Motor Served by a Single Disconnecting Means.—Each motor shall be provided with an individual disconnecting means, except that for motors of 600 volts or less a single disconnecting means may serve a group of motors under any one of the following conditions. The disconnecting means serving a group of motors shall have a rating not less than is required by the foregoing provisions for a single motor whose rating equals the sum of the horsepowers or currents of all the motors of the group.

a. If a number of motors drive several parts of a single machine or a piece of apparatus such as metal or woodworking machines, cranes and hoists.

b. If a group of motors is under protection of one set of overcurrent devices as permitted by paragraph *a*, page 528.

c. If a group of motors is in a single room within sight of the disconnecting means.

Readily Accessible.—The disconnecting means shall be readily accessible.

Requirements for Voltages Over 600 Volts

The following provisions recognize the additional hazard due to the use of high voltage. They are in addition to the amendatory of the provisions of this chapter.

Voltages of Over 7,500 Volts.—Motors operating at more than 7,500 volts between conductors shall be installed in fire resistive motor rooms.

Motor Overcurrent Protection.—Running overcurrent protection for a motor of over 600 volts shall consist of either a circuit breaker, or of overcurrent units, integral with the controller which shall simultaneously open all ungrounded conductors to the motor. The overcurrent device shall have a setting as specified elsewhere in this chapter for motor running protection.

Circuit Overcurrent Protection.—Each motor branch circuit and feeder of more than 600 volts shall be protected against overcurrent by one of the following means:

a. A circuit breaker of suitable rating so arranged that it can be serviced without hazard.

b. Fuses shall be of the oil filled or other suitable type. Fuses shall be used with suitable disconnecting means or they shall be of a type which can also be served as the disconnecting means. They shall be so arranged that they cannot be refused or replaced while they are energized.

Disconnecting Means.—The circuit breaker or the fuse as specified in the foregoing paragraph shall constitute the disconnecting means.

Protection of Live Parts; All Voltages

The following provisions specify that live parts shall be protected in a manner judged adequate to the hazard involved.

Where Required.—Exposed live parts of motors and controllers operating at 50 volts or more between terminals, except for stationary motors having commutators, collectors and brush rigging located inside of motor end brackets and not conductively connected to supply circuits operating at more than 150 volts to ground, shall be guarded against accidental contact by enclosure, or by location as follows:

a. By installation in a room or enclosure which is accessible only to qualified persons.

b. By installation of a suitable balcony, gallery or platform, so elevated or arranged as to exclude unqualified persons.

c. By elevation 8 feet or more above the floor.

d. So that it will be protected by a guard rail when the motor operates at 600 volts or less.

Guard for Attendants.—If the live parts of motors or controllers operating at more than 150 volts to ground are guarded against accidental contact only by location as specified in the foregoing paragraph, and if adjustment or other attendance may be necessary during the operation of the apparatus suitable insulating mats or platforms shall be provided so that the attendant cannot readily touch live parts unless standing on the mats or platforms. Where necessary steps and handrails should be installed on or about large machines to afford safe access to parts which must be examined or adjusted during the operation.

Grounding

The following provisions specify the grounding of motor and controller frames to prevent a potential above ground in the event of an accidental contact between live parts and frames. Insulation, isolation or guarding are suitable alternative for motors under certain conditions.

Stationary Motors.—The frames of stationary motors shall be grounded if any of the following conditions exist:

a. If supplied by means of metal-clad wiring.

b. If located in a wet place and not isolated or guarded.

c. If in a hazardous location.

d. If the motor operates with any terminal at more than 150 volts to ground. If the frame of the motor is not grounded it shall be permanently and effectively isolated from the ground.

Portable Motors.—The frames of portable motors which operate at 150 volts to ground shall be guarded or grounded.

It is recommended that the frames of motors which operate at less than 150 volts to ground be grounded if this can be readily accomplished.

Controllers.—Controller cases, except those attached to ungrounded portable equipment and except the lined covers of snap switches, shall be grounded regardless of voltage.

Method of Grounding.—Grounding where required shall be performed as prescribed by the *National Electrical Code*.

Grounding Through Terminal Housing.—If the wiring to fixed motors is in armored cable or metal raceways, junction boxes to house motor terminals shall be provided. These housings shall be of ample size to properly make connections, they shall be of substantial metal construction, and the armor of the cable or the metal raceway shall be connected to them in accordance with provisions of the *National Electrical Code*.

The foregoing junction box required may be separated from the motor not more than 6 feet, provided the leads to the motor are armored cable or armored cord, or are enclosed in flexible or rigid conduit or electrical metallic tubing not smaller than ⅜ inch electrical trade size, the armor or raceway being connected both to the motor and to the box.

Example.*—With reference to fig. 7,376, it is required to determine the conductor sizes, the motor running overcurrent protection, the branch circuit protection and the feeder protection for one 25 horsepower squirrel cage motor (full voltage starting) and two 30 horsepower wound rotor induction motors, all connected to a 440 volt, 3 phase 60 cycle system.*

Solution

Conductor Sizes.—The full load current of the 25 horsepower motor is 32 amperes (table 24, page 540-15). A full load current of 32 amperes requires a No. 8 type R, rubber covered conductor (column 2 table 20, page 540-11). The full load current of the 30 horsepower motor is 39 amperes (table 24, page 540-15). A full load current of 39 amperes requires a No. 6 type R rubber covered conductor (column 2, table 20, page 540-11).

The feeder conductor capacity will be 125 per cent of 39 plus 39 plus 32 or 120 amperes, see page 521. In accordance with table 1, page 540-6, this would require a No. 0 type R, rubber covered feeder.

Overcurrent Protection

Running.—The 25 horsepower motor, with a full load current of 32 amperes must have a running overcurrent protection of not

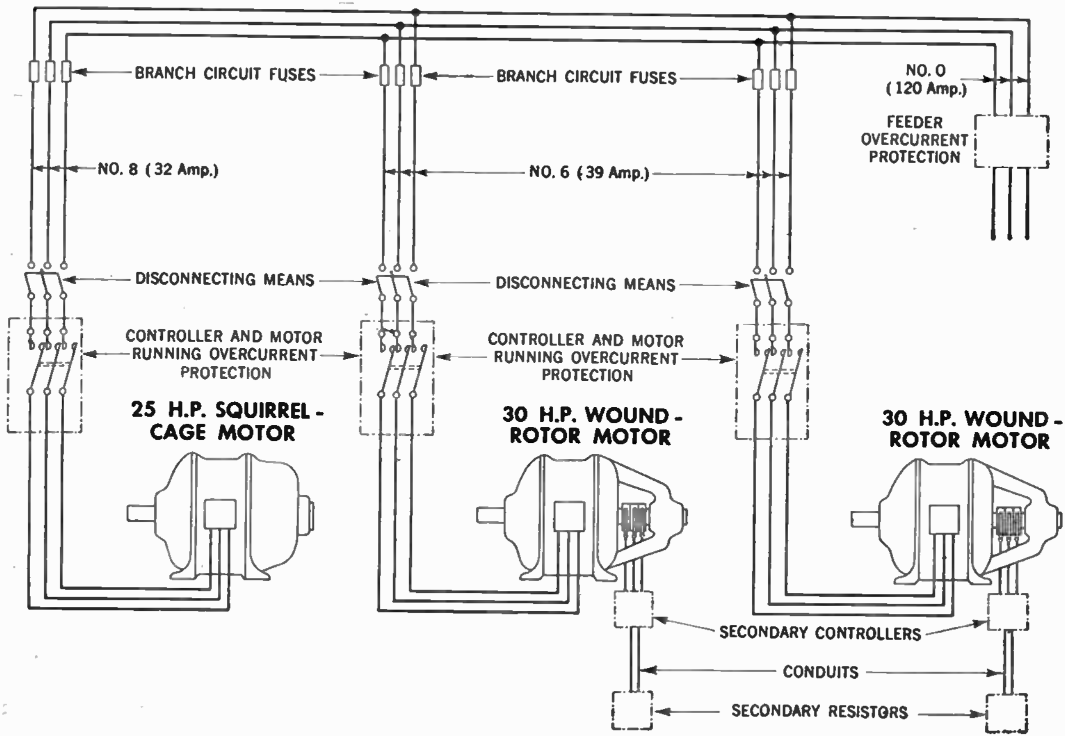


FIG. 7,376.—Wiring diagram showing individual branch circuits, feeder circuit and protective devices in a typical motor layout.

over 40 amperes (columns 5 and 6, table 20, page 540-11). The 30 horsepower must have a running overcurrent protection of not over 50 amperes (columns 5 and 6, table 20, page 540-11).

Branch Circuit.—The branch circuit of the 25 horsepower motor must have a branch circuit overcurrent protection of not over 100 amperes (column 7, table 20, page 540-11). The branch circuit of the 30 horsepower motors must have a branch circuit overcurrent protection of not over 60 amperes (column 10, table 20, page 540-11).

Feeder Circuit.—The rating of the branch circuit fuse for a 25 horsepower squirrel cage motor is 300 per cent of 32 amperes or 96 amperes (table 27, page 540-17); and for a 30 horsepower wound rotor motor is 150 per cent of 39 amperes or 59 amperes (table 27). The rating of a feeder fuse is therefore 96 plus 39 plus 39 or 174 amperes. Therefore a 175 ampere fuse is the maximum size which may be used (see page 531).

The setting of a motor branch circuit breaker for a 25 horsepower squirrel cage motor is 250 per cent of 32 amperes or 80 amperes (table 27), similarly for a 30 horsepower wound rotor motor the setting is 150 per cent of 39 amperes or 59 amperes. The maximum setting of a feeder circuit breaker is 80+39+39 or 158 amperes (see page 531).

TABLE 1—ALLOWABLE CURRENT-CARRYING CAPACITIES OF CONDUCTORS IN AMPERES

Not More Than Three Conductors in Raceway or Cable

(Based on Room Temperature of 30 C. 86 F.)

Size AWG MCM	Rubber Type R Type RW Type RU (14–6) / Thermoplastic Type T (14–4/0) Type TW (14–4/0)	Rubber Type RH	Paper / Thermoplastic Asbestos Type TA / Var-Cam Type V / Asbestos Var-Cam Type AVB	Asbestos Var-Cam Type AVA Type AVL	Impregnated Asbestos Type AI (14–8) Type AIA	Asbestos Type A (14–8) Type AA
14	15	15	25	30	30	30
12	20	20	30	35	40	40
10	30	30	40	45	50	55
8	40	45	50	60	65	70
6	55	65	70	80	85	95
4	70	85	90	105	115	120
3	80	100	105	120	130	145
2	95	115	120	135	145	165
1	110	130	140	160	170	190
0	125	150	155	190	200	225
00	145	175	185	215	230	250
000	165	200	210	245	265	285
0000	195	230	235	275	310	340
250	215	255	270	315	335	...
300	240	285	300	345	380	...
350	260	310	325	390	420	...
400	280	335	360	420	450	...
500	320	380	405	470	500	...
600	355	420	455	525	545	...
700	385	460	490	560	600	...
750	400	475	500	580	620	...
800	410	490	515	600	640	...
900	435	520	555	...	...	...
1,000	455	545	585	680	730	...
1,250	495	590	645	...	...	...
1,500	520	625	700	785	...	...
1,750	545	650	735	...	...	...
2 000	560	665	775	840	...	...

CORRECTION FACTOR FOR ROOM TEMPERATURES OVER 30 C. 86 F.

C. F.						
40 104	.82	.88	.90	.94	.95	...
45 113	.71	.82	.85	.90	.92	...
50 122	.58	.75	.80	.87	.89	...
55 131	.41	.67	.74	.83	.86	...
60 140	...	.58	.67	.79	.83	.91
70 158	...	.35	.52	.71	.76	.87
75 167	...	...	.43	.66	.72	.86
80 176	...	...	.30	.61	.69	.84
90 194	...	...	...	.50	.61	.80
100 212	...	...	...	...	.51	.77
120 248	...	...	...	...	...	.69
140 284	...	...	...	...	...	.59

See Notes Following Tables 1 and 2

TABLE 2—ALLOWABLE CURRENT-CARRYING CAPACITIES OF CONDUCTORS IN AMPERES

Single Conductor in Free Air

(Based on Room Temperature of 30 C. 86 F.)

Size AWG MCM	Rubber Type R Type RW Type RU (14–6) / Thermoplastic Type T Type TW	Rubber Type RH	Thermoplastic Asbestos Type TA / Var-Cam Type V / Asbestos Var-Cam Type AVB	Asbestos Var-Cam Type AVA Type AVL	Impregnated Asbestos Type AI (14–8) Type AIA	Asbestos Type A (14–8) Type AA	Slow-Burning Type SB / Weather-proof Type WP Type SBW
14	20	20	30	40	40	45	30
12	25	25	40	50	50	55	40
10	40	40	55	65	70	75	55
8	55	65	70	85	90	100	70
6	80	95	100	120	125	135	100
4	105	125	135	160	170	180	130
3	120	145	155	180	195	210	150
2	140	170	180	210	225	240	175
1	165	195	210	245	265	280	205
0	195	230	245	285	305	325	235
00	225	265	285	330	355	370	275
000	260	310	330	385	410	430	320
0000	300	360	385	445	475	510	370
250	340	405	425	495	530	....	410
300	375	445	480	555	590	....	460
350	420	505	530	610	655	....	510
400	455	545	575	665	710	....	555
500	515	620	660	765	815	....	630
600	575	690	740	855	910	....	710
700	630	755	815	940	1005	....	780
750	655	785	845	980	1045	....	810
800	680	815	880	1020	1085	....	845
900	730	870	940	....	....	....	905
1000	780	935	1000	1165	1240	....	965
1250	890	1065	1130	....	....	....	....
1500	980	1175	1260	1450	....	....	1215
1750	1070	1280	1370	....	....	....	....
2000	1155	1385	1470	1715	....	....	1405

CORRECTION FACTOR FOR ROOM TEMPERATURES OVER 30 C. 86 F.

C. F.							
40 104	.82	.88	.90	.94	.95	....	....
45 113	.71	.82	.85	.90	.92	....	....
50 122	.58	.75	.80	.87	.89	....	....
55 131	.41	.67	.74	.83	.86	....	....
60 140	....	.58	.67	.79	.83	.91	....
70 158	....	.35	.52	.71	.76	.87	....
75 167	....	....	.43	.66	.72	.86	....
80 176	....	....	.30	.61	.69	.84	....
90 194	....	....	....	.50	.61	.80	....
100 212	....	....	....	....	.51	.77	....
120 248	....	....	....	....	....	.69	....
140 284	....	....	....	....	....	.59	....

See notes following Tables 1 and 2.

TABLE 4—NUMBER OF CONDUCTORS IN CONDUIT OR TUBING

Rubber Covered, Types RF-32, R, RH, RW and RU
Thermoplastic, Types TF, T and TW
One to Nine Conductors

Size AWG MCM	Number of Conductors in One Conduit or Tubing								
	1	2	3	4	5	6	7	8	9
18	½	½	½	½	½	½	½	¾	¾
16	½	½	½	½	½	½	¾	¾	¾
14	½	½	½	½	¾	¾	1	1	1
12	½	½	½	¾	¾	1	1	1	1¼
10	½	¾	¾	¾	1	1	1	1¼	1¼
8	½	¾	¾	1	1¼	1¼	1¼	1½	1½
6	½	1	1	1¼	1½	1½	2	2	2
4	½	1¼	*1¼	1½	1½	2	2	2	2½
3	¾	1¼	1¼	1½	2	2	2	2½	2½
2	¾	1¼	1¼	2	2	2	2½	2½	2½
1	¾	1½	1½	2	2½	2½	2½	3	3
0	1	1½	2	2	2½	2½	3	3	3
00	1	2	2	2½	2½	3	3	3	3½
000	1	2	2	2½	3	3	3	3½	3½
0000	1¼	2	2½	3	3	3	3½	3½	4
250	1¼	2½	2½	3	3	3½	4	4	4½
300	1¼	2½	2½	3	3½	4	4	4½	4½
350	1¼	3	3	3½	3½	4	4½	4½	5
400	1½	3	3	3½	4	4	4½	5	5
500	1½	3	3	3½	4	4½	5	5	6
600	2	3½	3½	4	4½	5	6	6	6
700	2	3½	3½	4½	5	5	6	6	...
750	2	3½	3½	4½	5	6	6	6	...
800	2	3½	4	4½	5	6	6	...	...
900	2	4	4	5	6	6	6	...	...
1000	2	4	4	5	6	6	...	...	...
1250	2½	4½	4½	6	6	...	...	...	...
1500	3	5	5	6	...	...	...	...	...
1750	3	5	6	6	...	...	...	...	...
2000	3	6	6	...	...	...	...	...	...

See Note 4 to Tables 1 and 2.

*Where a service run of conduit or electrical metallic tubing does not exceed 50 feet in length and does not contain more than the equivalent of two quarter bends from end to end two No. 4 insulated and one No. 4 bare conductors may be installed in 1-inch conduit or tubing.

TABLE 18—PROPERTIES OF COPPER CONDUCTORS

Size AWG	Area Cir. Mils	Concentric Lay Stranded Conductors		Bare Conductors		D. C. Resistance Ohms/M Ft. At 25 C. 77 F.	
		No. Wires	Diam. Each Wire Inches	Diam. Inches	*Area Sq. Inches	Bare Cond.	Tin'd. Cond.
18	1624	Solid	.0403	.0403	.0013	6.510	6.77
16	2583	Solid	.0508	.0508	.0020	4.094	4.25
14	4107	Solid	.0641	.0641	.0032	2.575	2.68
12	6530	Solid	.0808	.0808	.0051	1.619	1.69
10	10380	Solid	.1019	.1019	.0081	1.018	1.06
8	16510	Solid	.1285	.1285	.0130	.641	.660
6	26250	7	.0612	.184	.027	.410	.426
4	41740	7	.0772	.232	.042	.259	.269
3	52640	7	.0867	.260	.053	.205	.213
2	66370	7	.0974	.292	.067	.162	.169
1	83690	19	.0664	.332	.087	.129	.134
0	105500	19	.0745	.373	.109	.102	.106
00	133100	19	.0837	.418	.137	.0811	.0844
000	167800	19	.0940	.470	.173	.0642	.0668
0000	211600	19	.1055	.528	.219	.0509	.0524
	250000	37	.0822	.575	.260	.0431	.0444
	300000	37	.0900	.630	.312	.0360	.0371
	350000	37	.0973	.681	.364	.0308	.0318
	400000	37	.1040	.728	.416	.0270	.0278
	500000	37	.1162	.814	.520	.0216	.0225
	600000	61	.0992	.893	.626	.0180	.0185
	700000	61	.1071	.964	.730	.0154	.0159
	750000	61	.1109	.998	.782	.0144	.0148
	800000	61	.1145	1.031	.835	.0135	.0139
	900000	61	.1215	1.093	.938	.0120	.0124
	1000000	61	.1280	1.152	1.042	.0108	.0111
	1250000	91	.1172	1.289	1.305	.00864	.00890
	1500000	91	.1284	1.412	1.566	.00719	.00740
	1750000	127	.1174	1.526	1.829	.00617	.00636
	2000000	127	.1255	1.631	2.089	.00539	.00555

* Area given is that of a circle having a diameter equal to the over-all diameter of a stranded conductor.

TABLE 19—DIMENSIONS OF CONDUIT OR TUBING

Size	Internal Diameter Inches	Area Square Inches	Size	Internal Diameter Inches	Area Square Inches
½	.622	.30	3	3.068	7.38
¾	.824	.53	3½	3.548	9.90
1	1.049	.86	4	4.026	12.72
1¼	1.380	1.50	4½	4.506	15.95
1½	1.610	2.04	5	5.047	20.00
2	2.067	3.36	6	6.065	28.89
2½	2.469	4.79			

TABLE 20—CONDUCTOR SIZES AND OVERCURRENT PROTECTION FOR MOTORS. See Tables 26 and 27.

Full load current rating of motor amperes	Minimum size conductor in raceways For conductors in air or for other insulations see tables 1 and 2		For Running Protection of Motors****		Maximum Allowable Rating or Setting of Branch Circuit Protective Devices			
	AWG and MCM Type R Type T	Type RH	Maximum rating of non-adjustable protective devices	Maximum setting of adjustable protective device	**With Code Letters** Single-phase and squirrel cage and synchronous. Full voltage, resistor and reactor starting, Code letters F to R inc. **Without Code Letters** Same as above.	**With Code Letters** Single-phase and squirrel cage and synchronous. Full voltage, resistor or reactor starting, Code letters B to E inc. Auto-transformer starting, Code letters F to R inc. **Without Code Letters** Squirrel cage and synchronous, auto-transformer starting, High reactance squirrel cage.*** Both not more than 30 amperes	**With Code Letters** Squirrel cage and synchronous Auto-transformer starting, Code letters B to E inc. **Without Code Letters** Squirrel cage and synchronous, auto-transformer starting, High reactance squirrel cage.*** Both more than 30 amperes.	**With Code Letters** All motors. Code letter A. **Without Code Letters** DC and wound-rotor motors.
			Amperes	Amperes				
Col. No. 1	2	3	5	6	7	8	9	10

1**	14	14	2*	1.25*	15	15	15	15
2**	14	14	3*	2.50*	15	15	15	15
3**	14	14	4*	3.75*	15	15	15	15
4**	14	14	6*	5.0 *	15	15	15	15
5**	14	14	8*	6.25*	15	15	15	15
6**	14	14	8*	7.50*	20	15	15	15
7	14	14	10*	8.75*	25	20	15	15
8	14	14	10*	10.0 *	25	20	20	15
9	14	14	12*	11.25*	30	25	20	15
10	14	14	15*	12.50*	30	25	20	15
11	14	14	15*	13.75*	35	30	25	20
12	14	14	15	15.00	40	30	25	20
13	12	12	20	16.25	40	35	30	20
14	12	12	20	17.50	45	35	30	25
15	12	12	20	18.75	45	40	30	25
16	12	12	20	20.00	50	40	35	25
17	10	10	25	21.25	60	45	35	30
18	10	10	25	22.50	60	45	40	30
19	10	10	25	23.75	60	50	40	30
20	10	10	25	25.0	60	50	40	30
22	10	10	30	27.50	70	60	45	35
24	10	10	30	30.00	90	60	50	40
26	8	10	35	32.50	80	70	60	40
28	8	10	35	35.00	90	70	60	45
30	8	8	40	37.50	90	70	60	45
32	8	8	40	40.00	100	80	70	50
34	6	8	45	42.50	110	90	70	60
36	6	8	45	45 00	110	90	80	60
38	6	6	50	47.50	125	100	80	60
40	6	6	50	50.00	125	100	80	60
42	6	6	50	52.50	125	110	90	70
44	6	6	60	56.0	125	110	90	70
46	4	6	60	57.50	150	125	100	70
48	4	6	60	60.0	150	125	100	80
50	4	6	60	62.50	150	125	100	80
52	4	6	70	65.0	175	150	110	80
54	4	4	70	67.50	175	150	110	90

Col. 1	2	3	5	6	7	8	9	10
56	4	4	70	70.00	175	150	120	90
58	3	4	70	72.50	175	150	120	90
60	3	4	80	75.00	200	150	120	90
62	3	4	80	77.50	200	175	125	100
64	3	4	80	80.00	200	175	150	100
66	2	4	80	82.50	200	175	150	100
68	2	4	90	85.00	225	175	150	110
70	2	3	90	87.50	225	175	150	110
72	2	3	90	90.00	225	200	150	110
74	2	3	90	92.50	225	200	150	125
76	2	3	100	95.00	250	200	175	125
78	1	3	100	97.50	250	200	175	125
80	1	3	100	100.00	250	200	175	125
82	1	2	110	102.50	250	225	175	125
84	1	2	110	105.00	250	225	175	150
86	1	2	110	107.50	300	225	175	150
88	1	2	110	110.00	300	225	200	150
90	0	2	110	112.50	300	225	200	150
92	0	2	125	115.00	300	250	200	150
94	0	1	125	117.50	300	250	200	150
96	0	1	125	120.00	300	250	200	150
98	0	1	125	122.50	300	250	200	150
100	0	1	125	125.00	300	250	200	150
105	00	1	150	131.5	350	300	225	175
110	00	0	150	137.5	350	300	225	175
115	00	0	150	144.0	350	300	250	175
120	000	0	150	150.0	400	300	250	200
125	000	00	175	156.5	400	350	250	200
130	000	00	175	162.5	400	350	300	200
135	0000	00	175	169.0	450	350	300	225
140	0000	00	175	175.0	450	350	300	225
145	0000	000	200	181.5	450	400	300	225
150	0000	000	200	187.5	450	400	300	225
155	0000	000	200	194.0	500	400	350	250
160	250	000	200	200.0	500	400	350	250
165	250	0000	225	206.	500	450	350	250
170	250	0000	225	213.	500	450	350	300

175	300	0000	225	219.	600	450	350	300
180	300	0000	225	225.	600	450	400	300
185	300	0000	250	231.	600	500	400	300
190	300	250	250	238.	600	500	400	300
195	350	250	250	244.	600	500	400	300
200	350	250	250	250.	600	500	400	300
210	400	300	250	263.	...	600	450	350
220	400	300	300	275.	...	600	450	350
230	500	300	300	288.	...	600	500	350
240	500	350	300	300.	...	600	500	400
250	500	350	300	313.	...	...	500	400
260	600	400	350	325.	...	...	600	400
270	600	400	350	338.	...	...	600	450
280	600	500	350	350.	...	...	600	450
290	700	500	350	363.	...	...	600	450
300	700	500	400	375.	...	...	600	450
320	750	600	400	400.	...	...	...	500
340	900	600	450	425.	...	...	...	600
360	1000	700	450	450.	...	...	...	600
380	1250	750	500	475.	...	...	...	600
400	1500	900	500	500.	...	...	...	600
420	1750	1000	600	525.	...	...	...	...
440	2000	1250	600	550.	...	...	...	...
460	....	1250	600	575.	...	...	...	...
480	....	1500	600	600.	...	...	...	...
500	....	1500	...	625.	...	...	...	...

TABLE 21—FULL-LOAD CURRENT*
Direct-Current Motors

HP	115V	230V	550V
½	4.6	2.3	.....
¾	6.6	3.3	1.4
1	8.6	4.3	1.8
1½	12.6	6.3	2.6
2	16.4	8.2	3.4
3	24.	12.	5.0
5	40	20	8.3
7½	58	29	12.0
10	76	38	16.0
15	112	56	23.0
20	148	74	31.
25	184	92	38.
30	220	110	46.
40	292	146	61
50	360	180	75
60	430	215	90
75	536	268	111
100		355	148
125		443	148
150		534	220
200		712	295

*These valnes for full-load current are average for all speeds.

TABLE 22—FULL-LOAD CURRENT*
Single-Phase A.C. Motors

HP	115V	230V	440V
1/6	3.2	1.6	
¼	4.6	2.3	
⅓	7.4	3.7	
½	10.2	5.1	
1	13.	6.5	
1½	18.4	9.2	
2	24.	12.	
3	34.	17.	
5	56.	28.	
7½	80.	40.	21.
10	100.	50.	26.

For full-load currents of 208 and 200-volt motors, increase corresponding 230-volt motor full-load current by 10 and 15 per cent, respectively.

*These values of full-load current are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current. in which case the nameplate current rating should be used.

TABLE 24—FULL-LOAD CURRENT*

Three-Phase A.C. Motors

HP	Induction Type Squirrel-Cage and Wound Rotor Amperes 110V	220V	440V	550V	2300V	Synchronous Type †Unity Power Factor Amperes 220V	440V	550V	2300V
½	4	2	1	.8	—	—	—	—	—
¾	5.6	2.8	1.4	1.1	—	—	—	—	—
1	7	3.5	1.8	1.4	—	—	—	—	—
1½	10	5	2.5	2.0	—	—	—	—	—
2	13	6.5	3.3	2.6	—	—	—	—	—
3	—	9	4.5	4	—	—	—	—	—
5	—	15	7.5	6	—	—	—	—	—
7½	—	22	11	9	—	—	—	—	—
10	—	27	14	11	—	—	—	—	—
15	—	40	20	16	—	—	—	—	—
20	—	52	26	21	—	—	—	—	—
25	—	64	32	26	7	54	27	22	5.4
30	—	78	39	31	8.5	65	33	26	6.5
40	—	104	52	41	10.5	86	43	35	8
50	—	125	63	50	13	108	54	44	10
60	—	150	75	60	16	128	64	51	12
75	—	185	93	74	19	161	81	65	15
100	—	246	123	98	25	211	106	85	20
125	—	310	155	124	31	264	132	106	25
150	—	360	180	144	37	—	158	127	30
200	—	480	240	192	49	—	210	168	40

For full-load currents of 208 and 200 volt motors, increase the corresponding 220-volt motor full-load current by 6 and 10 per cent, respectively.

*These values of full-load current are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current, in which case the nameplate current rating should be used.

†For 90 and 80 per cent P. F. the above figures should be multiplied by 1.1 and 1.25 respectively.

TABLE 26—MAXIMUM RATING OR SETTING OF MOTOR-BRANCH-CIRCUIT PROTECTIVE DEVICES FOR MOTORS MARKED WITH A CODE LETTER INDICATING LOCKED ROTOR KVA

Type of Motor	Per Cent of Full-Load Current: Fuse Rating (See also Table 20, Columns 7, 8, 9, 10)	Circuit-Breaker Setting: Instantaneous Type	Circuit-Breaker Setting: Time Limit Type
All AC single-phase and polyphase squirrel cage and synchronous motors with full-voltage, resistor or reactor starting:			
Code Letter A	150	......	150
Code Letter B to E	250	......	200
Code Letter F to R	300	......	250
All AC squirrel cage and synchronous motors with auto-transformer starting:			
Code Letter A	150	......	150
Code Letter B to E	200	......	200
Code Letter F to R	250	......	200

Synchronous motors of the low-torque, low-speed type (usually 450 RPM or lower), such as are used to drive reciprocating compressors, pumps, etc., which start up unloaded, do not require a fuse rating or circuit-breaker setting in excess of 200 per cent of full-load current.

For motors not marked with a Code Letter, see Table 27.

TABLE 27—MAXIMUM RATING OR SETTING OF MOTOR-BRANCH-CIRCUIT PROTECTIVE DEVICES FOR MOTORS NOT MARKED WITH A CODE LETTER INDICATING LOCKED ROTOR KVA

Type of Motor	Per Cent of Full Load Current		
	Fuse Rating (See also Table 20, Columns 7, 8, 9, 10)	Circuit-Breaker Setting Instantaneous Type	Time Limit Type
Single-phase, all types	300	—	250
Squirrel-cage and synchronous (full-voltage, resistor and reactor starting)	300	—	250
Squirrel-cage and synchronous (auto-transformer starting)			
Not more than 30 amperes	250	—	200
More than 30 amperes	200	—	200
High-reactance squirrel-cage			
Not more than 30 amperes	250	—	250
More than 30 amperes	200	—	200
Wound-rotor	150	—	150
Direct-current			
Not more than 50 H.P.	150	250	150
More than 50 H.P.	150	175	150

Synchronous motors of the low-torque low-speed type (usually 450 R.P.M. or lower) such as are used to drive reciprocating compressors, pumps, etc., which start up unloaded, do not require a fuse rating or circuit-breaker setting in excess of 200 per cent of full-load current.

For motors marked with a Code Letter, see Table 26.

Notes (See tables 1 and 2)

1. ***Aluminum Conductors.***—For aluminum conductors, the allowable current-carrying capacities shall be taken as 84% of those given in the table for the respective sizes of copper conductor with the same kind of insulation.

2. ***Bare Conductors.***—If bare conductors are used with insulated conductors, their allowable current-carrying capacity shall be limited to that permitted for the insulated conductor with which they are used.

3. ***Application of Table.***—For open wiring on insulators and for concealed knob-and-tube work, the allowable current-carrying capacities of Table 2 shall be used. For all other recognized wiring methods, the allowable current-carrying capacities of Table 1 shall be used, unless otherwise provided in this code.

4. ***More Than Three Conductors in a Raceway.***—Table 1 gives the allowable current-carrying capacity for not more than three conductors in a raceway or cable. If the number of conductors in a raceway or cable is from 4 to 6, the allowable current-carrying capacity of each conductor shall be reduced to 80% of the values in Table 1. If the number of conductors in a raceway or cable is from 7 to 9, the allowable current-carrying capacity of each conductor shall be reduced to 70% of the values in Table 1.

5. ***Neutral Conductor.***—A neutral conductor which carries only the unbalanced current from other conductors, as in the case of normally balanced circuits of three or more conductors, shall not be counted in determining current-carrying capacities as provided for in the preceding paragraph.

In a 3-wire circuit consisting of two phase wires and the neutral of a 4-wire, 3-phase system, a common conductor carries approximately the same current as the other conductors and is not therefore considered as a neutral conductor.

6. ***Ultimate Insulation Temperature.***—In no case shall conductors be associated together in such a way with respect to the kind of circuit, the wiring method employed, or the number of conductors, that the limiting temperature of the conductors will be exceeded.

7. ***Use of Conductors With Higher Operating Temperatures.***—If the room temperature is within 10 degrees C of the maximum allowable operating temperature of the insulation, it is desirable to use an insulation with a higher maximum allowable operating temperature; although insulation can be used in a room temperature approaching its maximum allowable operating temperature limit if the current is reduced in accordance with the table of correction factors for different room temperatures.

8. ***Voltage Drop.***—The allowable current-carrying capacities in Tables 1 and 2 are based on temperature alone and do not take voltage drop into consideration.

9. ***Overcurrent Protection.***—If the standard ratings and settings of overcurrent devices do not correspond with the ratings and settings allowed for conductors, the next higher standard rating and setting may be used, but not exceeding 150% of the allowable carrying capacity of the conductor.

10. ***Deterioration of Insulation.***—It should be noted that even the best grades of rubber insulation will deteriorate in time, so eventually will need to be replaced.

CHAPTER 24

Marine Wiring Practice

The regulations for electrical installation on merchant vessels are promulgated by the *Maritime Commission, Department of Commerce, Bureau of Marine Inspection and Navigation, Federal Communications Commission* and the *American Bureau of Shipping*, and are designed in accordance with the *Marine Standard* of the *American Institute of Electrical Engineers*, the practices on which this chapter is based. It is recommended, therefore, that reference always be made to their latest specifications and requirements.

The *Bureau of Marine Inspection and Navigation* has divided vessels into the following groups:

Group No. 1

Ocean-going vessels which navigate on any ocean or the Gulf of Mexico more than 20 miles off-shore.

Group No. 2

Ocean-going vessels which navigate on any ocean or the Gulf of Mexico but less than 20 miles off-shore.

Group No. 3

Vessels navigating Great Lakes only.

Group No. 4

Vessels navigating bays, sounds and lakes other than the Great Lakes.

Group No. 5

Vessels navigating rivers only.

Plans.—Every vessel should be provided with plans giving complete and detailed information as to circuits, wire sizes, loads, etc., for the light, power and interior communication systems. A symbol list giving the manufacturer's name, size, type, rating, catalog number or similar identification for all the equipment on the vessel should also be provided for the vessel's operating personnel.

Type of Current Used.—Distribution of electrical energy may be made either by direct or alternating current, but in present practice for electric auxiliaries direct current is usually employed. On this account, the main body of these recommendations covering auxiliaries relates to direct current installations.

Nature of Supply Source.—The following systems of distribution are recognized as standard:

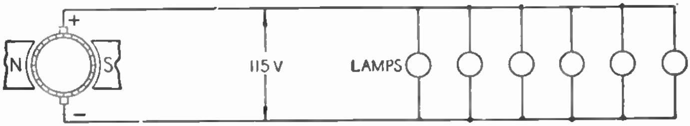
1. Two wire with direct or single phase alternating current.
2. Three wire with direct current or single phase alternating current.
3. Three phase three wire, alternating current.

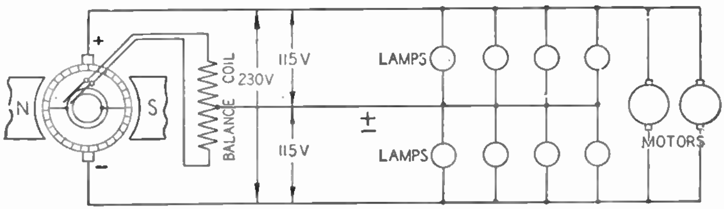
Standard Voltages.—The following voltages are recognized as standard:

	Direct Current	*Alternating Current*
Lighting....................	115 Volts	115 Volts
Power......................	115 and 230	115–220–440
Generators..................	120 and 240	120–230–450

Standard Frequency.—A frequency of 60 cycles per second is recognized as a standard for all alternating-current lighting and power systems.

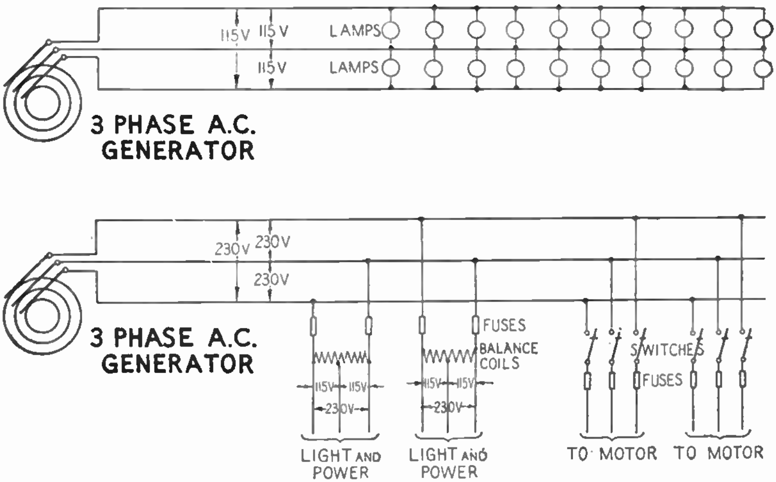
Selection of Voltage and Distribution System—D.C.—For vessels having little power apparatus, 120 volt generators are recommended with 115 volt light and power distribution systems. Where an appreciable amount of power apparatus is provided, 240 volt generators and 230 volt power distribution system with 115 volt lighting distribution system should be selected.





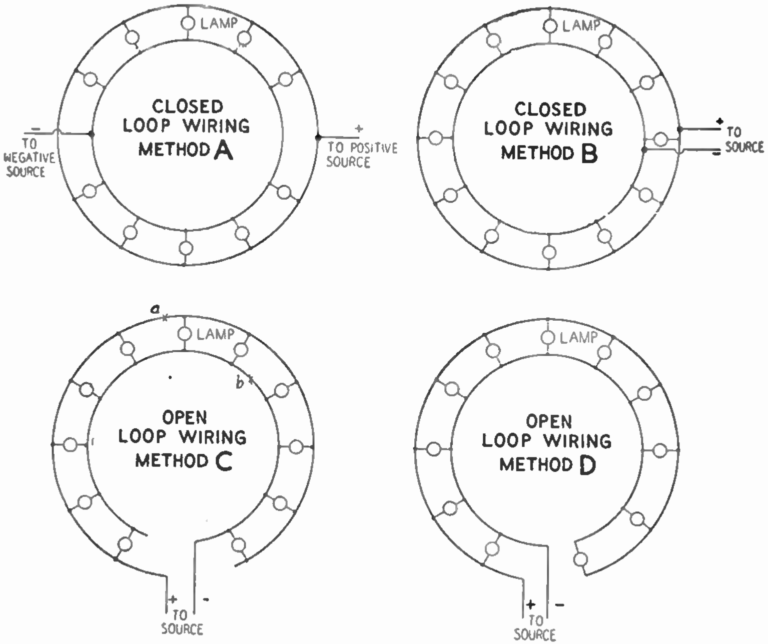
Figs. 1 and 2.—Direct current distribution systems. In the two-wire system the lamps are connected in parallel between the positive and the negative wires. The generator may be either shunt or compound wound. In fig. 2 the distribution is accomplished by means of a three wire direct current generator (Dobrowolsky system). The third wire (some times misleadingly called *neutral*) is obtained as follows: To any ordinary generator designed to give a terminal voltage equal to that between the two main wires, are added two slip rings as shown. From these slip rings two leads are brought out and connected to armature points located 180 electrical degrees apart. Collectors from the slip rings are connected to the two ends of the balance coil wound on an iron core and the middle point of this coil is finally connected to the third wire. It should be observed that in a system of this kind, it is necessary to balance the load between the two main wires and the wire leading from the balance coil as closely as possible, and the amount of unbalance should not exceed the manufacturer's specification, usually of from 10% to 15% of the total current.

Selection of Voltage and Distribution System—A.C.—For small vessels having little power, three phase, 120 volt generators may be used with the 115 volt lighting and power distribution system. For vessels requiring considerable power apparatus, three-phase, 230 volt generators are suggested with three-phase 220 volt distribution for the power system and 115 volt single phase two wire or 115/230 volt single phase three wire



Figs. 3 and 4.—Typical alternating current distribution systems. When it is desired to utilize 115 volts for light supply, balance coils are installed and connected as indicated. In a system of this kind, however, it is necessary that the lighting load be reasonably well balanced among the phases.

or 115 volt three phase three wire as obtained through transformers for distribution to the lighting system. Each of the three single phases should have about the same load so that currents will be about equal in each phase wire at the point where the three single phase systems are joined into one three phase system. For very large vessels with a large amount of power, the use of 450 volt three phase generators with 440 volts or 220 volts for power distribution and 115 volts for the lighting system as described for the 230 volt generator system may be considered.



Figs. 5A to 5D.—Showing various methods of loop-wiring. In order that all lamps in a circuit shall burn with equal brilliance at all times, it is necessary that the resistance of the circuit from the supply source to any lamp shall have a constant value, and be equal to the resistance through any other lamp. This is best accomplished in the *loop system* in which the mains are run in the form of a *closed loop*. With reference to figs. 5A and 5B, a break in either leg of the circuit will cause no break in the continuity of the circuit and all lamps will burn. It would require two breaks in any one leg to extinguish a lamp. If the loop be connected as shown in fig. 5C an analysis reveals that if a break occur at *a*, in the positive main all the lights toward the right of the open would be extinguished. Similarly a break in the negative main a' *b* would extinguish all lights to the left of the fracture.

Balancer Sets.—Balancer sets are not recommended for obtaining 120 volts from the 240 volt, two-wire direct current generators.

Rules Governing Direct Current Equipment and Installations

Installation and Location of Generator Sets.—Generating sets should be located in a well ventilated place as dry as possible. They should not be installed in the immediate proximity to water and steam piping, etc., and should be protected from dripping water, oil, etc.

Generating sets should always be installed with the shaft in the fore and aft position. There should be at least 18 inches between the set and surrounding objects to provide accessibility, and sufficient room should be provided to permit removal of the armature.

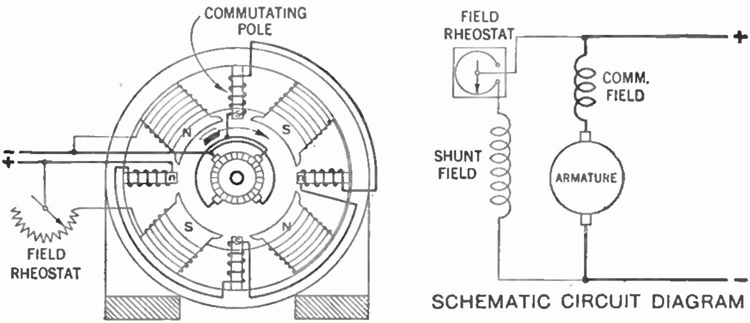
When diesel engine driven generating sets are located in deck houses, the enclosing structure should be steel or other approved fireproof material.

Generating Sets for Ship's Service—Number and Size.—In determining the capacities and number of generating sets to be provided for a vessel, careful consideration should be given to the *normal* and *maximum demands* as well as for the safe and efficient operation of the vessel when at sea and in port. The combined normal capacity of the operating generating sets should be at least equal to the *maximum peak load*, and in addition one *spare unit* should be provided. If the peak load and its duration be within the limits of the specified overload capacity of the generating sets, it is not necessary to have the combined normal capacity equal to the maximum peak load.

Generating Sets—Emergency.—In addition to the foregoing, the *Department of Commerce, Bureau of Marine Inspection and Navigation* requires the installation of a *diesel engine* driven generating set and (or) *storage batteries* located above the bulkhead deck for operating the emergency lighting and power systems.

Gasoline and semi-diesel engines are not recommended for the operation of emergency generators.

Generator Windings.—In the case of installations where the load does not fluctuate appreciably, *shunt-wound generators* without voltage regulators or the special type *compound-wound* generators may be used in lieu of *compound-wound generators.*

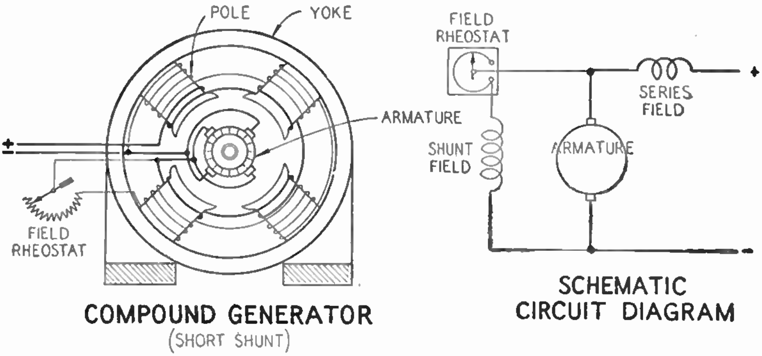


Figs. 6 and 7.—Connections of a shunt-wound generator with commutating poles and schematic diagram.

In the case of installations where the load is apt to fluctuate appreciably, *shunt-wound generators* with *voltage regulators*, or *compound-wound generators* should be used in the interest of substantially constant voltage.

Unless otherwise specified, all three-wire direct current generators should be designed for 25% unbalanced current.

In order to promote uniformity of practice for two-wire compound-wound generators, it is recommended that the series field terminal be negative.



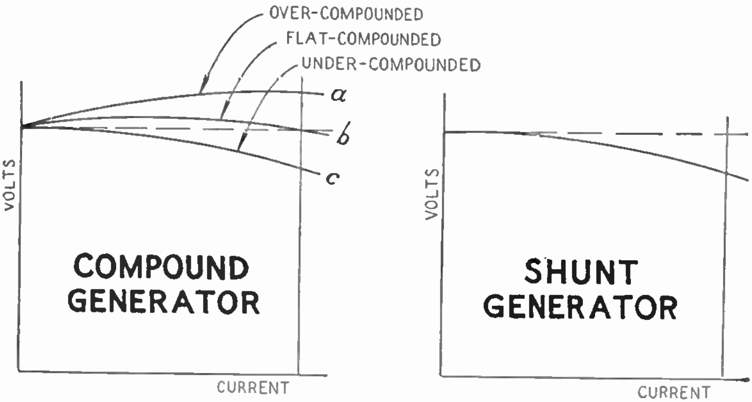
Figs. 8 and 9.—Connection of a compound wound generator with schematic circuit diagram.

Voltage Regulation and Compounding.—When the lighting load is *not* supplied by the *main generator*, the main generator should be shunt-wound and should have an inherent voltage regulation as follows:

Shunt-wound generating sets of 150 *k.w.* and above should be designed as to speed regulation and governing of the prime mover and inherent regulation of the generator so that at full-load operating temperature there will be a rise in voltage of not over 8% when the load is gradually reduced from 100% load to 20% load, and so that there will be a drop in voltage of not more than 12% when the load is gradually increased from 20% load to 100% load, based on 3.5 per cent speed regulation (drop in speed from no load to full load) of the prime mover. For each condition the field rheostat should be set for normal rated voltage at the beginning of each test.

Compound-wound generators should be designed as to governing of prime mover, compounding and regulation of the generator, so that with the generator at full-load operating temperature, and starting at 20% load with voltage within 1% of rated voltage, it should give at full load a voltage within 1½% of rated voltage. The average of the ascending and descending voltage regulation curves between 20% load and full load should not vary more than 3% from rated voltage, except for diesel engine driven generators, in which case it should not vary more than 4%.

The voltage regulation of a three-wire generator should be such that when operating at rated current on the heavier loaded side (i.e., positive or negative lead) with rated voltage between the positive and negative leads and a current of 25% of the generator current rating in the neutral wire, the resulting difference in voltage between the positive and neutral leads and negative and neutral leads should not exceed 2% of the rated voltage between the positive and negative leads.



Figs. 10 and 11.—Voltage drop characteristics of a compound and shunt-wound generator respectively. The compound generator may be designed to produce an almost constant voltage or even a rise in voltage as the load increases by placing on the field poles a few turns which may be connected in series with either the load or the armature. When the series ampere-turns on the field coils are adjusted so that the terminal voltage of the generator is greater at full load than at no-load the machine is said to be *over-compounded*. When the coils are adjusted to cause the generator to deliver the same terminal voltage at both full and no-load the machine is *flat-compounded*. When the adjustment is such that it causes the generator to deliver less voltage at full-load than at no-load the machine is *under-compounded*. See curves a, b, and c, fig. 10, respectively.

In the foregoing, the speed regulation curve of the prime mover should not vary more than 1% from a straight line drawn between the speeds at 20% load and 100% load.

The voltage regulation and compounding tests should be made at the works of the electrical manufacturer in accordance with his standard testing practice, using an approximately straight line speed regulation from 20% to 100% in amount as specified by the prime mover builder.

Parallel Operation.—Successful parallel operation is attained if the load on any generator does not differ more than plus or minus 15% of its rated kilowatt load from its proportionate

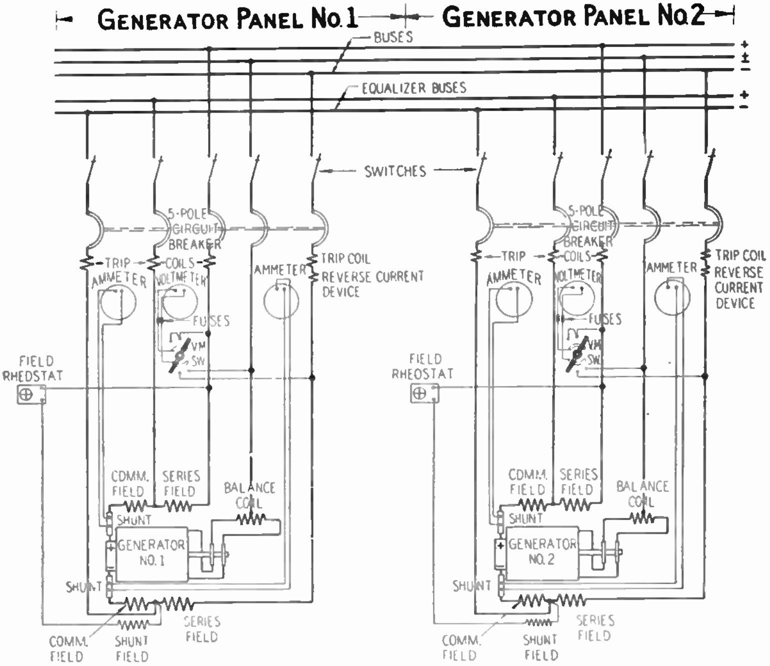


Fig. 12.—Connection diagram of two 120/240 volt three-wire compound-wound d.c. generators. The generators are arranged for parallel operation and require therefore a set of equalizer buses. With reference to diagram each generator has leading from the brushes a commutating and a series field on each leg of the circuit. Between these two fields on each leg is an equalizer connection. Since each generator has a positive, negative and neutral lead, in addition to a positive and a negative equalizer, the total number of outgoing main connectors are five in number. Each of these leads is connected through air circuit breaker and switches to their respective buses usually located in the rear of the generator panels. To prevent motoring of either unit one pole of each circuit breaker is equipped with a reverse current relay, in addition to the over-load trip feature. One voltmeter is provided with each generator, and permits the operator by means of the voltmeter switch to read the voltage between the positive and negative and also voltage positive and negative to neutral. By placing one ammeter in each outgoing leg it is possible to note the amount of unbalance in current at all times by a simple subtraction of readings.

share, based on the generator ratings, of the combined load, for any change in the combined load between 20% and 100% of the sum of the rated loads of all the generators. For this test the speed of the generators shall be constant or slightly decreasing, with the change in speed approximately proportional to the load. For *compound-wound machines*, series field equalizer connections are required, which, between any two machines, shall not have more than 20% of the resistance of the series field with resistors, if any, of the smaller machine.

Prime Movers.—Generating sets may be driven by *steam engines* either of the turbine or reciprocating type, or by *diesel engines*. Each prime mover should be fitted with an efficient speed regulating governor as well as an *automatic overspeed trip*. The automatic overspeed trip should function to shut down the unit automatically when the speed exceeds the designed maximum service speed by more than 15%. Each prime mover should, in addition, be under the control of an efficient *operating governor* capable of limiting the speed, when full load is suddenly removed, to at least 5% less than that of the overspeed trip setting. The overspeed trip should also be equipped with a means for manual tripping. Where a turbine prime mover is also fitted to utilize auxiliary exhaust, it should be provided with a properly arranged automatic shutoff, and where provision is made for extraction of steam, positive means should be provided for preventing a reversal of flow to the turbine.

All sets of 100 *k.w.* capacity and above should be provided with a coupling fitted to the armature shaft.

Mountings.—The generator and its driving unit should be mounted on a *common support* to *insure proper alignment*. Care should be exercised to secure a rigid foundation. Where a bedplate is used, each unit comprising the set should be provided with ample supporting feet secured to the bedplate.

Accessibility.—The design of generating sets should provide for accessibility to all parts requiring inspection during operation or dis-assembling for repairs.

Insulation of Windings.—All assembled armatures and also the armature coils for open slot construction should be immersed in insulating varnish and baked. All field coils should be treated with varnish or other insulating compound while being wound, or impregnated by the vacuum and pressure method. The finished winding should be water and oil resistant.

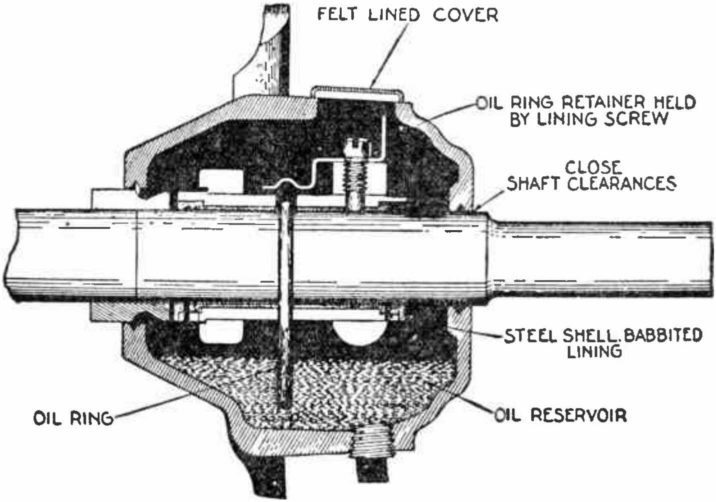


FIG. 13.—Sectional view of a typical self-oiling bearing. As shown the pedestal or bearing standard is cored out to form a reservoir for the oil. The rings are in rolling contact with the shaft, and dip at their lower part into the oil. *In operation*, oil is brought up by the rings which revolve because of the frictional contacts with the shaft. The oil is in this way brought up to the top of the bearing and distributed along the shaft gradually descending by gravity to the reservoir, being thus used over and over. A drain cock is provided in the base so that the oil may be periodically removed from the reservoir and strained to remove the accumulation of foreign matter. This should be frequently done to minimize the wear of the bearing.

Lubrication.—All generating sets should be located with their shafts in a *fore* and *aft direction* on the vessel and they should lubricate and operate satisfactorily when permanently inclined to an angle of 15° athwartship and 5° fore and aft, and arranged so that they will not spill oil under a vessel roll of 30° each side of the vertical. Turbine driven generating sets depending on forced lubrication should be arranged to shut down *automatically on loss of oil pressure.*

Corrosion-Resistant Parts.—To prevent deterioration and corrosion of interior bolts, nuts, pins, screws, terminals, brush-holder studs, springs, etc., and such other small parts as would be seriously damaged and rendered ineffective by corrosion, these should be made of corrosion-resistant material or steel suitably protected against corrosion. Steel springs should be treated to resist moisture in such a manner as not to impair their spring quality.

Terminal Arrangements.—

(1) *Generators* 50 *k.w. and above*

(a) *Side location*

Generators should be provided with an insulating terminal board having secured terminals to which the lugs of the incoming cables can be readily fastened. The terminal board should be enclosed in a drip-proof terminal box so constructed that the incoming cables can be led individually through an insulating cover screwed or bolted to the bottom or through a metal strip at least ¼ in. thick. If the cables enter through the bottom, ordinary clearance holes are recommended. If the cables enter through the top, individual terminal tubes should be used.

(b) *Top location*

Generators should be provided with an insulating terminal board as recommended in (a) enclosed in a drip-proof box having top and side sections at least ¼ in. thickness through which the individual cables can be entered through terminal tubes.

(c) *Bottom location*

Generators should be provided with strap terminals, secured to an insulating block, to which the connections (or straps) of the incoming cables can be fastened. The terminal board should be suitably protected.

(2) *Generators below* 50 *k.w.*

Generators should be provided with a side located, drip-proof conduit box with removable cover plate. The generator cables should be secured inside the conduit box. The arrangement should be such as to permit ready connection of the incoming cables.

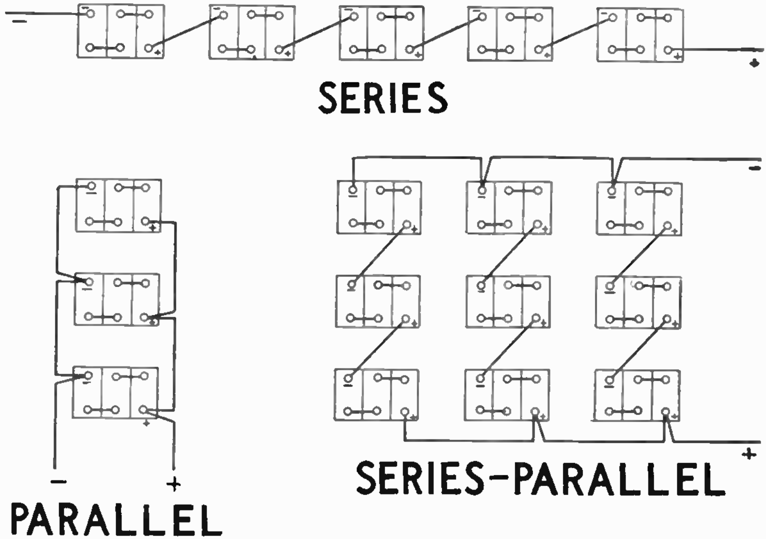
Storage Batteries

Installation and Location.—Storage batteries of either the *lead-acid* or *nickel-alkaline* type should be installed in a well ventilated room, but if no room be available, they may be installed in special deck boxes. The battery room should be large enough to provide adequate access for inspecting, testing and watering the battery.

For a *lead-acid* battery, the exposed metal in the battery room, including the battery and its connections, should be printed with corrosion-resistant paint. The floor of the battery room should be lined with 8 pound sheet lead, carried about 6 inches up the sides of the room and secured thereto or the batteries should be installed in lead-lined shelves with the lead carried up not less than 3 inches at the front, back and end of shelves. All joints in the lead lining should be lead burned watertight. A two inch space should be provided in back of the battery shelves to prevent pocketing of gases.

For a *nickel-alkaline* battery, the exposed metal in the battery room should be painted with corrosion-resistant paint. When the decks are made of ferrous metal, a steel pan should be provided with side walls 6 inches high and made liquid tight. Battery trays can be arranged in tiers, but each tier should be fitted with a pan to take the battery tray.

Where the decks are made of wood or non-ferrous metal, a steel pan of satisfactory thickness with side walls 6 inches high and made liquid tight should be provided. Where the battery rack is located in close proximity to a wooden or non-ferrous bulkhead, the size of the steel pan should be carried up the bulkhead to a point at least 1½ inches above the filler caps of the battery.



FIGS. 14 to 16.—Three principal methods of connecting batteries. For best results it is necessary that all inter-connected batteries be of an equivalent type, that is, their terminal voltage and internal resistance be equal.

The ventilating system for battery rooms should be carefully arranged to prevent the accumulation of pockets of *inflammable gases*. If the battery room be located in a deck house, natural ventilation may be used with adequate openings overhead, and near the deck. If the battery room be below deck, a motor driven exhaust fan, capable of changing the air every two minutes, should be provided for use when charging the battery. The fan should draw from top of room and openings for air inlet should be provided near the base of the room. The interior of the fan and ducts, if used, should be painted with corrosion-resisant paint.

If batteries are installed in engine rooms and machinery spaces, the ventilating systems of these spaces should be of a capacity to properly carry off all gases during the charging period and prevent the accumulation of pockets of *inflammable gases*. When *lead-acid* batteries are installed in special deck boxes, they should be lined with 4 pound sheet lead to a height of 10 inches. Ventilation should be provided by means of an inlet and outlet. The inlet should be turned down and the outlet should extend at least 4 feet above the battery box; both should be suitably protected against spray and painted with corrosion-resistant paint.

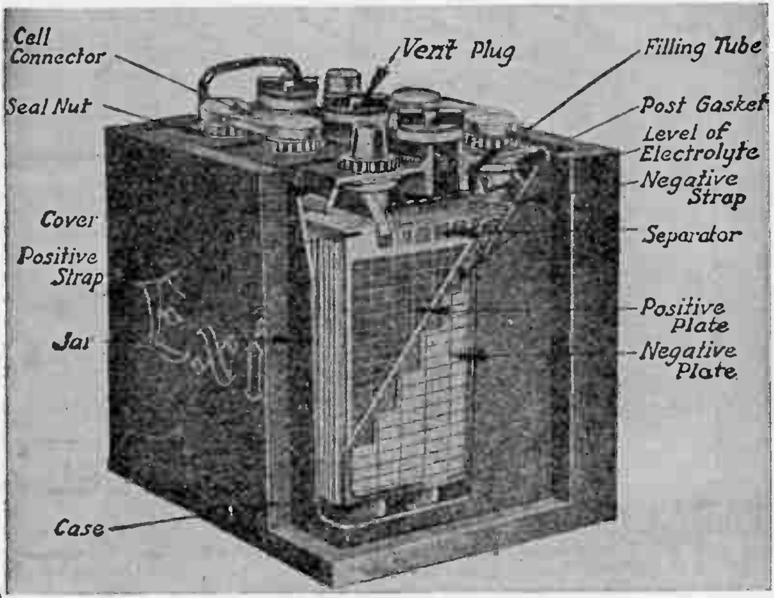


FIG. 17.—Sectional view of Exide battery showing construction. The active material is lead peroxide on the *positive* plate and finely divided or sponge lead on the *negative* plate. The plates are immersed in a solution of sulphuric acid and water called electrolyte. On discharge of the battery, both these active materials are quantitatively converted into lead sulphate at the expense of the acid radical of the electrolyte and the formation of water. Precisely the reverse action takes place upon the charge of the battery.

When *nickel-alkaline* batteries are installed in special deck boxes, the box should be lined with sheet steel of satisfactory thickness to a maximum height of 10 inches. The floor of the deck box shall be covered with removable wood strips of at least ½ in. thickness. In addition, the battery shall be securely blocked in place by means of wooden strips of ¾ in. x 1½ in. cross section permanently attached to the inner sides of the box and placed at least 1½ in. apart in such a way that all trays are held at least ¾ in. from the inner lining. A reasonable amount of ventilation should be provided by locating holes as high as possible on opposite sides or ends. Openings on one side or end are not enough to insure positive ventilation. All wooden lining bases and exposed steel surfaces should be covered with corrosion-resistant paint.

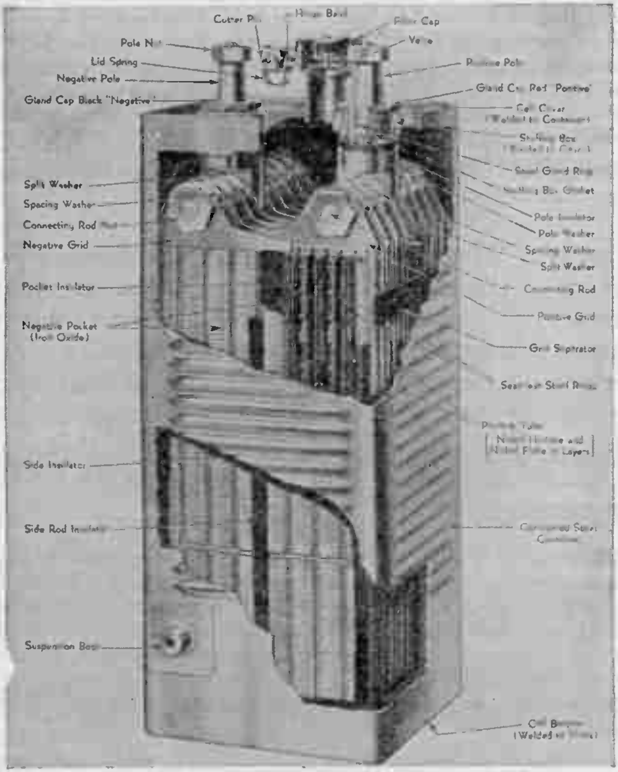


FIG. 18.—Sectional view of Edison Nickel-Iron Alkaline battery. The *positive* or nickel plate consists of a number of perforated steel tubes heavily nickel plated and filled with alternate layers of nickel and hydroxide and pure metallic nickel in thin flakes. The *negative* or iron plate consists of a grid of nickel plated cold rolled steel that holds a number of rectangular pockets filled with powdered iron oxide

When *radio*, *emergency radio* and *auto-alarm* batteries of the *lead-acid* type are installed in boxes, the boxes should be lined with 4 pound sheet lead to a height of 3 inches.

When *radio*, *emergency radio* and *auto-alarm* batteries of the *nickel-alkaline* type are installed in boxes, the interior of the boxes should be fitted with steel pans having a height of 4 inches.

The location of the battery should be carefully considered at the time of installation, and should be such as to protect the battery from damage in case of accident, so far as this is possible. Batteries used for emergency lighting or to operate radio equipment sets, should be located as high as possible, and never below the bulkhead deck level. In selecting the location, exposure to extreme heat or cold, vibration, steam or salt water should be avoided.

Storage batteries of either the *lead-acid* or *nickel-alkaline* type should not be installed in sleeping quarters.

Capacity.—When only a storage battery is required for the operation of the emergency lighting and power system, the capacity of the battery should be sufficient to operate the system for at least 12 hours. For passenger vessels where storage batteries are required for the operation of the emergency lighting and power system in conjunction with the diesel emergency generating set(s), the capacity of the battery should be sufficient to operate the portions of the emergency lighting and power system for at least 1½ hours.

The *capacity* of the *emergency lighting* and *power storage* battery should be such that when connected to the line for the purpose of supplying power, the initial voltage should not exceed the normal rated generator voltage by more than 5% and the final battery voltage at the end of full-rate discharge, should not be more than 12½ per cent below the normal rated generator voltage. The initial capacity of a lead plate type battery should be based on a specific gravity of electrolyte when fully charged between 1.210 and 1.220 at a temperature of 25°C.

The *capacity* of a battery that is normally floated on the power bus, so as to take care of load peaks, should be determined for each particular installation. The *generators* which must operate in parallel with the battery should have voltage characteristics suitable for the type and capacity of the battery, to insure stable operation. Automatic voltage regulators should be provided to protect the distribution circuits which will not function properly if operated above their designed voltage.

The *capacity* of batteries when provided as the only power supply for *signalling, communication* or *alarm systems*, should be sufficient to operate the equipment connected thereto under normal conditions for at least one week without charge. It is recommended that a standby battery be provided for such systems to permit operation from alternate sets.

It is recognized, however, that in special cases there may be some unimportant equipment where a capacity sufficient to operate the equipment for 72 hours may be adequate, when a spare set is provided and the ampere hour capacity is not less than sixty.

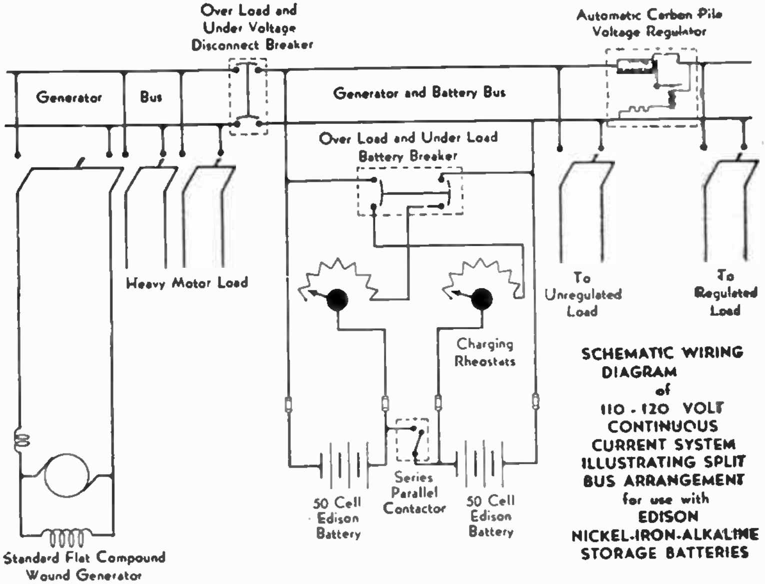


Fig. 19.—110-120 volt battery-generator circuit. An economical arrangement is obtained by means of a disconnect circuit breaker so located in the control circuit that it divides the heavy motor loads from the emergency and lighting loads. This circuit breaker accomplishes two purposes: it relieves the generator of any overload condition and because of the close limits over which the voltage relay operates it provides the emergency and lighting circuits with a continuous source of current through instantaneous transfer of these circuits from generator to battery. This transfer is made upon loss of the generator voltage from overload or any other cause. The generator is then forced to carry the heavy motor loads which are connected ahead of the disconnect circuit breaker.

Batteries for starting *marine diesel engines* and other service, shall have a fully charged specific gravity of not less than 1.275 to 1.285 at 25°C. Batteries shall have sufficient capacity for the necessary breakaway current voltage, and to crank the engine for not less than two minutes at a speed sufficient to insure starting the engine at the lowest temperature anticipated.

Batteries used for starting duty only may be furnished in thin positive plate construction (.100 to .150 thick); however, when auxiliary duties are to be performed from the battery, heavier positive plate construction shall be considered (.150 to .250 thick). *Exception*—Starting batteries which will be continuously exposed to tropical temperatures shall have a fully charged specific gravity of 1.210 to 1.220 at 25°C.

Batteries should develop at least 90% of their rated capacity within the first three cycles after assembly.

Accessibility.—The battery should be arranged so that the trays are readily accessible for care, inspection and removal. Lifting eyes or equipment should be provided over all large batteries to facilitate removal.

Voltage.—The emergency lighting and power batteries should supply a voltage equal to that of the vessel's supply.

Charging Equipment.—Where the voltage of the battery is the same as ship's supply, the battery may be split for the purpose of charging. The capacity of the charging equipment should allow the entire battery to be charged at once. Emergency lighting and power batteries should be charged at their normal charging rate, and time for complete recharge should not exceed 18 hours, based on the 1½ hour discharge rate. The battery and charging equipment should be protected against overload and reversal of current by means of efficient circuit interrupting devices.

The *charging panel* should include an ammeter and voltmeter of suitable range, provided when desired, with switches to read different circuits. A fixed resistor should be provided for each battery. The charging circuit of the battery should include an overload and underload, or overload and reverse-current circuit breaker. The use of an automatic charging panel is recommended.

Switches and other electrical fittings which are liable to cause an arc are not to be located in the battery room. Each conductor is to be fitted with a protective device which may be located in the battery room if it is enclosed in an explosion-proof casing; otherwise a protective device is to be fitted in each conductor immediately outside the room. Fuses on the *battery charging switchboard*, when in adjoining compartments, will meet this requirement. Fuses may be used for the protection of emergency lighting storage batteries instead of circuit breakers, up to and including 600 ampere rating.

Where conductors enter the battery room, the holes are to be substantially and tightly bushed as required for watertight bulkheads.

All connections within acid battery rooms should be lead covered cables, sealed tightly to resist the entrance of electrolyte by spray or creepage.

Switchboards

Installation and Location.—Switchboards should be installed in the same compartment with generating sets, in a dry place away from the vicinity of steam, water and oil pipes. The switchboards should be so located as to be accessible from front, rear and one end. The space in rear of switchboard should be ample to permit maintenance and should, in general, be not less than 18 inches in the clear. Ample clearance should be given for current carrying parts to ground. Asbestos barriers should be installed above the secondary contacts of air circuit breakers if less than 12 inches from ship's structure. If the space in the rear of the switchboard is accessible to unauthorized personnel, the space should be completely enclosed with metal grill provided with either sliding or hinged doors equipped with a lock.

An insulating grating should be provided on the deck in front and rear of switchboard, and grating should extend the entire length and be of sufficient width to provide adequate operating space. A non-conducting horizontal hand rail should be provided in front of the switchboard. When current carrying parts are located close to the deck, a guard should be provided to prevent accidental contact with live parts. Wood should not be used in the construction or protection of switchboards except for hand rails. For bulk oil carriers and vessels carrying oil having a flash point of less than 150°F., switchboards should not be located in spaces where vapor or gas is liable to accumulate.

Construction

1. **Panels.**—These should be of non-combustible, non-absorbent, insulating material, free from metallic veins, spots, etc., such as impregnated ebony asbestos lumber, or similar material. Impregnated material should be impregnated all the way through and properly buffed and finished a dull black on all surfaces to prevent accumulation of dust and moisture. Each panel should have a bevel on the front edge. The thickness of panels should be not less than one inch and generally not over two inches, depending upon the equipment installed and the size of the panel. Small panels are preferable.

2. **Framework.**—The supporting framework should consist of metal angle, channel or other shapes with a cross member or sill of liberal dimensions under the panels and rigid tie rods to the bulkhead or flexible ties to the deck above to allow for deflection of the deck without injury to the switchboard. A continuous strip of ⅛ in. rubber should be used between all non-metal panels and the vertical supports and a double strip between the bottom of panels and the horizontal member under them. Any other members necessary to make a rigid construction should be provided. Where self-supporting switchboards with complete box framing are used, the rods or braces to the ship structure should not be required.

3. Dead Front Switchboards.—It is recognized that this type of switchboard protects against accident or shock, and the use of such switchboards is desirable in certain installations. Metal panels may be used, providing all current carrying parts are properly insulated.

Equipment for Generator Switchboards.—The following should be supplied for a two-wire system:

Each generator of 25 *k.w.* and above should be protected by an independent arm or trip-free-from-handle circuit breaker with a separate pole for each power cable. These should be arranged to open at a predetermined overload and should be provided with a suitable *overload time-limiting* device. Generators of less than 25 *k.w.* may have fused knife switches or circuit breaker type switches. Compound-wound ordinary type generators arranged for parallel operations should be provided with equalizer switches and circuit breakers having overload and reverse current trip attachments.

An unfused generator switch which will completely disconnect the generator and the circuit breaker from the bus.

An ammeter for each generator.

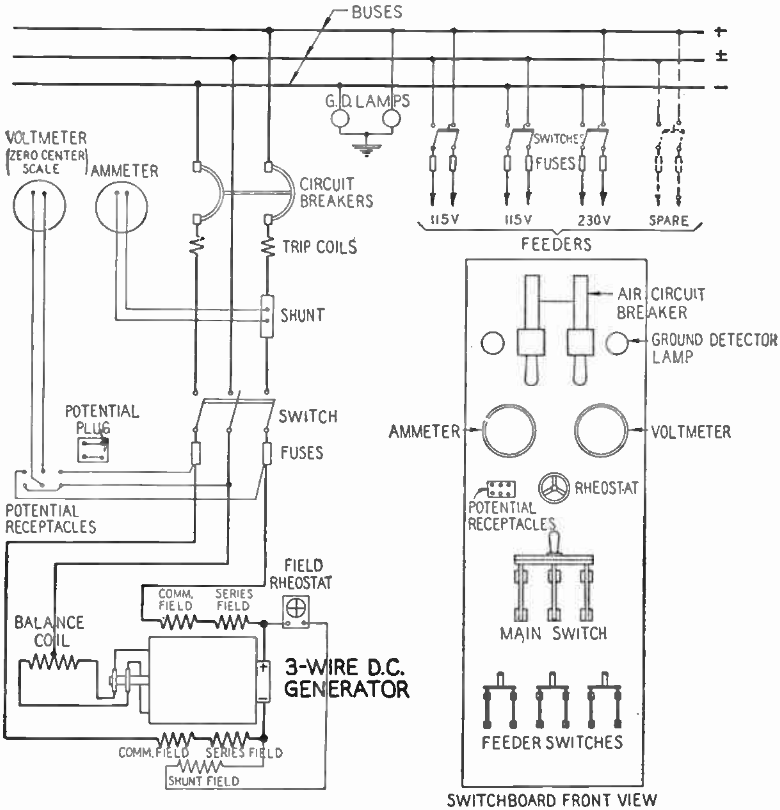
A voltmeter with selector switch for one generator and at least two voltmeters and selector switches for two or more generators.

A field rheostat for each generator.

A pilot lamp for each generator connected permanently between generator and circuit breaker which, in event of the tripping of the circuit breaker, will provide light for restoration of service.

For *ungrounded* systems, ground detector lamps and voltmeter connection or equivalent.

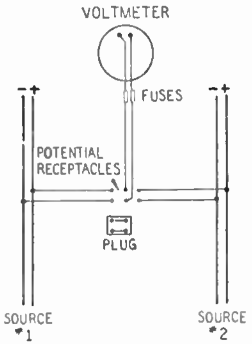
For generators of 500 *k.w.* rating and above, a single-pole field switch with discharge clips and resistor and a watt-hour meter are recommended.

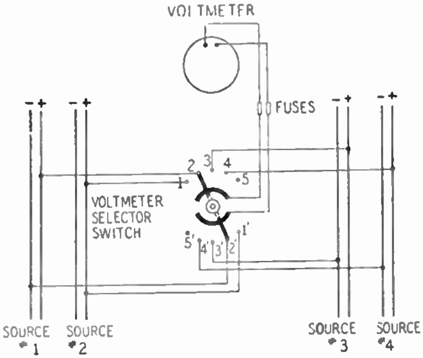


Figs. 20 and 21.—Typical wiring diagram and switchboard arrangement for a three-wire direct current generator. It is customary when using a supply system of this kind for operation of power and light, to connect the motors between the outside wires and the lights equally distributed between the positive and neutral and negative and neutral.

For a *three-wire* system the above recommendations should be followed except: Circuit breaker and disconnecting switches should be arranged in one of the following ways: (The first arrangement is recommended.)

1. A three pole circuit breaker and a five pole disconnect switch with one pole of the circuit breaker and disconnect switch in the neutral lead. The machine side of one breaker pole is connected to the positive armature lead. The other side of this breaker pole is connected through a pole of the disconnect switch to the positive equalizer bus and through half of the series



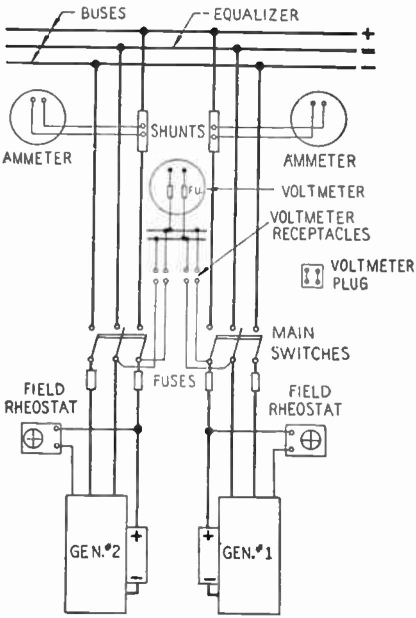


Figs. 22 and 23.—Methods of measuring voltage from two or more sources of power. In fig. 22 the voltage to be measured is transferred to the meter by the insertion of plug as shown. In the arrangement fig. 23 the voltages across the various sources are measured by means of a selector switch, the operation of which is accomplished by a rotative movement, thus paralleling the meter with the source whose voltage is to be determined.

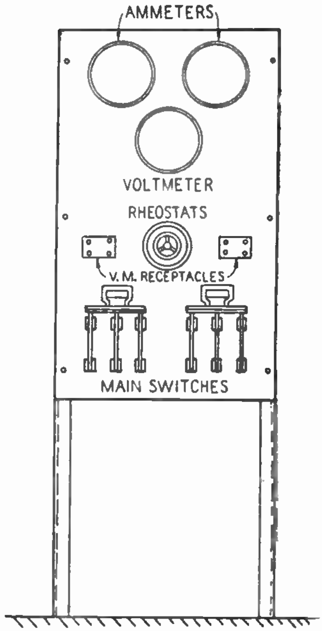
field and a pole of the disconnect switch to the positive bus. The machine side of the other breaker pole is connected to the negative armature lead. The other side of this breaker pole is connected through a pole of the disconnect switch to the negative equalizer and through the other half of the series field and a pole of the disconnect switch to the negative bus. This arrangement requires seven main leads from the generator to the switchboard. *Ammeter shunts* should be located on the switchboards.

2. A five pole algebraic sum circuit breaker with a pole in each armature lead, a pole in each equalizer lead and a pole in the neutral lead; and a five

pole disconnect switch with a pole in each lead. This arrangement requires three main and two equalizer leads from the generator to the switchboard. Ammeter shunts should carry the armature current which requires that they be located at the generator.



COMPOUND GENERATORS



SWITCHBOARD FRONT VIEW

Figs. 24 and 25.—Typical wiring diagram and switchboard arrangements for parallel operation of two compound generators. When two over-compounded generators are to be operated in parallel, it is necessary for a satisfactory division of loads, to parallel their respective series field. This is accomplished by connecting their negatives together and this common connector is usually referred to as the *equalizer*. The instruments and switches shown are connected in the usual manner, which are similar to those used for connection of shunt generators in parallel, the only addition being the equalizer and connections thereto. It should, however, be noted, that the ammeter for each machine should be connected in the lead from the armature to the main bus, and not in the lead from the series field, because if the ammeter be placed in the latter it will read the series field current which may be quite different from the current supplied by the generator to the load connected to the buses.

3. With either of these two arrangements an overload device may be used instead of a circuit breaker pole in the neutral lead, arranged to trip the circuit breaker. The circuit breaker should protect against a short circuit on the equalizer bus. An ammeter should be provided for positive and negative leads for each generator.

Grounding Three-Wire Dual Voltage Systems.—The neutral connection of three wire 230/115 volt direct current systems should be solidly grounded at the main switchboard with a center zero ammeter in the ground connection. The center zero ammeter should be equipped with a shunt, having a full scale reading of 150% of the neutral current rating of the largest generator and marked "plus" and "minus" to indicate the polarity of grounds.

The emergency lighting and power system is to be arranged so that when operating from a dual voltage emergency generator or storage battery, the neutral will be grounded but the ground connection at the emergency generator or storage battery should not be in parallel with the ground connection at the main generator. The ground connection should not prevent checking the insulation of the emergency generator to ground before the generator is connected to the bus.

Equipment for Distribution Switchboards.—Fuses in excess of 200 ampere rating should not be used for any circuits except for emergency system batteries. Circuits not protected by fuses should have each ungrounded conductor protected by an overload operated circuit breaker or circuit breaker type switch of the independent arm or *trip-free* type. The grounded neutral conductors of a *three-wire* feeder should be provided with a means for disconnecting and arranged so that the grounded conductor cannot be opened without simultaneously opening the ungrounded conductors. *Overload* protection is not necessary in the grounded neutral conductor. Circuit breaker type switches should provide overload and short-circuit protection.

Feeder circuits of 200 amperes or less may be provided with multiple lever type fused switches with one pole for each conductor instead of circuit breakers, except that for three-wire 230/115 volt feeders, no fuse is to be provided in the neutral. All fuses other than instrument fuses should be mounted on the front of the switchboard, except in the case of dead front switchboards. Arc searchlight circuits should be provided with a double-pole independent arm or a *trip-free*-from-handle type circuit breaker and an ammeter.

Two feeders should be provided from the main switchboard to the steering gear room. The overload protection for each steering gear feeder should be an instantaneous circuit breaker set at not less than 300% of the rating of the steering gear motor. The opening of the main switchboard steering gear circuit breaker should operate an audible alarm located adjacent to the principal propulsion control station.

Arrangement of Switchboard Equipment.—When facing front of switchboard, *left hand* contacts should be *negative* and *right hand* contacts *positive*. If, in special cases, it should appear necessary to use horizontal switches, the top contacts should be positive. If the buses are arranged horizontally, the positive bus should be nearest the panels; if arranged vertically, the positive bus should be at the top. Generator circuit breakers should be located at the top of the panels. Below the circuit breakers should be located the meters and if the general switchboard illumination is not sufficient for the scales of these meters other means of illumination should be provided. Below the meters should be located the ground detector and voltmeter switches and the rheostat handwheel, and below these the generator switch should be mounted. For small switchboards there may be room at the bottom of the generator panel for feeder switches.

On the feeder panels where circuit breakers are mounted above each other there should be adequate spacing for the arcing or otherwise protective barriers installed. Switches on feeder panels should be located with the largest ones at the bottom. Sufficient space should be allowed vertically between switches to avoid injury to the hand in operation. No part of any equipment should project beyond the edge of the panel. Metal framework and instrument cases should be grounded.

Arrangement of distribution boards when separate from the generator boards, should be the same as for generator switchboards as far as practicable.

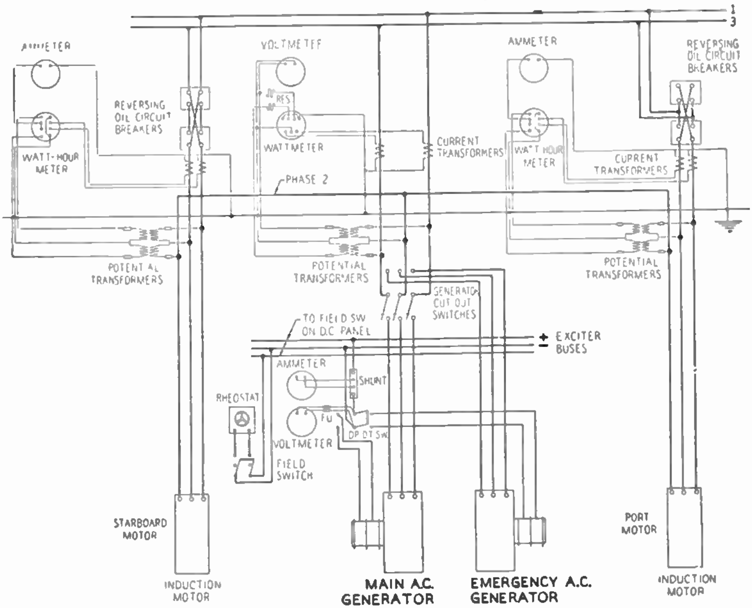
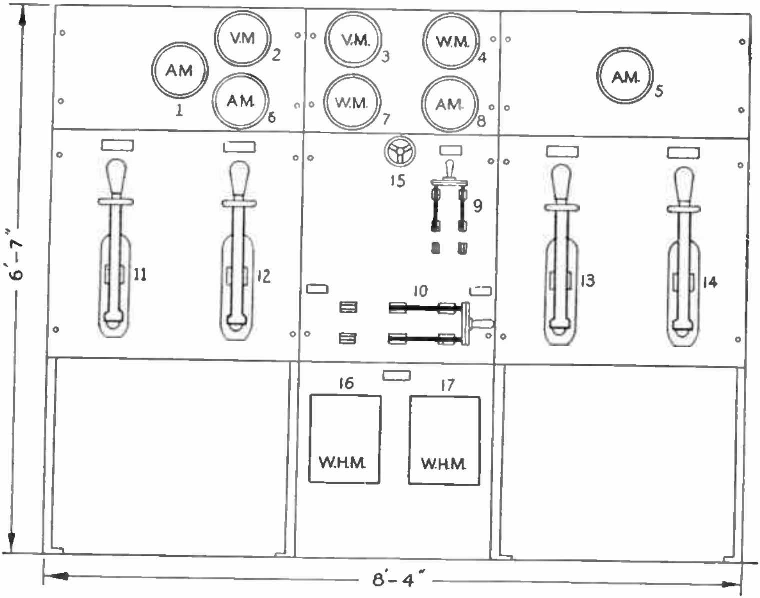


FIG. 26.—Typical wiring diagram of a twin screw turbo-electric propulsion drive with induction motors. The propelling machinery consists of one 5,500 *k.w.* turbo-generator, two induction motors, two water cooled rheostats, one main switchboard and one auxiliary propelling turbo-generator of 450 *k.w.* The machinery is all contained in one engine room. The main turbo-generator is mounted on its bed plate on the center line of the ship. The auxiliary generator is mounted on a platform above the main generator on the port side of the engine room. The two induction motors are connected directly to the two propeller shafts. The ship's 3–35 *k.w.* generators one of which may be used for excitation are located on a platform in the aft end of the engine room on the starboard side. At 15 knots the turbine makes 2,130 *r.p.m.* and the motors run 117 *r.p.m.*, the reduction being approximately 18 to 1. The electrical apparatus except those used for excitation, are of the three phase A.C. type. To reverse the direction of rotation of the propelling motors, it is only necessary to transpose two of the phases. This is easily accomplished by reversing oil circuit breakers operated by means of control levers situated on the control panels.



SWITCHBOARD FRONT VIEW

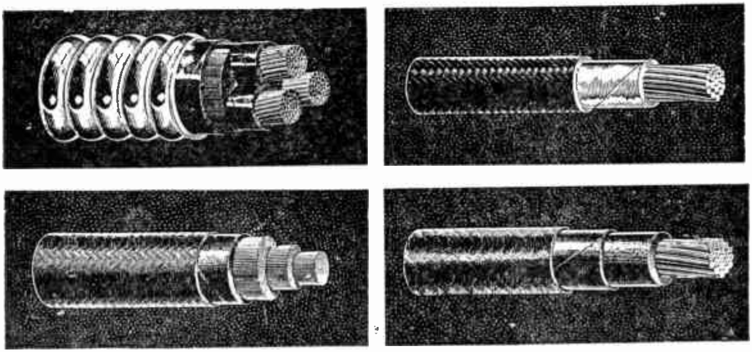
FIG. 27.—Front view of turbo-electric drive switchboard, connected as shown in fig. 26. The instrument and apparatus are: 1, ammeter; 2, volt-meter; 3, volt-meter; 4, watt-meter; 5, ammeter; 6, ammeter; 7, watt-meter; 8, field ammeter; 9, field switch; 10, D.P.-D.T. lever switch; 11 to 14, oil circuit breaker reversing switches; 15, field rheostat; 16 and 17, watt-hour meters.

Cables—Applications

Leaded and Armored Varnished Cambric Insulated.—Varnished cambric insulated cable may be used for all cable runs, and should be used for auxiliary power and lighting cables where the ambient temperature is in excess of 50°C. Where varnished cambric is used, the wire size should not be smaller than No. 12 AWG. (This necessitates the use of No. 12 wire for lighting branch circuits instead of No. 14.)

Leaded and Armored Rubber Insulated.—It is recommended that rubber insulated cable be used in all spaces where the ambient temperature does not exceed 50°C.

Steel, Bronze or Aluminum Armor.—Bronze or aluminum armor should be used for all cables exposed to weather. Steel, bronze or aluminum armor may be used for all other spaces.



FIGS. 28 to 31.—Various cables used in electrical installations. Fig. 28 illustrates varnished cambric-insulated cable with interlocked steel armor; fig. 29 glyptal cloth-insulated cable for hot and oily locations; figs. 30 and 31 varnished-cambric-insulated extra flexible apparatus leads and asbestos-varnished-cambric insulated cable respectively.

Armored Cable, Varnished Cambric and Rubber Insulated.—Rubber or varnished cambric insulated armored cables may be used only in quarters for officers and crew and passenger accommodations. Varnished cambric should not be used for wires having cross sectional areas less than No. 12 AWG.

Where lighting fixtures or sockets are not vented or designed to prevent the connecting wires from reaching an excessive temperature, rubber insulated wires should not be used where the conductor temperature will exceed 75°C.

Braided Cable.—Rubber insulated may be used in lighting fixtures except as noted in the previous paragraph. In multiple lamp fixtures 2,580 circular mils stranded, rubber and cotton braid insulated wire may be used for the individual lamps and may be spliced in the lighting fixtures.

Interior Communication Wires and Cables.—For call bell circuits of less than 25 volts, within passenger and crew accommodations, single-conductor bell wire may be used, if properly installed in protected raceways.

For interior communication apparatus, such as *fire alarms, telegraphs, telemotors, signalling circuits, control circuits*, etc., requiring two or more wires, interior communication cable should be used and should be either leaded and armored or armored, in accordance with the locations described in the preceding paragraph, except that twin conductor light and power cable may be substituted for twin conductor interior communication cable.

All telephones and telephone systems except those installed for the convenience of passengers and not essential for the operation of the vessel should be wired with either armored, or leaded and armored telephone cable as previously described.

Inter-cabin telephone cable of either the armored or leaded and armored type as described, may be used for the passenger non-essential telephone system.

The American Tel. & Tel. Specification Double-Silk Impregnated Lead Sheath Cable without armor may be used for telephone circuits where a large number of ship's service telephones are installed in passengers' and/or crew's quarters. Bridle wire in accordance with American Tel. & Tel. specifications may also be used for local wiring for ship's service telephones provided it is rigidly held in place, protected from mechanical injury and not exposed to moisture.

Portable Conductors

1. **Rubber-sheathed.**—Conductors for portable cargo fixtures, tools, watertight and non-watertight portables, signalling lights and all portable or semi-portable fixtures outside living quarters should be two-conductor portable rubber-sheathed.

2. **Armored.**—Armored portable conductor cable may be used for the foregoing applications and should be used where the cable is continuously in contact with oil.

3. **Braided.**—Conductors for portable or semi-portable apparatus such as desk lights, flat irons and curling irons used in living quarters may be two-conductor portable braided. However, the parallel conductor rubber-sheathed type portable cable is recommended.

Cable Installation

Cable Continuity and Grounding.—All cables should be continuous between outlet boxes, connection boxes, switchboards, panel boards, switch outlets, receptacle outlets, terminal equipment, etc. For any cable provided with a metallic sheath or armor, the sheath should be continuous from outlet to outlet and should be grounded at each end except that for final subcircuits the sheath may be grounded at the supply end only. Where sheathed or armored cable enters any box or wiring device the sheath should enter the box and should be secured by a clamp or connector to assure good electrical connection between the cable sheath or armor and the box.

Cable Locations.—Feeders of every description should be located with a view to avoiding spaces where excessive heat and gases may be encountered such as galleys, fire rooms, pump rooms and oil tanks; also spaces where exposed to damage such as cargo spaces and exposed sides of deck houses.

Cables should not be located behind or embedded in structural heat insulation and where they pass through such insulation each should be protected by a continuous pipe, preferably fitted with a watertight stuffing tube at each end.

Generator cables should not be located in bilges unless no other run is practicable.

Cable Protection.—All cables in bunkers and where particularly liable to damage such as locations in way of cargo ports, hatches and tank tops should be specially protected by metal coverings, angle irons or other equivalent means. Horizontal pipes or equivalent used for cable protection should have ¼ in. diameter holes for drainage every five feet.

Cable Support.—Cables where installed in groups should preferably be supported in metal hangers arranged as far as practicable to permit painting all around without undue disturbance of the installation. Cables grouped in a single hanger should preferably be limited to double banking.

Clips or straps used for cable support should each be secured by two screws except that clips for supporting one cable, No. 10 AWG twin or smaller, may be of the one-screw type. Cables supported by clips or straps on under side of beams should be run on backing plates or the equivalent. Cable supports should be spaced not more than 18 in. where vertical and 14 in. where horizontal.

Metal supports should be designed to secure cables without damage to armor or insulation and should be so arranged that the cable will bear for a length of at least ½ in.

Cables—Radius of Bends.—Leaded and armored cables should not be bent to a radius of less than 8 cable diameters. Other cables may be bent to a radius of 6 diameters.

Cables Through Bulkheads, Decks, Beams, Etc.—Where cables pass through watertight decks or bulkheads, a watertight stuffing tube capable of taking packing should be employed. Where cables pass through non-watertight bulkheads, beams, etc., a suitable bushing should be used of such a type as will permit drawing of the cable without damage. When the thickness of the bulkhead or web is ¼ in. or more the bushing may be omitted but the edges of the holes should be rounded.

Cable—Pulling in Force.—No cable should be drawn into wireways where the required pull exceeds twenty times the weight of the cable within the wireway and no appliance should be used which will damage the braid or armor.

Cables.—(Rat Proofing). During the installation of cables due consideration should be given to the feasibility of rat proofing as required by the *Public Health Service*.

Installation of Low Voltage Bell Wiring.—Wires serving low voltage circuits such as call bells for staterooms, public spaces, etc., should be neatly grouped and run together and distributed as required. These wires should be protected by molding, split fibre tubing or equivalent wrapping. The battery and branch leads may be tapped off by splicing. It is recommended that protected accessible connection blocks be used wherever possible instead of splicing within wireway enclosures. Low voltage circuits should be run entirely separate from other systems except when contained in interior communication cable.

Where the public spaces, passages, staterooms, etc., are ceiled, the call bell wiring should be run and secured above or behind the ceiling. Molding may be used in similar locations where there is no ceiling. Call bell wiring leading through crew's quarters and other living spaces where they may be subject to mechanical injury should be protected.

Holes for Cables.—The size of holes required for the installation of the cables for various systems should be such that they will not affect the structural strength of the various members through which they pass.

Distribution—D.C.

Distribution—General.—In general the methods of distribution are as follows: (the number and size of the sub-divisions depending on the size of the vessel and electric plant)—From the distribution section of the main or emergency generator switchboards to:—

1. A branch circuit for an individual controller and motor.

2. A power panel-board then to a branch circuit for an individual controller and motor.

3. A lighting branch circuit.

4. A panel-board then to lighting branch circuit.

5. More than one panel-board, each panel-board serving to subdivide the feeder to a sub-feeder supplying another panel-board or a branch circuit.

6. Another switchboard, then by any individual or combinations of (1) to (5) above, as desired.

Except in the case of small vessels and small electric plants, it is recommended that the lighting distribution system and the power distribution system be maintained as a separate distribution system from the main generator and emergency generator switchboards.

Location and Type of Panel-boards.—All panel-boards should be located so that they are readily accessible at all times to qualified personnel. They should not be located in bunkers, cargo holds and similar spaces. If the method of operation demands the operation of the switches by unqualified persons, the panel-board should be of the safety type. This type panel-board should be used for the distribution to all lighting branch circuits. Panel-boards located on weather decks or other spaces exposed to the weather or other severe moisture conditions should be watertight, elsewhere they may be of drip-proof construction.

Metallic Circuits.—All circuits should be completely metallic, and no ground return circuits should be employed except for aerial or submarine transmission.

Grounding of Portable Equipment.—Portable equipment such as portable motor units for life-boat hoisting or any other portable equipment fitted with portable cables and attaching devices and which operate on either two or three-wire circuits of 220 volts or more should have their frames grounded.

This should be accomplished by an additional conductor in the portable cable and grounding device in the attachment plug and receptacle.

Demand Factor and Voltage Drop for Generator and Bus.—Conductors from each generator to the generator switchboard should be *calculated for the rating*, including the *two-hour overload rating* (if provided) of each generator.

Conductors between generator switchboards of different generating stations should be *calculated on the basis of* 75% of the station having the *greatest generating capacity*. The drop in voltage from each generator to its adjacent generator switchboard *should not exceed one per cent.*

Conductors from storage batteries to the point of distribution should be calculated for a maximum charge, or discharge rate of the storage batteries, and the drop in voltage from the storage batteries to the point of distribution *should not exceed one per cent.*

Conductors from generator switchboard to outlet for receiving shore power should be calculated on the basis of the load required for this condition, or as specified, and the drop in voltage from the outlet to the generator switchboard *should not exceed two per cent.* Conductors should be *continuous* throughout their length.

Balance of Circuits for Three-Wire Systems.—Since branch lighting circuits are to be of the two-wire type, the three-wire system should not extend beyond the final panel-board. The 115-volt two-wire lighting branch circuits should be so disposed that the load will be *balanced within* 15 *per cent* at the individual panel-boards as well as for the complete lighting system.

Conductor Identification.—The individual conductors of branch circuit cables should have distinguishing colors, and in grounded systems, the grounded conductor should be connected to the shell of all sockets and all single-pole switches should be in the ungrounded conductor. The ungrounded systems, single-pole switches should be connected to similarly colored conductors.

Feeder Connections.—Where a feeder supplies more than one panel-board, the connection should be of a type that does not sever the conductor, and the connection should be within the panel-board or in a feeder junction box which is readily accessible at all times. In restricted spaces the feeder may be severed at the panel-board provided lugs and special bus bars of sufficient capacity for the entire load are provided which will permit through feed in the event it is desired to disconnect the local panel-board.

Distribution for Navigating Lights.—A separate feeder from the emergency switchboard to the pilot house should be installed for the running, and necessary navigating lights in the *pilot house* and on the *navigating bridge;* any other lights or small apparatus connected to this feeder should be on branch circuits fitted with fuses of no greater capacity than three amperes. Masthead, port, starboard, range and stern lights should be provided with duplicate lamps or a single lamp with two filaments. The duplicate lamps may be connected separately, by means of portable cable to two two-wire receptacles or as in the case of the two-filament lamp, by a single three-conductor portable cable to a three-wire receptacle.

Each receptacle should be connected to an *automatic indicator* located in the pilot house which will give an audible and visual signal on the occurrence of an open circuit. Each individual lamp circuit should be fused and provided with selective switches. The indicator should be enclosed in a steel case unless the magnets are properly shielded.

Distribution for Power Equipment.—In general, power feeders for cargo elevators, cargo hoists and cargo winches which are to be disconnected when the vessel is underway should not be used to supply ventilation sets, drainage pump motors or any apparatus required for the ship's operation.

Separate feeders should be run for engine and fire room auxiliaries, motors for cargo handling gear, steering gear, windlass, radio transmitters, searchlights and ventilation sets. Cargo ventilation fans and fans for ventilation of passenger accommodations should not be supplied from the same feeder.

Two feeders should be provided from the main switchboard to the steering gear room. These feeders should be widely separated so as to minimize failure of both feeders by collision, fire or other casualty. Each feeder should have a continuous current carrying capacity of not less than 125% of the rating of the motor or motors simultaneously operated therefrom.

In order to prevent the spread of fire, recent regulations of the *Bureau of Marine Inspection and Navigation* require arrangements to permit stopping all vent fans from a central point.

Distribution for Heating Equipment.—Separate feeders should be provided for air heaters when extensively used to augment or supplant other forms of heating and the aggregate capacity of the heaters in any one compartment exceeds 5 *k.w.* Isolated heaters, the aggregate of which does not exceed 5 *k.w.* may be taken from other power feeders which are normally energized. An isolated heater, not exceeding 1 *k.w.* may be connected by a separate circuit to a panel-board which is connected to a lighting feeder.

Motor Branch Circuits.—A separate branch circuit should be provided for each fixed motor having a full-load current rating of 6 amperes or more, and the conductors should have a carrying capacity of not less than 125 per cent of the motor full-load current rating. No branch circuit should have conductors less than No. 14 wire.

Heating Appliance Branch Circuits.—Fixed heating appliances having an aggregate rating of not more than 6 *amperes* may be grouped on a branch circuit wired with not less than *No.* 14 *wire* and fused not in excess of 10 *amperes*. Fixed heating appliances having an aggregate rating of not more than 15 *amperes* may be grouped on a branch circuit wired with not less than *No.* 12 *wire* and fused not in excess of 15 *amperes*. Fixed heating appliances having an aggregate rating of not more than 20 *amperes* may be grouped on a branch circuit wired with not less than *No.* 10 *wire* and fused not in excess of 20 *amperes*.

In these cases no other outlets or appliance should be connected to the branch circuit except that current-on indicating lights may be considered a part of the heater. Individual heating appliances with a rating of 15 amperes or more should be wired with a separate branch circuit having a current carrying capacity of not less than the full-load rating of the appliance and protected by a fuse of not greater rating or nearest larger size than the heater. Indicating lights within the heater may be considered to be protected by the branch circuit fuse. For range units, bake ovens, griddles, broilers, in which self-contained fuses are provided for each individually controlled heating element only one branch circuit need be provided for each assembled unit.

Motors Larger than One-Quarter H.P.—In general, motors larger than ¼ *h.p.* or apparatus consuming more than 660 *watts*, other than incandescent lamps, should not be connected to lighting circuits.

Receptacles for 230 Volt Portable Equipment.—In cases where it is necessary to use 230 volt portable motors the receptacles for their attachment should be permanently marked indicating the voltage and of a type which will not permit attaching 115 volt equipment.

Lighting Branch Circuits.—Connected Load.—It is recommended that in designing the lighting system, the maximum connected load on any branch circuit should not exceed 880 *watts*.

Lighting Branch Circuits—Wire Size.—All branch circuits should be wired with not less than No. 14 AWG conductors.

Lighting Branch Circuits—Over-current Protection.—Each lighting branch circuit should be protected by an over-current device in each wire of no greater capacity than 10 *amperes*, except branch circuits supplying only sockets or receptacles of the Mogul type and wired with not less than *No.* 12 *AWG wire* may be protected by fuses having a rated capacity not greater than 20 *amperes*.

Wire Connections.—Wire joints or connections should be made by screw connections or approved connectors in flame-proof outlet boxes and wiring appliances. Except for portable cords, bell wires and lighting branch circuits the individual wires should terminate in lugs. For lighting branch circuits, wire lugs may be used or the ends of the stranded wire may be formed into eyes and soldered. The lug should be of sufficient size so that it is unnecessary to reduce the wire cross section to permit proper entry into the lug except where the wire size has been increased to reduce voltage drop. Under this latter condition, strands may be removed at the lug entrance but in no case should the remaining cross sectional area be less than that required to carry the maximum current. This exception may not be applicable with some types of mechanical lugs due to the inability to obtain uniform bearing on the conductor.

Use of Outlet and Connection Boxes.—Outlet and connection boxes should be located in accessible locations and not in back of joiner panels unless the covering panels are hinged to permit ready access to the boxes.

Interior Communication Wire and Feeders.—Conductors for interior communication circuits should be calculated for carrying capacities for the rated current of the apparatus connected.

Interior Communication Circuits—Selection of Voltage.—All interior communication circuits should be designed for operation from a 20 volt or a 120 volt direct current or alternating current supply unless the circuits are simple when 12 or 6 volts should be satisfactory.

Interior Communication Circuits—Voltage Drop.—The maximum allowable drop on any circuit shall not exceed 5 per cent of the supply voltage from the point of supply to the most remote outlet under any operating condition.

Interior Communication Circuits—Over-Current Protection.—Where a common feeder is employed for a number of interior communication circuits, each circuit as well as the feeder should be fused and the feeder size based on the connected load.

Interior Communication Circuits—Wire Connections—Except for low voltage call bell circuits, all connections should be made with approved connector or terminal blocks in *flame-proof boxes*. It is suggested that properly protected and accessible terminal blocks be provided for low voltage call bells to facilitate maintenance.

Interior Communication Circuits—Connection Boxes.—Connection boxes where exposed to moisture or used with leaded and armored cable should be of the water-tight type and all others of the drip-proof type; water-tight boxes may be substituted for drip-proof wherever desired.

Special Requirements for Oil Tankers.—For requirements for tankers consult the *Bureau of Marine Inspection and Navigation*.

Conductors and Apparatus in Vicinity of Standard Compass

General.—It is an established fact that generators, motors and conductors carrying currents and particularly grounded circuits have an effect on *magnetic compasses*. The surroundings of the apparatus and wiring, if in steel houses, may reduce to a considerable extent this effect.

For small cables closely associated, carrying small currents, the effect is very slight and for a single lamp for lighting the compasses the conductor, when twisted, may be led inside the binnacle.

The compasses should be adjusted to meet the average operating conditions and the effect of electric circuits in close proximity should be checked by turning them on and off during adjustment.

Direct Current Motors

General.—All motors should be wound for operation on 230 volts direct current (except in the case of installations having a very limited amount of power apparatus where $^{1}/_{15}$ volt motors may be used).

Installation and Location.—Motors for mounting on open deck should be of the waterproof type or enclosed in metal housings giving the same protection as a waterproof motor frame. In the case of tank vessels, only enclosed separately ventilated motors should be installed in compartments which may be subject to inflammable gases. All other types of motors should be strictly prohibited in such locations.

Motors should be installed, as far as practicable, with the armature shafts in the fore and aft direction of the vessel. In case motors for service at sea are to be mounted in an *athwartship position*, the manufacturer should be notified.

Accessibility.—All motors should permit ready removal of the armature and field coils and bearings should be arranged to facilitate lubrication and flushing. Eye bolts should be provided for lifting motors of over 150 lb. in weight. All motors except fractional horse power motors should be provided on the commutator end with openings or removable covers of sufficient size and number to give easy access to brush rigging, etc., and permit direct view of the commutator and/or brushes while in operation.

Insulation of Windings.—All assembled armatures and also the armature coils for open slot construction should be immersed in insulating varnish and baked. All field coils should be treated with varnish or other insulating compound while being wound, or impregnated by the vacuum and pressure method. The finished winding should be water and oil resistant.

Lubrication.—Motors should operate successfully for continuous periods when tilted at an angle of 5° fore and aft, and 15° athwartship, and should not spill oil when the vessel rolls 30° either side of the vertical. (In cases where the shaft will be located athwartship, the manufacturer should be advised.)

Terminal Arrangements.—All motors except those of the waterproof type should be provided with drip proof terminal boxes and have the terminal leads suitably secured to the motor frame. The ends of these leads should be fitted with approved connectors. All connections to interior of motors as well as those to the current supply should be provided with efficient locking devices.

The leads of the waterproof motors should be brought out of the motor through waterproof junction boxes. All leads should be located on the *right-hand side* (facing the commutator) unless otherwise ordered. However, both sides of the motor should be so constructed that the waterproof device can be attached in case a change is desired after installation.

Corrosion-Resistant Parts.—All motor interior bolts, nuts, pins, screws, terminals, brush-holder studs, springs, hand-hole cover bolts, nuts and such other small parts, which would be seriously damaged and rendered ineffective by corrosion should be made of corrosion-resistant material or steel suitably protected against corrosion. Steel springs should be treated to resist moisture in such a manner as not to impair their spring quality.

Heating Equipment

Convector and Radiant Type.—Heaters should be suitable for 115 or 230 volts. The sizes recommended are 550, 660, 1000, 1500, 2000, and 3000 watts. The 550, 660, 1000 and 1500 watt sizes may be designed for single heat. The 2000 watt size and above should be designed for at least two heats. The construction of the heaters should be such as to heat the surrounding air by convection. The heaters should be strong, durable and all parts should be of solid construction, capable of withstanding abuse under service conditions. The framework should be metal of substantial proportion and securely fastened together. They should have *non-inflammable* heat insulating material, or adequate air circulation between the heater and surface, upon which it is mounted or to which it is adjacent. When heaters are of the portable type, a suitable clip or bracket should be fitted holding the heater in a fixed position.

Heaters installed on or adjacent to decks or bulkhead should be protected by a perforated or expanded metal covering or equivalent. The ends, back and top may be of solid material. Heaters with exposed surfaces installed flush with the bulkhead should have such exposed surfaces protected by a screen or guard similar to the other type with the same per cent openings, but the other sides of such heaters should be suitably protected by a solid metal enclosure so designed as to meet the specified temperature limitations. Heaters for mounting on bulkheads should have their top slanted or otherwise designed to prevent hanging towels, etc., on the heater.

The protecting guard should be strong enough to resist being forced against any current carrying part and give full protection from electrical or mechanical injury. The openings should be of small size to prevent the heating elements from being short-circuited or damaged by accident. All metal parts of the heater should be suitably protected against corrosion. The heater element may be of the open or enclosed types and the resistor material should be non-corrodible. If the heating unit is of the enclosed type, the enclosing case or jacket should be permanently corrosion-resistant. If the heating elements are of the open coil type, they should be so designed and supported as to withstand vibrations and prevent short circuit with adjacent elements.

The heating elements should be made up of uniform units easily installed and replaced. The elements should be of a material that will not corrode or oxidize. Alloys containing *zinc* are not recommended for this purpose. No material should be used which is *inflammable*. All connections of the heating elements should be *accessible* and so made that they will not become loose from vibration.

The elements should be wired to a terminal block with connectors and the leads brought out through insulating bushings. All insulated parts should be unaffected by the heat from the heating elements. The external temperature of the enclosing cases of the heaters should not exceed 125°C. except the flush type, in which case the temperature should not exceed 100°C. When the heaters are mounted upon or adjacent to the decks or bulkheads, the construction of the heater should be such that the nearest deck or bulkhead surface will not exceed a temperature of 55°C. For test purposes, an ambient temperature of 25°C. should be used. A suitable regulating switch mounted on an approved insulating base should be provided. Heaters should be equipped with a thermal cut-out of the manual reset type that will prevent overheating of the elements. The heater when hot should withstand 500 volts alternating current, 60 cycles for one minute applied between the frame and current-carrying parts.

Every piece of apparatus should have a name plate attached specifying *"Marine" manufacturer's name, volts, amperes, watts* and designating number.

Luminous heaters of a type approved by the *Underwriter's Laboratory* may be installed if desired by the owners.

Glow heaters of the incandescent lamp type in which the element is enclosed in an exhausted glass bulb, are not recommended, but should be constructed to recommendations previously stated, as regards fire risk, guarding, etc., and in addition the lamps should be supported in sockets of ample current carrying capacity, preferably of a spring or flexible type; an additional spring support should be fitted at two-thirds of height of lamps to prevent breakage from vibration.

Electric Heaters (Theory).—Electric heaters used aboard ships are for the purpose of *cooking* or for *heating* of *water* or *space*.

The heating effect received is due to the current flowing through its resistance coil. The resistance units are usually wound for the full line voltage of the supply. They are classified in accordance with the number of watts required to operate them, and also in accordance with the number of ways in which the units may be connected such as, *single heat*, *double heat*, *triple heat*, etc.

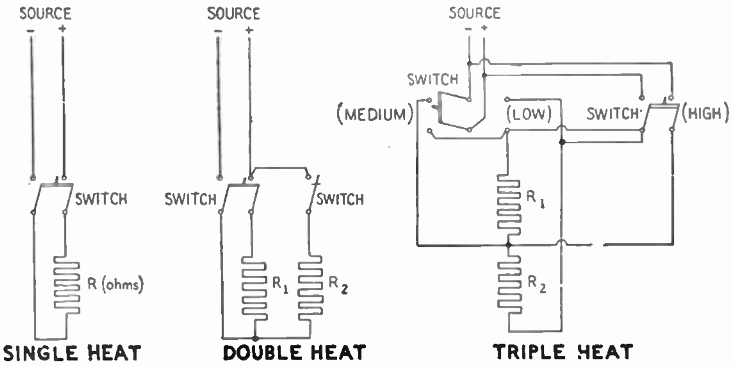
Single Heat Type.—In this type the resistance units are connected permanently in *series*, *parallel* or *series-parallel* and are operated by closing a switch, fig. 32.

Assuming a potential (E) across the heater coil or coils of (R) ohms resistance, then the heat generated is E^2/R joules per seconds.

Double Heat Type.—In the arrangement fig. 33 the heat is controlled by two switches connecting two equal resistance coils to the source. When closing the double pole switch only resistance R_1 is being heated. The amount of heat generated is E^2/R_1 joules per seconds.

If only the single pole switch be closed the heat generated is E^2/R_2 joules, but since R_1 equals R_2 it is evident that the heating will be the same in both cases. On the other hand if both switches be closed the heat generated will be $\left(\frac{R_1+R_2}{R_1R_2}\right)E^2$ joules per second or twice the amount generated with only one switch closed at a time.

Triple Heat Type.—With reference to fig. 34 low heat is obtained when the double throw switch is closed toward the right, connecting R_1 and R_2 in series. If E is the supply voltage, the heat generated is E^2/R_1+R_2 joules per second.



Figs. 32 to 34.—Various heat control circuits.

When the double throw switch is closed toward the left, medium heat is obtained R_1 is connected across the line and R_2 is cut out. The heat generated is now E^2/R_1 joules per second.

Finally when the double pole switch only is closed, R_1 and R_2 are connected in parallel.

The heat is now $\left(\frac{R_1+R_2}{R_1R_2)}\right)E^2$ joules per second. If R_1 equals R_2 the ratio of the heat obtained is 1/2R : 1/R : 2/R, that is the medium and high heat are two and four times respectively as high as that of the low heat.

Thermal Units.—The unit of *heat energy is the B.t.u.* (British thermal unit) and is defined as the *amount of heat necessary to raise the temperature of one pound of water one degree Fahrenheit.* An expression giving the relations between the electrical energy in a circuit and the heat in B.t.u. is:

$$H = 0.057t \frac{E^2}{R}$$

Where H = amount of heat in B.t.u.

E = potential of the source in volts

R = resistance of the circuit in ohms

t = time in minutes.

Example.—An electric heater having a resistance of 12.1 ohms is connected to a potential of 110 volts for one hour. How many *B.t.u.* are obtained?

Solution.—A substitution of values in the above formula gives

$$H = 0.057 \times 60 \times \frac{110^2}{12.1} = 57 \times 60 \text{ or } 3{,}420 \textit{ B.t.u.} \quad \textit{Ans.}$$

Example.—How much current does a 115 volt 1500 watt heater draw from the line? What should its fuse rating be?

Solution.—The current from Ohm's law is:

$$\text{amperes} = \frac{\text{watts}}{\text{volts}}$$

A substitution of values gives

$$\text{amperes} = \frac{1500}{115} = 13.04$$

The fuses should be the next commercial size above 13, say 15 amperes.

Lighting Equipment

Location of Fixtures.—Lamps should be located preferably overhead, except as a decorative feature in specially equipped rooms. The lamps and wiring appliances should have maximum protection and should not be obscured by moving or stationary objects. When located on bulkheads they should be about six feet above the deck.

Lamps and portable outlets in cargo spaces or on the underside of decks, subject to dropping of heavy weights, should not be fastened to decks, but to clips secured to the side of beams and brackets and should be protected in cargo spaces by metal rods or angles on each side of the fixture or portable outlet.

Attention is directed that some types of high wattage lamps are designed to operate only in either "base up" or "base down" position.

A tell-tale light should be installed outside each refrigerated space to indicate when the lights inside are energized.

Illumination Requirements.— Every compartment, stateroom, office, bath or lavatory should have at least the equivalent of a 25 *watt lamp* or portable for connecting same.

Single lamps or fixtures of more than 50 *watts* should not be used unless diffused by colored or ground glass, except for cargo lighting and for machinery spaces if mounted above range of vision.

Lamps.—All lamps should be selected for the voltage on which they will operate, generally 115 volts. Intermediate base with special shapes and sizes should be used only in spaces as a decorative feature. It is recommended except for instrument lighting that lamp bases not smaller than the intermediate type be used for decorative lighting purposes.

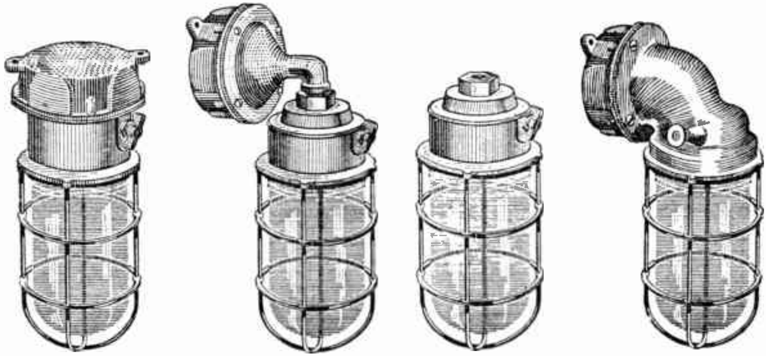
Arc Lamps.—Arc lamps should not be used except for searchlights or moving picture projectors.

Outlets for Portable Lighting Equipment.—Portable outlets of watertight type should be provided for chain lockers, windlass, deck machinery, steering gear, boiler man-holes, boiler rooms, bunkers, engine room, shaft alleys, refrigerating machinery pump rooms and wherever exposed to moisture.

Non-watertight outlets may be used in baggage rooms, mail rooms, deck lockers, store room, passenger and crew accommodations, deck fan rooms and similar places. All portable lights should be guarded, except when used for semi-decorative purposes in passenger and crew staterooms. Portable lights should not be used for built-in berths. Lights on beds or other furniture connected by portable cable should have the cable secured to the furniture to reduce the amount of loose cable to a minimum. Cords for bed lamps, floor lamps, table lamps and desk lamps for new installations should in general not exceed five feet in length.

Lighting for Cargo Handling.—Lighting of cargo spaces, hatches and cargo handling gear by large units should only be used when the lighting units are out of range of vision of the persons employed. Outside lighting for lighters, wharves, gangways, decks and hatches should be from overhead. In cargo spaces, lights should be so placed as to protect the light on the cargo ports and hatches.

Permanent Watertight Fixtures.—For outside use, forecastle, poop deck houses and mess spaces (not used as living quarters) cargo spaces, engine room, fire rooms, steering gear, windlass and pump room fixtures should be made of corrosion-resistant material and should be made watertight. The globe should be protected by a substantial guard.

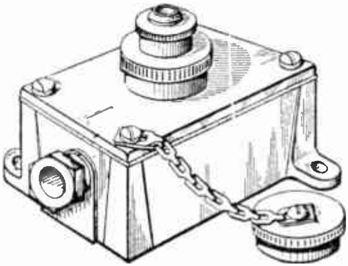


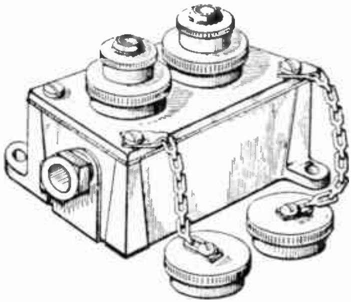
FIGS. 35 to 38.—Represent various types of permanent water-tight fixtures for outside use.

These fixtures should be so proportioned and constructed that when operating continuously with rated size lamp, the temperature will not exceed 35°C. above the surrounding air. Watertight globes should be flanged or of threaded type. Screw threads should conform to the following dimensions:

	Inside diameter of globe	Outside diameter across top of thread	Inside diameter across bottom of thread
Globes for 100 watt lamps	$4\frac{13}{32}$ in.	4.859 in. max. 4.844 in. min.	4.734 in. max. 4.719 in. min.
Globes for 50 watt lamps	$2\frac{27}{32}$ in.	3.297 in. max. 3.282 in. min.	3.1719 in. max. 3.1569 in. min.

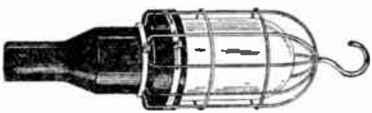
4 rh threads per inch with a minimum threaded distance of one inch. The radius of the thread should be 1/8 inch and the center of the first thread should be 1/4 inch from the edge of globe with threads spaced on 1/4 inch centers. The inside diameter of globe may have a variation of 1/32 inch. The base of the fixture should have no less than 2 1/2 threads for the reception of the globe and should be provided with external threads for the reception of the guard.

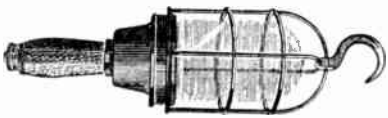




Figs. 39 and 40.—Water-tight receptacle and plugs for one and two outlets respectively.

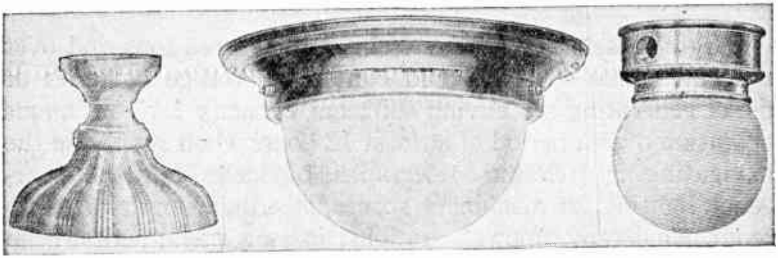
Portable Watertight Fixtures.—Watertight portables should be similar in construction to the permanent watertight fixtures. The guard should be provided with a hook or ring; also a handle with a stuffing tube for the cable and means to prevent strain on the connections. Portables with bodies of molded insulating material may be used. The use of brass shell sockets is not recommended.





Figs. 41 and 42.—Portable water-tight fixtures.

Portable Non-Watertight Fixtures.—These need not have a globe or stuffing tube, but should be equipped with guard except for semi-decorative desk lights, floor lamps, table lamps, etc., in living quarters and should preferably be composed of insulating material as far as possible. They should be provided with means to prevent strain on the connections.



FIGS. 43 to 45.—Cabin, stateroom and promenade deck fixtures respectively.

Interior Fixtures.—Fixtures for passenger accommodations and living quarters of crews should be substantially constructed and provided with sockets or receptacles which cannot become loose or disassembled through shock or vibration.

Dome fixtures should be ventilated and designed so that none of the adjoining woodwork is directly exposed to the heat of the lamps. Fire resisting material may be provided as a heat insulator. All fixtures should also be adequately vented to prevent excessive temperature from reaching the supply wires.

Emergency Light and Power System

General.—General requirements for this system will be found in *Department of Commerce, Bureau of Marine Inspection and Navigation Rules and Regulations*, and all details of this system are subject to the approval of the *Bureau of Marine Inspection and Navigation*. In general, the following recommendations, though somewhat more detailed, are in accordance with the

Bureau requirements but the latest requirements of the *Bureau* should be used as the authority for each vessel.

Every vessel equipped with an electric lighting plant should be provided with an independent emergency source of power installed above the bulkhead deck, as described in the following sections: *All emergency lights should bear a distinguishing mark for ready identification.* Emergency lights should form a part of the regular lighting system to insure readiness of burning.

Cargo Vessels.—For all vessels of 1600 gross tons and over the emergency source should consist of storage batteries or diesel generating set having sufficient capacity for continuous operation over a period of at least 12 hours when supplying the navigating light circuits, telegraphs, binnacles, and the emergency lighting for machinery spaces, steering gear room, radio room, emergency power stations, passageways, exits from crew's quarters and other spaces and equipment necessary for the operation of the vessel in an emergency. The emergency system should comprise independent circuits from the emergency panel, and be normally energized from the main power source.

Cargo Vessels Less Than 1600 Gross Tons.—Approved safety lanterns may be used for emergency lighting for vessels less than 1600 gross tons.

Passenger Vessels of 1600 Gross Tons or Over.—The emergency source for all vessels of 1600 gross tons and over should consist of one or more diesel engine driven generator sets having sufficient capacity and fuel supply to carry the full emergency load continuously for a period of at least 36 hours, and such final emergency source should be supplemented by a temporary emergency source of power for lighting, consisting of storage batteries having sufficient capacity for continuous operation over a period of at least 1½ hours.

The capacity of the temporary and final emergency sources should be determined by the maximum operating loads of the following groups of circuits. The temporary emergency circuits should provide continuous emergency lighting and power for essential communication circuits during the interval between the failure of main source and starting of the emergency generator.

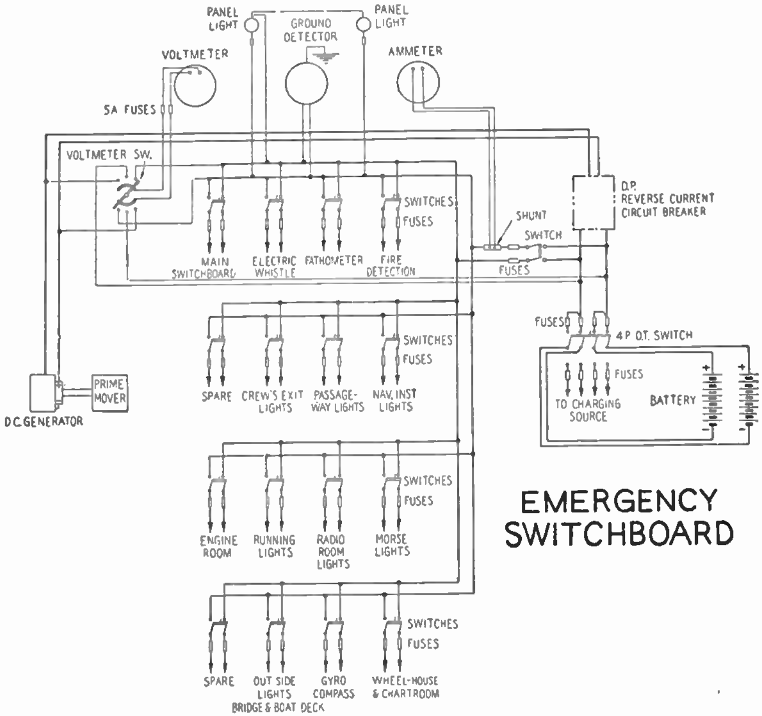


FIG. 46.—Typical emergency control switchboard. This switchboard is usually located on the boat deck and adjacent to the emergency generator set. Power is supplied to the emergency switchboard from the main board on normal operation, and from the diesel driven emergency generator or storage batteries on emergency operation.

The circuits recommended for connection to the temporary emergency lighting storage batteries are as follows:

1. *Temporary Emergency Lighting, Communication and Power Circuits.*

(a) Navigating lights

(b) Machinery space lighting

(c) Radio room lighting

(d) Passenger and crew exits and passageways (including public spaces) adequately to permit passengers and crew to readily find their way to the boat deck. Lights should be located at least at each end of each section of all fore and aft and athwartship passageways and at each stairway and exit on each deck. In no case should the distance between lights exceed 75 feet.

(e) At least one light on each berthing compartment accommodating 20 or more persons.

(f) One or more lights in the galley, pantry, steering gear room, emergency power station, generator space lighting, chart room, pilot house, public spaces, and at all other locations, gauge boards, gauge glasses, etc., essential for emergency operation of the vessel.

(g) Boat deck lighting.

(h) Power for essential communication circuits between bridge, engine room, steering station including telegraphs, if electric.

(i) Watertight door operating gear (if electric) and indicating system.

(j) General or emergency alarm and fire alarm system.

(k) Emergency loud speaker system.

2. Final Emergency Lighting, Communication and Power Circuits to be connected to the emergency generator:

(a) All items enumerated in No. 1.

(b) Life-boat flood lights. The lighting in the vicinity of the life boats and the boat handling equipment, including the flood lighting of water at the sides of the vessel, should be sufficient to permit the complete operation of loading, lowering and releasing of the life boats.

(c) Emergency bilge pump, one fire pump, and one sprinkler pump (if provided).

(d) Other interior communication systems essential for the emergency operation of the vessel.

(e) Radio equipment. (This is in addition to the separate storage battery source required by the Federal Communications Commission.)

The switchboard for the control of the emergency plant should be designed so that all emergency circuits are normally energized through the emergency switchboard from the main generating plant.

The temporary emergency lighting and communication circuits should be transferred to the storage battery automatically upon failure of the main generator supply. In general, all emergency circuits should be provided as independent circuits from the emergency power distribution source. Wire sizes, voltage drops and all other details should conform to the recommendations as previously given.

Passenger Vessels—100 to 1600 Gross Tons.—For passenger vessels of 100 gross tons and less than 1600 gross tons, the emergency source for lighting and power should consist of a diesel engine driven generating set or a storage battery having sufficient capacity to carry the full emergency load for a period of at least 12 hours.

Passenger Vessels—Less than 100 Gross Tons.—For passenger vessels of less than 100 gross tons the emergency lighting system may be approved safety lanterns.

Signal and Communication Systems

General.—Electrical signal systems forming part of the essential operating systems of the vessels should be as independent and self-sustaining as possible. When dependent on a current supply the source of energy should be capable of maintaining the *operation* of the *systems* for a period of *at least twelve hours* and should be independent of the generating plant or as required by the Bureau of Marine Inspection and Navigation.

Electrically operated signalling and indicating systems are recommended for such applications as engine, steering and docking telegraphs and rudder indicators, in preference to mechanical wire or shaft operated systems where the installation necessitates many turns which may be adversely affected by the varying stresses and strains due to loaded and light condition of the vessel.

Installation and Location of Instruments.—All instruments should be installed with a view to securing the greatest amount of mechanical protection. Lamp type indicating devices should be so located that they do not interfere with the vision of the helmsman for light navigation. Pedestal type instruments should preferably be installed on wood deck blocks and caulked at the deck to prevent water collecting under the pedestal base.

Instruments for bulkhead mounting should be rigidly secured in place and should be mounted at a convenient height for ease in reading. It is recommended that the designation plates and marking for all equipment located on the bridge, essential for the operation of the vessel, be of the luminous type.

Any attachments made to machinery or apparatus for the operation of electrical or mechanical indicators should be such that the derangement of the parts will not interfere with the operation of the machinery or apparatus and the deranged parts can be readily removed.

Instrument Construction.—The construction of the various telegraph instruments should be in accordance with the best standard practice for marine installation, the salient points for consideration being the following:

Instruments should as far as possible, be *water-tight*, fitted with suitable terminal tubes for cable entrance and a connection board with marked terminals for each wire.

The outer case should be of corrosion-resistant material and may be either casting, molding, stamping or fabricated construction. If molded composition be used, it should be flame-proof. All small parts should be of corrosion-resistant material or steel suitably protected against corrosion.

The current carrying parts should be of suitable material for the service, such as brushes, copper connection blocks, etc., and all wearing parts should be of sufficient hardness to prevent excessive wear.

All coils should be suitably insulated and impregnated to withstand the conditions of heat, oil or moisture that may be encountered within the instrument by virtue of its own operation or external conditions.

In all electrical instruments (transmitter, indicators, etc.) the transmitting segments, brushes, magnets, motors, etc., should conform to the best general practice as regards construction.

Push Buttons, Bells, Buzzers, Etc.—Construction.—The push buttons, bells and other fittings required in various systems mentioned hereinafter should meet the following general recommendations:

All small parts, including screws, contact elements, etc., should be of *corrosion-resistant material* or steel suitably protected against corrosion.

In all exposed locations, and in boiler rooms, engine rooms, crew's spaces, galleys, working passageways and all similar locations, *water-tight equipment* should be used. The water-tight enclosures for the operating mechanism should be of corrosion-resistant material.

Bells and buzzers should be of rugged construction, suitable for marine service, and not affected by vibration; the appliance to consist of box enclosing the mechanism, cover, and a gong, or vibrator; the mechanism should be readily accessible. The securing of the cover to the box for water-tight appliances should be by means of a coarse screw thread, with a ground joint, or a suitable rubber gasket with four or more securing screws. The box should be provided with at least three lugs for bulkhead mounting, and provide for mounting screws of not less than ¼ in. diameter. Suitable bosses should be provided on the side of the box for tapping for terminal tubes for incoming leads.

There should be at least ¼ inch clearance through air, and ½ inch creepage clearance between all live parts of opposite polarity and between inside of enclosure and any live parts for 115 volts or less.

The exterior surface of the bell box should be painted and gongs should be given a durable finish. The interior of the bell box should be given two coats of suitable insulating paint.

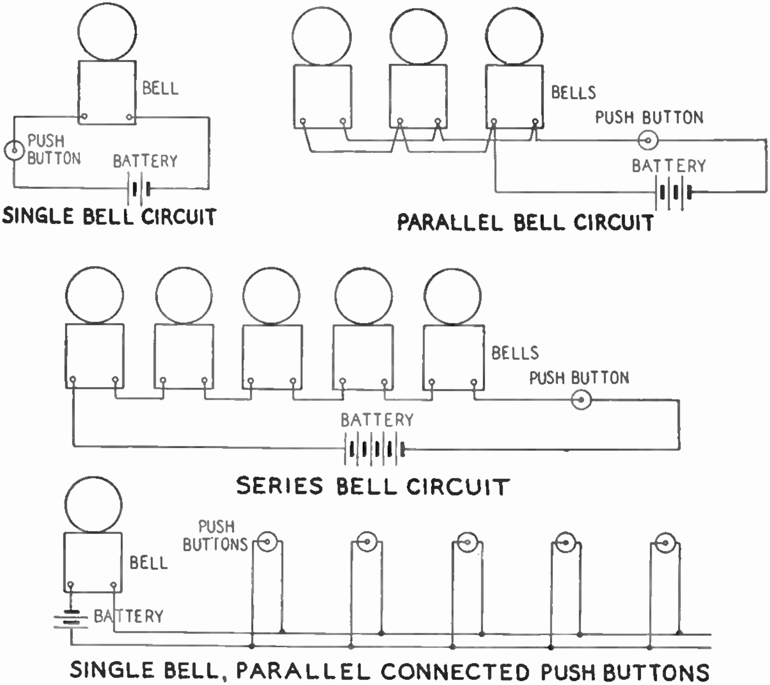
If the design of water-tight bells and buzzers is such that the bell clapper passes through the box, it should be made water-tight. The bell should operate on a 20% reduction in voltage.

Coils should successfully withstand, for a period of 5 seconds, the following high potential test between each electric circuit and ground:

(a) 1500 volts, 60 cylces, for 115 volt coils, or

(b) 200 volts, 60 cycles, for coils of 20 volts or less.

Succeeding the dielectric test the coils should show an insulation resistance of each electric circuit to ground or not less than 1 megohm at 500 volts.



FIGS. 47 to 50.—Various bell circuits. The series arrangement, fig. 49, however, is very seldom used. Since the bells are series connected the potential of the battery must be five times larger than that required by one bell. Another disadvantage is that an open connection anywhere in the circuit will put all bells out of service.

The operation of bells and buzzers should be unaffected by range of temperature from 20°C to 70°C and the winding should be such as to not have a rise in temperature above surrounding air of more than 30°C under 30 minute normal operation.

Name Plates.—All current consuming equipment including telegraphs, bells, buzzers, etc., should be equipped with a suitable *name plate*, giving manufacturer's name, voltage and current consumption or rating.

Engine Order Telegraphs.—Every vessel should be equipped with a *repeat-back signal system* from the navigating officer's station to the engine room.

Any system installed should check within ¼ an indication on the transmitter and receiver and the indication should retain this accuracy. This accuracy should be met with the vessel light and loaded and under the most severe weather conditions. There should be an audible signal with every change in the order and reply.

Mechanically operated telegraph transmitters at the forward and after end of large vessels should not be connected to the same engine room indicator.

Deck mounted transmitters should be mounted with the dials in a fore and aft position, and the movements of the operator's handle should be in the direction of the desired movement of the vessel. The dials should contain at least the following indications or their equivalent:

For Port Dial

Ahead—Full Half Slow

Standby Stop Finished with engines

Astern—Slow Half Full

and should be so constructed that they are plainly visible 10 feet distant and the bridges or deck transmitters should be illuminated from behind the dial for visibility at night. Indicators in the engine room should be mounted as near the operating gear as possible, and equipped with solid brass engraved or the equivalent dials.

Fireroom Order Telegraphs.—Telegraph systems for transmitting orders from engine room to boiler rooms should be of similar construction, installation and operation as engine telegraph system; the transmitters need not be illuminated. The markings should be suitable for the system of air, fuel and feed employed or as required.

Docking Order Telegraphs.—Telegraph systems for transmitting docking orders between the navigating positions and the after bridge, should be of the same construction, installation and operation as the engine telegraph systems. *Transmitters* and *indicators* should be *illuminated.*

Steering Order Telegraphs.—Telegraphs for transmitting steering orders should have a transmitter at the bridge, connected to an indicator at the after steering station and steering gear room. The after steering station and steering gear room indicator is to be fitted with a repeat back signal to the bridge, unless a rudder indicator is installed on the bridge.

Rudder Angle Indicator.—On passenger ships and other large ships as required, an electric rudder angle indicator system should be supplied. The transmitter should be located at the rudder head and actuated by the movement of the rudder, the angular movements being indicated in the pilot house. The *angle* of the *rudder* should be *indicated automatically* at the pilot house station and if the indicator does not move synchronously with the rudder but operates step by step, the minimum indications should be by degrees to ten, then 12½ degrees, 15 degrees and by 5's to 35 degrees. Wherever possible, synchronous type indicating equipment is recommended. The indicator located on the bridge and at the after steering station should be illuminated.

Mechanical Telegraph Installations.—For mechanical telegraph systems all wires, pulleys, chains, sheaves, turnbuckles, springs and wearing parts should be *corrosion-resistant metal.* Pulleys should be of at least 3¾ in. diameter and provided with suitable holes for oiling. All wire should be of brass, at least No. 10 AWG thoroughly stretched before installation. No splices in wire should be used. Chains in pulleys should be used at all turns; bell cranks should not be used. Wires should be turned and wrapped at gongs and pulls. At chains, they should be turned and provided with sleeves. Where necessary, systems should be provided with springs to take up slack wire in the system.

Mechanical telegraph systems operated by wires should be as direct and have as few turns as possible, and should be so installed as to be accessible at all times.

Wires should not be run behind *insulation* for *refrigerator spaces, through coal bunkers or cargo spaces*, except when *unavoidable* and then should be run through tubes for each wire; the tubes terminating so that wire may be *removed* and *renewed* with the bunkers and cargo spaces filled. Wires should not run *behind paneling of rooms* unless made readily accessible by suitable removable covers. Wire should be supported every three feet or when run through members of the ship's structures should be through holes having a diameter not less than two diameters of the wire and should be so installed that they do not bind on the supports or edge of the holes when in motion.

Wires should be protected by suitable covers throughout their length, except as provided for above and for risers in engine room and between decks, where all wires for a single system, not exceeding four, may be run in one tube and not less than three inch diameter. Wires should be spaced at least ⅝ inch horizontally and ¾ inch minimum vertically between centers throughout system.

Engine Order Bells.—For some groups of vessels, bell pulls instead of telegraphs are permitted by the *Bureau of Marine Inspection and Navigation.* The use of telegraphs is recommended in preference to bell pulls. Bell pull systems employing pulls in pilot house, on bridge and on deck houses operating hammer gongs and jingle bells in engine room should be provided with suitable sounding tube with a receiver embracing one-half the gong in the engine room connected by at least 1½ in. brass tubing to a flaring transmitter at all the pull stations; the transmission of sound should be such that it can be heard anywhere in the enclosure and five feet distant in open spaces. The material, installation and operation should be the same as described for mechanical telegraphs. The system should be provided with a *label plate* at each mechanical pull, gong and sound transmitter, giving the systems used.

For *Great Lakes* and *River Rules* see *Bureau of Marine Inspection and Navigation Latest Rules.*

Alarms for Cold Storage Spaces.—In order to prevent injury to personnel, all refrigerated spaces and ice boxes for the storage of ship's stores and provisions should be provided with *a mechanical or electrical signal*. A pull or push button should be *located inside* and at the *exit* of each storage space, and the signal

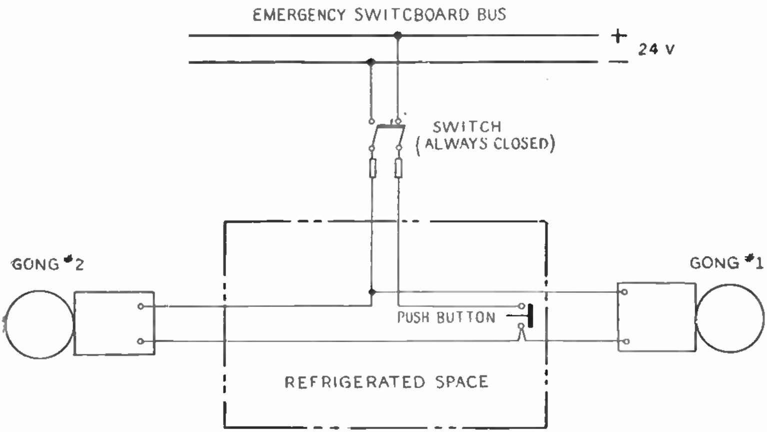


Fig. 51.—Cold storage space alarm wiring. This alarm is designed to protect anyone who may become locked in the cold storage area. The alarm operates from a push button located inside the refrigerated space through gongs or howler located in ship's passageway adjacent to the refrigerated area.

should be located within hearing distance of a location where a person is regularly employed. The signal and pull or push button should be provided with a suitable nameplate to designate its function.

Anchor Windlass Signal.—When the operator of the anchor windlass is out of sight of the man handling the chain, there should be installed between the two positions a bell pull system with a pull on deck and a six-inch gong at the operator's position, or in lieu of this, a 1½ in. voice tube.

General Alarm—(Passenger Ships).—A general alarm system is required by the regulation of the *Bureau of Marine Inspection and Navigation*. General alarm system should be provided on all vessels over 100 gross tons and should consist of not less than *eight inch diameter bells* producing signals of a distinctive type from other bells in the vicinity, and so located that their operation will be heard by all *passengers and crew*. These bells should be controlled by manually operated contact makers from the pilot house, fire control station or stations as determined by *Bureau of Marine Inspection and Navigation*. Each bell should be independently fused and the fuses located above the bulkhead deck. *The system should operate from a source of energy capable of supplying the system for a period of at least eight hours and independent of the main generating plant or as required by the Bureau of Marine Inspection and Navigation.*

Day Passenger Ships.—Same as previous except the bells should be so located that their operation will warn all the crew and the passengers occupying staterooms. *In public spaces and open decks alarm to crew should be visual instead of by bell.* The general alarm system is to comply with the *latest Rules of the Bureau of Marine Inspection and Navigation.*

Cargo Ships.—Same requirements as for Passenger Ships.

Call Bells.—On passenger vessels all staterooms should be equipped with a push button located at the head of the berth to permit a call for assistance, the bell or annunciator being located where there is someone always in attendance. The *voltage* for this system should not *exceed twenty volts*. Annunciators should be of a type requiring the attendant to restore the drop. Annunciator cases should be perfectly tight with holes for entrance of wire only. The wire should be a neat fit

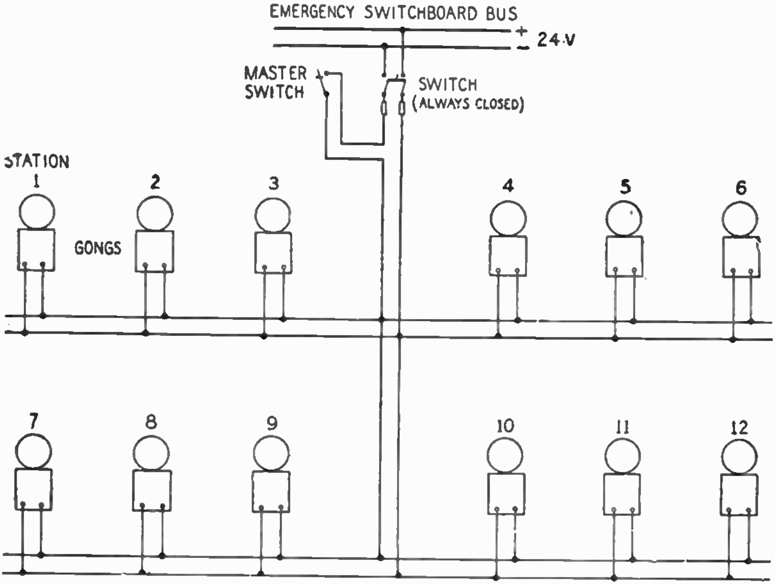
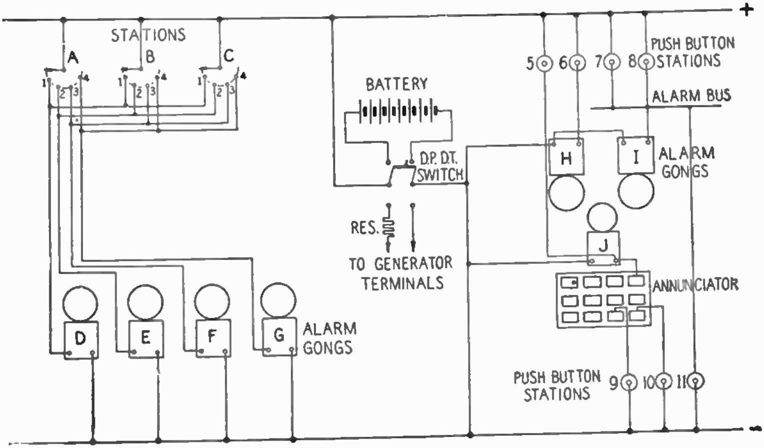


Fig. 52.—Typical arrangement of a general alarm system. The alarm gongs are simultaneously operated from a manual contactor or master switch located in the wheelhouse or at a fire control station. The gongs are spaced throughout the vessel where they may be heard by the crew and passengers at all times.

to exclude vermin. This should, if water-tight, be provided with a gasket between the fixed and movable sections.

If passenger staterooms are equipped with a telephone system that is maintained in operation at all times when at sea, the installation of a call bell system is not considered essential.

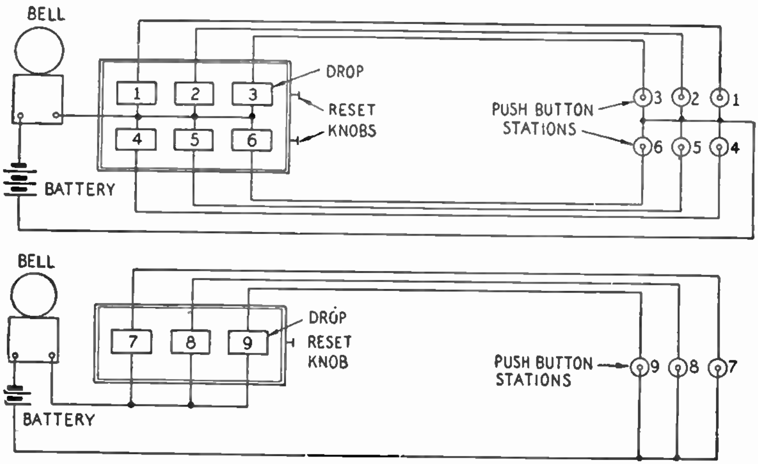
Other call bell systems such as for officers, smoking rooms, or other purposes are to be constructed and installed in accordance with the *Rules* set forth herein.



SHIPBOARD ALARM WIRING

FIG. 53.—Method of alarm wiring. The left part of the diagram illustrates how any one of four alarm gongs may be operated from any one of three alarm stations by moving the selector switch to the contact desired. The current is supplied to the buses through a double pole double throw switch connected either to a battery or to the generator. The operation of alarm gongs *H, I* and *J* is performed by pressing the various push buttons as indicated.

Whistle and Siren Control Systems.—There should be installed *mechanical means* for operating the *ship's whistle and siren* from every *navigating station* regardless of *other systems installed*. The lead should be as direct as possible, amply protected and when suspended for more than 15 feet should be supported from a corrosion-resistant cable with suitable bearers. The systems should be provided with amply corrosion-resistant springs to relieve all weight on the lever and for the proper functioning of the system. All materials should be as described for mechanical telegraph systems.



ANNUNCIATOR CIRCUITS

Figs. 54 and 55.—Typical annunciator circuit. With reference to circuit wiring, it is evident that when any one button is pressed it closes the circuit and energizes a bell at some convenient point and at the same time by a mechanical or electrical device indicates the location of the button.

When *electrically operated whistles and sirens are installed*, all parts should be *independent* of the *mechanical system*. If a motor operated timer is installed, particular attention should be given to its construction or location so that it will be *inaudible* in the *pilot house* and does not affect the *magnetic compass*. The supply for electrically operated signals should be taken from the *emergency system*.

When the electrically operated valve for this system is located more than five feet from the whistle an *automatic drain feature* for the *whistle steam pipe* should be installed.

Morse Telegraph Signalling Lamp.—A signalling lamp is required by the *Bureau of Marine Inspection and Navigation*

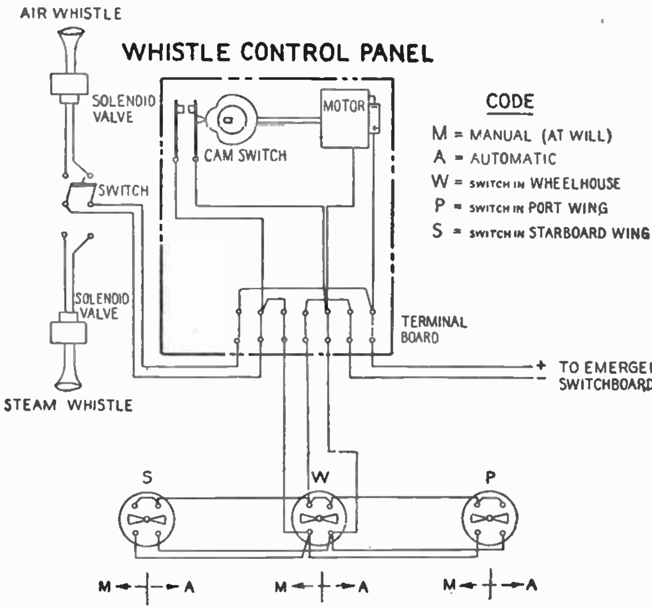


FIG. 56.—Electric whistle control circuit. Recently built ships make use of both electrically operated air and steam whistles. When they are used over a sustained period of time as in the case of fog, etc., an electric timer of the cam operated type is commonly employed. If it be desired to blow the whistle in some particular manner such as three short blasts the switch is pulled to the "*At will*" position three times for a short interval each time

and should comply with the *latest rules and regulations* of that *Bureau*. The signalling lamp should be of *water-tight* construction, fitted with a clear fresnel lens and a 100 watt high-speed lamp bulb, mounted at a height above the pilot house to show completely around the horizon. A number of small size lamp bulbs may be used in lieu of a single lamp bulb.

The signalling lamp should be operated by a *Morse telegraph key* fitted with a *condenser*. The key may be located in the pilot house, or may be provided with a portable cord of sufficient length to reach either wing of the bridge from a receptacle in the pilot house. The type of enclosure for the key should be weather proof if mounted in the pilot house, or water-tight if permanently mounted on either wing of the bridge.

The supply for the signal lamp should be from the *emergency lighting system*.

Alarm System for Lubricating Oils, Refrigeration and Other Circulating Systems.—Whenever a circulating system is installed, the functioning of which affects permanent operation of the ship or preservation of life such as lubricating oil systems for turbine drive, refrigerating systems for passenger or other ships, an alarm system for them should be installed.

On lubricating oil systems, the alarm system should be such as to indicate *audibly* and *visibly* at some definite location when the oil pressure fails, due to shut down of pump or any other cause. In the refrigerating system, the alarm should be such as to ring a bell at a predetermined point and shut down the refrigerating machine motor when the pressure in the circulating water-line to the machine reaches a predetermined low pressure.

The contact maker should be of rugged construction. If a pressure transmitter be provided which depends on electric current for operation, all of the contact parts, coils, etc., should conform to the general requirements given elsewhere.

If the pressure contact maker is of mechanical type, the construction should be strong and rugged.

In either of the foregoing types of pressure transmitters, the electric contacts and connection posts should be suitably protected from mechanical injury and so constructed as to be easily accessible for necessary adjustment.

Telephone Equipment.—All telephone transmitters and receivers substituted for voice tubes or essential for the operation of the vessel should be of *sound powered type* designed specifically for *marine use*, and should be of a type approved by the *Bureau of Marine Inspection and Navigation.* The manufacturer's name, type and model number should be stamped on each telephone.

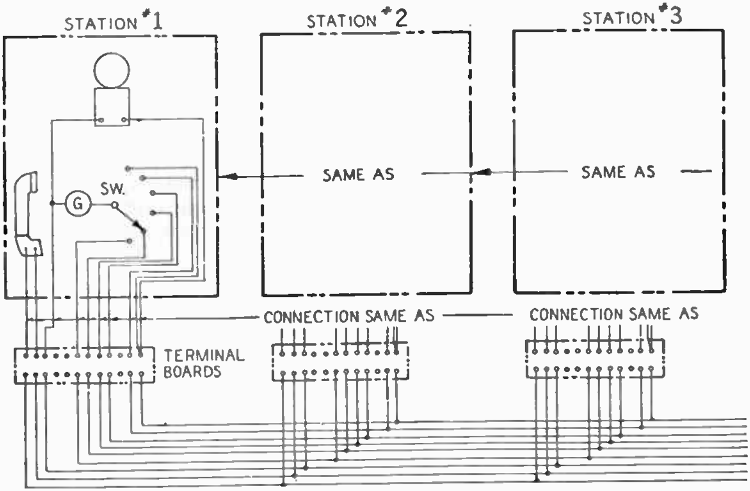


FIG. 57.—Connection diagram of telephone system. The systems now generally in use are of the *self-sufficent* "sound powered telephone" class which derives its power from a permanent magnet and a moving coil. It is sometimes termed a *moving coil microphone* or *dynamic microphone*. This system is used only for short distances, and is therefore limited to ships, buildings, etc. On merchant ships the usual arrangement is to have common talking and selective ringing, using a station selector switch and a hand operated generator.

A call signal and magneto should be provided at each telephone station. This signal may be a bell or other sound device which provides a distinctive signal throughout the space where the telephone is installed. On installations which are protected by water-tight boxes, all signals should be of such character as to comply with the foregoing when the box is closed. Ringers, if located outside the box, should be of *water-tight construction*. All bells and push buttons should be constructed in accordance with the requirements contained herein.

At each telephone installation a suitable hanger for the handset should be provided. It should be constructed in such a way as to hold the handset firmly in place and away from the bulkhead. The handset should not be dislodged from the hanger by the motion of the ship or by a severe shock near the mounting.

Telephones installed at external locations exposed to the weather or in locations subject to severe moisture conditions should be enclosed in a *substantial water-tight cast-metal box*. The cover should be hinged at the bottom of the box and when closed should be fastened by a simple substantial mechanism which, when operated, exerts sufficient pressure to make enclosure water-tight. The gasket should be fastened to and inserted in the edge of the box or cover. The signal generator and switches should be of *water-tight construction*. The generator and all switches should be installed inside the box.

At other locations where a *water-tight box* is not recommended, the telephone equipment should be of splash-proof construction and should be so installed as to mininize possibility of damage by external means. In engine rooms or noisy locations, a booth or other suitable auxiliary equipment should be provided if necessary in order that a telephone conversation can be carried on while the vessel is being navigated.

The system should be installed independent of any other systems of communication or of wiring, but may be extended to cover any other locations which are necesssary or desirable. Telephone cable should be of a type as recommended and should be run as close to the fore and aft centerline of the vessel as possible, and protected from external damage. In some cases *Bureau of Marine Inspection and Navigation* requires two sets of cables in parallel. It should be so installed as to minimize ingress of water and dampness.

The *talking circuit* should be *electrical independent* of the *calling circuit*. A short or open circuit or a ground on either side of the calling circuit should not affect the talking circuit in any way.

Emergency Loudspeaker Telephone Systems.—The *Bureau of Marine Inspection and Navigation* requires the installation of a loud speaker system on certain classes of passenger vessels. All materials, devices, equipment and the installation should be in accordance with the *Bureau of Marine Inspection and Navigation Rules*. For exact requirements, see *Bureau's* latest regulations.

Inter-cabin Type Telephone System.—Commercial type of equipment is recommended subject to the construction details to suit marine installations. Telephone sets may be of the wall type, desk type or hand type to best suit the location. Sets in exposed locations should be water-tight. The switchboard should be suitable for marine service and the ship's wiring and appliances should conform with the requirements of these recommendations.

The power supply should be as specified by the manufacturer and conform to other sections of these recommendations.

Other telephone system operating conditions of the larger size vessels may make the installation of one or more separate intercommunication systems or power amplifier systems with or without talk back desirable. All the equipment required for these systems and the installation thereof should be in accordance with the applicable recommendations specified herein.

Fire Alarm Systems

General.—All materials, devices, equipment and the installation thereof for both fire detection and manual fire alarm systems should be suitable for marine use and should be as approved by the *Bureau of Marine Inspection and Navigation.*

Automatic Fire Alarm System.—Passenger ships with berth or stateroom accommodations should be provided with *fire detecting and alarm systems which should automatically indicate audibly and register visually at the fire control station or stations the presence or indication of fire in spaces constructed of or stowed with inflammable material.*

The fire detection system may be electric, pneumatic tube, pneumatic bulb, smoke pipe, or automatic sprinkler, used singly or in combination with other equally effective systems. They may be either the fixed temperature type or the rate of rise type and the signals from the thermostats may be transmitted either pneumatically or electrically.

Classification of Types.—Electrical systems using thermostats or thermostatic wire actuated by heat to produce visual and audible signals. Pneumatic tube system using thermostats composed of copper tubing containing air, the expansion of which produces visual and audible signals, which are transmitted from the thermostat either pneumatically by copper tubing or electrically.

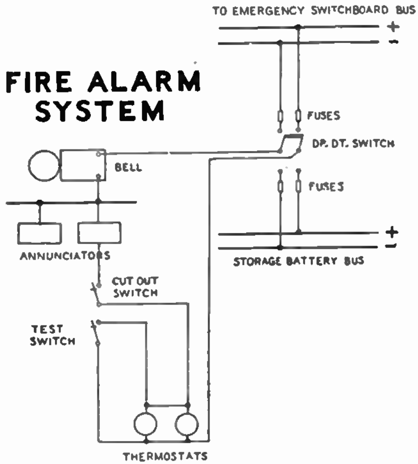


Fig. 58.—Elementary diagram of a fire alarm system. A modern fire alarm system consists of a series of thermostats, located at various points throughout the ship and connected electrically to an automatic, electrically supervised fire alarm circuit panel. The thermostats are arranged so as to make electric contact at some predetermined degree of temperature causing tne fire bells to ring and dropping two red flags, one on the master section of the panel, indicating the bell circuit is closed, and one on the line section indicating the location of fire.

Pneumatic bulb system using thermostats composed of copper bulb containing air, the expansion of which produces visual or audible signals which are transmitted from the thermostats either pneumatically by copper tubing or electrically.

Smoke pipe system in which fire is indicated audibly and visually by smoke drawn through pipes, the discharge of which is suitably illuminated.

Wiring.—*Fire Alarm Systems* should not be used for the transmission of other than *fire alarm signals*. In case of smoke detecting systems, the pipes may be used for the introduction of smothering gas.

All electrical systems should be normally free of electrical grounds, except a ground introduced for supervisory purposes.

All conductors should conform to the specifications for lighting, power and interior communication wiring, and the use of leaded and armored cable is recommended throughout the vessel.

The fire alarm annunciator should be so designed that an accidental cross of the fire alarm wiring with the lighting system will not damage or render the fire alarm system inoperable.

Electrical and Pneumatic Systems.—For detail requirements, consult the *Bureau of Marine Inspection and Navigation requirements.*

Location of Detectors—Electrical Systems.—For detail requirements, consult the *Bureau of Marine Inspection and Navigation requirements.*

Pneumatic Systems.—For detail requirements, consult the *Bureau of Marine Inspection and Navigation* requirements.

Zoning.—For detail requirements, consult the *Bureau of Marine Inspection and Navigation* requirements.

Manual Fire Alarm System (Passenger Ships).—*Manual fire alarm system should be provided on all ships and should consist of at least one manually operated fire alarm box, having a red finish,* for each detection zone (except cargo spaces, inaccessible during voyage) located in stairway enclosures, corridors and public rooms, readily accessible to passengers and crew.

The system should register visually for each detection zone in the fire control station or stations and should automatically ring gongs of a distinctive sound from other gongs in the fire control station or stations, the navigating station, the engine room and the quarters of the fire fighting crew.

In vessels fitted with an automatic fire detecting and alarm system in accommodation spaces, the manual system may be a part of the automatic system.

All materials, devices, equipment, etc., and the installation thereof are to be approved by and in accordance with the latest requirements of the *Bureau of Marine Inspection and Navigation.*

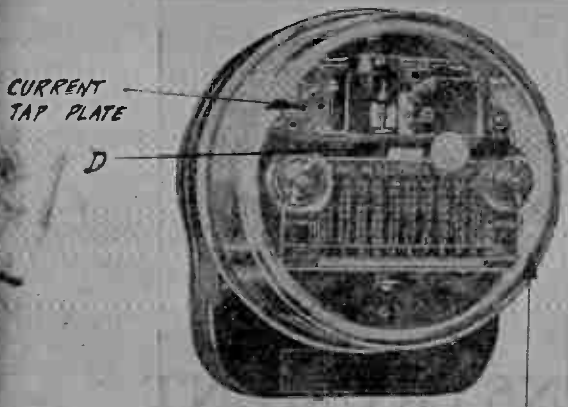
Smoke Pipe Systems.—The smoke pipe systems for fire detection consist of individual pipes installed from collectors located in the compartments to be protected to an indicating cabinet located in the pilot house or fire station. A circulation of air is maintained through the pipes by means of a suction fan located adjacent to the indicating cabinet. In case of fire in the compartment, the smoke is drawn through the pipe to the indicator cabinet.

This type of system should be fitted with an audible alarm that will call attention to the receipt of smoke in the indicator cabinet. Suction fans should be provided in duplicate and arranged so that the idle unit is ready for immediate operation in case of failure of the operating unit. All wiring should be in accordance with the recommendations given and all electrical circuits supervised so as to give a warning in case of failure of motor, wiring, main power supply, etc.

Automatic Sprinkler System.—Each system should have an annunciator with lamp or drop for each sprinkler zone. The indicating device should be located in the fire control station, or stations, and should *automatically ring gongs located in the fire control station, or stations, navigating control station, the engine room, and quarters of the fire fighting crew.* The *electrical supply* for this system should be from the *emergency lighting system.*

RELAYS AND INSTRUMENT CONNECTIONS

OVERLOAD RELAY

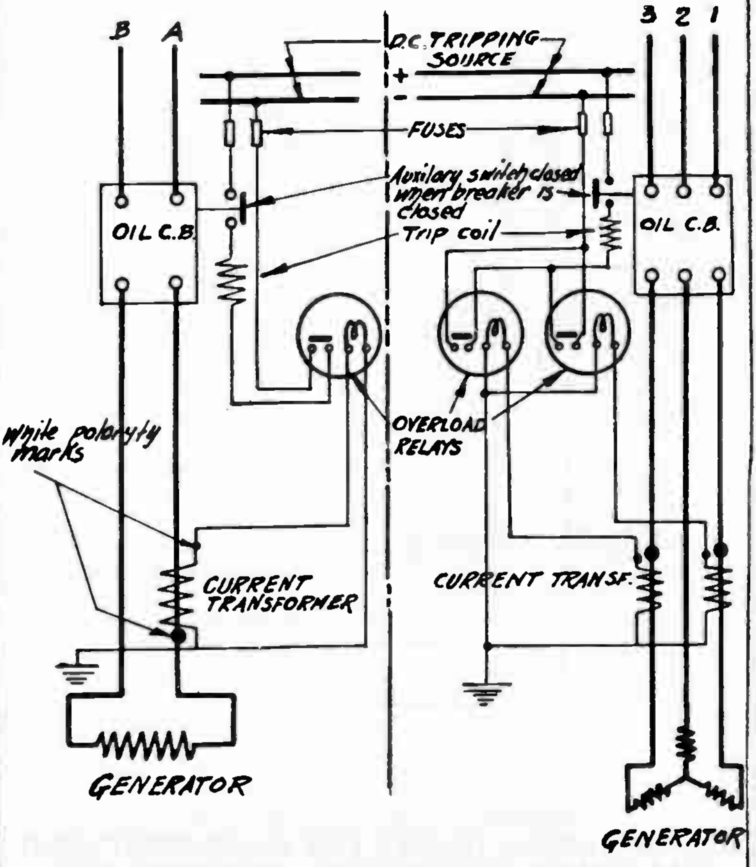


TIME LIMIT INDUCTION TYPE
OVERLOAD RELAY

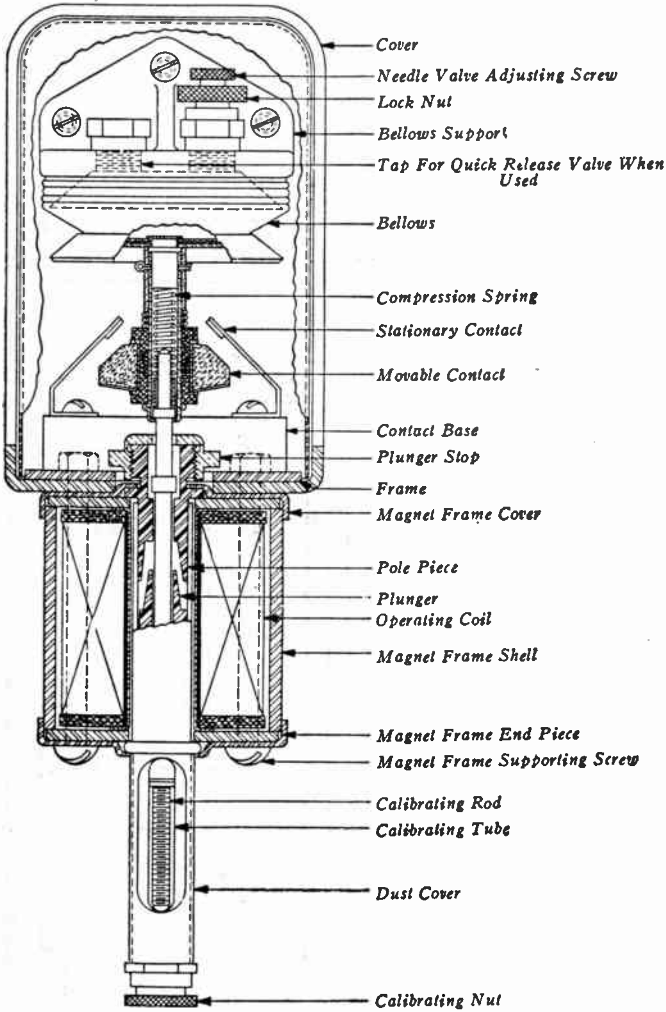
OPERATION: In general the relay operates as follows: When an overcurrent exceeding the setting at which the relay is to operate occurs, the rotation of the disk "D", actuated by a "U" shaped driving magnet and retarded by a pair of permanent magnets, causes the contacts to close after an interval of time which depends upon the amount of current passing through the relay, and also predetermined by the setting of the time lever.

For typical wiring diagram; see the following page.

OVERLOAD RELAY CONNECTIONS

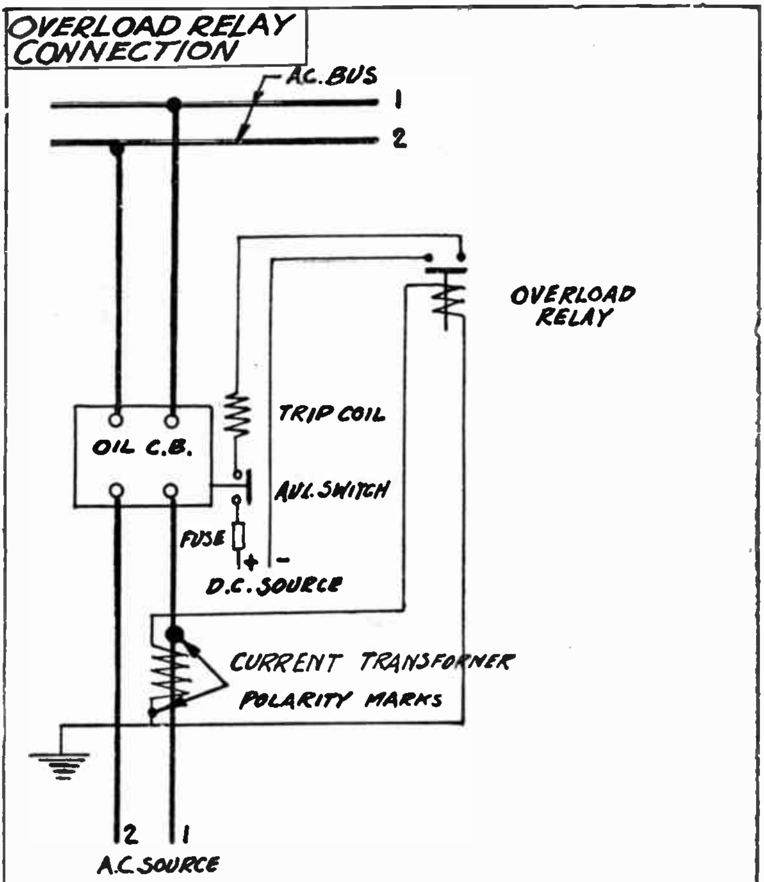


OVERCURRENT RELAY

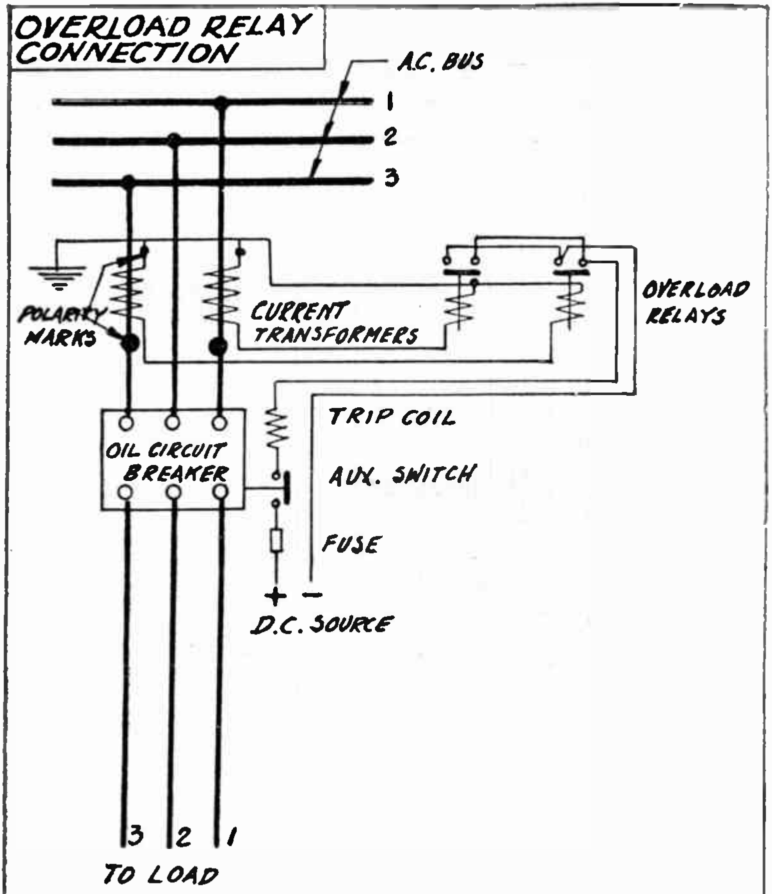


SECTIONAL VIEW OF PLUNGER TYPE OVERCURRENT RELAY

FOR APPLICATION AND CONNECTIONS, SEE FOLLOWING PAGES.

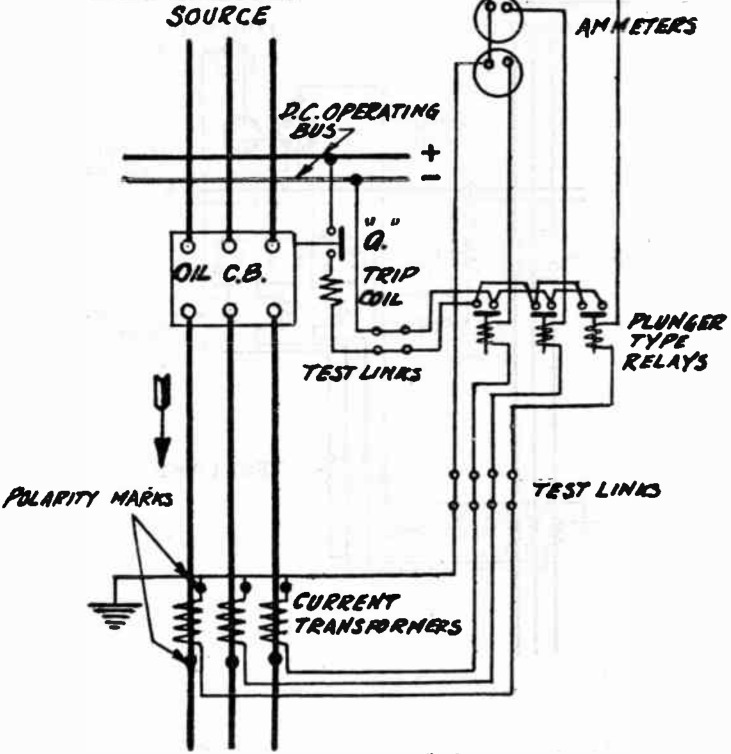


APPLICATION OF OVERLOAD PROTECTION TO SINGLE PHASE A.C. NETWORK.



APPLICATION OF OVERLOAD PROTECTION TO A THREE PHASE A.C. NETWORK.

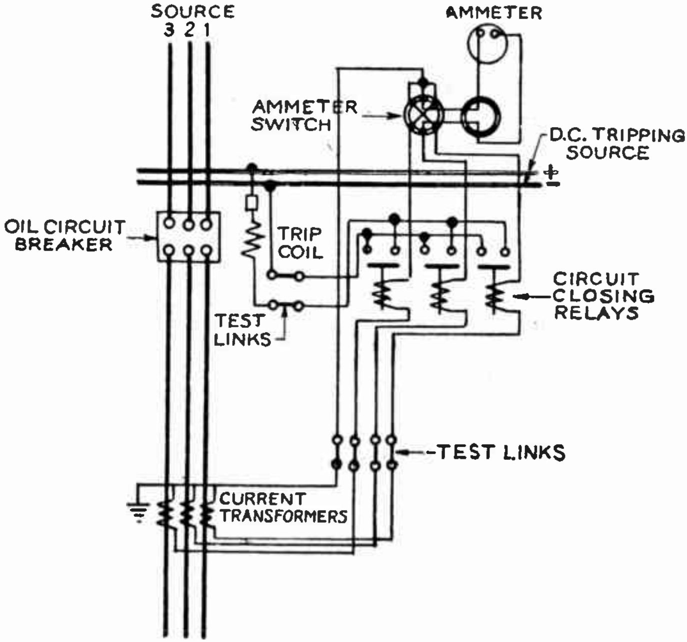
OVERLOAD RELAY CONNECTION



Note: "Q." AUXILIARY SWITCH CLOSED WHEN BREAKER IS CLOSED.

OVERLOAD PROTECTION OF A.C. FEEDER SHOWING APPLICATION OF TEST LINKS, FACILITATING TESTING RELAYS AND METERS.

OVER CURRENT PROTECTION



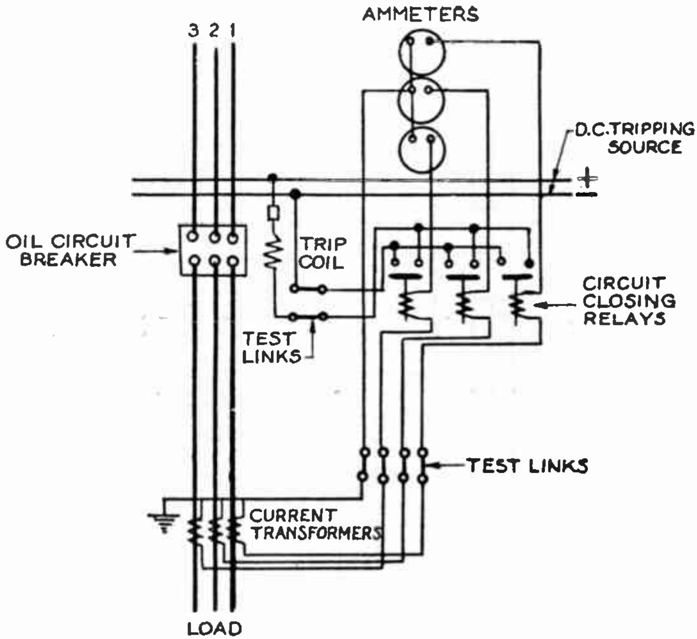
Overload protection on typical A.C. feeder circuit

OPERATION: When current exceeds the setting of the relays, the relays will close their contacts energizing the trip coil, which trips the oil circuit breaker.

The test links shown are optional but will, if used, facilitate the testing and calibration of instruments.

The current in each phase is measured by means of ammeter and three way switch.

OVER CURRENT PROTECTION



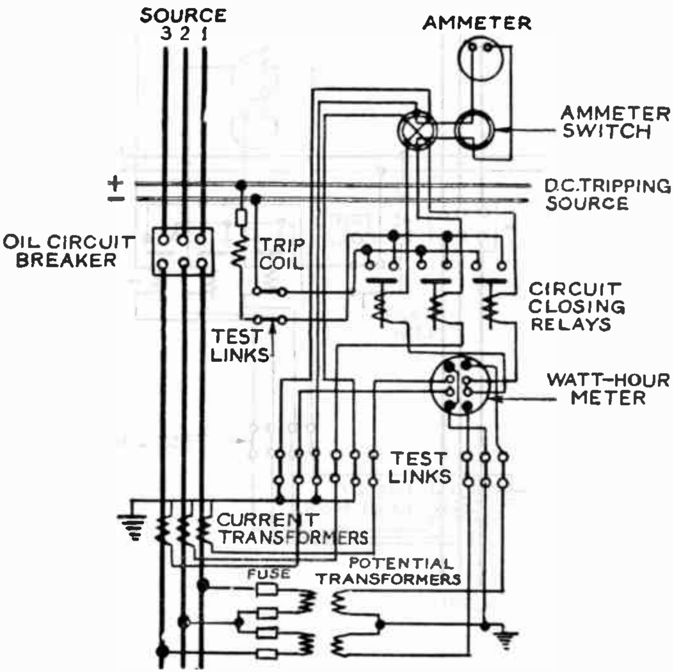
Overload protection on typical A.C. feeder.

<u>Operation</u>: When current exceeds the setting of the relays, the relays will close their contacts, energizing the trip coil which trips the oil circuit breaker.

The test links are optional but will, if used, facilitate testing or calibration of instruments.

The current in each phase is measured by individual ammeters.

OVER CURRENT PROTECTION



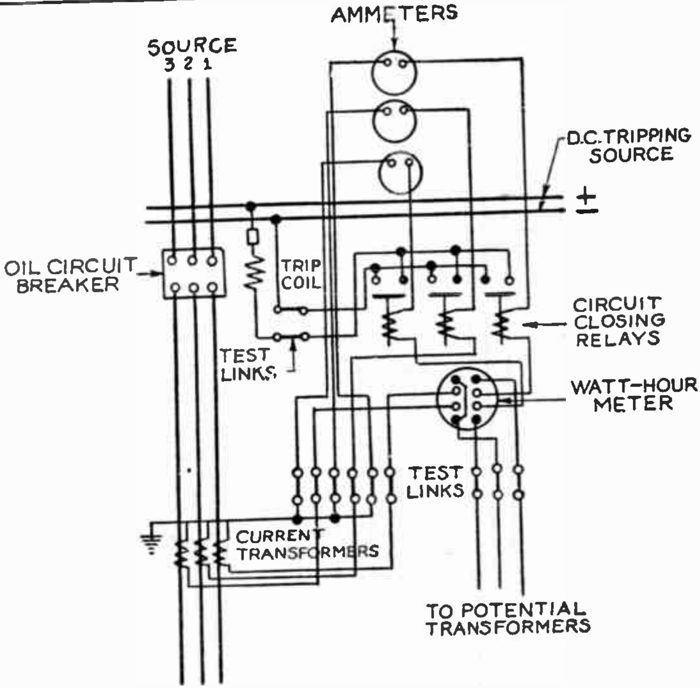
Overload protection on typical A.C. feeder.

OPERATION: When current exceed the setting of the relays, the relays will close their contacts, energizing the trip coil which trips out the oil circuit breaker.

The energy is measured by means of a watt-hour meter, and the current in each phase by ammeter and three way switch.

Test links shown are optional but will, if used, facilitate the testing of relays and instruments.

OVERLOAD PROTECTION

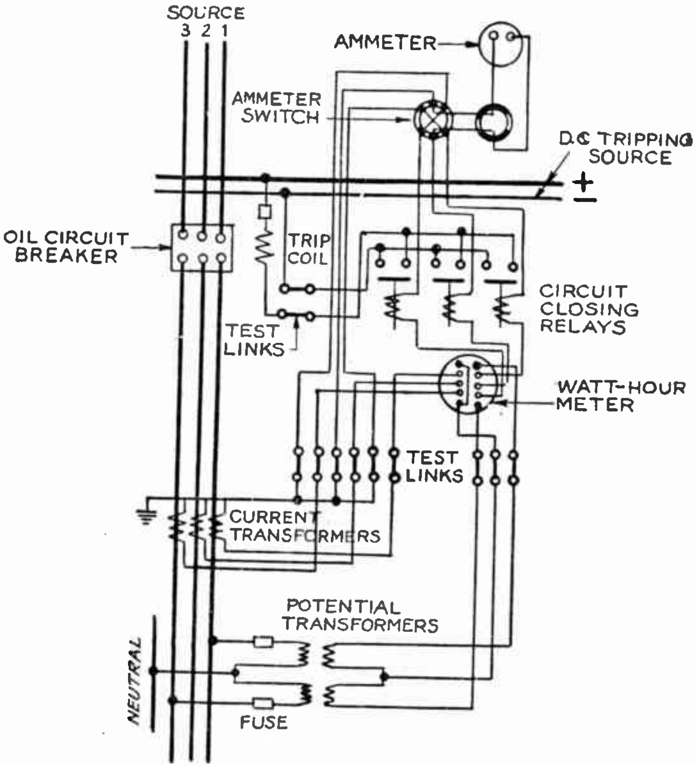


Overload protection on A.C. feeder.

Operation: When the current exceeds the setting of the relays, the relays will close their contacts, energizing the trip coil which trips out the breaker.

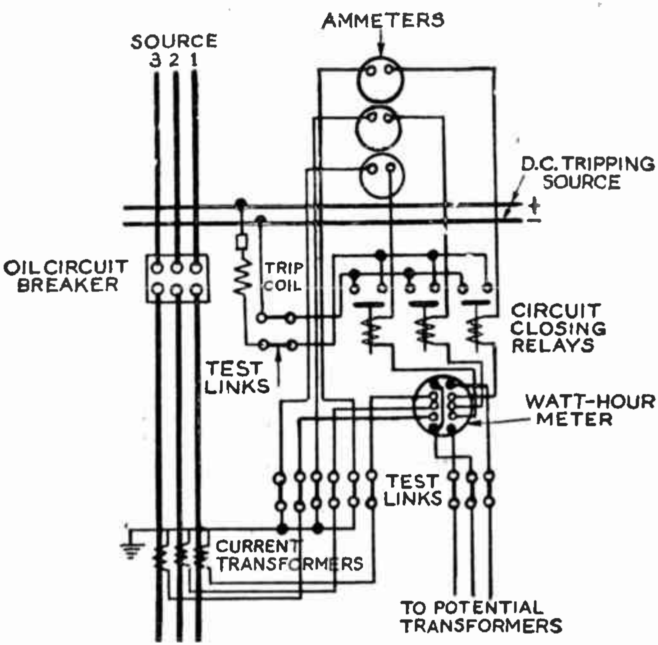
The energy is measured by means of a watt-hour meter, and the current in each phase by individual ammeters. Test links are optional but will, if used, facilitate the testing or calibration of relays and instruments.

OVER CURRENT PROTECTION



OPERATION: When current exceeds the setting of the relays, the relays will close their contacts energizing the trip coil, which trips out the oil circuit breaker.
The energy is measured by a watt-hour meter. and the current in each phase by ammeter and three way switch.
Test links are optional but will, if used, facilitate the testing and calibration of relays and instrument.

OVER CURRENT PROTECTION

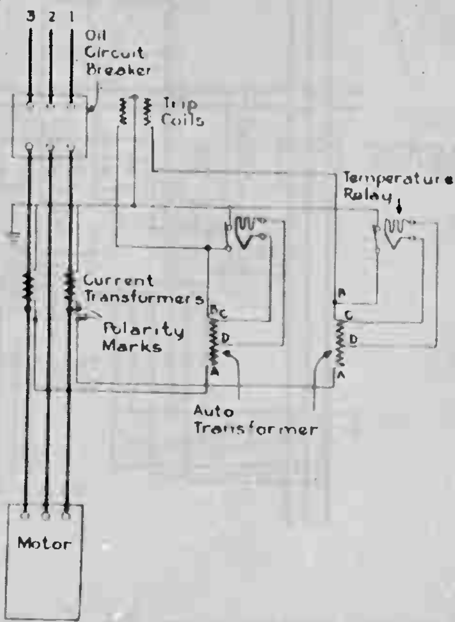


Overload protection on A.C. feeder.

OPERATION: When current exceeds the setting of the relays, the relays will close their contacts energizing the trip coil, which trips out the oil circuit breaker.

The energy is measured by means of a watt-hour meter, and the current in each phase by individual ammeters. Test links are optional but will, if used, facilitate the testing of relays and instruments.

TEMPERATURE OVERCURRENT PROTECTION



Temperature overcurrent protection for synchronous motor using temperature relays.

OPERATION: When the overcurrent exceed the rating at which the relays is set to operate, the heating effect of the current passing through the relays will cause the relay contacts to close and energize the trip coils which trips the oil circuit breaker. The relays operating charactaristics is usually inverse-time, in that the time to operate the relay varies inversely with the overcurrent applied.

CHAPTER 25

Cable Splicing

The proper *splicing* or *jointing* of electrical wires and cables is very important and unless properly done, costly failures are likely to occur.

In general, splicing of ordinary 600 volt, rubber insulated wire is not a very difficult task. The splicing of cables for higher voltages and cables of special construction such as armored cables or portable cables, however, requires a special technique.

Electrical Power Distribution Companies consider cable splicing a most exacting profession and have accordingly instituted *special schools* for the teaching of same to their employees.

Due to the adoption of higher voltages, a great deal of attention has been given to the general problems of joints because of the difficulties under which they are made. Such difficulties are: (1) *the necessity of working in cramped positions in moist manholes*; (2) *the lack of positive control of the workmanship in making joints, and* (3) *the required neatness in the work of handling and installing the conductors themselves.*

Also a great deal of attention and study has been given, not only to the materials by which the cable itself is insulated, but also to the question of securing a suitable compound with which to fill the joints of the cable. Obviously the standard of dependability of the joint must be equal to that of any part of the cable itself.

On the average there is about one joint for every 300 feet of lead covered underground cable installed in the various duct systems throughout the

United States. There are of necessity a large number of joints in an underground cable system of even moderate size.

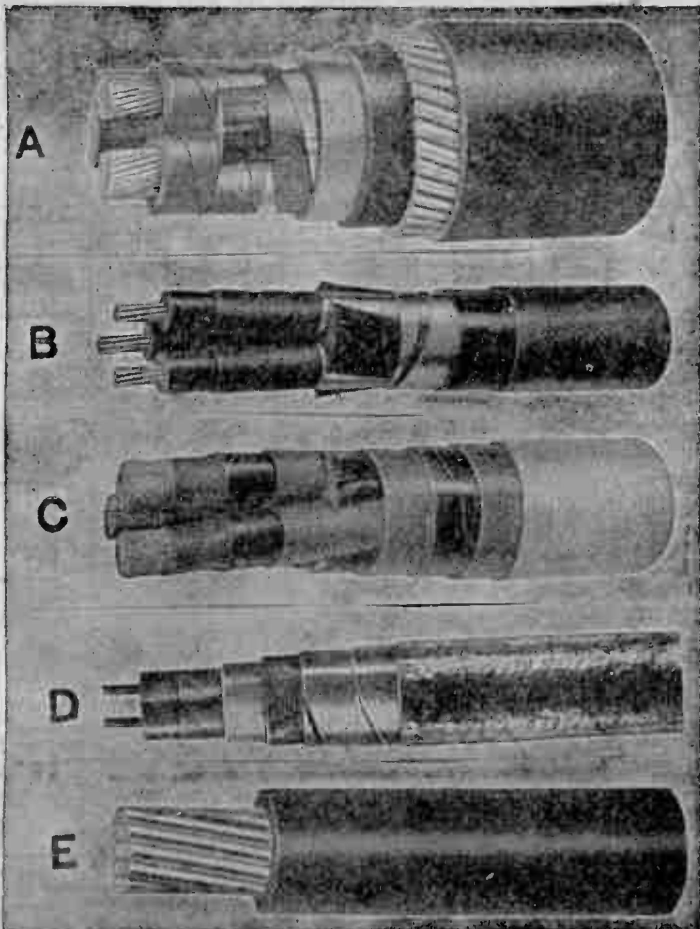
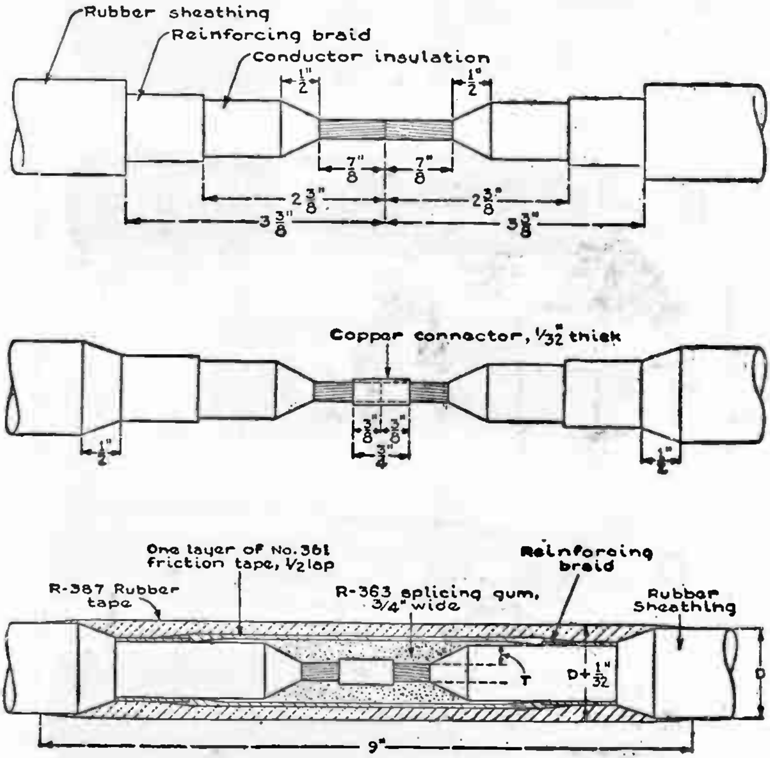


FIG. 7,396.—Illustrating various types of cables. Illustrations **A** represents an impregnated paper, lead sheathed power cable; **B**, aerial cable: **C**, asbestos cable; **D**, metallic armored parkway cable; **E**, super-sheath cable.

One of the most widely used methods of insulating joints on cables is to first wrap (after the metallic conductors have been properly soldered together) each of the exposed sections at the joint with some form of insulating tape which is built up in successive layers to the desired thickness. After the conductors are insulated singly, there is a further belt of insulation wrapped around the outside of the three conductors in the same manner as the insulation placed on the individual conductors. These



FIGS. 7,397 to 7,399.—Showing a step by step method of splicing a portable cable. In fig. 7,397 the rubber sheathing, reinforcing braid and conductor insulation are removed, and conductor insulation penciled. Fig. 7,398 shows the copper connector assembled in place and rubber sheathing penciled. Fig. 7,399 finally shows splice completed with splicing gum and friction and rubber tape applied. The joint should now be vulcanized.

wrappings although they may be put on as carefully as the limited facilities in the field will permit, cannot be applied as tightly uniformly or with the same certainty of the highest grade of workmanship as the insulation on the undisturbed section of the cable. The various uncertainties that creep into the making of cable joints in the field are due partly to the cramped conditions under which such joints are made, the occasional unfavorable weather and the impossibility of always insuring the first class quality of material and workmanship.

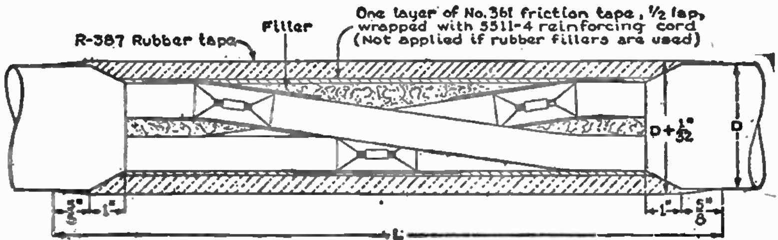


FIG. 7,400.—Showing joint for 600 volt portable type W cable, illustrating the staggering for individual splices.

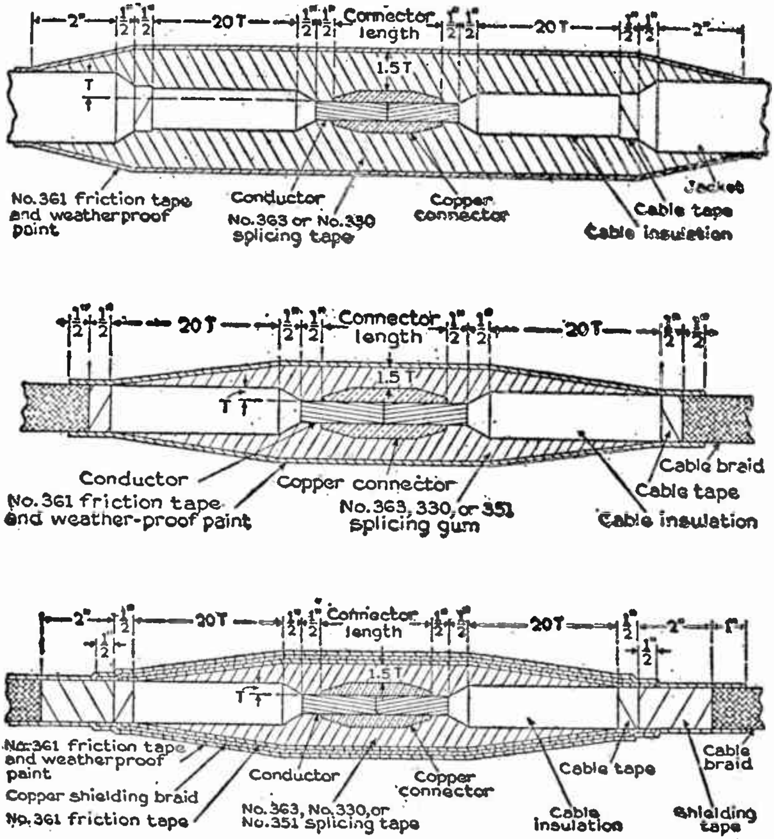
Effects of Air Pockets.—An additional factor of vital importance, but not affected by either moisture or careful workmanship is the necessity of excluding all air from the wrapped insulation as it is built up, or from the space within the sleeve which is supposed to be entirely filled with compound.

The result is occasional, although small air pockets in the insulation which invite the slow formation of ozone and consequently ultimate deterioration due to the resultant chemical action.

The net result with the best of workmanship, material and conditions is uncertain as to the dielectric quality of the joint. This uncertainty is particularly emphasized in the higher voltage cables due to the more rapid formation of ozone.

Function of Compounds.—This was formerly thought to be that of an insulator which could be put in place in liquid form and which, when so placed, could be sealed in against the possibility of escape.

No further requirements were considered necessary. Later investigation however, has shown that the problem of pre-



FIGS. 7,401 to 7,403.—Splicing methods for various power cable types. Fig. 7,401 shows splicing of a rubber-jacketed single conductor non-shielded cable. Fig. 7,402 splicing of a single conductor, braided rubber insulated non-shielded cable. Fig. 7,403 splicing of a braided single conductor shielded rubber insulated cable.

venting the occurrence of voids and air bubbles is one of the greatest importance, because, due to corona effect, ozone is formed in these air bubbles and this formation results in slow chemical deterioration of the insulation.

Cable Insulation.—Underground transmission cables as now manufactured are insulated with paper tape applied evenly in several layers to build up the desired thickness and then impregnated with rosin oil compound.

Tests of this kind of insulation indicate that owing to characteristics of the rosin oil compound, the critical temperature above which a cable cannot be safely operated is between 70° and 80° C. (158° to 176° F.) Beyond these temperatures the dielectric losses increase very rapidly, causing deterioration of the insulation and eventual breakdown.

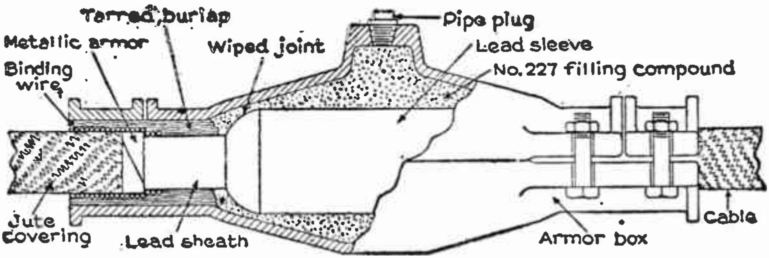
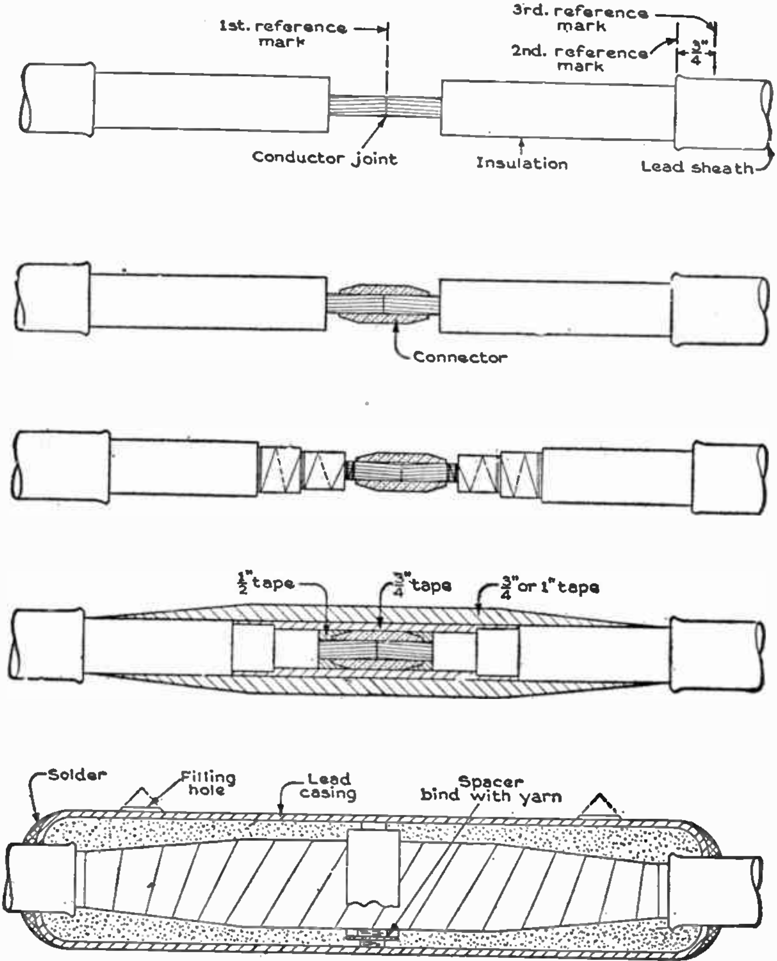


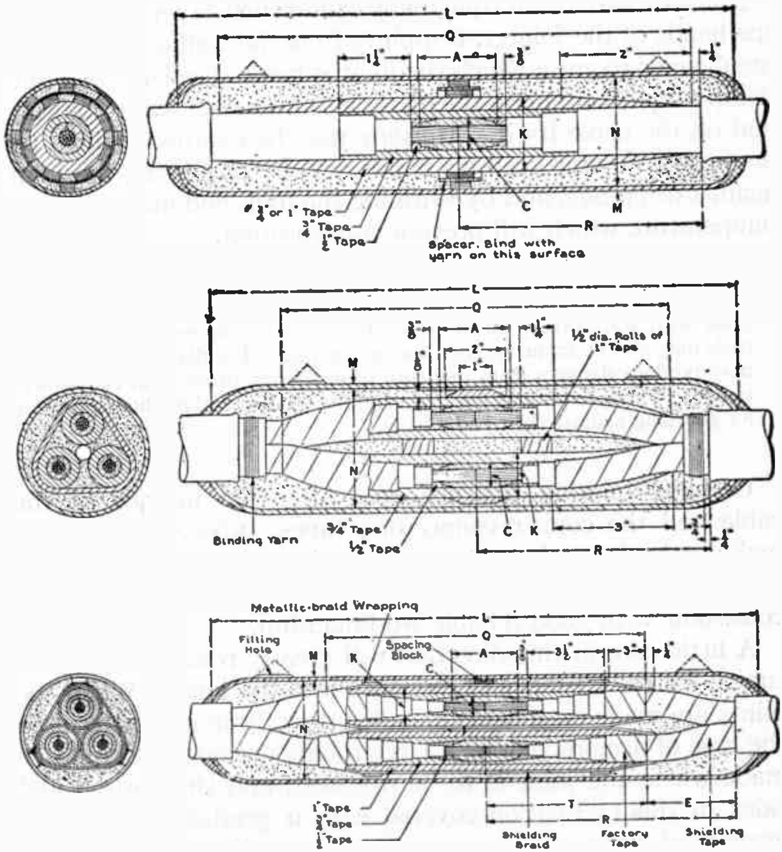
Fig. 7,404.—Showing method of installing an armor box over a lead-sleeve joint on leaded armored parkway cable.

Unsatisfactory Compounds.—Hard or waxy compounds are unsatisfactory fillers as they require very high temperatures to keep them in a fluid state so that they will run freely into all parts of the joint, and high temperatures as already explained are to be avoided as far as possible, so as not to endanger the



FIGS. 7,405 to 7,409.—Showing successive steps when splicing a leaded cable. In fig. 7,405 the cables are brought together, lead sheath removed and enough insulation removed to permit assembling the connector. In fig. 7,406 the connector is assembled centrally over conductor joint. Fig. 7,407 shows cable insulation stepped and bound. Fig. 7,408 reinforcement tape applied. Finally, fig. 7,409 shows the completed joint with spacer and casing in place and filled with compound.

insulation of the cable, particularly the insulation lying directly in front of the filling hole, against which the compound is poured at its highest temperature.



FIGS. 7,410 to 7,415.—Showing completed joints of various type cables. Where dimensions are indicated by letters, manufacturers recommendations should be obtained as these dimensions will vary depending upon cable size and voltage.

Excluding Moisture in Joint Making.—Moisture in the material of the cable itself, or on and in the copper connectors, tapes, insulating tubes and lead sleeves must be thoroughly removed and thereafter kept away.

Moisture may result from many causes such as perspiration on the hands of the jointer, drippings from the wall or roof of the manhole or room in which the joint is made, condensation in a damp atmosphere upon the materials and tools used in jointing and on the cable itself. *Moisture* may be guarded against by having the jointer keep his hands dry, by protecting the joint against drippings, and by warming the tools and materials to a temperature which will prevent condensation.

A convenient method of protecting the tapes or other fibrous insulating materials against moisture in the air is to have a metal box with a cover, filled with transformer oil in which they can be immersed. The small tools may also be immersed in a similar manner. Peculiar local conditions may produce dangers from moisture from sources other than those mentioned. These conditions must be carefully studied and methods provided for guarding against their bad effects.

General Jointing Instructions.—After the interior of the cable and the copper connectors, tapes, tubes, etc. used in making the joints have been exposed to the atmosphere, all operations should be carried through as rapidly as possible consistent with good reliable workmanship.

A little care in this direction will greatly reduce the opportunity for the entrance of moisture into the joint. When the joints are made on a cable installed directly in a trench, as in the case of armored cable, a large roomy excavation should be made where the joint is to be installed, and the bottom and sides of this excavation covered with a good-sized tarpaulin or piece of clean canvas so as to prevent dirt getting on the joint material. Only the most skilled workman can produce reliable joints particularly where the working voltages are high. Only proper tools, carefully maintained in condition, are permissible and they must be kept clean and dry. Knives or cutters used for cutting the insulation should be kept sharp so that the insulation may be cut readily without tearing.

The removal of the lead sheath must be performed in such a manner as to absolutely prevent any cut or indentation in the insulating belt underneath. Lead cutters or chipping knives should be used so as to cut the lead without producing an indentation in the underlying insulation. The belt insulation must also be carefully removed and cleanly cut so as to avoid any cutting of the insulation on the insulated conductor; and finally, in taking off the insulation from the conductor, strict attention must be paid by the jointer so that no cuts or nicks are made on the bare copper conductor.

Solder and insulating compound, as well as the pots and kettles in which they are melted, must be carefully watched and constant attention given to them, so as to avoid the presence and accumulation of dirt and foreign matter of any kind in these very important materials. A very slight quantity of metallic particles or other more or less conducting materials, in the insulating compound which is poured into a joint, will often result in a breakdown.

Making the Joint.—The various operations to be performed in joint making are shown in the accompanying illustrations, which are supplied by the courtesy of the *General Electric Company*.

Cable Maintenance.—Periodic inspection of cable and wire is the best assurance of preventing failure. Cable inspections need not be made as often as is necessary for electric equipment, but are, nevertheless, equally important. If a system of maintenance has not been in effect, the first thing to do is to inspect all cable and wire circuits for overloads, poor thermal conditions, and for potential danger spots.

All of these faults, after being listed, can be systematically eliminated. After the original inspection has been made, the period of inspections can be from six to twelve months.

Overloads can easily be checked by means of a hook-on ammeter, thus avoiding the necessity of disturbing cable connections. Cable temperatures can best be determined by placing a suitable thermometer on the cable surface.

Cable Testing

Tests on insulated wires and cables may be divided into two classes: (1) Factory test and (2) test on samples.

The factory test (usually made by the manufacturer) consists of: *High voltage test*; *ionization test* (change in power factor with voltage); *insulation resistance test* and *conductor resistance test.*

High Voltage Test.—This test is made to detect weak spots in the insulation and to determine whether its dielectric strength is sufficient to enable it to withstand the voltage it is likely to meet in actual service, with a suitable factor of assurance.

It is made in applying A.C. voltage of suitable magnitude between the conductor (or conductors in multiple conductor cables) and sheath or water.

The initially applied voltage must not be greater than the working voltage, and the rate of increase must be approximately uniform, not over 100% in 10 seconds and not under 100% in 60 seconds. The voltage must be applied for a duration of time as specified for the various types of wires and cables.

If for any reason the high-voltage test is interrupted, the total duration shall be increased 20% of the specified values.

The frequency of the test source shall be between 25 and 60 cycles per second, preferably 60 cycles. The voltage wave source of energy shall be of ample capacity.

Ionization Test.—This test is made only on paper insulated cable designed for over 7.5 kv. operating voltage, and then only when specified by the Engineering authorities.

The power factor of the dielectric shall be measured at room temperature with an alternating current voltage corresponding to 20 and 100 volts per mil of the prescribed thickness of the wall of insulation under test. In no case shall the high voltage (100 volts per mil) be less than 150% of the rated voltage of the cable.

The power factor of a cable may be determined as follows:

$$\text{Power factor} = \frac{W}{EI}$$

Where W = Dielectric loss (in watts).
I = Charging current (in amperes).
E = Impressed potential (in volts).

The difference between the power factor determined at the two prescribed voltage shall not exceed the values specified by the Engineering authorities. This test is made to determine to some degree, the proper impregnation of the insulation.

Insulation Resistance Test.—Insulation resistance of cables is measured either by a "Megger" or by a high resistance voltmeter. The formula for insulation resistance for one mile is:

$$R = Lr_o\left(\frac{E-V}{V}\right)10^{-6}$$

Where E = Battery potential.
V = Voltmeter reading.
r_o = Resistance of voltmeter.
L = Length of line in miles.

A voltmeter having a resistance of 100,000 ohms is generally used, with a source of potential of 100 to 150 volts.

CHAPTER 26

Sign Flashers

There are two advantages in favor of using a flasher: 1, it causes the passerby to look at the sign, and 2, reduces the cost of electricity, because the lamps are switched off periodically.

There are numerous kinds of flasher, and they may be classified, according to construction of the switch contacts, as:

1. Carbon 2. Brush 3. Knife

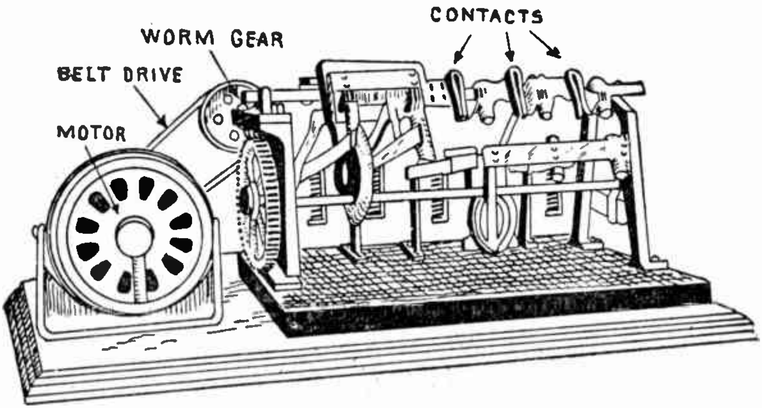
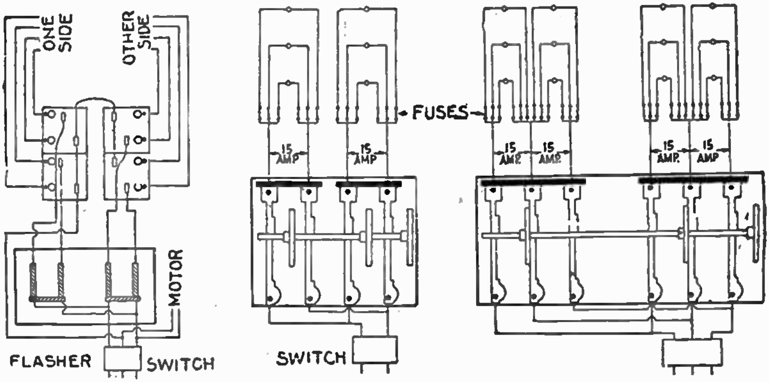


FIG. 7,421.—Dull's carbon type flasher. This is a main line flasher; that is, it is set into the main wires instead of carrying down each circuit. The circuits are opened and closed on carbon contacts, reinforced with standard knife switches. The blades are opened and the current broken by gravity alone. Each switch can be made to hold the lights for any period from 18% to 81% of a revolution of the shaft. They can throw on the circuits progressively or all on and all off together. Again, the circuits may be closed progressively, remain on a few seconds, and then be opened progressively. No circuit or circuits can be closed more than once per revolution.

Again, with respect to operation or the electrical effects, they may be classified as:

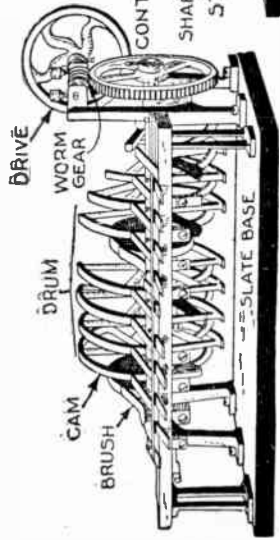
1. Simple on and off
2. High speed
3. Lightning
4. Script
5. Chaser
6. Thermo
7. Carriage
8. Talking
9. Electric.

Carbon Flashers.—In this type of flasher, carbon breaks are provided, that is, the arc which is formed when the circuit is



FIGS. 7,422 to 7,424.—Wiring diagrams for Dull's carbon flashers. Fig. 7,422, usual method of wiring. The load is balanced by running the neutral wire around the machine, to the cut outs, breaking the outside "legs" only of a 220-110 volt sustem. While this method of wiring is entirely feasible, it is no harder on the contacts, and permits the use of a cheaper machine, but it is technically a violation of the underwriters' rules, which say that all circuits of more than 660 watts must be broken double pole. If the load be balanced there would be double pole break at 220 volts, and the lamps would be in series, but if the load be not exactly balanced, there would be single breaking to the extent of the amperes over the average balance. In other words, it is a double break and it is not according to circumstances, and the use of this machine wired as above is a matter that should be taken up with the local inspector before installing. Fig. 7,423, diagram for connecting a straight two wire carbon flasher on a two wire system. Fig. 7,424, diagram for connecting a straight three wire carbon flasher on a three wire system and breaking the neutral.

broken, falls on carbon, while metal switches are provided to carry the load. Thus the carbon gets the arc which prevents the switches burning, while the switches carry the load to prevent the carbons becoming heated and disintegrated. The carbons must



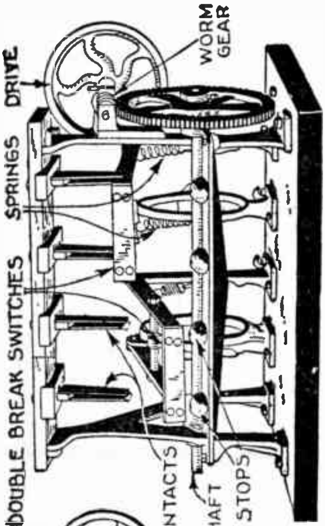


FIG. 7,425.—Reynolds' brush type flasher. The brush type, as its name indicates, is of brush construction and is limited to 5 amperes capacity on each switch. The cams constituting a drum are of heavy construction while the brushes are of fine copper several leaves thick. It is most commonly used for spelling signs, that is, for letter by letter flashing.

FIG. 7,426.—Reynolds' knife type of flasher with metal contacts. The construction is cheaper than the carbon type. It is mounted on a slate base, and is heavily built throughout. The switches are designed for 15 amperes capacity double break.

be adjusted occasionally according to the load they are carrying. Carbon machines are made either double, triple, or series break.

Brush Flashers.—These machines are provided with brush contacts. These bear on cams constituting a drum, and they are usually made of several strips of copper. Brush flashers are generally used for spelling out signs one letter at a time, or work of a similar nature.

Knife Flashers.—This type of construction is cheaper than the carbon type. The switches are of the knife type with metal contacts. One manufacturer states that it is not advisable to build knife flashers for more than 15 amperes per double pole switch, as they cannot be depended upon to break a greater load for any length of time.

Simple On and Off Flashers.—These are used for flashing whole signs or heavy loads on and off. A flasher of this type

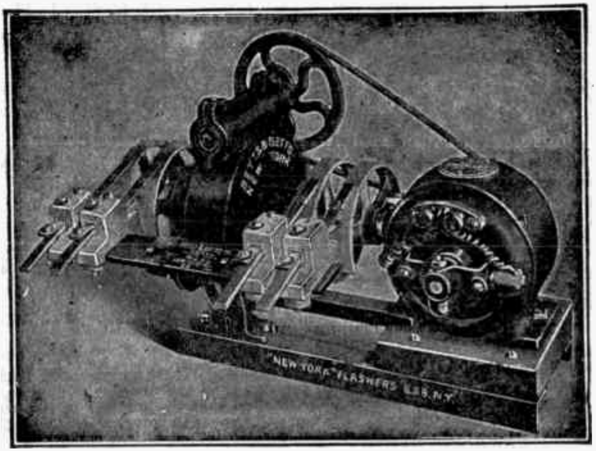


FIG. 7,427.—Simple on and off double pole flasher for "all on" or "all off" sign flashing The machine is furnished with any number of switches ranging from 5 amperes up.

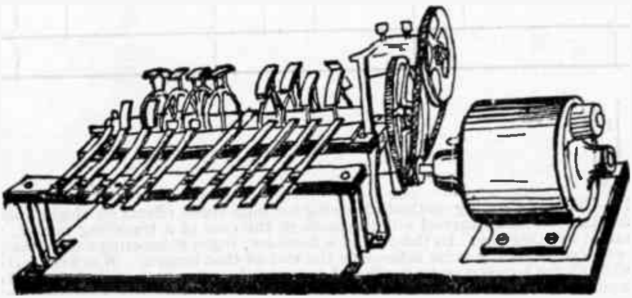
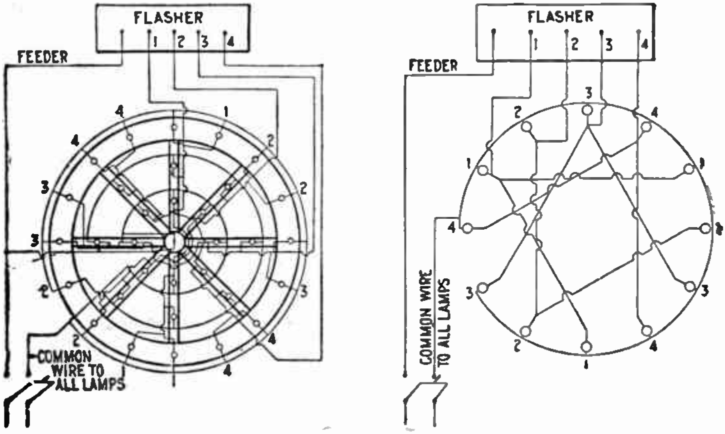


FIG. 7,428.—Dull's high speed flasher. It is mounted on a slate base 12 inches wide, the length being governed by the size of the machine. Motion is given to the rotary switches through worm and belt gearing. Iron cams are used, the current being taken therefrom by six-leaf brushes, provided with stiffeners. The wiring for the machine is simple; 4 *c.p.* lamps can be run on one wire. A border or ornament containing 160 lamps requires 12 wires between the sign and flasher. The flasher is made in 4 switch sizes only, viz.: No. 4, 8, 12, 16, etc. This is due to the fact that there are three parts of light to one of darkness.



FIGS. 7,429 and 7,430.—Wiring diagrams for high speeds. Where a high speed flasher is used on a spoked wheel containing more lamps in the rim than the number of spokes, the extra rim lamps must be connected to the spoke circuits, so that the number of rim circuits will equal the number of spokes; otherwise, the rim will appear to travel slower than the spokes.

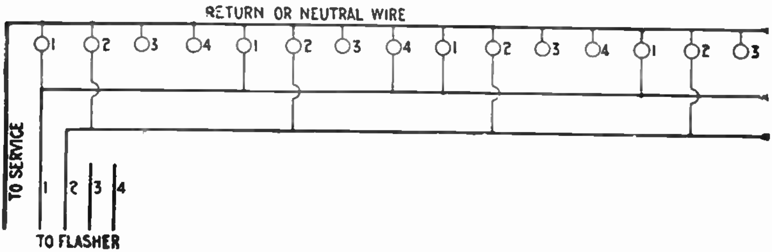
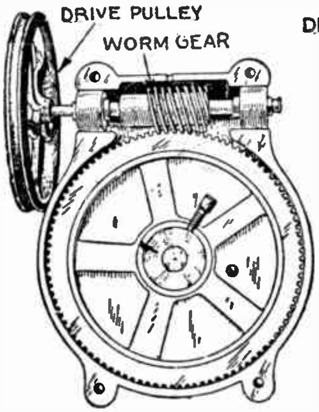


FIG. 7,431.—Diagram showing method of wiring for high speed effects on single lines. This wiring diagram would be carried out the same in the case of a travelling border, whether it be straight or otherwise. In the case of a fountain, begin numbering each stream at the bottom and carry out the same scheme to the end of that stream. When several streams are parallel, all the lamps may be connected in a row the same as though they were an individual lamp. Care should be taken not to get more than twenty No. 1 lamps on a circuit. Among the effects that may be obtained are a revolving wheel, a column of flame, and a straight travelling border with part of the No. 1 lamps from each effect to the same No. 1 wire, carry it back to any No. 1 switch on the machine, and the effect will come out right. *For instance,* in a flame effect with sixteen No. 1 lamps, four No. 1 lamps could be taken in the straight border, and put on the same wire, and the effect would come out right. The spacings for high speed effects vary, according to the size of the sign. Travelling borders around an ordinary sign 3×10 feet should have their lamps spaced about six inches apart. In a fountain fifteen feet high. the lamps should be spaced about nine inches apart.

consists essentially of a revolving double pole switch with reducing gear and connection to a small motor for operating same.

The machine may have only one switch or any number of switches. The connection to motor may be by belt or chain, or the motor may be directly connected to the worm gear.

High Speed Flashers.—Machines of this type are used for giving what is generally known as *high speed effects*, such as



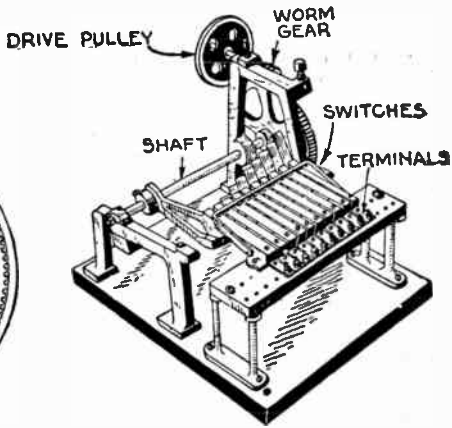


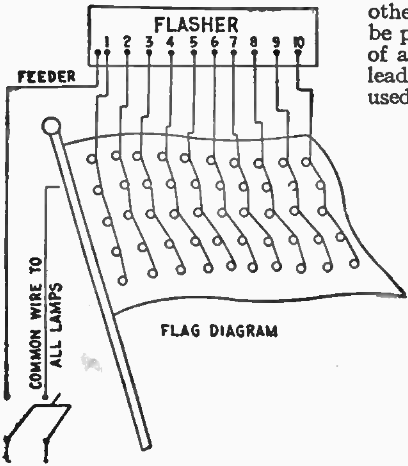
FIG. 7,432.—Sign flasher transmission gearing. The view shows an oil tight gear case with cover plate removed. The gears are equipped with ball bearings and run in graphite grease. By means of the worm gear the large speed reduction necessary between the flasher shaft and motor is obtained without a multiplicity of gear wheels.

FIG. 7,433.—Dull's lightning type flasher for giving the appearance of a streak of lightning going across a display.

fountains, water, steam, smoke and fire effects, whirling borders, revolving wheels and work of a similar nature.

Lightning Flashers.—These machines are for giving the appearance of a streak of lightning going across a display. There is very little expense attached to their operation, because not more than two-thirds of the lamps are turned on at one time, and this number for only about one-sixth of the time, as compared with the sign burning steadily.

Lightning strokes can be utilized in various ways, either alone or with other advertising pieces. Alone they can be placed along a cornice, across the front of a building, up and down the corners leading to a doorway, etc. They can be used in the center of a sign with letters



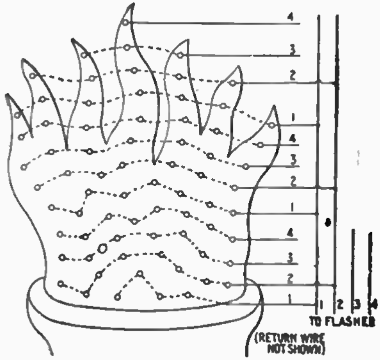


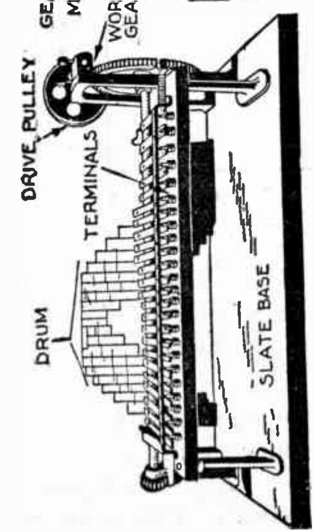
FIG. 7,434.—Wiring diagram for flags. These may be wired for high speed flashers by gradually increasing the lamp centers between the vertical rows from the flag staff to the end.

FIG. 7,435.—Method of wiring for a torch. This wiring diagram gives the correct method of wiring smoke, flames, steam, and water effects. It may be the flame in the top of a torch as here shown, liquid pouring out of a bottle, smoke rising from a cigar, or dust behind an automobile wheel. The only difference being in the direction each goes and the outline of the bank of lamps. Wire the lamps in unequal lines across; avoid any straight lines, because it gives a mechanical effect which is not natural. If the effect be to rise, mark the lower row No. 1, the next row above No. 2, etc. Pick up all the No. 1 rows until there are twenty lamps, and attach them to No. 1 wire which will go back to any No. 1 switch on the machine. Do the same with the other numbers. Do not overload line as this will decrease the life of the contacts.

above and below. In this case, it is best to alternate the stroke with the letters, that is, flash the wording on and then off. As soon as it goes out, the stroke flies across in the darkness. then the wording comes up again, say six times a minute.

In the case of a sign already in use, on the front of a building or over the sidewalk, a stroke can be placed leading to the sign from any point above. The flash goes down and when it hits the sign the latter lights up, holds a few seconds, goes out, and repeats about four times a minute.

Lightning flashes are not usually constructed for heavy loads, the one shown in fig. 7,433 being designed for two amperes.



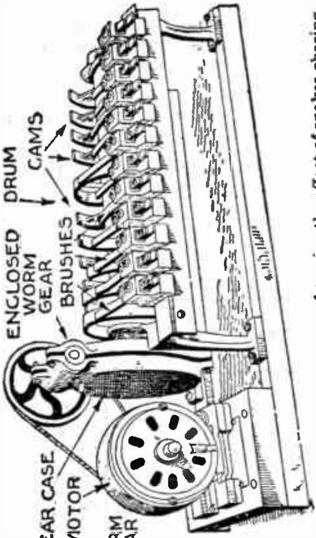


FIG. 7,436.—Reynolds' chaser type of flasher, as used on electric signs whose amps are arranged to give the effect of snakes chasing each other around the border of a sign.

FIG. 7,437.—Betts' script breaker (brush type). This flasher is especially designed for spelling out signs one letter at a time, or work of a similar nature. The brushes for the revolving cam contacts are of copper, several leaves thick and provided with special brush holder to prevent loose contact and abnormal burning.

Chaser Flashers.—This class of flasher is designed to operate signs whose lamps are arranged to give the effect of snakes chasing each other around the border.

This peculiar effect is produced by having a separate wire and a separate switch on the flasher for each two lamps in the border.

The mechanism so arranged that when the tenth lamp is lighted (assuming the snake to be ten lamps long) the first lamp goes out.

When the eleventh is lighted, the second goes out, etc., progressing in this way around the entire border.

In operation, the lamps are turned on and off so rapidly that it produces the effect of snakes.

It is not advisable to build these signs small nor cheaply, as in order to produce the desired effect, the curved path taken by the snake should cover at least 10 inches width, which would mean a total of 20 inches lateral space for the snake in addition to the electric letters in the center. In order to get the proper effect, the sign should be at least ten feet long.

Chaser signs are expensive because of the care required in their construction, large amount of wiring necessary and large flasher required.

There are several ways of operating these signs. The border is generally working continuously, while the center can be flashed or not, as may be desired. Flashing the wording reduces the current expense, which offsets in a measure the extra cost of the sign. The border, although working continuously consumes very little current.

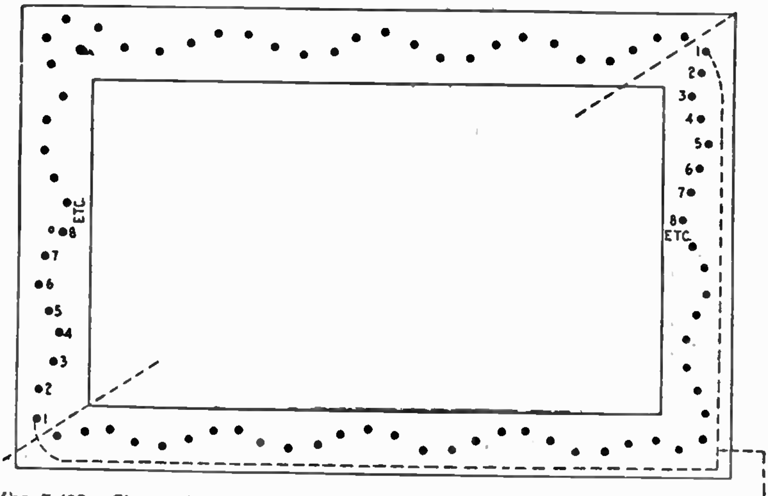


FIG. 7,438.—Chaser wiring diagram for two snakes. Draw a line diagonally through the sign (as shown in dotted line) so that one-half the total lamps will be on either side. Begin to number from one consecutively to the line. Over the line commence again at 1, and number as before. For three snakes, divide total lamps into three parts and number as before *In each case,* connect all lamps of the same number to the same wire whether the sign be single or double face. The wire containing all the No. 1, lamps goes to the No. 1 switch on the flasher, and the remaining sets are connected similarly.

Script Breakers.—Flashers of this type are used for breaking large script signs, one socket at a time; that is, each lamp is lighted one after another until all are on. After a few seconds they all go out simultaneously and repeat. This gives the appearance of an invisible hand, writing the name in the darkness, and is very effective. The result can be accomplished only with script, and to get the proper effect the smallest letter in a sign should be not less than two feet high; the larger the letter, the better the effect.

Script breakers are also used for fancy border signs of other kinds, and in order to produce these results, it is necessary that

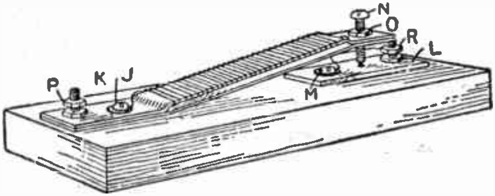


FIG. 7,439.—Thermo flasher. *It consists of* two metal strips, one of brass and the other of iron, about 5″×½″×1/32″ each. The brass strip is provided with a winding of fine wire over asbestos and the two strips are connected to the base as shown. One terminal of the winding is connected to J, and the other end to M. At the end of the strips is a small contact screw N, with locknut O, and below is a contact plate L, fastened to the base and terminal post R. The flasher is connected at P and R, in series with the lamp it is to flash, and N, adjusted so that it clears the plate about 1/32 inch when there is no current flowing in the winding. When the switch is turned on there will be a current through the lamp and winding in series. The brass strip will be heated more than the iron and it will expand more, thus forcing the point of the screw N, down upon the brass plate, which will result in the winding about the brass strip being shorted and the full voltage will be impressed upon the lamp, and it will burn at normal candle power. When the coil is shorted there will of course be no current in its winding and the brass strip will cool down, the screw N, will finally be drawn away from contact with the brass plate, and the winding again connected in series with the lamp. The lamp will apparently go out when the winding is in series with it, as the total resistance of the lamp and winding combined will not permit sufficient current to pass through the lamp to make its filament glow. The time the lamp is on and off may be varied to a certain extent by adjusting the screw N.

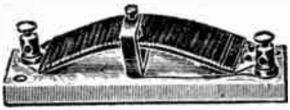


FIG. 7,440.—Thermal flasher. This simple flasher consists of a brass strip fixed at each end to a porcelain base and slightly arched upwards. The amount of this arching, however, is much less than is shown in the figure. The center of the strip carries a platinum contact on its upper surface, and opposite this is a platinum tipped contact screw which is carried in a brass angle piece fixed to the base. One terminal is fitted on one end of the strip, and the other is connected, through the angle piece, with the contact screw. The strip is wound from end to end with an insulated resistance wire, one end of this being soldered to the strip, and the other connected to the right hand terminal. When this device is switched into circuit with the lamps, the current first flows through the resistance, which cuts it down so much that the lamps are not visibly affected. The heat generated in the resistance causes the strip to curve still more, till at length contact is made, the resistance short circuited, and the lamps lighted.

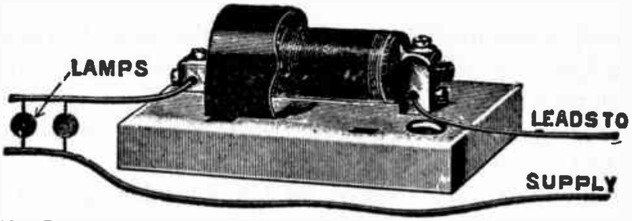


FIG. 7.441.—General Electric thermal flasher. *It consists of* a small brass cylinder fixed at its left hand end to one of the terminal blocks. The junction between the two is hidden by a portion of the cover, which is shown broken away. The right hand end of the cylinder carries a cross piece bearing a platinum contact; and opposite this is the platinum tip of a contact screw carried in the other terminal block. The cylinder is wound with a heating coil of manganin resistance wire, one end being soldered to the cylinder and the other to the right hand terminal. When the current is switched on, the coil and the cylinder warm up and the cylinder elongates sufficiently to make contact and light the lamps. The coil being then short circuited, it and the cylinder cool down and contact is broken, whereupon the coil is put in circuit once more, and warms up again. In some sizes of this flasher, the contact gap is shunted by a small condenser fitted beneath the base. This helps to eliminate the sparking at the contacts.

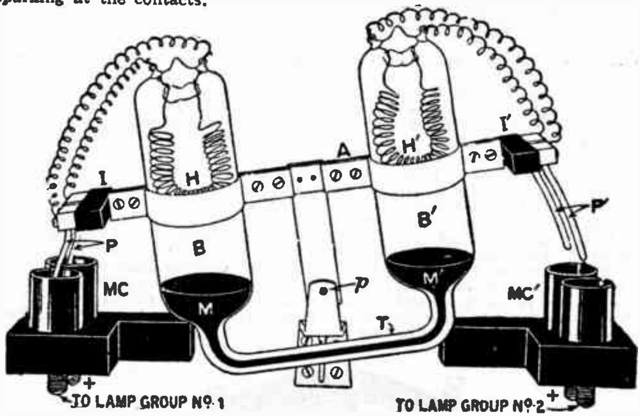


FIG. 7.442.—Two way thermal flasher. The moving portion consists of a rocking arm *A*, pivoted at *p*, and carrying two sealed bulbs, *B*,*B'*, whose bottoms are united by the tube *T*. Inside there is sufficient mercury *M*, to fill *T*, and the bottoms of the bulbs, the remainder containing air. At each end of *A*, is fixed an insulating block *I*,*I'*, carrying two contact prongs *P* and *P'*, which are connected together at the top through heater wires *H*, *H'*, sealed in the bulbs *B* and *B'*, respectively. *MC*, *MC'*, are pairs of mercury cups, the further one of each pair whose stud is marked +, being connected together to the positive pole of the circuit, while the front ones are joined up to the respective groups of lamps. *In operation*, if the apparatus be in the position illustrated, when the circuit is closed at the time *B*, is down, lamp group No. 1 will light up the current passing through *H*, on its way. The air in *B*, consequently expands, and gradually forces the mercury down in *B*, along *T*, and up in B'. The arm *A*, will gradually become horizontal, and will then over-balance, *P*, being withdrawn from *MC*, and *P'*, dipped into *MC'*. Lamp group No. 1 will consequently be extinguished and lamp groupNo. 2 lighted; *H*, will cool down, and *H'*, will warm up. Thus, in due course, *A*, will be titled the other way again.

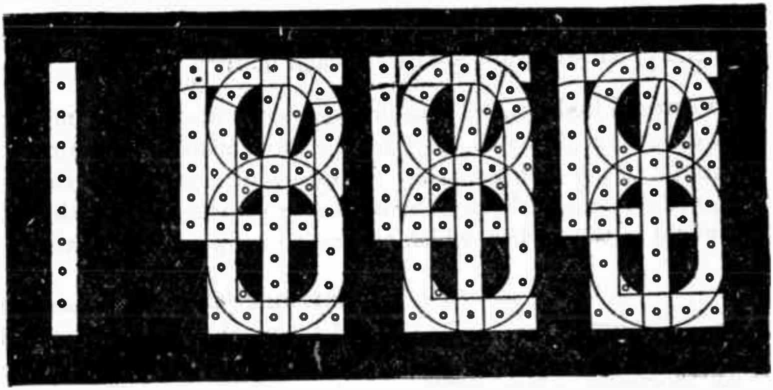


FIG. 7,443.—Clock monogram or electric sign clock, operated by the mechanism shown in fig. 7,444.

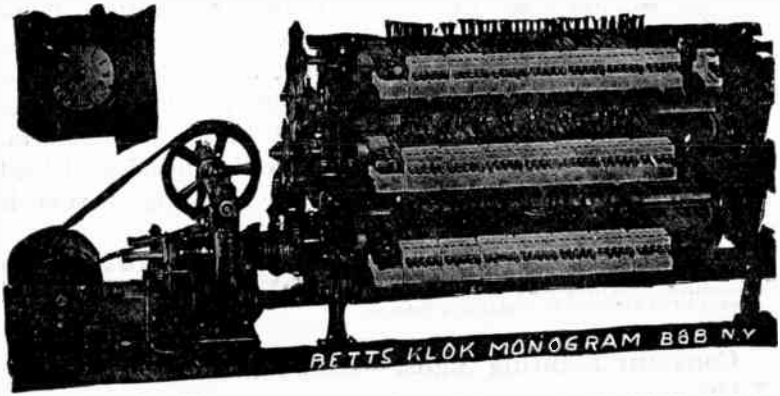
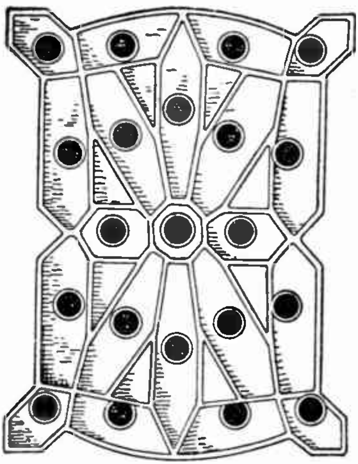


FIG. 7,444.—Betts' clock mechanism for operating electric monogram time flasher. The secondary mechanism consists of a three cylinder flasher and is controlled by a master clock which transmits an electric impulse through a relay switch one each minute. This flashes the time in figures on the monogram, viz.: 11.45, 11.46, 11.47, 11.48, etc. The first monogram to the left consists simply of a vertical row of lights representing the figure one. Each of the other monograms of metal compartments so arranged that any figure may be produced by lighting the proper combination of lamps.

the return wire of every lamp go back to the flashers independently, which means a wire for each lamp.

Thermo Flashers.—These flashers work on the thermo or heat expansion principle, that is, the movement of the contact points of the flasher necessary to open and close the circuit is obtained automatically by the alternate heating and cooling of the metal of the flasher, which causes it to expand and contract.



Carriage Calls.—These are used to avoid the confusion and noise at the theatre, club house or department store when vehicles are called by a megaphone. The flashing of a number is controlled by a keyboard or switch which may be placed in any convenient location. When the switch and call are connected together, any numeral may be flashed by pressing the corresponding key. The numeral automatically remains lighted until the releasing button is pressed.

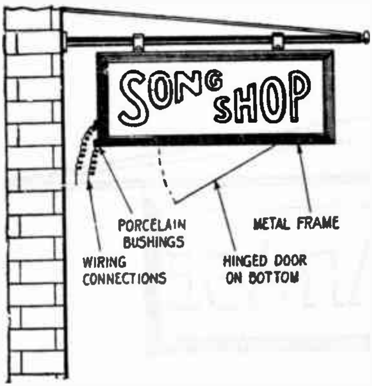
FIG. 7,445.—Monogram or unit for carriage call or talking sign. It consists of a collection of metal compartments each arranged to receive an incandescent lamp. The purpose of these compartments is to confine the light to a certain space, thus forming a clearly defined number or letter which can be read from a distance.

Constant Lighting Signs.—These signs, as shown in fig. 7,446, are usually placed over door of stores. The frames of all signs should be of metal, usually they are made on a frame of angle iron and covered over with sheet iron.

The use of metal is required by ordinances in all large cities.

Sign Wiring.—These are usually placed on separate circuits with a double pole if a 2 wire, and a triple pole switch, if three wire, to control sign.

Usually conduit or lead covered B.X. cable is used to connect the sign to the service mains. Fig. 7,447, shows how a difficult bend around a building cornice is made with Greenfield cable with lead covered wires inside.



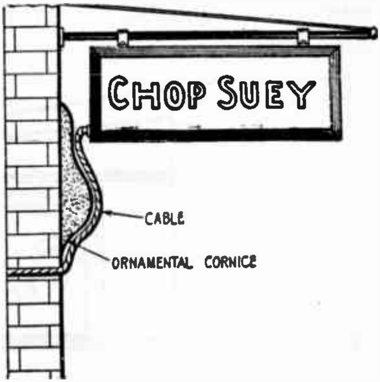


FIG. 7,446.—Small constant lighting sign. A one inch pipe supports the sign. This pipe is set into a hole drilled into the building wall 6 in. or more, the size of the pipe depending upon the size of the sign, usually a 1 in. or 1¼ in. galvanized iron water pipe is used, an ornament or cap is placed over the end of the pipe to give it a finished appearance and to keep out water from the pipe. A stranded galvanized guy wire is attached to the end of the pipe to keep the weight of the sign, from the pipe also to keep the sign from swinging in all directions. Usually a turn buckle is used to adjust the tension on the guy wires. Note on all kinds of outside signs it is advisable to use none but galvanized fittings as fittings are always exposed to the weather and soon rust. The height of the bottom of the sign from the sidewalk is subject to city ordinances. These should be consulted before a sign is erected.

FIG. 7,447.—Method of wiring the sign with lead covered B.X. cable or Greenfield cable with lead covered wires inside.

The wires are usually brought out from the frame of the sign in porcelain bushings, but on the larger types the conduit is usually brought directly into the sign. Sheet metal used in electric signs must not be less than No. 28 U. S. metal gauge. All metal must be galvanized, enameled or painted over three times with black aphaltum or tar paint to prevent rust. Only rubber covered wire is permissible on the inside of the sign. All wires must be soldered to the terminals of all receptacles. After the wires have been soldered to the terminals they should be painted over (the terminals) with black asphaltum or any other good insulating paint to prevent rust.

Special receptacles must be used for sign work and must be so installed so as to prevent them turning. When wiring the interior of signs great care should be taken to see that the wires are at least one inch from the entire surface wired over. Where the receptacles are placed over 4½ ft. apart they must be supported on cleats or knobs, where the receptacles are placed not over one foot apart and wires are secured to these receptacles, a support every 4½ ft. will not be required as above.

Not over 1,320 watts lamp load should be placed on any circuit.

Interior Wiring of Signs.—Constant burning signs are connected in parallel for small signs and in series parallel for large signs.

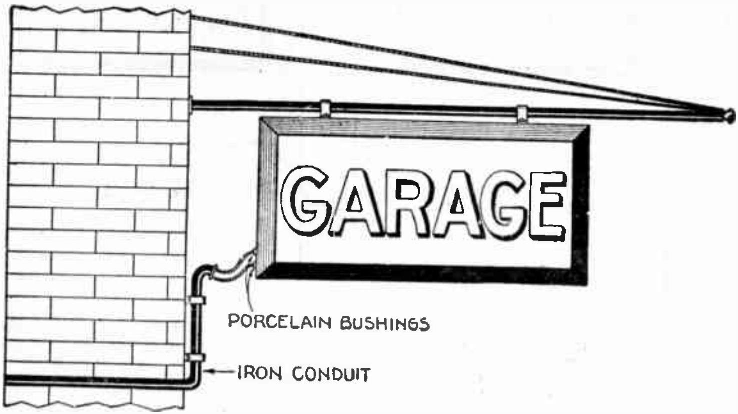
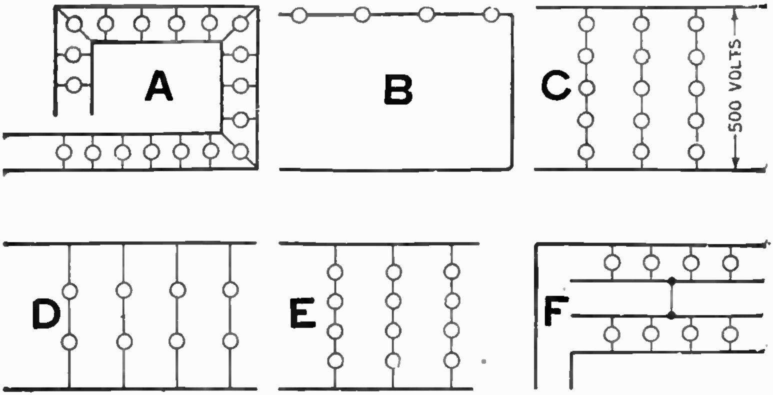


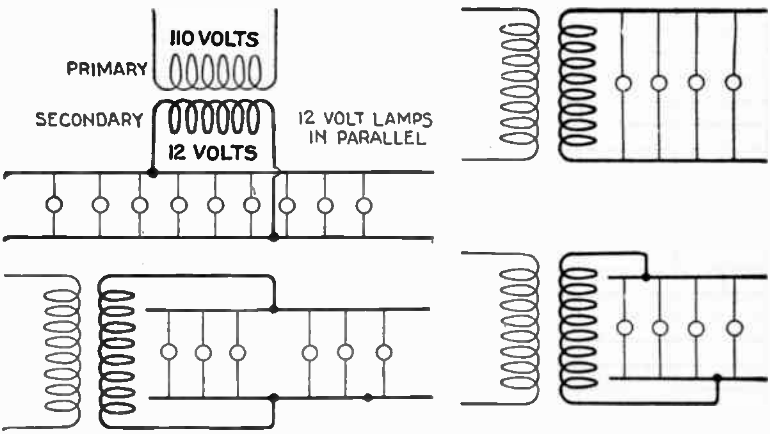
FIG. 7,448.—Method of wiring the sign with iron conduit.

Where 500 volt service is only obtained, the lamps should be wired in series 5—100 volt lamps of the same size as in fig. 7,451(C). Where it is desired to use more than 5 lights on 500 volt sign, they are connected in parallel series. Where only 220 volts 2 wire is available, 2-110 volts lamps may be placed in series, or 4-55 volt lamps placed in series. See fig. 5,452(D) and 5,453(E) or fig. 5,454(F) where lamps are wired parallel series.

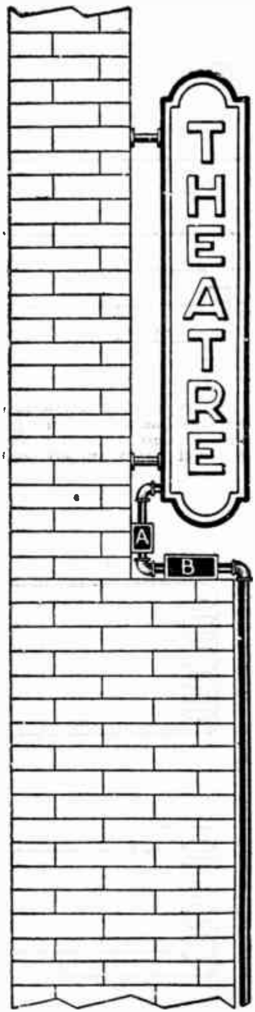
Where *d.c.* service is only available the lamps are wired in series or series parallel, 2 lamps to a series the same number of lamps must be in each parallel, otherwise they will burn dimmer or brighter than the others. Low voltage are used where a great number of lamps are used on a sign; these are placed in series of 10-12 volt lamps being used on 120 volt systems. The various wiring connections for signs are shown in figs. 7,455 to 7,458.



FIGS. 7,449 to 7,454.—Various wiring connections for signs. Fig. A, parallel connection for a small sign; fig. B, 500 volt connection—5 one hundred volt lamps connected in series; fig. C, five 100 volt lamps; fig. D, two 110 volt lamps in series on 220 volts; fig. E, four 55 watt lamps in series on 220 volt; fig. F, ten 110 volt lamps on 220 volt circuit.



FIGS. 7,455 to 7.458.—Various wiring connections for signs using transformers.



The principal objection to the use of the series parallel system is that if one lamp of a series burn out, the rest of the lamps do not burn as shown in fig. 7,453, where one letter of a sign forms a series, thus if one lamp should burn out the whole letter is dark.

When signs are to be supplied by *a.c.* current they should be wired in multiple using low voltage lamps (preferably 12 volt) in connection with a low voltage sign lighting transformer as shown in fig 7,455.

The run from the transformer to the sign should be as short as possible. Most sign makers fasten the transformer on the bottom of the sign. The reason for this is to reduce the drop of voltage due to resistance of the wires having such an effect on this low voltage (12 volts). This is not noticeable on higher voltages but on 12 volts much difference can be noticed. Fig. 7,449 shows the improper way to connect a parallel as the first lamp will burn brighter than the last lamp due to the drop of voltage.

The parallel series connection is used on large signs without transformers such as on *d.c.* or *a.c.* where no transformer is desired. The only objection to this form of connection is that if one lamp will burn out it reduces the resistance causing the rest of the lamps in this multiple to burn brighter while the rest of the multiples will burn dim. To prevent this no less than 10 lamps should be placed in a parallel, so that very little difference will be noticed. Any number of lamps may be used in a multiple but each multiple must have the same amount of lamps and their power must not be any more than 10 multiples on a 120 volt system, using 12 volt lamps.

Fig. 7,459.—Flashing theatre sign and method of placing transformer and flasher near sign. A. transformer; B, metal cabinet containing motor flasher.

CHAPTER 27

Electric Lighting

Light—Light is the term applied to that form of radiant energy which is capable of producing vision. By definition, light is radiant energy traveling in the form of electro-magnetic waves. It is measured in units such as *ergs*, *Joules*, *calories* or *kilowatt hours*.

Visible radiation or luminous flux lies roughly between 0.00038 and 0.00076 millimeters, which is less than one octave of the electromagnetic spectrum.

It may be classified in what is known as the *ether spectrum*, with other types of radiant energy in the form of electro-magnetic waves, all of which travel through space at a velocity of approximately 186,000 miles per second, and manifest themselves in a variety of ways, depending upon their wave length characteristics.

The longer wave lengths are used in radio communications, whereas the extremely short waves appear as X-rays, gamma and cosmic rays as shown on page 715.

The Visible Spectrum.—As previously mentioned, only those waves lying between the approximate limits of 0.00038 and 0.00076 millimeters in length are capable of producing vision. These limits are more commonly expressed in terms of a unit of length known as the *angstrom* and equal to 1/10,000,000 of one millimeter. In terms of this unit, the visible range is said to lie between 3,800 and 7,600 angstroms. It is interesting to notice that the upper wave length limit is just twice the lower, so that the visible range may be said to consist of one octave of an ether spectrum in which sixty odd such octaves are known to exist.

Within the visible range, the different wave lengths produce different color sensations as indicated in the enlarged portion as shown on page 715. Colors can be distinguished because of their characteristic hues which are produced by the different wave lengths of light. When all wave lengths are present in approximately equal intensities, the sensation of white light is produced. When white light is broken up, as by passing through raindrops, or a prism, the various wave lengths are separated and appear as all the different colors of the rainbow, extending from red at the longer wave lengths through orange, yellow, green and blue to violet at the shorter wave lengths.

Sensitivity Characteristics of the Human Eye.—The human eye is not equally sensitive to all colors in the visible spectrum for the same intensity of radiant flux. For example, if a yellow light, a blue light and a red light have the same intensity of radiant flux, that is, if they radiate to a surface the same amount of energy per unit area, per unit time, the yellow light produces much more illumination or luminous flux than the blue or the red. It has been found that yellow-green light of 5,500 *Angstroms* wave length has the greatest luminosity; its visibility is therefore taken as 100% and that of other colors expressed in terms of it. The average results of a large number of observations have been plotted in the form of an eye sensitivity curve, fig. 7460, showing the relative visibility at each wave length throughout the visible range. From this curve it will be observed that the visibility of the colors at the extreme ends of the spectrum is almost insignificant in comparison with that of yellow-green. It is interesting to notice in this connection that the radiation from the sun has its maximum intensity at a point corresponding closely to the maximum of this human visibility curve.

This has led to the theory that the visual sensitivity of the human eye has been determined by its development under the influence of sunlight. This particular form of its development has, in fact, given rise to the great variety of problems with which the illuminating engineer has been faced in his efforts to substitute artificial illuminants for sunlight. In almost every case a satisfactory solution has come through a study of the visual apparatus itself.

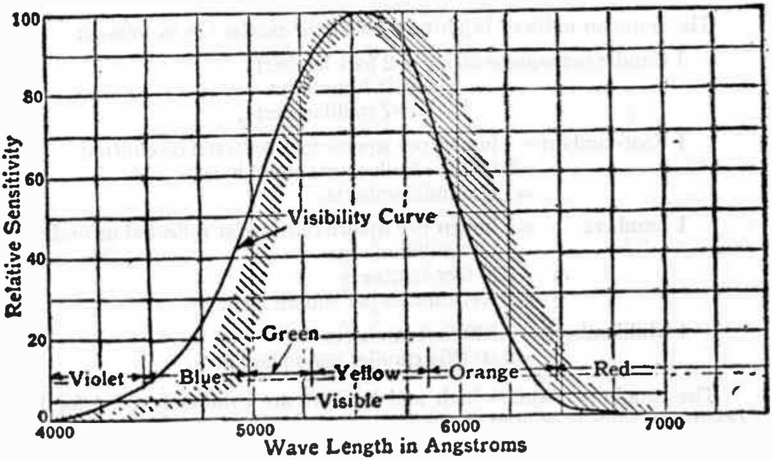


FIG. 7,460.—Eye sensitivity curve. The eye sensitivity curve indicates the relative visibility at each wavelength throughout the visibility range based upon wavelength 5,500 Angstrom as 100%.

Terms and Definitions

The definition of terms and units which follow should be carefully noted.

Absorption.—The loss occurring when light traverses a designated medium or reflects from a designated surface. The ratio of the absorption to the incident light is called *Absorption Factor*. For any surface or medium, *Absorption* + *Transmission* + *Reflection* = Incident Light. For any surface or medium *Absorption Factor* + *Reflection Factor* + *Transmission Factor* = 1.00.

Brightness.—The degree of brilliancy of any part of a surface or medium, when viewed from a designated direction. It is measured by the ratio of the candlepower emitted in that direction, to the area as projected in that direction (*i.e.*, the apparent area as seen from that direction). It may also be expressed in lumens per unit of area of a perfectly diffusing surface of equal brightness. Since most surfaces or mediums are not perfectly diffusing, the brightness varies with the point of view. In all ordinary cases brightness is independent of the distance of observation.

The common units of brightness and their relation is as follows:

1 Candle per square inch	=452 foot-lamberts
	=0.487 lamberts
	=487 millilamberts.
1 Foot-lambert	=1 lumen per square foot reflected or emitted
	=0.00221 candles per square inch
	=1.076 millilamberts.
1 Lambert	=1 lumen per square centimeter reflected or emitted
	=1,000 millilamberts
	=929 foot-lamberts
	=2.054 candles per square inch.
1 Millilambert	=0.929 foot-lamberts
	=0.002054 candles per square inch.

The candle per square inch and lambert are commonly used for high brightness such as of light sources.

The foot-lambert and millilambert for ordinary illuminated surfaces.

The foot-lambert = incident footcandles × reflection factor, assuming a diffusing surface or medium.

Brightness is assuming more and more importance in planning for ability and comfort of seeing. Either extremely high brightness, or excessive contrast of brightness—high *Brightness Ratio* is liable to cause glare. Very low brightness lessens ability to see.

Candle.—The use of the candle in the definition of light units is a natural outcome of the fact that measurements of light first were undertaken seriously at the time when the newer light sources began to replace the candle. A similar situation led to the introduction of the term horsepower when steam engines began to replace the horse. It was soon found that in order to use a candle as a standard, it had to be made according to strict specifications regarding size and ingredients and burned under prescribed conditions. The light in a horizontal direction would then have a certain intensity which could be taken as a standard.

Since 1909 the standard of luminous intensity has been the international candle, a unit developed originally from flame standards, and established by agreement among the three national standardizing laboratories of France, Great Britain, and the United States. The constancy of the standard is maintained by a group of carbon filament lamps in the national laboratory of each country, which are carefully compared with each other, and occasionally with lamps from other countries.

A candlepower measurement specifies the luminous intensity of any light source in a given direction and represents the light density in that direction. However, the candlepower measured in one direction is no indication of the total amount of light produced by the illuminant. Candlepower read in one direction is analogous to the depth of a pool of water at one given point, a measurement which is useful for certain purposes, but which is of no value in determining the total quantity of water in the pool. Just as it is necessary to know the dimensions of a pool and the depths at all points before its total contents can be established, so it is necessary to know the candlepower of an illuminant in all directions before its total light output can be determined.

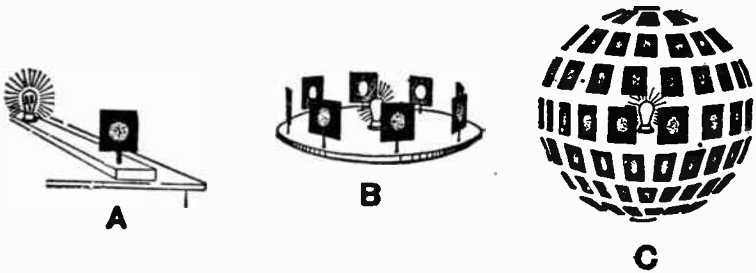


FIG. 7,461.—Measurement of candlepower.

There are three ways in which candlepower measurements are ordinarily made, as indicated in fig. 7,461. In **A**, the candle power of light radiating in only one direction is measured. When a number of readings are taken at uniform intervals in a horizontal plane, as indicated in **B**, and then averaged, the result is the mean horizontal candlepower of the light source. Instead of taking a large number of individual readings, this result is obtained in ordinary practice by rotating the illuminant rapidly about its vertical axis while a single reading is taken. The intensity of light in all directions can be ascertained as indicated in **C**, by measuring the candlepower at uniform intervals around the light source. An average of these readings will give the mean spherical candlepower of the illuminant. In the past, it was quite common to rate light sources in terms of this unit, since it is directly related to the total light output of the lamp. At the present time, however, a unit known as the lumen is much more commonly used for this purpose.

Color of Light.—Average daylight (color temperature approximately 6,000°) is scientifically taken as the standard of white light, though daylight itself is subject to a variation due to position of the sun, state of cloudiness, reflection from buildings, foliage and indoors, room finishes. *North skylight* is more blue than average daylight, and has been used as a standard in dyeing and other color work because less subject to variation, although average daylight would be more representative of conditions of use. *Direct sunlight* is always yellow tinted and when the sun is near the horizon decidedly yellow tinted. Incandescent light is yellow tinted, the more efficient lamps producing the closer approximation to daylight.

Diffusion.—A scattering of light rays, so as to cross each other, as opposed to regular radiation of light from a point source. Diffusion may be introduced by reflection from a matte surface or transmission through a frosted or opal glass. This tends to enlarge the image of the light source (*e.g.*, lamp filament) reducing its brightness and breaking up its outline.

Distribution of Illumination.—The manner in which the foot-candles of illumination vary over a specified area (*e.g.*, the horizontal working plane—30 in. or 36 in. above the floor). Even distribution occurs when there is relatively little variation. Spotty distribution refers to extreme variation. In an artistic interior a certain amount of variation is usually desirable.

Distribution of Light.—For a light source or complete luminaire, refers to the candlepower emitted in various directions. For most illuminants, the candlepower is substantially equal in all directions about the vertical axis. For such symmetrical distribution, it is customary to plot polar curves of which the radius representing any angle of elevation is proportional to the candles toward that elevation. (See fig. 7,462.)

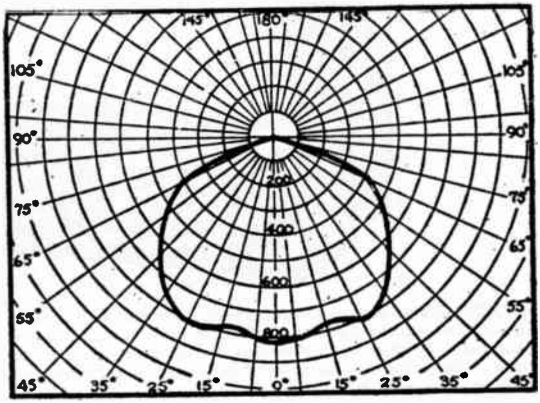
Efficiency.—For electric lamps or luminaries, the lumen output per watt of power supplied. For lamps requiring power consuming regulators or ballasts, a distinction should be made between the efficiency of the lamp proper and the lower *over-all efficiency* of the practical lighting equipment. For reflectors, globes and other accessories used with an incandescent lamp or other lamp, the efficiency is the ratio of the lumens delivered by the accessory to the total light of the lamp, expressed as a percentage.

Flux of Light.—Light actually represents a flow of energy and its volume is treated scientifically as a time rate or flux. In practice, however, the rate of flow in artificial lighting is usually considered constant and treated as a static condition. Flux is measured in lumens. (See Lumens.)

Footcandle.—The unit of illumination and the measure of density ot the light falling on any surface. It is equal to one lumen per square foot of area. When light from a point source falls perpendicularly on a plane—the illumination in footcandles on the plane is equal to the candles, emitted by the source in that direction, divided by the square of the distance in feet. Footcandles at any point on a plane can be measured by a light meter.

ANGLE	CANDLE POWER
0	815
5	810
15	787
25	803
35	745
45	623
55	525
65	416
75	77
85	10
90	0

A



B

FIG. 7,462.—Typical candlepower distribution curve. The tabulation in **A**, shows the result of tests on a standard dome reflector equipped with a 200 watt inside frosted Mazda lamp. In the table 0° refers to a position directly beneath the unit and 90° represents the horizontal. The cnadlepoer at 0° was found to be 815 and for this type of reflector the candlepower at 90° and all higher angles is zero.

Glare.—A condition of lighting in which part of the light interferes with seeing, causes eyestrain or discomfort. Common causes of glare are (1) viewing a brilliant light source, directly or by reflection; (2) high contrast of brightness, especially when trying to see in the field of lower brightness; (3) an excessive volume of light reaching the eyes.

Illumination.—*Illumination is the density of luminous flux on a surface. It is the quotient of the flux by the area of the surface when the latter is uniformly illuminated. (See Efficiency.)

*NOTE.—The term "*illumination*" is also commonly used in a quantitative or general sense to designate the act of illuminating or the state of being illuminated. Usually the context will indicate which meaning is intended, but occasionally it is desirable to use the expression *amount of illumination* to indicate that the quantitative meaning is intended.

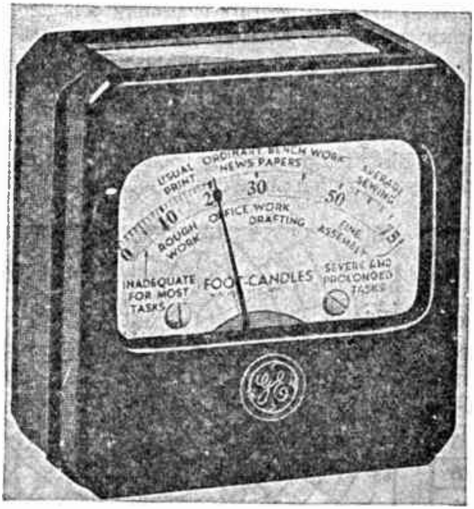


FIG. 7,463.—Showing typical light meter equipped with a light sensitive cell. The light sensitive cell is located on the top surface at right angles to the scale face. This arrangement not only makes it convenient for taking footcandle readings, avoiding observer's shadow, but permits the meter to be used for the measurement of reflection factors of ceiling, walls or other light reflecting surfaces as well.

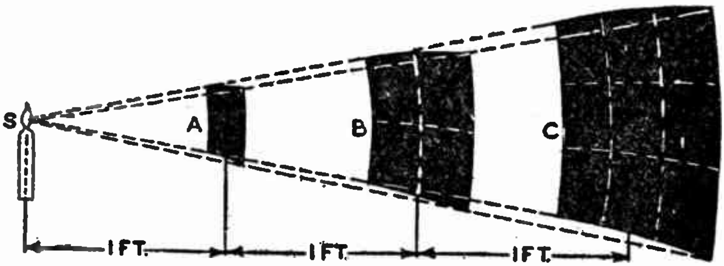


FIG. 7,464.—Illustrating the inverse square law.

Inverse Square Law.—The intensity of illumination produced by a point source varies as the square of the distance from the source. With reference to fig. 7,464 illustrating this law, it may be observed that if the source of light be in candlepower, the illumination on a spherical surface one foot distant, as illustrated by **A,** is one foot-candle. If surface **A** is removed, the same amount of light passes to surface **B,** two feet away, and here covers four times the area of **A.** Since light travels in straight lines and in this case it may be assumed that none of it is lost, the average level of illumination on **B,** two feet away, is one-fourth as great as that on **A,** one foot away, or one-fourth of a foot-candle.

If **B** be removed and the same amount of light falls on surface **C,** three feet away from the source, it will be spread over an area nine times as great as at **A.** The resulting illumination is, therefore, one-ninth of a foot-candle. At a distance of five feet, the illumination would be only one-twenty-fifth of a foot-candle. Illumination decreases not in proportion to distance, but in proportion to the *square of distance.* This fact is referred to as the inverse square law. It should be emphasized that this law is based upon a point source of light from which the light rays diverge as shown. Practically it applies with close approximation where the diameter of the light source is not greater than about one-tenth the distance to the illuminated surface.

It is obvious that if in fig. 7,464 the light source, which gives one candlepower in the direction of the surface **A,** be replaced by a source of two candlepower, the illumination at **A** will become two foot-candles. Likewise, the illumination on **B,** if **A** be removed, will be twice one-fourth, or one-half of a foot-candle, and similarly for **C.** To sum up, it is possible to formulate a general law that *the illumination from a point source is equal to the candlepower of the source in the direction of the surface divided by the square of the distance in feet from the source to the surface.*

Louver.—A shield used in connection with a lamp or luminaire to intercept light traveling in undesirable directions, used for glare prevention, for accurate control or for other reasons.

Lumen.—Light, as previously mentioned, is a form of energy in motion; it is not a concrete object which may be weighed or touched, but light (or more correctly *light flux*) coming from a source, may be considered to do so at a constant rate of speed. Hence, for all practical photometric measurement, and light considered as a definite quantity.

The unit of this light flux or light quantity is the *lumens.* It is equal to the flux through a unit solid angle (steradian) from a uniform point source of one candle, or to the flux on a unit surface all points of which are at unit distance from a uniform point source of one candle.

It is more commonly, however, defined as the amount of light falling on the surface one square foot in area, every point of which is one foot from a uniform source of one candlepower.

With reference to fig. 7,465 if the opening indicated by area **ABCD**, be one square foot of the surface area of the sphere of one-foot radius, the light escaping will be one lumen. If the area of this opening be doubled, it will be two lumens. If it be remembered that the area for any sphere is $4\pi r^2 = \pi d^2 = 12.57r^2$, it follows that the total surface area of a sphere with one foot radius is 12.57 square feet. Since the total surface area of a sphere with a one-foot radius is 12.57 square feet, a uniform one-candlepower source of light emits 12.57 lumens. Thus a light source of 100 mean spherical candlepower emits 125 lumens. Since an area of one square foot on the surface of a sphere of one-foot radius subtends a unit solid angle at the center of the sphere, the lumen may also be defined as the amount of light emitted in a unit solid angle by a source having an average of one candlepower throughout the solid angle. From this point of view candlepower may be considered as the number of lumens in a solid angle and is thus a measurement of the light density in a given direction.

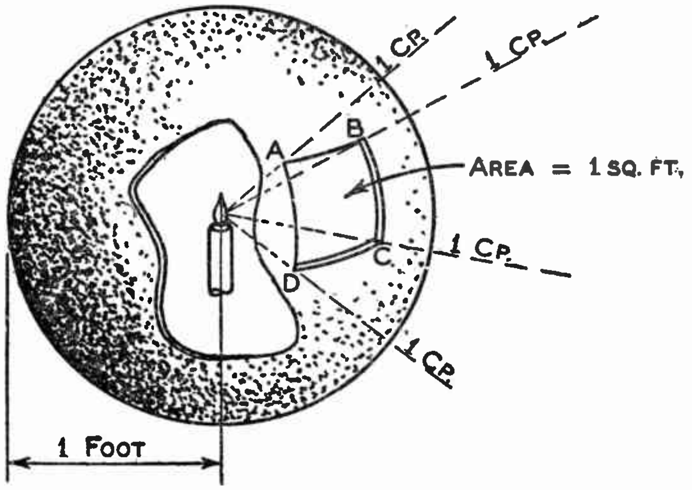


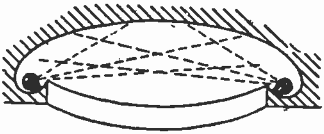
FIG. 7,465.—Relations of candles to lumens.

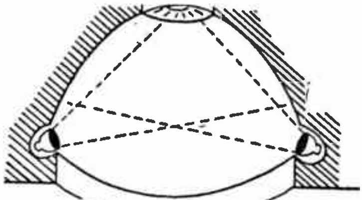
Summarizing these definitions of candlepower and lumen, it will be seen that candlepower measures luminous intensity or light density of a light source in one direction only. It is no indication of quantity of light flux. The lumen, on the other hand, measures this quantity of light flux and does so irrespective of direction. When the various candlepowers in any solid angle are averaged (which may be considered as eliminating direction) there is then a definite relationship of the candlepower to the lumens in that particular solid angle. *This is expressed by the statement that a source of unit spherical candlepower gives* 12.57 *lumens.*

Luminaire.—A complete lighting equipment consisting of a light source together with its direct appurtenances such as globe, reflector, refractor, housing and such support as is integral with the housing. Designates completely equipped lighting fixtures, chandeliers, wall brackets, portable lamps and other units of which the prime function is the production of illumination.

Luminous Efficiency.—The luminous efficiency of radiant energy is the ratio of the luminous flux to the radiant flux. The luminous efficiency is usually expressed in lumens per watt of radiant flux. It should not be confused with the term efficiency as applied to a practical source of light since the latter is based upon the power supplied to the source instead of the radiant flux from the source.

Luminous Flux.—This is the time rate of flow of light. It is expressed in lumens.





FIGS. 7,466 and 7,467.—Showing typical mounting of lamps in parabolic reflectors.

Parabolic Reflector.—A reflector or mirror which has its reflecting surface in the form of a paraboloid. Possesses the property of reflecting the light from theoretical point source located at the focus with all rays parallel to the axis. In practice, high concentration can be obtained, but the divergence of the beam will be proportional to the angle subtended by the source in relation to the focal length of the reflector used. The spread is increased by moving the source away from the focal point.

Reflection Factor.—The ratio of the light reflected by a designated surface or body to the incident light. For surfaces having both diffuse and regular reflection, it is the sum of the *diffuse reflection factor* and *regular reflection factor*. (See Absorption.)

Transmission Factor.—The ratio of the light transmitted by a transparent or translucent medium (*e.g.*, opal glass) to the light incident upon it. Transmission may be regular or diffuse. The *Regular Transmission Factor* +*Diffuse Transmission Factor* = *Transmission Factor*. (See Absorption.)

Light Sources

The generation control and transmission of electricity has been treated elsewhere, and it remains to study the common methods of producing light by electricity. The well known devices in use are:

1. Incandescent lamps;
2. Electric discharge lamps, and
3. Arc lamps.

The Incandescent Lamp.—The modern incandescent lamp operates on the principle of heating a wire or filament to incandescence by sending an electric current through it. They are manufactured in two principal froms; the *vacuum* and the *gas-filled types*.

Nitrogen, an inert gas which forms approximately 80% of the atmosphere used in early gas-filled lamps, is now largely superseded by argon, another inert gas. The reason for using argon is that this gas does not conduct heat from the filament as rapidly as nitrogen and therefore makes possible a more efficient lamp.

It should be pointed out here, that the present incandescent "Mazda" lamp is the product of a series of improvements which has been made possible by the incessant research of our large electrical manufacturers, always eager to present the best possible lamp at the lowest possible price.

With reference to fig. 7,468 the incandescent lamp has three principal parts, viz: *bulb*, *base* and *filament*.

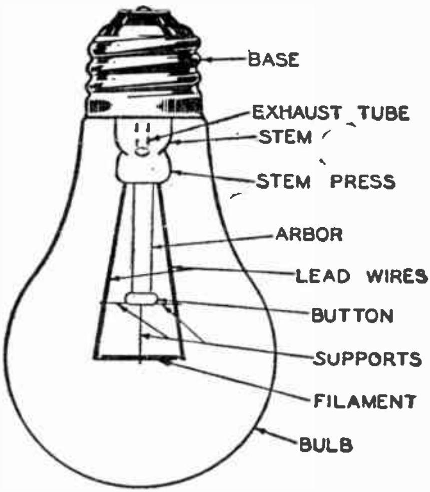


Fig. 7,468.—Showing principal parts of an incandescent lamp.

The Bulb.—Every incandescent lamp uses an enclosing glass bulb to prevent air from reaching the extremely hot filament, as the presence of oxygen would cause the filament to burn up instantly. It is important to distinguish here between the words *bulb* and *lamp*.

The bulb is the enclosing glassware of an incandescent light source; the lamp is the complete light source. Through common usage, the words bulb and lamp have become almost synonymous. While in most cases this would cause no confusion, the lighting engineer should learn to express himself correctly when speaking of his own tools. *Lamp*, of course, is used frequently to refer to an entire fixture.

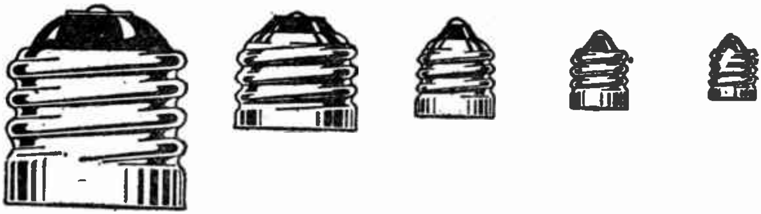
The most widely used bulb finish is the inside frost. This consists of a very light chemical etching applied to the inner surface of a bulb. A multiple etch process *fortifies* the bulb resulting in high glass strength, and being on the inside of the bulb the frosting collects little dirt and the lamp is easily cleaned. The frost diffuses slightly the direct rays from the filament, making the whole bulb appear luminous rather than simply the filament.

Inside frosting is applied to all standard 115 volt lamps from 15 to 150 watts, and to many other lamps in the various voltage and wattage ranges. The loss of light due to the inside frosting is less than two per cent. Another common finish that is applied to lamp bulbs to diffuse the light is known as *white bowl*. This is a translucent finish applied to the bowl of the bulbs of many high wattage lamps when they are to be used in open mouth reflectors. The loss of light with this finish is somewhat greater than that with inside frost, but better diffusion is obtained.

Other types of finish are used to produce colored or tinted light. These are applied to either the outside or the inside of the bulb, but most frequently to the inside. Inside coloring is protected from the elements and the bulb may be cleaned without danger of scratching or removing the color. Outside coloring, on the other hand, is suitable only for use indoors. While most bulbs are made of colorless glass, there are two types of lamps which require bulbs of colored glass. The most common of these is the daylight lamp which uses a bulb of special blue glass (either clear or inside frosted) to absorb the excess red and yellow rays in the light from an incandescent filament, resulting in light more nearly approximating average daylight in quality. The loss due to this absorption is about 35 per cent, and therefore, these lamps should be used only when this quality of light is specifically desired. When substantially pure colored light is desired, lamps with natural colored glass bulbs may be used. Although the color of these bulbs is permanent, they have the disadvantage of being relatively high in price. For this reason, it usually is more economical to produce colored light in quantities by the use of color screens with standard clear or inside frosted lamps.

The Base.—For conveniently connecting the filaments of lamps to electrical circuits certain standard types of bases have been evolved, as shown in figs. 7,469 to 7,473.

The most important of these is the screw type base which is made in five different sizes. These are, in order of increasing size; the miniature, candelabra, intermediate, medium (the size commonly used in the home), and the mogul. Types other than the screw base are the bayonet, prefocus, and the bipost. The bayonet base, made in a number of different sizes, is cylindrical in shape, having two projecting side pins which seat in slots in the socket. The most common size is the bayonet candelabra used on automobile lamps.



FIGS. 7,469 to 7,473.—Showing various types of screw base used in incandescent lamps.

The prefocus base is also cylindrical (either medium or mogul in size) with two side fin projections. It is really a double base, so assembled at the factory that when it is placed into a socket, the filament of the lamp always assumes a definite position with respect to the optical systems with which it is used. This is important for accurate light projection. The bipost base consists of two metal pins sealed into the lower portion of the bulb. This type of base offers the means for accurate placement of the filament with respect to axial alignment and the light center length, and also insures proper positioning of the filament.

The Filament.—In the modern incandescent lamp, this is made of tungsten wire usually coiled in the form of a long helical spring. It is connected at each end to *lead-in* wires, which conduct electricity from the base, and is held in position by intermediate supports. In lamps for use in light projecting devices, the filament is concentrated into as small a space as possible. For ideal control, a point source of light would be required, but this is a physical impossibility. In some types of projection lamps, the coiled filament is coiled upon itself in order to obtain maximum concentration.

While some lamps are designed to be burned in any position; that is, base up, base down, etc., some are restricted in burning position in order to gain greater efficiency or more satisfactory performance. For example, certain street lighting lamps are designed for burning in either a base-up or a base-down position, because by so doing the bottom filament supports may be eliminated with a resultant reduction in the cooling effect and a gain of 7 to 15 per cent in efficiency.

The size of the incandescent lamp is usually expressed by the number of watts consumed by it. The size (diameter) of the tungsten filament must be such as to offer a resistance which will allow the proper current to give the desired number of lumens at the voltage for which the lamp is designed.

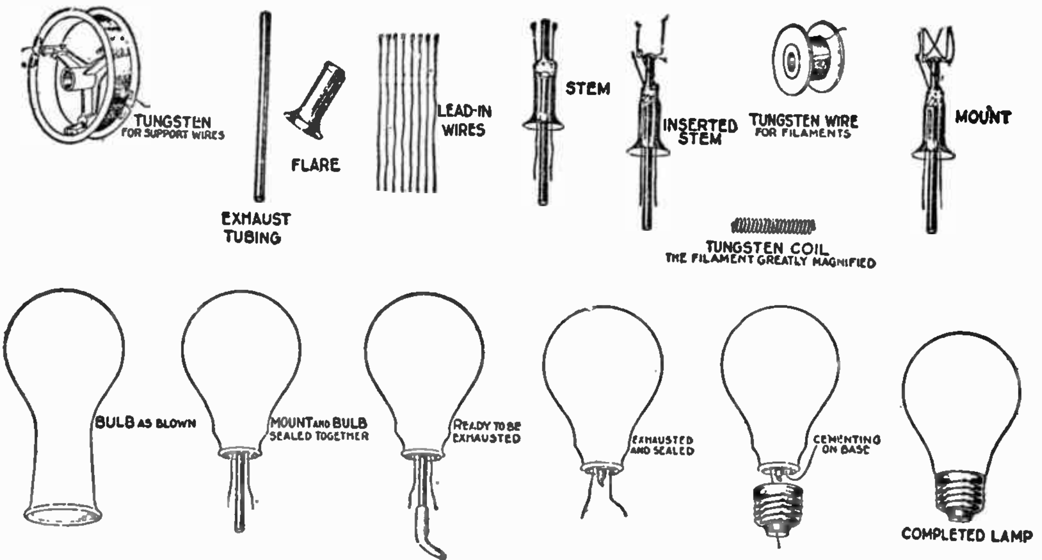
The efficiency of ordinary vacuum lamps varies from 6 to 10 lumens per watt and that of gas filled lamps from 10 to 30 lumens per watt. In general, lamp efficiencies increase with rated wattage, because of a decreasing heat loss in percentage of the total wattage of the lamp and because of the ability of thicker filaments to withstand higher operating temperatures.

Methods of Lamp Manufacture.—With the aid of automatic machinery incandescent lamps are manufactured at a rapid rate.

The following description briefly explains the various steps:

The glass bulbs are blown from molten glass coming from a furnace, and by successive puffs of air are shaped to almost the form required and then surrounded by moulds which put them into exact shape, the excess glass or stem is cut off by gas flame.

A tube, known as the stem, is blown which afterwards is welded to the bulb and contains the leading-in wires and tubes for supporting the filament and exhausting the air. The tip is not visible on the bulb as the air is exhausted from the bottom and the sealed end concealed in the base.



Figs. 7,474 to 7,488.—Making an incandescent lamp. The stem and inserting machine bring together the flare, exhaust tubing and lead-in wires, assembling all in one complete stem, and finally inserting the support wires ready for mounting the filament. These stems are then transferred by a conveyor to operators who mount the filament on the supports. The sealing in and exhaust machine seals the mount in the bulb after which it exhausts the air, and, in the case of gas filled lamps, fills the bulb with inert gas. The operator inserts a mount and places a bulb over it as each successive loading position passes. The bulbs are rotated with a gas flame plating on the bulb where the bulb and flare are to be welded together, and at each successive stage in their travel, are heated just the right temperature by tongue-like flames to make a perfect seal. When the seal has been made, air pumps cut in to exhaust the bulb. On the basing machine the lamp is capped with a brass base having a lining of plastic cement; one lead wire makes contact with the shell and the other is threaded through to the contact to the end. As the lamps pass through a heated oven the cement hardens and mechanical fingers drop a touch of solder on the lead wires and the excess length is cut off. As the lamp nears the end of its final circle in a lamp making machine, it is lighted for inspection.

Leading in wires are made of special metal so that the rate of expansion and contraction will be similar to that of the glass and thereby form a solid connection between the wires and the glass. Supports are set in the glass tube in the bulb for holding the filament and serve as anchors for the filament.

The entire element is then set into the bulb, the bottom sealed and the exhaust tube placed on the exhaust pump. When the desired vacuum is obtained the tube is sealed, the end broken off and the lamp is ready for the base.

In gas filled lamps, gas is inserted before the stem is sealed.

Lighting Calculations

There are three principal methods used in calculating illumination requirements. They are:

1. Point by point.
2. Lumen method, and
3. Watts per square foot.

Point by Point Method.—By this method it is possible to determine the illumination at any given point by means of simple mathematical formulae.

This involves the candlepower distribution of the light source and its position with respect to the point in question. Although this method is not commonly employed because of its complicity, it is however, used in certain lighting problems and so a description of it is included here.

The point-by-point method of lighting calculations is based on the "inverse square law" (see page 671), that is, that the intensity of the distance from the light source to the point of measurement. From a candlepower distribution curve of a reflector, the footcandle at any given point may be computed from the formulae:

$$\underset{\text{(normal to the beam)}}{\text{Footcandles}} = \frac{\text{CP(candlepower)}}{\text{D}^2\text{(distance in feet)}} \qquad (1)$$

$$\underset{\text{(on horizontal plane)}}{\text{Footcandles}} = \frac{CP}{D^2} \times \text{cosine of angle } \theta \qquad (2)$$

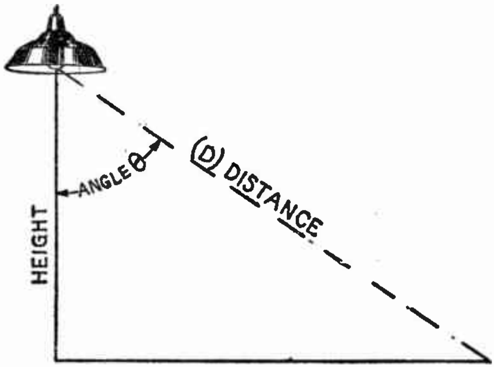


FIG. 7,489.—Illustrating point by point method of lighting calculation.

Lumen Method.—This method is based upon the average of level illumination desired over a given area. Since one foot-candle is equal to one lumen per square foot, the total number of lumens which must be delivered to the area in question may be obtained by multiplying this area by the required level of illumination in footcandles. To calculate the total number of lumens which must be generated by the lamps in order to deliver the required lumens to the working plane, proper allowances must be made for the losses due to the absorption of light both in the fixture and by the walls of the room as well as for the depreciation of the entire system due to the collection of dirt and dust. The calculations are carried out by means of design tables which are not difficult to use, and yet allow for all the important variables.

The required level of illumination is determined by reference to tables listing recommended values for various interiors. Next, the type of lighting unit is selected and the mounting height and spacings to be used determined from the general dimensions of the room. The relationship of these units determines a factor known as the room factor or room index. With this information and the efficiency and type of distribution of the lighting equipment plus the reflection factors of the walls and ceiling, the coefficient of utilization can be determined. This coefficient represents the percentage of generated light which actually reaches the working plane, a depreciation factor must be estimated and then the solution of the following equation gives the total number of lumens required from each lamp:

$$\text{Lumens required from each lamp} = \frac{\text{footcandles desired} \times \text{Area per lamp in sq. ft.}}{\text{coefficient of utilization} \times \text{depreciation factor}}$$

or, when computing for lamps of various sizes, the equation becomes:

$$\text{Footcandles} = \frac{\text{Lamp lumens} \times \text{coeff. of util.} \times \text{depreciation factor}}{\text{Area per lamp in sq. ft.}}$$

It is usually not possible, however, to procure a lamp giving the exact number of lumens obtained as a result of this calculation, therefore, the nearest lamp size is selected. It is then a simple matter to calculate the actual illumination expected from the lamp selected.

Simplified Method of Light Determination.—The previously outlined *lumen* or *flux of light* method involves a number of tabled data and cross references from one to another.

It is not a difficult matter, but the amount of cross-references required may be reduced by the use of tables which summarize the results for the more common types of lighting units. This *simplified* method is thus based on the *flux of light* method and the same procedure is used in determining the footcandles to be obtained and in selecting the fixtures, spacings and mounting height. The entire procedure is outlined herewith:

Outline of procedure (Interior lighting Installation).—When designing for a strictly interior lighting system the following five principal items should be obtained:

1. Determine the spacing of lighting units.
2. Obtain the room factor (Room index).

3. Determine the footcandles required.
4. Determine the wattage of lamp or lamps.
5. Calculate wire capacity.

Spacing of Units.—The correct spacing of units to obtain substantially uniform illumination throughout the room involves several factors.

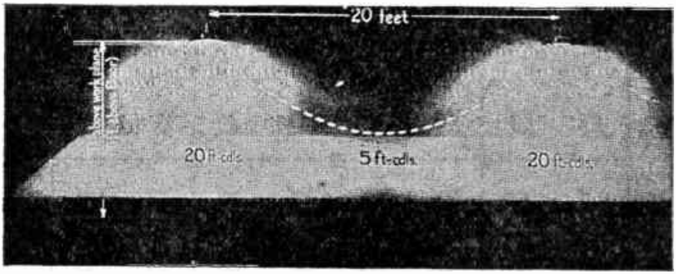


FIG. 7,490.—Illustrating variation in footcandle due to improper spacing of lighting units. Units spaced too far apart for their height furnish very uneven illumination, in this case a 4 to 1 variation, and work positions midway between units will be inadequately lighted; harsh shadows will also result. The remedy is to mount the units higher, or if that is impossible, to space them closer as illustrated in fig. 7,491.

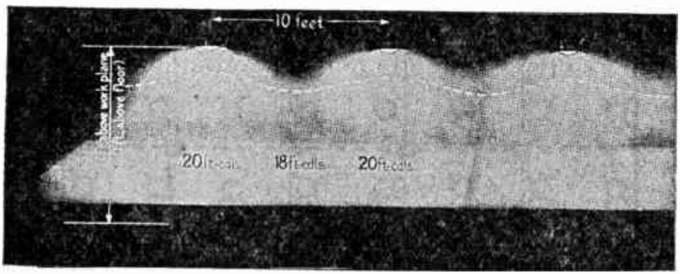


FIG. 7,491.—Showing normal spacing of lighting units. It will be noted that if the permissible ratio between spacing and mounting height is not exceeded, uniform illumination will be produced. Note also the overlapping of light which serves to eliminate shadows as the units are brought closer together.

Mounting Height.—Strictly speaking, the spacing for uniform illumination on the work depends upon the height of the light source to be illuminated. The ceiling height or rather the height which units may be mounted clear of obstructions, therefore limits the maximum permissible spacing. The spacing of lighting units is not influenced by the size or type of lamp used, but is regulated by the distribution characteristics of the reflector.

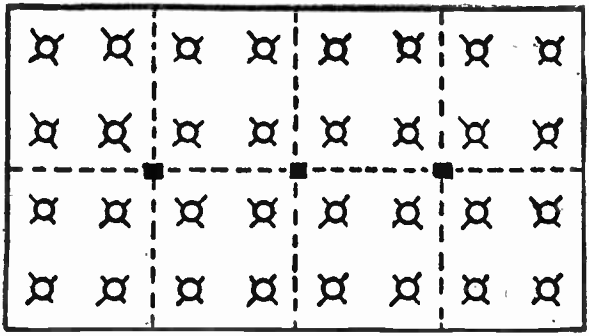


FIG. 7,492.—Showing a four units per bay lighting scheme. This is the most common system of the square bay of usual dimensions.

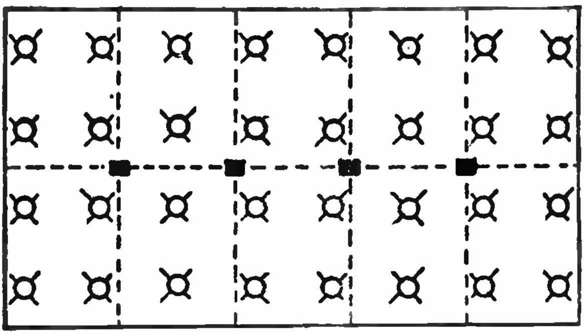


FIG. 7,493.—Four-two system layout. This system is equivalent to three units per bay and alternative to four per bay where spacing allows.

Many interiors are divided by columns or beams into a number of definite sections or bays, and it is usually desirable in order to obtain a symmetrical layout in accordance with the bays, partitions or architectural features to space the units as indicated in a number of typical layouts shown in figs. 7,492 to 7,497. The arrangements in which each bay is treated as a separate unit have the additional advantage that no change in lighting units will be required if certain bays are later partitioned to make separate rooms.

Room Factor.—A room must be appraised first from the standpoint of its general proportions; second, from the reflec-

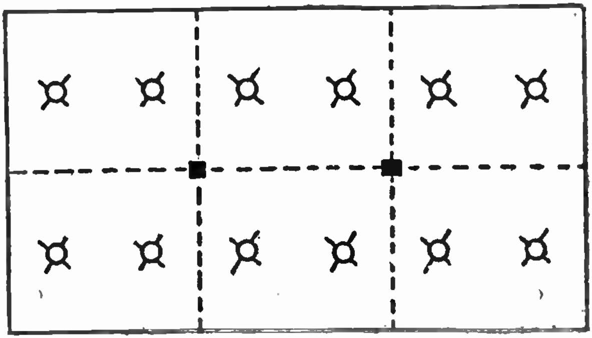


Fig. 7,494.—Two units per bay layout. A spacing of this type is usually applicable only in narrow bays where the width is less than two-thirds of the length.

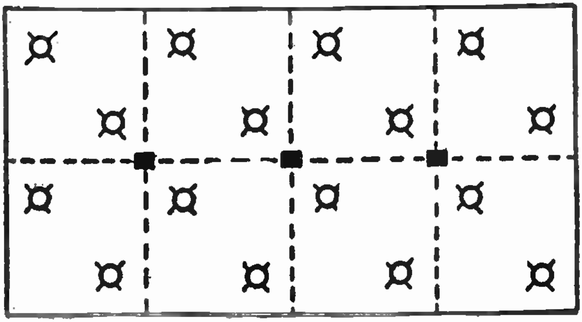


Fig. 7,495.—Two units per bay staggered layout. Generally acceptable in larger interiors where permissible spacing does not dictate fo— per bay.

tion factors of its walls and ceiling in order to determine what percentage of light is lost in its travel from the lamp to the working level and third, from the type of equipment to be used.

In general, large rooms of average height use light more efficiently than do small rooms of the same height because less of the total generated light is absorbed by the walls. In order

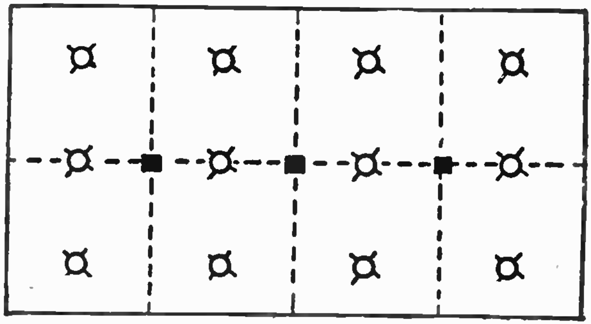


FIG. 7,496.—Inter-spaced layout. A lighting layout of this type is applicable in rectangular bays, but suited only where the center row will not interfere with future structure changes such as added office partitions.

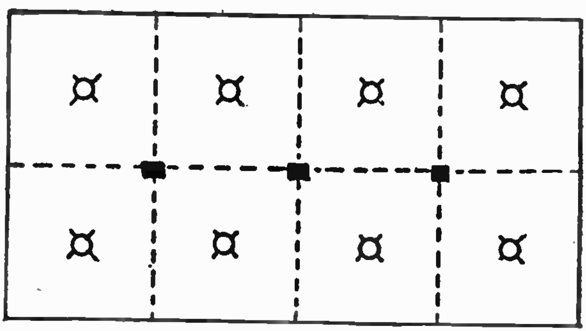


FIG. 7,497.—One unit per bay layout. This system is satisfactory only where the bay side is no greater than the maximum allowable spacing. This occurs only in exceptionally high ceilinged rooms.

to use the simplified method of design described in this chapter, it is only necessary to note whether the room width is approximately equal to two, three or four times the ceiling height.

Next note color of the walls and ceiling. The illumination in any room is dependent upon the amount of light reflected from the walls and ceiling. White walls reflect more light than gray walls—gray walls reflect more light than black walls. Therefore, in appraising the color of the walls and ceiling, three general classifications are used, light, medium and dark.

Table I, page 687, gives some idea of the colors in these three classifications and their different reflecting properties. Each paint manufacturer's reflection values differ for similar colors, but the values shown in the table give some idea of the colors which usually fall in the classification shown.

Table I.—Per Cent Light Reflected from Typical Walls and Ceilings

Surface	Class	Color	Light Reflected Per Cent
Paint	Light	White	81
Paint		Ivory	79
Paint		Cream	74
Caen Stone		Cream	69
Paint	Medium	Buff	63
Paint		Light Green	63
Paint		Light Gray	58
Caen Stone		Gray	56
Paint	Dark	Tan	48
Paint		Dark Gray	26
Paint		Olive Green	17
Paint		Light Oak	32
Paint		Dark Oak	13
Paint		Mahogany	8
Cement		Natural	25
Brick		Red	13

NOTE.—Each paint manufacturer's reflection values differ for similar colors, but the above table gives some idea of the colors in these three classifications and of the average reflecting qualities.

After having determined these three conditions which affect the room factor, refer to Table II, page 688, and obtain the ratings—such as A, B, C, D, or E.

Table II.—Room Factor

Proportions of Room	Color of Ceiling and Upper Sidewalls	Direct Lighting		Semi-Direct Lighting	Semi-Indirect Lighting	Indirect Lighting
		Distributing	Concentrating			
Width Approxim'ly Four or More Times Ceiling Height	Light	A	A	C	C	C
	Medium	A	A	C	D	D
	Dark	A	A	D	D	E
Width Approximately Twice Ceiling Height	Light	B	A	C	C	D
	Medium	B	B	D	D	D
	Dark	B	B	D	E	—
Width Approximately Equal to Ceiling Height	Light	C	B	D	D	D
	Medium	C	B	E	E	E
	Dark	C	B	E	—	—

Lighting Equipment.—As a preface to selecting the type of lighting units, it is necessary to have a thorough understanding of the various type of lighting equipment used.

The lighting "*fixture*" is undergoing significant changes with the development of new diffusing and reflecting materials, with design trends affecting appearance and styling, and with the growing acceptance of "built-in" architectural systems. These changes are influenced by (1) the generally higher levels of illumination desired; (2) refinement in quality and character of illumination with the result that users are becoming less and less tolerant of lighting that is uncomfortable and irritating; and (3) flexibility and convenience of switching and control.

The departures from older forms offer a much wider range of choice of methods of lighting but affect basic design procedure and calculation very little.

Lighting systems may be grouped into four types; (1) Direct: (2) Semi-direct: (3) Semi-indirect, and (4) Indirect. The general characteristics of any system prevail even though details of equipment design and installation may vary considerably.

Direct Lighting.—Defined as any system in which substantially all of the light on the working surfaces is essentially downward and comes directly from the lighting units. Direct lighting methods may range from concentrating and spotlight types of equipment through the many types of bowl and dome type reflectors to extended light source areas such as large glass panels and skylights. To provide high levels of illumination without glare with open type reflectors, though most efficient, is difficult unless considerable care is taken in locating and shielding such sources.

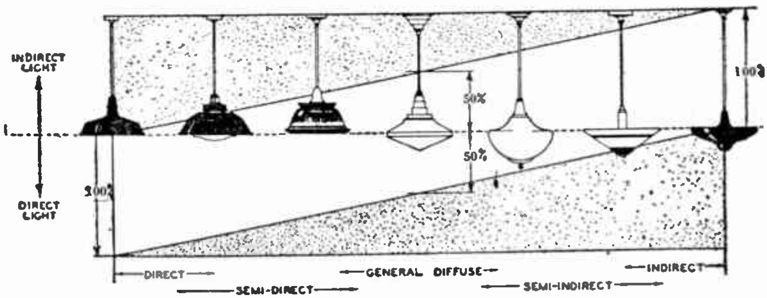


FIG. 7,498.—Illustrating general classification of luminaires.

This has led to many modern systems employing louvered downlights with concentrating reflector or lens control to confine the light narrowly to the seeing plane, with a minimum of light in the direction of the eyes; proper location of equipment is very important to obtain good distribution, to avoid harsh shadows, and to minimize glaring reflections from shiny or polished surfaces. Large area sources of low brightness and good diffusion approach the characteristics of indirect lighting, in that harsh shadows and both direct and reflected glare are minimized.

Semi-Direct.—This classification refers to systems where the predominant light on horizontal working surfaces comes from the lighting units, but where there is also a considerable contribution by reflection from the ceiling, as would be the case with enclosing opal or prismatic glass globes. Such units direct the light out at all angles, and are likely to be too bright for offices, schools and other similar locations unless oversize globes are used.

Installation of such units can oftentimes be greatly improved by equipping the globes with parchment shades to reduce the brightness toward the eye and at the same time redirect the light more efficiently to the work surfaces.

Semi-indirect.—Defined as any system in which some light—usually from 5 to 25%, is transmitted directly downward but over half of the emitted light is upward depending largely upon reflection from the ceiling. Luminaires of good design should be of such density and diffusion that the surface brightness of the bowl will not exceed 500 foot-lamberts. Semi-direct illumination has the same general characteristics and field of application as indirect lighting, but is sometimes preferred because of the luminous appearance yet low brightness of the luminaires. Opaque units which employ baffles or shielded openings to redirect a small part of the light to their undersurfaces for decorative effect only would be classed as indirect units.

Indirect.—Characterized by the soft, subdued atmosphere created by low brightness and by the absence of sharp shadows, since practically all of the light is diffusely reflected from large ceiling areas. Permits a wide range of installation technique from simple suspended or portable luminaires to built-in concealed sources in the form of coves, ceiling coffers, column urns, and wall boxes. Appearance demands a fair uniformity of ceiling brightness. In long, low-ceilinged rooms, large expanses of ceiling area are brought within the normal line of vision and may become uncomfortable after a few hours in installations intended to produce 25 footcandles or more. This condition is less serious where ceiling areas are divided by projecting crossbeams, or where occasional ceiling valences are employed to break up an otherwise flat, expansive ceiling area.

Level of Illumination.—The footcandle values of illumination that have been found by research and experience to be desirable for quick and comfortable vision are given in table III.

The desired illumination differs rather widely, depending upon the conditions of any particular installation, such as the accuracy of the operation and fineness of detail to be observed and the color of the objects worked on or handled.

Table III.—Footcandles for Interior Lighting.

These footcandle values represent order of magnitude rather than exact illumination.

Cars	*Footcandles*
baggage, day coach, dining, Pullman	15
Mail	
bag racks and letter cases	20
storage	5
street railway, trolley, bus and subway	15
motor bus	10

Office Buildings

bookkeeping, typing and accounting 50

Conference Room

general meetings 10
corridors and stairways 5

Desk Work

intermittent reading and writing 20
prolonged close work, computing, studying, designing, etc. 30–50
reading blueprints and plans 30

Drafting

prolonged close work-art drafting and designing in detail. 30–50
rough drawing and sketching 30
filing and index references 20
lobby 10
mail sorting 30
reception rooms 10

Stenographic Work

prolonged reading shorthand notes 30–50
vault 10

Professional Offices

waiting rooms 10
consultation rooms 20
general offices 20

Restaurants, Lunch Rooms and Cafeterias

dining area 10

Schools

auditoriums 10
class and study rooms—desks, blackboards 20
corridors and stairways 5
drawing room 30–50
gymnasium 20

Laboratories and Manual Training Rooms

general 20

Lecture Rooms	
general	10
library and offices	20
Sight-Saving Classrooms	
desks, blackboards	30–50
Service Space	
Corridors	5
elevators—freight and passenger	10
halls and stairways	5
lobby	10
Storage	5
toilets and wash rooms	5
Telephone Exchanges	
operating rooms	10
terminal rooms	15
cable vaults	5
Theatres	
auditoriums	5
foyer	10
lobby	15
Armories	
drill sheds and exhibition halls	10
Art Galleries	
general	5
Auditoriums	5
Automobile showrooms	20
Banks	
lobby	15
offices	20
Churches	
auditoriums	5
Sunday school rooms	10
pulpit or rostrum	20

Club or Lodge Rooms	
lounge and reading rooms	20
auditoriums	5
Courtrooms	10
Dance halls	5
Drafting rooms	30–50
Fire Engine Houses	
when alarm is turned in	10
at other times	2
Garages—Automobile	
storage—dead	2
live	10
Hangars—Airplane	
storage—live	10
Hospitals	
corridors	5
laboratories	20
lobby and reception room	10
operating room	20
private rooms and wards (with local illumination)	20
Hotels	
Lobby	10
dining room	5
kitchen	20
guestrooms	10
corridors	2
writing rooms	20
Libraries	
reading room	20
stack room	10
Moving Picture Theatres	
during intermission	5
during pictures	0.1
Museums	
general	10
Night clubs and bars	5

Lamp Wattage.—Having selected the illumination level from Table III it is now possible to obtain the lamp wattage from Tables IV to VII.

Locate the spacing value already decided upon in the second vertical column. Check the minimum mounting height given in the first column to make sure the mounting height to be used is greater than the minimum height listed for the spacing being considered. To the right in the column headed *Room Factor*, select the factor previously determined (**A, B, C, D**, or **E,** as the case may be). Following horizontally to the right on this line, locate the column which contains the footcandle value recommended for the installation. At the head of the column will be found the size of the Mazda lamp required.

Wire Capacity.—The need for adequate wire capacity cannot be too strongly emphasized. Not only does the operation of lighting systems under poor wiring conditions prevent the user from obtaining the benefits of better lighting, but in many cases of overloaded circuits, present operation is uneconomical to the extent that losses are suffered each year sufficient to pay for good wiring. Overloaded circuits are not only a nuisance from the standpoint of fuse trouble, which is indicative of a hazard, but unstable voltage conditions, which are inevitable, cause unsatisfactory performance of electrical devices. Lamps operated below their rated voltage are inefficient in the production of light. Much current is wasted in heating the wires instead of being converted into light—the main purpose of the system.

Where an attempt to correct this is made by substituting lower voltage lamps, some compensation is obtained, although this results in erratic performance of lamps, and early burnouts due to over-voltage operation when the load is reduced.

Table IV.—Design data for R.L.M. Dome reflectors (Direct lighting luminaries).

The values in this table have been calculated using the following data:

Reflector efficiency (white bowl lamp) 65 %
Allowance for depreciation 30 to 40 %

These data apply to R.L.M. Dome reflectors equipped with white bowl Mazda lamps or slightly etched glass cover plate or glass ring when used with High Intensity Mercury Vapor Lamp. For clear or inside frosted Mazda lamps increase the average foot-candle values 10%.

Minimum Mounting Height (Feet)	Approximate Luminaire Spacing (Feet)	Floor Area per Outlet (Sq.Ft.)	Room Factor	Average Foot-candles: Mazda Lamps 100 Watt	150 Watt	200 Watt	300 Watt	500 Watt	750 Watt	1000 Watt	1500 Watt	Mercury Lamps 250 Watt	400 Watt
8	8 x 8	60-70	A	8.5-12	15-19	21-27	35-44	56-75				42-56	
			B	6.5-8.5	11-15	16-21	26-35	43-56				32-42	
			C	5.0-6.5	8.5-11	12-16	19-26	33-43				25-32	
8½	9 x 9	70-90	A	7.5-10	12-17	17-23	27-38	47-65				35-48	
			B	5.5-7.5	8.5-12	13-17	20-27	36-47				26-35	
			C	4.0-5.5	6.5-8.5	9.5-13	15-20	26-35				19-26	
9½	10 x 10	90-110	A	6-8	10-13	13-18	22-30	35-50	52-73			26-37	57-80
			B	4.5-6.0	7.5-10	10-13	16-22	27-35	40-52			20-26	44-57
			C	3.5-4.5	5.5-7.5	7.5-10	12-16	21-27	31-40			16-20	34-44
10½	11 x 11	110-130	A	5.0-6.5	8-11	11-15	18-24	30-41	44-60			22-31	48-66
			B	4-5	6-8	8.5-11	13-18	23-30	34-44			17-22	37-48
			C	3-4	4.5-6.0	6.5-8.5	10-13	18-23	26-34			13-17	29-37
11	12 x 12	130-150	A	4.5-5.5	7-9	10-13	16-20	26-35	38-50	55-72		19-26	42-55
			B	3.5-4.5	5.5-7.0	7.5-10	12-16	20-26	29-38	42-55		15-19	32-42
			C	2.5-3.5	4.0-5.5	5.5-7.5	9-12	15-20	22-29	32-42		11-15	24-32
11½	13 x 13	150-180	A		6-8	8-11	13-18	22-30	33-44	44-62		17-23	36-48
			B		4.5-6.0	6-8	10-13	17-22	25-33	34-44		13-17	27-36
			C		3.5-4.5	4.5-6.0	7.5-10	13-17	19-25	26-34		9.5-13	21-37
12	14 x 14	180-210	A		5.5-6.5	7.5-9.0	11-15	18-25	27-36	39-52		14-19	30-40
			B		4.0-5.5	5.5-7.5	8.5-11	14-18	21-27	30-39		11-14	23-30
			C		3-4	4.0-5.5	6.5-8.5	11-14	16-21	23-30		8-11	20-23
12½	15 x 15	210-240	A		4.5-5.5	6-8	9-13	17-22	23-31	34-44	53-70	13-16	25-34
			B		3.5-4.5	4.5-6.0	7-9	13-17	18-23	26-34	40-53	10-13	20-25
			C		2.5-3.5	3.5-4.5	5.5-7.0	9.5-13	14-18	20-26	31-40	7-10	16-20
13½	16 x 16	240-270	A		3.5-5.0	5-7	8.5-11	14-19	21-27	30-39	47-61	11-14	23-30
			B		2.5-3.5	4-5	6.5-8.5	11-14	16-21	23-30	36-47	8-11	18-23
			C		2.0-2.5	3-4	5.0-6.5	8.5-11	12-16	18-23	28-36	6.5-8.0	13-18
14	17 x 17	270-300	A			5-6	8-10	13-17	18-24	27-35	42-54	10-13	20-26
			B			4-5	6-8	9.5-13	14-18	21-27	32-42	7-10	16-20
			C			3-4	4.5-6.0	7.5-9.5	11-14	16-21	25-32	5.5-7.0	12-16
15	18 x 18	300-340	A			4.5-5.5	6.5-9.0	11-15	17-22	23-31	37-49	8-11	19-24
			B			3.5-4.5	5.0-6.5	9-11	13-17	18-23	28-37	7-8	15-19
			C			2.5-3.5	4-5	7-9	10-13	14-18	22-28	5-7	11-15
15½	19 x 19	340-380	A			3.5-5.0	6-8	10-13	15-19	22-27	33-43	7.5-10	17-21
			B			2.5-3.5	4.5-6.0	8-10	12-15	17-22	26-33	6.0-7.5	13-17
			C			2.0-2.5	3.5-4.5	6-8	9-12	13-17	20-26	4.5-6.0	10-13
16	20 x 20	380-420	A				5.5-7.0	9-12	13-17	18-25	30-39	7-9	15-19
			B				4.0-5.5	7-9	10-13	14-18	23-30	5-7	11-15
			C				3-4	5.5-7.0	8-10	11-14	18-23	4-5	9-11
17	21 x 21	420-460	A				5.0-6.5	8.5-11	13-16	17-22	26-35	6.5-8.0	15-18
			B				4-5	6.5-8.5	10-13	13-17	20-26	5.0-6.5	11-15
			C				3-4	5.0-6.5	7.5-10	10-13	16-20	4-5	8-11
18	22 x 22	460-500	A				4.5-6.0	8-10	11-14	16-20	24-32	6.0-7.5	12-16
			B				3.5-4.5	6-8	8.5-11	12-16	19-24	4.5-6.0	9.5-12
			C				2.5-3.5	4.5-6.0	6.5-8.5	9.5-12	15-19	3.5-4.5	7.0-9.5
19	23 x 23	500-550	A				4.0-5.5	6.5-9.0	10-13	14-19	23-29	5-7	11-15
			B				3-4	5.0-6.5	8-10	11-14	18-23	4-5	9-11
			C				2.5-3.0	4-5	6-8	8.5-11	14-18	3-4	6.5-9.0

Table V.—Design data for semi-direct lighting luminaires.

The values in this table have been calculated using the following data:

Luminaire efficiency 75 to 90 %
Allowance for depreciation 30 %


Prismatic Glass


Opal Glass

Minimum Mounting Height (Feet)	Approximate Luminaire Spacing (Feet)	Floor Area per Outlet (Sq.Ft.)	Room Factor	Average Foot-candles: 100 Watt	150 Watt	200 Watt	300 Watt	500 Watt	750 Watt	1000 Watt	1500 Watt
8	8 x 8	60-70	C	7.5-11	12-18	19-28	29-42	50-72			
			D	5.0-7.5	9-12	13-19	20-29	34-50			
			E	3.5-5.0	6-9	8.5-13	14-20	23-34			
8½	9 x 9	70-90	C	6.5-9.5	11-16	15-22	24-36	40-62	56-80		
			D	4.5-6.5	7-11	9.5-15	16-24	27-40	38-56		
			E	3.0-4.5	4.5-7.0	6.5-9.5	11-16	18-27	26-38		
9½	10 x 10	90-110	C	5.0-7.5	7.5-12	12-17	19-28	32-48	46-70	65-100	
			D	3.5-5.0	5.0-7.5	8-12	13-19	22-32	31-46	44-65	
			E	2.5-3.5	3.5-5.0	5.5-8.0	8.5-13	15-22	21-31	30-44	
10½	11 x 11	110-130	C	4.5-6.0	6.5-10	9.5-14	16-23	26-39	38-57	54-81	
			D	3.0-4.5	4.5-6.5	6.5-9.5	11-16	18-26	26-38	37-54	
			E	2-3	3.0-4.5	4.5-6.5	7.5-11	12-18	18-26	25-37	
11	12 x 12	130-150	C		6.0-8.5	9-12	14-20	23-33	35-48	47-68	75-108
			D		4-6	6-9	9.5-14	16-23	24-35	32-47	51-75
			E		3-4	4-6	6.5-9.5	11-16	16-24	22-32	35-51
11½	13 x 13	150-180	C		5.0-7.5	6.5-10	12-17	19-29	28-42	38-59	63-93
			D		3.5-5.0	4.5-6.5	8-12	13-19	19-28	26-38	43-63
			E		2.5-3.5	3.0-4.5	5.5-8.0	9-13	13-19	18-26	29-43
12	14 x 14	180-210	C			6.0-8.5	9.5-14	16-24	23-35	35-49	54-76
			D			4.5-6.0	6.5-9.5	11-16	16-23	24-35	37-54
			E			3.0-4.5	4.5-6.5	7.5-11	11-16	16-24	25-37
12½	15 x 15	210-240	C			5.0-7.5	9-12	14-20	19-30	29-42	47-67
			D			3.5-5.0	6-9	10-14	13-19	20-29	32-47
			E			2.5-3.5	4-6	7-10	9.5-13	14-20	22-32
13½	16 x 16	240-270	C				7.5-11	12-18	18-26	26-37	41-58
			D				5.0-7.5	8.5-12	12-18	18-26	28-41
			E				3.5-5.0	6.0-8.5	8.5-12	12-18	19-28
14	17 x 17	270-300	C				6.5-9.5	11-16	16-23	23-33	37-52
			D				4.5-6.5	7.5-11	11-16	16-23	26-37
			E				3.0-4.5	5.5-7.5	8-11	11-16	17-26
15	18 x 18	300-340	C				6.0-8.5	10-14	15-21	21-30	32-47
			D				4.5-6.0	7-10	10-15	15-21	22-32
			E				3.0-4.5	5-7	7-10	10-15	15-22
15½	19 x 19	340-380	C				5.0-7.5	9-13	12-18	19-26	29-41
			D				3.5-5.0	6.5-9.0	9-12	13-19	20-29
			E				2.5-3.5	4.5-6.5	6-9	8.5-13	14-20
16	20 x 20	380-420	C					7.5-11	11-16	16-23	26-37
			D					5.5-7.5	8-11	11-16	18-26
			E					4.0-5.5	5.5-8.0	8-11	12-18
17	21 x 21	420-460	C					7-10	11-15	15-21	23-33
			L					5-7	7.5-11	10-15	16-23
			E					3.5-5.0	5.0-7.5	7-10	11-16
18	22 x 22	460-500	C					6.5-9.5	9.5-14	13-19	21-30
			D					4.5-6.5	6.5-9.5	9.5-13	15-21
			E					3.0-4.5	4.5-6.5	6.5-9.5	10-15
19	23 x 23	500-550	C					6.0-8.5	9-12	12-18	19-28
			D					4.5-6.0	6-9	9-12	13-19
			E					3.0-4.5	4-6	6-9	6.5-13

Table VI.—Design data for semi-indirect luminaires.

The values in this table have been calculated using the following data:

Luminaire efficiency 65 to 85 %
Allowance for depreciation 30 %


Opal Glass


Prismatic Glass

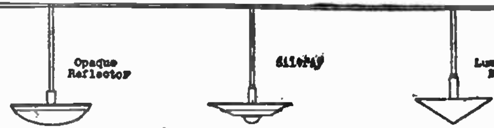

Open Bowl

Minimum Ceiling Height (Feet)	Minimum Hanger Length (Feet)	Approximate Luminaire Spacing (Feet)	Floor Area per Outlet (Sq.Ft.)	Room Factor	Average Foot-candles							
					100 Watt	150 Watt	200 Watt	300 Watt	500 Watt	750 Watt	1000 Watt	1500 Watt
8	½	8 x 8	60-70	C D E	6.0-9.5 4-6 2.5-4.0	9.5-16 6.0-9.5 4-6	14-22 8.5-14 5.5-8.5	23-36 15-23 9-15	39-60 25-39 16-25			
8½	1	9 x 9	70-90	C D E	5-8 3-5 2-3	8-13 4.5-8.0 3.0-4.5	12-19 7-12 4.5-7.0	18-30 11-18 7-11	31-52 19-31 12-19	44-75 28-44 18-28		
9½	1½	10 x 10	90-110	C D E	4-6 2.5-4.0 1.5-2.5	6.5-10 4.0-6.5 2.5-4.0	9-15 5.5-9.0 3.5-5.5	15-24 9.5-15 6.0-9.5	24-36 16-24 10-16	36-59 23-36 15-23		
10½	2	11 x 11	110-130	C D E		6.0-8.5 3-5 2-3	8-12 4.5-8.0 3.0-4.5	12-19 8-12 5-8	21-33 13-21 8.5-13	30-48 19-30 12-19	44-68 28-44 18-28	
11	2	12 x 12	130-150	C D E			6-10 4-6 2.5-4.0	10-16 7-10 4.5-7.0	17-28 11-17 7.5-11	26-40 17-26 11-17	36-57 23-36 15-23	
11½	2	13 x 13	150-180	C D E			5.0-8.5 3-5 2-3	8.5-14 5.5-8.5 3.5-5.5	15-24 9.5-15 6.0-9.5	22-35 14-22 9-14	31-50 20-31 13-20	48-78 31-48 20-31
12	2½	14 x 14	180-210	C D E			5.0-7.5 3-5 2-3	8-12 4.5-8.0 3.0-4.5	13-20 8-13 5-8	19-29 12-19 7.5-12	27-41 17-27 11-17	41-65 26-41 17-26
12½	2½	15 x 15	210-240	C D E				6-10 4-6 2.5-4.0	11-17 7-11 4.5-7.0	16-25 10-16 6.5-10	23-35 15-23 9.5-15	36-56 23-36 15-23
13½	3	16 x 16	240-270	C D E				6-9 4-6 2.5-4.0	9.5-15 6.0-9.5 4-6	14-22 9.5-14 6.0-9.5	20-31 13-20 8.5-13	31-49 20-31 13-20
14	3	17 x 17	270-300	C D E				4.5-8.0 3.0-4.5 2-3	8.5-13 5.5-8.5 3.5-5.5	12-19 8.5-12 5.5-8.5	17-28 11-17 7.5-11	29-43 19-29 12-19
15	3	18 x 18	300-340	C D E					8.5-12 5.5-8.5 3.5-5.5	11-17 7-11 4.5-7.0	16-25 10-16 6.5-10	26-39 17-26 11-17
15½	3	19 x 19	340-380	C D E					7-11 4.5-7.0 3.0-4.5	10-15 6.5-10 4.0-6.5	14-22 9.5-14 6.0-9.5	23-35 15-23 9.5-15
16	4	20 x 20	380-420	C D E					6.0-9.5 4-6 2.5-4.0	9.5-14 6.0-9.5 4-6	13-20 8.5-13 5.5-8.5	20-31 13-20 8.5-13
17	4	21 x 21	420-460	C D E					5.5-8.5 4.0-5.5 2.5-4.0	8.5-13 5.5-8.5 3.5-5.5	12-18 8-12 5-8	19-28 12-19 8-12
18	4	22 x 22	460-500	C D E					5-8 3-5 2-3	7-11 4.5-7.0 3.0-4.5	11-16 7-11 4.5-7.0	16-25 11-16 7-11
19	4	23 x 23	500-550	C D E						7-10 4.5-7.0 3.0-4.5	9.5-15 6.0-9.5 4-6	15-23 10-15 6.5-10

Table VII.—Design data for indirect lighting luminaires.

The values in this table have been calculated using the following data:

Luminaire efficiency 65 to 85 %
Allowance for depreciation 30 %



Minimum Ceiling Height (Feet)	Minimum Hanger Length (Feet)	Approximate Luminaire Spacing (Feet)	Floor Area per Outlet (Sq.Ft.)	Room Factor	Average Foot-candles 100 Watt	150 Watt	200 Watt	300 Watt	500 Watt	750 Watt	1000 Watt	1500 Watt
8	½	8 x 8	60-70	C D E	5.0-8.5 3-5 2-3	8-14 5-8 3-5	11-19 7.5-11 4.5-7.5	20-32 12-20 7-12	33-54 20-33 12-20	49-78 30-49 18-30		
8½	1	9 x 9	70-90	C D E	4-7 2.5-4.0 1.5-2.5	7-12 4-7 2.5-4.5	10-17 5.5-10 3.5-5.5	16-27 9-16 5.5-9.0	28-46 17-28 9.5-17	41-67 23-41 14-23		
9½	1½	10 x 10	90-110	C D E			8-13 5-8 3-5	13-21 7.5-13 4.5-7.5	22-36 13-22 8-13	32-52 19-32 11-19	43-74 26-43 16-26	
10½	2	11 x 11	110-130	C D E			6.5-11 4.0-6.5 2.5-4.0	11-17 6.5-11 4.0-6.5	18-29 11-18 6.5-11	26-42 16-26 9.5-16	38-60 23-38 14-23	67-95 41-67 25-41
11	2	12 x 12	130-150	C D E			6-9 3.5-6.0 2.0-3.5	10-15 6-10 3.5-6.0	15-25 9-15 5.5-9.0	22-36 13-22 8-13	33-51 20-33 12-20	50-80 34-50 21-34
11½	2	13 x 13	150-180	C D E			4.5-8.0 2.5-4.5 1.5-2.5	8-13 5-8 3-5	13-21 7.5-13 4.5-7.5	18-31 11-18 7-11	26-44 16-26 10-16	43-69 28-43 18-28
12	2½	14 x 14	180-210	C D E				6.5-11 4.0-6.5 2.5-4.0	11-18 6.5-11 4.0-6.5	16-26 10-16 6-10	23-37 14-23 8.5-14	39-58 24-39 15-24
12½	2½	15 x 15	210-240	C D E				5.5-9.0 3.5-5.5 2.0-3.5	9-15 5.5-9.0 3.5-5.5	13-22 8-13 5-8	21-38 13-21 7.5-13	31-50 19-31 12-19
13½	3	16 x 16	240-270	C D E				5.5-8.0 3.5-5.5 2.0-3.5	8-13 5-8 3-5	12-19 7.5-12 4.5-7.5	18-28 11-18 6.5-11	26-43 16-26 10-16
14	3	17 x 17	270-300	C D E					8-12 5-8 3-5	11-17 6.5-11 4.0-6.5	16-25 10-16 6-10	24-39 15-24 9-15
15	3	18 x 18	300-340	C D E					6.5-11 4.0-6.5 2.5-4.0	9-16 5.5-9.0 3.5-5.5	13-22 8-13 5-8	21-35 13-21 8-13
15½	3	19 x 19	340-380	C D E					6.0-9.5 4-6 2.5-4.0	8.5-14 5.0-8.5 3-5	12-20 7.5-12 4.5-7.5	20-31 12-20 7.5-12
16	4	20 x 20	380-420	C D E					5.0-8.5 3.5-5.5 2.0-3.5	8-12 5-8 3-5	11-18 6.5-11 4.0-6.5	18-28 11-18 6.5-11
17	4	21 x 21	420-460	C D E						6.5-11 4.0-6.5 2.5-4.0	10-16 6.5-10 4.0-6.5	16-25 10-16 6-10
18	4	22 x 22	460-500	C D E						6.5-10 4.0-6.5 2.5-4.0	9.0-14 5.5-9.0 3.5-5.5	14-23 9-14 6.5-9.0
19	4	23 x 23	500-550	C D E						6.0-9.5 3.5-6.0 2.0-3.5	8-13 5-8 3-5	13-21 8-13 5-8

General Wiring Data.—The National Electrical Code merely specifies wiring conditions with regard to fire hazards, with little consideration to economy of operation. The size of wire for a lighting installation may conform strictly to the Code and yet, because of length of circuit, produce excessive voltage drop with consequent inefficient lamp performance and unsatisfactory lighting.

On new or remodeling jobs where actual wattage to be installed is known, wiring specifications should be based on this load with capacity allowed for the next larger size lamps to be used in the future. In general, double the capacity can be installed initially at about one-third extra cost.

The following wiring recommendations may serve as a guide in good wiring practice:

Branch Circuits for General Illumination.—The allowable voltage drop should not exceed 2 volts between panelboard and outlet.

Load and Length of Run.—For 15 amp. circuits the initial load per circuit should not exceed 1,000 watts with No. 12 minimum wire size to be used where length of run does not exceed 50 feet; No. 10 wire for runs between 50 and 100 feet; No. 8 wire for runs between 100 and 150 feet.

For heavy duty lamp circuits (the National Electrical Code permits 8 mogul sockets, 40 amperes per circuit) 3,000 watts with No. 8 wire up to 50 foot runs; No. 6 wire 50 to 100 foot runs; No. 4 wire for runs from 100 to 150 feet. It is recommended that panelboards be so located that the length of run does not exceed 100 feet, if practical to do so.

Panelboards.—One spare circuit should be provided for each five circuits used in the initial installation. Concealed branch circuit conduit should be large enough for one additional circuit for every five or less circuits it contains.

Table VIII.—Wire size required (Computed for maximum of 2-volt drop on two-wire 120 volt circuit).

Load per Circuit	Current 120-Volt Circuit	LENGTH OF RUN (Panel Box to Load Center)—Feet																	
Watts	Amps.	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200
500	4.2	14	14	14	14	14	14	12	12	12	12	12	12	10	10	10	10	10	10
600	5.0	14	14	14	14	14	12	12	12	12	10	10	10	10	10	10	10	8	8
700	5.8	14	14	14	14	12	12	12	10	10	10	10	10	10	8	8	8	8	8
800	6.7	14	14	14	12	12	12	10	10	10	10	10	8	8	8	8	8	8	8
900	7.5	14	14	12	12	12	10	10	10	10	8	8	8	8	8	8	8	8	6
1000	8.3	14	14	12	12	10	10	10	10	10	8	8	8	8	8	8	6	6	6
1200	10.0	14	12	12	10	10	10	10	8	8	8	8	8	6	6	6	6	6	6
1400	11.7	14	12	10	10	10	8	8	8	8	8	6	6	6	6	6	6	6	6
1600	13.3	12	12	10	10	8	8	8	8	6	6	6	6	6	6	6	6	4	4
1800	15.0	12	10	10	10	8	8	8	6	6	6	6	6	6	4	4	4	4	4
2000	16.7	12	10	10	8	8	8	6	6	6	6	6	6	4	4	4	4	4	4
2200	18.3	12	10	10	8	8	8	6	6	6	6	6	4	4	4	4	4	4	2
2400	20.0	10	10	8	8	8	6	6	6	6	6	4	4	4	4	4	4	2	2
2600	21.7	10	10	8	8	6	6	6	6	4	4	4	4	4	4	4	4	2	2
2800	23.3	10	8	8	8	6	6	6	6	4	4	4	4	4	4	4	2	2	2
3000	25.0	10	8	8	6	6	6	6	6	4	4	4	4	4	4	2	2	2	2
3500	29.2	10	8	8	6	6	6	4	4	4	4	2	2	2	2	2	2	2	2
4000	33.3	8	8	6	6	6	4	4	4	4	2	2	2	2	2	2	1	1	1
4500	37.5	8	6	6	6	4	4	4	2	2	2	2	2	2	1	1	1	1	1

Service and Feeders (Maximum feeder drop—2 Volts).—The carrying capacity of service wiring and feeders should be sufficient for the normal branch circuit load with no more than a 2 volt drop. Normal diversity of branch circuit load in many cases reduces required feeder capacity below the actual total branch circuit load; the National Electrical Code allowances for this demand factor should govern. Provision should be made for increasing feeder capacity to take care of next larger lamp size (50% increase) than installed initially.

Convenience Outlets for Lighting.—Should not be connected to branch circuits which supply fixture outlets as a part of the general illumination system. No wire smaller than No. 12 should be used; No. 10 if the length of run exceeds 100 feet.

In *office space* there should be one convenience outlet circuit for each 800 square feet of floor area with at least one duplex outlet for each 20 linear feet of wall.

In *manufacturing spaces* there should be one convenience outlet for each 1,200 square feet or fraction of floor space with at least one duplex outlet in each bay.

In *stores* there should be at least one convenience outlet in each supporting column or at least one floor outlet for each 400 square feet or fraction of floor space. For windows, at least one outlet for each 5 linear feet of plate glass, with an additional floor outlet for each 50 square feet of platform area. Provision for signs should be made by installing a 1-inch conduit from the distribution panel to the front face of the building for each individual store space.

Watts per Square Foot

In determining the illumination on a "watt per square foot" basis, the floor area shall be computed from the outside dimensions of the building, apartment or area involved and the number of floors, not including open porches, garages in connection with dwelling occupancies, nor unfinished spaces in the basements or attics.

Although the "watts per square foot" basis is not exact, the level of illumination may be fairly well established in this manner.

One watt per square foot may produce from 3 to 10 footcandles depending upon the size of the room, color of ceiling and walls, and type of lighting units or method of lighting employed. For that reason any *"watt per square foot"* load estimates should be based not only on the footcandle to be provided, but should be tempered always by the knowledge of the utilization factors which so vitally affect the attainment of the desired level.

In the following paragraphs a brief outline is given of wattage per square foot, allowing for various classes of occupancies.

One Watt per Square Foot.—For corridors, locker rooms, dead storage areas and inactive spaces where the illumination requirements are of the order of 5 footcandles. In factories, commercial buildings, and public interiors, it is often desirable to convert storage spaces into active work areas to meet immediate needs; it is recommended that such areas be wired for at least two watts per square foot.

Two Watts per Square Foot.—Will provide for illumination levels of 10 to 15 footcandles in industrial areas, 8 to 12 in commercial areas with standard reflecting equipment. This order of illumination is the lower range of recommended values suitable for rough manufacturing work, packing, crating, storage and such areas occupied by mechanical and processing equipment where only casual and intermittent attention is required.

Four Watts per Square Foot.—Minimum provision to attain average levels of 20 footcandles; recommended for schools, offices, stores and for the large proportion of general industrial areas. In large areas with direct lighting industrial reflectors, this allowance with a combination of favorable conditions would be sufficient for as high as 30 footcandles. In small offices or stores with indirect lighting, this allowance would permit only 15 footcandles which represents the lower limits of modern practice, and is not sufficient for any future increase in the level of illumination.

Six Watts per Square Foot.—Should be allowed as a minimum in all areas where general illumination of 30 footcandles is recommended, but particularly in general offices, stores, and other commercial interiors. In small offices and similar small interiors such as sight-saving classrooms where indirect lighting would logically be used, even higher allowance should be made.

Eight Watts per Square Foot.—Rooms less than 20 x 20, typical of the small private office, lighted by modern indirect systems, require installed wattage of this order to attain the 30 to 35 footcandles that are being provided today. This order of wattage is also necessary for the many forms of louvered units, troughs and luminous architectural panel treatments where illumination of the order of 20 to 30 footcandles is desired.

Many of the more modern examples of lighting practice, where unusual treatment and lighting effect are desired, have as high as 12 to 15 watts per square foot installed. In the achievement of atmosphere and decorative effect, efficiency is of secondary importance and in such cases the actual illuminaton secured may be as low as 1 to 2 footcandles per watt per square foot as compared with 5 to 7 to be expected from conventional methods with average conditions prevailing.

CHAPTER 28

NEON

and Other Discharge Lamps

The difference between the ***incandescent lamp*** and the ***discharge lamp*** is mainly that while the incandescent type produces a continuous spectra dependent almost entirely upon the temperature of the filament, the electric discharge lamps produce lines of discontinuous spectra which are characteristic of the particular gas or vapor used.

An additional difference is, that generally the electric discharge group requires a current limiting device, consisting of an impedance coil, transformer or resistor, depending upon the particular lamp or circuit used.

The electric discharge group includes:

1. Neon lamps
2. Mercury vapor lamps
3. Sodium vapor lamps
4. Ultra-violet lamps
5. Fluorescent lamps

Neon Lamps.—The neon lamp, well known due to its employment in neon signs, contains a small amount of neon gas and an electrode at each end of the sealed glass tube.

From 2,000 to 15,000 volts is applied across the electrodes from its transformer.

Color Effect.—To obtain the brilliant orange-red color effect generated by the gas, the gas must be extremely pure, since a mixture of as little as 1% of nitrogen, for example, will result in a radiation completely dominated by the latter gas.

Various other gases such as *argon* or *helium* alone or in combination, are used to obtain a variety of colors. For a blue light, for example, mercury is introduced into the tube. Color effects can be further modified by the use of various colored glass to obtain the wide variety needed for decorative lighting and sign advertising.

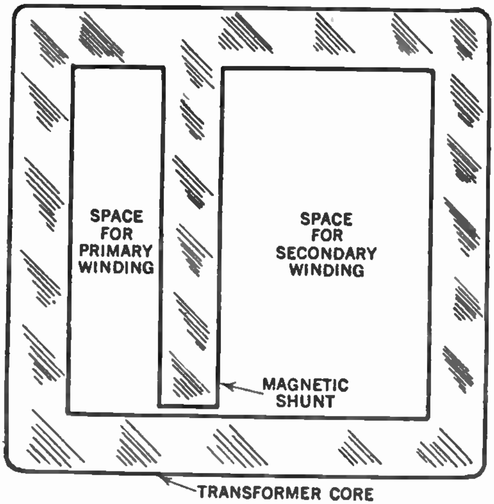
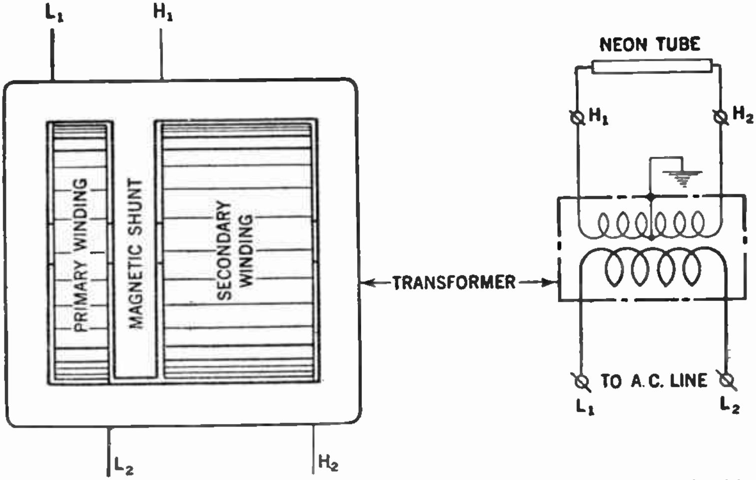


FIG 1.—Outline of neon sign transformer core.

Neon Tube Auxiliaries.—When the neon tube is utilized for sign service, the important auxiliaries besides switches, high-voltage cable and insulators, is the ***step-up potential transformer.***

This transformer differs in certain respects from the well known light and power type, in that it generally has:

1. A large ratio of transformation
2. Small power requirement
3. A special magnetic shunt



FIGS. 2 and 3.—View of neon sign transformer with windings in place, and schematic wiring diagram.

The secondary voltage usually varies of from 2,000 to 15,000 volts, which if transformed from the usual 110 volt lighting current, gives a ratio of transformation of from 18.2 to 136. That is, the secondary winding of the transformer must have from 18.2 to 136 times the number of the primary turns.

Power requirements vary with the amount of tubing to be made luminous and may be from 40 up to 900 volt-amperes.

The function of the special magnetic shunt, fig. 1, is to act as a current regulator for the transformer. It is necessary as a current limiting feature because of the fact that the higher the current through the tube the lower its resistance becomes.

If a neon tube be connected to a transformer of the light and power type (i.e., without the special magnetic shunt) then as the tube is heated up the current would increase. As the current increased, the resistance of the gas would decrease, in turn increasing the current until either the transformer or the tubing would burn out.

Because of the previously mentioned current limiting feature, when the current in the secondary increases, more and more of the magnetic lines are by-passed by the magnetic shunt and as a result, less of the lines connect the secondary winding, until the neon tube reaches a state of equilibrium at which point the secondary current reaches a constant value.

In common with all inductive circuits the transformer has a lagging power factor. The equipment needed for power factor improvement is usually supplied with the transformer.

Neon Glass Tubing.—The fundamental requirements for neon glass tubing are:

1. It must have considerable physical strength
2. It must melt at a convenient temperature, so that it may be worked easily in ordinary gas flames
3. It must be able to withstand sudden and extreme temperature changes without breaking.

There are two general kinds of glass used in neon tubing, namely: *Lead* and *pyrex glass*.

Lead glass tubing contains a considerable amount of lead oxide as the name implies. It is made from silicon oxide and lead oxide melted together with potash and other substances and carefully cooled.

The glass tubing can be bent and shaped with ease over any ordinary illuminating gas flame, the bending sequence depending upon the design of the letters or any other particular geometrical features.

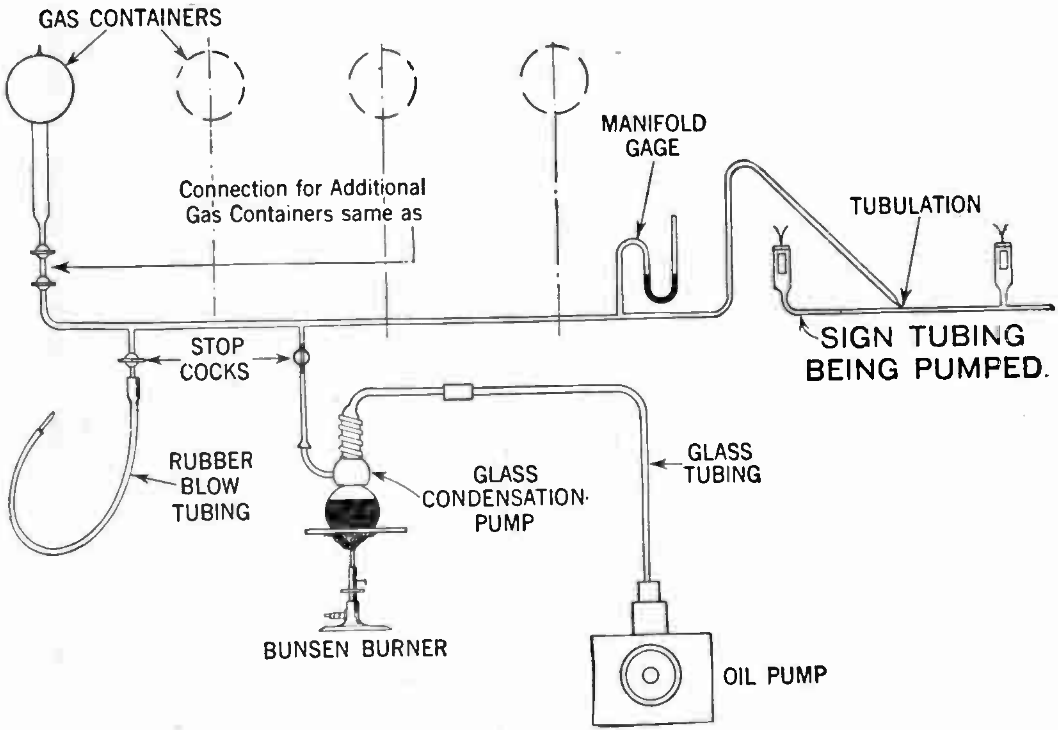


FIG. 4.—Diagram of manifold system showing principal connections.

Pyrex glass can not be bent as easily as lead glass, and requires an oxygen-fed flame. In its physical properties it differs considerably from lead glass, in that it can easily withstand the most extreme temperature changes, and is also mechanically stronger than the former.

Neon Sign Construction.—The first part in the construction of a neon sign is the design of the letters, after which the glass is heated, bent to shape, spliced together, and then a continuous complete tube open at each end is formed.

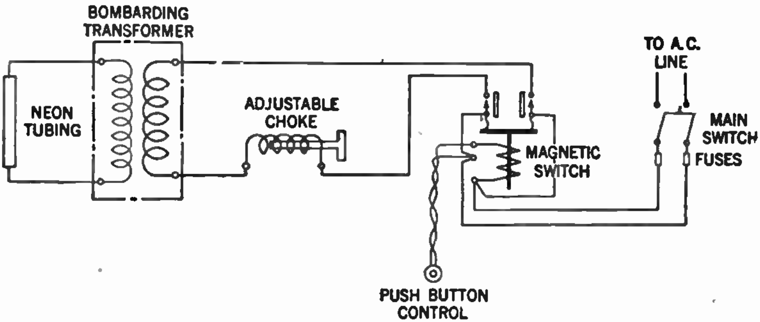


Fig. 5.—Schematic wiring diagram of bombarding transformer with auxiliary equipment.

Next, a hole is made in the center of the tubing and a small tube is attached for the purpose of connecting it to the pump. The electrodes with their glass jackets, are then inserted at each end of the tube, and the pump attached to the entire tubing.

After the pressure in the tube has been reduced slightly as indicated by the vacuum gauge, the stop cock leading to the pump is turned off, so that the pump is disconnected from the tube.

The bombarding operation, to remove the chemical impurities, next takes place. This operation consists in connecting of a high potential current across the electrodes of the tube. This bombardment is kept up for a length of time depending upon the size of the tube and other particulars.

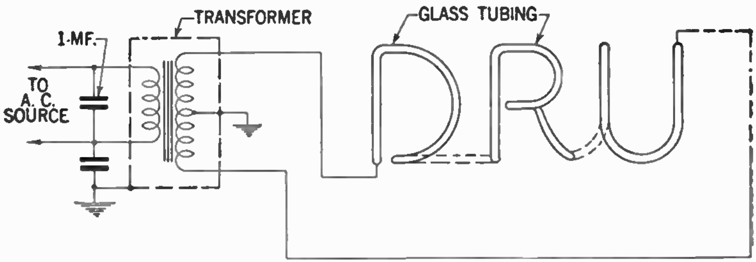


FIG. 6.—Typical wiring diagram showing radio interference suppressor in transformer primary.

At the completion of this process the pump stop-cock is again opened, and the pump again reduces the pressure and removes the impurities being loosened by the bombarding process.

The pump stop-cock is now turned off, and the stop-cock leading to the rare gas flask is opened slowly to admit gas to the tubing.

When the proper pressure as indicated by the vacuum gauge is reached, the stop-cock is turned off, the tubulations leading from the pumps are sealed, thus completing the process.

Other Classes of Neon Lamps.—The more recent types of neon vapor devices are the *hot cathode tube* and the *glow lamp*. In the former device one of the terminals is heated to incandescence. This allows the lamp to be operated at a considerable lower voltage and provides a considerable higher efficiency than normally obtained by discharge through neon.

The *glow lamp* has found an extensive use on pilot lights, current indicators, signal lamps and for stroboscopic work. Its main characteristics are: 1, *low current consumption;* 2, *long life;* 3, *low brilliancy;* 4, *ability to withstand shocks and vibration.*

Both of these lamps may be used on either *a.c.* or *d.c.* current. When used on *d.c.* current only one electrode glows, thus indicating polarity, which factor extends its use for various testing purposes.

With most lamps of this type a current limiting resistance is built into the base and external auxiliaries such as are associated with other discharge lamps are not required.

The Mercury Vapor Lamp.—The extensive use of the mercury vapor lamp depends entirely upon the versatility of the mercury vapor as regards pressure, temperature, voltage and other characteristics, each change resulting in a lamp of different spectral quality and efficiency.

The lamps of the group utilized for general lighting service are usually described as the high intensity mercury lamp. The pressure within the enclosure varies from one atmosphere up to as much as 80 atmospheres for special lamps.

Operating Features.—The mercury vapor lamp usually contains a small amount of argon gas to facilitate starting, since mercury is normally a liquid at room temperature, and even in partial vacuum has very little vapor pressure.

After a few minutes of electrode heating the arc vaporizes enough mercury to reach the point of stabilization. The exact point is dependent on each particular lamp, and is controlled by the design of the auxiliaries.

As the mercury pressure increases, the arc becomes concentrated at the center of the bulb, usually tubular in shape. Under certain conditions the lamp can be burned only in a vertical position as otherwise the concentrated arc will bow, touching the glass and causing its breakage.

The intense heat of the arc in some of the mercury lamps requires the use of a quartz envelope rather than glass.

When the current of any high pressure lamp is interrupted, a few minutes of cooling is required.

The consequent lowering of internal pressure allows the arc to again strike and normal operation is resumed.

Color Effect.—The light produced by high intensity vapor lamps shows three main lines—*yellow, yellow-green and violet.* Due to the energy concentration in the yellow-green area of the spectrum, the luminous efficiency is very high—the human eye being most responsive to color in this area.

Sodium Vapor Lamps.—Scientists have long been familiar with the fact that high luminous efficiencies could be obtained by the use of sodium vapor as a light source.

The development of a practical lamp of this type, however, was delayed since ordinary glass cannot withstand the chemical action of hot sodium.

With the development of special resistant glass, the sodium vapor lamp has now reached the practical stage.

Operation.—Principally the sodium vapor lamp consists of a bulb containing a small amount of metallic sodium, neon gas, and two sets of electrodes connected to a pin type base.

In order to conserve the heat generated and assure the lamp operating at normal air temperatures, it must be enclosed in a special vacuum envelope designed for this purpose.

The presence of neon gas serves to start the discharge and to develop enough heat to vaporize the sodium. This condition accounts for the red-orange glow during the first few minutes of operation.

The metallic sodium gradually vaporizes and then ionizes, thereby producing the characteristic monochromatic yellow light. The lamp will come up to its rated light output in approximately 15 to 20 minutes. It will restart immediately should the power supply be momentarily interrupted since the presence of vapor is quite low and the voltage applied sufficient to restrike the arc. The major application of this type of lamp is for *highway* and general *outdoor lighting* where color discrimination is not required.

Ultra-Violet Lamps.—The increasing application of ultra-violet radiation has resulted in the development of a number of different sources which produce this short-wave energy.

Ultra-violet radiations are commonly produced by carbon and tungsten arcs and also in various gaseous discharge lamps. The term *ultra-violet radiation* in general, refers to that part of the electro-magnetic spectrum adjacent to the visible spectrum and extending roughly from 1000 to 3800 Angstrom units.

This band may be divided into four narrower bands each with distinct characteristics, thus:

(A) 3,200 to 3,800 Angstrom is useful in certain types of photography and fluorescent displays.

(B) 2,800 to 3,200 Angstrom known as the *biologically* effective band which produces sunburn and tan.

(C) 2,000 to 2,800 Angstrom, the bacterial band which is lethal to most micro-organisms.

(D) 1,000 to 2,000 Angstrom, the ozone producing band about which very little is hitherto known.

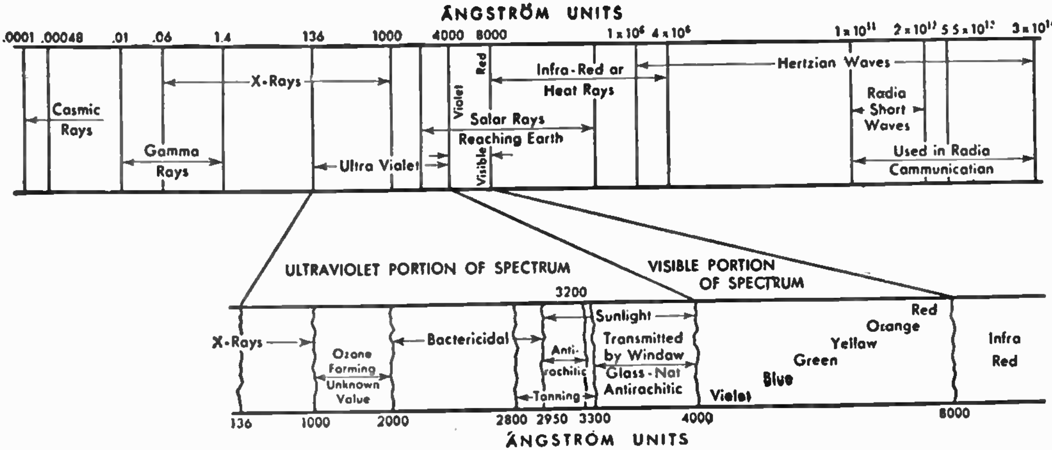


Fig. 7.—The spectrum. The angstrom unit is used to express the wave length of light and ultra-violet radiations. One angstrom unit is equal to 1/10,000,000 of a millimeter or approximately 1/250,000,000 of an inch.

Steri-Lamps.—The fact that ultra-violet radiation destroys micro-organisms has made this type a most useful tool for all sorts of sterilizing purposes.

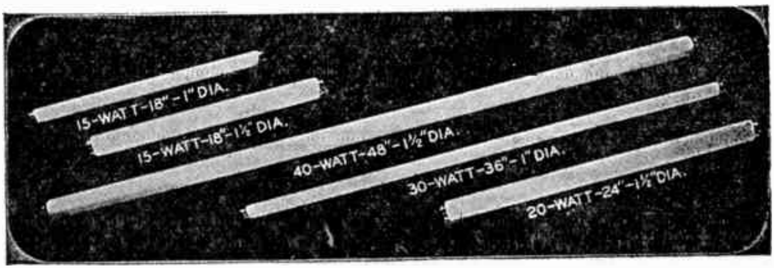
They are being used successfully for sterilizing air in ducts of air-conditioning equipment, for prevention of the formation of mould in food industries, such as walk-in meat coolers, domestic refrigerators, bakeries, dairies, and in hospitals, etc.

Just what the ultimate fields of application for these lamps will be, no one can predict. One use leads to another, and unquestionably many applications will develop as time goes on. It is, however, already apparent that there are now available new tools in the form of light sources that will contribute much to human welfare and industrial progress.

CHAPTER 29

Fluorescent Lamps

In contrast to the well known filament lamp in which electricity flows from one lead wire to another through the solid tungsten wire, thus heating it to incandescence, the fluorescent lamp in common with other electric discharge devices makes use of ultra-violet energy to activate a **fluorescent material** coated on the inside of the bulb's surface.



Figs. 1 to 5.—Various size fluorescent lamps.

The coating material used depends upon the color effect desired and may consist of ***zinc silicate, cadmium silicate*** or ***calcium tungstate.*** These organic chemicals are known as ***phosphors,*** which powder transforms short-wave invisible radiation into visible light.

Construction of Fluorescent Lamps.—The lamp in its present form consists of a tubular glass-bulb with two external contacts at each end, which are connected to filament-type electrodes made of coiled tungsten wire (See fig. 6). These filament electrodes are coated with an active electron emissive material.

Within the bulb there is a small drop of mercury and also a low pressure (a few millimeters) of pure argon gas to facilitate the starting.

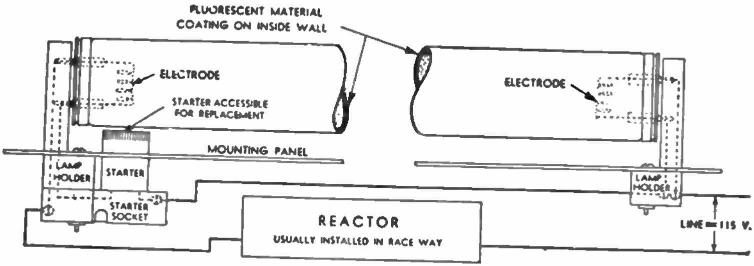


FIG. 6.—Assembly of typical fluorescent lamp showing auxiliaries and connections.

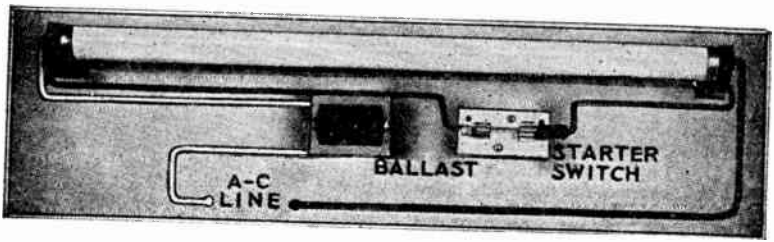


FIG. 7.—Simplified diagram of fluorescent lamp and auxiliaries. The ballast choke coil performs the function of limiting the current to the designed value required by the lamp. The starter switch (shown as a simple knife switch for the sake of clearity) momentarily closes the heating circuit through the filament electrodes to facilitate starting.

Starting Auxiliaries.—Fluorescent lamps in common with all electric discharge apparatus requires *auxiliary control equipment*. The function of the starting auxiliaries is to create *a momentarily high-voltage impulse* in order to establish an arc between the electrodes at the opposite ends of the tubular lamp.

The auxiliary consists of two principal elements: 1, an iron core choke coil (ballast) which limits the arc current, and 2, a starting switch which momentarily closes and then opens the electrode heating circuit. See figs. 7 and 8.

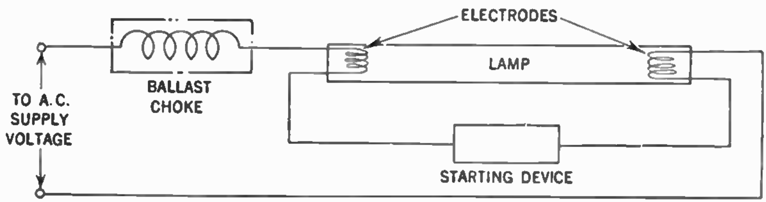


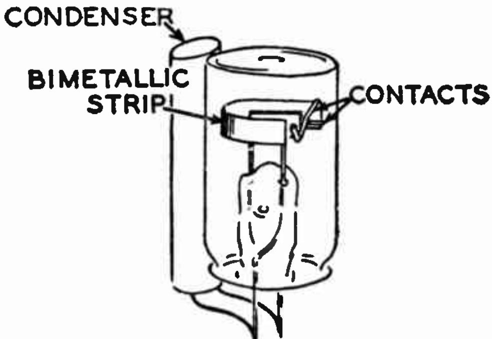
FIG. 8.—Schematic diagram showing connection of fluorescent lamp.

Each lamp requires a separate auxiliary, although the elements for two or more lamps may be contained in a single unit. Specifically designed ballast equipments are required *for each wattage size, for each frequency* and *for each voltage range.*

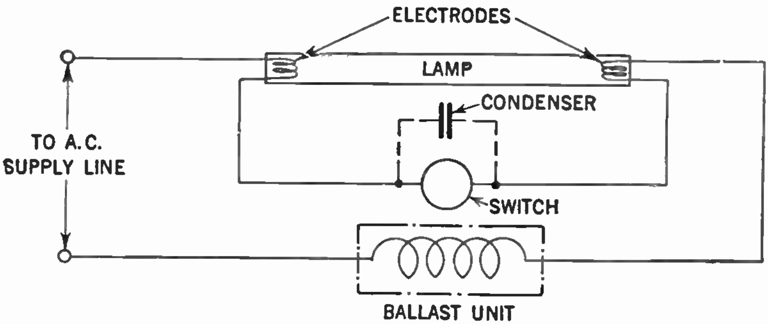
When the lamp was first introduced a number of starting methods such as the thermal switch, resonant and magnetic switch type were exclusively utilized. Recently, however, a switch known as the *glow switch* operating on the thermal principle has been manufactured.

Operation of Glow Switch.—This new starting device is about 1 in. long and about ⅜ in. in diameter and resembles a miniature electric lamp, but contains an easily ionized gas and two bi-metallic electrodes which serve as the switch contacts.

The switch is connected in series with the fluorescent lamp electrodes; when the current is turned on a glow discharge is created between the normally open switch contacts on the bi-metallic electrodes.



INTERNAL ELEMENTS OF THE STARTER



FIGS. 9 and 10.—Glow switch starter and connection to lamp unit.

The heat of the glow causes the contacts to close. At this point the lamp electrodes are heated to a bright red color. When the contacts close the glow discharge automatically ceases, allowing the bi-metal elements to cool and separate, opening the switch and striking the arc.

The whole operation from the time the current is applied and until the arc is established requires only one or two seconds.

As used in the new fluorescent lamp starter, the glow switch and a tiny condenser to eliminate radio interferenece are housed in a small aluminum shell equipped with a bayonet-type end and inserted in a special socket attached to the standard fluorescent lamp holder. Thus the starting unit is readily accessible and replaceable. Since it is now separate from the starting unit and need not be accessible after installation, choke or ballast device (necessary to limit the operating current) is made more compact and may be mounted in any convenient place.

Need for Power Factor Correction.—It is a well known fact that power consuming apparatus of the *inductive class* such as coils and other current limiting devices has a *lagging power factor* i.e., the current is lagging the voltage by a certain amount depending upon the size of the coil or device in question. Thus, for example, the equation for power in all direct current circuits and in alternating current circuits containing only pure ohmic resistance is,

$$\text{watts} = \text{volts} \times \text{amperes}.$$

If, however, other circuit elements be present, as in the case of the fluorescent lamp circuit, with the inductive choke coil in series with it, the equation for true power becomes

$$\text{watts} = \text{volts} \times \text{amperes} \times \text{power factor}.$$

The power factor of the average fluorescent lamp itself is approximately 90%, practically, however due to the ballast choke the power factor for the complete unit is reduced to from 50% to 60%.

It is evident from the above, that especially where a large number of lamps be required, certain corrective equipment is required to increase the power factor and thus increase the economy of operation. An effective method of *improving* the *power factor* to unity (or nearly so) is to connect a suitable condenser across the choke coil in the case of single lamp ballast and in case of two lamps ballast to use the "split phase" principle with one of the lamps ballasted by inductive reactance only and the other by inductance and capacitance in series, as shown in figs. 11 to 14.

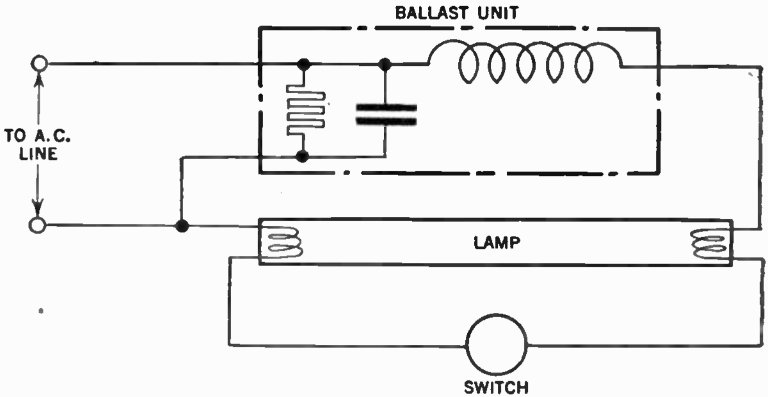


FIG. 11.—Method of connection for single unit fluorescent lamp, with corrected power factor.

Useful Lamp Life.—In general, fluorescent lamps lose their usefulness because of decrease in light output before they fail to operate. Darkening of the bulb occurs because of the effect of mercury on the fluorescent coating and because of the material given off by the electrodes. The latter especially causes darkening at the ends of the bulb late in life. The rate of depreciation in light output diminishes throughout life; the first hundred hours produce about as much darkening as the following 1000 hours. Rated output is based on conditions at 100 hours.

Frequent starting of lamps may take more life out of the electrodes than long hours of burning because momentarily there is a higher than normal voltage drop at the electrodes which causes the active material to sputter or evaporate off. If a lamp be started once a minute, for example, the hours of burning will be shorter than normal, but if it be turned on and burned continuously, its life will be longer than normal. When the active material on the electrodes is nearly exhausted, the voltage required for starting will rise and may equal or exceed the available supply. This may occur after the lamp has been started thousands of times or burned beyond its rated life. Sometimes the end of life is indicated by the lamp flashing momentarily and then going out.

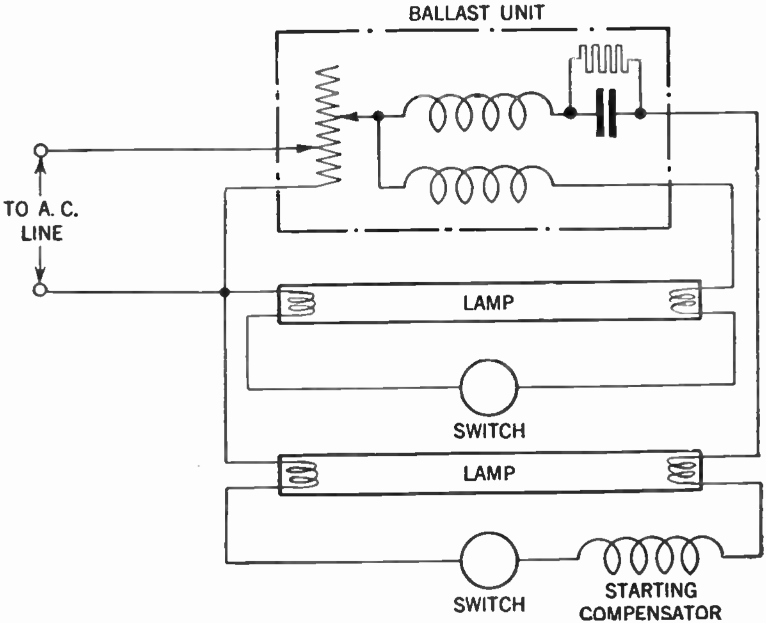


Fig. 12.—Method of connection for two unit fluorescent lamps, with corrected power factor.

Lamp Quality.—Quality in a fluorescent lamp, aside from the purely mechanical features to insure sturdy base pins, end seals and electrode construction, is largely a matter of efficiency of light production and uniformity in spectral quality. Shortcomings in mechanical construction quickly manifest themselves in service and the necessary requirements in mechanical design become apparent and are easily corrected. Less obvious but of more permanent significance is the control of those elements that make for efficiency and spectral quality. On these latter factors alone rests the principal interest in this new illuminant. These permit new perspectives in artificial lighting.

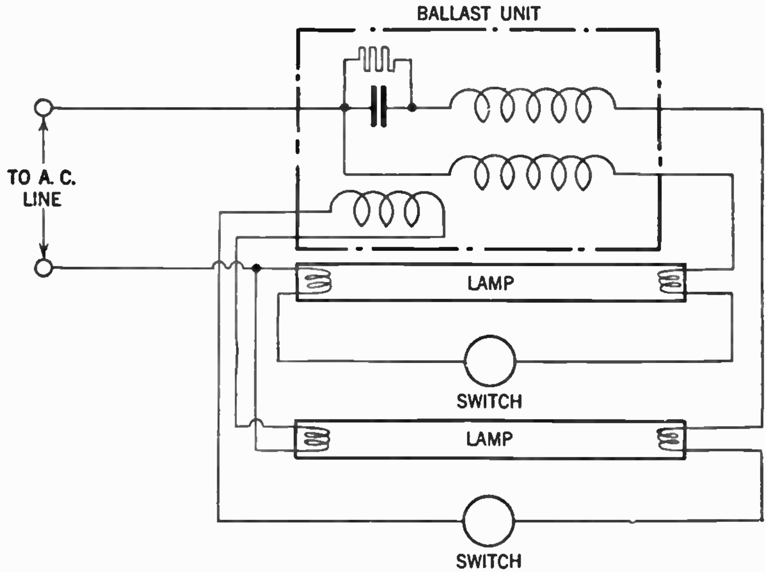


FIG. 13.—Another method of connection, for two unit fluorescent lamps, with corrected power factor.

To produce light by fluorescent principles is relatively simple, but it *takes skill* to produce the *highest efficiency* and integrity of spectral color quality. This involves the utmost in purity of materials and timing of chemical processing of the *phosphors* used. It involves, also, precise blending of basic *fluorescent chemicals* and invariable competent engineering to furnish high quality, dependable lamps.

Fluorescent lamps will burn in any position, although when burned in a vertical position the condensing mercury may cause a slight streaking of the powders upon condensation. Like filament lamps the larger sizes as represented by length are more efficient than shorter length lamps. This is because there is a fairly constant wattage loss at the electrodes regardless of length of lamp. Efficiency is also dependent upon fine relationship of current density and vapor pressure. These are in turn affected by operating temperature.

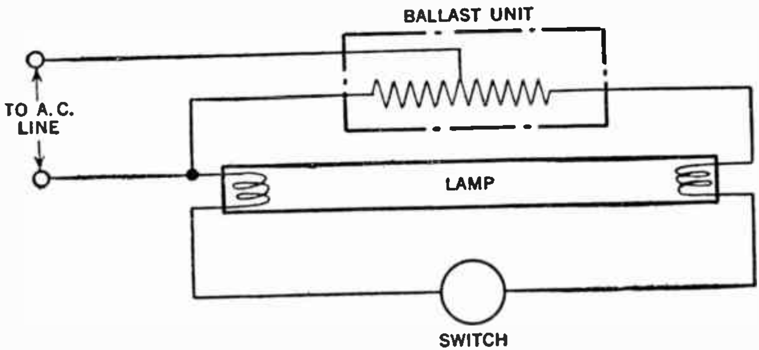


FIG. 14.—Method of connection for single unit fluorescent lamp, with uncorrected power factor.

Radiant Heating Effects.—Confusion is sometimes expressed at the assertion that fluorescent lamps produce cooler foot-candles than do incandescent lamps. While a kilowatt-hour represents over all a heating effect of 3,414 B.t.u.'s regardless of how consumed, the lesser sensation of heat from fluorescent lamps lies in the fact that only about 35 or 45% of the energy is radiated as compared to 75 to 85% for the filament lamp.

Because the efficiency of light production by fluorescent lamps is about double that of filament lamps, and also because the radiant heat is only half that of filament lamps, this is the basis of the statement that the sensation of heat from fluorescent lamps is, roughly, only one-fourth that from filament lamps for the same amount of light delivered.

Stroboscopic Effect.—As the line frequency of the alternating current in most localities is 60 *cycles per second*, the standard line of fluorescent equipment is manufactured for that frequency.

This in practical terms means that the light output will be passing from its maximum to its minimum value 120 times per second. It is possible that this may, in some instances, give rise to a *stroboscopic effect*, that is moving objects such as *rotating parts of machinery*, illuminated by this light, may appear to be moving in disunity or jerks, or rotating more slowly than their actual speed.

In actual application, however, where this effect might cause annoyance, it can be practically eliminated in a three lamp unit by connecting each lamp on a separate phase of a three phase system, and it can be greatly reduced in a two lamp unit by the use of a two lamp control unit, which employs a condenser in the ballast of one of the lamps as shown in figs. 12 and 13.

The current through the lamps is thrown almost 90° out of phase and under these conditions the light output of one of the lamps is at a maximum. This method has an additional advantage of producing a combined power factor of nearly unity for the two lamps.

Radio Interference.—The fluorescent lamp in common with most electrical devices may cause a certain amount of radio interference. This interference may be caused by one of the following factors:

1. Direct radiation from the bulb to the antenna. This effect diminishes rapidly as the radio is separated from the lamp. Thus, for example, at a radius of 9 ft. interference from this cause is negligible.

2. Line radiation from the electric supply line to the antenna.

3. Line feed-back from the lamp through the line to the radio.

Interference from line radiation and line feed-back can be minimized by proper application of line filters.

The latter two causes of radio interference effects may be reduced to a minimum by incorporation of *proper condensers* in the equipment.

Installations.—While fluorescent lamp installations may not match the simplicity associated with the incandescent lamps, the choice between the two systems should rest on both the engineering and economic consideration involved in each individual case. The following considerations should be followed in the use of fluorescent lamps:

1. That only power factor corrected auxiliaries be used
2. That only replaceable starter auxiliaries be considered for all except specialized installations.
3. That both lamp size and ballast equipment be chosen to make up the most economical installation

Like filament lamps, the **efficiency** of fluorescent lamps increases with the **increase** in *wattage sizes.*

The *replaceable starter* system makes it practical to locate the ballast at some distance from the lamps, because two wires are eliminated which were formerly needed to connect auxiliaries with built-in switches.

This is particularly advantageous for installation where lamp space is restricted, or where the application requires a special location of the ballast equipment.

Lamp Sizes.—The lamps are at present manufactured in four wattage sizes: **15, 20, 30 and 40,** with the lengths varying from **18 to 48 inches.** It should be noted that the *larger lamps are more efficient.* Hence for large illumination projects the larger lamps are more practical because of the lower lamp cost per foot, and also because of the higher efficiency.

Circuit Voltages.—With fluorescent lamps, voltage regulation depends upon the choke used and not on the starting mechanism. The voltage, unless otherwise stated, is alternating current at a *frequency of* 60 *cycles per second*, although special auxiliaries are manufactured for use on other commercial frequencies as well as on direct current.

The voltage range of the lamps including ballast is from 110 to 250 volts.

Wiring.—The assembly and wiring of the fluorescent lamp does not differ markedly from any other light wiring schemes. It is evident that the **National Electric Code** giving the regulations of the **National Board of Fire Underwriters** or additional local requirements should be strictly adhered to.

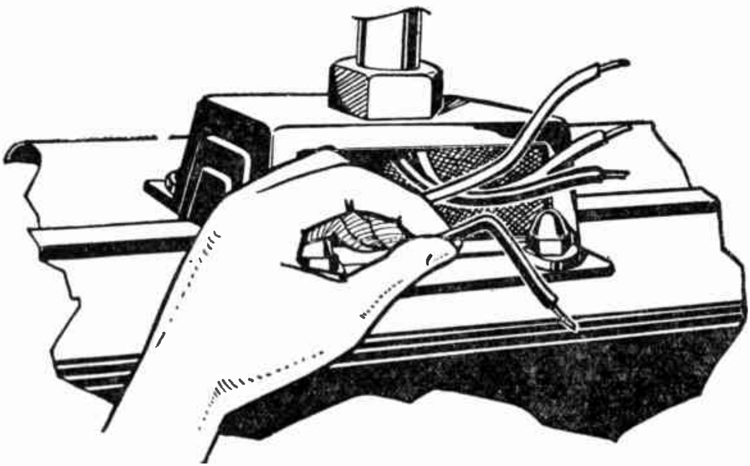


FIG. 15.—Splice box with cover removed, showing wires ready for splicing.

Particular attention should be observed in regard to installation of lamps with uncorrected power factor. Such units with their auxiliaries have an average power factor of only from 50 to 60%.

In addition to being a source of annoyance to the power supply companies, installations of such units will cause undue heating and danger due to insufficient wire capacity.

As an illustration of the effect of power factor, suppose that a load of 250 watts is connected to a 125-volt circuit. The current in this circuit will be 2 amperes if the power be unity or 100%, but if it be only 60%, for example, 3⅓ amperes will be required to supply the same power. In other words, an extra 1⅓ amperes must be circulated through the transmission system producing heating of the wires with a consequent loss of power.

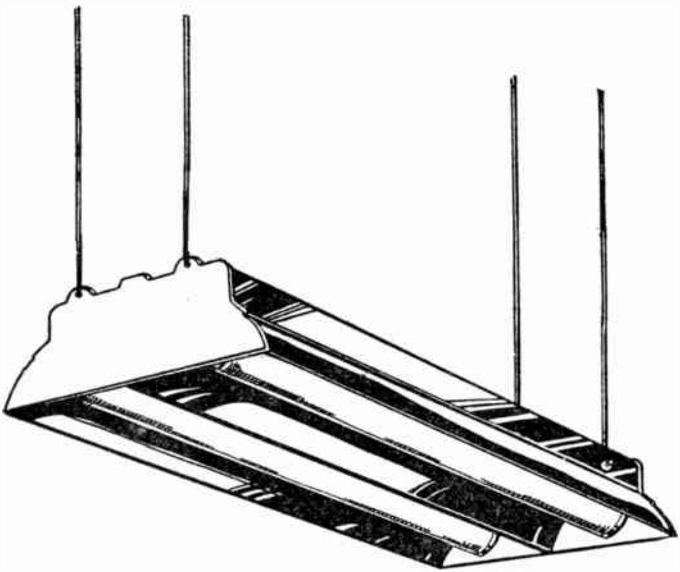


Fig. 16.—Typical two-unit fluorescent lamps assembled with reflector.

With large loads and low power factor this condition may become very serious from the point of view of the power supply company since the capacity of their entire system must be designed on the basis of the current that flows through it.

Mounting of the Lamps.—The lamps may be hung in any position desired, and may be purchased either with or without their auxiliaries. The units are usually provided with hangers for supporting from a rigid conduit and this hanger is usually supplied with a splice box as shown in fig. 15.

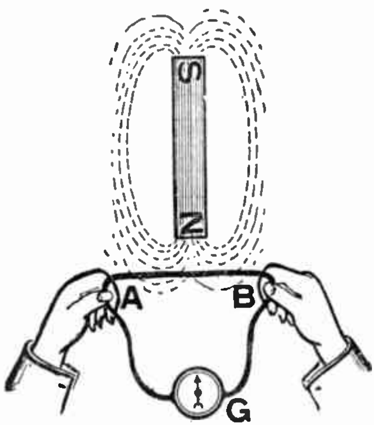
Reflectors are designed to provide for either direct, semi-indirect or indirect illumination. A typical two-lamp unit fully assembled is shown in fig. 16. Lamp holders are wired to auxiliaries according to manufacturers, instructions. Either thermal or magnetic type starting switches may be used, although the previously discussed glow switch, operating on the bi-metallic thermostatic principle, if used, will greatly simplify wiring and also facilitate switch trouble location.

CHAPTER 30

Electro-magnetic Induction

The tendency of electric currents to flow in a conductor when it is moved in a magnetic field so as to ***"cut"*** *lines of magnetic force* is known as electro-magnetic induction.

Faraday discovered that if he took a wire, joined its ends and moved it in front of a magneto, a current would be induced in the wire. The current is called the *induced current* and that part of the wire moved in the magnetic field, the *inductor.*



All dynamos of whatever from, are based upon this discovery made by Faraday in 1831, which in rule form is as follows:

Rule 25.—FARADAY'S DISCOVERY—*Electric currents are generated in conductors by moving them in a magnetic field, so as to cut magnetic lines of force.*

FIG. 7,518.—***Faraday's discovery:*** If a loop of wire be connected to a galvanometer and a section of the wire AB, be moved through a magnetic field as shown, the galvanometer will be deflected indicating that an electrice current is generated when *a conductor is moved in a magnetic field so as to* ***cut*** *lines of force.* A thorough understanding of the term ***cut*** *lines of force* is highly important.

NOTE.—***Michael Faraday,*** born 1791, died 1867. He was an English scientist, famous for his discoveries in chemistry, electricity and magnetism. He first produced the rotation of the magnetic needle around the electric current (1821) based upon Oersted's discovery of electro-magnetism in 1820; he discovered electro-magnetic induction (1831), a principle upon which is founded the development of dynamo machinery; specific inductive capacity (1838); magnetic polarization of light (1845); diamagnetism (1846). He was a brilliant experimenter, and contributed greatly to the knowledge upon which is based present day practice of electricity.

It is very important to understand the meaning of the term "*cut lines of force*":

A conductor, forming part of an electric circuit, **cuts** *lines of force when it moves across a magnetic field in such manner as to alter the number of magnetic lines of force which are embraced by the circuit;* the term is fully illustrated in the accompanying figures.

The proper name for a "conductor" which moves across a magnetic field is an *inductor*.

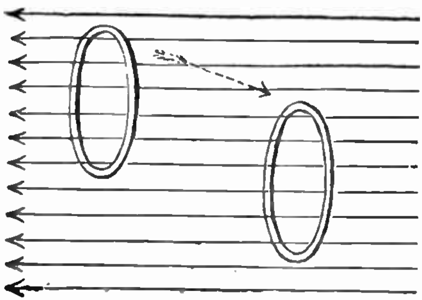


FIG. 7,519.—*Electromagnetic induction 1:* In order to induce a current by electromagnetic induction, an inductor must be so moved through a magnetic field *that the number of lines of force passing through it (that is, embraced) are altered.* If a coil be given a simple motion of translation in a uniform magnetic field as indicated in the figure, no current will be induced *because the number of lines of force passing through it are not changed*, that is, during the movement as many lines are lost as are gained.

Laws of Electro-Magnetic Induction.—The principles of electro-magnetic induction are set forth in the following laws:

Rule 26.—FARADAY'S DISCOVERY—*To induce a current in a circuit, there must be a relative motion between the circuit and a magnetic field, of such a kind as to alter the number of magnetic lines embraced in the circuit.*

Rule 27.—*The voltage induced in a circuit is proportional to the rate of increase or decrease in the number of magnetic lines embraced by the circuit.*

Rule 28.—*When a straight wire cuts* 100,000,000 *lines of force at right angles per second, an electric pressure of one volt is induced.*

***Rule 29.**—By joining in series a number of inductors or coils moving in a magnetic field, the electric pressure in the separate parts are added together.*

Example.—If a coil of wire of 50 turns cut 100,000 lines in $^1/_{100}$ of a second, what will be the induced voltage?

The number of lines cut per second per turn of the coil is

$$100{,}000 \times 100 = 10{,}000{,}000$$

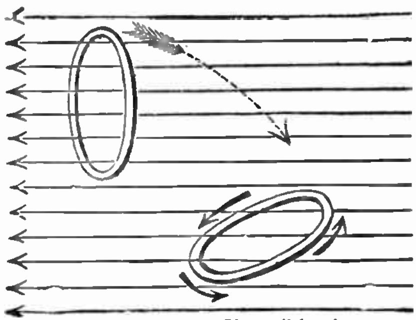


FIG. 7,520.—***Electromagnetic induction 2:*** If a coil be given a motion of rotation from any point within its own plane so that it passes through a uniform magnetic field, a current will be induced in the coil *because the number of lines of force passing through it is altered.*

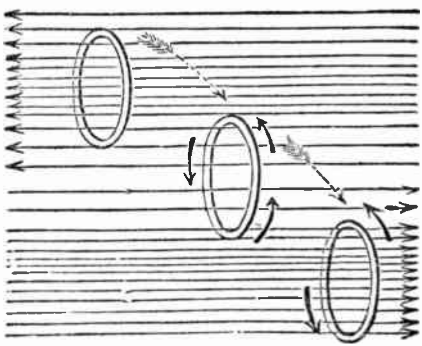


FIG. 7,521.—***Electromagnetic induction 3:*** If a coil be given a simple motion of translation in a non-uniform or variable magnetic field, a current will be induced in the coil, whether the motion be from the dense to the less dense region of the field or the reverse, *because the number of lines of force passing through the coil is altered.*

The total number of lines cut by the coil of 50 turns is

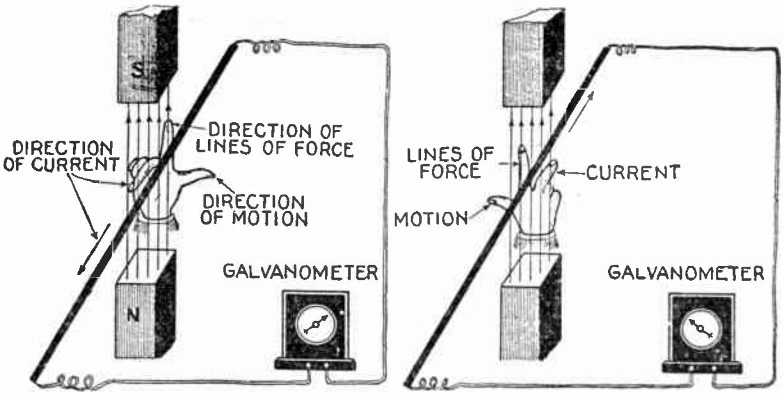
$$10,000,000 \times 50 = 500,000,000$$

which will induce a pressure of

$$500,000,000 \div 10^8 = 5 \text{ volts}$$

Rule 30.*—A decrease in the number of magnetic lines which pass through a circuit induces a current around the circuit in the positive direction.*

The term positive direction is understood to be the direction along which a free N pole would tend to move.



FIGS. 7,522 and 7,523.—Fleming's rule for direction of induced current. *Extend the thumb, fore finger and middle finger of the right hand so that each will be at right angles to the other two. Place the hand in such position that the thumb will point in the direction in which the conductor moves, the fore finger in the direction of the lines of force (N to S), then will the middle finger point in the direction in which the induced current flows.* This is a very useful rule and the author recommends that it be thoroughly understood.

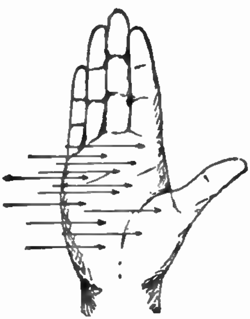


FIG. 7,524.—The palm rule for direction of induced current: *If the palm of the right hand be held against the direction of the lines of force, the thumb in the direction of the motion, then the fingers will point in the direction of the induced current.*

***Rule 31.**—An increase in the number of magnetic lines which pass through a circuit induces a current in the negative direction around the circuit.*

***Rule 32.**—The approach and recession of a conductor from a magnet pole will yield currents alternating in direction.*

Since the strength of the field depends on the proximity to the pole, the approach and recession of a conductor involve an *increase* and *decrease* in the rate of cutting of magnetic lines, hence a reversal of current.

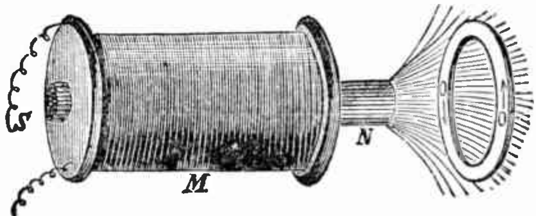


FIG. 7,525.—Experiment I illustrating Lenz's law. If a copper ring be held in front of an ordinary electro-magnet, and the current circulating through the coil of the magnet be in such a direction as to magnetize the core as indicated by the letters S.N, then as the current increases in the coil more and more of the lines of force proceeding from N, pass through the ring OO, from left to right. While the field is thus increasing current will be induced in the copper ring in the direction indicated by the arrows, such currents tending to set up a field that would pass through the ring from right to left, and would therefore *retard* the growth of the field due to the electro-magnet M.

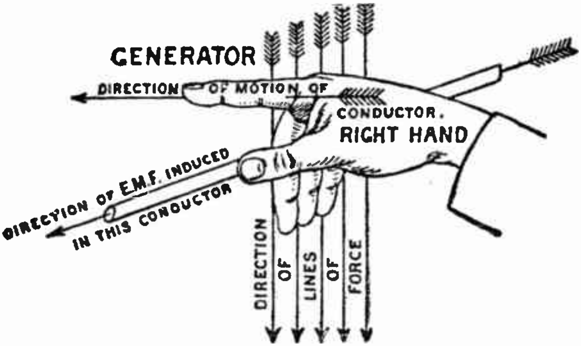


FIG. 7,526.—A rule for direction of induced current which, in some cases, is more conveniently applied than Fleming's rule: *Hold the thumb, fore finger and remaining fingers of the right hand at right angles to each other; place the hand in such position that the fore finger points in the direction of motion of the conductor, the three fingers in the direction of the lines of force, then will the thumb point in the direction of the induced current.*

Rule 33.*—The more rapid the motion, the higher will be the induced magnetic force.*

Rule 34.—LENZ LAW—*The direction of the induced current is always such that its magnetic field* **opposes** *the motion which produces it.*

Hence, because of this opposition, power must be expended to operate a dynamo.

Self-Induction.—This term signifies *the property of an electric current by virtue of which it tends to resist any change of value*

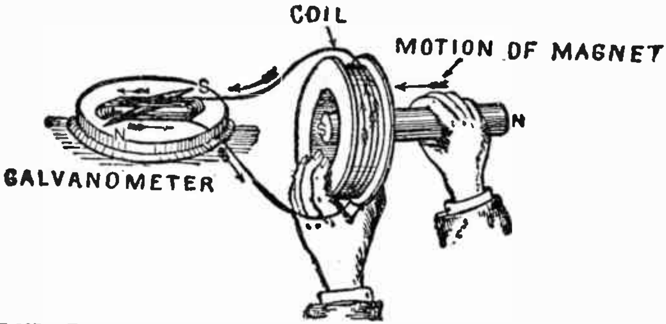


FIG. 7,527.—Experiment illustrating Lentz' law. In order to produce the induced current energy must be expended in bringing the magnet to the coil and in taking it away. This is just what happens in producing an electric current with a dynamo—*it takes power to drive the machine.*

Self-induction is sometimes spoken of as *electromagnetic inertia*, and is analogous to the mechanical inertia of matter.

Ques.—Why do sparks sometimes appear at the brushes of a dynamo?

Ans.—Because of self-induction when the brushes are not properly adjusted.

Mutual Induction.—This is a particular case of electromagnetic induction in which the magnetic field producing an electric pressure in a circuit is due to the current in a neighboring circuit.

CHAPTER 31

Dynamos

A dynamo, or so-called "generator" converts mechanical energy into electrical energy by means of electromagnetic induction.*

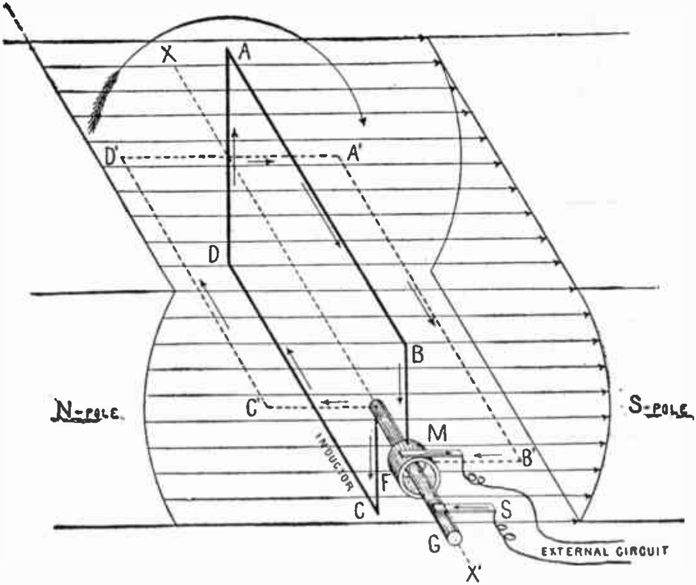


FIG. 7,528.—Simple elementary alternator. *Its parts are* a single conducting loop, A,B,C,D, placed between the poles of a permanent magnet, and having its ends connected with a ring F, and shaft G, upon which bear brushes M and S, connected with the external circuit. When the loop is rotated clockwise the induced current will flow in the direction indicated by the arrows during the first half of the revolution.

*NOTE.—The author objects to the term "generator" because the machine does not generate electricity but simply pumps it from a low to a high pressure. similar to the operation of a pump in pumping water. Hence a dynamo is an electric pump.

The three essential parts of a dynamo are: *the field* magnets which provide the magnetic field; 2, *the armature*, containing the conducting loops (winding) which are arranged to rotate in the field and which cut the magnetic lines of force, and 3, *the commutator*, which takes off the current generated in the armature, converting it from alternating current to direct current.

Operation.—*The current generated by a loop rotating in a magnetic field is alternating;* that is, it flows in one direction

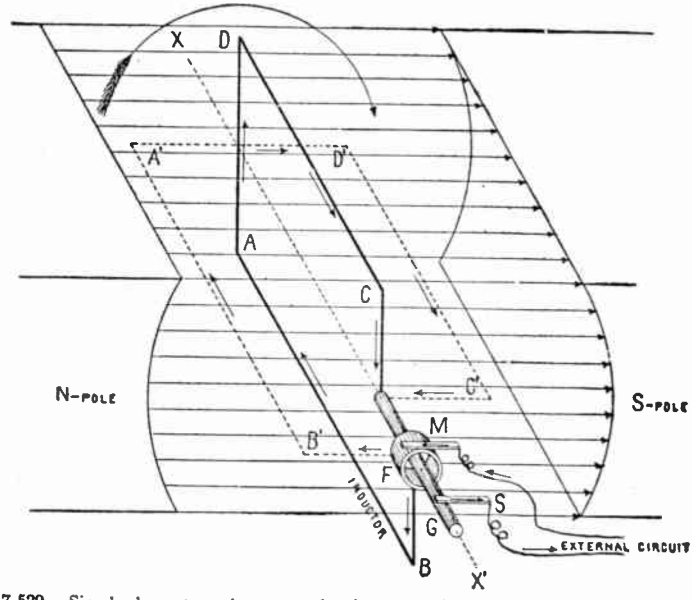
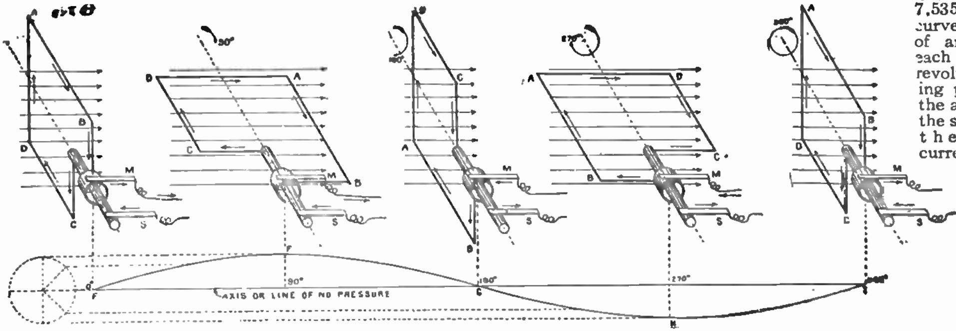
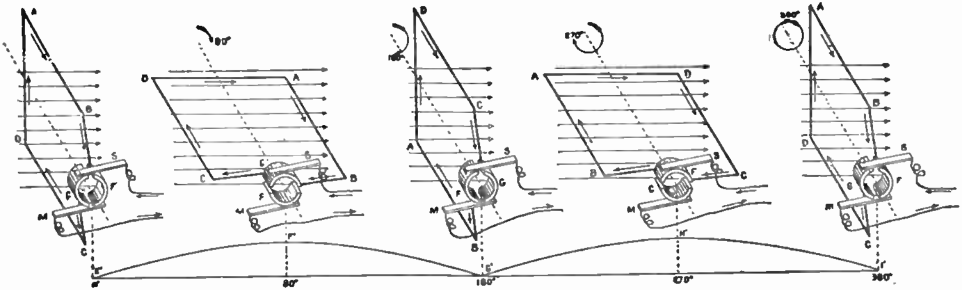


FIG. 7,529.—Simple elementary alternator, showing reversal of current when the loop has made one half revolution from the position of fig. 7,528. It should be noted that A B, for instance, which has been moving *downward* during the first half of the revolution (fig. 7,528), moves *upward* during the second half (fig. 7,529); hence, the current during the latter interval flows in the opposite direction.

doing one-half revolution, and in the other doing the second half. Hence, to understand how a dynamo works, first consider the elementary alternator in figs. 7,528 and 7,529, which delivers alternating current as shown in figs. 7.530 to 7,535.



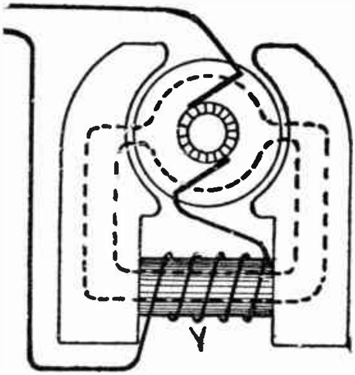
FIGS. 6,530 to 7,535.—The sine curve, with view of armature for each 90° of the revolution, showing progressively the application of the sine curve to the alternating current cycle.

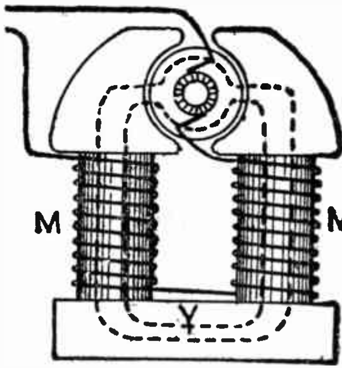


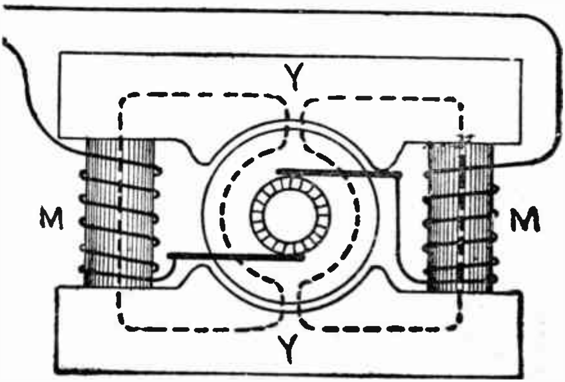
FIGS. 7,536 to 7,541.—Commutation of the current. These figures show how a dynamo transforms alternating into the so called direct current. During the first half of the revolution the current flows in the direction A B, out through segment F, of the commutator and brush M, returning through brush S and segment G, figs. 7,536 and 7,537. At the beginning of the second half of the revolution, fig. 7,538, the current in the armature reverses and flows around the loop in the direction B A. At this instant the brushes M and S, pass the gaps between the commutator segments, thus reversing contact with the segments, and causing the current in the external circuit to remain in the same direction.

Now once a dynamo must deliver *direct current*, a commutator or device for converting alternating to direct current is necessary. This device consists of a series of copper bars or segments arranged side by side and insulated from each other. The way it works is shown in figs. 7,536 to 7,541.

Field Magnets.—The object of the field magnets is to produce an intense magnetic field within which the armature revolves.







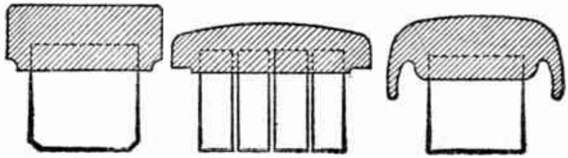
FIGS. 7,542 to 7,544.—Various field magnets; fig. 7,542, salient pole, bipolar field magnet with single coil wound around the yoke; Fig. 7,543, salient pole, bipolar field magnet with two coils wound around the cores. 1, fig. 7,544, consequent pole, bipolar field magnet with two coils on the cores. This is known as the "Manchester" type in which the cores are connected at the ends by two yokes—so named from its original place of manufacture at Manchester, England.

For this, ***permanent magnets*** are used in magnetos and ***electro-magnets*** in dynamos.

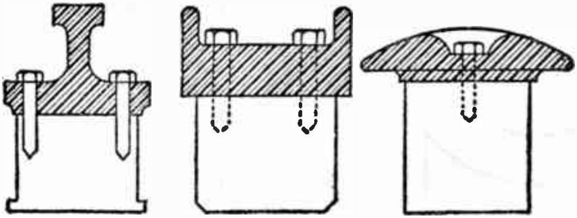
A field magnet consists of: 1, yoke; 2, cores; 3, pole pieces; 4 coils. Various types of field magnets are shown in figs. 7,542 to 7,544. One method of securing the coils in position is shown in fig. 7,568.

The materials generally used for magnets are wrought iron for the cores, copper for the winding, and cast iron for the yokes.

The pole faces are made larger than the coils in order to reduce the reluctance of the "air gap" or space between the pole face and armature. The projecting sides of the pole face are called *horns*. Machines are said to be

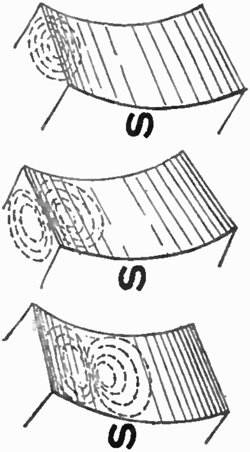


FIGS. 7,545 to 7,547.—Various sections of cast iron yoke. In form, these yokes may be either circular or segmental.

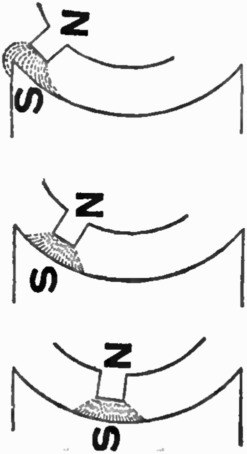


FIGS. 7,548 to 7,550.—Various sections of cast steel yoke. The ribs shown in figs. 7,548 and 7,549 are provided to secure stiffness.

FIGS. 7,551 to 7,553.—Some methods of attaching detachable cores. The core seat is machined to receive the core, it being necessary to secure good contact in order to avoid a large increase in the reluctance of the magnetic circuit.



FIGS. 7,554 to 7,556.—Alteration of magnetic field due to movement of mass of iron in the armature. *If the masses of iron in the armature be so disposed that as it rotates, the distribution of the lines of force in the narrow field between the armature and the pole piece is being continually altered, then, even though the total amount of magnetism of the field magnet remain unchanged, eddy currents will be set up in the pole piece and will heat it.*



FIGS. 7,557 to 7,559.—Eddy currents induced in pole pieces by movement of masses of iron. These diagrams correspond to those of figs. 7,554 to 7,556. The strongest current flows between the vortices and is situated just below the projecting tooth, where the magnetism is most intense; it moves onward following the tooth.

bi-polar when they have two poles, and *multi-polar*, when there are more than two poles.

Eddy Currents; Laminated Fields.—The field magnet cores and pole pieces, as well as the armature of a dynamo are specially subject to *eddy currents*.

Eddy currents are induced electric currents occurring when a solid metallic mass is rotated in a magnetic field.

These currents consume a large amount of energy and often occasion harmful rise in temperature. This loss may be almost entirely avoided by laminating the pole piece, or both pole piece and core.

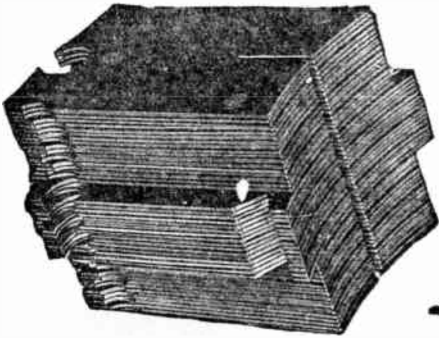
A laminated pole is one built up of layers of iron sheet, stamped from sheet metal and insulated.

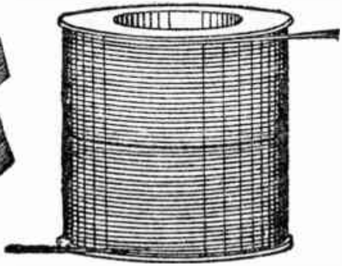
In best construction these laminated pole pieces are cast welded into the frame or yoke to reduce the reluctance of the magnetic circuit.

The Magnetizing Coils. The object of these is ***to provide the number of ampere turns of excitation required to produce the required magnetic flux through the armature.***

The coils may be *spool* or *former* wound. The spools upon which coils are wound are usually insulated with several layers of paper preparations.

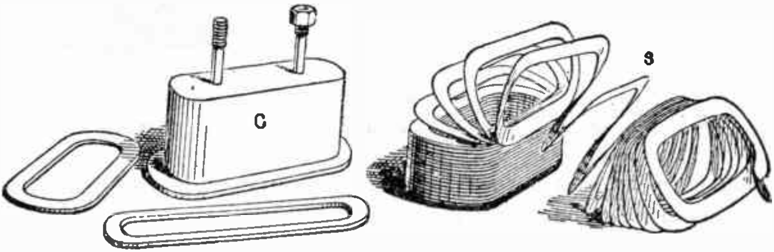
Where pole pieces are simply extensions of the cores without enlargement, the coils can be slipped over the ends, but some kind of clamping device is necessary to hold them in place.





FIGS. 7,560.—Fort Wayne laminated pole piece before being cast welded into frame. ***In construction,*** the above core and pole piece is made up of sheets of annealed steel of two different widths assembled together to form proper size and shape. The minute spacing between these laminations and the slight oxidation on each surface is sufficient to reduce considerably the eddy currents. By cast welding the pole piece into the frame, a low reluctance is secured.

FIGS. 7,561.—Method of winding magnet spool so that the two ends of the coil will come to the outside.



FIGS. 7,562 to 7,565.—Core and edge strip winding for shunt field coils of large multipolar dynamo. S, copper strip; C, core. ***The winding consists of*** a copper strap S, carefully insulated and placed edgewise on the core C, in a single layer of winding. With this arrangement, the space occupied by insulation is reduced to a minimum.

Coils are generally united in series so that the same magnetizing current may flow through all of them. The coils should be so connected that they produce alternate north and south poles.

Heating.—Dissipation of the heat generated in the magnetizing coils takes place in three ways: by induction, radiation, and connection. In large multipolar machines the metal in the

FIGS. 7,566 and 7,567.—Square and hexagonal order of "bedding." The term bedding is an expression used to indicate the relation between the cross sectional area of the winding when wound square, as in fig. 7,566, and when wound in some other way, as in fig. 7,567. In the square order of bedding, the degree of bedding equals zero.

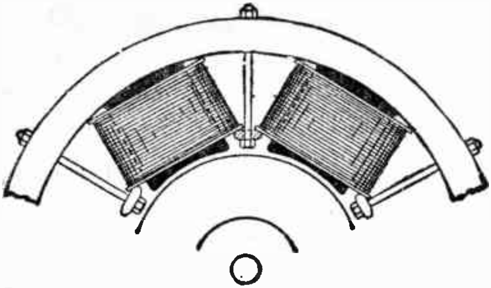


FIG. 7,568.—Method of securing coils in position when the pole pieces are simply extensions of the core without enlargement.
FIG. 7,569.—Fort Wayne compound wound rectangular ventilated spool field coil.

pole cores and frames are more efficient in carrying off heat than the external surface of the coil.

Ventilation.—Sometimes provision is made for ventilation of the field magnet coils as shown in fig. 7,569.

The Armature.—This, by definition, is *a collection of* ***inductors (erroneously called conductors)*** *mounted on a shaft and arranged to rotate in a magnetic field with provision for collecting the currents induced in the inductors.*

The inductors consist of coils of insulated wire.

There are three kinds of armature: 1, ring; 2, ***drum,*** and 3, disc. Of these, the drum armature is the prevailing type; it requires less wire and magnetizing current for a given output because the

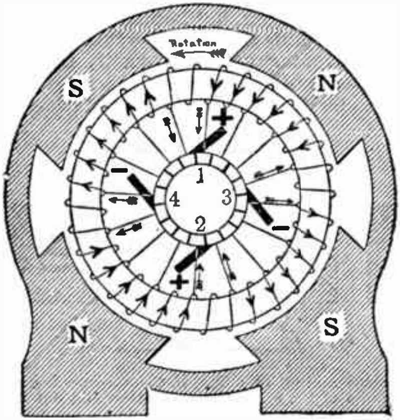


FIG. 7,570.—***Ring*** armature of four pole dynamo showing winding connections and direction of the induced currents.

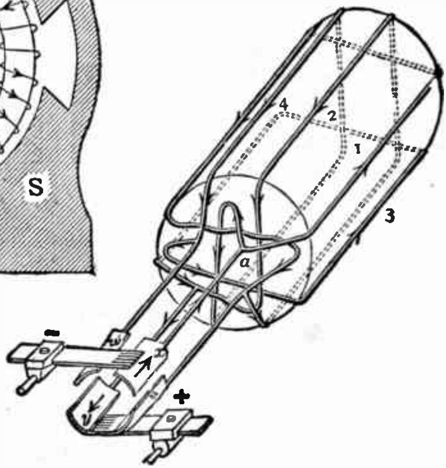
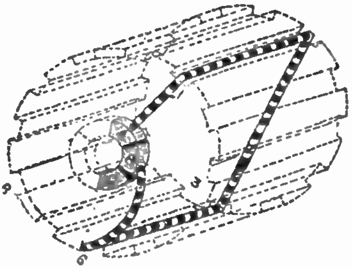


FIG. 7,571.—Elementary four coil ***drum*** armature showing winding, connections and current conditions. Starting from the part *a*, and following the winding around without reference at first to the commutator, it will be found that the rectangular turns of the wire form a closed circuit, and are electrically in series with one another in the order of the numbers marked on them. With respect to the connections to the four segments *w*,*x*,*z*, of the commutator it will be found that at two of these *x* and *y*, the pressures in the windings are both directed from, or both directed *toward* the junction with the connecting wire. At the other two segments, *z* and *w*, one pressure is toward the junction and the other directed from it. If, therefore, the brushes be placed on *x* and *y* they will supply current to an external circuit, *z* and *w*, for the moment being the segments.

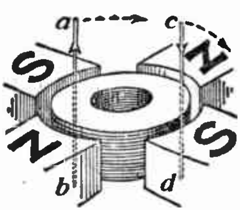
inductors of a ring armature which lie on the inner side of the iron ring, being screened from practically all the lines of force, do not produce any current.



In the drum armature only the end connectors are inactive.

The inductors of disc armatures move in a plane, perpendicular to the direction of the lines of force, about an axis parallel to them. They were introduced in an effort to avoid the losses due to eddy currents and hysteresis present in the other types of armature, but because of difficulty in making them durable their inherent advantages failed to justify the existence of the type.

FIG. 7,572.—Skeleton view of wooden armature core showing in position the first coil of the winding indicated in the table below.



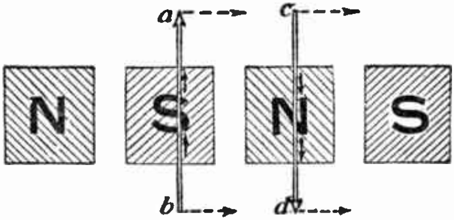
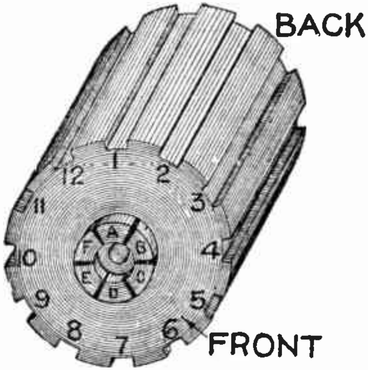


FIG. 7,573.—Partial sketch of a four pole machine laid on its side. If the observer imagine himself placed at the center, and the panorama of the four poles to be then laid out flat, the developed view thus obtained would appear as in fig. 7,574.

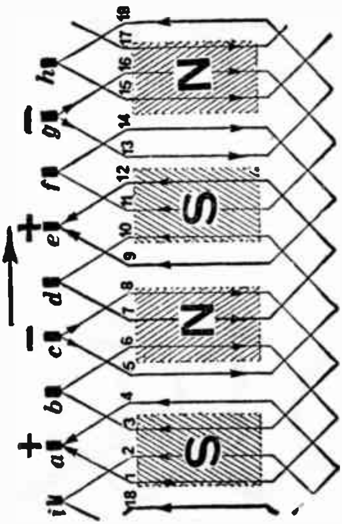
FIG. 7,574.—Developed view of the four pole field shown in perspective in fig. 7,573.



WINDING TABLE

	A	1	6	B
	B	3	8	C
	C	5	10	D
	D	7	12	E
	E	9	2	F
	F	11	4	A

FIGS. 7,575 and 7,576.—Wooden armature core and winding table for practice in armature winding. By using strings of different colors to represent the various coils, the path of each coil is easily traced when the winding is completed.



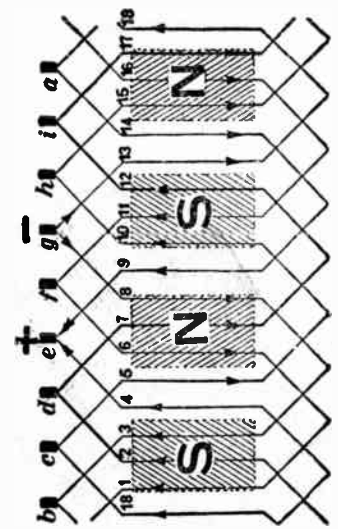


FIG. 7,577.—Developed view of a typical lap winding. From the figure it is seen that at the back of the armature each inductor is united to one five places further on, that is, 1 to 6, 3 to 8, etc., and at the front end of the winding, after having made one "element," as for example *d*-7-12-*e*, then forms a second element *e*-9-14-*f* which "laps" over the first, and so on all around until the winding returns on itself.

FIG. 7,578.—Developed view of a typical wave winding. This winding, instead of lapping back toward the commutator segment from whence it came, as in lap winding, turns the other way. For instance *d*-7-12 does not return directly to *e*, but goes on to *i*, whence another element *i*-17-4-*e* continues in a sort of zigzag *wave*.

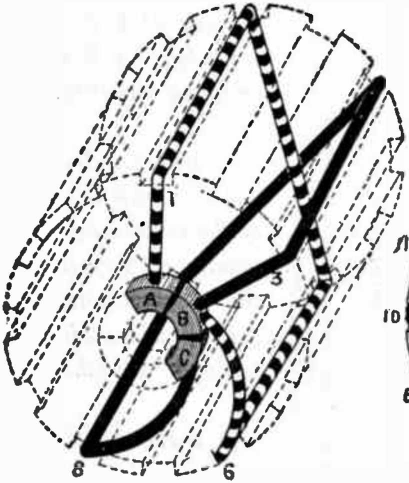
Armature Windings.—There are two distinct methods employed in winding armatures known as: 1, *parallel or* ***lap*** *winding*, and, 2, *series or* ***wave*** *winding.*

A ***lap*** *winding is one in which the ends of the coils come back to adjacent segments of the commutator; the coils of such a winding lap over each other.*

A ***wave*** *winding is one in which the coil ends diverge and go to segments widely separated, the winding to a certain extent resembling a wave*

Directions for the order of winding are usually given in the form of a table. Thus, tables for the *lap*, and *wave* windings of figs. 7,580 and 7 583, are as follows:

Lap winding	Wave winding
A — 1 — 6 — B	A — 1 — 4 — C
B — 3 — 8 — C	B — 3 — 6 — D
C — 5 — 10 — D	C — 5 — 8 — E
D — 7 — 2 — E	D — 7 — 10 — A
E — 9 — 4 — F	E — 9 — 2 — B



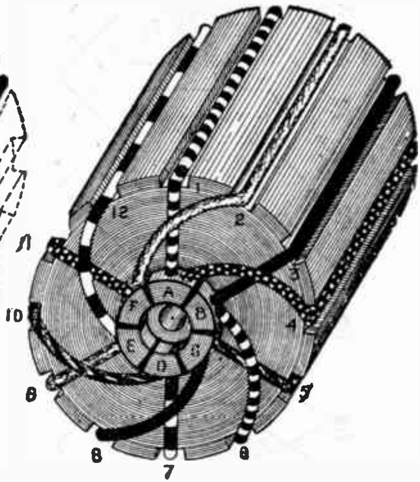


FIG. 7,579.—Skeleton view of wooden armature core showing in position the first two coils of the winding indicated in the above table for *lap winding.*

FIG. 7 580.—View of completed winding as indicated in the table above. Thus the path of the first coil, according to the table is A—1—6—B which means that the coil begins at segment A, of the commutator, rises to slot 1, and proceeds through the slot to the back of the drum; thence across the back to slot 6, through the slot and ending at segment B. The other coils are wound in similar order as indicated in the table.

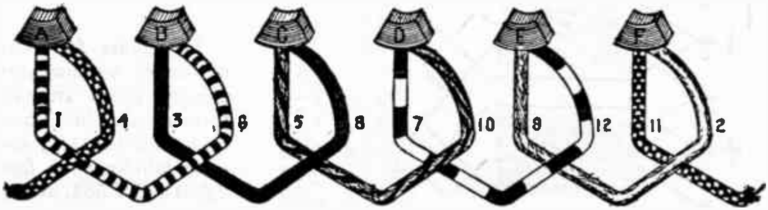


FIG. 7,581.—Developed view of the winding shown above in perspective in fig. 7,580.

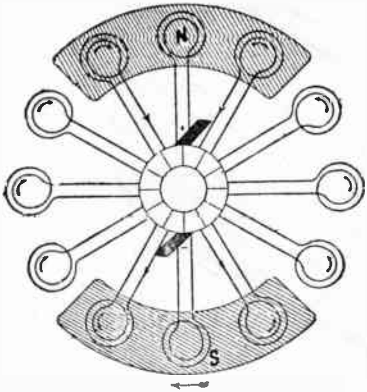


FIG. 7,582.—*Disc* armature of Niaudet. It is equivalent to a ring armature, having the coils turned through an angle of 90° so that all the coils lie in a plane perpendicular to the axis of rotation.

Of course in larger machines many more inductors are used than in the tables here given. The *back pitch* is the number of spaces or teeth between the two inductors of a coil; front pitch means commutator pitch. Single winding consisting of one set of coils is called *simplex* as distinguished from a multiplex winding which consists of *two or more independent sets of coils.*

Instead of independent commutators for the several windings, they are combined into one having two or more sets of segments interplaced around the circumference. Multiplex windings reduce the tendency to sparking because of the division of the current and also because adjacent commutator bars belong to different windings.

Windings are said to be *right* or *left* handed according as they progress clockwise or counter clockwise, as in figs. 7,590 and 7,591.

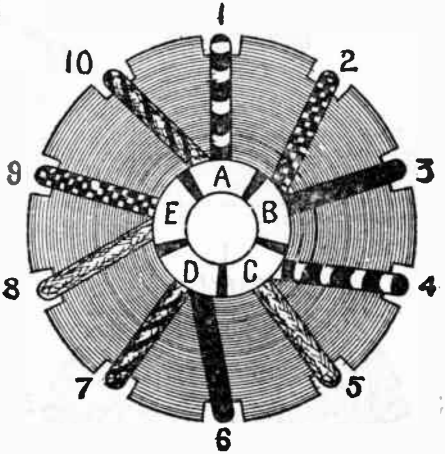


FIG. 7,583.—Five coil wave winding for a four pole machine. In this winding only two brushes are used, there being only two paths trough the armature.

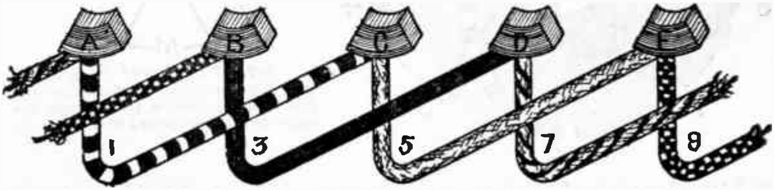


FIG. 7,584.—Developed view of the five coil wave winding shown in fig. 7,583.

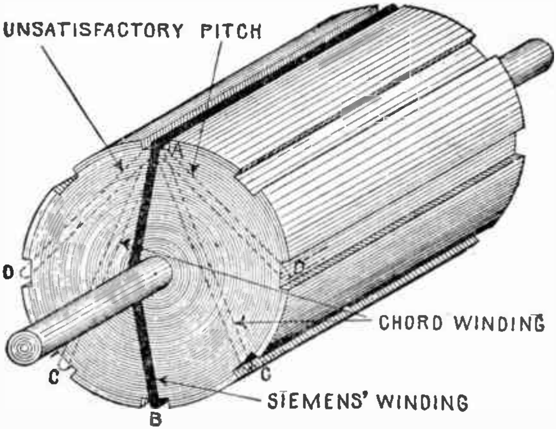
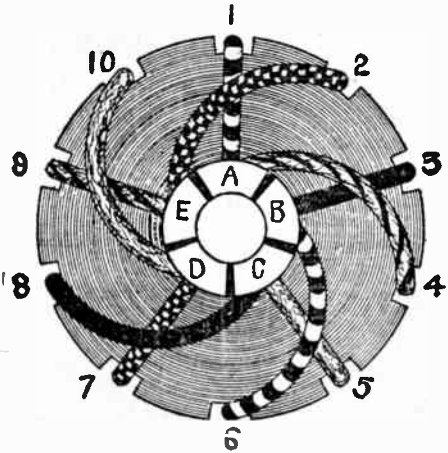


FIG. 7,585.—Distinction between *Siemens winding* and *chord winding*. In cases where the front and back pitches are so taken that the average pitch differs considerably from the value obtained by dividing the number of inductors by the number of poles, the arrangement is called a chord winding. In this method each coil is laid on the drum so as to cover an arc of the armature surface nearly equal to the angular pitch of the poles; it is sometimes called *short pitch winding*.



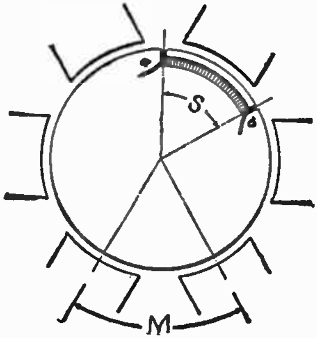
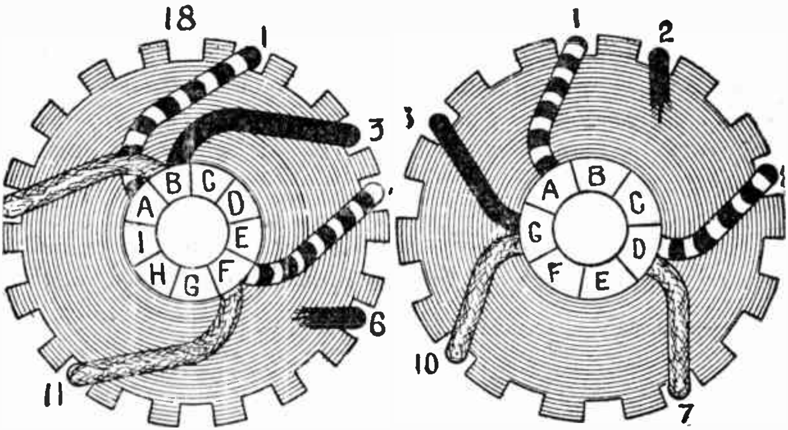
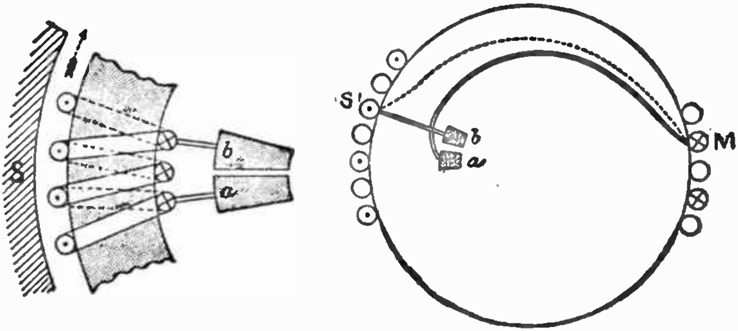


FIG. 7,587.—End view of drum armature of a multipolar machine showing one coil in position to illustrate the *angular pitch* or spread of drum coils.

FIG. 7,586.—Lap winding for bipolar machine, with uneven number of coil; in this case the rear connectors may be made directly across a diameter as shown.



Figs. 7,588 and 7,589.—***Progressive*** and ***retrogressive*** wave windings. *If the front and back pitches of a wave winding be such that in tracing the course of the winding through as many coils as there are pairs of poles, a segment is reached in advance of the one from which the start was made, the winding is said to be progressive, as in fig. 7.588. If the pitches be such that in tracing the winding through as many coils as there are pairs of poles, the first segment of the commutator is not encountered or passed over, the winding is said to be* ***retrogressive****, as in fig. 7,589.*



Figs. 7,590 and 7,591.—Right and left hand windings. These consist respectively of turns which pass around the core in a right or left handed fashion. Thus in fig. 7,590 in passing around the circle clockwise from *a*, to *b*, the path of the winding is a right handed spiral. In fig 7,591, which shows one coil of a drum armature, if *a*, be taken as the starting point, in going to *b*, *a*, must be connected by a spiral connector across the front end of the drum to one of the descending inductors such as M, from which at the back end another connector must join it to one of the ascending inductors, such as S where it is led to *b* thus making one right handed turn.

Number of Brushes Required.—For ***lap winding***, there will be *as many brushes as there are poles*, situated in regular order around the commutator and *at angular distances apart equal to the pole pitch*. For ***wave winding***, *only* ***two*** *brushes are required for any number of poles*, the angle between the two brushes being the same as the angle between any N and S pole.

Number of Armature Circuits.—For a simplex spirally wound ring, *the number of paths in parallel is equal to the number*

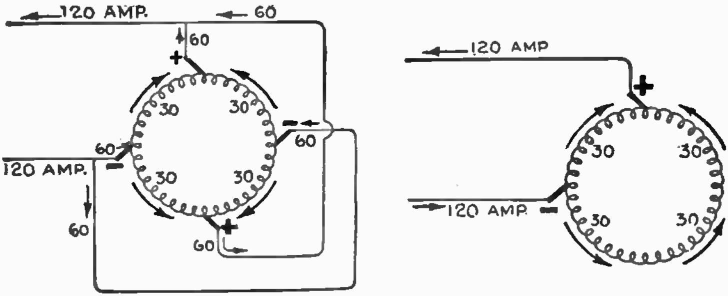


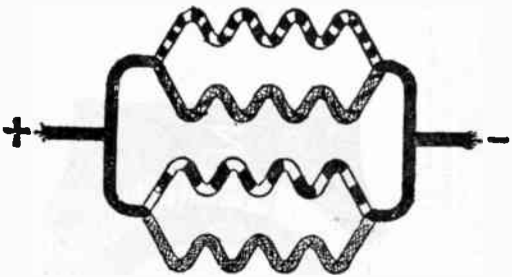
FIG. 7,592.—Distribution of armature currents in a four pole lap wound dynamo having four brushes and generating 120 amperes.

FIG. 7,593.—Showing effect of removing two of the brushes in fig. 7,592. If no spark difficulties occur in collecting the current with only two brushes, the arrangement will work satisfactorily, but the heat losses will be greater than with four brushes.

of poles, and for a simplex series wound ring, *there will be two paths*. In the case of multiplex windings *the number of paths is equal to that of the simplex winding multiplied by the number of independent windings*.

In large multipolar dynamos it is, as a rule, inadvisable to have more than 100 or 150 amperes in any one circuit, except in the case of special machines for electro-chemical work.

Equalizing Rings.—There are sometimes provided on parallel wound armatures *to counteract the effect of unbalancing*



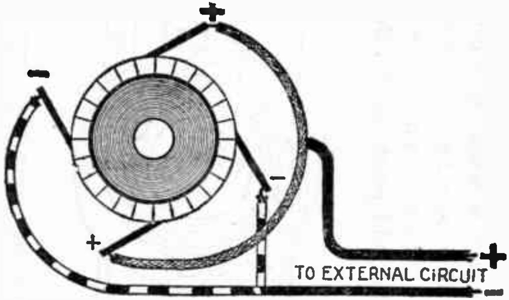


FIG. 7,594.—Diagram showing current distribution through armature of a four pole machine with like brushes connected. There are four paths in parallel, hence the induced voltage will equal that of one set of coils, and the current will be four times that flowing in one set of coils.

FIG. 7,595.—Brush connections for four pole dynamo. ***In a four pole machine,*** two separate currents can be obtained by omitting the parallel brush connections.

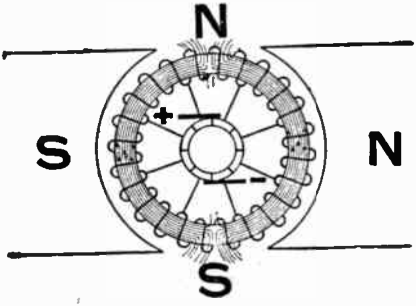
by which the current divides unequally among the several paths through the armature.

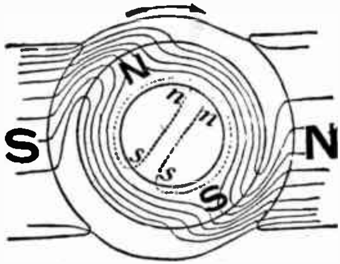
On multipolar machines any two or more points may be connected by equalizer rings that during the rotation are at nearly equal voltage.

Drum Winding Requirements.—The following points on drum winding are important:

1. There cannot be an odd number of inductors.
2. Both the front and back pitches must be odd in simplex windings.
3. The average pitch should approximately be equal to the number of inductors divided by the number of poles.

Field Distortion.—In the operation of a dynamo with load, the induced current flowing in the armature winding, converts the armature into an electro-magnet setting up a field across or at right angles to the field of the machine. This cross magnetization of the armature tends to distort the field produced by the





FIGS. 7,596 and 7,597.—*Cross magnetization.* If the armature be at rest and a current be passed through it as indicated to represent the induced current, a north pole will be formed at the top and a south pole at the bottom of the armature as shown. Now *in operation,* the effect of this armature magnetization is to distort the field of the magnets giving a resultant or distorted field as in fig. 7,597. A drag or resistance to the rotation of the armature is caused by the attraction of the north and south poles on the armature and pole pieces respectively. Field distortion causes unsatisfactory operating and numerous attempts have been made to overcome this, as by: 1, various forms of pole piece; 2, lengthening the air gap; 3, slotting the pole pieces, and 4, using auxiliary poles.

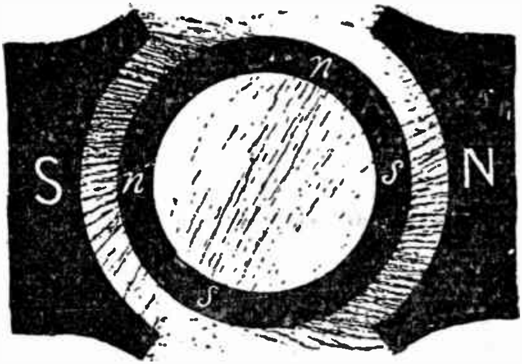
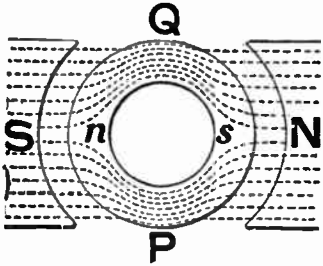


FIG. 7,598.—Actual distortion of field resulting from cross magnetization as shown by iron filings.



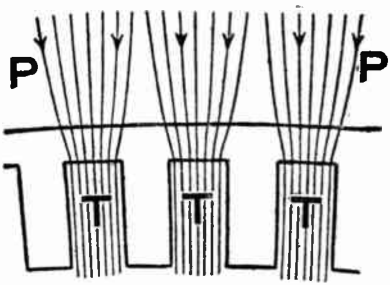
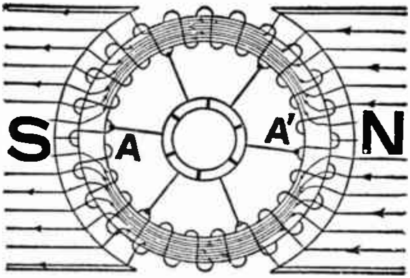


FIG. 7,599.—Magnetic hysteresis in armature core. Unlike poles are induced in the core opposite the poles of the field magnet. Since on account of the rotation of the core the induced poles are reversed a thousand or more times a minute, considerable energy is required to change the positions of the molecules of the iron for each reversal, resulting in the generation of heat at the expense of a portion of the energy required to drive the armature.

FIG. 7,600.—Effect of slotted armature. The teeth, as they sweep past the pole face, cause oscillations of the magnetic flux in the iron near the surface because the lines in the pole piece PP, tend to crowd toward the nearest teeth, and will be less dense opposite the slots. This fluctuation of the magnetic lines produces eddy currents in the pole faces unless laminated. The armature inductors, being screened from the field, are relieved of the drag which is taken by the teeth.



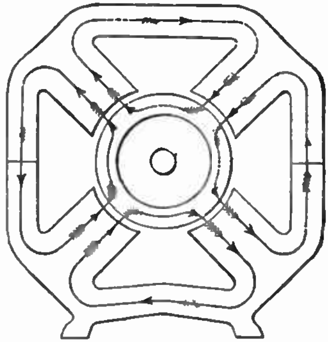


FIG. 7,601.—Distribution of magnetic lines through a ring armature. Since the lines follow the metal of the ring instead of penetrating the interior, no electric pressure is induced in that portion of the winding lying on the interior surface of the ring. There is, therefore, a large amount of dead wire or wire that is ineffective in inducing electric pressure; this is the chief objection to the ring type of armature.

FIG. 7,602.—Distribution of magnetic lines through solid drum armature of a four pole machine.

field magnets, the effect being known as *armature reaction*, as shown in figs. 7,597 and 7,598.

Magnetic Hysteresis in Armature Cores.—When an Armature rotates in a magnetic field, the armature coil *is subjected to opposite magnetic inductions which occur with great rapidity*, resulting in the generation of heat at the expense of a portion of the energy required to drive the armature

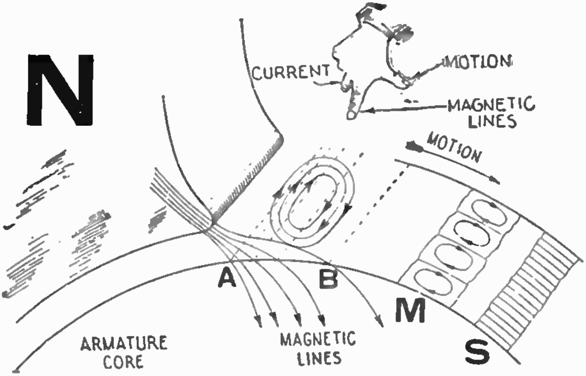


FIG. 7,603.—Foucault or "eddy" currents in solid armature core. Since the magnetic field is more dense at A, near the pole tip than at B, remote from the pole tip, the *rate* at which an element of the core in passing from A, to B, cuts magnetic lines is *altered*, hence eddy currents are set up as shown. To break up the path of these eddy currents the core is laminated or built up of thin steel stampings as indicated at S, which interposes resistance between each stamping, thus opposing the formation of these currents. If the laminations were few and thick as at M, currents would be set up in each lamination as indicated. *In practice* the thin metal discs at S, are usually about No. 18 gauge thick.

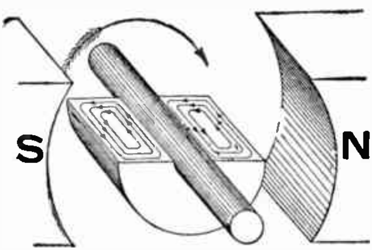
This loss of energy is due to the work required to change the position of the molecules of the iron, and takes place both in the process of magnetizing and demagnetizing; *the magnetism in each case lagging behind the force.*

Self-Induction in the Coils.—In an armature coil *the adjacent turns act inductively upon each other upon the principle of the mutual induction arising between two separate adjacent circuits*

This self-induction opposes a rapid rise or fall of the induced current, the effect being similar to the inertia of matter which prevents any instantaneous change in its motion. The self-induction is one of the factors which enters into brush adjustment requring additional lead to prevent sparking.

Eddy Currents in Armature Core.—Armature cores as well as field cores, are subject to eddy currents which consume considerable energy and often cause harmful rise of temperature.

To reduce eddy currents to a minimum, armature cores are **laminated.**



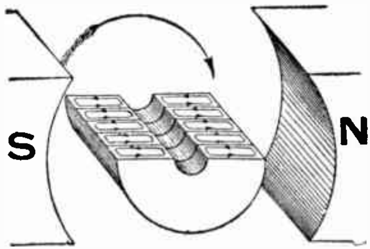
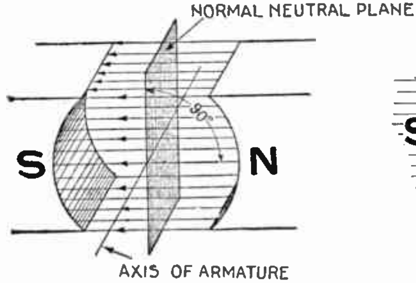


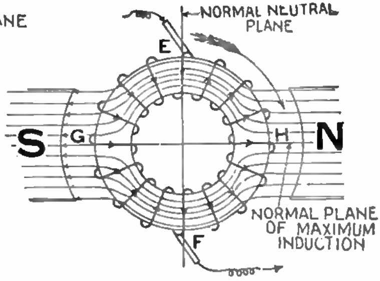
FIG. 7,604.—Eddy currents induced in a solid armature core. Eddy currents always occur when a solid metallic mass is rotated in a magnetic field, because the outer portion of the metal cuts more lines of force than the inner portion, hence the induced electric pressure not being uniform, tends to set up currents between the points of greatest and least pressure. Eddy currents consume a considerable amount of energy and often occasion harmful rise in temperature.

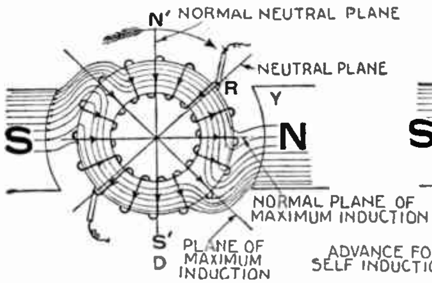
FIG. 7,605.—Armature core with a few laminations showing effect on eddy currents. In practice the core is made up of a great number of thin sheet metal discs, about No. 18 gauge, and introduces so much resistance between the discs that the formation of eddy currents is almost entirely prevented.

NOTE.—*Foucault or "eddy" currents* in armature core. When the construction of the armature core and inductors does not fulfil the necessary conditions required for the prevention of eddy currents, such as the laminations not being sufficiently insulated or numerous enough, a great heating of the whole of the armature results, which may even extend to the bearings. There is no remedy for this defect other than the purchase of a new armature, or the entire reconstruction of the old. The fault may be detected by exciting the field magnets and running the machine on open circuit, with the brushes raised off the commutator for some time, when the armature will be found to be excessively heated.

NOTE.—*Jean Bernard Leon Foucault,* born 1819, died 1868, was a French scientist and inventor, noted for his optical researches and his investigations in connection with eddy currents, these being called Foucault currents after him.







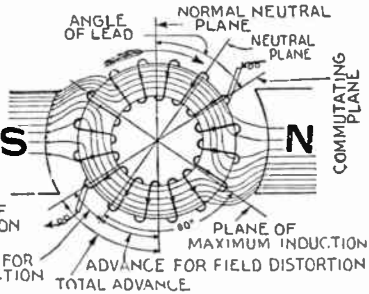
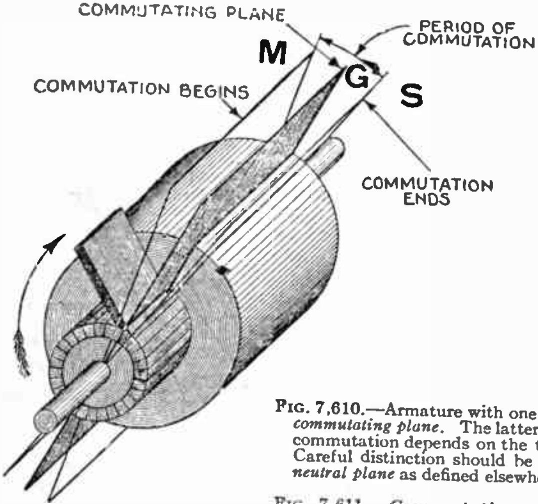


FIG. 7,606.—Normal neutral plane. This is a reference plane from which the lead is measured. As shown, the normal neutral plane lies at right angles to the lines of force of an undistorted field.

FIG. 7,607.—The proper position of the brushes, if there were no field distortion, self-induction in the armature coils would be in the normal neutral plane. In the actual dynamo these two disturbing effects are present which makes it necessary to advance the brushes as shown in figs. 7,608 and 7,609 to secure sparkless commutation.

FIG. 7,608.—Brush adjustment for ***field distortion.*** The effect of the latter is to twist the lines of force around in the direction of rotation, thus maximum induction takes place in an inclined plane. The brushes then must be advanced to the *neutral plane* which is at right angles to the plane of maximum induction. This gives the proper position of the brushes *neglecting self-induction*.

FIG. 7,609.—Brush adjustment for ***self-induction.*** By advancing the brushes beyond the neutral plane as shown, commutation takes place with the short circuited coil cutting the lines of force so as to induce a current in the opposite direction which opposes the continuance of current in the short circuited coil due to self-induction, brings it to rest and starts it in the opposite direction thus preventing sparking.



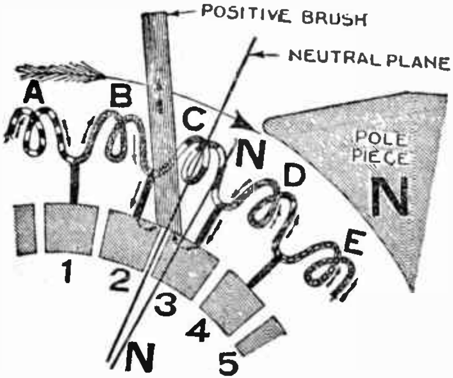
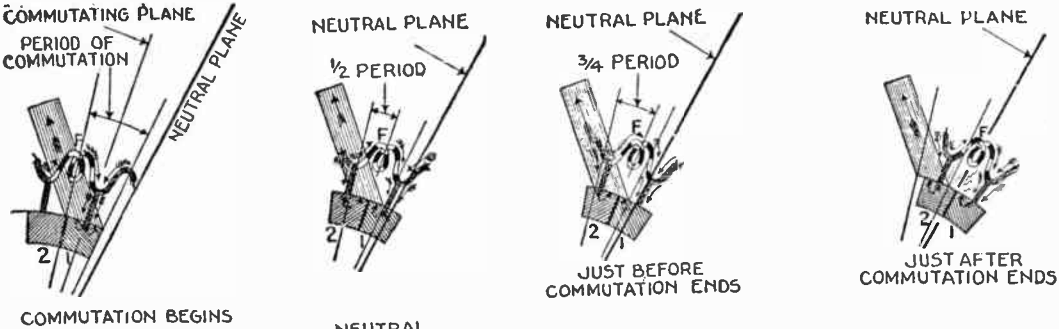
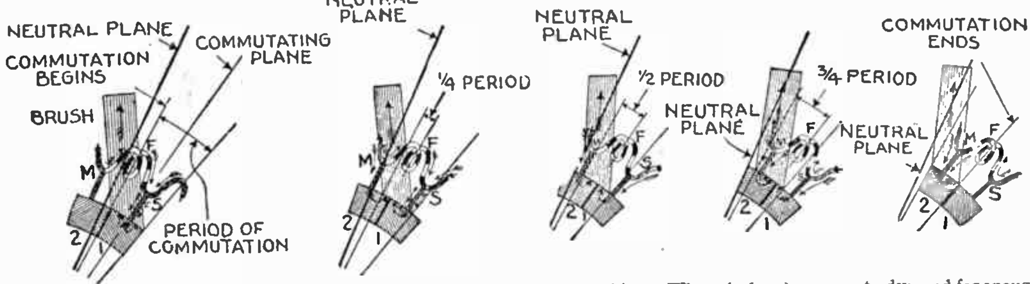


FIG. 7,610.—Armature with one brush in position to illustrate the *period of commutation* and *commutating plane*. The latter is called "commutating line" by some writers. The period of commutation depends on the thickness of the brush end in contact with the commutator. Careful distinction should be made between *commutating plane*, *neutral plane*, and *normal neutral plane* as defined elsewhere.

FIG. 7,611.—*Commutation.* Here the coils A,B,C,D,E, are connected to commutator segments 1,2,3,4, and the positive brush is shown in contact with two segments 2 and 3, the brush being in the neutral position. Currents in the coils on each side of the neutral line flow to the brush through segments 2 and 3; the brush then is positive. Now, as the armature turns, the commutator segments come successively into contact with the brush. In the figure, segment 3, is just leaving the brush and 2, is beginning to pass under it, hence, for an instant the coil C, is short circuited. Previous to contact with sement 2, current flowed in coil C, in the same direction as in coil B. While the brush is in contact with segments 2 and 3, the current in C, is stopped and started again in the opposite direction. Similarly each coil of the armature as it passes the brush will be short circuited and have its current reversed. This is known as *commutation.*

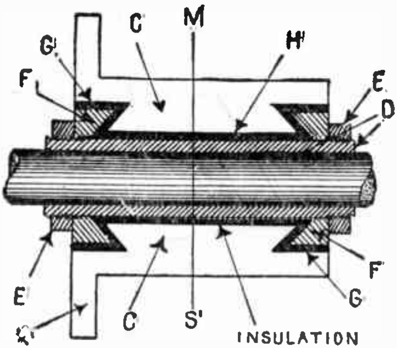
Commutation.—*This takes place during the brief interval in which any two segments of the commutator are bridged by the brush.*



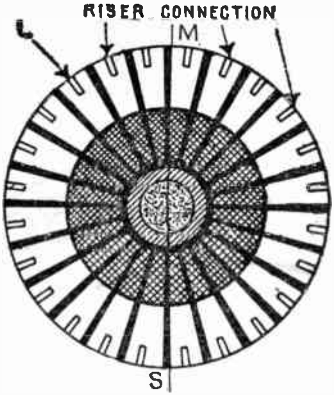


FIGS. 7,612 to 7,615.—Improper brush adjustment resulting in excessive sparking. When the brushes are not advanced far enough, commutation takes place before the short circuited coil reaches the neutral plane, hence, its motion is not changed with respect to the magnetic field so as to induce a reverse current till after commutation. There is then no opposing force, during commutation, to stop and reverse the current in the short circuited coil, and when the brush breaks contact with segment 1, as in fig. 7,615, the "*momentum*" of the current in coil F, causes it to jump the air gap from segment 1 to segment 2 and the brush, against the enormous resistance of the air, thus producing a spark whose intensity depends on the momentum of the current in coil F. Sparking, if allowed to continue, will injure the brushes and commutator segments.

FIGS. 7,616 to 7,720.—How sparkless commutation is obtained by advancing the brushes beyond the neutral plane; commutation progressively shown.



SECTION ON LINE MS



SECTION ON LINE M'S'

Figs. 7,621 and 7,622.—Side and end sectional views of commutator showing construction. The parts are: C, segments; D tubular iron hub; E, end nuts; F, clamps; G, insulation· L, riser connection.

Fig. 7,616 to 7,620—*Text.*

Fig. 7,616.—Commutation begins; current flows up both sides of the armature, uniting at S and flowing to the brush through commutator segment 1 as indicated by the arrow.

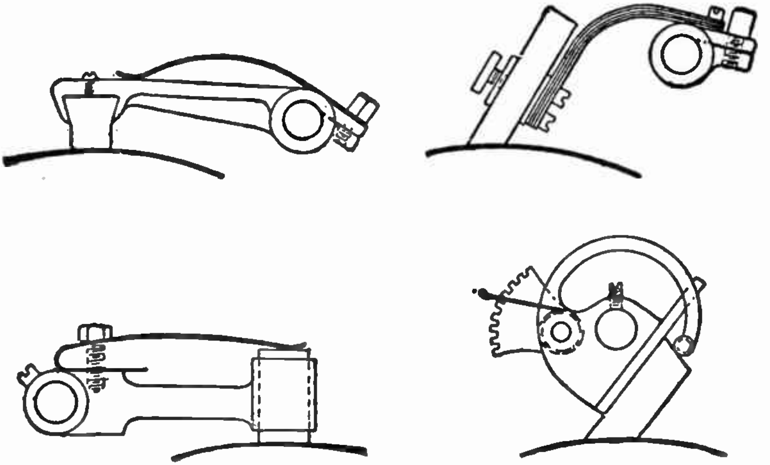
Fig. 7,617.—Segment 2 has come into contact with the brush and coil F, in which commutation is taking place, is now short circuited. The current now divides at M, part passing to the brush through segment 2, and part through coil F, and segment 1. Although coil F, is short circuited and having passed the neutral plane, is cutting the lines of force so as to induce a current in the opposite direction, it still continues to flow with unchanged direction against these opposing conditions. This is due to *self-induction* in the coil which resists any change just as the momentum of a heavy moving body, such as a train of cars, offers resistance to the action of the brakes in retarding and stopping its motion.

Fig. 7,618.—Segment 2 has moved further under the brush, and the opposition offered to the forward flow of the current in the short circuited coil F, by the reverse induction in the magnetic field to the right of the neutral plane has finally brought the current in F, to rest. The currents from each side of the armature now flow direct to the brush through their respective end segments 1 and 2.

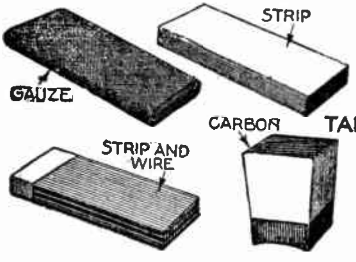
Fig. 7,619.—Segment 1 is now almost out of contact with the brush. A current has now been started in the coil F, in the reverse direction due to induction in the magnetic field to the right of the neutral plane; it flows to the brush through segment 2. The current has not yet reached its full strength in F, accordingly part of the current coming up from the right divides at S, and flows to the brush through segment 1.

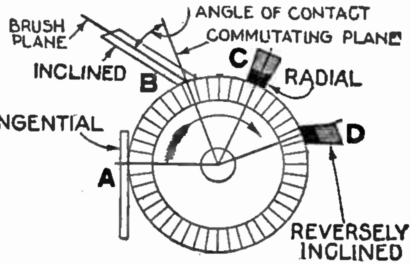
Fig. 7,620.—Completion of commutation in segments 1 and 2; the brush is now in full contact with segment 2, the current in coil F, has now reached its full value, hence the current flowing up from the right no longer divides at S, but flows through F, and segment 2 to the brush. If the current in F, had not reached its full value, at the instant segment 1 left contact with the brush, it could not immediately be made to flow at full speed any more than could a locomotive have its speed instantly changed. This, as previously explained, is due to self-induction in the coil or the so-called "inertia" of the current which opposes any sudden change in its rate of flow or direction. Accordingly that portion of the current which was flowing up from the right and passing off at S, to the brush through segment 1 as in fig. 7,619, would, when this path is suddenly cut off as in fig. 7,620, encounter enormous opposition in coil F. Hence, it would momentarily continue to flow through segment 1 and jump the air gap between this segment and the brush, resulting in a more or less intense spark depending on the current conditions in coil F.

The coil connecting with the two segments under the brush is thus short circuited. During commutation the current in the short circuited coil is brought to rest and started again in the reverse direction against the opposition offered by its so-called inertia, or effect produced by self-induction.



FIGS. 7,623 to 7,626.—Various types of brush holder. Fig. 7,623, arm or lever type; fig. 7,624, spring arm type; fig. 7,625, box type; fig. 7,626, reaction type.





FIGS. 7,627 to 7,630.—Various forms of brush. Fig. 7,627, gauze brush; fig. 7,628, laminated or strip brush; fig. 7,629, strip and wire brush as used on the early Edison machines; fig. 7,630, carbon brush. Carbon is preferred to copper for brushes on account of the reduction of sparking secured by its use.

FIG. 7,631.—Contact angle for the different types of brush. At A, is shown a brush with tangential contact, and at B, a so-called tangent brush; the latter is properly called an inclined brush. Sheet copper brushes are set tangentially as at A, and gauze brushes inclined as at B. Carbon brushes are placed radially as at C, when mounted in box holders, and inclined opposite to the direction of rotation when used with reaction holders.

different materials, such as copper or brass gauze, bundles of wire, carbon blocks, etc.

Copper brushes tend to tear and roughen the surface of the commutator while carbon brushes tend to keep the surface smooth. Copper brushes will carry from 150 to 200 amperes per sq. in. of contact surface; carbon brushes, from 40 to 70. Usual contact pressure 1¼ to 1½ lbs. per sq. in. Commutator rim velocities vary from about 1,500 to 2,500 feet per minute. The voltage drops for carbon brushes is about .8 to 1 volt at each contact.

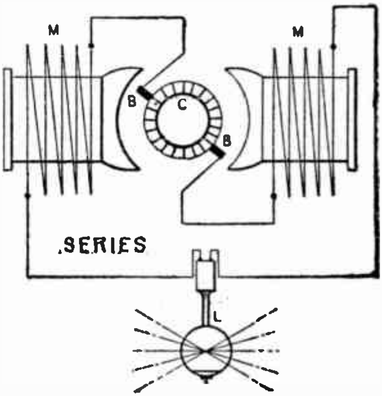


FIG. 7,632.—*Series* dynamo, used for series lighting, and as a booster for increasing the pressure on a feeder carrying current furnished by some other dynamo. The coils of the field magnet are in series with those of the armature and external circuit, and consists of a few turns of heavy wire. MM, field coils; BB, brushes; C, commutator; L, lamp. ***Characteristics:*** It furnishes current with increasing voltage as the load increases. If overloaded, the voltage will drop.

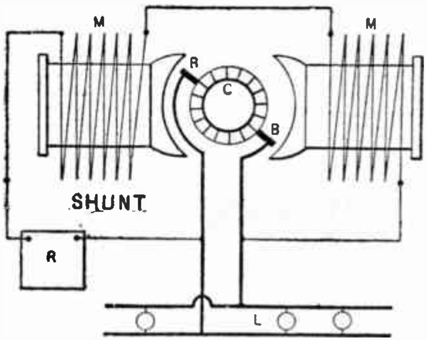


FIG. 7,633.—***Shunt dynamo,*** used for parallel circuit incandescent lighting, and for mill and factory power. The coils of the field magnet form a shunt to the main circuit; they consist of many turns of fine wire and consequently absorb only a small fraction of the current induced in the armature. MM, field coils; BB, brushes; C, commutator; L, lamp circuit; R, field rheostat. ***Characteristics:*** It gives practically constant voltage for all loads within its range. If overloaded the voltage will drop and the machine cease to generate current.

Classes of Dynamo.—With respect to the field winding, dynamos may be divided into three important types: 1, series; 2, shunt, and 3, compound.

A ***series dynamo*** is one in which all the current produced flows through the field winding.

In a ***shunt dynamo*** only a portion of the total current passes through the field magnet.

A ***compound dynamo*** has a *series winding* around which the main current flows, and a *shunt winding* through which a fraction of the main current flows. These various windings are shown in the accompanying cuts.

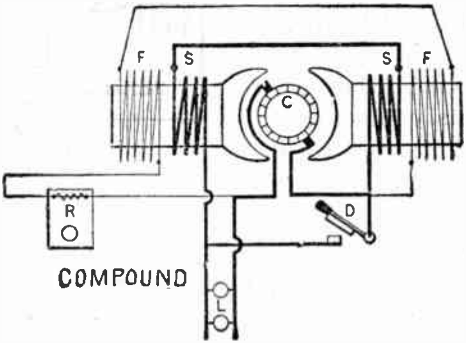


FIG. 7,634.—***Compound dynamo***, used when better automatic regulation of voltage on constant pressure circuits is desired than is possible with the shunt machine, as for incandescent lighting or long lines. The compound dynamo is a combination of the series and shunt types, that is, the field magnet is excited by both series and shunt windings. SS, series winding; FF, shunt winding; P, shunt rheostat; C, commutator; L, external circuit; D, series cutout switch which permits dynamo to run as a simple shunt machine. ***Characteristics:*** The series coils strengthen the field as the load rises, and by varying the number of series turns, different results may be obtained. If the series coils be of many turns, the field magnets will be so strengthened as to cause the voltage to rise with increase of load. This is called *over compounding*.

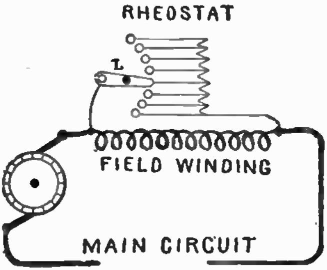
OPERATION

Starting Dynamo.—The different types of dynamos will require different treatment in starting, as follows:

Series Dynamo.—The extended circuit should be closed, otherwise a closed circuit will not be formed through the field magnets and the machine will not "build up." The term *build up* means the gradual increase of voltage to maximum.

Shunt Dynamo.—All switches controlling the external circuits should be opened, as the machine excites best when this is the case. If the machine be provided with a rheostat or hand regulator and resistance coils, these latter should all be cut out of circuit, or short circuited, until the machine excites, when they can be gradually cut in as the voltage rises.

When the machine is giving the correct voltage, as indicated by the volt meter or pilot lamp, the machine may be switched into connection with the external or working circuits.



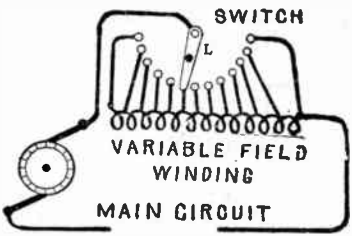


FIG. 7,635.—The two path method of regulatinga series dynamo. The shunt current is regulated by the rheostat. In this way the field strength is easily regulated by switch L.

FIG. 7,636.—Regulation of series dynamo by variable field. A multi-point switch L is provided with connections to the field winding at various sections, thus permitting more or less of the field winding to be cut out to regulate its strength.

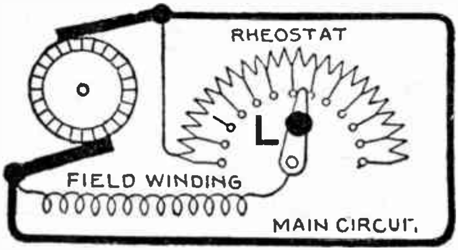
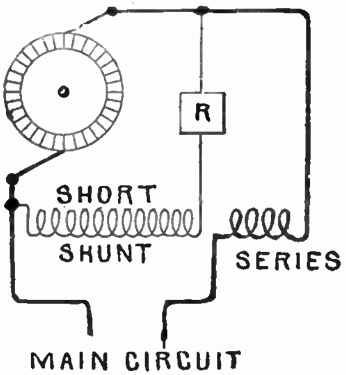
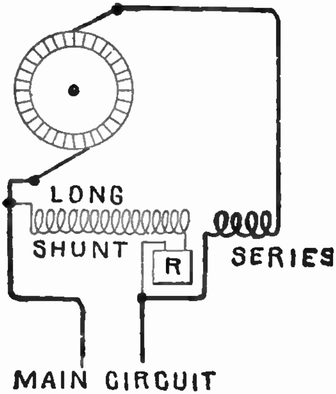


FIG. 7,637.—Regulation of shunt dynamo by method of varying the field strength with rheostat switch L.

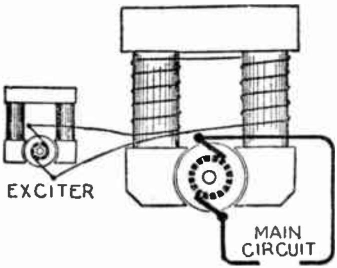
If the machine be working on the same circuit with other machines, or with a storage battery, it is, of course, necessary to make the voltage of the machine equal to that on the line before connecting it in the circuit.

If the machine work alone, the switch may be closed either before or after the voltage comes up. The load will be thrown on suddenly if the switch be closed after the machine has built up its voltage, thus causing a strain on the belt, and possibly drawing water over the engine cylinder,





FIGS. 7,638 and 7,639.—Short and long shunt types of compound wound dynamos. The distinction between the two is that the ends of the short shunt connect direct with the brush terminals, while in the long shunt type, fig. 7,639, one end of the shunt connects with one brush terminal and the other with the terminal connecting the series winding with the external circuit. R, is the shunt field rheostat for regulating the current through the shunt.



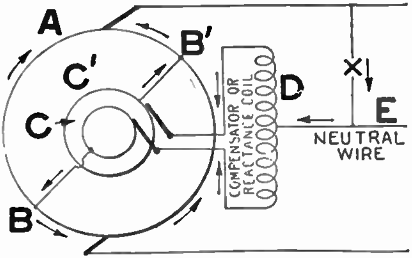


FIG. 7,640.—Separately excited-dynamo. This method of field excitation is seldom used except for alternators; it is, however, to be found occasionally in street railway power houses, the shunt fields of all the dynamos being separately excited by one dynamo. *Characteristics:* With the exception of armature reaction, the magnetism in its field and therefore the total voltage of the machine is independent of variations in the load.

FIG. 7,641.—Dobrowolski three wire dynamo used for three wire system without balancer. The armature A, is tapped at two points, B and B′, and connected to slip rings CC′. A compensator or reactance coil D, between the two halves of which there is minimum magnetic leakage, is connected to C and C′, by brushes, and has its middle point tapped and connected to the neutral wire E. *Characteristic:* The machine is capable of feeding unbalanced loads without serious disturbance of the pressure on either side of the system. Evidently, from the symmetry of the arrangement, the center point of the coil must always be approximately midway in pressure between that of the brushes, and hence any unbalanced current will return into the armature, dividing equally between the two halves of the coil.

Again, if the switch be closed before the voltage of the machine has come up, the load is picked up gradually, but the machine may be slow or may even refuse to pick up at all. Failure to pick up may be due to: 1, too little external resistance; 2, improper brush adjustment; 3, loss of residual magnetism; 4, wrong field connections, etc.

Compound Dynamo.—Cut in all field resistance and bring machine up to speed; cut out field resistance until voltage of dynamo equals or is a trifle above that of bus bar; throw on the load.

Coupling of Dynamos.—For very large and variable loads two or more dyamos are used, the number coupled together at

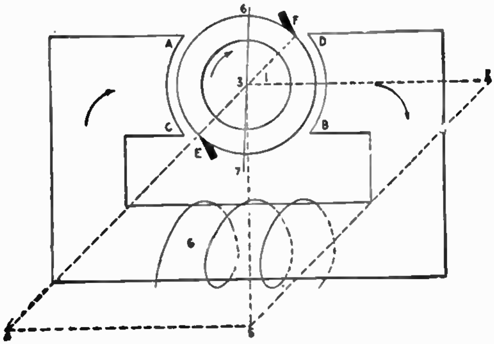


FIG. 1,642.—Diagram illustrating forces acting on a dynamo armature. ***In the figure*** the normal field magneto-motive force is in the direction of the line 1,2, produced by the field circuit G, if there were no current in the armature. But as soon as the armature current flows, it produces the opposing force 3,4, which must be combined with 1,2 to give the resulting force to produce magnetism and hence voltage. The resultant 1,5, if 3,4 be large enough, does not differ much from the original force 1,2. Or, expressed in a more physical way, the brushes E,F, rest on the commutator and all the turns embraced by twice the angle 6,3, F, oppose the flow of flux through the armature core as well as all the turns embraced by twice the angle, 7,3,E. The remaining turns distort the flux, making the pole corners at A and B, denser, and at C and D, rarer. So that all the effect is to kill an increase of flux, or voltage. This cross magnetism tends also to decrease the flow of flux, for the extra ampere turns required to force the flux through the dense pole tips are greater than the decreased ampere turns relieved by the reduction of flux at the other pole tips; this follows, since iron as it increases in magnetic density requires ampere turns greater in proportion than the increase of flux.

any time depending on the current demand; then the output of one can be added to that of another, so that the dynamos actually at work at any moment can be operated as nearly as possible at full load.

In coupling dynamos in series, the current capacity of the plant is kept at a constant value, while the output is increased in proportion to the pressures of the machines in circuit.

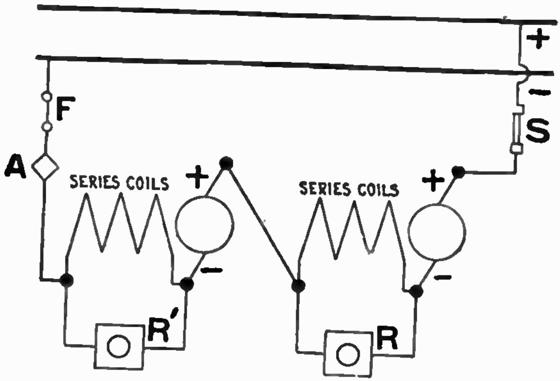


FIG. 7,643.—*Series dynamos in series.* The positive terminal of one dynamo is connected to the negative terminal of the other, and the two outer terminals are connected directly to the two main conductors or bus bars through the ammeter A, fuse F, and switch S. If it be desired to regulate the pressure and putput of the machines, variable resistances, or hand regulators R, R¹, may be arranged as shunts to the series coils as shown, so as to divert a portion or the whole of the current therefrom.

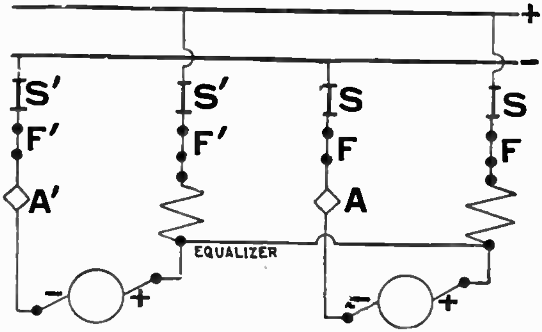


FIG. 7,644.—*Series dynamos in parallel.* The ends of the series coils are connected where they join on to the armature circuit by a third connection called the *equalizer* which prevents the tendency in series dynamos to reverse, that is, the fields in the dynamos being maintained constant or to vary equally, the tendency for the firemen of one dynamo to fall below that of the others is diminished. AA′, ammeters; FF′, fuses; SS′ switches. Series dynamos are very seldom connected in parallel because of the difficulty of regulating the voltage.

When connected in parallel, the pressures of all the machines are kept at a constant value, while the output of the plant is increased in proportion to the current capacities of the machines in circuit.

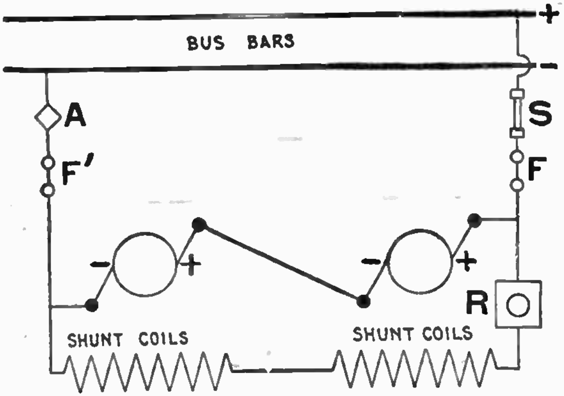


FIG. 7,645.—*Shunt dynamos in series.* The positive terminal of one machine is joined to the negative of the other, and the two outer terminals connected through the ammeter A, fuses FF′, and switch S, to the two main conductors or "omnibus bars." The ends of the shunt coils may be connected to the terminals of their respective machines, or they may be connected in series as shown.

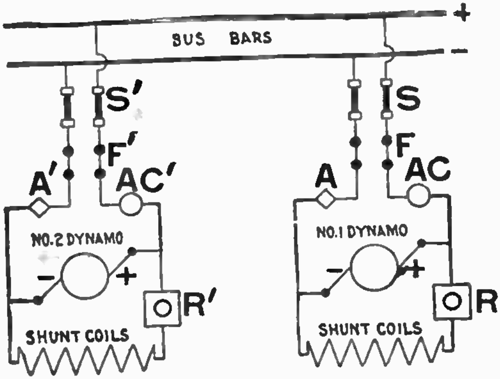


FIG. 7,646.—*Shunt dynamos in parallel.* The terminals are connected in parallel to the bus bars through the double pole switches SS, and fuses F,F′. Ammeters AA′, are inserted, and automatic cutouts AC, AC′, are sometimes provided. Both the shunt coils are connected in series and a field rheostat R, provided. Sometimes the shunt coils are connected to the terminals of each machine with individual field rheostats but the former method is better.

Uncoupling of Dynamos in Parallel.—The load of a compound dynamo, as in the case of a shunt machine, is first reduced to a few amperes, either by easing down the engine, or by cutting resistance into the shunt circuit by means of the hand regulator, and then opening the switch.

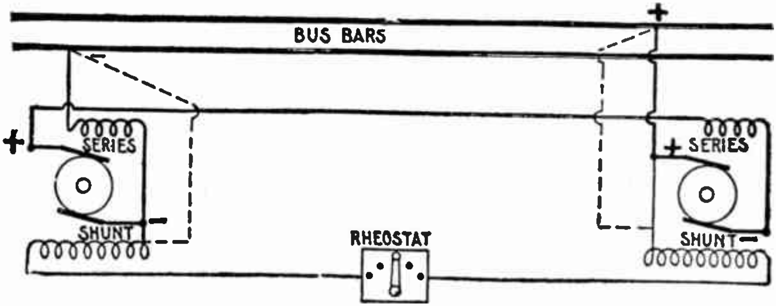


FIG. 7,647.—*Compound dynamos in series. Short shunt* connection. The dotted lines indicate the changes necessary for *long shunt* connection.

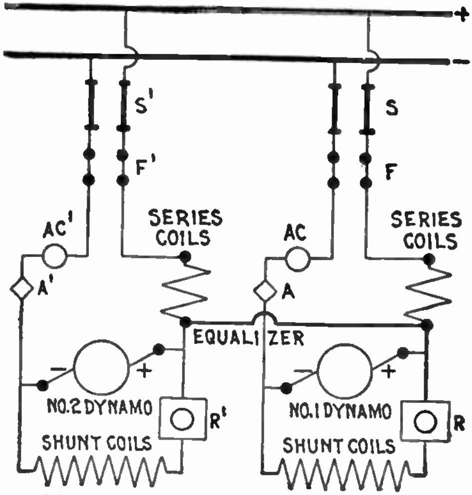


FIG. 7,648.—*Compound dynamos in parallel.* The equalizer for the series coils is necessary for satisfactory operation as in series dynamos. S,S′, switches; F,F′, fuses; A,A′, ammeters; AC, AC′, automatic cutouts; V, voltmeter; R,R′, shunt field rheostats.

Previous to this, however, it is advisable to increase the voltage at the bus bars to a slight extent, as while slowing down the engine the load upon the outgoing dynamo is transferred to the other dynamo armatures, and the current in their series coils not being increased in proportion, the voltage at the bus bars is consequently reduced somewhat.

Attention While Running.—An important item is the adjustment of brushes, because if this be neglected, the machine may spark badly which will necessitate frequent refiling of the commutator and brushes to secure good contact. The best lead for brushes can be found by rotating the rocker.

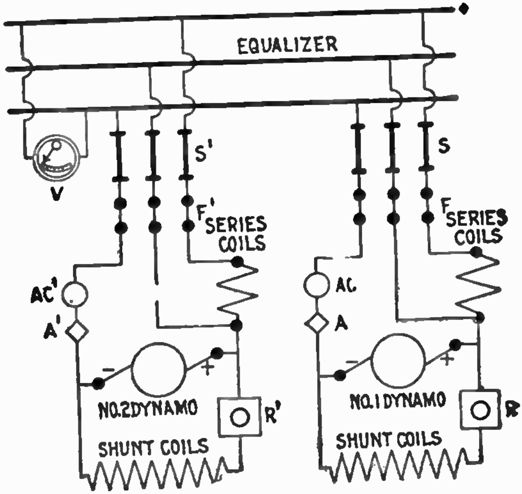
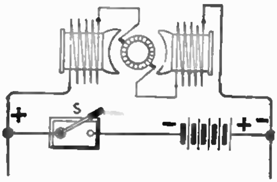


FIG. 7,649.—Diagram showing another and better method of coupling compound dynamos in parallel. With this arrangement the idle machines are completely disconnected from those at work. The same reference letters are common in both diagrams. S, S', are switches; F, F' fuses; A, A', ammeters, which indicate the total amount of current generated by each of the machines; AC, AC', automatic switches, arranged for automatically switching out a machine in the event of the pressure at its terminals being reduced through any cause; R,R', are hand regulators, inserted in the shunt circuits of each of the machines, by means of which the pressures of the individual machines may be varied and the load upon each adjusted. The pressure at the bus bars is given by the volt meter V, one terminal of which is connected to each of the bars; a second volt meter may be used, to give the pressure of any individual machine, by connecting "volt meter keys" to the terminals of each of the machines, or a separate volt meter may be used for each individual machine. The only essentia ldifference between figs. 7,644 and 7,449 is, that in fig. 7,644 the equalizer is connected direct to the positive brushes of all the dynamos, while in fig. 7,449 the equalizer is brought up to the switch board and arranged between the two bus bars, a switch being fitted for disconnecting it from the circuit when the machine to which it is connected is not working.

Stopping a Dynamo.—First reduce load gradually by slowing down engine, and do not open main switch until machine is supplying little or no current.

This reduces sparking at switch contact and prevents engine racing. When volt meter almost indicates zero raise brushes to prevent damage in case engine makes a backward movement (especially a gas engine) before coming to rest. *Caution*, if brushes be raised while there is much voltage the insulation of machine may be damaged, and with large shunt machines operator is liable to receive a severe shock.



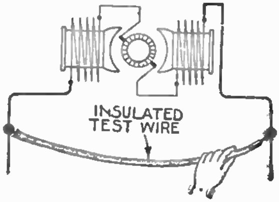


FIG. 7,650.—Method of overcoming insufficient residual magnetism. When connected as shown and circuit completed by switch S, the voltage of the battery will be added to any small voltage generated in the armature. When the machine is started, the combined voltages will probably be able to send sufficient current through the shunt to excite the machine. As the voltage rises and the strength of the current in the shunt windings increases, cut out battery by opening switch S.

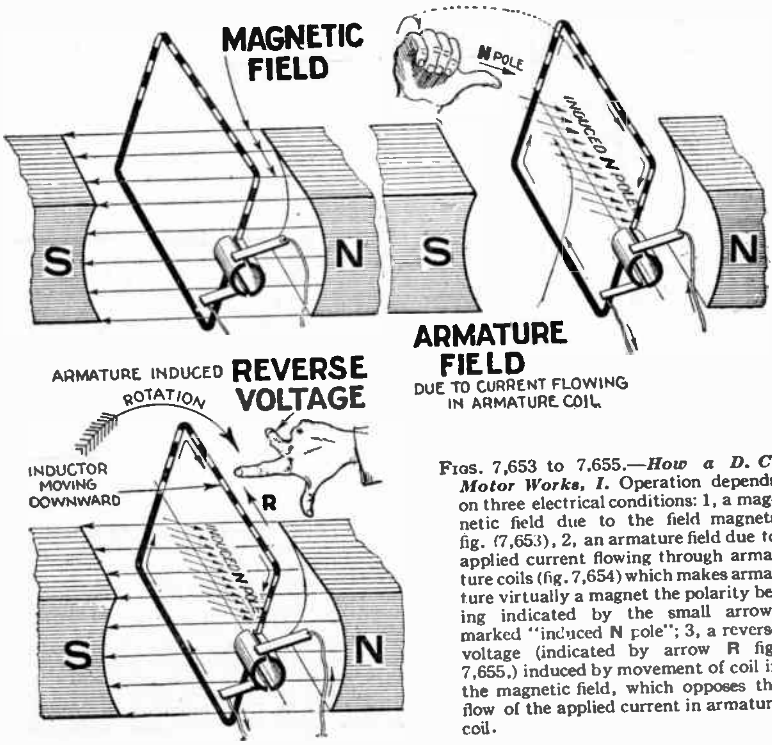
FIG. 7,651.—Method of testing for break by short circuiting the terminals of the machine. If the external circuit test out apparently all right, and there be no defective contacts in any part of the machine, and all short circuiting switches, etc., be cut out of circuit, the machine still refusing to excite, short circuiting the terminals of the machine should be tried. This should be done very cautiously, especially in case of a high tension machine. It is advisable to have, if possible, only a portion of the load in circuit, and the short circuit should be effected as shown in the figure. The short circuit may be made by momentarily bridging across the two terminals of the machine with a single piece of wire. As this, however, is liable to burn the terminals, a better plan is to fix a short piece of scrap wire in one terminal, and then with another piece of insulated wire make momentary contacts with the other terminal and the short piece of wire. If the machine excite, it will be at once evident by the arc which occurs between the two pieces of wire.

FIG. 7,652.—Method of testing dynamo for short circuits. T, T, are terminals under test. *In testing*, of a deflection of the needle be produced when the galvanometer terminal is in contact with either, the terminals are in contact with the frame, and they should then be removed, and the fault repaired by additional insulation or by reinsulating

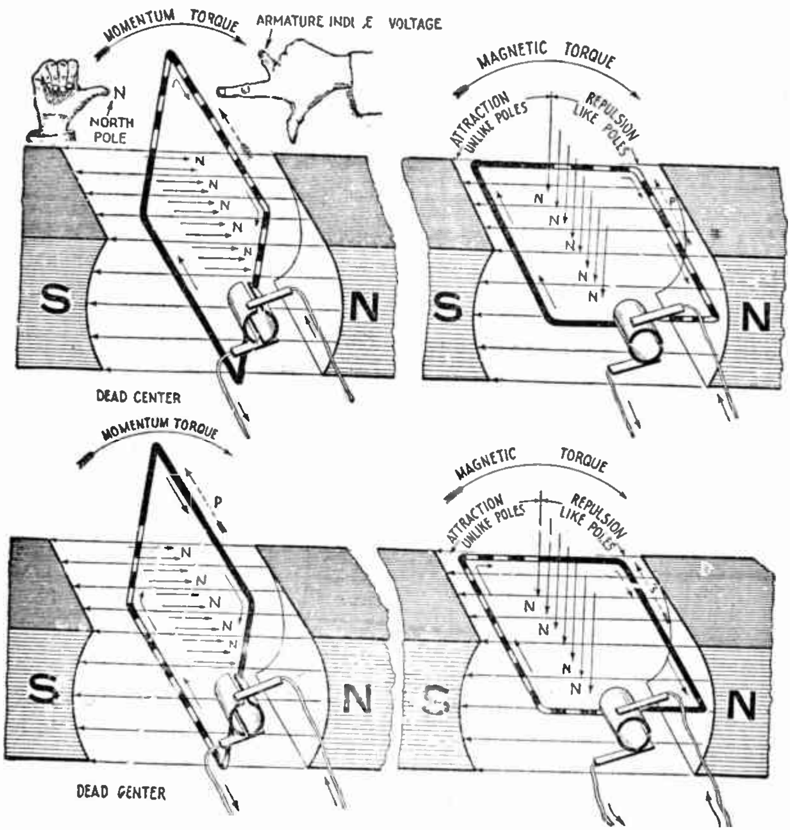
CHAPTER 32

D. C. Motors

A motor is *a machine for converting electrical energy into mechanical energy;* it is constructed in the same manner as a



FIGS. 7,653 to 7,655.—*How a D. C. Motor Works, I.* Operation depends on three electrical conditions: 1, a magnetic field due to the field magnets fig. (7,653), 2, an armature field due to applied current flowing through armature coils (fig. 7,654) which makes armature virtually a magnet the polarity being indicated by the small arrows marked "induced **N** pole"; 3, a reverse voltage (indicated by arrow **R** fig. 7,655.) induced by movement of coil in the magnetic field, which opposes the flow of the applied current in armature coil.

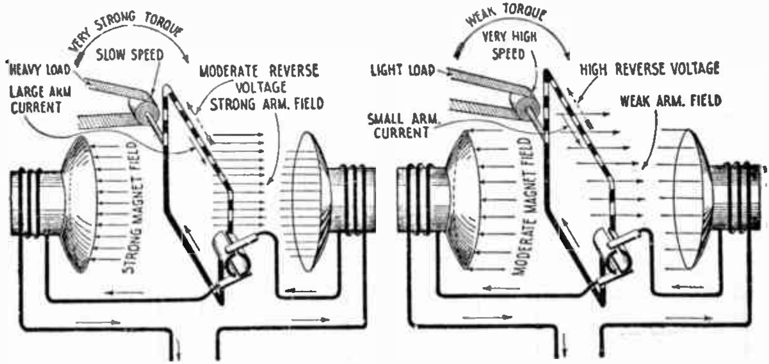


FIGS. 7,656 to 7,659.—*How a D.C. Motor Works, II:* Cycle of operation: Fig. 7,656, beginning of revolution, armature and magnet poles in opposite directions and hence *they* ("like" poles) ***oppose each other.*** This is the dead center position as there is no magnetic tendency to rotate armature, since magnetic lines of magnets and armature are parallel, but *momentum* of the armature (assured to be rotating) carries it past this dead center (just as a steam engine passes its dead center), when a clockwise torque is produced by the opposition of like poles. Fig. 7,657, ¼ revolution position; armature poles at right angles or midway between magnet poles; here the torque is due to ***the equal turning forces of repulsion of like poles and attraction of unlike poles.*** Fig. 7,658, ½ revolution position; at this instant *the armature polarity is reversed* by the reversal of current flowing in the armature coil due to brushes passing to opposite segment of commutator; the magnetic lines being parallel, give a second dead center ***with like poles repelling each other*** similar as in fig. 7,656, ***momentum carrying the armature p the dead center.*** Fig. 7,659, ¾ revolution position. armature poles *again* at right dynamo. As with dynamos, there are three general types of motors:

1. Series; 2. Shunt; 3. Compound.

Their characteristics are given below.

Series Motor.—It is inherently a variable speed motor starting with very powerful torque. On very light load the speed becomes dangerously high, hence it should be used only where the load is never entirely removed or where close attention is maintained. *Should never be used with a belt*, but always by coupling chain or gear. Used chiefly for hoists, cranes, street railways, and fans.



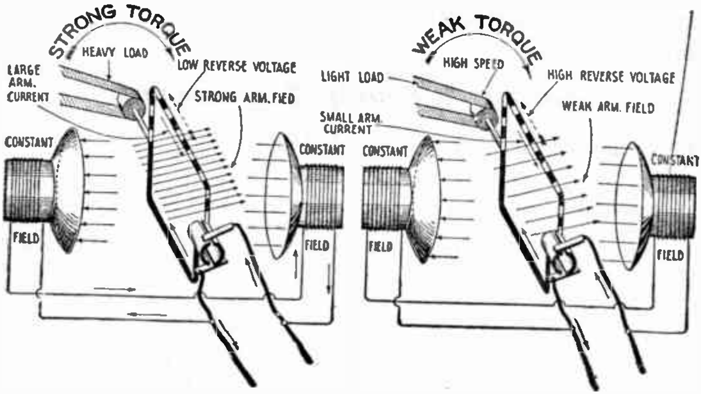
FIGS. 7,660 and 7,661.—*How a D. C. Motor Works, III: Series motor with variable load.* Since the same current passes through both the armature and field coils *the strength of the magnet field varies with that of the armature field.* Now if a heavy load cause the motor to slow down as in fig. 7,660, the reverse voltage will be reduced and a large current will flow through both armature and magnets producing a very strong toruqe to carry the load. Again, if the load be reduced, as in fig. 7,661 the motor will speed up and increase the reverse voltage which by cutting down the current will weaken both the armature and magnet fields until equilibrium with the load is established.

Shunt Motor.—The speed is practically constant. It will not start heavy loads, and is best adopted to constant loads such as pumps, fans, etc.

Compound Motor.—Since this motor is a combination of the shunt and series types, it partakes of the properties of both. The series winding gives it strong torque at starting (though not as strong as in the series

FIGS. 7,656 to 7,659.—*Text continued.*

angles or midway between magnet poles; here, (as in fig. 7,657) the torque is due to the equal *turning forces of repulsion of like poles* and *attraction of unlike poles*. Now at all times the rotation of the armature induces an electric pressure in the coil in a direction opposite to the current applied to the armature as indicated by the dotted arrow, called the *reverse voltage*; which tends to reduce the current applied to armature.



FIGS. 7,662 and 7,663.—*How a D. C. Motor Works, IV: Shunt motor with variable load. The strength of the magnet field remain constant while that of the armature field varies.* Now if a heavy load cause the motor to slow down as in fig. 7,662, the reverse voltage will be reduced allowing more current to flow through the armature which increases the torque till equilibrium is established between torque and load. Again, if the load be reduced, the motor will speed up, and since the field strength remains constant (instead of being reduced as in the series motor) this acceleration is quickly checked by the rapid rise of reverse voltage, there being very little difference in speed for either heavy or light load.

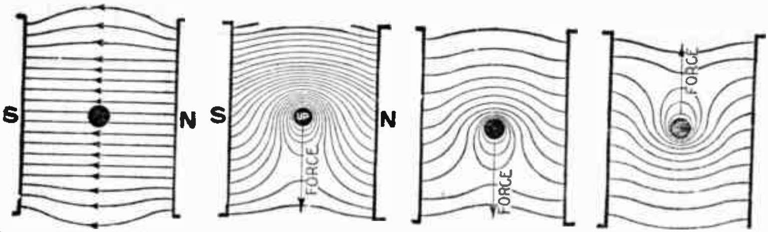


FIG. 7,664.—Conductor, lying in a magnetic field and carrying no current; the field is not distorted whether the conductor be at rest or in motion.

FIG. 7,665.—Conductor carrying a current in a magnetic field. The current flowing in the conductor sets up a magnetic field which distorts the original field as shown, making the magnetic lines denser on one side and less dense on the other. This results in a force upon the wire, which, in the case of a dynamo (fig. 7,665) opposes its movement, and which forms the *propelling drag* in the case of a motor (fig. 7,666).

FIGS. 7,666 and 7,667.—Action of the magnetic force in a dynamo and motor. In the first instance, according to Lenz' law, the direction of the current induced in the wire is such as to oppose the motion producing it. In the operation of a motor, the current supplied in flowing through the armature winding distorts the field and thus produces rotation. In the figures, the direction of the force is clearly indicated by remembering that the distorted lines of force act like rubber bands tending to straighten and shorten themselves.

motor), while the presence of the shunt winding prevents excessive speed. The speed is practically constant under all loads within the capacity of the machine.

A compound motor should be used in preference to a shunt motor where frequent starting and reversing are necessary. For severe mill service, the winding is heavily compounded (called *over-compounded*), having only enough shunt winding to limit the light load speed. At heavy loads such motors act virtually as series motors.

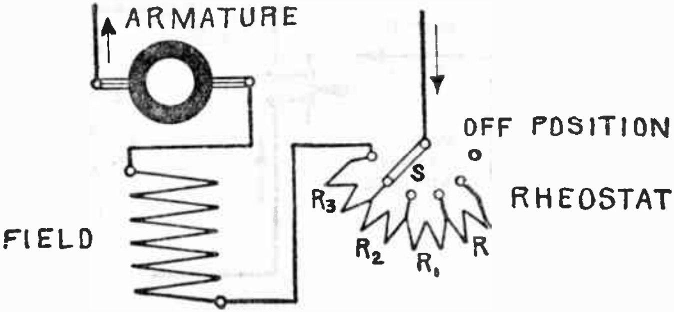


FIG. 7,668.—Series motor connections. ***To start*** the motor, the circuit is completed through a variable resistance or rheostat by moving the switch S, so that the resistance R,R_1,R_2,R_3, are gradually cut out of the circuit. ***To stop,*** the switch S, is moved back to its "off" position.

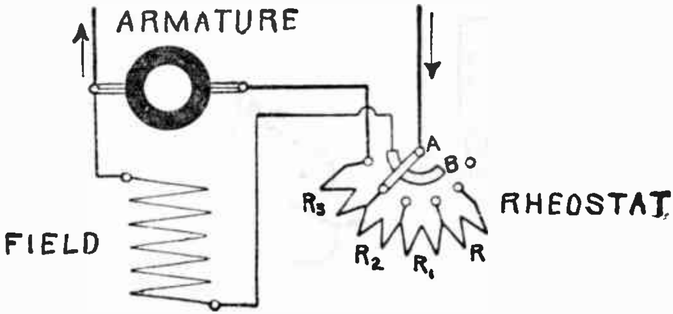
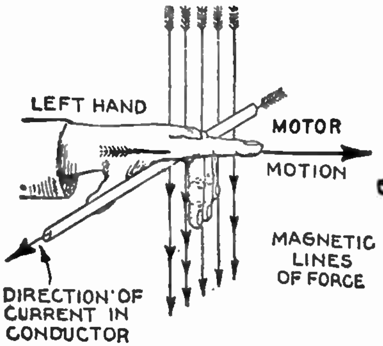


FIG. 7,669.—Shunt motor connections. ***In starting, unless the field magnets be put in the circuit first,*** the armature, at rest because of its low resistance would probably burn out. ***To start,*** the switch is closed, and the rheostat lever pushed over so as to make contact with A and B, thus *first* exciting the magnets. On further movement of the lever, the rheostat resistance R,R_1,R_2,R_3, etc., are gradually cut out as the speed increases, until finally all the resistance coils are cut out. ***To stop,*** the lever is brought back to its original position.

A series motor has usually only two terminals coming out from the case, whereas a shunt machine has three or four; three, by bringing together one armature and one field terminal inside of machine, if the the direction of rotation be fixed



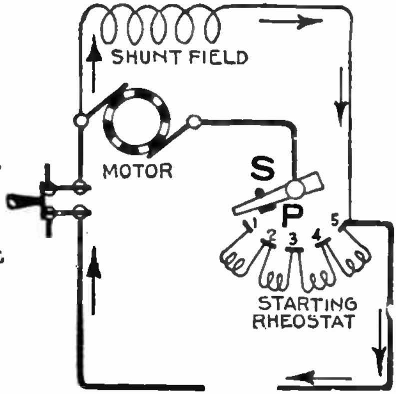
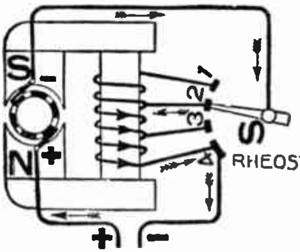


FIG. 7,670.—The "left hand rule" for direction of motion in motors. *Place the left hand, as shown, so that the thumb points in the direction of the current, the 3rd, 4th and 5th fingers in the direction of the lines of force, then will the 2nd or forefinger, at right angles to the others, point in the direction in which the conductor is urged.*

FIG. 7,671 —Speed regulation of shunt motor by inserting variable resistance in the armature circuit.



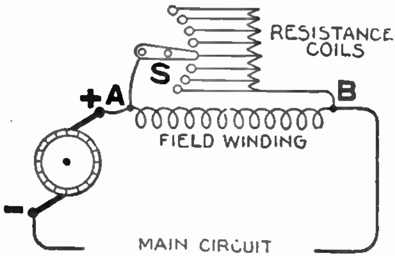


FIG. 7,672.—Speed regulation of series motor by cutting out sections of the field winding. By moving the lever S, downward the current will flow through one or more sections of the field winding, thus decreasing or increasing the ampere turns and thereby providing means of regulation.

FIG. 7,673.—Speed regulation of series motor by two path method. The current passing from A, to B, divides between the magnet coils and the rheostat coils; the higher the resistance of the rheostat the less current passes through it, and the more through the magnet coils, hence the stronger the field magnet.

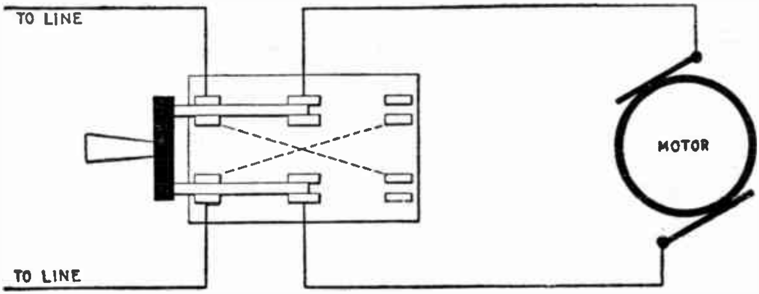
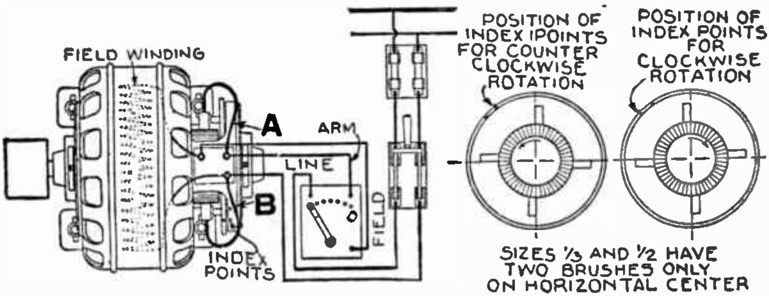
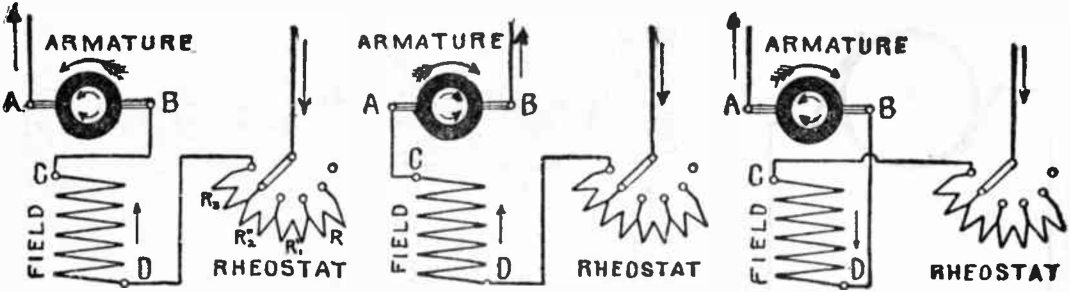


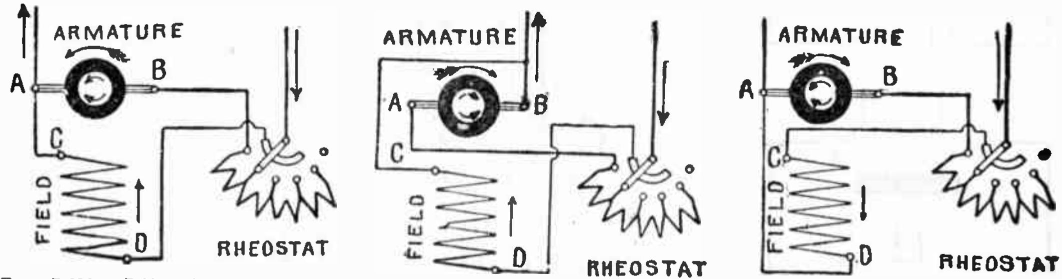
Fig. 7,674.—Motor reversing switch. A motor is reversed *by changing the direction of current in either the armature or field coils.* It is preferable to reverse armature current.



Figs. 7,675 to 7,677.—Holter-Cabot shunt wound motor; diagrams showing connections and positions of index point for forward and reverse rotation. ***To reverse,*** interchange leads A and B, and shift brush ring as shown. ***Before starting,*** see that armature revolves freely, fill bearings with oil and inspect oil rings. ***Starting,*** 1, see that rheostat lever is on off contact, 2, close main switch, 3, gradually cut out starting resistance with rheostat lever. ***If motor do not start,*** trouble may be due to *a*, wrong connections; *b*, too great load on the motor; *c*, the motor brushes not in proper position; *d*, an open circuit of some kind; *e*, a short circuit of some kind. In case of trouble make sure that fields are magnetized. To do this, close main switch, put rheostat on front contact and place a screw driver or other piece of iron against pole piece. A heavy pull will result on iron if fields be magnetized. ***Stopping.*** Open main switch and lever of rheostat (if automatic) will after a brief interval fly back to first contact. ***Running temperature.*** If motor feel too hot to the hand, test by placing thermometer for 10 minutes against frame covering with a cloth or piece of waste. The temperature should not be over 75° Fahr. above that of the surrounding air. ***Oiling.*** Use good "dynamo oil"; if in dirty place draw off and refill every two or three months. ***Care of motor.*** The motor must be kept clean. If the commutator become rough, smooth it up with No. 00 sand paper moistened with oil. When fitting new brushes or changing them, always sand paper them down until they fit the commutator perfectly, by passing to and fro beneath the brush a strip of sand paper, having the rough side toward the brush. Brushes must *always* be renewed before the metal of the holder comes in contact with the commutator. Don't use anything on commutator except good mineral machine oil, or kerosene, and this only in very small quantities applied with a cloth having no lint or threads



FIGS. 7,678 to 7,680.—Reversing the direction of rotation of a series motor. Fig. 7,678 shows the connections for counter clockwise rotation. The motor may be reversed: *1*, by allowing the current to flow in its original direction (from D. to C) in the field magnet coils, and altering the direction of the armature current by changing the two connections on the brushes A, and B, thus connecting C, to A, and B, to the return wires as in fig. 7,679; or *2*, by leaving the direction of the current in the armature in its original direction, and reversing that of the field current, as in fig. 7,680. If the wires leading to the rheostat and motor directly were reversed there would be no reversal of the motor, because by so doing, both the armature and field magnet currents would be reversed.



FIGS. 7,681 to 7,683.—Reversing the direction of rotation of a shunt motor. Fig. 7,681 shows the connections for counter clockwise rotation. The motor may be reversed: *1*, by allowing the current to flow in its original direction through the field magnet coils (from D, to C), and reversing its direction through the armature (from A to B) as in fig. 7,682; or *2*, by allowing the armature current to flow in its original direction (from B, to A), and reversing the current through the field coils (from C, to D), as in fig. 7,683.

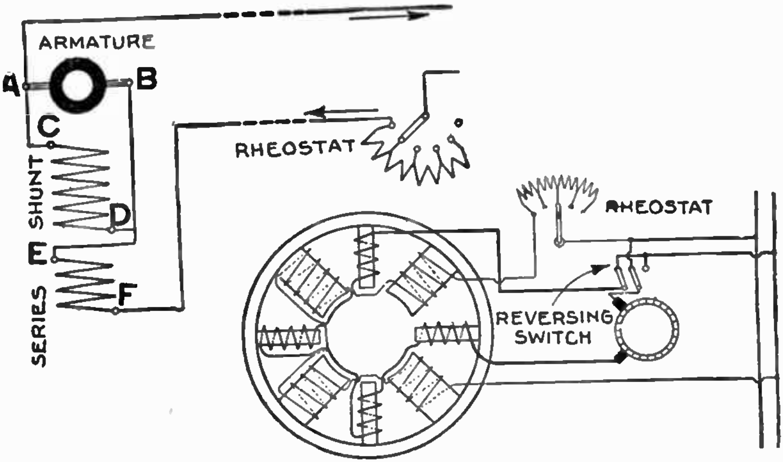


FIG. 7,684.—Compound motor connections for starting from a distant point.

FIG. 7,685.—*Interpole* motor. The object of the interpole winding is *to assist in the reversal of the current under the brushes to prevent sparking.*

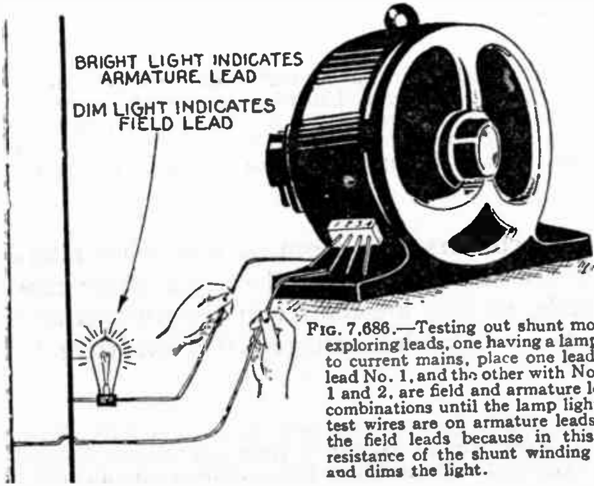


FIG. 7,686.—Testing out shunt motor circuits. With two exploring leads, one having a lamp in series and connected to current mains, place one lead in contact with motor lead No. 1, and the other with No. 2. If lamp do not burn 1 and 2, are field and armature leads. Now try different combinations until the lamp lights. If it burn brightly, test wires are on armature leads; if dimly, they are on the field leads because in this case the considerable resistance of the shunt winding cuts down the current and dims the light.

CHAPTER 33

Alternators

An alternator is *a machine for producing alternating current.* There are many types of alternator and these may be classified

1. With respect to the current as

   a. Single phase
   b. Two phase
   c. Three phase

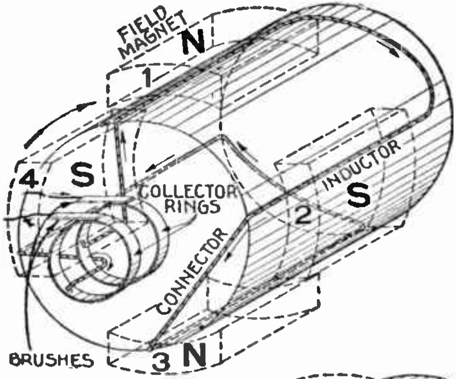
2. With respect to construction, as

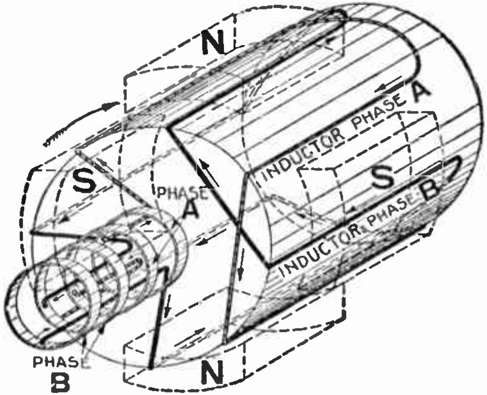
   a. Stationary field
   b. Revolving field
   c. Inductor

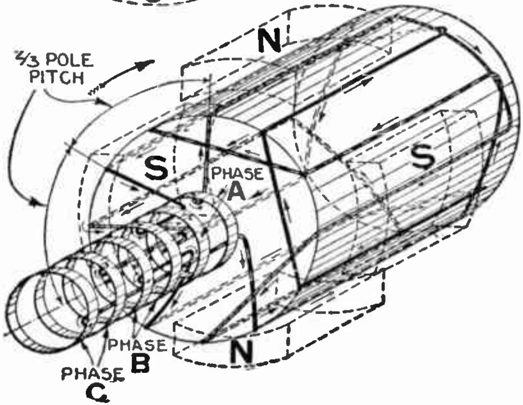
Alternators are usually multipolar, having north and south poles alternating around the field. The number of changes of direction of the current per revolution is the same as the number of coils in the armature or poles in the field, the armature coils in simple current machines being equal in number to the poles. The field magnets are often excited by a separate generator.

Single Phase Alternators.—As a general rule, when alternators are employed for lighting circuits, the single phase machines are preferable, as they are simpler in construction and do not generate the unbalancing voltages often occurring in polyphase work.

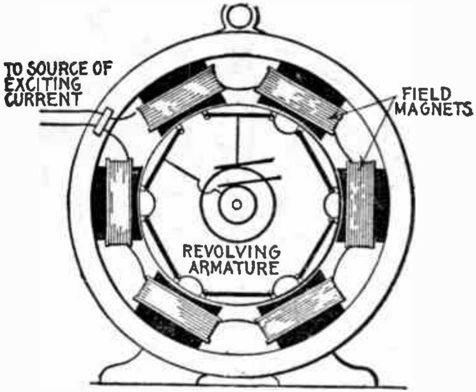
A single phase alternator consists essentially of an armature, single phase winding, field magnets and two collector rings and brushes through which the current generated in the armature passes to the external circuit.







FIGS. 7,687 to 7,689.—Elementary four pole alternators; fig. 7,687, one phase; fig. 7,688, two phase; fig. 7,689, three phase. Each winding consists of *one inductor per pole per phase*, the inductor of each phase being connected by *connectors*, to the *collector rings*. The poles being alternate N and S, there will be two cycles of the current per phase per revolution of the armature. Applying Fleming's rule for induced currents, the direction of the current induced in the inductors is easily found as indicated by the arrows. The field magnets are excited by coils supplied with direct current, usually furnished from an external source; for simplicity this is not shown. The magnets may be considered as of the permanent type.



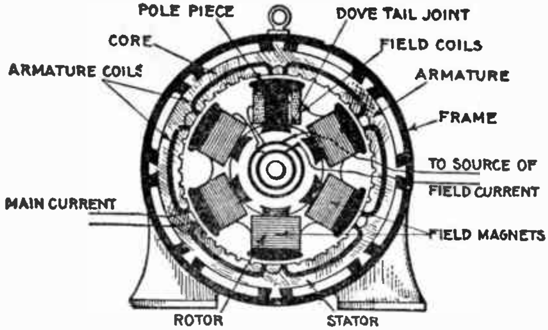


FIG. 7,690.—Revolving armature alternator. These are suitable for machines generating current at comparatively low pressure, as no difficulty is experienced in collecting such current. Revolving armature alternators are also suitable for small power plants, isolated lighting plants, where medium or small size machines are required.

FIG. 7,691.—Revolving field alternator. For medium and large machines *the advantages are:* 1, superior insulation permitting higher voltages; 2, no collector rings for armature current; 3, armature terminals may be enclosed.

Polyphase Alternators.—A multi- or polyphase alternator is *one which delivers two or more alternating currents differing in phase by a definite amount.*

Such alternators are employed rather for power purposes than for lighting; for lighting purposes the phases are isolated in separate circuits, that is, each is used as a single phase current. For driving motors the circuits are combined to facilitate starting.

Stationary Field Alternators.—In this type *the armature revolves while the field* *magnets are attached to the circular frame*, similar to dynamo construction. The machine may be single or polyphase and is used where the pressure and current are moderate.

Stationary Armature Alternators.—In this type *the field revolves while the armature is attached to the circular frame*.

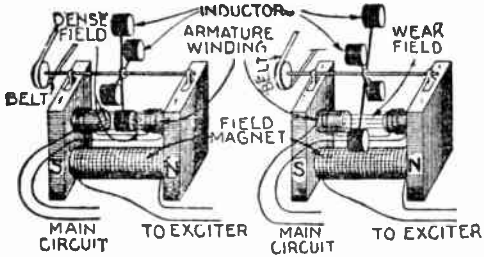
Since ***motion** is purely a **relative matter*** it makes no difference whether the armature or field revolves.

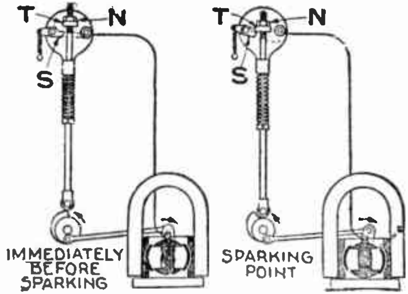
FIG. 7,692.—Marine view, showing that *motion is purely a relative matter*. In order that there may be motion something must be regarded as being stationary. *The small dory* running at a speed of four miles per hour against the current is *moving* at that velocity *relative* to the current, yet is at a standstill relative to the cat boat. In this instance both cat boat and dory are moving with respect to the water if the latter be regarded as stationary. Again if the earth be regarded as being stationary, the two boats are at rest and the water is moving relative to the earth. Hence, it makes no electrical difference if an alternator be constructed so that the armature revolve (regarding the earth as stationary) as in fig. 7,690, or the field magnets revolve as in fig. 7,691.

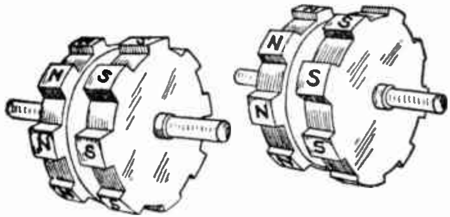
The advantage of making the armature stationary and letting the field revolve, is that in the case of large size machines, the difficulty of taking off currents of high amperage or high voltage from collector rings is avoided.

The terms *stator* and *rotor* are usually applied to the armature and field magnets with respect to which is stationary and which moves.

Inductor Alternator.—In this class, *both armature and field magnets are stationary*, a current being induced in the armature







Figs. 7,693 to 7,696.—Elementary inductor alternator (figs. 7,693 and 7,694) and its application to low tension or make and break ignition. *In construction* inductors consisting of iron discs are arranged on a shaft to rotate through the air gaps of the magnetic poles, resulting in a variable (undulating) flux which induces a current in the winding. *For ignition work* it has the advantage of a stationary winding which avoids the use of brushes to collect the current. Figs. 7,695 and 7,696 show an oscillating inductor low tension ignition magneto. The inductor is rotated to and fro by means of a link, one end of which is attached to the inductor crank, and the other to the igniter cam, as shown. Two views are shown· immediately before and after sparking. S, is the grounded electrode of the igniter; T, an adjustable hammer which is secured in position by a lock nut N.

Figs. 7,697 and 7,698.—Homopolar and heteropolar "inductors." Homopolar inductors have their N and S poles opposite each other, while in the heteropolar type, they are "staggered" as shown.

winding by the action of a so-called inductor or mass of iron moving through the magnetic field so as to periodically vary its instensity

A peculiarity of this type is that the current does not reverse, hence the total number of armature

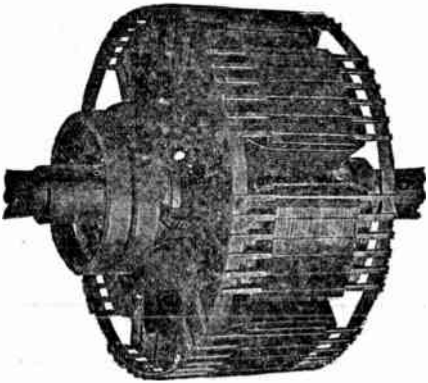
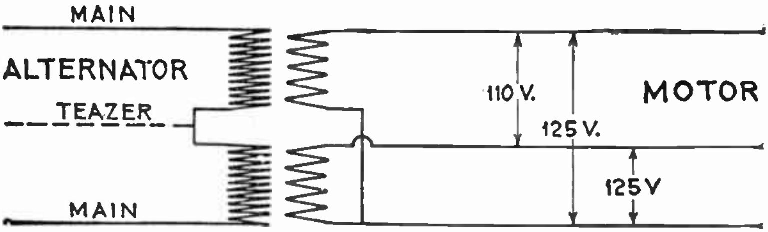


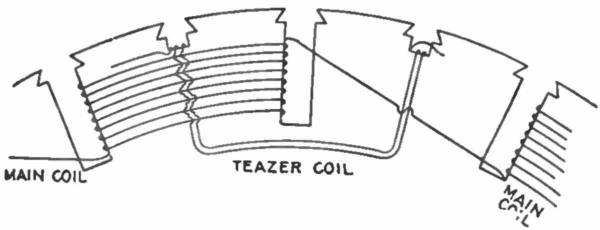
FIG. 7,699.—Westinghouse field with amortisseur or "damper" winding for 75 kva. and larger belted alternators, which prevents hunting and reduces eddy currents in the pole pieces. The copper bars of the amortisseur cage winding are arranged in partially closed slots in the pole pieces.

turns (for given magnetic flux) necessary to produce a given pressure is twice that required in an alternator having an alternating flux through its armature windings.

Hunting or Singing.—Hunting is a term applied to the state of two parallel connected alternators running out of step, or not synchronously, that is, "see sawing."

When two machines are operated in parallel with "peaked" current wave it is difficult to keep them in step. Any difference in the phase relation which is set up by the alternation will cause a local or synchronizing





FIGS. 7,700 and 7,701.—Monocyclic diagrams showing transformer connections and alternator armature winding. In fig. 7,700, the main coils are wound on every other tooth, and the *teaser* coils are placed in quadrature with them, as shown.

current to flow between the two machines and at times it becomes so great that they must be disconnected. This trouble is avoided by the use of *dampers* and *amortisseur* windings. The latter are often erroneously called *squirrel cage* windings.

Monocyclic Alternators.—These are *single phase machines provided with an additional coil, called a* ***teaser coil,*** *wound in two phase relationship with and connected to the center of the main single phase coil.*

The monocyclic alternator is provided with three collector rings; two for the single phase coil, and one for the free end of the *teaser coil.*

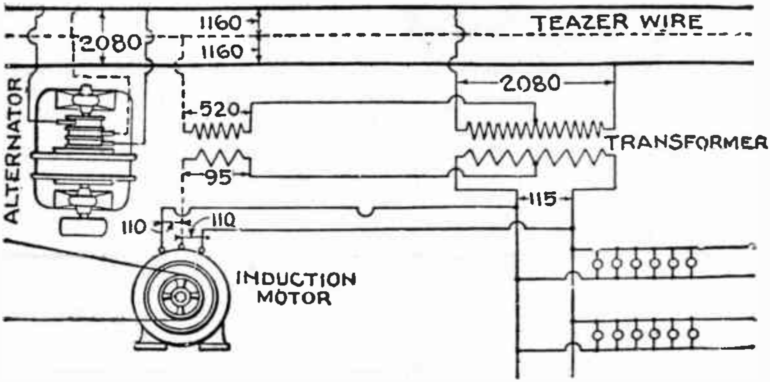


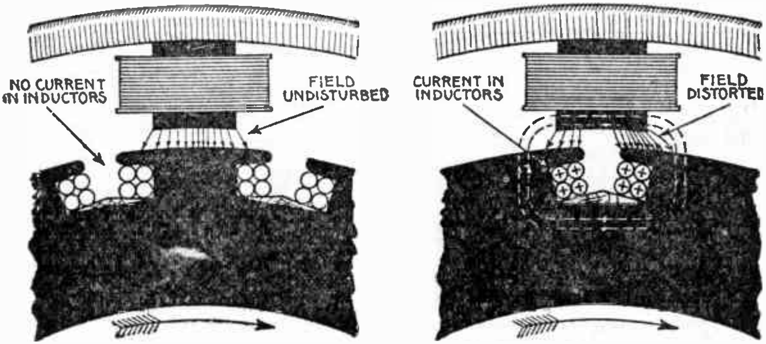
FIG. 7,702.—Diagram of monocyclic system showing connections. The monocyclic system is a single phase system primarily intended for the distribution of lights with an incidental load of motors. The lighting load is entirely connected to one single phase circuit, and the motors are started and operated from this circuit with the assistance of the teazer wire. The teaser coil to which this wire is connected generates a pressure in quadrature with that of the main coil. This pressure is combined with the main pressure of the alternator by transformers, so as to give suitable phase relations for operating induction motors.

By this arrangement ordinary single phase incandescent lighting can be accomplished by means of a single pair of wires taken from the single phase coil.

Where three phase motors have to be operated, however, a third wire, called the *power wire*, which is usually smaller than the main single phase wires, is carried to the point at which the motor is located, and by the use of two suitably connected transformers three phase currents are obtained from the combined single phase and power wires for operating the motors. This type of alternator was designed prior to the introduction of the polyphase systems, to overcome the difficulty of starting encountered in the operation of single phase alternators as motors.

Armature Reaction.—Every conductor carrying a current ***creates*** *a magnetic field around itself, whether it be embedded in iron or lie in air.*

Armature inductors, therefore, create magnetic fluxes around themselves, and these fluxes will, in part, interfere with the main flux from the poles of the field magnet, tending: 1, to *distort*, or 2, to *weaken* the field. Armature reaction is especially marked in slotted armatures.



FIGS. 7,703 and 7,704.—Section of armature and field showing ***distorting effect*** of armature reaction on the field. When a coil is opposite a pole as in fig. 7,703, no current is flowing (assuming no self-induction) and the field is undisturbed, but, as the inductors pass under a pole face as in fig. 7,704, current is induced in them, and lines of force are set up as indicated by the dotted lines. This distorts the main field so that the lines of force are crowded toward the forward part of the pole face as shown.

Magnetic Leakage.—In the design of alternators *the drop of voltage on an inductive load is mainly dependent upon the magnetic leakages, primary and secondary.*

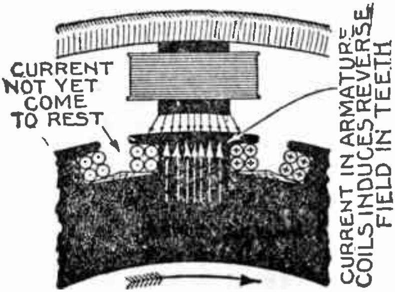
They increase with the load, and, what is of more importance, they increase with the fall of the power factor of the circuit on which they may be working. This is one reason why certain types of alternator, though satisfactory on a lighting circuit, have proved themselves unsatisfactory when applied to a load consisting chiefly of motors.

In general, to keep the leakage small, the pole cores should be short, and of minimum surface, the pole shoes should not have too wide a span nor be too thick, nor present needless corners, and the axial length of the pole face and of the armature core should not be too great in proportion to the diameter of the working face.

Field Excitation.—The fields of alternators *require a separate source of direct current for their excitation*, and this current should be preferably automatically controlled.

In the case of alternators that are not self-exciting, the dynamo which generates the field current is called the *exciter*.

A self-excited alternator has, in addition to the main winding, another winding connected to a commutator for furnishing direct field exciting current.



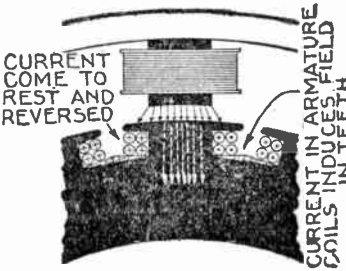
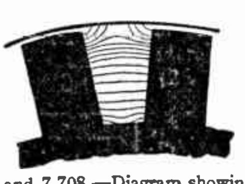
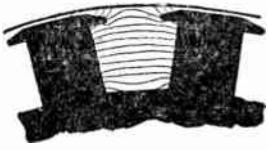


FIG. 7,705.—Section of armature and field showing *weakening effect* of armature reaction in the field. Self induction being present (as it almost always is), the current lags more or less behind the pressure, so that when the coil is in the position of zero induction, as shown, the current has not yet come to rest. Accordingly, lines of force (indicated by the dotted lines) are set up by the current flowing through the coils which are in opposition to the field, thus weakening the latter. The dots and crosses in inductor sections, have their usual significance in defining the direction of current, representing respectively the heads and tails of arrows.

FIG. 7,706.—Section of armature and field showing *strenghtening effect* of armature reaction when the current leads the pressure. If the circuit contain an excess of capacity the current will lead the pressure, so that when the coil is in the position of zero induction, as shown, the current will have come to rest and reversed. Accordingly, lines of force (indicated by the dotted lines (are set up by the current flowing through the coil and which are in the same direction as the lines of force of the field, thus strenghtening the latter.





FIGS. 7,707 and 7,708.—Diagram showing respectively the character of stray field between adjacent straight poles, and between adjacent poles with shoes.

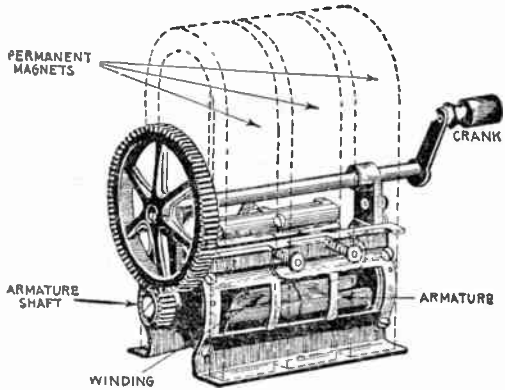


FIG. 7,709.—Connecticut *permanent magnet self-excited* magneto. This type of magneto was formerly used extensively to generate current for operation of telephone call bells. At present the principal use of magnetos is for gas engine ignition.

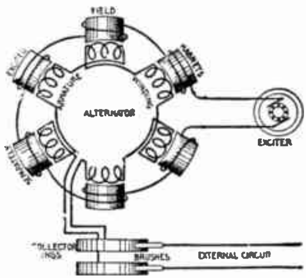


FIG. 7,710.—Diagram of separately excited alternator. The field winding is supplied with direct current, usually at 125 volts pressure by a small dynamo called the "exciter." The latter may be driven by independent power, or by belt connection with the main shaft, and in some cases the exciter is directly connected to the alternator shaft.

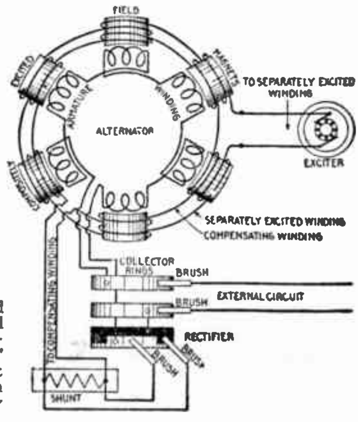
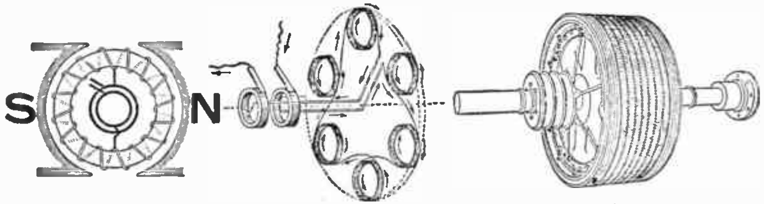


FIG. 7,711.—Diagram of compositely excited alternator. The current for exciting the field magnets is obtained, partly from an exciter and partly from the windings of the alternator, being transformed into direct current by the rectifier. The connections are as shown. ***In operation,*** the separately excited coils set up the magnetism necessary for the generation of the voltage at no load. The main current coming from the armature is shunted, part going through the shunts and the remainder around the compensating winding, furnishing the additional magnetism necessary to supply the voltage to overcome the armature impedance.

CHAPTER 34

Alternator Construction

The construction of alternators follows much the same lines as dynamos, especially in the case of machines of the revolving armature type. Usually, however, more poles are provided thar on direct current machines, in order to obtain the required fre quency without being driven at excessive speed.



FIGS. 7,712 to 7,714.—Various armatures. Fig. 7,712, ring; fig. 7,713, disc; fig. 7,714, drum; —the prevailing type.

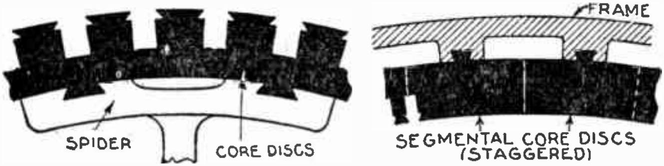
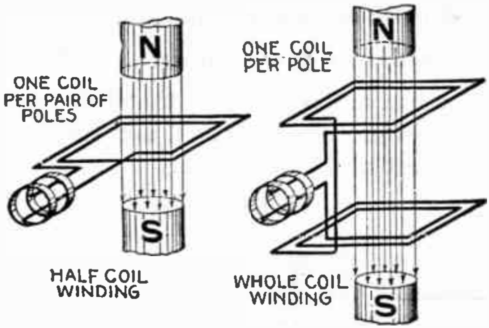
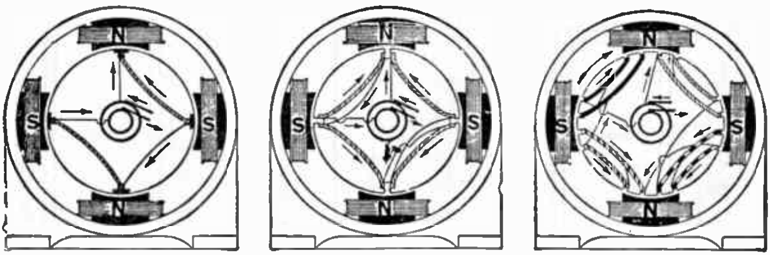


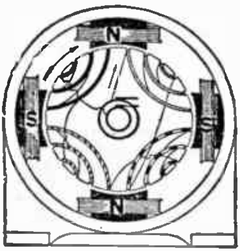
FIG. 7,715.—Large *revolving* armature construction with segmental discs *dovetailed to spider.*

FIG. 7,716.—Large *stationary* armature construction with segmental discs *dovetailed to frame.* In both revolving and stationary armatures, the joints are staggered in building up the core, that is, they are overlapped so as not to unduly increase the reluctance of the magnetic circuit. Dovetail joints obviate the use of through bolts which, if not insulated, are liable to give rise to eddy currents by short circuiting the discs.



FIGS. 7,717 and 7,718.—Elementary bipolar alternators with *half coil* and *whole coil* windings. In a half coil winding there is one coil per phase *per pair of poles*; in a whole coil winding there is one coil per phase *per pole*.





FIGS. 7,719 and 7,720.—Concentrated windings. A concentrated winding is one in which the armature has only *one tooth per phase per pole*, that is, the number of teeth equals the number of poles. A concentrated winding of the half coil type has only one side of a coil in each slot as in fig. 7,719. In the whole coil variety, each slot contains neighboring sides of adjacent coils, as in fig. 7,720.

FIG. 7,721.—Partially distributed winding. Each coil unit is here divided into two concentric coils of different dimensions and connected in series, as shown in detail in the figure. This being a "whole coil" winding the several units are so connected that the winding of adjacent units proceeds in opposite directions, that is, one coil is wound clockwise, and the next counter clockwise, etc., so that the induced currents flow in a common direction as indicated by the arrows for the position shown.

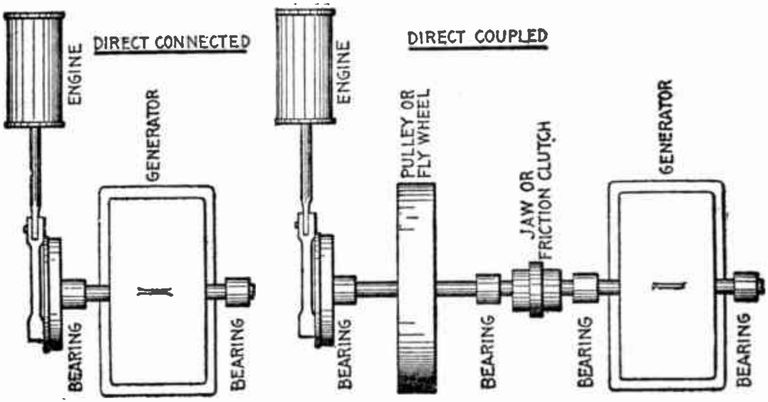
FIG. 7,722.—Fully distributed winding. Each coil consists of so many sub-coils that the winding occupies the entire surface of the armature core; that is, there are no extensive spaces unoccupied, the spacing being uniform as shown.

The essential parts of an alternator are:

1. Field magnets; 2. Armature; 3. Collector rings;

and in actual construction, in order that these necessary parts may be retained in proper co-relation, and the machine operate properly there must also be included:

4. Frame; 5. Bed plate; 6. Pulley.



FIGS. 7,723 and 7,724.—Diagram showing the distinction between *direct connected* and *direct coupled* units. In a ***direct connected*** unit, fig. 7,723, the engine and generator are permanently connected on one shaft, there being one bed plate upon which both are mounted. An engine and generator are said to be ***direct coupled*** when each is independent, as in fig. 7,724, being connected solely by a jaw or friction clutch or equivalent at times when it is desired to run the generator. At other times the generator may be disconnected and the engine run to supply power for other purposes.

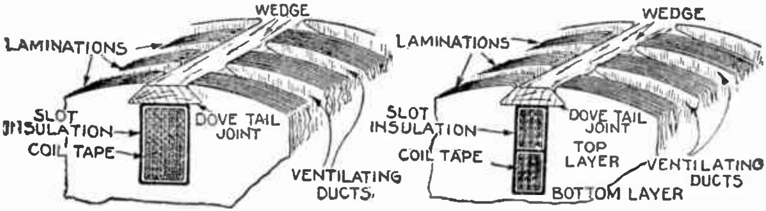
NOTE.—***Belt or Chain Driven Alternators.***—The mode in which power is transmitted to an alternator for the generation of current is governed chiefly by conditions met with where the machine is to be installed. In many small power stations and isolated plants the use of a belt drive is unavoidable. In some cases the prime mover is already installed and cannot be conveniently arranged for direct connection, in others the advantage to be gained by an increase in speed more than compensates for the loss involved in belt transmission. There are many places where belted machines may be used advantageously and economically. Where there is sufficient room between pulley centers, a belt is a satisfactory medium for power transmission, and one that is largely used. It is important that there be liberal distance between centers, especially in the case of generators or motors belted to a medium or slow speed engine, because, owing to the high speed of rotation of the electric machines, there is considerable difference in their pulley diameters and the drive pulley diameter; hence, if they were close together, the arc of contact of the belt with the smaller pulley would be appreciably reduced, thus diminishing the tractive power of the belt.

Field Magnets.—Alternators *are built with three kinds of electro-magnets*, classed according to the manner in which they are excited, the machines being known as:

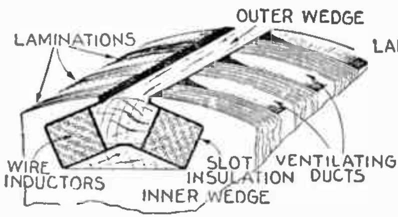
1. Self-excited; 2. Separately excited; 3. Compositely excited.

The two principal types of field magnet are the stationary, and the revolving.

In construction of stationary magnets, laminated pole pieces are used, each pole being made up of a number of steel stampings riveted together and bolted or preferably cast into the frame of the machine. The field coils are machine wound and carefully insulated. After winding they are taped to protect them from mechanical injury. Each coil is then dipped in an insulating compound and afterwards baked to render it impervious to moisture.



Figs. 7,725 and 7,726.—Single and double layer multi-wire inductors and methods of placing them on the core. Here the term layer means unit, in fact each unit is made up of several "layers" of wires.



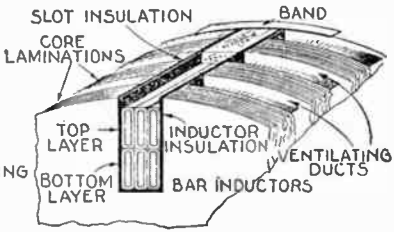
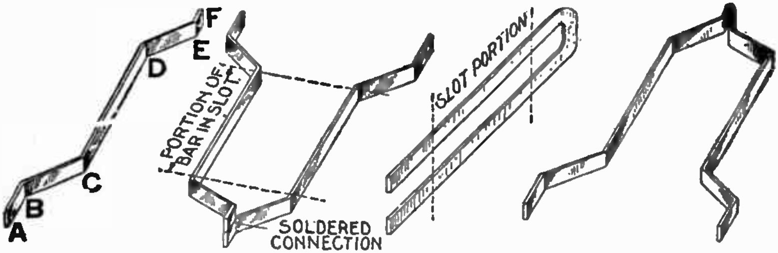


Fig. 7,727.—Two coil slot for whole coil winding. *In assembling* the winding, the inner wedge is first placed in position and then the slot lined with the insulating material. This usually consists of alternate layers of mica and pressboard. The coils composed of several turns of wire or copper strip are wound in place, and after covering with a layer of insulation, the outer wedge is pushed in place to retain the inductors in position.

Fig. 7,728.—Slot for two layer bar winding. Bar inductors, on account of the shape of their ends, must be placed in the slots from the top, because the bent ends do not admit of pushing them in. Straight slots are therefore necessary, the inductors being held in placed by wooden strips and tie bands as shown.

The entire structure or rotor of a revolving field consists of a shaft, hub or spider, laminated field magnets and slip rings. The insulated *slip rings* mounted on the shaft receive direct current for the revolving magnet, as distinguished from *collector rings* which collect the alternating current.



FIGS. 7,729 and 7,730.—Bent bar inductor and method of connection with soldered joint. Fig. 7,729 shows one bar and shape of bent ends. The portion from C, to D, is placed in the slot; B, to C, and D, to E, bent or connector sections; A, to B, and E, to F, ends bent parallel to slot for soldering. Fig. 7,730 shows two bar inductors connected.

FIGS. 7,731 and 7,732.—Method of avoiding a soldered joint at one end of a bar inductor by using a bar of twice the length shown in fig. 7,729, and bending it into a long U form, as in fig. 7,731, after which it is spread out forming two inductors, as in fig. 7,732.

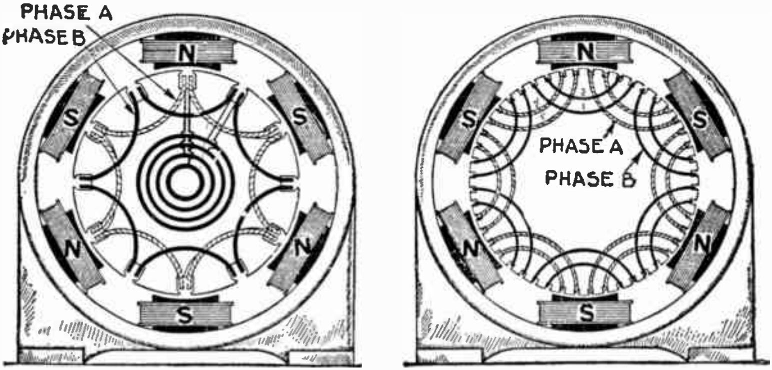


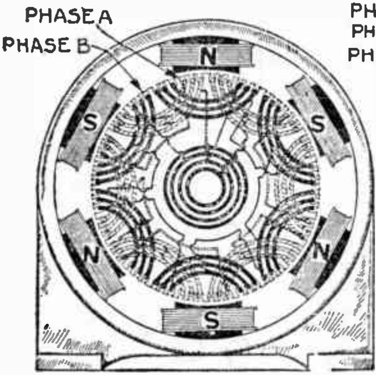
FIG. 7,733.—Two phase concentrated whole coil winding. The total number of slots is twice the number of poles, or one slot per pole per phase. It comprises two windings spaced 90 polar degrees as shown. The two circuits are independent, the windings terminating at the four collector rings.

FIG. 7,734.—Two phase winding in two slots per pole per phase. This stamping distributes the coils of each phase into two sections as A and B. The coils are of the "whole" type and with six poles the total number of slots is 4 × 6 = 24, uniformly spaced as shown.

Armatures.—In construction *these are similar to dynamo armatures.*

They are in most cases simpler than direct current armatures due to the smaller number of coils, absence of commutator with its multi-connections, etc.

Alternator armatures may be classified in several ways:



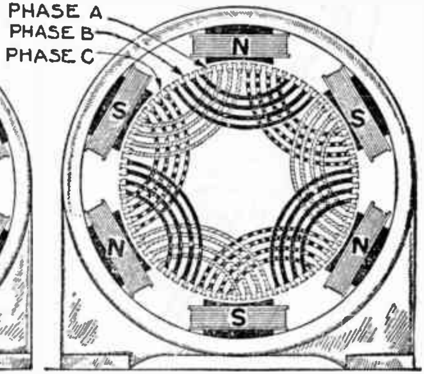


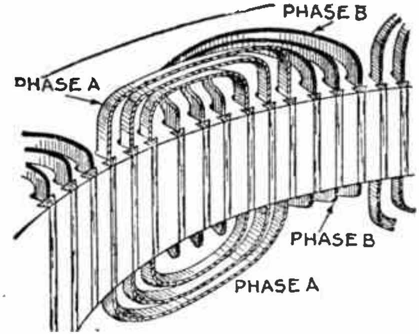
FIG. 7,735.—Two phase winding in three slots per pole per phase. The coils of each phase are of the partially distributed type, each coil being made up of three sections as shown. The direction of winding is alternately reversed.

FIG. 7,736.—Three phase winding with distributed coils—wound in four slots per pole per phase; diagram showing placement of the coils.

1. With respect to operation, as
   a. Revolving;
   b. Stationary.
2. With respect to the core, as
   a. Ring;
   b. Disc;
   c. Drum.
3. With respect to the core surface, as
   a. Smooth;
   b. Slotted.

Both types of class 1 are in general use, whereas, in classes 2 and 3, the drum, and slotted core forms are the prevailing types.

Alternator Windings.—These are usually described *in terms of the number of slots per phase per pole.*



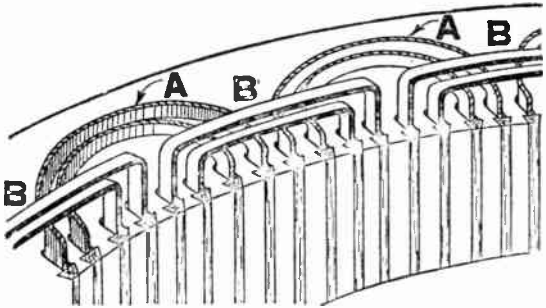
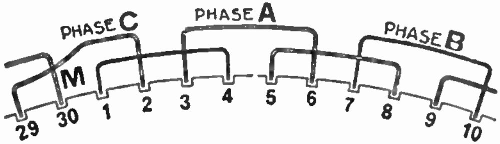


FIG. 7,737.—Section of two phase winding showing shaping of the coil ends. Every other coil is flat, while the alternates have their ends bent up as shown. With respect to the shaping of the coil ends, it is called a *two range winding*.

FIG. 7,738.—Treatment of coil ends in two phase, two range windings. In this arrangement *straight out* B and *bent up* A, coils are used which are placed on the armature as is clearly shown in the illustration.



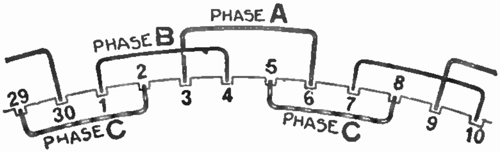
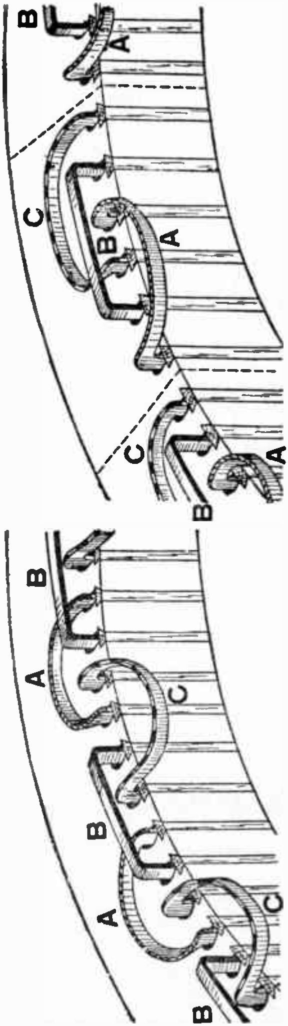


FIG. 7,739.—Three phase, 10 pole, 30 slot winding in two ranges. In this winding perfect symmetry occurs after every four poles. Accordingly in the case of an odd number of pairs of pole, one of the coils must necessarily be a skew going from the inner to the outer range as at M.

FIG. 7,740.—Three phase 10 pole 30 slot winding in three ranges. The coils of each phase are alike, those of the A phase being all in the straight out range, those in the B phase, in a bent up range, and those in the C phase in a bent down range.



FIGS. 7,741 and 7,742.—Treatment of coil ends in three phase, three range windings. Fig. 7,741, inadmissible arrangement in which the field magnet cannot be withdrawn; fig. 7,742, admissible arrangement in which the armature segments can be divided. This enables the top half of armature to be removed by disconnection without unwinding any coil.

For instance, if the armature of a 20 pole three phase machine have 300 slots, it has 15 slots per pole or 5 slots per each phase per pole, and will be described as a five slot winding. Therefore, in order to trace the connections of a winding, it is necessary to consider the number of slots per pole for any one phase on one of the following assumptions: 1, that each slot holds one inductor; 2, that there is one side of a coil in each slot; and 3, that one side of a coil is subdivided so as to permit of its distribution in two or more adjacent slots.

The voltage depends upon ***the number** of inductors in a slot.*

The breadth coefficient and wave form are influenced by the number of slots per pole, and not by the number of inductors within the slots.

Alternator windings may be classed with respect to the

1. Form of the armature, as
   a. Revolving;
   b. Stationary.

2. Mode of progression, as
   a. Lap winding;
   b. Wave winding.

3. Relation between poles and coils, as
   a. Half coil winding;
   b. Whole coil winding.

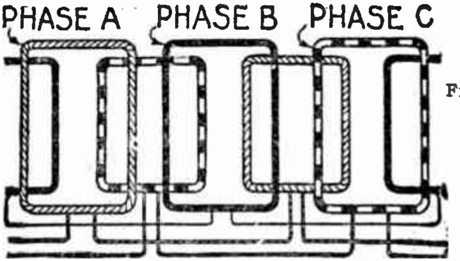


FIG. 7,743.—Three phase winding with half coils, which permit arranging of the ends in two ranges as shown. There is *one slot per phase per pole*, that is, total nmubers of slots = 3 × number of poles.

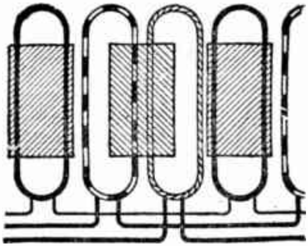
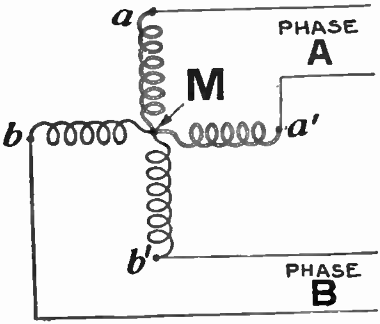


FIG. 7,744.—Three phase winding with short coils. The use of short coils as here shown, in which the coil breadth = ⅔ pole pitch, avoids the necessity of overlapping.



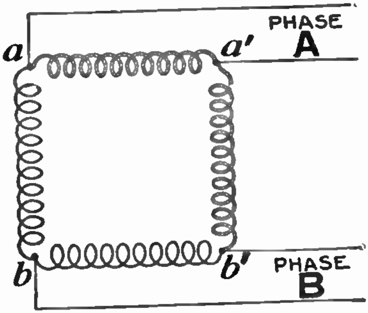


FIG. 7,745.—Two phase *star grouping* diagram. ***In connecting***, the middle point of each of the two phases are united to a common junction M, and the four ends are brought out to four terminals, *a*,*a'*,*b*,*b'*, as shown, or in revolving armatures to four slip rings. This grouping is equivalent to a four phase system.

FIG. 7,746.—Two phase *mesh grouping* diagram. ***In connecting***, the two phases are divided into two parts, and the four parts are connected up in cyclic order, the end of one to the beginning of the next, so as to form a square the four corners of which are connected to the four terminals *a*,*b*,*a'*,*b'*, as shown or in the case of revolving armatures, to four slip rings.

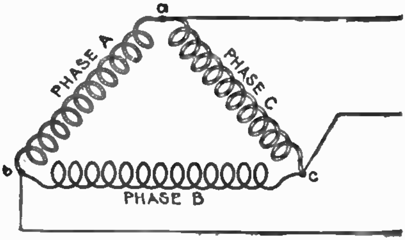


FIG. 7,747.—Three phase *mesh grouping* diagram. *In connecting,* the three circuits are joined to form a triangle and leads to terminals attached at the junctions *a,b,c,* or in revolving armatures to three slip rings.

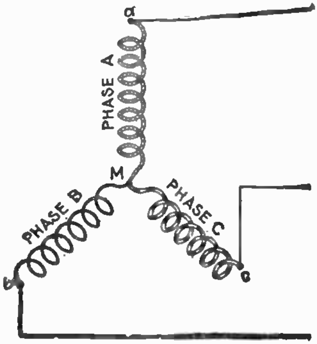
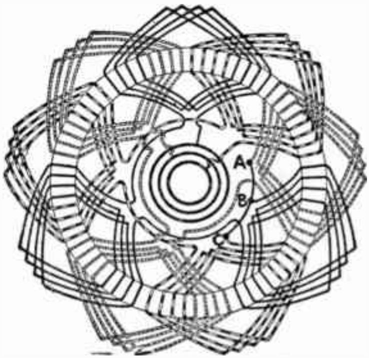


FIG. 7,748.—Three phase *star grouping* diagram. *In connecting,* one end of each of the three circuits is brought to a common junction M, usually insulated, and the three other ends are connected to three terminals—*a,b,c,* as shown, or in revolving armatures to three slip rings.



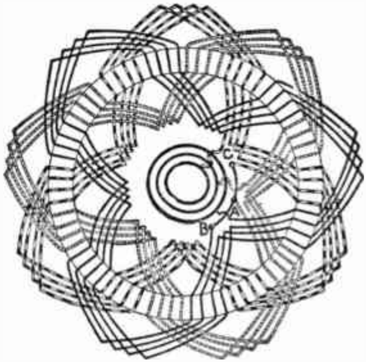
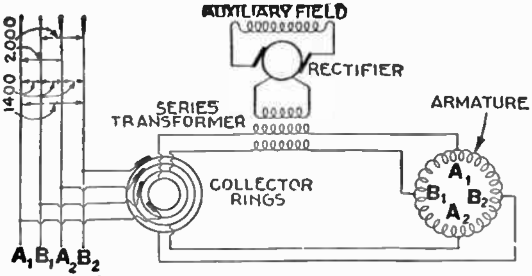


FIG. 7,749.—Radial diagram of three phase *lap winding* with *star connection.* The bar with connections at A,B,C, comprises the star point or common terminal.

FIG. 7,750.—Radial diagram of three phases *wave winding* with *star connection. To find* the proper ends (A,B,C,) to connect to the common terminal: Assume that the inductor opposite the middle of a pole is carrying the maximum current, and mark its direction by an arrow. Then the current in the inductors on either side of and adjacent to it will be in the same direction. As the maximum current must be *coming from* the common terminal, the end toward which the arrow points must be connected to one of the rings, while the other end is connected to the common terminal. The current in the two adjacent inductors evidently must be flowing into the common terminal, hence the ends toward which the arrows point must be connected to the common terminal, while their other ends are connected to the remaining two rings.



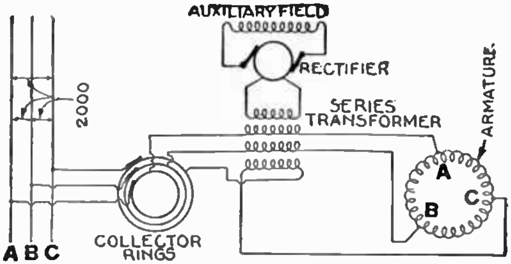
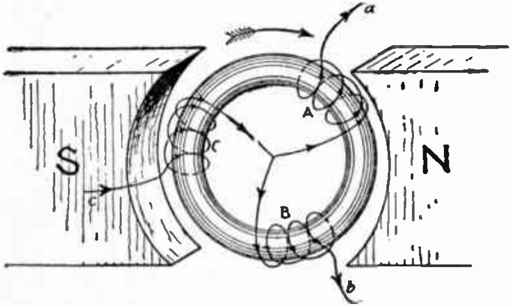
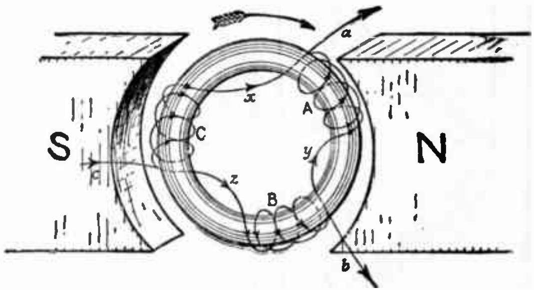


FIG. 7,751.—Diagram of Westinghouse two phase composite wound alternator, showing connections between two phase armature and a single phase rectified and composite field winding. The arrangement makes use of a series transformer, mounted on the spokes of the armature. By means of this series transformer the voltage delivered to the rectifying commutator and the fields is much less than that generated by the machine.

FIG. 7,752.—Diagram of Westinghouse three phase composite wound alternator. The armature inductors are of the closed coil or delta connected type, but are tapped at three points per pair or poles to the three collector rings. All three connections between the armature coils and the collector rings run through primary circuits of the series transformer within the armature, these three primaries each giving their own effect upon the secondary.





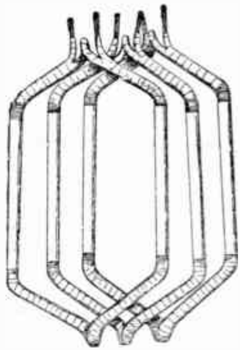
FIGS. 7,753 and 7,754.—Gramme ring amatures showing three phase star and mesh connections, respectively, with direction of currents in the coils. In the figures, the coils A.B.C, are spaced at equidistant positions on the ring core.

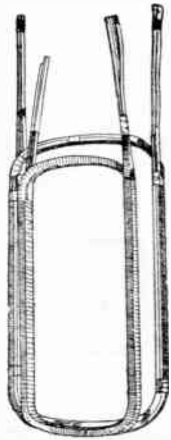
4, Number of slots, as

a. Concentrated or uni-coil winding;

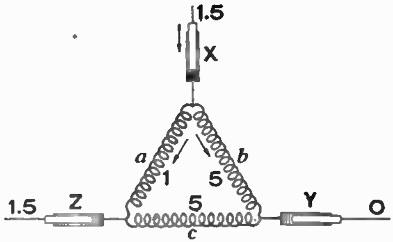
b. Distributed or multi-coil winding.

Partially distributed:
Fully distributed.





FIGS. 7,755 to 7,757.—Separate coils, and section of Allis-Chalmers alternator with coils in place.



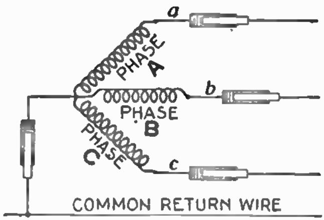


FIG. 7,758—Diagram showing determination of path and value of current flowing in delta connected armature. The total watts is equal to $\sqrt{3}$ multiplied by the product of the line current and the line voltage. The delta connection gives a lower line voltage than the star connection for the pressure generated per phase, and cuts down the current in the inductors; since the inductors, on this account, may be reduced in size, the delta connection is adapted to machines of large current output.

FIG. 7,759.—Diagram of Y connection with a common return wire. When the three lines leading from *a*,*b* and *c*, are equal in resistance and reactance, or in other words when the system is *balanced*, the currents of the three phases are equal and are 120° apart in phase (each current lagging behind its pressure by the same amount as the others) and their sum is at each instant equal to zero. In this case the resultant current being equal to zero there is no need of a common return wire. However, in some cases, where power is distributed from transformers or three wire systems, the different branches are liable to become unbalanced. Under such circumstances the common return wire is sometimes used, being made large enough to take care of the maximum unbalancing that may occur in operation. The return wire is used sometimes on alternators that furnish current mostly for lighting work.

5. Form of the inductors, as

   a. Wire winding;
   b. Strap winding;
   c. Bar winding.

6. Coils per phase per pole, as

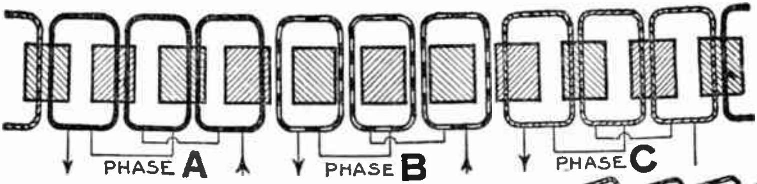
   a. One slot winding;
   b. Two slot winding; etc.

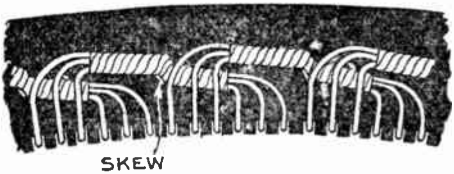
7. Kind of current delivered, as

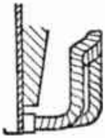
   a. Single phase winding;
   b. Two phase winding;
   c. Three phase winding.

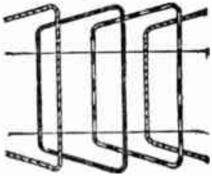
8. Shape of coil ends, as

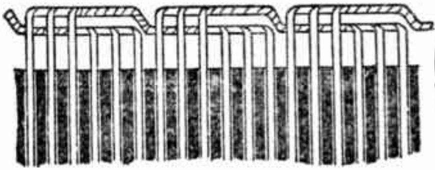
   a. Single range;
   b. Two range; etc.











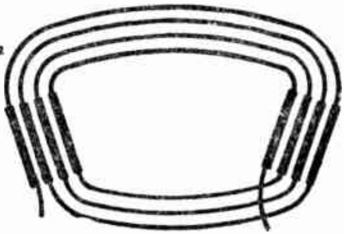


FIG. 7760.—Creeping winding of three coils subtending four poles.

FIGS. 7,761, 7,762 and 7,764.—Views of a section of skew coil winding; so called on account of the skew shape given to the coil ends in order that all the coils may be of one shape.

FIG. 7,763.—Diagram showing chain winding. In this method of winding, the coils are all similar with long and short sides. It obviates the extra cost of making coils of several different shapes. The diagram represents a winding for one slot per pole per phase.

FIG. 7,765.—Diagram showing a spiral coil. This type of coil is one in which each successive turn lies entirely within the previous turn, starting with the outermost turn of the coil. The successive turns of a spiral coil are thus not of the same size, and are not over-lapping as in a "lap" coil.

In addition to these there are a number of miscellaneous windings such as

a. Chain or basket winding;
b. Skew coil winding;
c. Fed-in winding;
d. Imbricated winding;
e. Mummified winding;
f. Spiral winding;
g. Shuttle winding;
h. Creeping winding;
i. Turbine alternator winding.

All these various windings are shown in the accompanying cuts.

Arrangement of Phases.—In polyphase alternators *the separate windings of the various phases may be grouped in two ways,* as 1, ***star or Y*** *connection, or* 2, ***mesh or delta*** *connection.*

The star connection is sometimes called a Y connection on account of its resemblance to that letter; the mesh connection is sometimes called a *delta* connection owing to its resemblance to the Greek letter Δ. In star grouping the point where the phases join is called the *star point*. In a three phase *star connected alternator* the voltage between any two collector rings is equal to *the voltage generated per phase multiplied by* $\sqrt{3}$ *or 1.732.* The total output is equal to the sum of the output of each of the three phases. When working on a non-inductive load, the total output of a star connected alternator is equal to $\sqrt{3}$ multiplied by the product of the line current and line voltage.

In a three phase *delta connected* alternator, the line current is equal to the *current in each phase multiplied by* $\sqrt{3}$; the total output with non-inductive load is equal to $\sqrt{3}$ *multiplied by the product of the line current and line voltage.* Star connection gives a higher line voltage than the delta connection for the same pressure generated per phase, hence it is suited for machines of high voltage and moderate current.

Delta connection gives a lower line voltage than the star connection for the pressure generated per phase, and cuts down the current in the inductors; since the inductors, on this account, may be reduced in size, the delta connection is adapted to machines of large current output.

CHAPTER 35

A. C. Motors

The fact that many central stations furnish only alternating current has caused manufacturers to perfect many types of *a.c.* motors to meet the needs of all classes of industrial devices. The multiplicity of types thus produced may be classed as:

1. SYNCHRONOUS MOTORS
2. ASYNCHRONOUS MOTORS

   a. **Induction motors**

   b. **Commutator motors** { *series; compensated; shunt;* **repulsion.**

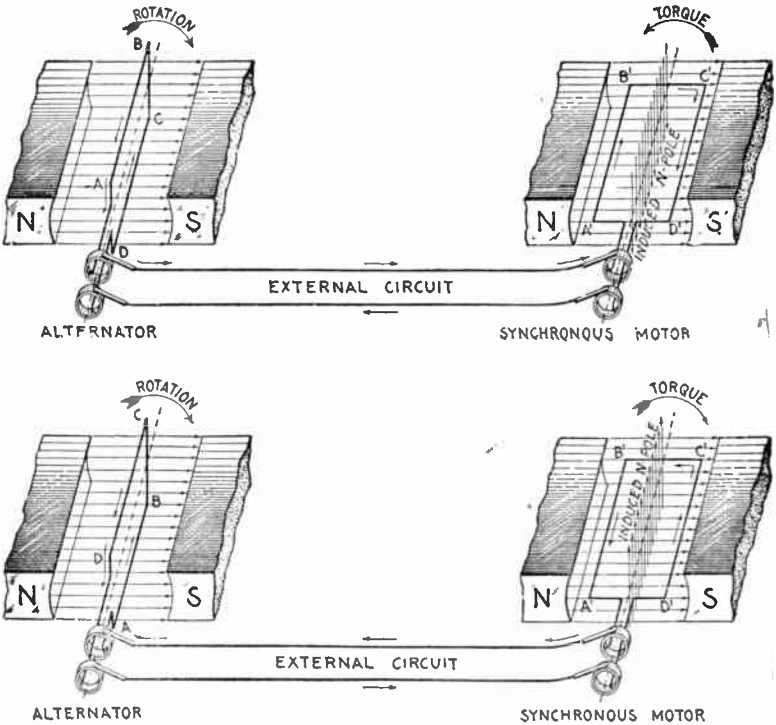
1. Synchronous Motors

The term "synchronous" means *in unison*, that is, *in step*. A so-called synchronous motor, then, as generally defined, *is one which rotates in unison or in step with the phase of the alternating current which operates it.*

Strictly speaking, however, it should be noted that this condition of operation is only approximately realized as will be later shown.

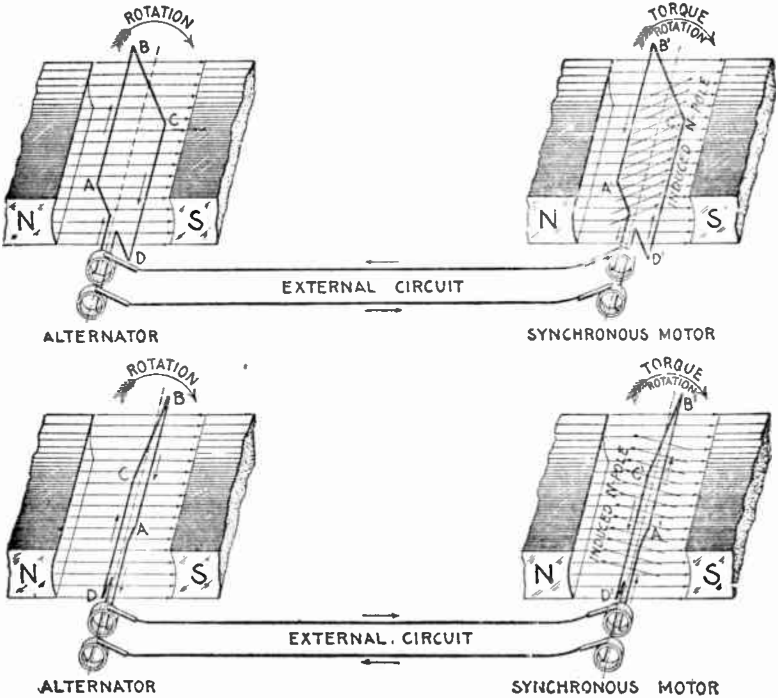
In construction, synchronous motors are almost identical with the corresponding alternator and consists essentially of, 1, *an armature*, and 2, *a field*, either of which may revolve.

The field is separately excited with direct current. In operation. when the field is thus excited and alternating current is



FIGS. 7,766 to 7,769.—Synchronous motor principles: *I. A single phase synchronous motor is not self-starting.* The figures show an elementary alternator and an elementary synchronous motor, the construction of each being identical as shown. If the alternator be started, during the first half of a revolution, beginning at the initial position ABCD, fig. 7,766, current will flow in the direction indicated by the arrows, passing through the external circuit and armature of the motor, fig. 7,767, inducing magnetic poles in the latter as shown by the vertical arrows. These poles are attracted by unlike poles of the field magnets, which tend to turn the motor armature in a counter-clockwise direction. Now, ***before the torque thus set up has time to overcome the inertia of the motor armature and cause it to rotate, the alternator armature has completed the half revolution***, and beginning the second half of the revolution, as in fig. 7,768, ***the current is reversed*** and consequently ***the induced magnetic poles in the motor armature are reversed also.*** This tends to rotate the armature in the reverse direction, as in fig. 7,769. *These reversals of current occur with such frequency that the force* ***does not act long enough in either direction to overcome the inertia of the armature; consequently it remains at rest***, or to be exact, ***it vibrates.*** Hence, a single phase synchronous motor must be started by some external force and brought up to a speed that gives the same frequency as the alternator before it will operate. A single phase synchronous motor, then, is not self-starting, which is one of its disadvantages; the reason it will operate after being speeded up to synchronism with the alternator and then connected in the circuit is explained in figs. 7,770 to 7,773.

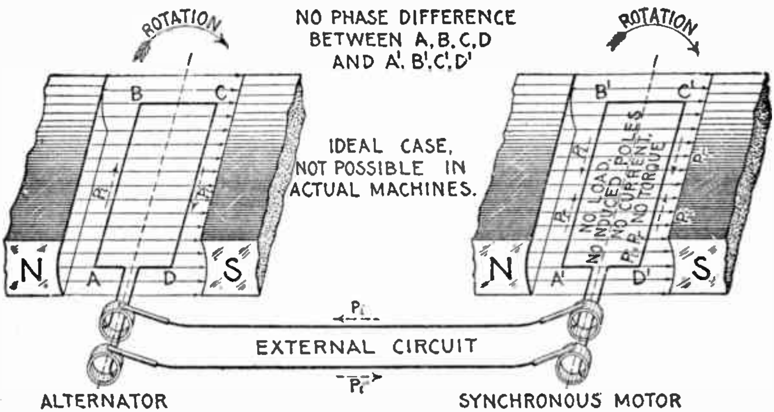
applied to the armature of a single phase motor, it will produce alternately N, and S, poles, the reaction between these *induced* poles and the *field* poles tending to rotate the armature first in one direction, then in the other.



FIGS. 7,770 to 7,773.—***Synchronous motor principles: II.*** *The condition necessary for synchronous motor operation is that the motor be speeded up until it rotates in synchronism, that is, in step with the alternator.* In figs. 7,770 and 7,771, assuming synchronism, the arrows indicate the direction of the current for the armature position shown. The current flowing through the motor armature induces magnetic poles which are attracted by the field poles, thus producing a torque in the direction in which the armature is rotating. After the alternator coil passes the vertical position, the current reverses as in fig. 7,772, and the current flows through the motor armature in the opposite direction, thus reversing the induced poles as in fig. 7,773. *This brings like poles near each other, and since the motor coil has rotated beyond the vertical position* ***the repelling action of the like poles,*** *and also* ***the attraction of unlike poles,*** *produces a torque acting in the direction in which the motor is rotating.* Hence, when the two armatures move synchronously, the torque produced by the action of the induced poles upon the field poles is always in the direction in which the motor is running, and accordingly, tends to keep it in operation.

Because of the very rapid reversals in direction of the torque thus set up, there is not sufficient time **to overcome the inertia of the armature** *before the current reverses and produces a torque in the opposite direction, hence, the armature remains stationary or, strictly speaking,* **it vibrates.**

Now if the motor armature be first brought up to a speed corresponding in frequency to that of the alternator before connecting the motor in the circuit, the armature will continue revolving at the same frequency as the alternator.

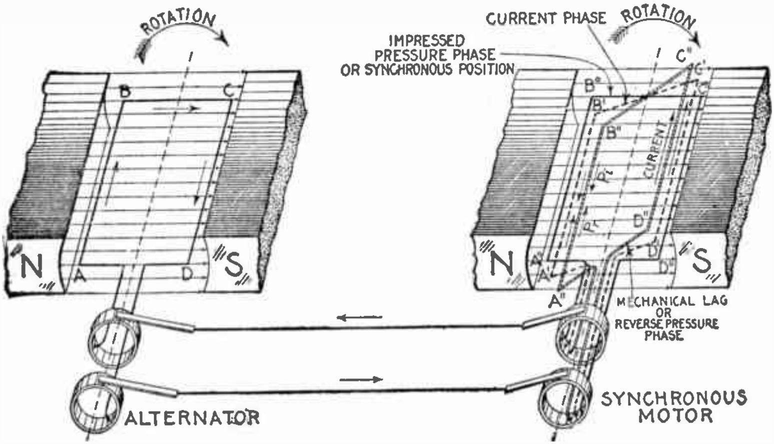


FIGS. 7,774 and 7,775.—**Synchronous motor principles: III.** *The current which flows through the armature of a synchronous motor is that due to the effective pressure.* Since the motor rotates in a magnetic field, a pressure is induced in its armature in a direction opposite to that induced in the armature of the alternator, and called the *reverse pressure*, as distinguished from the pressure generated by the alternator called the *impressed pressure. At any instant, the pressure available to cause current to flow through the two armatures, called the* ***effective pressure****, is equal to the difference between the pressure generated by the alternator or* ***impressed pressure*** *and the* ***reverse pressure*** *induced in the motor.* Now if the motor be perfectly free to turn, that is, without load or friction, the reverse pressure will equal the impressed pressure and no current will flow. This is the case of real synchronous operation, that is, not only is the frequency of motor and alternator the same, but the coils rotate without phase difference. In figs. 7,774 and 7,775, the impressed and reverse pressures are represented by the dotted arrows Pi and Pr, respectively. Since in this case these opposing pressures are equal, the resultant or effective pressure is zero; hence there is no current. *In actual machines this condition is impossible*, because even if the motors have no external load, there is always more or less friction present; hence, in operation there must be more or less current flowing through the motor armature to induce magnetic poles so as to produce sufficient torque to carry the load. The action of the motor in automatically adjusting the effective pressure to suit the load is explained in figs. 7,776 and 7,777.

The armature continues revolving, because, **at synchronous speed,** *the field flux and armature current are always in the same relative position,* producing a torque which always pulls the armature around in the same direction.

A polyphase synchronous motor is self starting, because, before the current has died out in the coils of one phase, it is increasing in those of the other phase or phases, so that there is always some turning effort exerted on the armature.

The speed of a synchronous motor is that at which it would have to

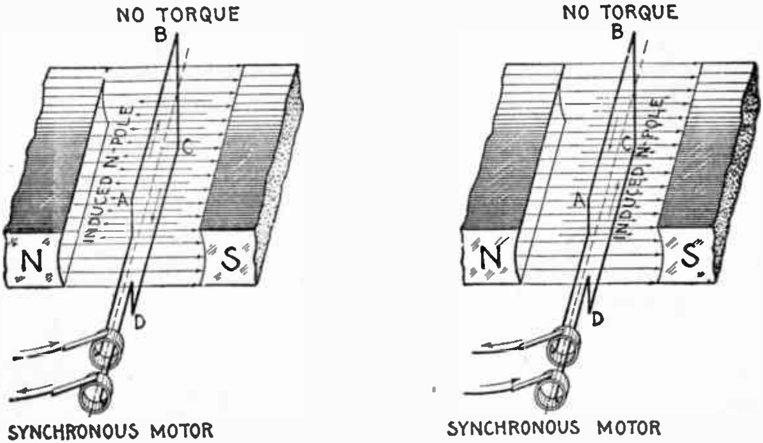


FIGS. 7,776 and 7,777.—Synchronous motor principles: *IV—A synchronous motor adjusts itself to changes of load by changing the phase difference between current and pressure.* If there be no load and no friction, the motor when speeded up and connected in the circuit, will run in true synchronism with the alternator, that is, at any instant, the coils ABCD, and A°B°C°D°, will be in parallel planes. When this condition obtains, no current will flow and no torque will be required (as explained in figs. 7,774 and 7,775). If a load be put on the motor, the effect will be to cause A°B°C°D°, to lag behind the alternator coil to some position A″B″C″D″, and current to flow. The reverse pressure will lag behind the impressed pressure equally with the coil, and the current which has now started will ordinarily take an intermediate phase so that it is *behind the impressed pressure but in advance of the reverse pressure.* These phase relations may be represented in the figure by the armature positions shown, viz.: 1, the synchronous position A°B°C°D°, representing the impressed pressure; 2, the intermediate position A′B′C′D′, the current; 3, the actual position A″B″C″D″, (corresponding to mechanical lag), the reverse pressure. From the figure it will be seen that the current phase represented by A′B′C′D′, is in advance of the reverse pressure phase represented by A″B″C″D″. Hence, by *armature reaction, the current leading the reverse pressure weakens the motor field and reduces the reverse pressure*, thus establishing equilibrium between current and load. As the load is increased, the mechanical lag of the alternator coil becomes greater and likewise the current lead with respect to the reverse pressure, which intensifies the armature reaction and allows more current to flow. In this way equilibrium is maintained for variations in load within the limits of zero and 90° mechanical lag. The effect of armature reaction on motors is just the reverse to its effect on alternators, which results in marked automatic adjustment between the machines especially when a single motor is operated from an alternator of about the same size. In other words, the current which weakens or strengthens the motor field, strengthens or weakens respectively the alternator field as the load is varied.

run, if driven as an alternator, to deliver the number of cycles which is given by the supply alternator.

Any synchronous motor if supplied with motive power can be converted without any change to an alternator or any alternator can be run as a synchronous motor if supplied with an alternating current of the same voltage and phase values.

Synchronous motors are used principally for power factor corrections, such as in a plant, where a large inductive load is used such as arc lamps, transformers, and motors, which reduces the power factors so much, that it causes trouble at the power house.

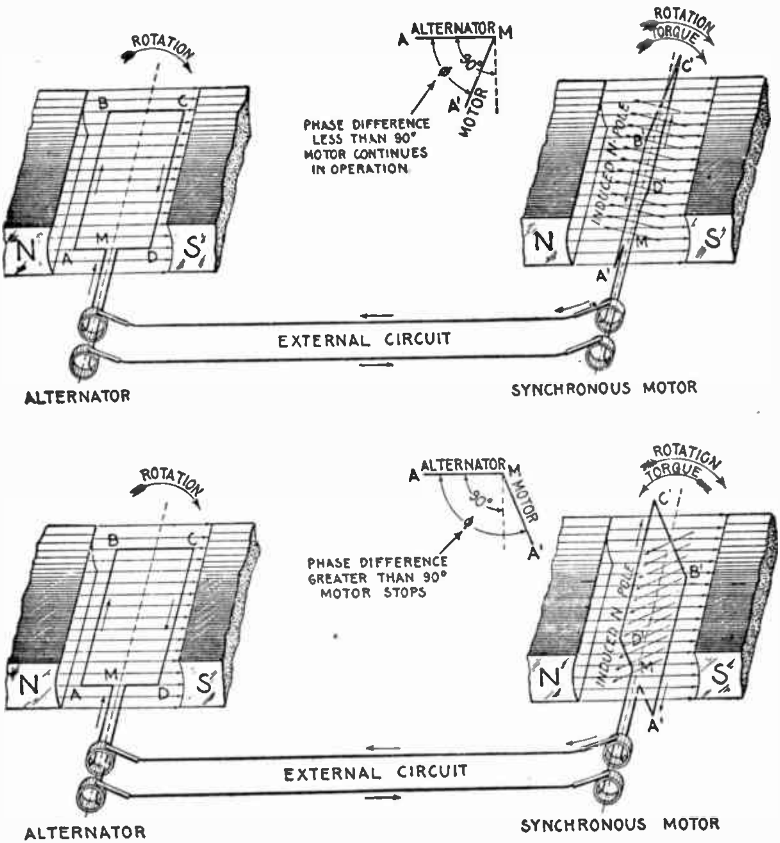


FIGS. 7,778 and 7,779.—*Synchronous motor principles: VI. A single phase synchronous motor has "dead centers," just the same as a one cylinder steam engine.* Two diagrams of the motor are here shown illustrating the effect of the current in both directions. When the plane of the coil is perpendicular to the field, the poles induced in the armature are parallel to field for either direction of the current; that is, the field lines of force and the induced lines of force acting in parallel or opposite directions, no turning effect is produced, just as in analogy when an engine is on the dead center, the piston rod (field line of force) and connecing rod (induced line of force) being in a straight line, the force exerted by the steam on the piston produces no torque.

Synchronous motors produce a leading power factor which thereby helps to increase the power factor to unity.

There are two types of synchronous motors, classed with respect to the method of starting:

1. Auxiliary motor type;
2. Self-starting type.



Figs. 7,780 to 7,785.—Synchronous motor principles. *VII. An essential condition for synchronous motor operation is that the mechanical lag be less than 90°.* Figs. 7,780 to 7,782 represent the conditions which prevail when the lag of the motor armature A'B'C'D' is anything less than 90°. As shown, the lag is almost 90°. The direction of the current and induced poles are indicated by the arrows. *The inclination of the motor coil is such that* ***the repulsion of like poles*** *produces a torque* ***in the direction of rotation***, thus tending to keep motor in operation. Now, in figs. 7,783 to 7,785, for the same position of the alternator coil ABCD, *if the lag be greater than 90°, the inclination of the motor coil A'B'C'D' is such that at this instant* ***the repulsion of like poles*** *produces a torque in a direction* ***opposite to that of the rotation, thus tending to stop the motor***. In actual operation this quickly brings the motor to rest, having the same effect as a strong brake in overcoming the momentum of a revolving wheel.

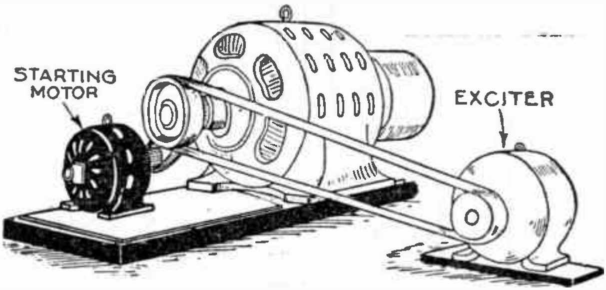
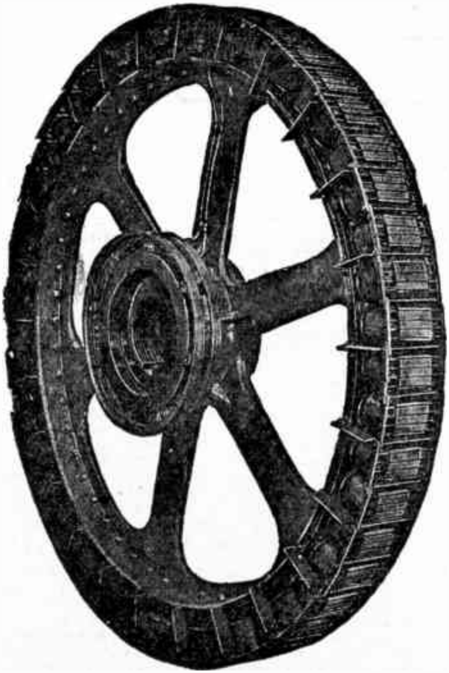


FIG. 7,786.—*Auxiliary starting* type synchronous motor, showing exciter and starting induction motor.



The usual type of synchronous motor is started by means of an auxiliary induction motor, whose shaft is connected to the synchronous motor shaft by means of a silent chain. The teeth on gears of starting motor shaft and of synchronous motor shaft are so selected that when the auxiliary motor has attained full speed the synchronous motor runs slightly above synchronous speed. The starting motor switch is then opened and the synchronous motor is allowed to coast down to synchronous speed, which is indicated by lamps or synchroscope.

The synchronous motor line switch is then closed at the proper instant. The size of the auxiliary starting induction motor depends upon the friction

FIG. 7,787.—Rotor field of General Electric 360 horse power *self-starting* type synchronous motor, showing the amortisseur or squirrel cage starting winding in the pole faces. The synchronous motor can use a high resistance squirrel cage winding because when operating in synchronism, there is practically no loss in the winding.

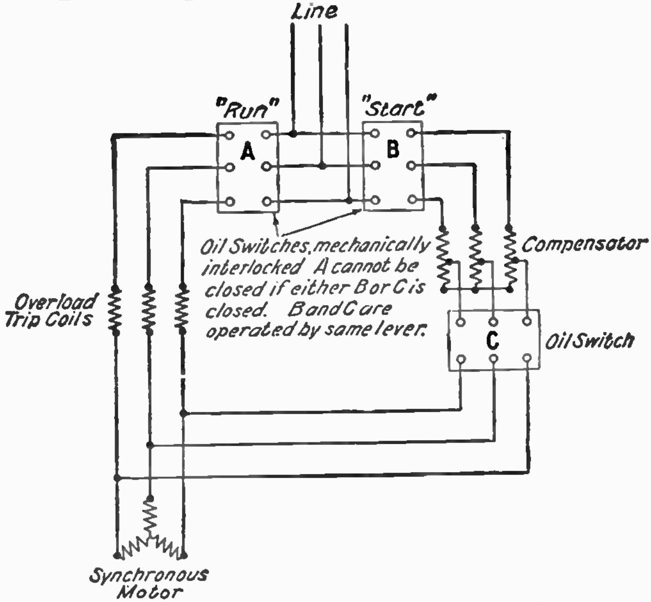


FIG. 7,788.—Starting connections for self-starting synchronous motor. ***In starting:*** 1, Open field switch completely if the excitation voltage be 125 volts; If the excitation voltage of the motor be higher than 125 volts, the field switch should not be opened completely but left in the clips connected to the discharge resistance. This prevents any high induced voltage across the collector rings. ***Exception:*** If the motor be part of a motor generator set (other than a frequency converter set) the field switch should be left in the clips connected to the discharge resistance irrespective of the degree of field excitation. Note that frequency degree converter sets should be started in accordance with the general rule given above; 2, Throw compensator lever to "start" position. (If oil switches be used, close the switch marked "start.") 3. After the motor has reached constant speed close the field switch; the field rheostat having been previously adjusted to give a field current corresponding approximately to no load, normal voltage, with machine running as a generator. 4. Throw compensator lever quickly to the "run" position. (If oil switches be used, open the switch marked "start," and after this, as quickly as possible, close the switch marked "run.") ***Cautions:*** 1. Do not touch collector rings or brushes when the motor is being started. An induced pressure of about 2,000 volts exists across the rings at the moment of starting. This voltage decreases as the motor speeds up, reaching zero at full speed. 2. The motor should be started on the lowest tap of the compensator that will start it promptly and bring it to full speed in about one minute. If two or three minutes are consumed in coming to full speed, there is danger of burning the squirrel cage winding. *Special cases.* There are a few instances where requirements of torque and line current, or perhaps a demand for a high excitation voltage (which involves a high induced voltage at starting) make it necessary to modify the procedure in starting. ***Closing running switch before synchronizing.*** There are rare cases where severe requirements of "pull-in" torque make it necessary to close the running switch, throwing on full line pressure before the field switch is closed. That is operation 3 above should follow 4. ***Closing field current through resistance.*** There are two occasions for closing the field circuit through a resistance as part of the starting procedure. In one case the object is to increase the torque near full speed; in the other, to prevent high induced pressure across the collector rings at starting. With the proper value of resistance across the collector rings the torque near full speed is increased. A change frictional load of the synchronous motor and the synchronous motor load. In some instances this may require an excessively large auxiliary motor, which makes its cost prohibitive.

This type of synchronous motor may be used successfully where reliable attendance is at hand, quickness of start is not important, and sufficient floor space is available.

The self-starting type is provided with a squirrel cage winding on the rotor which serves as an induction motor secondary winding during starting.

The motor is started by means of applying a reduced voltage directly to the armature winding by means of an auto transformer with taps brought out for different starting voltages.

The voltage is applied to the motor by means of an auto starter switch which acts as a combined starting and line switch.

On account of the fact that during the starting a dangerous voltage would be induced in the field winding if the field circuit were left open, it is necessary to short circuit the field. In cases where individual exciters are used, the motor field is left connected across the exciter armature while starting.

When the motor is excited from an exciting bus, a double throw field switch is provided for short circuiting the field while starting. The field rheostat is included in the circuit with the field winding, during starting, and to limit the current which would otherwise decease the starting torque.

A synchronous motor is desirable for large powers where starting under

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FIG. 7,788.—*Continued*

from this resistance in either direction will decrease the torque. At starting, however, any value of resistance will decrease the torque which the motor would develop with collector rings open. Hence, when a motor at the time it is purchased is required to pull into synchronism a large percentage of normal load, or when conditions arise in service where the "pull-in" torque requirements prove to be greater than were anticipated, the above scheme is sometimes resorted to. An accurate and convenient way of determining the proper resistance is to bring the motor to constant speed at full line voltage with the load it has to pull into synchronism; then by means of a water box connected across the collector rings, determine the resistance which will increase the speed to the highest value. This will be the proper resistance. The field discharge resistance in such case is increased to the proper value and capacity for this added service. Here, the switching procedure is only slightly modified. When the motor is running on the last tap, or on the line, as the case may be.—that is, when in the standard case, the next operation would be to close the field switch—close the field switch on the first point thereby throwing the resistance across the field. A moment later say 5 or 10 seconds, close the field switch entirely. On a given machine, the higher the excitation voltage for which the field winding is designed, the higher the induced voltage across the collector rings at starting. Motors which are designed for normal excitation voltages higher than 125 volts, or those which form part of motor generator sets other than frequency converter sets, should have the field winding short circuited through the discharge resistance at starting. This will prevent the high induced voltage across the collector rings. It is standard practice to make all discharge resistances for synchronous motors of ample capacity for this service.

load is not necessary. Its power factor may be controlled by varying the field strength. The power factor can be made unity and further, the current can be made to lead the pressure.

A synchronous motor is frequently connected in a circuit solely to improve the power factor. In such cases it is often called a "condenser motor" for the reason that its action is similar to that of a condenser.

The stationary armature type is adapted to high voltages because of the absence of slip rings in the armature circuit.

The disadvantages of a synchronous motor are that it requires an auxiliary power for starting, and will stop if, for any reason, the synchronism be destroyed; collector rings and brushes are required. For some purposes

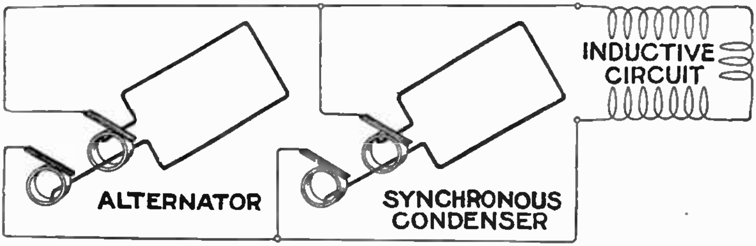


FIG. 7,789.—Diagram illustrating the use of a synchronous motor as a condenser. If a synchronous motor be sufficiently excited the current will lead. Hence, if it be connected across an inductive circuit as in the figure and the field be over excited it will compensate for the lagging current in the main, thus increasing the power factor. If the motor be sufficiently over excited the power factor may be made unity, the minimum current being thus obtained that will suffice to transmit the power in the main circuit. A synchronous motor used in this way is called a *rotary condenser* or *synchronous compensator*. This is especially useful on long lines containing transformers and induction motors.

synchronous motors are not desirable, as for driving shafts in small workshops having no other power available for starting, and in cases where frequent starting, or a strong torque at starting is necessary. A synchronous motor has a tendency to *hunt* and requires intelligent attention; also an exciting current which must be supplied from an external source.

Hunting of Synchronous Motors.—Since a synchronous motor runs practically in step with the alternator supplying it with current when they both have the same number of poles, or some multiple of the ratio of the number of poles on each machine, it will take an increasing current from the line as its speed drops behind the alternator, but will supply current to the line as a generator if for any reason the speed of the alternator should drop behind that of the motor, or the current wave lag behind, which produces the same effect, and due to additional self-induction or inductance produced by starting up or overloading some other motor or rotary converter in the circuit.

When the motor is first taking current, then giving current back to the line, and this action is continued periodically, the motor is said to be *hunting*.

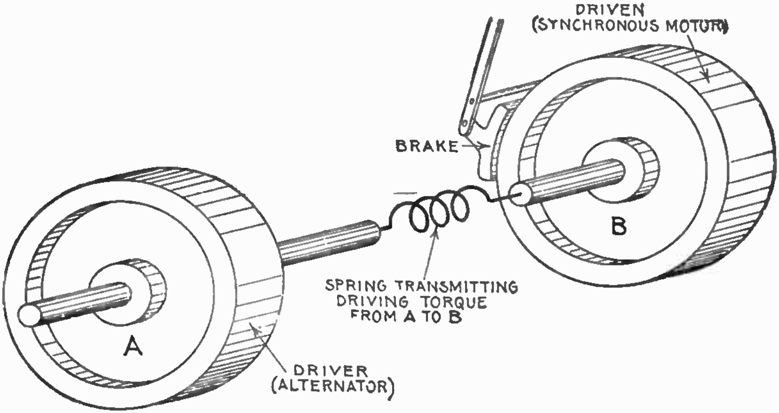


FIG. 7,790.—Mechanical analogy illustrating "hunting." The figure represents two fly wheels connected by a spring susceptible to tortion in either direction of rotation. If the wheels A, and B, be rotating at the same speed and a brake be applied, say to B, its speed will diminish and the spring will coil up, and if fairly flexible, more than the necessary amount to balance the load imposed by the brake; because when the position of proper torque is reached, B, is still rotating slightly slower than A, and an additional torque is required to overcome the inertia of B, and bring its speed up to synchronism with A. Now before the spring stops coiling up the wheels must be rotating at the same speed. When this occurs the spring has reached a position of too great torque, and therefore exerting more turning force on B, than is necessary to drive it against the brake. Accordingly B, is accelerated and the spring uncoils. The velocity of B, thus oscillates above and below that of A, when a load is put on and taken off. Owing to friction, the oscillations gradually die out and the second wheel takes up a steady speed. A, similar action takes place in a synchronous motor when the load is varied.

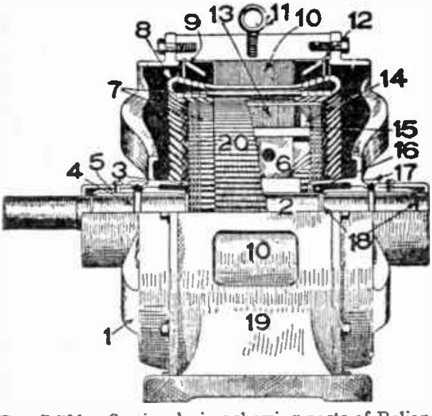
The *term surging* is used to describe the current fluctuations produced by hunting. The accompanying series of illustrations of synchronous motor principles, show in a very simple way how a synchronous motor works.

2. Asynchronous Motors

a. Induction Motors

*An induction motor consists essentially of an armature and a field magnet, there being, in the simplest and most usual types, no electrical connection between these two parts.**

There are two general types of induction motor:



1. Single phase;

2. Polyphase.

The operation of an induction motor depends on the production of a magnetic field by passing an alternating current through field magnets.

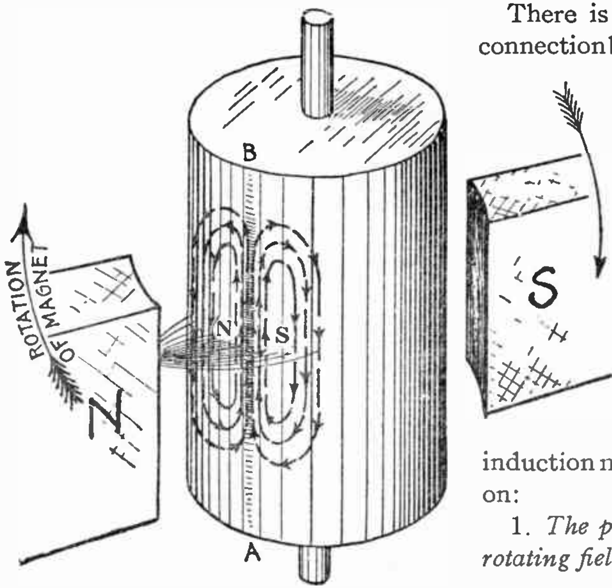
FIG. 7,791.—Sectional view showing parts of Reliance polyphase induction motor. A special feature of the squirrel cage armature construction is the multiplicity of short circuiting rings. The holes in the rings are bored slightly smaller than the diameter of the copper rods, and the force fit gives good contact. The rings having been forced in place are dip soldered in an alloy of tin of high melting point. The motor parts are: 1, end yoke; 2, shaft; 3, armature short circuiting rings; 4, oil ring; 5, self-aligning bearing bushing; 6, spider; 7, armature bars; 8, field coils; 9, field lamination end plate; 10, field laminations; 11, eye bolt; 12, stator locking key; 13, armature laminations; 14, armature lamination end plate; 15, armature locking key; 16 dust cap; 17 oil well cover; 18 oil throws; 19, field frame; 20, squirrel cage armature.

*NOTE.—The autnor prefers the terms armature and field magnet, instead of "primary," "secondary," "stator," "rotor," etc., as used by other writers, the armature being the part in which currents are induced and the field magnet (or magnets) that part furnishing the field in which the induction takes place.

The character of this field is either **oscillating** *or* **rotating**, *according, as single or* **polyphase** *current is respectively used.*

Since a single phase motor must start with a rotating field and come up to speed before the oscillating field can be employed, a knowledge then of the production of a rotating field is necessary to understand the action of the single phase motor at starting, hence the polyphase motor will be explained first.

Polyphase Induction Motor.—The construction of an induction motor is very simple. It consists of only two parts, *an armature and field magnets.*



There is no electrical connection between these parts, hence such motors are adapted for use in places where special precautions against fire are necessary. The operation of a polyphase induction motor depends on:

1. *The production of a rotating field;*

FIG. 7,792.—Elementary induction motor consisting of a copper cylinder and rotating magnet *illustrating the principle of operation of an induction motor* as explained in the accompanying text. ***In operation,*** the speed of the copper cylinder armature depends upon the load; it must always turn *slower* than the magnet, in order that its elements may cut magnetic lines and induce poles to produce the necessary torque to balance the load. The difference in speed of the magnet and cylinder is called the *slip*. Evidently the greater the load, the greater is the slip required to induce poles of sufficient strength to maintain equilibrium. The figure is drawn somewhat distorted, so that both eddies are visible.

2. *Induction of current in the armature;*

3. *Reaction between the revolving field and the induced currents.*

In practice the *rotating field* is produced without any movement of the mechanical parts of the electro-magnets, but for simplicity in explaining the principle of operation, the rotating magnetic field may be supposed to be produced by a pair of magnetic poles placed at opposite sides of the armature and revolved around it as in fig. 7,792, which shows an elementary induction motor.

The armature here consists of a copper cylinder.

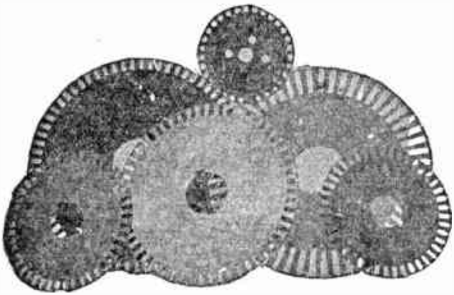


FIG. 7,793.—Mechanical Appliance Co. solid core discs as used on small and medium size induction motors.

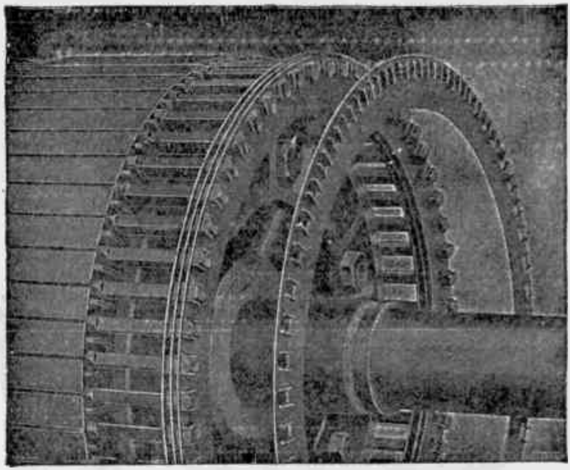
Now, for instance in starting, the cylinder being at rest any element or section of the surface as the shaded area AB, will, as it comes into the magnetic field of the rotating magnet, cut magnetic lines of force inducing a current therein, whose direction is easily determined by applying Fleming's rule.

Since the field is not uniform, but gradually weakens, as shown, on either side of the shaded area (which is just passing the center), the pressure induced on either side will be less than that induced in the shaded area AB, giving rise to eddy currents as shown. These eddy currents induce poles as indicated at the centers of the whorls, the polarity being determined by applying the right hand rule for polarity of solenoids, as given on page 49.

By inspection of fig. 7,792, it is seen that *the induced pole toward which the magnet is moving is of the same polarity as the magnet; therefore it is* **repelled,** *while the induced pole from which the magnet is receding, being of opposite polarity, is* **attracted.** *A torque is thus produced tending to rotate the cylinder.*

It must be evident that this torque is greatest when the cylinder is at rest, because the magnetic lines are cut by any element on the cylindrical surface at the maximum rate.

Moreover, as the cylinder is set in motion and brought up to speed, the torque is gradually reduced, because the rate with which the magnetic lines are cut is gradually reduced.



The essential condition of operation of an induction motor is that the armature, or part in which currents are induced, ***must*** *rotate at a speed slower than that of the rotating magnetic field.*

FIG. 7,794.—General Electric soldered form of end ring construction on squirrel cage armatures. The armature inductors or copper bars laid in the core slots are short circuited by these end rings, which are also made of copper. For the smaller sizes, the rings are thin, but of considerable radial depth and are held apart by spacing washers. They have rectangular holes punched near their outer peripheries through which the bars pass. Lips are formed on the rings, as shown to which the bars are soldered.

This difference of speed is called the *slip*, which is necessary in order to produce a torque that will balance the load.

The copper cylinder armature shown in fig. 7,792 would not be desirable in practice because there is no definite path provided for the induced currents.

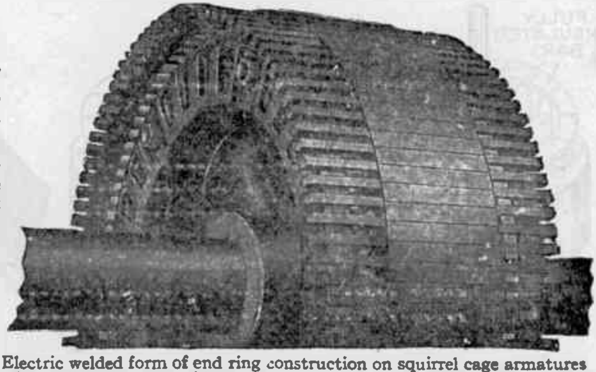
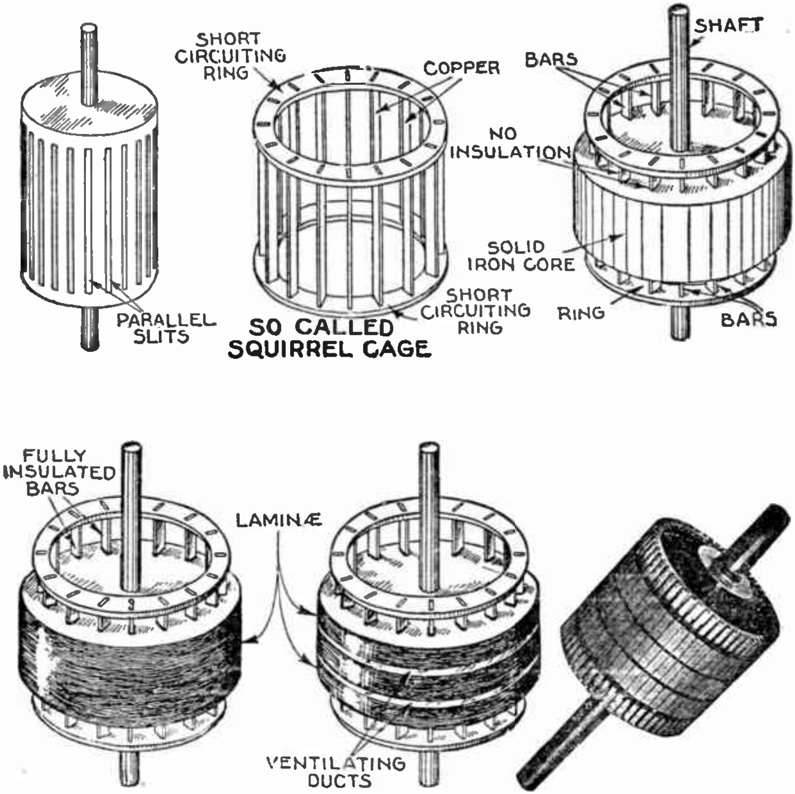
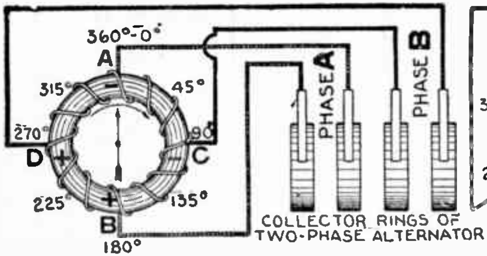


FIG. 7,795.—General Electric welded form of end ring construction on squirrel cage armatures Space limitations make it difficult to provide parallel soldered rings of sufficient area for large motors; hence, on such machines welding is resorted to, as shown. The ring in welded construction is placed beneath the bars at each end of the armature. Short radial bars are welded to the edges of these rings and to the inductors or squirrel cage bars, thereby making good electrical contact.

Obviously, a better result is obtained if the downward returning currents of the eddies are led into some path where they will return across a field of opposite polarity from that across which they ascended, as in such case, the turning effect will be doubled. Such modification was made by cutting a number of parallel slits in the copper cylinder, leaving at each end an uninterrupted *ring* of metal as in fig. 7,797. Later a built up construction (fig. 7,797) was embedded in a solid mass of iron as in fig. 7,798.



FIGS. 7,796 to 7,801.—Development of the squirrel cage armature. Fig. 7,796, slotted copper cylinder; fig. 7,797, so called squirrel cage; fig. 7,798, squirrel cage embedded in solid iron core; fig. 7,799, squirrel cage with insulated bars, laminated core; fig. 7,800. squirrel cage with insulated bars, laminated core with ventilating ducts; fig. 7,801, modern squirrel cage armature.



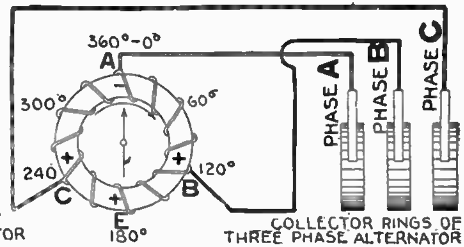


FIG. 7,802.—Production of a rotary magnetic field by two phase current. If only one current *a*, entered the ring at A, and the direction of the winding be suitable, a negative pole (—) will be produced at A, and a positive pole (+) at B, so that a magnetic needle pivoted in the center of the ring would tend to point vertically upward toward A. Now suppose that at this instant, corresponding to the beginning of an alternating current cycle, a second current *b*, differing in phase from the first by 90 degrees, be allowed to enter the ring at C. As shown, when the pressure of the current *a*, is at its maximum, that of the current *b*, is at its minimum; therefore, even a two phase current, at the beginning of the cycle, the needle will point toward A. As the cycle continues, however, the strength of *a*, will diminish and that of *b*, increase, thus shifting the induced pole toward C, until *b*, attains its maximum and *a*, falls to its minimum at 90° or the end of the first quarter of the cycle, when the needle will point toward C. At 90°, the phase *a*, current reverses in direction and produces a negative pole at B, and as its strength increases from 90° to the 180° point of the cycle, and that of phase *b* diminishes, the resultant negative pole is shifted past C, toward B, until *a*, attains its maximum and *b*, falls to its minimum at 180°, and the needle points in the direction of B. At the 180° point of the cycle, *b*, reverses in direction and produces a negative pole at D, and as the fluctuation of the pressure of the two currents during the second half of the cycle, from 180° to 360°, bear the same relation to each other as during the first half, the resultant poles of the rotating magnetic field thus produced carry the needle around in continuous rotation so long as the two phase current traverses the windings of the ring.

FIG. 7,803.—Production of a rotary magnetic field by three phase current. At the instant when the current *a*, flowing in at A, is at its maximum, two currents *b* and *c*, each one-half the value of *a*, will flow out B and C, thus producing a negative pole at A, and a positive pole at B, and at C. The resultant of the latter will be a positive pole at E, and consequently, the magnetic needle will point towards A. As the cycle advances, however, the mutual relations of the fluctuations of the pressures of the three currents, and the time of their reversals of direction will be such, that when a maximum current is flowing at any one of the points A, B, and C, two currents each of one-half the value of the entering current will flow out of the other two points, and when two currents are entering at any two points, a current of maximum value will flow out of the other point. This action will produce one complete rotation of the magnetic field during each cycle of the current.

A solid cylinder of iron will of course serve as an armature, as it is magnetically excellent; but the high specific resistance of iron prevents the flow of induced currents taking place sufficiently copiously; hence a solid cylinder of iron is improved by surrounding it with a mantle of copper, or by a squirrel cage of copper bars (like fig. 7,801), or by embedding rods of copper (short circuited together at their ends with rings) in holes just beneath its surface. However, since all eddy currents that circle round, as those sketched in fig. 7,792, are not so efficient in their mechanical effect as currents confined to proper paths, and as they consume power and spend it in heating effects, the core was then constructed with laminations lightly insulated from each other, and further the squirrel cage copper bar inductors were fully insulated from contact with the core Tunnel slots were later replaced by designs with open tops.

Slip.—This is a vital factor in the operation of an induction motor since *there must be slip in order that the armature inductors shall cut magnetic lines* to **induce** (hence the name ***"induction"*** motor) currents therein so as to create a driving torque.

The slip usually varies from about 2 to 5% of synchronous speed depending upon the size, that is, the armature turns from about 2 to 5% *slower* than the rotating magnetic field. There is ordinarily very little slip because due to the very low resistance of the armature, very little pressure is required to produce current therein of sufficient strength to give the required torque.

The revolutions of the rotating field per minute or synchronous speed is determined by the following formula:

$$\text{synchronous speed} = \frac{2 \times \text{frequency}}{\text{number of poles}} \times 60$$

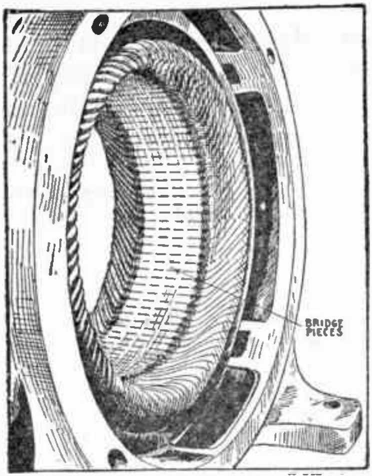
The following table gives the synchronous speed for various frequencies and different numbers of poles:

Frequency	R.P.M. of the rotating magnetic field, when number of poles is						Frequency	R.P.M. of the rotating magnetic field, when number of poles is					
	2	6	10	16	20	24		2	6	10	16	20	24
25	1,500	500	300	188	150	125	100	6,000	2,000	1,200	750	600	500
60	3,600	1,200	720	450	360	300	120	7,200	2,400	1,440	900	720	600
80	4,800	1,600	960	600	480	400	125	7,500	2,500	1,500	938	750	625

Rotating Magnetic Field.—It should be understood that the term *rotating field* does not signify that the magnets revolve (as in fig. 7,792), the expression merely refers to the magnetic lines of force set up by the field magnets without regard to whether the latter be the stationary or rotating member.

A rotating field then may be defined as *the resultant magnetic field produced by a system of coils symmetrically placed and supplied with polyphase currents.*

A rotating magnetic field may be produced either by



1. Two phase currents as in fig. 7,802, or by
2. Three phase currents as in fig. 7,803.

The Field Magnets.—The construction of the field magnets, which, when energized with alternating current produce the rotating magnetic field, is in many respects identical with the armature construction of revolving field alternators.

FIG. 7,804.—Field construction of Crocker Wheeler induction motor with *magnetic bridge.* Steel bridges are inserted in the grooves where the coils are placed, to protect them from dirt and mechanical injury, and at the same time to provide a path for the magnetic flux which has a nearer uniform reluctance, thereby insuring a better distribution of the flux in the air gap and at the same time retaining open slot construction from which the coils can be readily removed.

The field magnets consist essentially of: 1, yoke or frame; 2, laminæ, or core stampings; 3, winding. The yoke and laminæ are in every way similar to the armature frame and core construction of revolving field alternators.

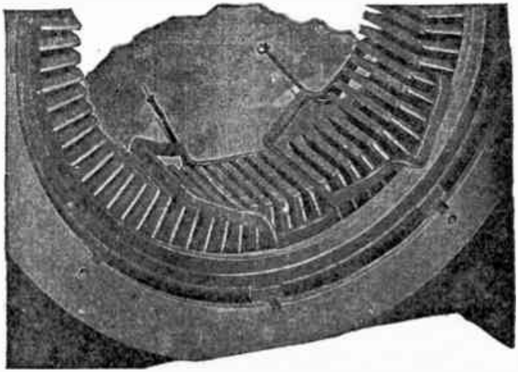
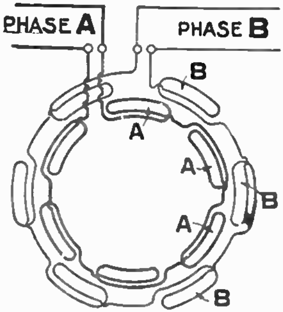


FIG. 7,805.—Western Electric core construction and method of winding field of skeleton frame induction motor. The coils are wound on forms to give them exact shape and dimensions required. They are pressed into hot moulds to remove any irregularities and then the coils are impregnated with hot cement, to bind the layers together in their permanent shape. The portion of the coil which fits into the slot is wrapped with varnished cloth and a layer of dry tape is wound over the entire coil The coils are then impregnated with an insulating compound and baked, the process being repeated six times Coils for 1,100 and 2,200 volt motors have an extra covering of insulation and double the amount of impregnating and baking.

Field Windings for Induction Motors.—The field windings of induction motors are almost always made to produce more than two poles in order that the speed may not be unreasonably high. This will be seen from the following:

If P, be the number of *pairs* of poles per phase, f, the frequency, and N, the number of revolutions of the rotating field per minute, then

$$N=\frac{60\times f}{P}$$



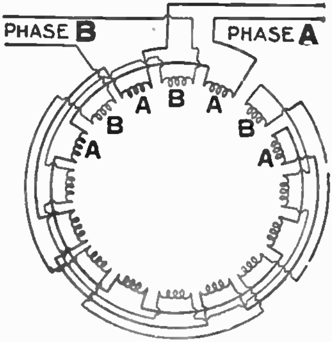


FIG. 7,806.—Diagram of two phase, six pole field winding. There are six coils in each phase as shown. The coils of each phase are connected in series, adjacent coils being joined in opposite senses, thus, for each phase, first one coil is wound clockwise, and the next counter clockwise.

FIG. 7,807 —Diagram of two phase, eight pole field winding. The winding is divided into 16 groups (equal to the product of the number of poles multiplied by the number of phases). Each group such as at A, comprises a number of coils in series, each coil being located in a separate pair of slots, the end of one being connected to the beginning of the next. When the currents are in the same direction, the currents circulate in the same direction in two adjacent groups, a pole then with this arrangement being formed by two groups, both phases contributing to the formation of the pole. After ½ cycle when the current in each phase reverses, the pole advances the angular distance, covered by two groups; hence the field completes one revolution in eight alternations of current.

Thus for a frequency of 100 and one pair of poles, N = 60 × 100 ÷ 1 = 6,000. By increasing the number of pairs of poles to 10, the frequency remaining the same, N = 60 × 100 ÷ 10 = 600. Hence, in design, by increasing the number of pairs of poles the speed of the motor is reduced.

An objection to very high speed of the rotating field is the increased difficulty of starting. Hence, in practice there are a multiplicity of field poles, and in some cases low frequency current is used to reduce the speed of the rotating field. Where the current is used both for power and lighting, low frequency is objectionable because of the resulting "flicker" in the lamps which is perceptible.

In general the field core slots contain a distributed winding of substantially the same character as the armature winding of a revolving field polyphase alternator.

The poles are formed *by properly connecting the groups of coils* and not by windings concentrated at certain points on salient or separately projecting masses of iron, as in direct current machines.

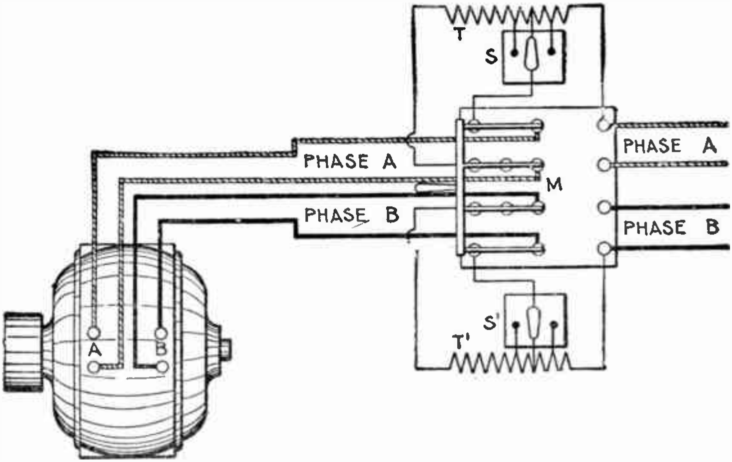


FIG. 7,808.—Westinghouse auto-transformer or compensator. ***It consists of*** two auto tranformers T and T', each having only a single winding for both primary and secondary which are tapped at certain points by switches, thus dividing the winding into a number of loops, so that one of several voltages may be applied for starting, and the starting torque thus adjusted to the work that has to be performed. At the highest points tapped by the switches S and S', the full pressure, and at the lowest points, the lowest pressure, is applied to the motor by the operation of the main switch M. This switch has four blades and three positions. When thrown to the left as indicated, it connects the auto-transformers T and T', across the circuits A and B, respectively, so that the pressure across the transformer coils, as determined by the position of the switches S and S', is applied to the motor circuits A and B. The intermediate position of the switch M, interrupts both circuits. ***To start the motor,*** switch M, is thrown to the left and a reduced pressure applied; after the motor has started and come up to speed the switch M, is thrown to the right, thus cutting out the transformer and connecting the motor directly to the circuit.

In grouping the coils, three phase windings are usually Y connected. In some cases Y grouping is used for starting and Δ grouping for running.

Starting of Induction Motors.—Because of the very low resistance of the armature, the machine, unless of very small size, would probably be destroyed by the heat generated before it could come up to speed. Accordingly some form of starting device is necessary. There are several methods of starting, as with:

1. Resistances in the field;
2. Auto-transformer or compensator·
3. Resistance in armature.

In the first method variable resistances are inserted in the circuits leading to the field magnets and mechanically arranged so that the resist-

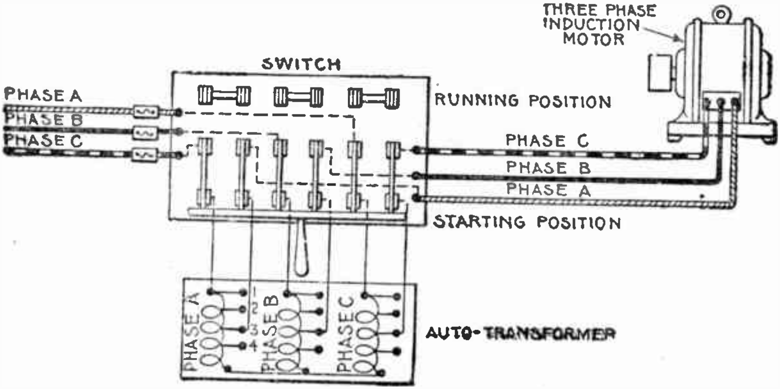


FIG. 7,809.—Auto-transformer or compensator connections for three phase induction motor. ***In operation,*** when the double throw switch is thrown over to starting position, the current for each phase of the motor flows through an auto-transformer, which consists of a choking coil for each phase, arranged so that the current may be made to pass through any portion of it (as 1,2,3) to reduce the voltage to the proper amount for starting. After the motor has come up to speed on the reduced voltage, the switch is thrown over to running position, thus supplying the full line voltage to the motor. ***In actual construction*** fuses are usually connected, so that they will be in circuit in the running position, but not in the starting position, where they might be blown by the large starting current.

ances are varied simultaneously for each phase in equal amounts. These starting resistances are enclosed in a box similar to a direct current motor rheostat.

An objection to this method is that it is less efficient than the use of variable inductances.

In the second method, variable inductances or auto-transformers are inserted in the field magnet circuits.

In the third method, variable resistances are inserted in the armature circuit, and according to the location of these resistances, the machine is classed as an internal resistance motor, or an external resistance (slip ring) motor.

Internal Resistance Induction Motors.—The armature of this type of induction motor differs from the squirrel cage variety in that the winding is not short circuited through copper rings, but, in starting, is short circuited through a resistance mounted directly on the shaft in the interior of the armature.

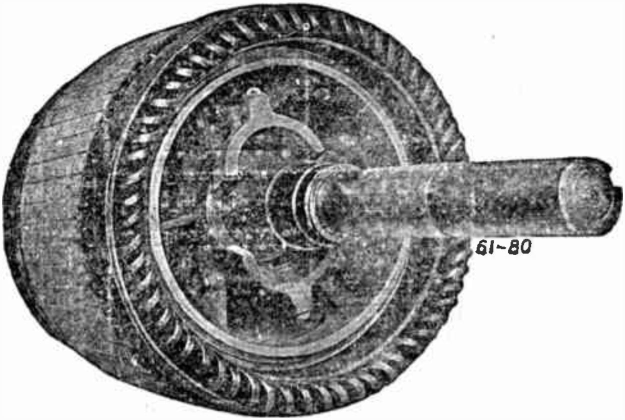


FIG. 7,810.—View of armature interior of Wagner poplyphase induction motor with wound armature, showing the centrifugal device which at the proper speed short circuits all the coils, transforming the motor to the squirrel cage type. The winding is connected with a vertical "commutator" so called. Inside the armature are two governor weights, which are thrown outward by the centrifugal force when the machine reaches the proper speed thus pushing a solid copper ring (which encircles the shaft) into contact with the inner ends of the "commutator" bars, in this way completely short circuiting the armature winding.

When the motor is thrown in circuit, a very low starting current is drawn from the line due to the added resistance in the armature. As the motor comes up to speed, this resistance is gradually cut out, and at full speed the motor operates as a squirrel cage motor, with short circuited winding.

The starting resistance is gradually cut out by operating a lever which engages a collar free to slide horizontally on the shaft. The collar moves

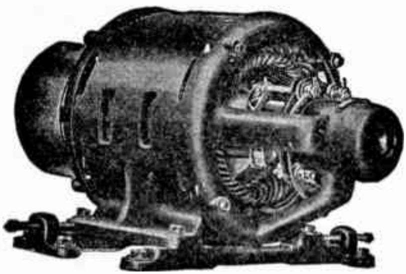


FIG. 7,811.—Richmond slip ring motor.

over the internal resistance grids (located within the armature spider), thus gradually reducing their value until they are cut out.

This arrangement is suitable for small motors, but is objectionable on large motors because of the considerable heat produced.

The initial rush of current when a squirrel cage motor is thrown on the line is more or less objectionable and there are central stations which allow only resistance type of induction motor to be used on their lines.

As with the internal resistance motor, the armature winding of a slip ring motor is not short circuited through copper rings in starting, but through a resistance, which in this case is located externally.

External Resistance or Slip Ring Motors.—In large machines, and those which must run at variable speed, such as is required in the operations of cranes, hoists, dredges, etc., it is advisable that the regulating resistances be placed externally to

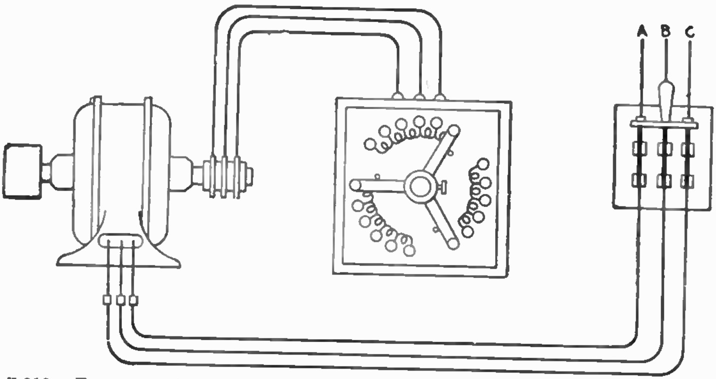


FIG. 7,812.—External resistance or slip ring induction motor connections. The squirrel cage armature winding is not short circuited by copper end rings, but connected in Y grouping and the three free ends connected to three slip rings, leads going from the brushes to three external resistances, arranged as triplex rheostat having three arms rigidly connected as shown, so that the three resistances may be varied simultaneously and in equal amounts.

the motor. Motors having this feature are commercially known as **slip ring motors,** because *connections are made between the external resistances and the armature inductors by means of slip rings.*

The armature winding is connected in Y grouping and the free ends connected to the slip rings, leads going from the brushes to the variable resistances as in fig. 7,812.

FRACTIONAL HORSEPOWER MOTORS

By definition, a fractional horsepower motor *is a motor built in a frame smaller than that having a continuous rating of one horsepower, open type, at* 1,700–1,800 *revolutions per minute.*

It should be noted however, that this does not indicate that the horsepower is *less* than *one*, because a 1-hp. 3,450 r.p.m. 60 cycle motor is a *fractional* rating, while a ¾ *h.p.* 1,140 *r.p.m.* for example is an *integral* rating.

Single Phase Motor Classification.—Single phase motors may be divided into several classes, depending upon construction and method of starting as:

1. Split phase.
2. Capacitor start.
3. Capacitor.
4. Repulsion.
5. Shaded pole.
6. Universal, etc.

The Split Phase Induction Motor.—This motor is one of the most popular of the fractional horsepower types. Fig. 7,814 shows an arrangement of the windings. The motor consists essentially of squirrel cage rotor, and has two stator windings, a main winding and a starting winding. The main winding is connected across the supply lines in the usual manner, and has a low resistance and a high inductance. The starting or auxiliary winding which is physically displaced in the stator from the main winding, has a high resistance and a low inductance. This physical displacement, in addition to the electrical phase displacement produced by the relative electrical resistance values in the two windings, produce a weak rotating field which is sufficient to provide a low starting torque.

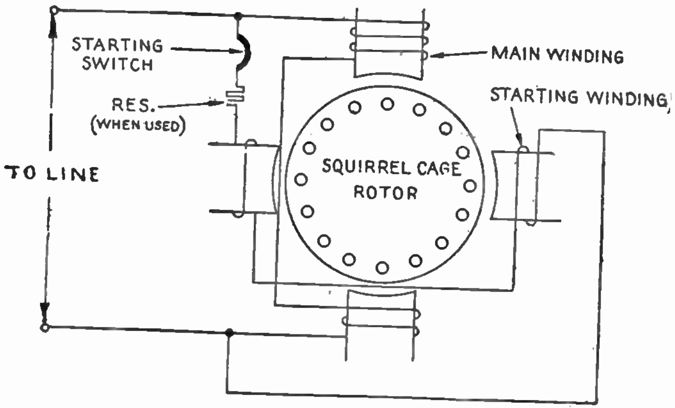


Fig. 7,814.—Schematic diagram illustrating circuit arrangement of a split phase induction motor.

After the motor has accelerated to 75 or 80 per cent of its synchronous speed, a starting switch (usually centrifugally or magnetically operated) opens its contacts to disconnect the starting winding.

The function of the starting switch is to prevent the motor from drawing excessive currents from the line and also to protect the starting winding from damage due to heating. The motor may be started in either direction by reversing either the main or auxiliary winding.

The characteristics of a resistance type split phase motor are shown in fig. 7815. The split phase motor is most commonly used in sizes ranging from $^1/_{30}$ to ½ horsepower for applications such as fans, business machines, automatic musical instruments, buffing machines, grinders and numerous other applications.

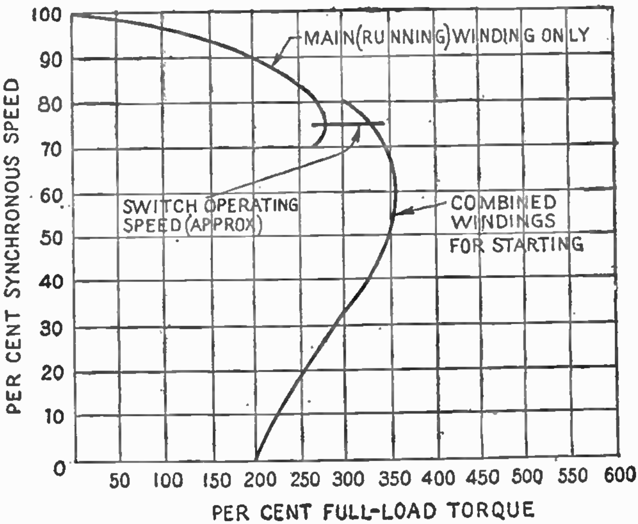


Fig. 7,815.—Typical speed torque characteristics of a split phase induction motor.

The Resistance-Start Motor.—This if a form of split phase motor having a resistance connected in series with the auxiliary winding. As in the split phase motor, the auxiliary circuit is opened when the motor has attained a pre-determined speed.

The Reactor-Start Motor.—This is a form of split phase motor designed for starting with a reactor in series with the main winding. The reactor is short circuited or otherwise made ineffective and the auxiliary circuit is opened when the motor has attained a pre-determined speed. A circuit arrangement of the motor is shown in fig. 7,816. The function of the reactor is to reduce the starting current and to increase the angle of lag of the main winding current behind the voltage. This motor will develop approximately the same torque as the split phase motors discussed previously.

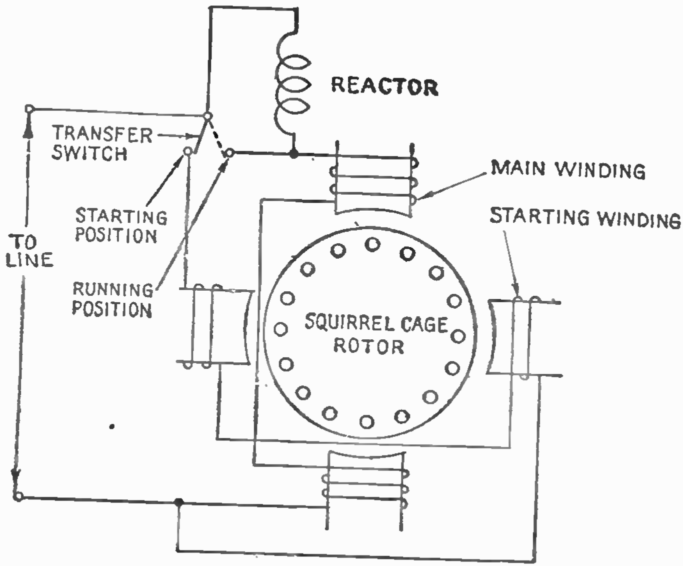


FIG. 7,816.—Circuit arrangement of a reactor-start motor.

The centrifugally operated starting switch must be of the single pole double throw type for proper functioning.

The Capacitor-Start Motor.—This is another form of split phase motor having a capacitor or condenser connected in series with the auxiliary winding. The auxiliary circuit is opened when the motor has attained a pre-determined speed. The circuit, fig. 7,817 shows the winding arrangement.

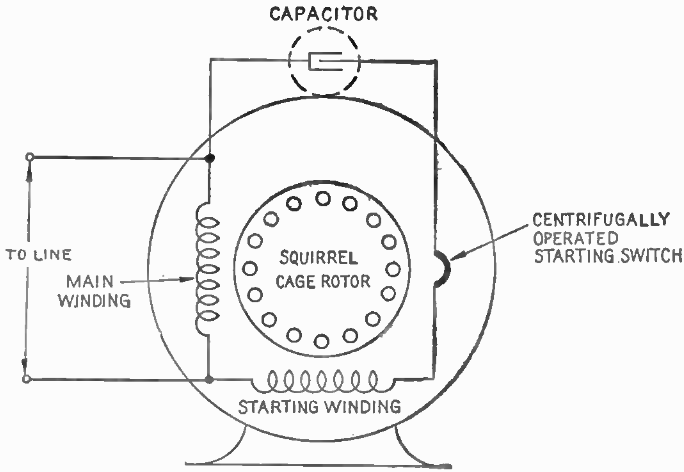


FIG. 7,817.—Circuit arrangement of a capacitor-start motor.

The rotor is of the squirrel cage type as in other split phase motors. The main winding is connected directly across the line, while the auxiliary or starting winding is connected through a capacitor which may be connected into the circuit through a transformer with suitably designed windings and capacitor, the two windings will be approximately 90 degrees apart electrically.

This type has certain advantages over the previously described types in that it has a considerable higher starting torque accompanied by a high power factor.

The Capacitor Motor.—This form of single phase induction motor has the main winding connected directly to the power supply and the auxiliary winding connected in series with a capacitor. The capacitor and auxiliary winding remains in the circuit while the motor is in operation. There are several types of capacitor motors differing from one another, mainly in the number and arrangement of capacitors employed.

The running characteristics of this type of motor are extremely favorable and the torque is fixed by the amount of additional capacitance added to the auxiliary winding during the starting period.

The simplest type mechanically is the *low* torque, permanent-split capacitor-motor fig 7,818. Here a capacitor is permanently connected in series with the auxiliary winding. This type of motor can be arranged for adjustable-varying speed by the use of a tapped winding or autotransformer regulator.

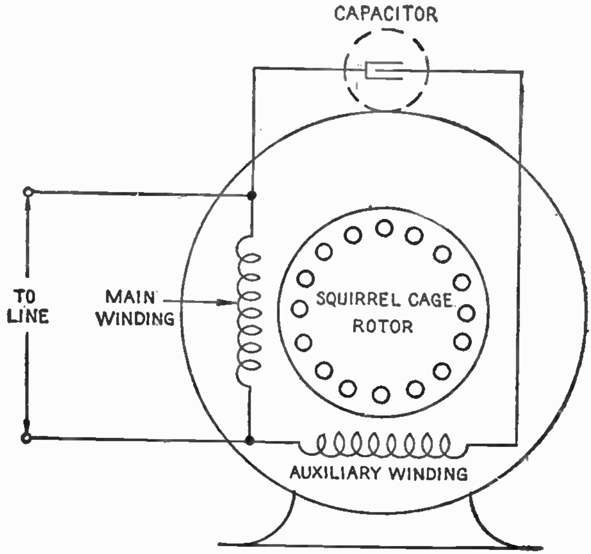


FIG. 7,818.—Circuit arrangement of a permanent split-wound capacitor motor.

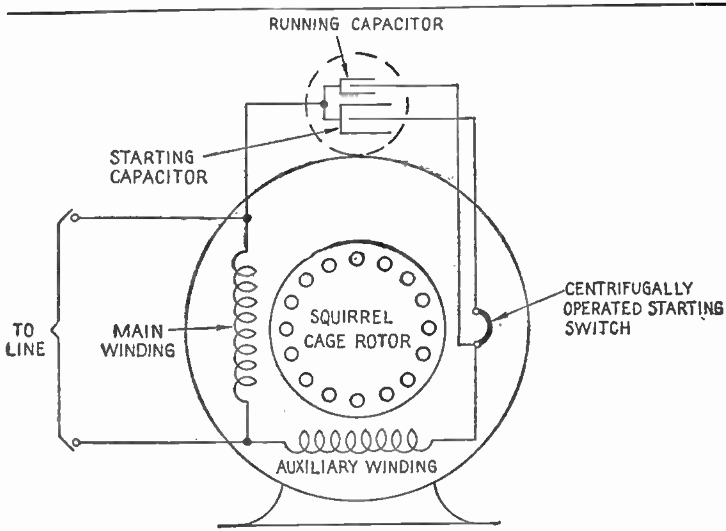


FIG. 7,819.—Circuit arrangement in a high torque type capacitor motor.

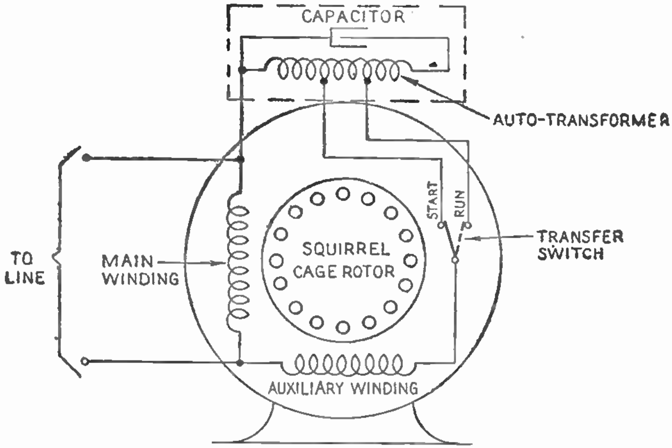


FIG. 7,820.—Circuit arrangement in a high torque type capacitor motor using auto-transformer. In a circuit arrangement of this type, a single pole, double throw transfer switch connects the capacitor in such a way as to provide a voltage of approximately 700 volts at starting. After the motor has reached a predetermined speed, the transfer switch operates and connects the capacitor to a permanent running voltage which is approximately 300 volts.

High torque motors are usually provided with one running and one starting capacitor connected in parallel as shown in fig. 7,819 or by means of an autotransformer connected to increase the voltage of the capacitor during the starting period as indicated in fig. 7,820.

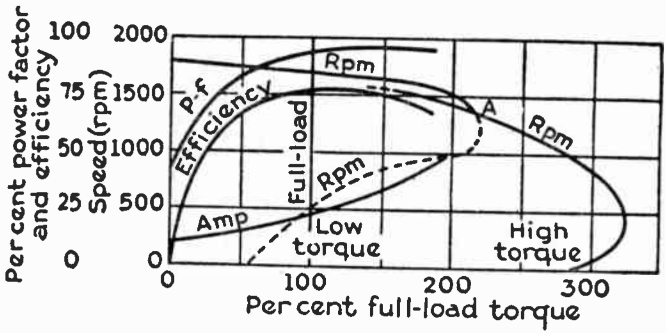


FIG. 7,821.—Typical operating characteristics of high and low torque type capacitor motors.

The Repulsion Motor.—This is a single phase motor which has a stator winding arranged for connection to the source of power and a rotor winding connected to a commutator. Brushes on the commutator are short-circuited and are so placed that the magnetic axis of the rotor winding is inclined to the magnetic axis of the stator winding. This type of motor has a varying speed characteristic.

Principally it has a stator like that of a single phase motor, but has a rotor like the armature of a direct current motor, with the opposite brushes on the armature short-circuited, that is, connected together by a connector with a negligible resistance.

The brushes are placed so that a line connecting them makes a small angle with the neutral axis of the magnetic field of the stator. The stator induces a current in the armature which produces an armature field with poles in the neighborhood of the brushes. These have the same polarity as the adjacent field poles and are repelled by them so that this repulsion causes the armature to revolve. From this action the motor derives its name.

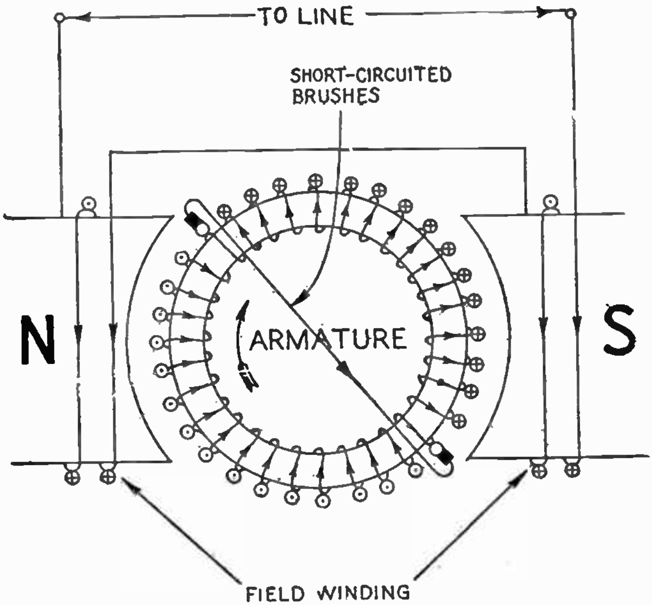


FIG. 7,822.—Circuit arrangement of a simple series repulsion motor.

A repulsion motor of this original type has characteristics similar to the series motor. It has a high starting torque and moderate starting current. It has low power factor except at high speeds. For this reason it is often modified into the "compensated repulsion motor," which has another set of brushes placed midway between the short-circuited set and this added set is connected in series with the stator winding.

Compensated Repulsion Motor.—This is simply a repulsion motor with an added winding to improve the power factor. It may be designed with constant or varying speed characteristics.

Repulsion-Start Induction Motor.—This type of single phase motor is widely used in sizes up to about five horsepower. A repulsion start induction motor is a single phase motor having the same windings as a repulsion motor, but at a pre-determined

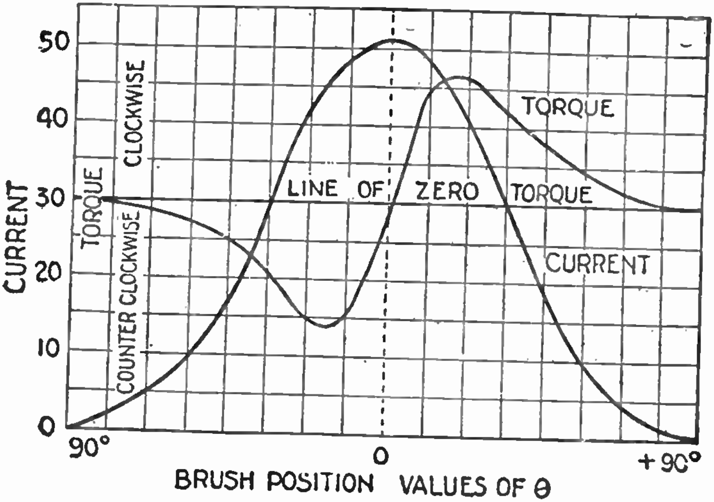


Fig. 7,823.—Curves for repulsion motor showing the effect on current and torque due to shifting of the brushes. Note that the current and torque vary greatly with the position of the brushes.

speed the rotor winding is short circuited or otherwise connected to give the equivalent of a squirrel cage winding. This type of motor starts as a repulsion motor but operates as an induction motor with constant speed characteristics.

The repulsion start induction motor has a single phase distributed field winding with the axis of the brushes displaced from the axis of the field winding. The armature has an insulated winding. The current induced in the armature or rotor is carried by the brushes and commutator resulting in high starting torque. When nearly synchronous speed is attained the commutator is short circuited so that the armature is then similar in its functions to a squirrel cage armature.

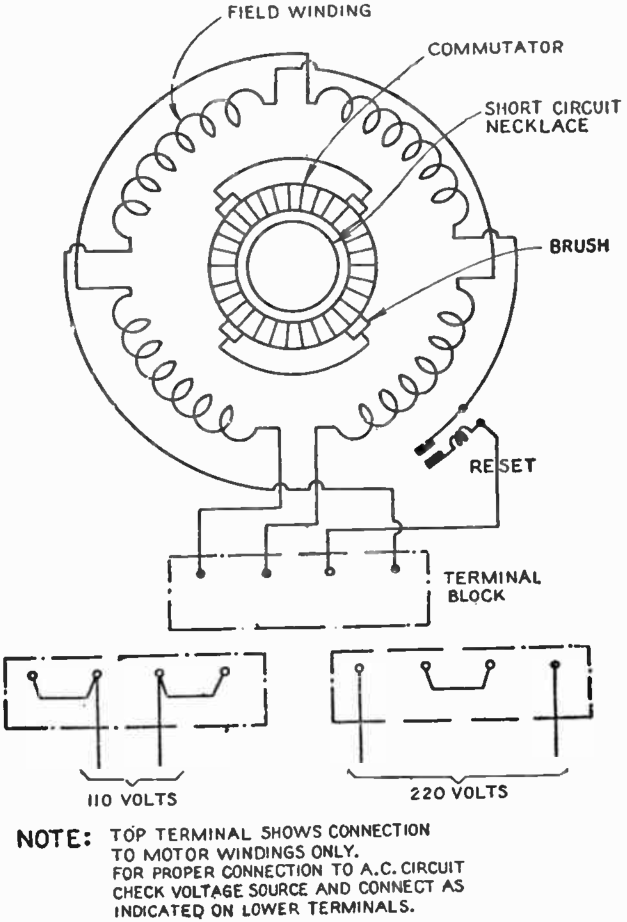


FIG. 7,824.—Typical coil relationship in single phase repulsion-start induction motor.

The diagrams figs. 7,825 to 7,827J show the working principles of the mechanism for simultaneously lifting the brushes and short circuiting the commutator to change the operation from *repulsion* to *induction*. The object of lifting the brushes is to eliminate wear of the commutator during the running periods as it makes no difference electrically whether the brushes be in contact or not after the motor comes up to speed.

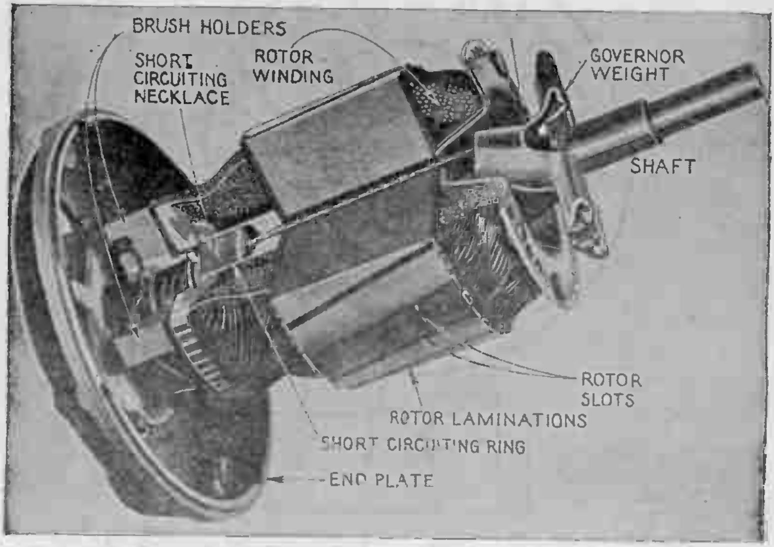


FIG. 7,825.—Shows position of short-circuiting necklace and brush mechanism while motor is starting.

This motor has gone through many stages of improvement since its first appearance on the market, although its general principle has remained the same. The general reliability of this type of motor is largely governed by the reliability of the short circuiting mechanism. For this reason, it has been the constant aim of engineers to improve on the principle and construction of the short circuiting switch. Centrifugal force, as a means to accomplish the best results, was early resorted to and still remains the most practical method, because the weight being once determined, will always throw out and short circuit the commutator at the same speed.

Since the motor starts on the repulsion principle, it has the same starting characteristics as the repulsion motor described previously, namely, high starting torque and low starting current.

As the motor speeds up the torque falls off rapidly. At some point on the speed torque curve after the repulsion curve has crossed the induction motor curve, usually at about 80% of synchronism, the commutator is automatically short circuited, producing the effect of a cage winding in the armature, and the motor comes up to speed as an induction motor.

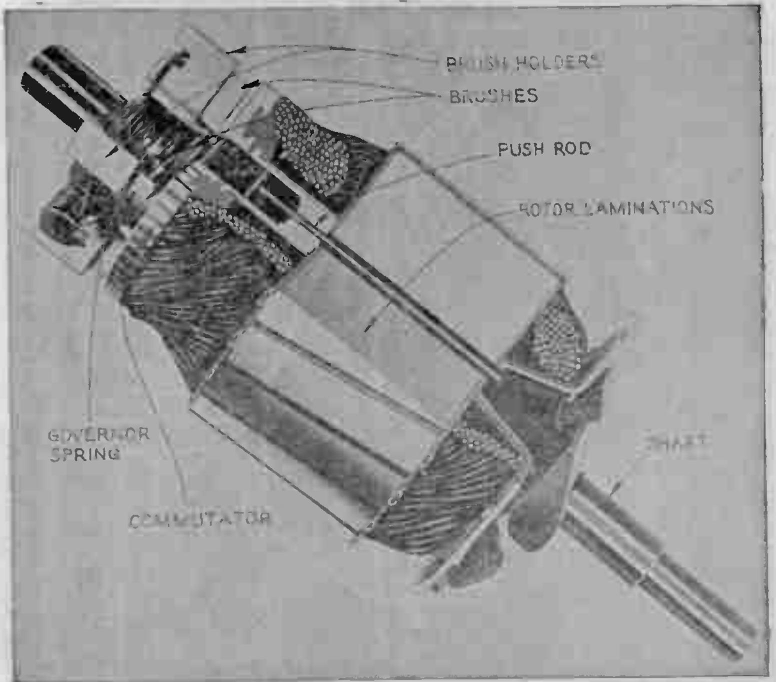
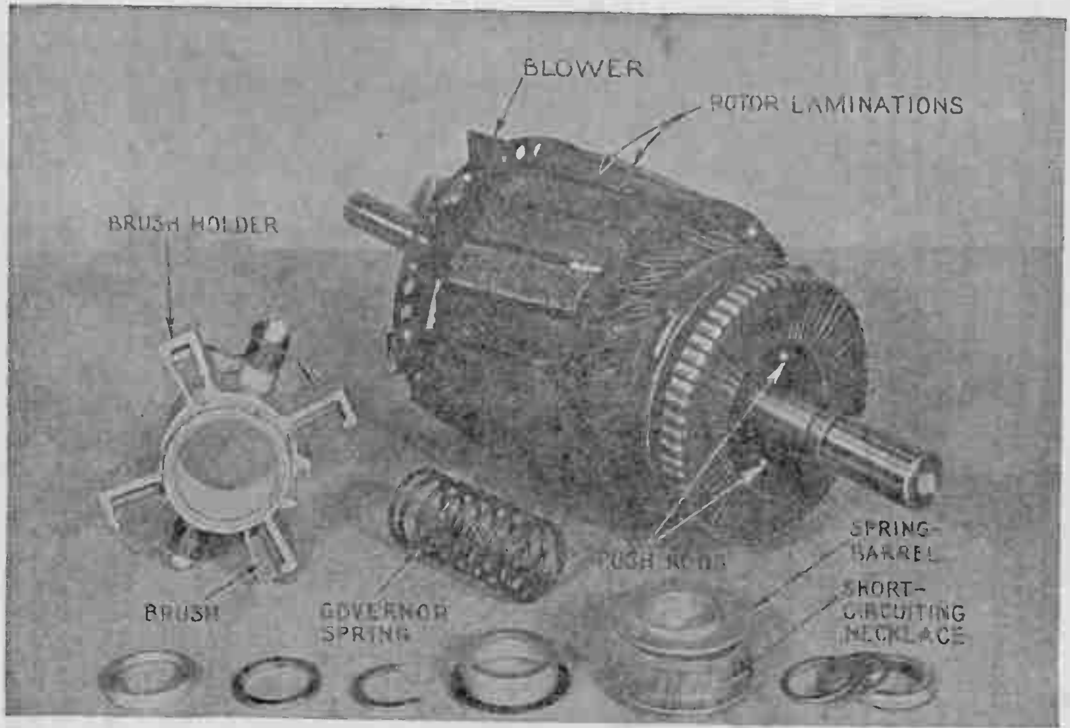


FIG. 7,826.—Shows position of short-circuiting necklace and brush mechanism after governor weights have operated.

After the commutator has been short circuited, the brushes do not carry current and therefore, may be lifted from the commutator, but lifting the brushes is not necessary.



FIGS. 7,827 to 7,827J.—Dismantled rotor showing items making up short-circuiting and brush-lifting mechanism. Governor weights (not shown) are at opposite end of rotor.

The curve in fig. 7,827K shows the speed torque characteristics of a typical repulsion-start induction motor. The short circuiting mechanism operates at point A. At this point the induction motor torque is greater than the repulsion motor torque, which means that if the repulsion winding have sufficient torque to bring the load up to this speed, there will be sufficient torque as an induction motor to bring the load up to full speed.

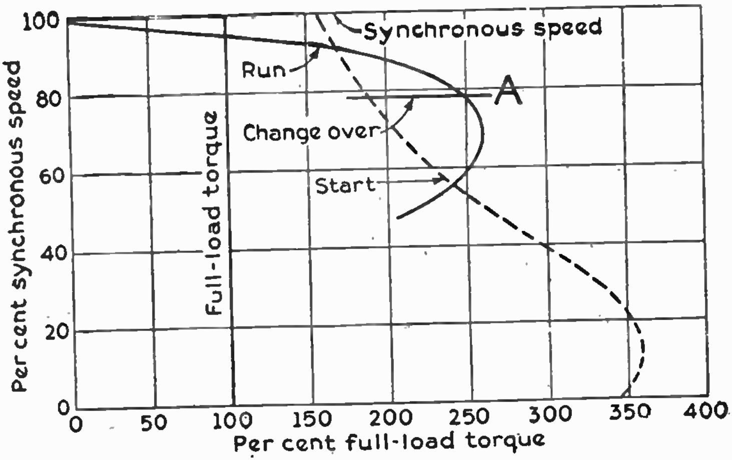


FIG. 7,827K.—Speed-torque characteristics of a typical repulsion-start induction motor.

The higher the speed at which the short circuiting mechanism operates, the lower will be the induction motor current at that point and consequently the less disturbance to the line. After the commutator has been short circuited, the motor has the same characteristics as the single phase induction motor previously described.

If the short circuiting mechanism operate, before the repulsion curve crosses the induction motor curve, and the torque of the induction motor be less than that required to accelerate the load, the motor may slow down until the short circuit is removed from the commutator, in which case the motor will again operate repulsion. The armature will then speed up until the commutator is again short circuited after which the armature will slow down until it again becomes repulsion. This cycle will be repeated over and over again until some change takes place.

The efficiency and maximum running torque of the repulsion start induction motor are usually less than those of a cage wound induction motor built of the same parts. In other words, the repulsion start induction motor must be larger than a cage wound motor of the same rating to give the same performance.

Repulsion Induction Motors.—This is another form of repulsion motor which has a squirrel cage winding in the rotor in addition to the repulsion motor winding. A motor of this type may have either a constant speed or varying speed characteristics.

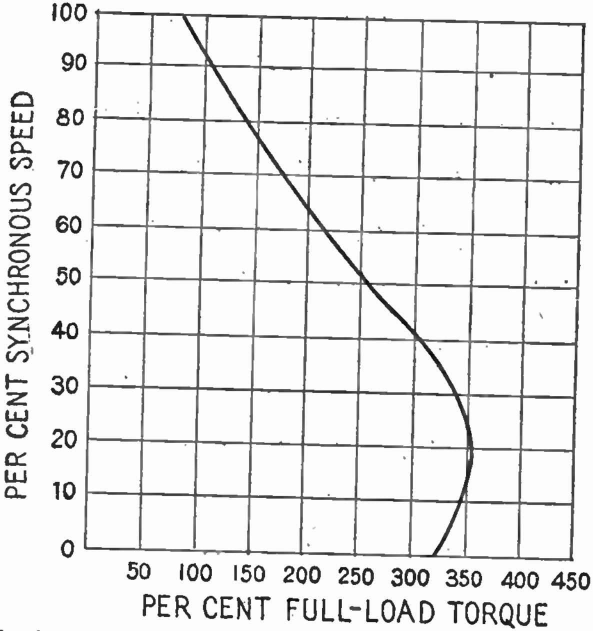


FIG. 7,827L.—Speed-torque characteristics of a typical repulsion induction motor.

Specifically this motor is a combination of the repulsion and induction types and operates on the combined principle of repulsion and induction. It is sometimes termed a *squirrel cage* *repulsion motor.* In this motor the desirable starting characteristics of the repulsion motor and the constant speed characteristics of the induction motor is obtained. It is of course, impossible to combine the two types of motor and obtain only the desirable characteristics of each.

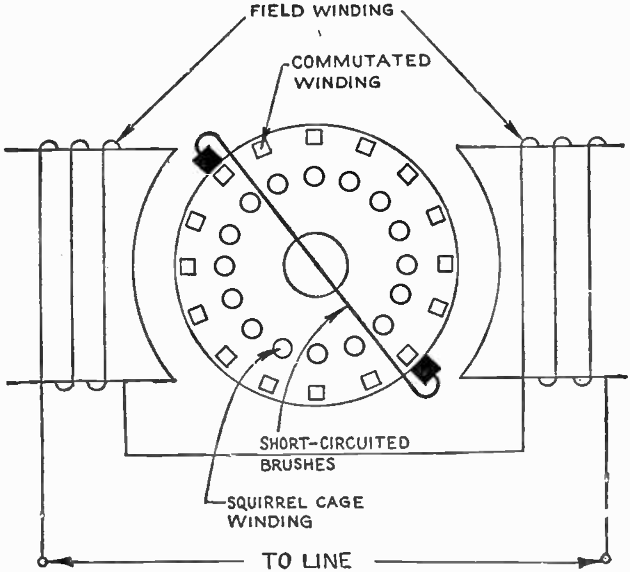


FIG. 7,827M.—Illustrating circuit arrangement of a repulsion induction motor.

The field has the same type of windings as used in the repulsion start induction motor. The armature has two separate and independent windings. They are:

1. Squirrel cage winding; and
2. Commutated winding.

Both of these armature windings function during the entire period of operation of the motor. There are no automatic devices such as the starting switch of the split phase motor, or the short circuiting device of the repulsion start induction motor.

The cage winding is located in slots below those which contain the commutated winding. The slots which contain the two windings may or may not be connected by a narrow slot. Usually there are the same number of slots in the two windings. It is not, however, absolutely essential that they be the same, as before stated.

Due to its construction, the squirrel cage winding has inherently a high inductance. Its reactance with the armature at rest is therefore high.

The commutated winding has a low reactance and the current will flow mainly in this winding. The ideal condition at starting would be for all of the flux to pass beneath the commutated winding and none of it to pass beneath the cage winding. If this condition could be obtained, this motor would have the same starting characteristics as the repulsion start induction motor.

At full load speed, which is slightly below synchronism, the reactance of the cage winding is low, and most of the mutual flux passes beneath the cage winding.

Both windings produce torque and the output of the motor is the combined output of the cage winding and the commutated winding.

The commutation of the motor is good at all speeds. The no load speed is above synchronism and is limited by the combined effect of the field winding on the commutated winding and the cage winding and the action of the two armature windings on each other. At synchronous speed, a squirrel cage motor has no torque. At synchronous speed, and for a short distance above synchronous speed, the torque of a repulsion induction motor is greater than that of the commutated winding alone, which shows that due to the interaction between the two armature windings ,the squirrel cage supplies torque instead of acting as a brake.

At full load speed, and up to about the maximum running torque point, the torque of this motor is greater than the sum of the torques of the cage winding and the commutated winding. The inherent locked torque curve of a repulsion induction motor is similar to that of the repulsion motor shown in fig. 7.827L. At soft neutral, the primary winding carries the squirrel cage current in addition to the exciting current of the motor. Since the starting current of the repulsion induction motor is low, it may be operated from lighting circuits when driving frequently starting devices.

The repulsion induction motor is especially suitable for such applications as household refrigerators, water systems, garage air pumps, gasoline pumps, compressors and similar applications. This motor may also be arranged for reversing service by the same method described for the repulsion motor, that is by the use of one transformer field and two main field windings.

The Shaded Pole Motor.—This is a single phase induction motor equipped with an auxiliary winding displaced in magnetic position from, and connected in parallel with the main winding.*

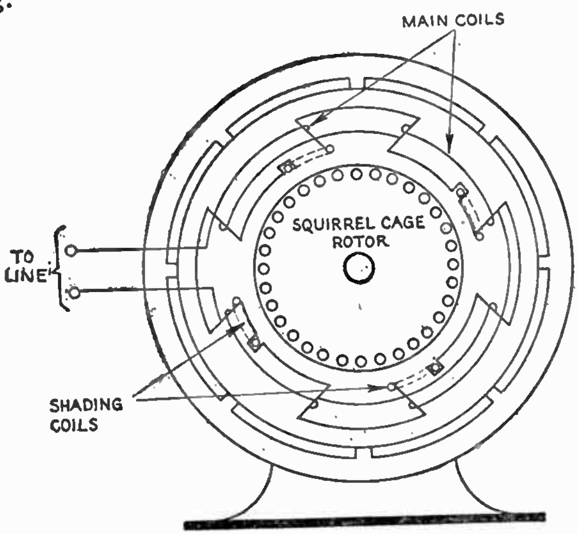


FIG. 7,827N.—Single phase fan motor with *shading coils* for starting. In addition to the main field coils, one tip of each pole piece is surrounded by a short circuited coil of wire or frame of copper, as indicated in the figure. This coil, or copper frame, is called a shading coil, and it causes a phase difference between the pulsating flux that emanates from the main portion of each polar projection and the pulsating flux which emanates from the pole tip, thus introducing an approach to two phase action on the armature.

* NOTE.—Unless otherwise specified, however, the auxiliary circuit is assumed to be opened when the motor has attained a pre-determined speed. The term split phase motor, used without qualification, describes a motor to be used without inpedance, other than offered by the motor windings themselves, other types being separately defined.

These are manufactured in fractional horsepower sizes, and have found employment in a variety of household appliances such as fans, blowers, hair driers and other applications requiring a low starting torque. It is operated only on alternating current, usually non-reversible, is low in cost and extremely rugged and reliable.

Although there are a number of different construction methods employed, principally the motor operates as follows:

The shading coil (from which the motor has derived its name) consists of low resistance copper links embedded in one side of each stator pole, and are used to provide the necessary starting torque.

When current increases in the main coils, a current is induced in the shading coils that opposes the magnetic field building up in the part of the pole pieces they surround. This produces the condition shown in fig. 7,827O where the flux is crowded away from the portion surrounded by the shading coil.

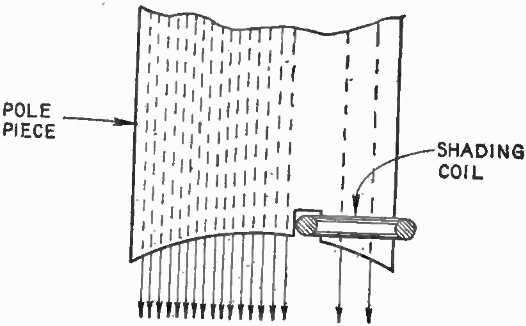


FIG. 7,827O.—Diagram showing action of shading coil in alternating current motor. The extremities of these pole pieces are divided into two branches, in one of which a copper ring called a *shading coil* is placed as shown, while the other is left *unshaded*. The action of the shading coil is as follows: Consider the field poles to be energized by single phase current and assume the current to be flowing in a direction to make a north pole at the top. Assume the poles to be just at the point of forming. Lines of force will tend to pass through the shading coil and the remainder of the pole. Any change of lines within the shading coil generates a voltage, which causes to flow through the coil a current of a value depending on the voltage, and always in a direction to oppose the change of lines. The field flux is therefore, partly shifted to the free portion of the pole, while the accumulation of lines through the shading coil is retarded.

When the main coil current decreases, that in the shading coils also decreases until the pole pieces are uniformly magnetized. As the main coil current and the pole piece magnetic flux continue to decrease, current in the shading coils reverses and tends to maintain the flux in part of the pole pieces.

When the main coil current drops to zero, current still flows in the shading coils to give the magnetic effect which causes the coils to produce a rotating or magnetic field which makes the motor self-starting. This type of motor is suited to applications where starting torque is low, such as small fans, and comes only in fractional horsepower sizes.

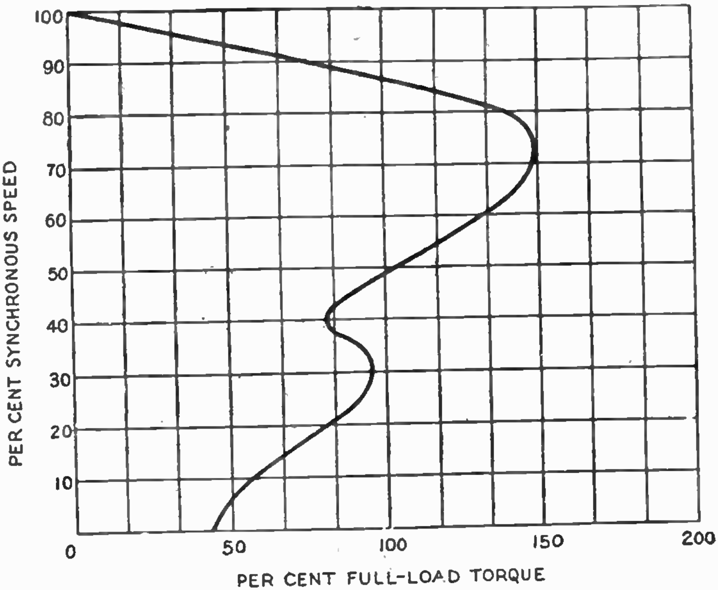


FIG. 7,827P—Speed torque characteristics of a typical shaded pole motor.

The Universal Motor.—A universal motor is a series-wound or compensated series-wound motor which may be operated either on *direct current* or on single phase *alternating current* at approximately the same speed and output. These conditions must be met when the direct current and the alternating current voltages are approximately the same and the frequency of the alternating current is not greater than 60 cycles per second.

Universal motors are commonly manufactured in fractional horsepower sizes and are because of their use on either *a.c.* or *d.c.* currents, preferred, particularly in areas where the Power Companies supply both types of current.

As previously noted all universal motors are series wound, therefore their performance characteristics are very much like those of the usual *d.c.* series motor. The no-load speed is quite high but seldom high enough to damage the motor, as in the case with larger *d.c.* series motors. When a load is placed on the motor, the speed decreases and continues to decrease as the load increases. Although universal motors of several types of construction are manufactured, they all have the varying speed characteristics just mentioned.

Due to the difficulty in obtaining like performance on *a.c.* and *d.c.* current for motors designed to operation at low speeds, most universal motors are designed for operation at speeds of 3,500 *r.p.m.* and higher. Motors operating at a load speed of 8,000 to 10,000 *r.p.m.* are common.

Small stationary vacuum cleaners and the larger sizes of portable tools have motors operating at speeds of 3,500 to 8,000 *r.p.m.*

The speed of a universal motor can be adjusted by connecting a resistance of proper value in series with the motor. Advantage of this characteristic is obvious in such application as motor driven sewing machines, where it is necessary to operate the motor over a large range of speed. In such applications adjustable resistances are used and the speed is varied at will.

When considering the use of universal motors to drive any apparatus, the following characteristics of the motor will be considered:

1. Change in speed with change in load.
2. Change in speed with change in frequency of power supply.
3. Change in speed due to change in applied voltage.

Since a large percentage of all small motors is connected to lighting circuits where the voltage conditions are not always the best, this last item is of the utmost importance. This condition should also be kept in mind when determining the proper motor to use for any application regardless of type. In general, the speed of the universal motor varies with the voltage.

The starting torque of universal motors is usually much more than that required in most applications and does not have to be considered.

Universal motors are manufactured in two general types. They are:

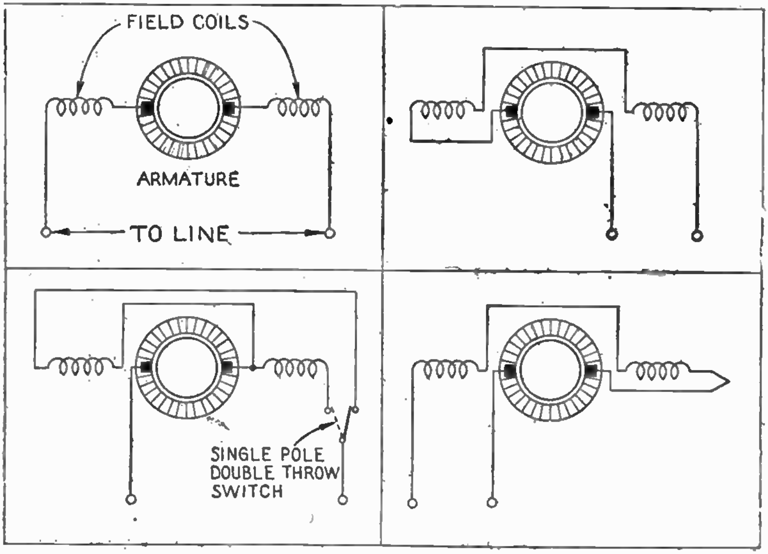
1. Concentrated-pole, non-compensated; and
2. Distributed field compensated.

Most motors of low horsepower rating are of the concentrated pole, non-compensated type, while those of higher ratings are of the distributed-field, compensated type. The dividing line is somewhere near ¼ horsepower, but the type of motor to be used is determined by the severity of the service and performance required. All of the motors have wound armatures of the same construction as the ordinary *d.c.* motor.

The concentrated pole, non-compensated motor is exactly the same in construction as a D.C. motor except that the magnetic path is made up of laminations. The laminated stator is made necessary because the magnetic field is alternating when the motor is operated on alternating current. The stator laminations are punched with the poles and the yoke in one piece.

The compensated type of motor has stator laminations of the same shape as those in an induction motor. These motors have stator windings in one of two different types.

The non-compensated motor is more simple and less expensive than the compensated motor and would be used over the entire range of ratings if its performance were as good as that of the compensated motor. The non-compensated type is used for the higher speeds and lower horsepower ratings only. Figs. 7,827V and 7,827W show the speed torque curves for a compensated and non-compensated motor respectively. It will be noted in fig. 7827V that although the rated speed is relatively low for a universal motor, the speed torque curves for various frequencies lie very close together up to 50 per cent above the rated torque load.



FIGS. 7,827Q to 7,827T.—Various circuit arrangements for concentrated pole non-compensated Universal motors. Figs. 7,827Q and 7,827R shows connections for non-reversible two wire motors, whereas figs. 7,827S and 7,827T are split-series, three and four wire reversible motors respectively.

In fig. 7,827W the performance of a much higher speed, non-compensated motor is shown. For most universal motor applications the variation in speed at rated loads as shown on this curve is satisfactory. However, the speed curves separate rapidly above full load. If this motor had been designed for lower speed, the tendency of the speed torque curves to separate would have been more pronounced. The chief cause of the difficulty in keeping the speeds the same is the reactance voltage which exists when the motors are operated on A.C. current. Most of this reactance voltage is produced in the field windings by the main working field. However, in the non-compensated motor some of it is produced in the armature winding by the field produced by the armature amper turns. The true working voltage is obtained by subtracting the reactance voltage vectorially from the line voltage. If the reactance is high, the performance at a given load will be the same as though there were no reactance voltage and the applied voltage had been reduced with consequent reduction in speed.

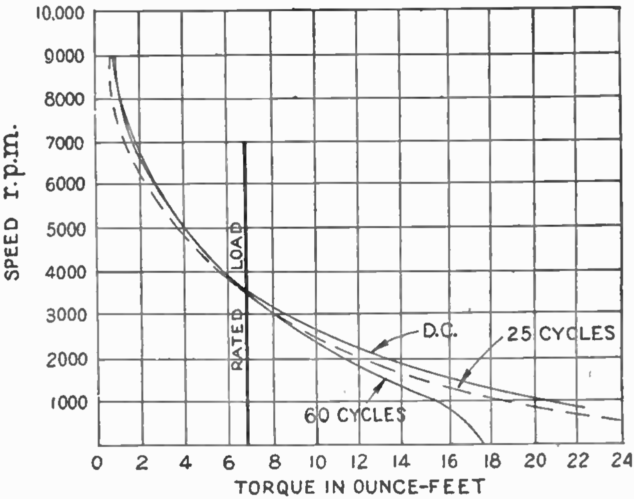


FIG. 7,827V.—Characteristics of a Universal ¼ horsepower 3,400 r.p.m. compensated motor.

Applications of Single Phase Motors.—Although single phase motors are most commonly used in fractional horsepower sizes certain application and power supply conditions make use of single phase motors in sizes of up to 25 *h.p.*

For extremely small capacities up to 1/40 *h.p.*, the shaded pole type of motor is most frequently used. This type of motor provides sufficient torque for fans, blowers and other devices and the starting current is not objectionable on lighting lines.

The split phase motor is the most commonly used in sizes ranging from 1/30 to ½ *h.p.*, particularly for fan and similar drives where the starting torque is low. In this type of motor a built in centrifugal switch is usually provided to disconnect the starting winding as the motor comes up to speed.

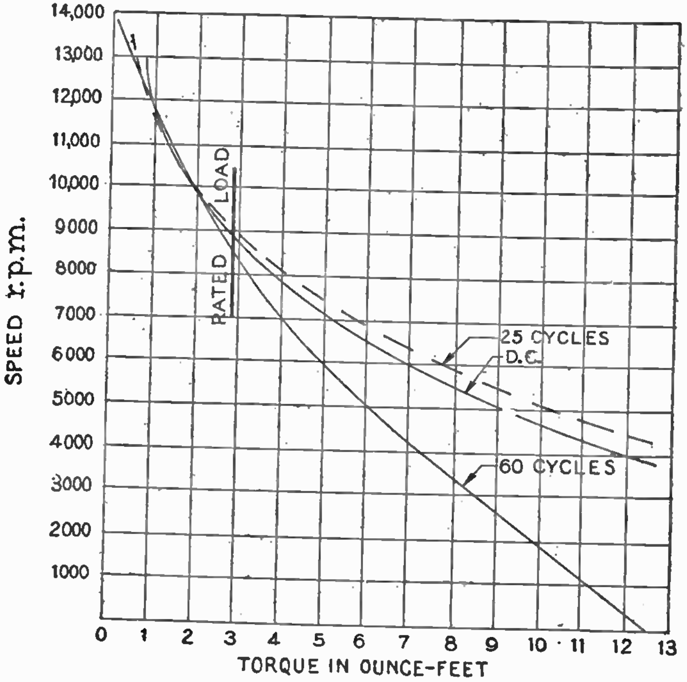


FIG. 7,827W.—Characteristics of a Universal ¼ horsepower 8,000 r.p.m. non-compensated motor.

In sizes above a ¼ *h.p.*, the capacitor motor with 300% starting torque may be used to advantage, especially for pump and compressor drives. It may also be used for fan drives in the lower capacities at higher speeds, in the overlapping ratings; however, it does not offer sufficient advantages over the split phase motor to warrant its higher cost.

At low speeds (below 900 *r.p.m.*) where centrifugal switches are less successful) and in ratings say from ¾ to 3 *h.p.* at all speeds, the capacitor motor finds its widest field of application in fan drives.

The running characteristics of this motor are extremely good and the starting torque is fixed by the amount of additional capacitance added to the auxiliary motor winding during the starting period.

The low torque capacitor motor with no capacitance added to the auxiliary winding during the starting period provides approximately 50% starting torque. This is considered sufficient for directly connected fans, if the unit be one of constant speed or is always started on the high speed position of the starting switch. Where the fan is coupled or belted to the motor the "high torque" type with the additional starting capacitance is preferable.

The change over from "start" to "run" of the high-torque type may be accomplished through the use of a centrifugal switch or by electrical means responsive to curent decay or voltage rise as the motor approaches normal running speed.

The repulsion-induction and the repulsion-start induction motors have ratings paralleling those of the capacitor types. These motors have commutators to provide the starting torque. Under normal running conditions, the commutator of the repulsion start, induction-run type is short circuited, and the motor operates as an induction motor. This differs from the repulsion induction motor in which the commutator is not short circuited. A squirrel cage winding deep in the rotor is inactive at starting, but takes up load as the rotor accelerates to full speed, where the normal load is about equally divided between the repulsion and the squirrel cage winding. The starting efficiency of both types is high and the 300% or more starting torque that is available makes them suitable for compressor drives.

CHAPTER 36

Armature Winding and Repairs

When a repair man is called upon to rewind or reconnect an armature for different operating conditions he must solve such problems as, the order of winding, what size wire to use, how many turns per slot, etc.

Of course, if the winding of the armature to be repaired has not been removed, these difficulties are not encountered, but in the absence of the winding there is nothing to indicate the size of wire, number of turns, etc.

1. CALCULATIONS

Armature Calculations.—In the design of a dynamo or motor, it is usual to first design the armature and make the other parts fit around it.

Accurate design, is a matter of both calculation and experiment because many of the factors involved cannot be determined by calculation alone.

The principal item to be considered is the size of the wire.

In order to deliver a certain current, the number of poles, etc., being fixed, a certain size wire must be used. As must be evident, the heating

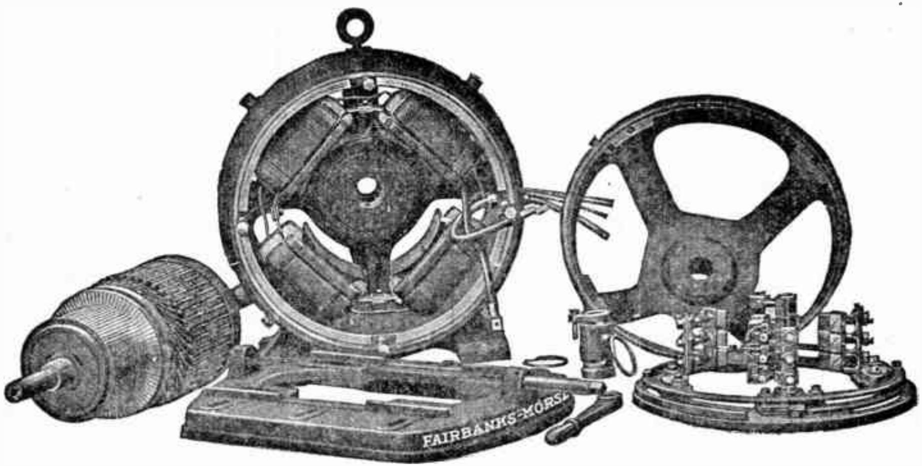


FIG. 7,828.—Fairbanks standard type TR machine disassembled.

of the wire is what governs the size. For a given current the smaller the wire the greater the heating.

Example in Design.—Determine size of wire, number of turns, etc., for an 8×8 in. armature, for a flux of 30,000 lines per sq. in., 110 volts, 1,200 *r.p.m.*, 5 horse power.

Cross sectional area of armature = 8×8 = 64 sq. ins.

Total flux through armature = 30,000 × 64 = 1,920,000 lines.

Now, since it requires 10^8 or 100,000,000 lines of force cut per second to generate one volt, for the given 110 volts, the required rate of cutting is

TABLE I.—3 sq. ins.

Capacity of Wires at various depths of winding, 3 sq. in. radiating surface per watt

(According to Horstmann and Tousley)

B. & S. Gauge.	Diameter bare.	Resistance per foot 140° F.	Diameter D. C. C.	Amperes at different depths of winding layers.						Number of wires per inch.	I^2
				1	2	3	4	5	6		
4	.2043	.000283	.224	56.28	39.74	32.42	28.12	25.15	22.97	4.45	3166
5	.1819	.000357	.200	47.30	33.46	27.33	23.66	21.16	19.31	5.00	2240
6	.1620	.000450	.180	40.00	28.28	23.08	20.00	17.88	16.34	5.5	1600
7	.1413	.000567	.158	33.40	23.60	19.28	16.67	14.93	13.63	6.3	1114
8	.1285	.000715	.144	28.35	20.04	16.37	14.17	12.68	11.57	7.0	805
9	.1144	.000902	.130	24.00	16.97	13.85	12.00	10.72	9.74	7.7	576
10	.1019	.001137	.117	20.27	14.31	11.70	10.14	9.05	8.24	8.6	411
11	.0907	.001436	.106	17.19	12.12	9.69	8.60	7.68	7.00	9.6	295
12	.0808	.00181	.093	14.31	10.09	8.24	7.14	6.40	5.83	10.7	205
13	.0719	.00228	.084	12.12	8.54	7.00	6.08	5.38	4.89	11.9	147
14	.0640	.00288	.075	10.19	7.21	5.91	5.09	4.58	4.12	13.3	104
15	.0570	.00362	.067	8.60	6.08	4.95	4.30	3.87	3.50	15.0	74
16	.0508	.00458	.059	7.14	5.04	4.12	3.57	3.19	2.91	17.0	51
17	.0452	.00575	.053	6.08	4.30	3.5	3.04	2.64	2.47	19.0	37
18	.0403	.00727	.048	5.09	3.60	2.94	2.54	2.28	2.08	21.0	26
19	.0358	.00916	.044	4.36	3.08	2.52	2.18	1.97	1.78	22.7	19
20	.0319	.01153	.040	3.74	2.64	2.16	1.87	1.67	1.52	25.0	14
21	.0284	01454	.036	3.14	2.22	1.81	1.57	1.39	1.28	28.0	9.9
22	.0253	.01845	.033	2.66	1.87	1 54	1.33	1.19	1.09	30.3	7.1
23	.0225	.0231	.030	2.28	1.61	1.30	1.14	1.01	.94	33.3	5.2
24	.0201	.0295	.028	1.94	1.37	1.14	.97	.86	.80	35.7	3.8
25	.0179	.0365	.026	1.70	1.18	.98	.85	80	.74	38.4	2.9
26	.0159	.0461	.024	1.41	1.00	.82	.71	.63	.57	42.0	2.0
27	.0142	.0603	.022	1.18	.78	.68	.59	52	.47	45.5	1.4
28	.0126	.0744	.021	1.04	.72	.60	.52	47	.42	48.0	1.1
29	.0112	.0925	.020	.92	.65	.52	.46	42	.38	50.0	.86
30	.0100	.1181	.018	.77	.54	.44	.38	.35	.31	56.0	.61

$$\frac{\text{required rate of cutting}}{\text{total flux}} = \frac{11{,}000{,}000{,}000}{1{,}920{,}000} = 5{,}728 \text{ lines per sec.}$$

The number of inductors (wires) necessary to place on the armature to cut 5,728 lines per second will depend on the speed, thus

$$\text{number of inductors} = \frac{\text{total lines per wire per sec.}}{\text{revolutions per second}} = \frac{5{,}728}{\frac{1}{60} \text{ of } 1{,}200} = 286$$

For five horse power, at 110 volts

$$\text{watts} = 746 \times 5 = 3{,}730; \quad \text{amperes} = \frac{3{,}730}{110} = 34$$

Since there are two paths through the armature in parallel,

$$\text{amperes per circuit} = 34 \div 2 = 17$$

The size wire to be used is based upon a certain radiating surface per unit of energy consumed. The greater this radiating surface, the less will be the heating. The amount of ratiating surface allowed in armatures varies from 1 sq. in. per watt to 3 sq. ins. About 1.75 will insure a cool operating armature. In the accompanying tables, the current capacity is given for 3 sq. in. and for 1 sq. in. per watt. An inspection of the tables will show that the capacity of wires depends also upon the kind of winding —whether single layer or more than one layer—because radiation is more effective in carrying off the heat with outside wires than with those embedded under an outer layer of wires.

Now, since the diameter of the core is 8 ins.

$$\text{its circumference} = 8 \times 3.1416 = 25 \text{ ins.}$$

and the number of inductors per inch of circumference is

$$\text{for single layer winding } 286 \div 25 = 11.4$$

$$\text{for double layer winding } \tfrac{1}{2} \text{ of } 286 \div 25 = 5.7$$

Allowing 3 sq. ins. radiating surface per watt, the size of inductor required to carry 17 amperes is (from Table I, page 860).

for single layer winding, No. 11, B. & S. gauge

for double layer winding, No. 9 B. & S. gauge

Example.—With the armature of the previous example running at same speed and same flux conditions what is the maximum capacity that could be obtained with a two layer winding of larger size wire and same number of inductors? As calculated, the number of inductors per inch of core circumference is 5.7, hence, for table I, for 5.5 inductors per inch a No. 6 wire may be used, and for a two layer winding it may carry 28.28 amperes. Now since there are two paths in parallel through the armature

TABLE II.—1 sq. in.

Capacity of Wires at various depths of winding, 1 sq. in. radiating surface per watt

(*According to Horstmann and Tousley*)

B. & S. Gauge.	Diameter bare.	Resistance per foot 140° F.	Diameter D. C. C.	Amperes at different depths of winding layers.						Number turns per inch	I^2
				1	2	3	4	5	6		
4	.2043	.000283	.224	97.36	68.75	55.88	48.64	43.50	39.73	4.45	9498
5	.1819	.000357	.200	81 82	57.88	47.27	40.87	36.60	33.40	5.00	6720
6	.1620	.000450	.180	69.20	48.92	39 92	34.60	30.93	28.28	5.5	4800
7	.1413	.000567	.158	57 78	40.82	33 35	28.91	25.86	23 60	6.3	3344
8	.1285	.000715	.144	49.04	34.66	28 37	24.57	21.97	20.07	7.0	2416
9	.1144	.000902	.130	41.52	29.37	24 00	20.76	18.60	16.97	7.7	1728
10	.1019	.001137	.117	35.06	24.81	20.27	17.54	15.71	14.35	8.6	1233
11	.0907	.001436	.106	29.74	21.02	17.17	14.86	13.30	12.12	9.6	885
12	.0808	.00181	.093	24.79	17.52	14 31	12.40	11.09	10 09	10.7	615
13	.0719	.00228	.084	21.00	14 86	12.12	10.50	9 38	8.54	11.9	441
14	.0640	.00288	.075	17.66	12.49	10.19	8.83	7.88	7.21	13.3	312
15	.0570	.00362	.067	14.89	10.53	8.60	7.44	6.66	6.08	15.0	222
16	.0508	.00458	.059	12.40	8.77	7.21	6.20	5.56	5.09	17 0	154
17	.0452	.00575	.053	10.53	7.44	6.08	5.26	4 71	4.30	19.0	111
18	.0403	.00727	.048	8.88	6.28	5.12	4.44	3.97	3.63	21.0	79
19	0358	.00916	.044	7.54	5.34	4.35	3.76	3 37	3.08	22 7	57
20	.0319	.01153	.040	6.49	4 58	3.74	3.24	2 89	2.64	25.0	42
21	.0284	.01454	.036	5.38	3 80	3.11	2 68	2.40	2 19	28.0	29
22	.0253	.01845	.033	4.58	3.24	2.64	2.28	2 04	1.87	30 3	21
23	.0225	.0231	.030	4.00	2.82	2.30	2 00	1.78	1.64	33.3	16
24	.0201	.0295	.028	3.37	2 38	1.94	1.67	1.51	1.37	35.7	11.4
25	.0179	.0365	.026	2.93	2 07	1.67	1 44	1.30	1.18	38.4	8.6
26	.0159	.0461	.024	2.49	1.76	1.44	1 22	1 09	1.00	42.0	6.2
27	.0142	.0603	.022	2.07	1.44	1.18	1.04	.94	.84	45.5	4.3
28	.0126	.0744	.021	1.78	1.26	1.04	.89	.78	.71	48.0	3.2
29	.0112	.0925	.020	1.61	1 14	.94	.79	.71	.65	50 0	2.6
30	.0100	.1181	.018	1 34	.95	.78	.64	.60	.55	56.0	1.8

total current = 2 × 28.28 = 56.6 amperes

and capacity at 110 volts, or

watts = 56.6 × 110 = 6,226

Such 1 horse power = 746 watts,

capacity = 6,226 ÷ 746 = 8.4 horse power

In the case of slotted armatures, which is the prevailing type, a considerable portion of the circumference is taken up with the teeth that cannot be used for the winding, hence it is necessary to allow for this in figuring the number of inductors per inch of circumference.

FIG. 7,829 —Fairbanks Morse type TR machine armature construction. *The armature core* is built up of thin sheet steel laminations with notches in the circumference, which, when the discs are placed together, form grooves or slots to receive the armature coils. With specially designed tools these notches are so accurately spaced that no filing of the slots is required. The armature cores for the Nos. 23, 24, 25, 26, 27, 28 and 29, machines are mounted on a cast iron spider, which also carries the commutator, making the two parts entirely self-contained, and with this construction, it is possible to remove the armature shaft, without disturbing the core, commutator or windings.

To calculate the size wire for a slotted armature a single slot should be considered, and the wire chosen if possible with reference as to how it will fit in the slot, that is, the size should be such as to fill the slot with the least amount of waste space. In design, the approximate width of the slot is obtained by *multiplying the diameter of the wire over insulation by the number of turns per layer*, and the depth of slot obtained by *multiplying the number of layers by 86*.

To find the number of inductors per slot when the speed and flux are fixed the following formula may be used:

$$\text{inductors per slot} = \frac{10^8 \times \text{volts}}{\text{flux} \times \text{slots} \times \text{rev. per sec.}} \quad \ldots\ldots\ldots\ldots (1)$$

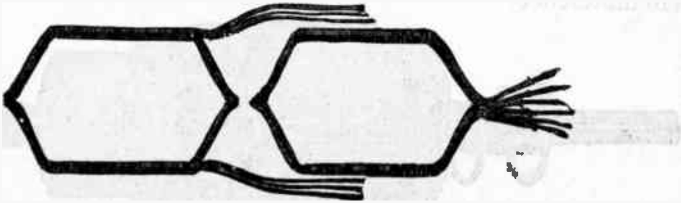
Example.—How many inductors per slot are required, to generate 110 volts, with a total flux of 1,920,000 lines, 24 slots and 1,200 revolutions per minute?

$10^8 = 100,000,000$ and 1,200 rev. per minute =
$1,200 \div 60 = 20$ rev. per sec. Substituting in (1)

$$\text{inductors per slot} = \frac{100,000,000 \times 110}{1,920,000 \times 24 \times 20} = 11.9 \text{ say } 12$$

Example.—If the slots of a 24 slot armature be ½ in. wide and there are 12 inductors per slot arranged as a three layer single coil winding, what is the maximum size wire that can be used, and current capacity for a four pole machine? If flux be provided to generate 110 volts what horse power will be developed?

Table 3 relation between slot sizes and various practical arrangements



FIGS. 7,830 and 7,831.—Fairbanks Morse wire wound armature coils of type TR machine *In construction*, the coils are form wound and are thoroughly insulated and baked before assembling in the slots. Material of great mechanical strength as well as high insulating value is used, and the coils are subjected to repeated dippings in insulating compound and to repeated bakings, thus thoroughly driving out all moisture and making a coil which is practically water proof and which will withstand rough handling. These coils when completed, are placed in the slots, where they are retained by bands on the three smaller sizes and by hardwood wedges on the larger sizes. Cores of all sizes are provided with ventilating spaces, running from the surface to the central opening of the core, so that air is drawn through the core and blown out over the windings by the revolution of the armature.

of standard double cotton wires B. & S. guage. Allowance is made in the slot widths for ⅛ in. total insulation besides the cotton wrapping on the wire, when there is only one coil per slot.

For each additional coil per slot, ⅛ in. of extra insulation is allowed. In slot depths, .17 in. beside the cotton on the wire is provided.

In the example since there are 12 inductors per slot and the winding is in 3 layers

$$\text{number of wires abreast} = 12 \div 3 = 4$$

Referring to the table it will be found that a slot .49 in. wide will accommodate four No. 10 inductors abreast. Allowing 3 sq. in. radiation per watt, the carrying capacity (from table No. 1) for a 3 layer winding of No. 10 wire is 11.7 amperes.

Since the number of paths is equal to the number of poles

$$\text{total current output} = 11.7 \times 4 = 47 \text{ amperes}$$

At 110 volts

$$\text{watts} = 47 \times 110 = 5{,}170, \text{ and}$$
$$\text{horse power} = 5{,}170 \div 746$$

After having determined the size of wire, number of turns per coil, the drop or loss of voltage due to the resistance of the winding should be determined to see if this loss be within limit.

Example.—If the average length per turn of the coils in the armature of the previous example be 2 ft., what is the drop or loss of voltage in the armature?

Since the winding is of the single coil type each coil will occupy two slots, hence

$$\text{total number of coils} = 24 \div 2 = 12$$

For 12 turns per coil,

$$\text{length of each coil} = 12 \times 2 = 24 \text{ ft.}$$

Now, since the machine has 4 poles, there are 4 paths in parallel, hence, only ¼ of the coils or 3 coils need be considered in determining the drop. Accordingly,

$$\text{length of 3 coils} = 24 \times 3 = 72 \text{ ft.}$$

According to table 1 (page 860), the resistance of No. 10 wire at 140° Fahr. is .001137 ohm per foot, hence

$$\text{resistance of 3 coils} = 72 \times .001137 = .08 \text{ ohms}$$

According to Ohms law

$$\text{current} = \frac{\text{volts}}{\text{ohms}} \text{ or volts} = \text{current} \times \text{ohms}$$

NOTE.—*To find the speed* when the volts, flux and number of inductors are fixed use this formula:

$$\text{rev. per sec.} = \frac{100{,}000{,}000 \times \text{volts}}{\text{flux} \times \text{number of slots} \times \text{inductors per slot}}$$

NOTE.—*To find the strength of field* when the volts, inductors and speed are fixed, use the formula:

$$\text{flux} = \frac{100{,}000{,}000 \text{ volts}}{\text{inductors per slot} \times \text{number of slots} \times \text{rev. per sec.}}$$

NOTE.—*To find the volts* when the inductors, flux, and speed are fixed use the formula:

$$\text{volts} = \frac{\text{flux} \times \text{inductors per slot} \times \text{number of slots} \times \text{rev. per sec.}}{100{,}000{,}000}$$

Substituting in the expression for volts,

$$\text{volts or "drop"} = 11.7 \times .08 = .94 \text{ volt}$$

which may be considered within satisfactory limit.

Magnet Calculations.—In figuring field magnets, the unit ampere turn is frequently employed and is defined as *the magnetic force due to a current of one ampere flowing through one turn of a magnet winding* numerically it is equal to the *product of one turn multiplied by one ampere.*

Thus, one ampere flowing through 10 turns, gives 1 × 10 = 10 ampere turns. Again, 10 amperes flowing through 10 turns gives 10 × 10 = 100

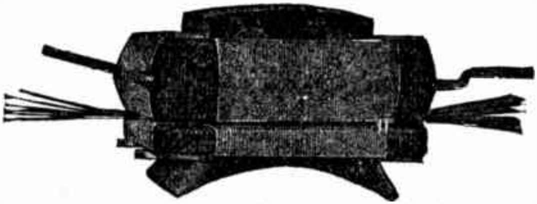


FIG. 7,832.—Fairbanks Morse field coils of type TR machine. *In construction,* the coils are wound upon iron forms, each layer treated with insulating compound. Afterward they are removed from the forms and baked hard and dry and finally wrapped with insulating materials and finished with black insulating enamel.

ampere turns. Having fixed the voltage and size of wire it makes no difference in the magnetic effect how many turns are contained in the winding, that is, for a given voltage and size of wire *the ampere turns remain the same regardless of the number of turns in the winding.*

Thus, if 10 amperes flow through 10 turns of the winding the result is 10 × 10 = 100 ampere turns. Now, if the number of turns be doubled, the resistance of the winding will be doubled which will cut down the current one half, that is, 5 amperes × 20 turns = 100 ampere turns. Of course, this is not strictly true where the magnet is made up of more than one layer, because the diameter of an outer turn being greater than that of an inner turn, its length and resistance is greater, the resulting effect being to slightly decrease the ampere turns as each layer is added. The reason then for increasing the number of turns in a magnet winding is *to cut down the current sufficently to prevent overheating of the winding.*

Example.—If the winding on a spool 8 ins. in diameter be one inch thick, what is the average diameter of the turns?

The diameter of the inner layer turns are 8 ins., and the outer layer turns 8 + 2 = 10 turns, hence,

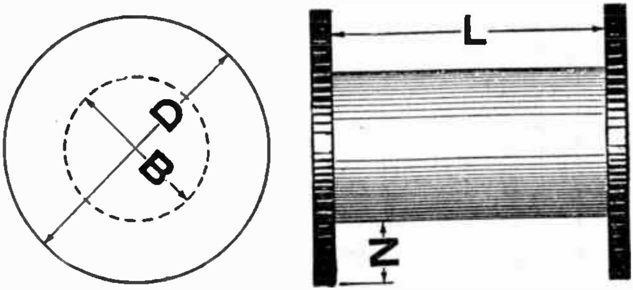
$$\text{average diameter of the turns} = \tfrac{1}{2}(8 + 10) = 9 \text{ ins.}$$

Example.—If the magnet of the previous example contain 500 turns, what is the length of the winding?

The average diameter of the turns, as obtained, being 9 ins.,

$$\text{length of winding} = \frac{9 \times 3.1416 \times 500}{12} = 1{,}178 \text{ ft.}$$

Example.—If a winding one inch deep be placed on an 8 in. spool, what is the smallest size wire that will give 10,000 ampere turns with 110 volts?



FIGS. 7,833 and 7,834.—Magnet spool with essential dimensions necessary for calculation. ***Formulæ:*** $d = \sqrt{(L \times N) \div T}$; $L \times N = d^2 \times T$; $l = (D^2 - B^2)L = k$; $W = (D^2 - B^2)L \times c$; $R = (D^2 - B^2)\ L \times a$; $rs = D \times 3.14 \times L$. In the formulæ, d = diam. of wire over insulation; l = length of wire on spool; T = number of turns; r = resistance of one foot of wire; rs = radiating surface; B = diam. of core and insulation; D = diam. over outside of completed winding; L = length of winding spaces on spool; N = depth of winding core to outside; W = weight of wire; a, c, k, constants whose values are given on next page. All dimensions in inches.

$$\text{Average diameter of turns} = \tfrac{1}{2}(8 + 10) = 9 \text{ ins.}$$

$$\text{length of average turn} = \frac{9 \times 3.1416}{12} = 2.36 \text{ ft.}$$

The sectional area of the smallest wire (in circular mils) is obtained from the formula

$$\text{*area wire} = \frac{12 \times \text{length average turn in feet} \times \text{ampere turns}}{\text{volts}} \quad \ldots\ldots\ldots (1)$$

Substituting

$$\text{area wire} = \frac{12 \times 2.36 \times 10{,}000}{110} = 2{,}575 \text{ circular mils}$$

nearest size wire from table is No. 16 B. & S. gauge.

*NOTE.—In the formula, 12 is the resistance of 1 mil foot of copper at 130° Fahr.

Having determined the minimum size of wire, the next step is to find how many turns must be placed on the spool to prevent undue heating.

The watts lost by the current heating the winding *is equal to the square of the current multiplied by the resistance*, that is

watts lost = *amperes*^{2} × *ohms*.

In proportioning the winding for depth and length, the deph of the winding must be such that there will be from 1 to 2 sq. ins. of surface

Table of Constants

B & S. Gauge.	*k* Constant for Length.			*c* Constant for Weight.			*a* Constant for Resistance.		
	Double Cotton	Single Cotton	Single Silk	Double Cotton	Single Cotton	Single Silk	Double Cotton	Single Cotton	Single Silk
20	40.9	50.4	56.7	.137	.162	.177	.415	.512	576
21	50.4	64.1	72.7				.638	.812	.920
22	60.2	78.0	89.7				.97	1.257	1.445
23	68.8	89.7	104.7				1.387	1.82	2.08
24	88.6	118.5	135.	.1115	.149	.169	2.14	2.91	3.46
25	97.2	125.	168.				3.14	4.86	5.27
26	114.	163.	202.				4.65	6.65	8.24
27	135.	202.	255.				6.94	11.75	13.1
28	148.	226.	291.	.0845	.122	.148	9.60	14.62	16.82
29	182.	291.	387.				14.85	23.7	31.6
30	201.	334.	454.				20.7	34.4	46.8
31	226.	387.	542.				29.36	50.25	70.4
32	255.	454	655.	.0687	.1045	.132	41.8	74.4	107.2
33	291.	542.	812.				60.33	114.5	168.
34	334.	656.	1023.				87.1	170.5	266.5
35	354.	712.	1140.				116.2	234.	374.8
36	387	811.	1340	.0492	.0825	1115	160.	335.5	555.
37	422.	897.	1582.				220.5	468.	806.
38	457.	1023.	1825.				308.	674.	1192.
39	496.	1170.	2165.				412	972.	1795.
40	532.	1300.	2525.	.038	.0615	.0888	557	1360.	2645.

per watt. With 1 sq. in. per watt, the magnet in operation will be "hot," and with 2 sq. ins., "warm."

Example.—How much radiating surface (neglecting the ends) on a magnet whose outside dimensions are 9 ins. diameter, 6 ins. long

area outer cylindrical surface = 9 × 3.1416 × 6 = 188½ sq. ins.

Example.—An 8 in. spool is to be wound with No. 16 wire to a depth of 1 in., which, as calculated in a previous example, is the smallest size wire that will give a required 10,000 ampere turns with 110 volts. How many turns of wire must be wound on the spool to prevent undue heating?

For winding magnets what is known as *magnet wire* is used, the wire generally having a single cotton covered insulation.

By reference to the accompanying table the number of turns per linear

TABLE III—*Properties of Insulated Wires*

(According to Houstmann and Tousley)

B. & S.	Single silk		Double silk		Dble. cotton		Resistance	I^2	I^2	I^2
	Turns per inch	Radiating Surface	Turns per inch	Radiating Surface	Turns per inch	Radiating Surface		3 sq. in. per watt. Cool	2 sq. in. per watt. Warm	1 sq. in. per watt. Hot
40	193	.016	143	.022	90	.036	.273	.027	.04	.08
39	181	.017	133	.024	87	.047	.216	.036	.055	.11
38	169	.018	126	.025	84	.037	.172	.046	.07	.14
37	156	.020	119	.026	81	.039	.136	.070	.10	.20
36	143	.022	111	.028	77	.041	.108	.086	.13	.26
35	131	.024	104	.030	73	.043	.075	.13	.20	.40
34	120	.026	97	.032	69	.045	.068	.15	.23	.46
33	111	.028	91	.035	66	.047	.054	.22	.32	.64
32	101	.031	83	.038	63	.050	.043	.29	.44	.88
31	91	.034	77	.041	59	.053	.034	.37	.56	1.12
30	83	.038	71	.044	55	.056	.027	.54	.81	1.62
29	76	.041	67	.047	53	.059	.022	.72	1.07	2.14
28	68	.046	60	.052	48	.065	.017	1.0	1.5	3.00
27	63	.050	55	.056	45	.069	.014	1.3	2.0	4.00
26	56	.055	50	.062	41	.075	.011	1.9	2.8	5.60
25	50	.062	46	.069	38	.081	.0084	2.7	4.1	8.2
24	45	.069	42	.075	35	.088	.0070	3.5	5.3	10.6
23	41	.077	37	.083	32	.095	.0053	5.2	7.8	15.6
22	36	.086	34	.092	30	.104	.0042	7.3	11.0	22.
21	33	.094	31	.101	28	.113	.0034	10.	15.0	30.
20	29	.106	27	.113	25	.126	.0026	14.	21.	42.
19	26	.119	25	.126	22	.138	.0021	20.	30.	60.
18	24	.132	22	.138	21	.151	.0017	27.	40.	80.
17	21	.148	20	.154	19	.166	.0013	39.	59.	118.
16	19	.166	18	.173	17	.185	.0011	52.	78.	156.
15			16	.191	15	.204	.00083	70.	105.	210.
14			15	.213	14	.226	.00066	107.	161.	322.
13			13	.238	12	.251	.00053	149.	224.	448.
12			12	.267	11	.279	.00042	217.	325.	650.
11			11	.298	10	.311	.00033	301.	451.	902.
10			9.5	.329	9.1	.342	.00026	421.	632.	1264.
9			8.4	.370	8.1	.383	.00021	587.	880.	1760.
8			7.5	.414	7.3	.428	.00016	842.	1262.	2524.
7			6.9	.455	6.8	.468	.00013	1167.	1750.	3500.
6			6.0	.521	5.8	.534	.00010	1680.	2521.	5042.

inch or per sq. in. of cross sectional area. Considering a portion of the winding covering an inch length of spool, 1 in. deep, the sectional area of this portion is 1 sq. in. Referring to the table of magnet wire, No. 16 wire single covered, will wind 306 turns per sq. in., that is, per inch length of spool. The length of the average turn being 2.36 ft. (as calculated in a previous example)

$$\text{length of winding per inch of spool} = 306 \times 2.36 = 722 \text{ ft.}$$

and from table its resistance being 6.39 ohms per 1,000 ft.

$$\text{resistance of winding per inch of spool} = \frac{722}{1{,}000} \text{ of } 6.39 = 4.6 \text{ ohms}$$

The outside diameter of the winding being 10 ins.,

$$\text{radiating surface per inch of spool} = 10 \times 3.1416 = 31.4 \text{ sq. ins.}$$

Now, from any electric circuit, the energy lost by heating the wire, or

$$\text{watts} = \text{amperes} \times \text{ohms} \ldots\ldots\ldots\ldots (1)$$

but by Ohm's law

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

Substituting this value for amperes in equation (1)

$$\text{watts} = \frac{\text{volts}^2}{\text{ohms}^2} \times \text{ohms} = \frac{\text{volts}^2}{\text{ohms}}$$

And if the coil be designed for "warm" working by allowing 2 sq. in. radiating surface per watt, then it must be so proportioned that

$$\text{radiating surface} = 2 \times \text{watts} = 2 \times \frac{\text{volts}^2}{\text{ohms}} \ldots\ldots\ldots\ldots (2)$$

In order to determine the length of the coil, first find what resistance would be necessary if the winding were to consist of only the one inch portion just considered. To do this, solve equation (2) for resistance, thus

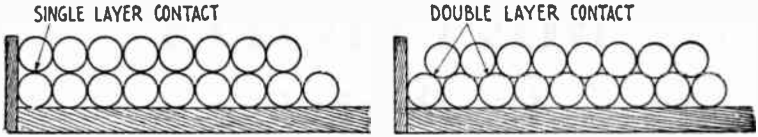
$$\text{ohms} = \frac{2 \times \text{volts}}{\text{radiating surface}} \ldots\ldots\ldots\ldots (3)$$

This will give a resistance much greater than the 4.6 ohms as calculated for that portion of the winding, hence, the spool length of the winding must be increased until the resistance of the winding has a value as obtained by equation (3). Thus substituting in equation 110 volts, and 31.4 sq. ins. radiating surface in equation (3), the necessary resistance of the winding for "warm" working, or

$$\text{ohms} = \frac{2 \times 110}{31.4} = 7$$

Accordingly, since the resistance of the winding is proportional to its length,

$$\text{length of winding} = 1 \text{ in.} \times \frac{7}{4.6} = 1.5 \text{ ins.}$$



FIGS. 7,835 and 7,836.—Square and hexagonal order of "bedding." The term bedding is an expression used to indicate the relation between the cross sectional area of the winding when wound square, as in fig. 7,835, and where wound in some other way, as in fig. 7,837. In the square order of bedding, the degree of bedding equals zero.

NOTE.—***Number of armature slots.*** As a rule there are not less than ten slots per pole. In multiple machines there are at least three or four slots in the space between adjacent pole tips. The area per slot on machines above five horse power is approximately one sq. in. and roughly the capacity of a slot of this area is about 1,000 ampere turns for machines designed to work on less than 500 volts.

NOTE.—***Number of commutator bars.*** This depends on the voltage between the bars. The number of bars may be a multiple of the number of slots. A large number of commutator bars improves the commutation but this advantage is offset by increased difficulties encountered in construction.

NOTE.—***Current density in armature inductors.*** In determining the intensity of current much depends upon the provision for ventilation and operating conditions. *In general* 600 to 700 circular mils per ampere is safe. For short overloads or for operation in hot engine rooms, 1,000 circular mils per ampere may be used.

NOTE.—***Magnetic densities.*** In small machines the ***density in the air gap*** is rarely over 32,000 lines per sq. in.; in large machines the density may be as high as 60,000 lines per sq. in. ***Density in teeth*** is usually about 100,000 lines per sq. in., being somewhat less in very small machines. ***Density in magnet core:*** cast iron may be worked up to about 40,000 or 50,000 lines per sq. in.; wrought iron and cast steel being about 95,000 to 105,000 or more lines per sq. in. ***Density in yoke:*** for cast iron the density should be about 30,000 lines per sq. in.; for cast steel, about 75,000 lines, and for wrought iron forgings about 85,000 lines. ***Density in armature core:*** this may be taken at from 85,000 to 90,000 lines per sq. in. for drum armatures.

NOTE.—***Dynamo losses.*** These are the *mechanical loss* due to friction, and *electrical losses* in the core, field, and armature. ***Friction loss.*** This ranges from 3 to 5 % in respectively small and large machines of good design. ***Core loss.*** In well designed machines this should not exceed 2% of the output at full load. ***Field loss.*** The portion of the electrical energy generated in the armature which is lost in exciting the field magnets varies from 00 to 0% of the total energy generated. ***Armature loss.*** This is usually termed the *copper* loss since it is due to the resistance of the winding; it is a very variable quantity and is equal to *the square of the current multiplied by the resistance of a section of the winding between brushes.*

NOTE.—***Armature paths in wave and lap windings.*** A wave winding has but two paths through the armature, regardless of the number of poles; whereas a lap winding has as many paths as there are poles. This distinction is important in figuring the size of wire for the winding to carry the current without undue heating.

2. REPAIR SHOP METHODS

A. Rewinding

Dismantling.—When an armature is brought into the shop

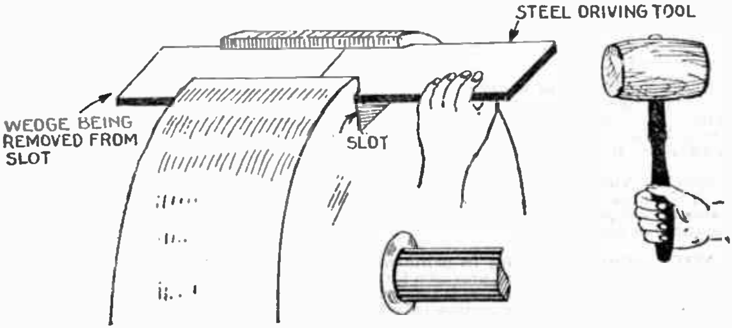


FIG. 7,837.—Operation of removing wedge from slot of armature by use of steel driving tool.

to be rewound, it must first be stripped of the old winding and re-insulated throughout. Before doing this the winding should be examined and a complete winding data sheet made out so that in rewinding, the workman will know what size wire to use, number of turns per slot, pitch of coil, and the numerous other items necessary to duplicate the former winding.

In dismantling, the first operation is to remove the banding wires, being careful if these be cut with a chisel not to dent the teeth.

Next, unsolder the commutator leads and remove slot wedges with a steel drive of the same size as the wedge. Now remove coils by raising the top sides for a distance of the throw, when the bottom side of each coil can be reached and the others taken out. Take out one coil as carefully as possible without disturbing its shape so that it will serve as a guide in forming the new coils. After all coils have been removed, the slots should be cleaned of the old insulation by burning with a torch and any burrs or rough places smoothed with a file.

Winding Methods.—The new coils are made to conform with the data taken in dismantling the old coils. In large repair shops coils are made either by winding on a mould, former, or shuttle.

Mould coils are wound by rotating the mould in a lathe. Former coils

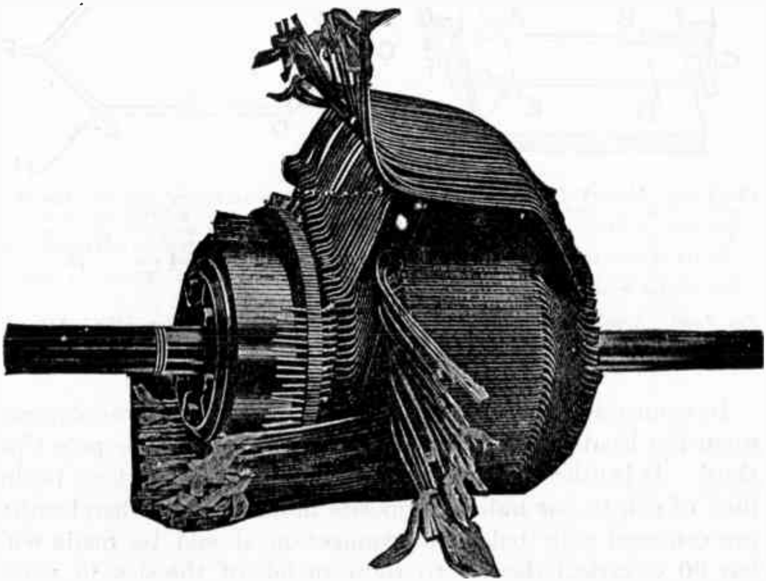
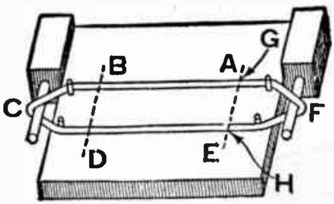


FIG. 7,838.—Holter-Cabot partially wound barrel wound armature showing arrangement of coils. The core is built up of thin discs of soft annealed steel, which are slotted to allow the wire to sink below the surface, this being sometimes called *iron clad construction.* The discs are held by end plates, clamped with through bolts. The coils are machine formed of round ribbon or bar copper depending on the size and purpose of the machine, being without joint except at the commutator. They lie in insulated troughs, the upper layers being insulated from the lower layers by fibre.

are made over stationary forms, using levers or mallets to force the coil to the proper shape. Shuttle coils are wound on a shuttle fastened in a lathe and then pulled on a coil puller to the required shape.

Commutator Connections.—Before winding, the commutator should be tested for grounds. In winding as each coil is put in its slot the sleeving on the ends of the lower leads should be fastened to the wire by friction tape and these leads inserted into the slits of the proper commutator bars.



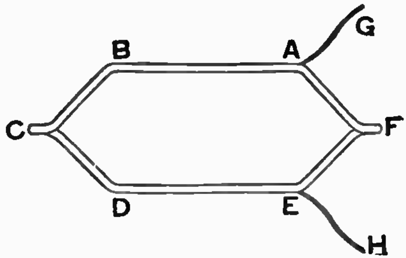
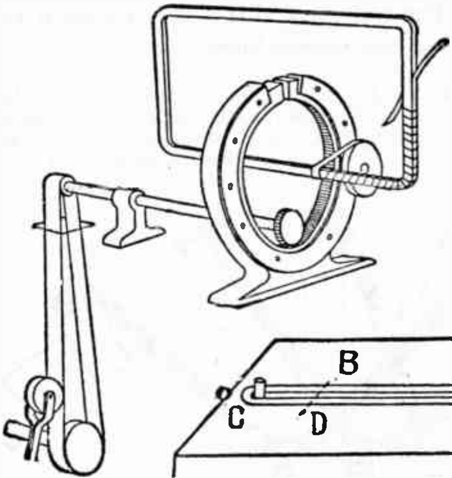


FIG. 7,839.—Method of winding "straight out" coils. There are several ways of making these coils. A former may be prepared, as shown in the figure, with a board having inserted four pins, and having attached two blocks at the ends carrying horizontal pins as shown. Around the several pins, the coil is wound to the required number of turns and taped. This coil differs from the evolute coil in that the two halves are of equal size, the parts which act respectively as upper and under inductor being of equal length. The coil as shown is suitable for wave winding.

FIG. 7,840.—Appearance of straight out coil after being opened out. *In opening out* the coil, the ends C and F, are put into a clamp and twisted at right angles to the plane of the coil. The letters correspond to the points indicated in fig. 7,839.

In connecting the first lead, the proper bar to use depends upon the location of the brushes with respect to the pole tips, thus: If brushes be midway between poles connecting beginning of coil to bar radially opposite inductor slot; when brushes are centered with poles, the connection should be made with bar 90 electrical degrees to right or left of the slot in which the beginning or bottom side of the coil is located.

In soldering care should be taken that molten solder do not fall or run down back of the commutator which would cause a short circuit. Never use an acid flux; a good preparation consists of a solution of rosin in alcohol.



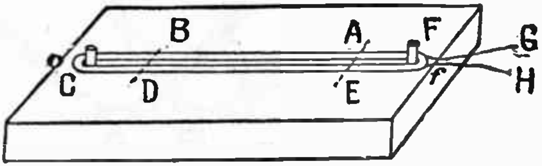


FIG. 7,841.—Armature coil taping machine. Numerous machines have been invented for taping armature coils. They consist essentially of a device which revolves a roll of tape around the coil, in such a direction that the tape is unwound from the roll and rewound on the coil. The speed at which the coil is fed through the machine will determine the overlapping of the tape.

FIG. 7,842.—Another and simpler method of winding a "straight out" coil. A board with only two pins is employed as shown; this plan, however, gives more trouble in the subsequent opening out of the coil.

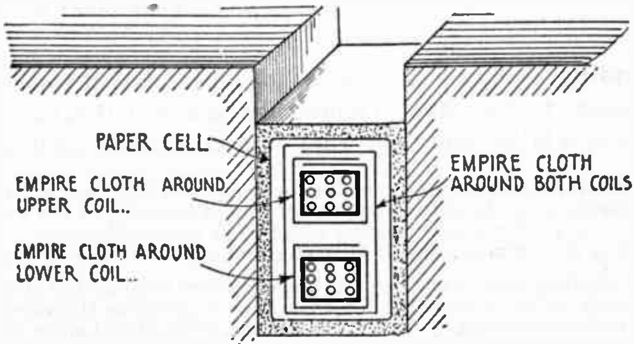


FIG. 7,843.—Method of insulating double layer winding in semi-closed slot.

Lighting Out Test.—The object of this test is to see if the leads have been connected to the proper bars.

In testing, use a lamp tester placing one terminal on a commutator bar and touch the top leads of several coils until the lamp lights. This locates the top side of the coil corresponding to the bottom side connected to the test lamp. If the lamp light on more than one lead it indicates a short circuit.

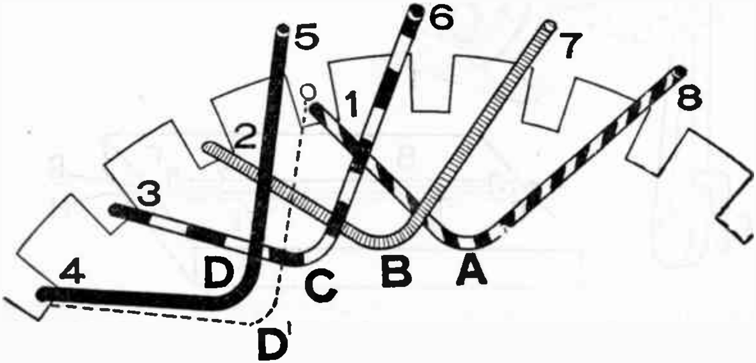


FIG. 7,844.—Method of placing two layer lap winding coils in armature slots. In a two layer winding one side of a coil will be at the bottom of a slot and the other at the top of another slot. To place coils in slot, put in the lower sides first as, 1, 2, 3, 4, of coils A, B, C, D, leaving the other side of each coil outside its slot. Evidently when enough coils to make up the inner layer have been placed this way, the upper layer side of the last coil so placed can be put into the slot. Thus, after lower layer side 4, of coil D, is put in the slot, the upper layer side 5, may be put in position on top of side 1 of coil A. Thus moving the last coil from point D to D′ indicated by the dotted line.

Banding.—Since heat causes the coil insulation to shrink, it is necessary to first put on a temporary banding to heat armature, mount in a lathe, and then wind on a temporary binding.

After the armature cools, remove the temporary banding, and put on a permanent one. In putting on the permanent banding, in the absence of a banding machine, pass banding wire two or three times around a round banding stick about 2 ins. in diameter and adjust tension by hand.

In starting, wind a few turns at one end, then wind all the groups continuously to avoid fastening the ends of each group as they are wound. The ends are fastened by means of narrow tin strips placed under the wires, bent back over the top and held by tin solder. Insert these strips about every 3 ins., while the wire is being wound on.

The end windings are secured by groups of wire wound on insulating boards.

The tension on banding wires should be from about 200 to 400 lbs., depending on the size of the wire.

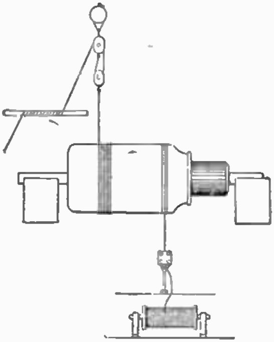


FIG. 7,845.—Method of binding armature winding. Complete appliances for handling armatures in making repairs are usually not available with most street railway companies, since they are so seldom required. When needed, therefore, some temporary contrivance must be resorted to for help in the dilemma. Should an armature burn out, some local concern that makes coils and rewinds armatures may be available to do the work; again, it will be necessary to send to the manufacturers for a man, as soon as coils can be made ready for the work. In no case should any but an experienced man be given charge of this work. But if there be any doubt as to whether the armature is really burnt out, let a competent man be the judge. When a large armature needs repairing, a pair of chain tongs can be used on some part of the shaft when putting in the coils, and a block and tackle, as shown, can be used, when putting on the band wires. Do not finish one band and then cut off the wire, but run it over for the next, etc. Then solder and trim off the wires.

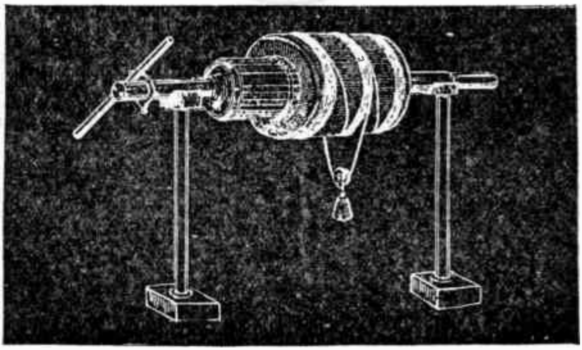


FIG. 7,846.—Method of securing tension in bending wire by use of weighted pulley.

B. COMMUTATOR REPAIRS

Grinding of Commutators.—When a new or reassembled armature has been in use some time, the shrinkage of the insulation causes the commutator bars to settle resulting in an uneven surface. This must be trued up by turning in a lathe when in very bad condition but otherwise a grinding tool, or simply an application of very fine sand paper No. 00 will do.

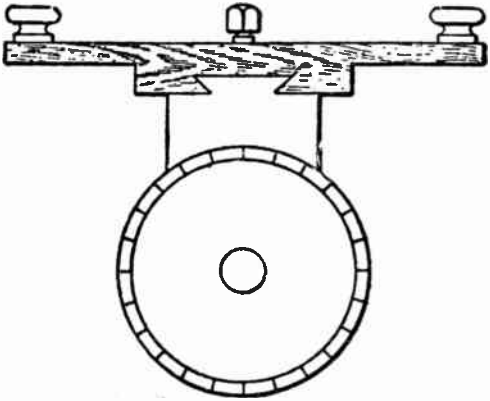


FIG. 7,847.—Method of smoothing commutator with a stone. The proper stone to use is made out of white sandstone similar to that used for grindstones, but a trifle softer. It is dovetailed into a holder, as shown in the illustration, and held in place by a set screw. When being used, one knob is grasped in one hand and the other knob in the other hand, the stone being moved back and forth along the length of the commutator. As the stone will become coated with copper at first, it must be cleaned frequently by means of coarse sand paper. The fine dust from the stone will get under the brushes and wear them to a very close fit. After using the stone, finish with fine sandpaper.

On small machines this may be applied by inserting under a brush, utilizing the brush tension to press the paper against the commutator, but on larger machines the brushes should be lifted to prevent the dust becoming imbedded in the brush contact surface, which tends to cause poor commutation.

High Mica.—This condition obtains after considerable wear and results in heating of the commutator bars due to arcing.

In severe cases the solder melts resulting in short circuits and open circuits due to leads becoming disconnected. To remedy this condition the mica must be under cut.

Undercutting of Mica.—The mica insulation between the commutator bars should be undercut from 1/32 to 1/16 in. below the surface of the bars.

In doing this be careful to avoid leaving thin slivers of mica next to

Figs. 7,848 and 7,849.—Mica segment F, cut from sheet using bar L, as pattern. Such a segment is cut large at top and at ends so as to turn down evenly with copper bars when commutator is finally surfaced.

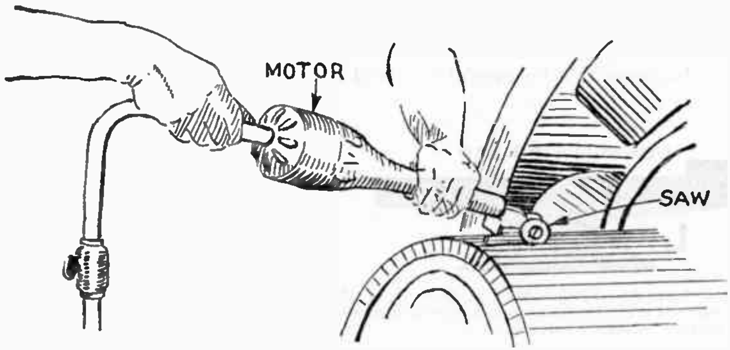
the bars. Special motor driven saws are available for cutting the mica. Small commutators may be machine cut on a milling machine. Various hand tools also have been devised for cutting the mica.

High and Low Commutator Bars.—When a commutator is hot the shellac in the mica being in a soft state will allow the bars to move more or less under centrifugal force due to rotation which is frequently the cause of high or low bars.

NOTE.—*Commutator Slotting.*—For slotting, a home made outfit is frequently used. A good cutting tool consists of a circular saw or miller ¾ to 1¼ in. in diameter with from 15 to 30 teeth. The thickness of the saw should be slightly greater than that of the mica, that is for mica .03 in. thick a .035 in. saw should be used. In this way the mica can be removed completely with no thin layers left at the sides. This saw may be mounted on the tool carriage of a lathe as here shown, and driven at from 1,200 to 1,800 *r.p.m.* by a belt from the line shaft or by a small motor mounted on the carriage. With a spacer of the same width as the commutator bars two saws may be used and the slotting operation be performed in half the time. Instead of the circular saw, a lathe tool ground to fit the slots may be used, by mounting it in the tool post and moving back and forth across the commutator by operating the carriage. It may also be mounted on a special stationary post and moved back and forth by a hand lever. These methods require a lathe which is not always available, and several types of machines avoiding this are in use

To remedy this defect let machine run till hot, then take up on commutator ring, repeating the process several times if necessary. High or low bars can sometimes be re-aligned by respectively tapping down, or prying up and inserting underneath a narrow strip of mica.

Burn Outs.—This trouble which occurs between commutator



FIGS. 7,850.—Rotary hand tool for undercutting mica and method of using. The saw is mounted between two handles and adjustable shoes are provided on each side so that the depth of the slot may be gauged and kept uniform. The saw may be driven by a small stationary motor through a flexible shaft or by a compressed air drill. In this case the armature is simply placed on a pair of V supports and clamped to prevent it turning if necessary.

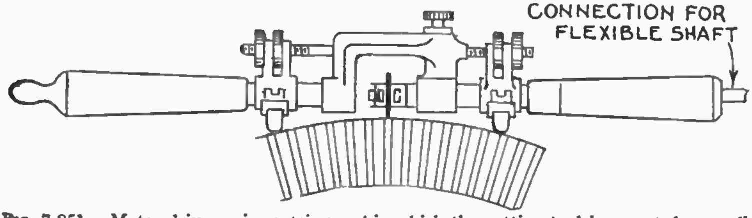
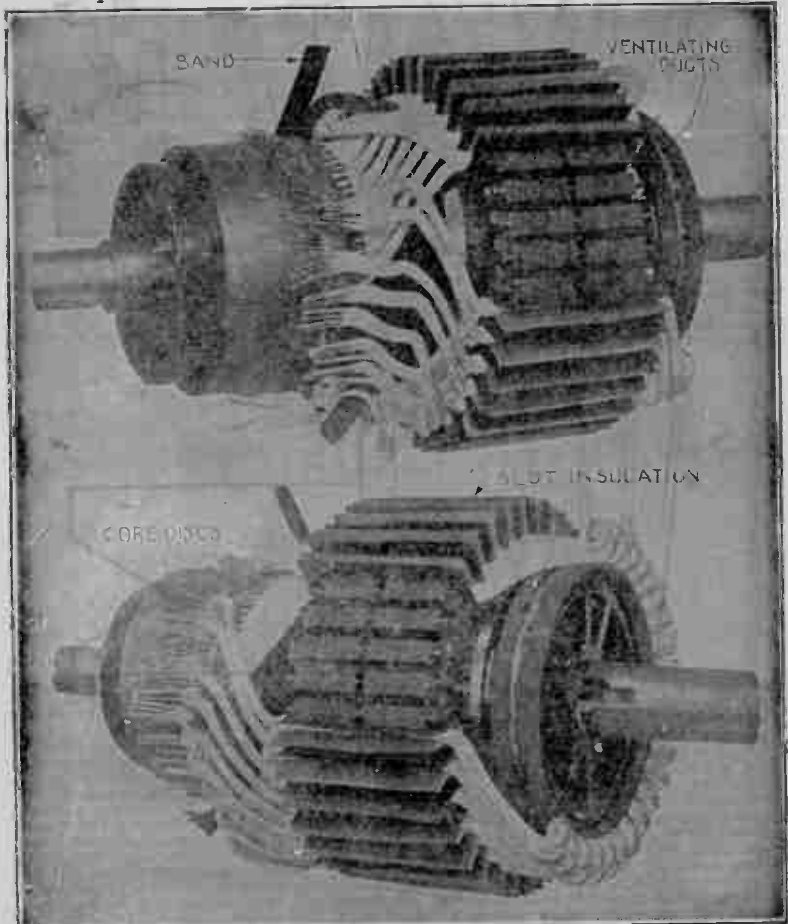


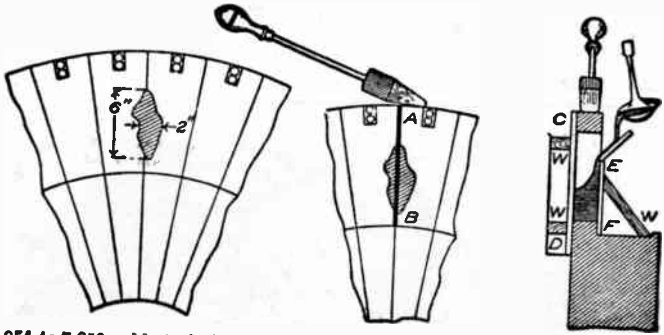
FIG. 7,851.—Motor driven mica cutting tool in which the cutting tool is mounted on a slide and moved back and forth by hand. The drive is through a flexible shaft as shown, or a belt may be used.

bars is usually due to oil which collects dust, causing leakage of current from bar to bar with resulting carbonizing of the mica and finally a short circuit

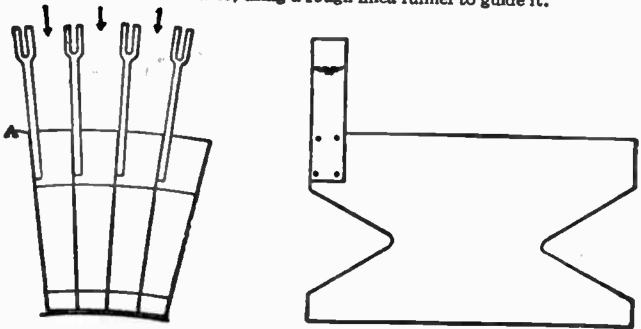
Plugging.—When the mica is not burned too deep, clean out the hole thoroughly and plug with a filling made of two parts of plaster of paris, one part powdered mica and enough glue to make a thick paste.



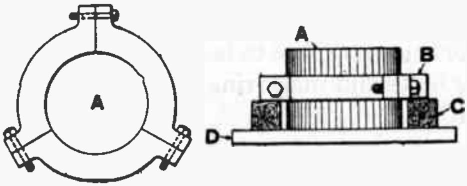
Figs. 7,852 and 7,853.—Commutator and rear ends of General Electric Standard type R.C. wave wound armature using strap coils.



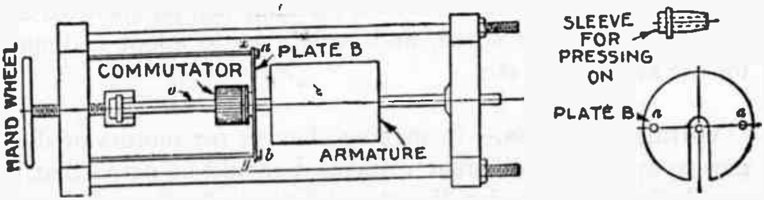
FIGS. 7,854 to 7,856.—Method of repairing a large hole burned in two adjacent bars of a commutator. Fig 7,854 shows the hole. The first operation is to clean carefully and tin the surface of the hole. The two bars are then wedged apart and mica strips, A,B, fig. 7,855, of the requisite size and thickness forced in. The commutator must now be warmed up as much as possible by means of soldering irons, and strips of mica, C,D,E, F, fig. 7,856 placed at the front and back of the hole, being kept in position by pieces of wood W. Solder is poured into the hole from a ladle, using a rough mica funnel to guide it.



FIGS. 7,857 and 7,858.—Method of repairing broken joint between commutator segment and lug. To repair such a break, push asbestos in between adjacent bars, so that heat from the torch will not affect them. Asbestos should also be worked in at the back if possible, for the purpose of keeping solder from places where it would cause trouble. Then unsolder the armature leads from the lug and remove the latter. Next, with specially made cape chisels, cut in a slot in the commutator bar for a new lug. Care and skill are required not to destroy the mica insulation between the segments. The slot should be cut one-quarter to three-eighths inch deep. The connector is then soldered in place. With care a satisfactory connection can be made in this way, which will last well. If it do not last, the trouble in almost every case is due to poor soldering. Short circuits sometimes occur after this operation, because of solder falling in at the back and lodging on lower connections. In large machines, the excessive current flowing is quite likely to melt this solder, and the machine may buck, throwing out the melted solder, after which it may be all right again. While the bar connector is out, however, asbestos should be packed in back of it to prevent this occurrence, which may be a serious affair. All surplus solder and the asbestos packing should be removed after the connection is finished, and the connections cleaned with compressed air. The armature should be turned over slowly, air being applied all the while.



FIGS. 7,859 and 7,860.—Ring or clamp for holding commutator bars together when assembling and method of using. The clamp should be slightly smaller than the diameter of the commutator. *In using,* wooden blocks C, may be used as distance pieces to align the clamp at the middle of the commutator. D is an iron face plate. The distance pieces C, and clamp B, are placed on the plate D, as shown, and the bars and mica segments stacked in a circular form within it. Be careful not to omit any of the mica segments, so that each bar is insulated. Carefully count the bars to be sure that the correct number are in position. Take several pieces of copper wire (about No. 9 B. & S. gauge) and remove the insulation. Place these around the commutator near the top and lower ends to act as band wires, and twist them tight. The clamp may then be removed, and the commutator straightened. Bring out the mica segments even with the surface of the bars by holding the fingers against the inside edge of the segments and tapping the bars on the outside with a small mallet. Place a square or steel scale on the face plate and tap the bars on the outside with a small mallet. Place the square of steel scale on the face plate and see that the bars line up perpendicularly with one edge of the square. If they do not, a gentle pressure one way or the other on the top end of the commutator with the palm of the hand will bring them in line. See that each bar and segment is down flat against the surface of the plate, since that end will be fastened to the face plate on the lathe facing off the ends of the bars. Tap each bar and segment down solid with a square ended punch, a little narrower than the thickness of the bar. When this has been done, the band wires can be drawn a little tighter and the surface of the commutator, where the clamp will fit, should be filed to remove any protruding mica, and present a smooth surface for the clamp. Replace each section of the clamp about the commutator again using the wooden blocks mentioned before. Draw the clamp tight, being sure to leave the same amount of space between each clamp section. A small gas burner, or some other source of heat should be handy, and the commutator placed over it and heated. When it is good and hot to the hand, tighten the clamp, allow it to cool, and again tighten.



FIGS. 7,861 to 7,863.—Press for forcing on and removing a commutator. Small commutators are pressed on to the shaft by a hand press. All of the larger commutators are pressed on by means of a power press. In the above figure is shown a hand press. The plate B, is used in removing old commutators. It is placed back of the commutator as at x,y, with the slot C, over the shaft. Bolts a,b, are passed through the holes in the plate and secured by nuts. The commutator can then be forced off the shaft. In pressing on a commutator, a sleeve is placed over the shaft at O, and against the commutator. The rear end of the shaft is secured so it will withstand the pressure, and the commutator is forced on. The power presses are built on the principle of a hydraulic press. In pressing on a commutator a piece of babbit metal or soft brass should be used against the end of the shaft. The shaft should be painted with white lead before having the commutator pressed on, in order to lubricate the shaft so that the commutator will press on easily. The wiper rings are pressed on after the commutator and then the armature is ready to be connected.

Dissembling Commutator for Repairs.—If a burned commutator bar or mica strip are to be removed for repairs, unloosen clamping ring bolts and mark ring so that it can be replaced in the same position.

Remove clamping ring and if the mica ring be stuck to commutator it should be heated to soften the shellac. After the ring is taken off it is easy to remove any of the bars. In replacing a bar the mica segment should be put in first, being careful to first see that there is no dust or solder lodged on the back of mica ring.

Tightening a Repaired Commutator.—When assembled put on clamp ring and screw up bolts. Bake in oven to drive out the shellac, let cool and again take up on ring bolts.

Repeat operation one or more times until there is no slack in the bolts.

B. RE-CONNECTING D.C. MACHINES

Repairmen are frequently called upon to make changes in a dynamo or motor such that the machine can be operated at a different voltage or speed, and sometimes to adopt a dynamo for use as a motor, etc.

Voltage Changes.—In making changes for motors or dynamos to operate on different voltages it should be noted that the speed of a motor varies directly with the voltage.

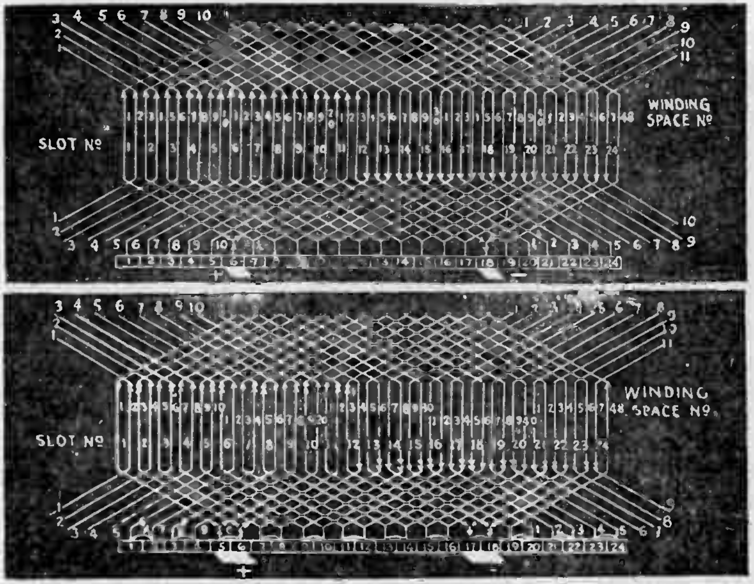
The variation of voltage affects the excitation of the fields, and after saturation is reached the speed only approximately varies with increase of voltage. Small speed change may be effected by changing the width of the air gap.

Changes for Half Voltage Operation.—Arrange the shunt field coils in two groups and connect the groups in parallel.

With this arrangement evidently on half voltage circuit, the voltage per field coil will be the same, hence the flux will be the same but the speed will be only half what it was before the changes were made. To bring speed up to normal, place resistance in the shunt field and increase air gap as much as possible. The foregoing changes reduce the horse power one half.

Changes for Double Voltage Operation.—The field coils must be rewound in case with the shunt fields in series the smallest air gap cannot be used. Changing for double voltage, gives twice the horse power.

Armature Winding Changes for Voltage Changes.—



FIGS. 7,864 and 7,865.—A 240 volt, 24 slot lap winding and method of reconnecting or rewinding for 120 volts. When a *d.c.* armature is to be rewound or reconnected for a change in voltage *the number of turns in series between the brushes, will vary directly as the voltages*, and *the cross sectional area of the wire will vary inversely as the voltages.* To reduce the voltage from 240 to 120 and do the same amount of work, twice the current will be required and accordingly, twice the cross sectional area of wire. The winding may be reconnected so that two coils are in parallel and bridge the commutator bars in pairs as in fig. 7,865, or the machine may be rewound with a wire of double the cross sectional area.

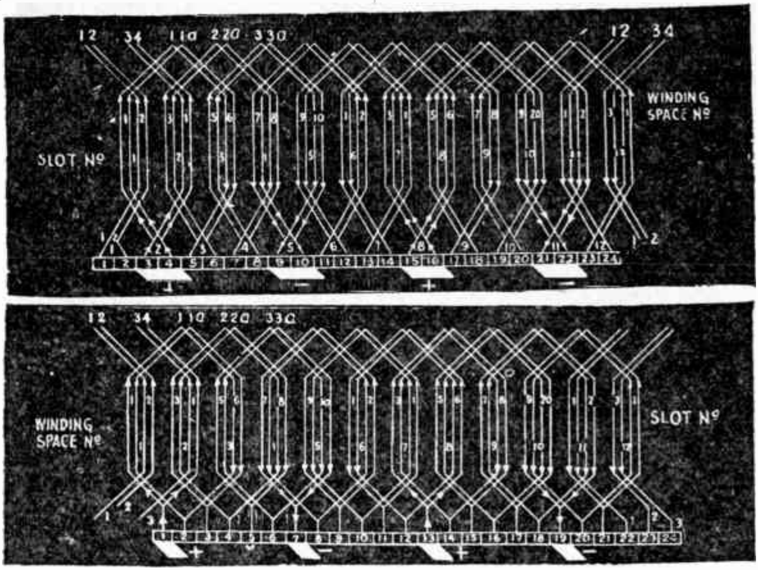
An armature can usually be adapted to a lower voltage either by reconnecting or by rewinding.

In making changes it should be noted that the sectional area of the wire for the coils and number of turns in series vary inversely as the old to the new voltage. In determining the form of coil and number of turns to be used in rewinding the slot space available must be considered.

Speed Changes.—By adjusting the air gap of a motor the speed may be varied from 10 to 15%. To increase speed, increase air gap; to reduce speed, reduce air gap.

Dynamo Operated as Motor.—Give backward lead to brushes for the correct rotation of the armature.

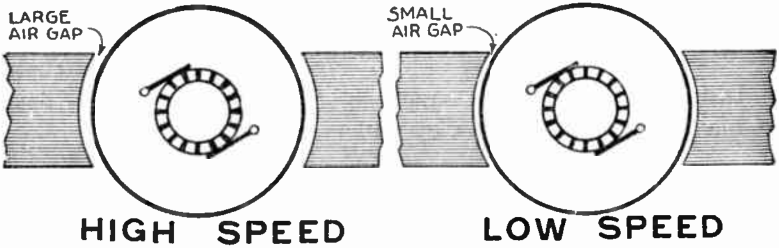
Motor Operated as Dynamo.—The brushes should be given forward lead and the air gap reduced to a minimum for equal or



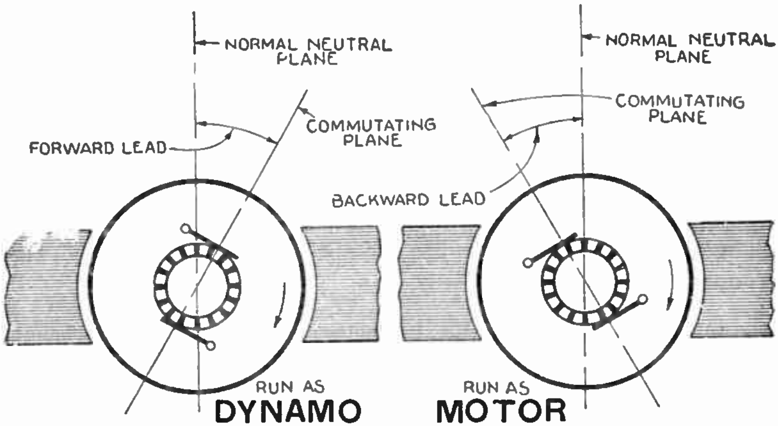
FIGS. 7,866 and 7,867.—Duplex lap winding for 120 volts, and method of reconnecting for 240 volts. On armatures having duplex windings there are usually twice as many commutator bars as there are slots and each of the two wires is connected to separate bars. The brush will however cover at least 1½ to 2 bars. To change from 120 to 240 volts, reconnect the winding so that adjacent pairs of coils will be in series as in fig. 7,867 instead of in parallel as in fig. 7,866, and reduce width of brushes to that of one commutator bar.

higher voltage, but for lower voltage the same air gap can usually be used.

Wrong Field Connections.—Sometimes due to error in the shop a new motor may have one or more magnets reversed, resulting in little or no torque. Trace out connections or test polarity of magnets by means of a compass.



FIGS. 7,868 and 7,869.—Method of changing the speed of a motor by adjusting the air gaps.



FIGS. 7,870 and 7,871.—Machine operated as dynamo and as motor. When the machine is operated as dynamo the brushes should be given *forward* (positive) *lead*, and when operated as a motor, *backward* (negative) lead

Wrong Rotation.—In the case of a motor the direction may be changed by reversing the field connections.

If the field of a dynamo be reversed to change rotation, the magnetism induced by the winding will oppose the residual magnetism and the machine may not *build up*. Instead of reversing the field, reverse the armature leads. A multipolar machine can be reversed by reversing the brushes on the studs and then relocating them.

C. Reconnecting A. C. Machines

Induction Motors.—Changes in voltage alone are the easiest to make, but phase changes are seldom advisable.

In making changes the repair man should first examine the winding and note throw and connection of coils, number of turns in coil, size of wire, etc., so that he can get an idea of the possibilities of the machine.

Voltage Changes.—Nearly all commercial motors are arranged so that they can be reconnected for two voltages.

To make these changes, the polar groups are connected in series for the higher voltage and in parallel for the lower voltage.

In changing to higher voltages it should be noted that motors as manufactured are provided with insulation good for 500 volts or for 2,500 volts. The capacity of the insulation should accordingly be considered and no change be made beyond the capacity of the insulation.

Frequency Changes.—For the same number of poles a change in frequency will cause the speed to vary directly as the frequency.

In order to maintain the speed constant in making a frequency change, the voltage on the motor should be varied in the same proportion as the frequency is changed.

Phase Changes.—The change most frequently desired is from two to three phases, or from three to two phases.

For the same voltage there should be about 25% more total turns in a two phase winding than in a three phase winding, hence, unless the voltage be reduced a three phase motor connected for two phase will overheat.

A two phase motor has too many coils for three phase operation, hence, in this case, about 1/5 of the total coils might be dead ended to secure the proper voltage on the other coils. In doing this the dead coils should be distributed as symmetrically as possible.

Reversing Polyphase Induction Motors.—For a two phase four wire machine, interchange the connections of the two leads on either phase.

For a two phase three wire motor, interchange the two outside leads.
For a three phase machine, interchange the connections of any two leads.

Method of Soldering Wires to Lugs.—The *Code* requires that all stranded wire above No. 8 B. & S. gauge shall be soldered to all terminal lugs or terminal connectors. The following is the approved method:

First, coat the lug with laundry soap; this is to prevent surplus solder sticking to outside surface of lug, making an unsightly job. Next, fill lug with soldering paste, and hold lug in flame of a gasoline torch, when soldering paste begins to bubble, put a little solder in the lug; this will melt very easily as the lug is now heated to the proper temperature.

Skin or remove insulation of wire, and clean same with file until it shows the copper to be bright. Coat end of wire with paste in flame of torch; when paste bubbles, insert wire into lug, which contains melted solder, remove flame of torch from lug and do not move the arms until the solder has set; a quick method is to apply wet rag to lug to cool solder. Now, take pliers and try to twist off lug from wire. This is a test to prove if wire be securely soldered to lug. If lug come off wire, this indicates that it has not been properly soldered. Next clean off soap and polish lug; tape up any bare spaces on wire.

The following points should be remembered:

Use plenty of paste.

Wire to be soldered must be as hot as the solder

Wire and interior of lug must at all times be clean.

Do not use cutting pliers to hold lug in flame as this softens the cutters and thereby ruins the pliers.

Use a good solder having a good combination of lead and tin; 50-50 recommended or 60-40 is the standard for electrical work.

If solder do not hold in lug, this is due to poor solder, dirt in lug—dirty wire. Remedy: fill lug with paste melt solder in lug, dump out solder, then repeat as described and it will be found that the lug will hold.

TROUBLES

Failure to Excite.—In starting a dynamo it should be remembered that shunt and compound machines require an appreciable time to build up, hence, it is best not to be too hasty in hunting for faults.

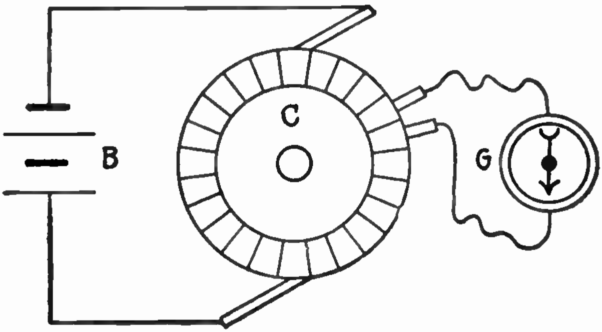


FIG. 7,872.—Method of locating short circuited armature coil. Connect apparatus as shown, pass 20 to 100 amperes from a battery or another dynamo. Now having previously well cleaned commutator, measure voltage between adjacent segment all around. A zero reading will indicate a short circuit, which may be permanent or intermittent; when intermittent i may be carried by wire coming into contact due to centrifugal force developed while armature is rotating.

The principal causes which prevent a dynamo building up are:

1. Brushes not properly adjusted;
2. Defective contacts;
3. Incorrect adjustment of regulators;

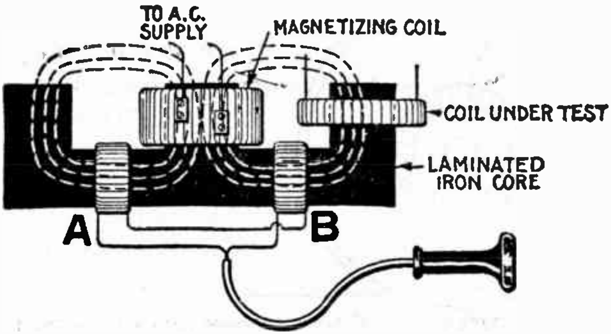
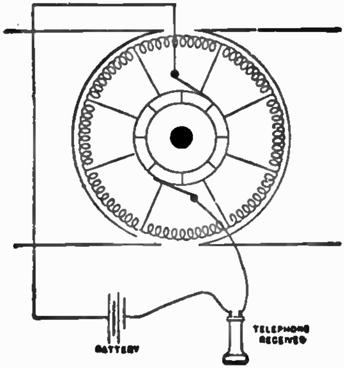


FIG. 7,873.—Field coil testing with telephone receiver. In the method here shown, a telephone receiver is connected in series with two symmetrically placed coils A and B. Very little sound will be heard when the flux through the two coils AB is the same; but if a short circuited coil is being tested, the fluxes through the coils A, B will not be equal and a noise can be heard in the receiver.



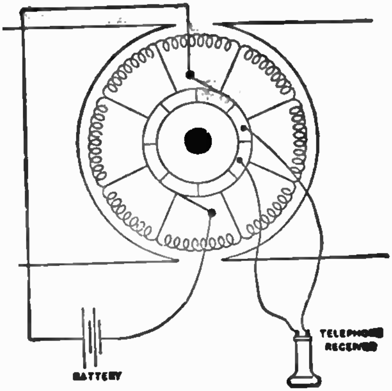
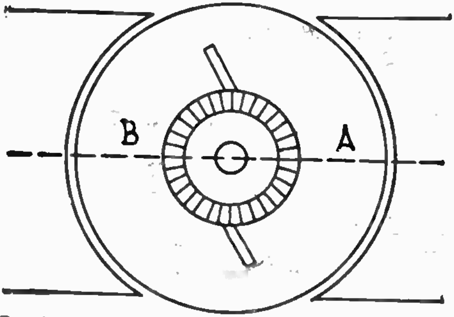


FIG. 7,874.—Test for break in armature lead. Connect apparatus as shown and clean commutator. Rotate armature slowly; telephone receiver "clicks" as brush makes contact with each good segment; a faulty segment gives no response. Note:—Brushes must not cover more than a single segment.

FIG. 7,875.—Bar to bar test for open circuit. In coil or short circuit in one coil or between segments. If, in testing as in fig. 206, on rotating the armature completely around, the receiver indicate no break in the leads, connect battery as here shown, and touch the connections from the receiver to two adjacent bars, working from bar to bar. The clicking should be substantially the same between any two commutator bars; if the clicking suddenly rise in tone between two bars, it indicates a high resistance in the coil or a break (open circuit).



4. Speed too low;
5. Insufficient residual magnetism;
6. Open circuits;
7. Short circuits;
   a. In external circuits;
   b. In dynamo.
8. Wrong connections;
9. Reversed field magnetism

FIG. 7,876.—Method of locating short circuits between adjacent armature coils. Excite fields with coils in parallel. It will now require considerable force to rotate the armature, and then it will move quite slowly, except at one position. When this position has been found, mark the armature at points in the center of the pole pieces at points A and B and at both ends of the armature. The "cross" or "short" circuit is nearly always found on the commutator end in the last half of the winding, where the wires pass down through the first half terminals. This applies to an unequal winding. In armatures where the windings are equal, it is as liable to occur at one point as at another.

Armature Faults.—The chief mishaps to which armatures are subject are:

1. Short circuits:
   In individual coils; between adjacent coils; through frame or core; between sections of armature; partial short circuits
2. Grounds;
3. Breaks in armature circuit.

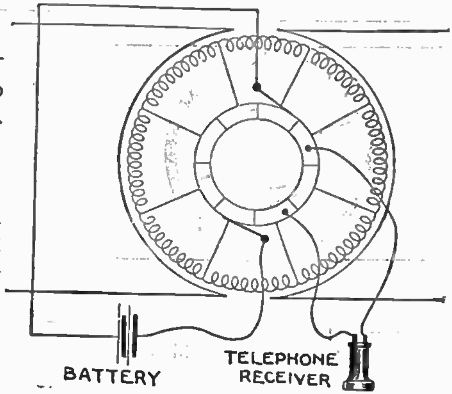


FIG. 7,877.—Alternate bar test for short circuit between sections. Where two adjacent commutator bars are in contact, or a coil between two segments becomes short circuited, the bar to bar test described in fig. 7,875 will detect the fault by the telephone receiver remaining silent. If a short circuit be found, receiver leads should straddle three commutator bars as shown. The normal click will then be twice that between two segments until the faulty coils are reached, when the clicking will be less. When this happens, test each coil for trouble and, if individually they be all right, the trouble is between the two. To test for a ground, place one terminal of the receiver on the shaft or frame of the machine, and the other on the commutator. If there be a click, it indicates a ground. Move the terminal about the commutator until the least clicking is heard and at or near that point will be found the contact Grounds in field coils can be located in the same manner.

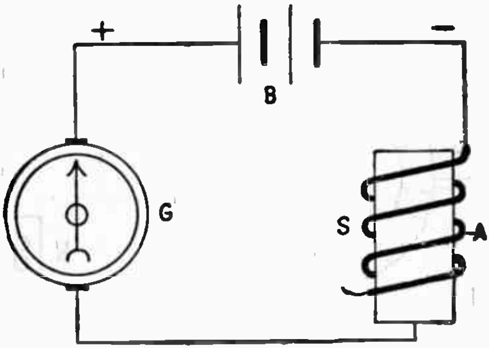


FIG. 7,878.—Method of locating short circuit between coils through armature coil. *Connect* as shown, then connect free terminal of galvanometer to shaft. If then some portion of the wire insulation be abraided or destroyed, as at A, the galvanometer needle will be deflected.

Commutator Troubles.—In badly designed or constructed dynamos, sparking occurs at all positions, no matter where the brushes are placed, and in such dynamos it is therefore impossible to prevent this no matter how well they are adjusted.

Sparks due to bad adjustment of brushes are generally of a bluish color; when produced by dirty or neglected state of commutator, the color is reddish and there is a spluttering or hissing sound. The chief causes of sparks are:

1. Bad adjustment of brushes;
2. Bad condition of brushes;
3. Bad condition of commutator;
4. Overload of dynamo;
5. Loose connections, terminals, etc.;
6. Breaks in armature circuit;
7. Short circuits in armature circuit;
8. Short circuits or breaks in field magnet circuit.

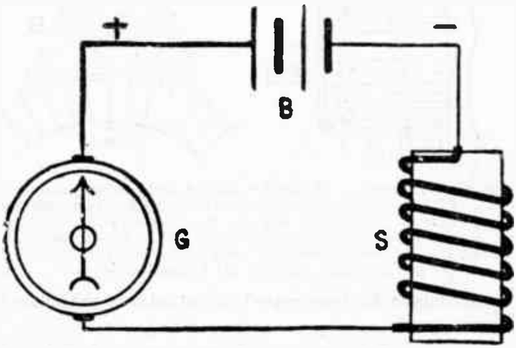
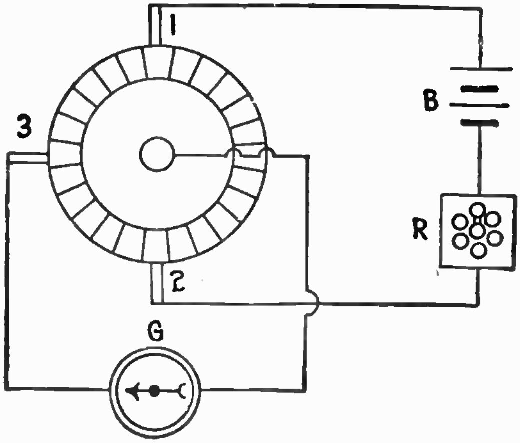


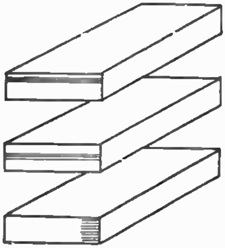
FIG. 7,879.—Method of testing for breaks. Connect as shown. Galvanometer deflection indicates that wire of coil S, being tested is unbroken. No deflection indicates a break or faulty terminal connection

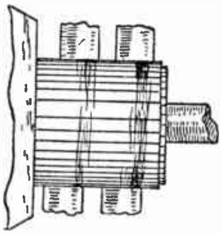
Heating.—When the machine heats, a common mistake is to suppose that any part found to be hot is the seat of the trouble.

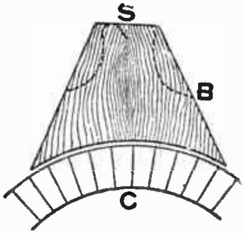


Hot bearings may cause the armature or commutator to heat, or vice versa. All parts of the machine should be tested to ascertain which is the hottest, since heat generated in one part is rapidly diffused. This is best done

FIG. 7,880.—Method of locating grounded armature coil. Connect as shown; assume a steady current to be flowing from battery through the armature; touch the commutator with brush 3, and a current will flow through the galvanometer. Slowly rotate the armature or the brush 3, until the galvanometer shows no deflection. The coil in contact with 3, will be found to be *grounded*. A rheostat may be inserted in series with the battery or dynamo circuit to regulate the strength of the current passing.







FIGS. 7,881 to 7,883.—Brushes making bad contact. A brush making a bad contact, as only at the shaded portion of figs. 7,881 and 7,882, will not allow the short circuited coil enough time to reverse, causing sparking and heating. The latter will also result from bad contact on account of the surface being too small for the current to be carried off. This form of bad contact is worse than that shown in fig. 7,883, where the area of contact surface only is lessened. If the brushes do not make good contact, they should be ground down.

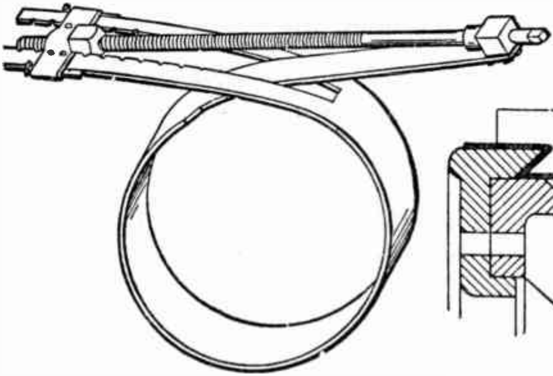
FIG. 7,884.—Rough and grooved commutator due to improper brush adjustment and failure to keep brushes in proper condition

FIG. 7,885.—Sandpaper block. It is made to fit the surface of the commutator. At S, is a saw cut into which the ends are pushed after being wrapped around the block. The latter should be cut down on the dotted lines to form a handle. The dotted line extending to B, indicates the portion of the block cut away to afford a good grip. C, commutator.

by starting with the machine cold; any serious trouble from heating isusually percep tible after a run of a few minutes at full speed with the field magnets excited.

Heating may be due to various electrical or mechanical causes, and it may occur in the different parts of the machine, as in:

1. The connections;
2. The brushes and commutator;
3. The armature;
4. The field magnet;
5. The bearing.



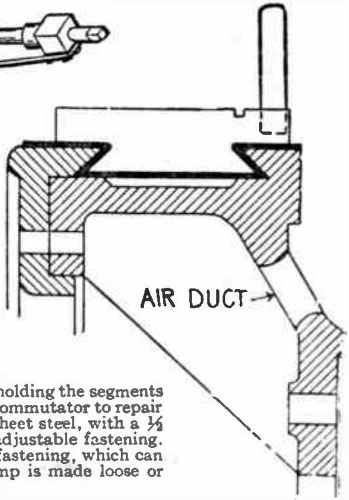


FIG. 7,886.—Commutator clamp; a useful device for holding the segments firmly in position in taking out the end rings of the commutator to repair for internal grounds. It is made of 2 × 1/8 inch sheet steel, with a 1/2 inch screw. The illustration clearly shows the adjustable fastening. The notches fit around rivets on one side of each fastening, which can be moved by removing the two cotters. The clamp is made loose or taut by screwing the bolt in the nut.

FIG. 7,887.—Ventilated commutator; Sectional view showing air ducts for maintaining low temperature.

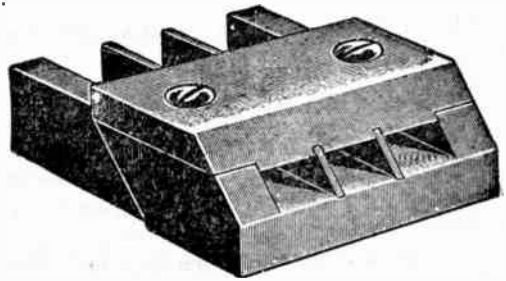


FIG. 7,888.—Jig for filing brushes to the correct level; used with copper brushes to fit them to the commutator.

1. Split Phase Motor Troubles

Speed Too Low.—This may be due to any of the following causes, which may be corrected by the remedies given.

1. Wrong voltage and frequency.
2. Overload reduce low on motor, replace with a larger motor is necessary.
3. Grounded starting and running windings. Test out with magneto lamp bell or voltmeter.
4. Short circuited or open winding in field current. Test out as above.
5. Too small connection wires. Increase size of wires.

Faulty Starting.—Motor starts, runs slowly, will not pick up to normal full load speed, and blows fuses, due to:

1. Failure of cut out to work properly. Test out cut out for grounds or short circuit. Oil pivots and springs, sand paper rough spots.
2. Grounded plate, test with lamp or magneto, one wire to each slip ring or contact plate.
3. Open circuit in starting or running winding.
   Test out with magneto or lamp.
4. Grounded or short circuited starting or running winding.
   Test out with magneto, Bell and battery or voltmeter.

Motor Fails to Start.—This fault is sometimes encountered. In such cases

1. Test line voltage with lamp.
2. Test fuses with lamp.
3. Trace out all connections for grounds, open or short circuit.
4. See if brushes be making proper contact with collector riugs or contact plates.
5. See that rotor is free to rotate in bearings.

Motor Fails to Start and Hums Loudly.—This may be due to the starting winding being burnt out, open, or grounded.

If motor hum, this indicates that the main or running winding is not open; the motor may be started by rotating the armature by hand until it reaches its normal rated speed.

Sparking At the Brushes.—As the brushes of split phase motors are only used in starting, sparking may be due only to worn and loose brushes, or dirty slip rings.

Clean slip rings with a benzine soaked rag. Apply a little vaseline with the finger to each slip ring to prevent cutting by the brushes.

Heating of the Windings.—This may be due to any of the following causes:

1. Moisture in windings. Dry out in an oven.
2. Short circuit or ground. Test out with magneto, lamp, bell or voltmeter.
3. Overload. Reduce load or install a larger motor.
4. Too low line voltage. Check up with voltmeter.
5. Too high line voltage. Any voltage in excess of 5% on 220 volts, 10% on 110 volts should be reduced at this will cause the windings to burn out.
6. Wrong frequency. A 40-cycle motor cannot be used on 60 cycle current as the rotor will not revolve in synchronism with the alternator.
7. Wrong voltage connections to motor.
8. Connection wires too small This will cause a voltage drop.

Heating of the Rotor.—This is usually caused by overloading the motor or by broken soldered connections of end bars. Reduce load or solder broken connections.

2. Fractional Horse Power Motor Troubles

Motor Fails to Start.—Be sure that the wires connected to the motor terminals make good contact; that each of the brushes of the motor makes perfect contact with the commutator; that the connected load is not too great for the size of motor used.

Motor Hums Loudly and Refuses to Start.—The fault may be due to

1. Short circuited field windings.
2. Grounded connections, or cut out switch.

Test out individual windings with volt meter, holding one wire to frame, the other to each lead of field windings.

Test out cut out switch with magneto, one wire to shaft the other to each half of cut out plates.

Motor Runs Too Slow.—This fault may be due to

1. Burnt out, short circuited, or grounded winding.
2. Grounded cut out switch.
3. Cut out switch refuses to short circuit itself.

This may be due to corroded springs, dirty plates, dirt in springs and pivots.

Care of Compensators.—These should be inspected once a year and the oil changed. Use only oil as furnished with the compensator by the manufacturer, as this has been found to give the best results; any other grades of oil will cause a lot of unnecessary trouble.

If the contact fingers on the switch of the compensator be scortched or burnt they should be smoothed with a piece of sand paper, if they be too far burnt or worn, they should be replaced with new ones.

Tighten all springs on switch and no voltage release, so that contact fingers press firmly on all contact.

Oil all exterior moving parts of switch handle, also the no voltage release.

Grounding of Compensators.—The cases of all compensators should be grounded especially when installed on high voltage circuits, to insure safety to the operator if for any reason the current carrying parts should accidentally come in contact with the case.

A good contact is obtained by securing the ground wire under a screw or bolt on the compensator.

The ground wire should be run to a water pipe as required in the *Code*.

3. *Compensator Troubles*

Motor Fails to Start.—If the fuses and motor be in good condition, examine all contacts and see if contact fingers make contact.

Press with a screw driver all contacts and see if motor start. Trace out all leads from terminal block to contacts. Examine all transformer taps. In case of a burn out on one coil of a three phase compensator the coil may be cut out by a slight change in connections and the compensator used temporarily until a new set of coils can be obtained.

Compensator Hums.—This is due to an improper sealing surface of the no voltage release or loose laminations of the solenoid or transformer.

Tighten all screws on the no voltage release solenoid plunger and no voltage coil, also tighten screws on transformer.

No Voltage Release Fails.—If the voltage release fail to hold switch in running position, the fault may be due to:

1. Burnt out no voltage coil.

   Test with a magneto.

2. Wrong connections.

3. Latch of no voltage release stuck.

   This may be due to dirt or foreign object. Remove same.

4. Overload relay plunger stuck.

   This causes an open circuit in the no voltage release circuit. Inspect all relays, and try moving by hand, and note if they make contact.

CHAPTER 37

Power Stations

There are three general classes of power stations:

1. Central stations. 2. Sub-stations. 3. Isolated stations.

and these may be classed:

1. With respect to their function, as

a. Generating stations. *b.* Distributing stations. *c.* Converting stations.

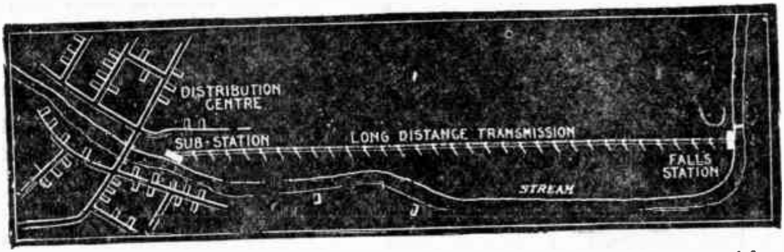


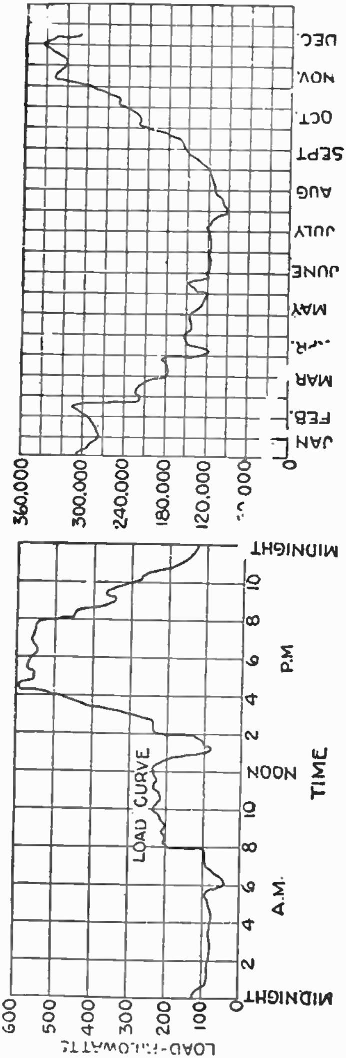
FIG. 7,889.—Example of central station located remote from the distributing center and furnishing alternating current at high pressure to a sub-station where the current is passed through step down transformers and suplied at moderate pressure to the distribution system. In some cases the sub-station contains also converters supplying direct current for battery charging, electro-plating, etc.

2. With respect to the form of power used to generate the current, as

a. Steam electric. *b.* Hydro-electric *c.* Gas electric.

3. With respect to the kind of current generated, as

a. Direct *b.* Alternating. *c.* Direct and alternating



FIGS. 7,890 and 7,891—Power station load curves; fig. 7,890, load curve for one day; fig. 7,891, load curve for one year.

Location of Central Stations. — Usually they are located so that the average line drop is a minimum. this point of location being called the center of gravity of the system.

In practice this is rarely the best location because the price of land, difficulty of obtaining water, facilities for delivery of coal and removal of ashes, etc., may more than offset the minimum line losses and copper cost due to locating the station at the center of gravity of the system. There should be room for future extension of the plant.

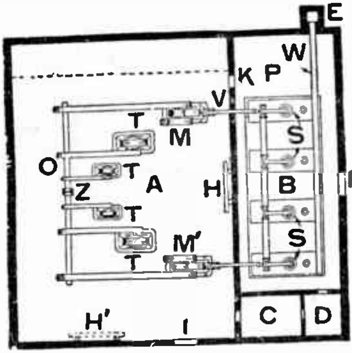
Choice of System.—The chief considerations in the design of a central station are *economy and capacity*.

When the current has to be transmitted long distances for either lighting or power purposes, economy is attainable only by reducing the weight of the copper conductors. This can be accomplished only by the use of the high voltage currents obtainable from alternators.

Again, where the consumers are located within a radius of two miles from the central station, thereby requiring a transmission voltage of 550 volts or less, dynamos may be employed with greater economy.

Alternating current possesses serious disadvantages for certain important applications.

For instance, in operating electric railways and for lighting it is often necessary to transmit direct current at 500 volts a distance of five or ten miles. In such cases, the excessive drop cannot be economically reduced by increasing the sizes of the line wire, while a sufficient increase of the voltage would cause serious variations under changes of load. Hence, it is common practice to employ some form of auxiliary dynamo or booster, which when connected in series with the feeder, automatically maintains



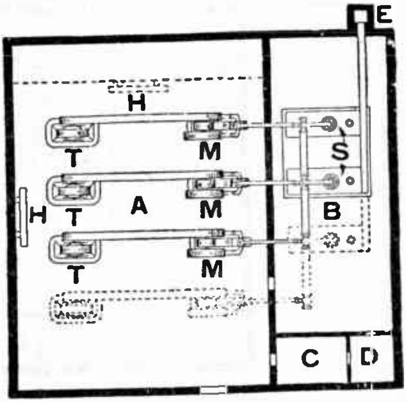


FIG. 7,892.—Floor plan of station having belted drive with countershaft A, engine and dynamo urn; B, boiler room; C, office; D, store room; E, chimney connected with the boilers by flue W;S,S, boilers; V, V, steam pipes; M, M, engine; O, countershaft; T, T, T, T, generators; H, switch board. A pulley may be mounted on the countershaft O, with a friction clutch. A jaw clutch may also be provided at Z, thus permitting the shaft O, to be divided into two sections. It is therefore possible by this arrangement to cause either of the engines to drive any one of the generators, or all of them, or both of the engines to drive all of the generators simultaneously.

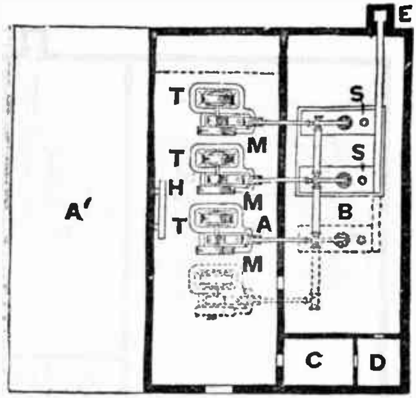
FIG. 7,893.—Plan of electrical station with belt drive without counter shaft. The installation here represented consists of two boilers, S, etc., and three sets of engines and generators, T, M, etc. Sufficient allowance has been made in the plans, however, for future increase of business, as additional space has been provided for an extra engine and generator set, as indicated by the dotted lines. Other reference letters are the same as in fig. 7,892.

the required pressure in the most remote districts so long as the main dynamos continue to furnish the normal or working voltage.

The advantage of a direct current installation in such cases over a similar plant supplying alternating current line is the fact that a storage battery may be used in connection with the former for taking up the fluctuations of the current, thereby permitting the dynamo to run with a less variable load, and consequently at higher efficiency.

Size of Plant.—Before any definite calculation can be made, or plans drawn, the engineer *must determine the probable load.*

This is usually ascertained in terms of the number and distances of lamps that will be required, by making a thorough canvass of the city or town, or



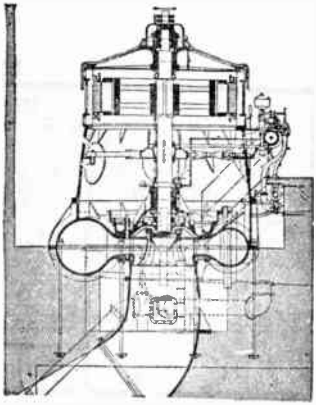


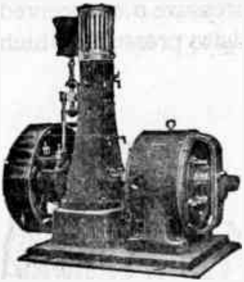
FIG. 7,894.—Plan of electrical station containing direct connected units. *As shown,* space is provided for an extra boiler and engine and generator set, as indicated by the dotted lines. Space also exists for a storage battery room if necessary, and the partition dividing this room from the engine and dynamo room is shewn by a dotted lines.

FIG. 7,895.—Sectional elevation of one of the 5,000 horse power vertical Pelton-Francis turbines directly connected to generator, as installed for the Schenectady Power Co.

that portion for which electrical energy is to be supplied. The probable load that the station is to carry when it begins operation, the nature of this load, and the probable rate of increase are matters upon which the design and construction chiefly depend.

General Arrangement.—In designing an electrical station, it is preferable that whatever rooms or divisions of the interior space are desired should determine the total outside dimensions of the plant in the original plans of the building than that these latter dimensions be fixed and the rooms, etc., be fitted in afterward.

The engines and generators will occupy the majority of the space, and these are usually placed in one large room; in some stations, however, they are located respectively in two adjacent rooms. The boilers are generally located in a room apart from the engines and generators.



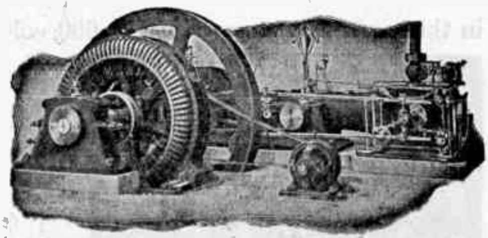


FIG. 7,895.—Triumph dymano set with upright slide valve engine.

FIG. 7,896.—Murray alternating current direct connected unit with high speed Corliss engine and belt driven exciter, 50, 75 and 100 *kva.* alternator and 150 *r.p.m.* engine.

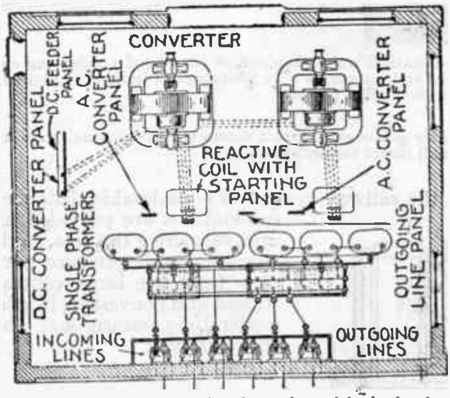
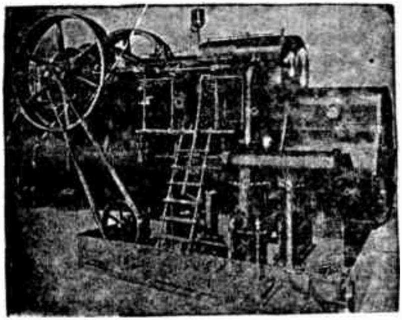


FIG. 7,897.—Plan of small sub-station with single phase oil insulated self-cooling transformers and hand operated oil switches 11,000 or 13,200 volts, overhead high tension lines.

In general, the boilers should be near the engines to avoid loss of heat and pressure drop in steam pipe, and the condensers should be near the engines (especially in case of turbines) to avoid excess back pressure. The location of engines and boilers, and details of station construction are given in Chapter 39 on Installation.

Isolated Plants.—The average type of isolated plant has enlarged from a small dynamo driven by a little slide valve engine located in an out of the way corner to direct connected generator and engines of hundreds and even thousands of horse power assembled in a large room specially adapted to the purpose.

Sub-Stations.—As usually defined, a sub-station is a building provided with apparatus for changing high pressure *a.c.* received from the central station into *d.c.* of the requisite pressure. which in the case of railways is 550 to 600 volts.



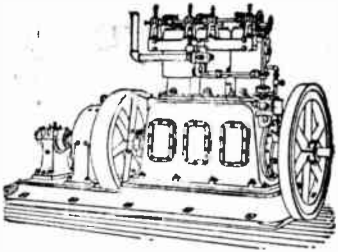


FIG. 7,898.—Buckeye-mobile, or self-contained unit consisting of compound condensing engine, boiler, superheater, reheater, feed and air pumps. It produces one horse power on 1½ lbs. of coal. Built in sizes from 75 to 600 horse power.

FIG. 7,899.—Westinghouse three cylinder gas engine, direct connected to dynamo, showing application of gas engine drive for small direct connected units.

Where traffic is heavy and the railway system of considerable distance, sub-stations are provided at intervals along the line, each receiving high pressure current from one large central station and converting it into moderate pressure *d.c.* for their districts.

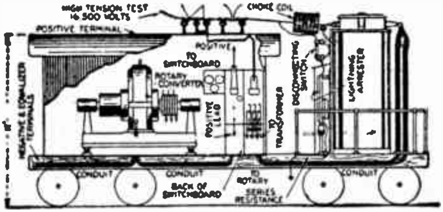


FIG. 7,900.—Portable (outdoor transformer type) sub-station. *In railway service,* direct current can be provided at any point on the system where there is track at the high pressure line. The direct current can be made available very quickly as its production involves only the transferring of the sub-station and its connections to the high pressure line.

CHAPTER 38

Management

Broadly, the term *management* embraces: 1, selection; 2, location; 3, erection; 4, testing; 5, running; 6, care, and 7, repair.

The designer of the plant, specifies or "selects" the machines. An

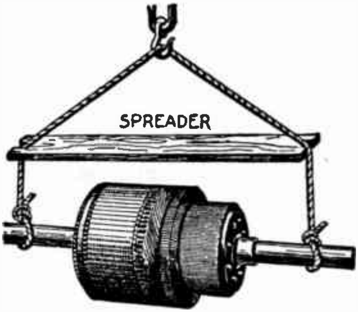


Fig. 7,901.—Method of moving armature to prevent injury to commutator or winding.

erector should install them, but usually this job is left to the man in charge who in most small and medium size plants is the chief steam engineer, who also must run, care for and repair the machines.

Selection.—To properly select a machine, such items as 1, type; 2, capacity; 3, efficiency, and 4, construction, should be considered.

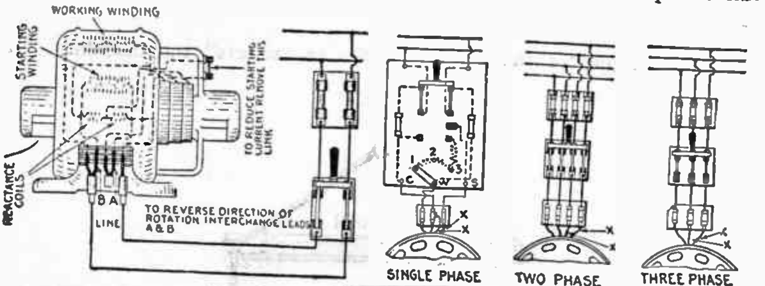
The type depends on the system in use.

In *a.c.* constant pressure transmission circuits, average voltage is 2,200 with transformer ratios of 1/10 and 1/20. Standard frequencies are 25 and 60.

In fixing the capacity of a machine, *careful consideration should be given to the conditions of operation both present and future* in order that the resultant efficiency may be maximum.

Installation.—Small parts may readily be placed in position, either by hand, by erecting temporary supports which may be moved from place to place as desired, or by rolling the parts along on the floor upon a piece of iron pipe.

Large and heavy parts necessitate the use of a crane. Special care



Figs. 7,902 to 7,905.—Wiring diagram and starter connections for Holzer-Cabot *a.c.* motors. ***Single phase motors are started*** by first throwing the starting switch down into the starting position, and when the motor is up to speed, throwing it up into the running position. *Do not hold the switch in starting position over 10 seconds.* Starter for single phase motors above ½ H.P. are arranged with an adjusting link at the bottom of the panel. The link is shown in the position of least starting torque and current. Connect from W, to 2, or W to 3, for starting heavier loads. *Two or three phase* motors are started simply by closing the switch. ***To reverse*** the rotation interchange the leads marked XX. The single phase self-starting motor fig. 7,902 is provided with a link across two terminals on the upper right hand bracket at front of motor and this connection will start considerable overloads. Interchange leads A and B to reverse rotation.

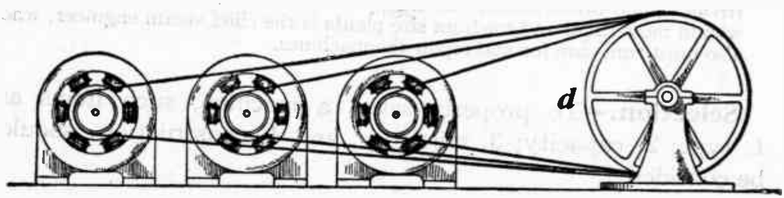


Fig. 7,906.—Tandem drive for economizing floor space.

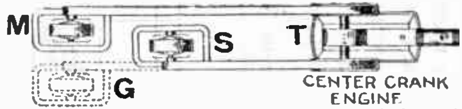
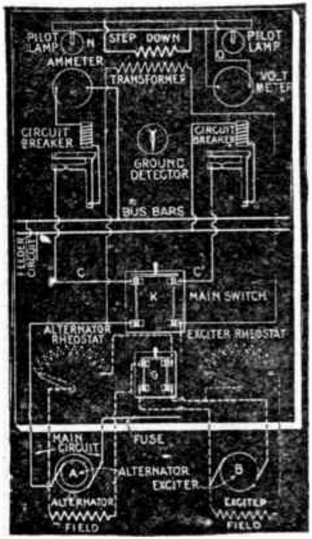


FIG. 7,907.—Separately excited belt driven alternator showing method of economizing floor space by locating exciter at S, instead of at M.

FIG. 7,908.—Double pulley drive for economizing floor space. If the generators thus belted were placed at M and G, yet still more floor space would be saved by having them occupy the positions indicated at M and S.



should be exercised in installing electric machines as the insulations of the windings are very easily injured. The prick of a pin or tack, a bruise, or a bending of the wires by resting their weight upon them or by their coming in contact with some hard substance, will often render a field coil or an armature useless.

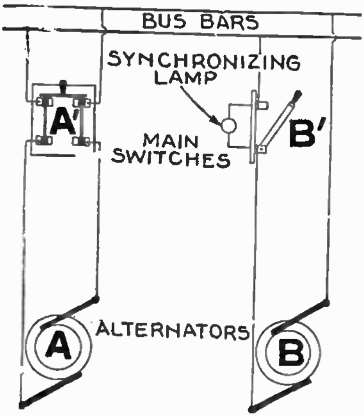
Operation of Alternators.—The exciter must first be started. This is done in the same way as for any shunt dynamo.

At first only a small current should be sent through the field winding of the alternator; then, if the exciter operate satisfactorily and the field magnetism of the alternator show up well, the load may gradually be thrown on until the normal current is carried, the same method of procedure being followed as in the similar case of a dynamo.

FIG. 7,909.—Switch board wiring for a single phase separately excited alternator. The direct current circuits are represented by dotted lines, and the alternating current circuit, by solid lines.

Synchronizing.—When it becomes necessary to run more than one alternator to carry the load, before they can be connected in parallel *they must be synchronized*; that is, the alternating cycles must be in step with each other, otherwise one machine will be short circuited through the other and serious results will follow.

In other words the speed, phase and voltage of each machine must be the same before connecting in parallel. Synchronizing is accomplished in several ways, as by dark, and brilliant lamp methods.



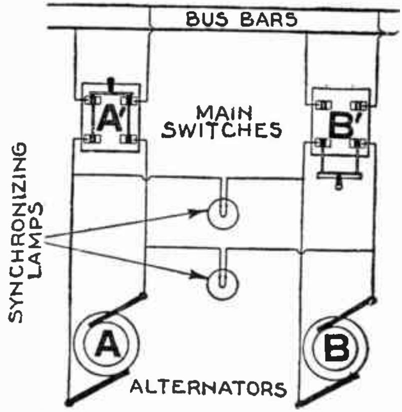


FIG. 7,910.—Synchronizing *one dark lamp method*. Assuming A, to be in operation, B, may be brought up to approximately the proper speed, and voltage. Then if B, be run a little slower or faster than A, the synchronizing lamp will glow for one moment and be dark the next. When the lamp remains dark the machines are in synchronism and switch may be thrown in.

FIG. 7,911.—Synchronizing two dark lamp method. When the machines are in phase there will be no difference of pressure between the left hand terminals or between the right hand terminals of the two machines. Hence, if the synchronizing lamps be connected as shown, both will be dark, and the switch may be thrown in connecting the machines in parallel.

Cutting Out Alternator.—To properly cut out an alternator: 1 reduce driving power until load has been transferred to the other alternators, adjusting field rheostats to obtain minimum current; 2, open main switch; 3, open field switch. Never open field switch before main switch.

Transformers.—The kind of efficiency of transformers the station master is interested in is the *all day efficiency**.

Mineral oil is used in oil cooled transformers. *It must be free from moisture.* To test, thrust a red hot iron rod in the oil; if it "crackle," moisture is present. The presence of moisture reduces the insulation value of the oil.

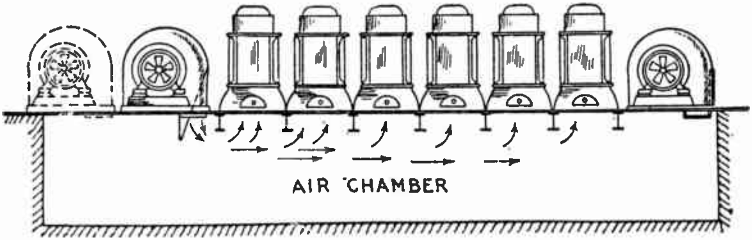


FIG. 7,912.—General arrangement of air blast transformers and blowers.

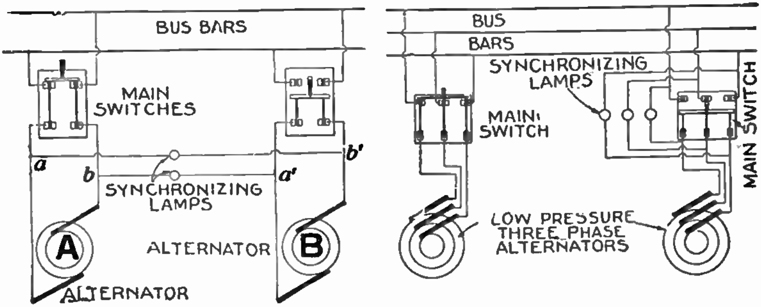


FIG. 7,913.—Synchronizing brilliant lamp method. When the voltages are equal and the machines in phase, the difference of pressure between *a*, and a given point is the same as that between *a'*, and the same point; this obtains for *b* and *b'*. Accordingly, a lamp connected across *a b'*, will burn with the same brilliancy as across *a' b*; the same holds for the other lamp. When the voltages are the same and the phase difference is 180° the lamps are dark, and as the phase difference is decreased, the lamps glow with increasing brightness until at synchronism they glow with maximum brilliancy. Hence the incoming alternator should be thrown in at the instant of maximum brilliancy.

FIG. 7,914.—Synchronizing three phase alternator, being an extension of the single phase method. Three lamps are only necessary to insure that the connections are properly made after which one lamp is all that is required.

*NOTE.—***All day efficiency.** This expression, as commonly met with in practice, denotes *the percentage that the amount of energy actually used by the consumer is of the total energy supplied to his transformer during 24 hours.*

Motor Generators.—These are frequently *used as boosters to raise or boost the voltage near the extremities of long distance, d.c. transmission lines.*

Dynamotors.—A dynamotor is a *combination dynamo and motor having both windings on one core.*

With this construction armature reaction due to the one winding is neutralized by the reaction caused by the other winding. There is,

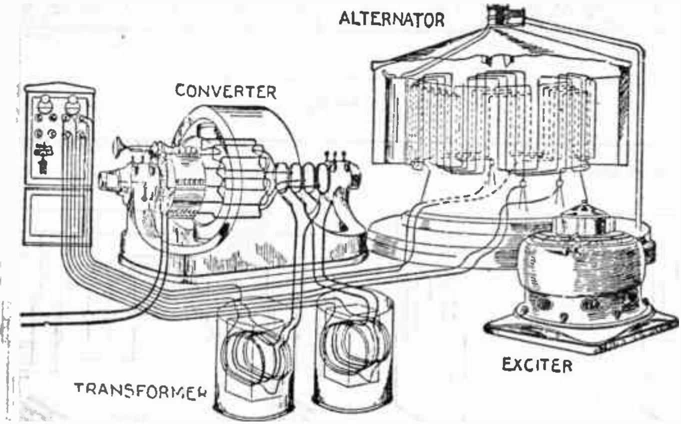
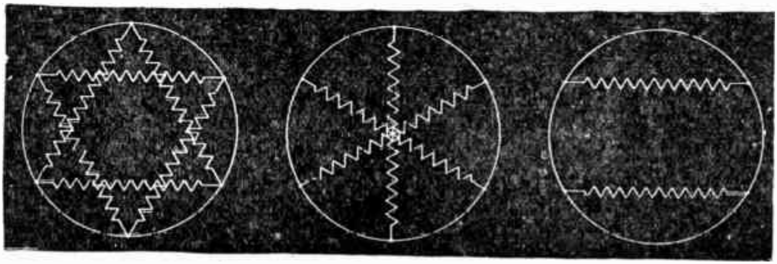
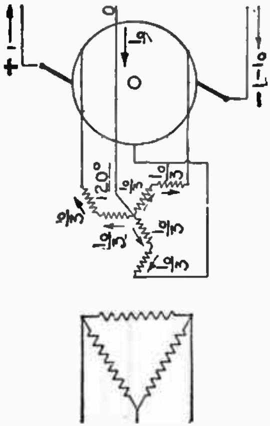


FIG. 7,915.—Wiring diagram of alternator, exciter, transformer and converter showing also switch board connections.



FIGS. 7,916 to 7,918.—Converter connections. Fig. 7,916, double delta connection; 7,917, diametrical connection; 7,918, two circuit single phase connection.



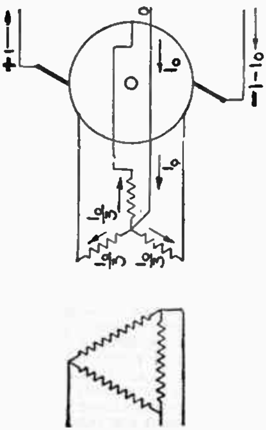


FIG. 7,919.—Wiring diagram for three wire synchronous converter with delta-Y connetced step down transformer with the neutal brought out.

FIG. 7,920.—Wiring diagram of three wire synchronous converter with distributed Y secondary. This system avoids the flux distortion due to the unbalanced *d.c.* in the neutral.

consequently, little or no tendency for sparking to occur at the brushes, and they therefore need not be shifted on this account for different loads.

A dynamotor is connected at its motor end and started in the same manner as any shunt wound motor.

Rotary Converters.—This type of machine is a *combination of an a.c. motor and a dynamo.*

It has practically become a fixture in all large electric railway systems and in other installations where heavy direct currents of constant pressure are required at a considerable distance from the generating plant.

When driven by *d.c.*, a rotary converter operates the same as a *d.c.* motor; when driven by *a.c.*, it operates the same as a synchronous motor. The commutator is the most troublesome part.

If it be found advisable to start the converter with *d.c.*, the same connections would be made between the source of the direct current and the armature terminals on the commutator side of the converter as would be the case were a direct current shunt motor of considerable size to be started; this naturally means that a starting rheostat and a circuit breaker will be introduced in the armature circuit.

A polyphase converter may be started with *a.c.* by applying the *a.c.* pressure directly to the collector rings while the armature is at rest.

The electrical difficulty experienced with rotary converters is the regulation of the *d.c.* voltage; the mechanical difficulty is hunting due to variations in frequency. Hunting is best prevented by the damping method.

Electrical Measuring Instruments.—Voltmeters in most common use have capacities of 5, 15, 75, 150, 300, 500 and 750 volts each, although in the measurement of very low resistances such as those of armatures, heavy cables, or bus bars, voltmeters having capacities as low as .02 volt are employed.

In operation if the hand of an instrument do not readily come to rest

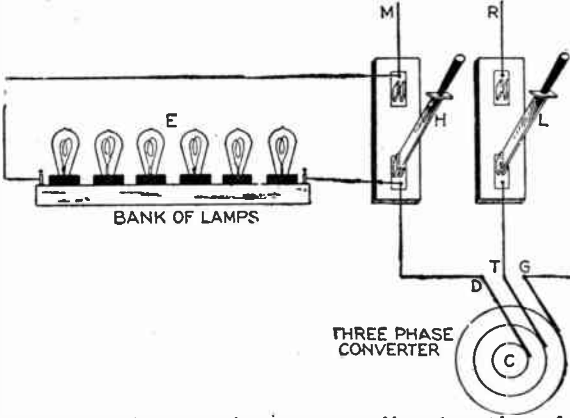
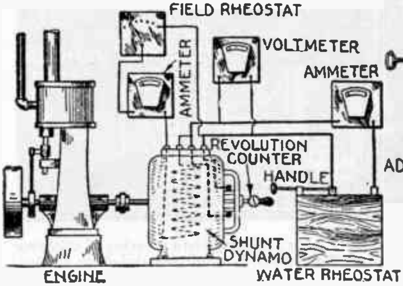


FIG. 7,921.—Wiring diagram showing arrangement of incandescent lamps for determining the proper phase relations in starting a rotary converter. The alternating current side of a three phase converter is shown at C. The three brushes, D, T and G pressing on its collector rings are joined in order to the three single pole switches H, L and B, which can be made to connect with the respective wires M, R, and V, of the alternating current supply circuit. Across one of the outside switches H, for example, a number of incandescent lamps are joined in series as indicated at E, while the three pole switch (not shown) in the main circuit, between the alternator and the single pole sw tches is open. If then the main switch just mentioned and the middle switch L, be both closed, and the armature of the alternator be brought up to normal speed by running it as a direct current motor, the lamps at E, will light up and darken in rapid succession; the lighting and darkening of the lamps will continue until, by a proper adjustment of the speed, the correct phase relations be established between the alternating current in the supply circuit and the alternating current developed in the armature of the converter. As this condition is approached, the intervals between the successive lighting up and darkening of the lamps will increase until they remain perfectly dark. There is then no difference of pressure between the supply circuit M,R,V, and the rotary converter armature circuit, so the source of the direct current may at that instant be disconnected from the machine, and the switches H and B, closed. If the change over has been accomplished before the phase relations of the two circuits differed, the converter will at once conform itself to the supply circuit and run thereon as a synchronous motor without further trouble.

gently tap it. Before connecting up instruments *it should be known that the pressure or current to be measured is within the range of the instrument otherwise the latter may be burnt out.*

Do not place instruments near conductors carrying large current and expect to get an accurate *a.c.* An *a.c.* voltmeter will work on a *d.c.* circuit, but a *d.c.* voltmeter will not work on an *a.c.* circuit.

The usual capacities of *a.c.* voltmeters are 3, 7.5, 10, 12, 15, 20, 60, 75, 120, 150, 300 and 600 volts but these capacities may be increased by the use of *multipliers*. Ammeters should be cut out of circuit except while taking reading to avoid error due to heating. To correct 3 or 4% error in voltmeter readings, straighten pointer, vary tension of spiral springs, renew jewel in bearings, alter value of the high resistance, etc.



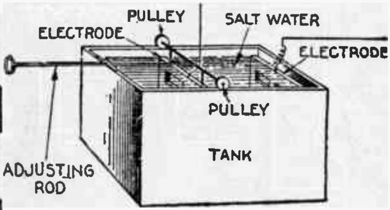


FIG. 7,922.—Dynamo test. During the test, one man should be assigned to the tachometer, another man to the water rheostat, and there should preferably be one man at each of the electrical measuring instruments. In order to enable the man at the tachometer to keep the speed constant, he should be in communication either directly or indirectly with the source of the driving power, and the man at the water rheostat should be in plain view of the man reading the ammeter so that the latter party may signal him for the proper adjustment of the rheostat in order that the desired increase of current be obtained for each set of readings.

FIG. 7,923.—Water rheostat. ***It consists essentially of*** a tank of suitable size containing salt water into which are placed two electrodes having means of adjustment of the distance separating them. The solution depends on the voltage. With current density of one ampere per sq. in., a water solution gives a drop of 2,500 to 3,000 volts per inch distance between the plates. Where high voltage is used, the water must be circulated through and from the tank by rubber hose allowing for 2,500 volts, a length of 15 to 20 feet of 1 inch hose to prevent grounding.

How to Test Dynamos.—The instruments needed are, voltmeter, ammeter, speed indicator, and the usual switches and rheostats, connected as in fig. 7,922.

In the case of a shunt machine, the speed should be made normal and the field rheostat adjusted until the voltmeter reading indicates the rated voltage of the machine at no load and readings taken.

The electrodes of the water rheostat should be adjusted for maximum resistance and main circuit closed, and a second set of readings taken. Several sets of readings are taken, with successive reductions of water rheostat resistance. The results are then plotted on coördinate paper.

To obtain the commercial efficiency the *input* and *output* must be found and compared for different loads, thus

$$\text{input in brake horse power} = \frac{2\,\pi\,L\,W\,R}{33{,}000} \quad\text{..............(1)}$$

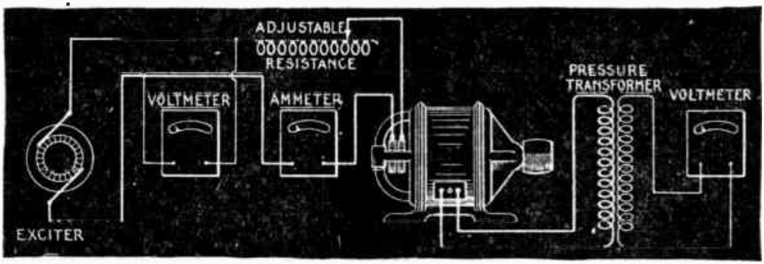


FIG. 7,924.—Test to obtain saturation curve of an alternator. *In testing* a series of observations of the voltage between the terminals of one of the phases, is made for different values, of the field current. If the machine be two phase or three phase, the volt meter may be connected to any one phase throughout a complete series of observations.

in which L = length of Prony brake lever; W = pounds pull at end of lever; R = revolutions per minute.

The output or electrical horse power for the same load is easily calculated from the formula

$$\text{output in electrical horse power} = \frac{\text{amperes} \times \text{volts}}{746} \quad\text{.........(2)}$$

After obtaining value for (1) and (2), the commercial efficiency for the load taken is obtained from the formula

$$\text{commercial efficiency} = \frac{\text{output}}{\text{input}} \quad\text{................(3)}$$

CHAPTER 39

Motor Driven Tools

There is a constantly increasing demand for small portable motor driven tools which has resulted in a multiplicity of highly developed devices designed for numerous duties formerly performed by hand in machine and carpenter work, etc., such as

FIG. 7,925.—Chicago "Little Giant" electric track-drills reaming joint holes on the tracks of the Pittsburgh Railways Co.

drilling, grinding, buffing, screw driving, hammering, etc., the saving in labor accomplished by the use of these tools is very great.

According to the kind of power used, motor driven tools may be classed as

1. Electric
2. Pneumatic.

Electric Drive.—The extensive demand for motor driven tools has resulted in many improvements in the design of the driving mechanism and they may be obtained suitable for almost any kind of electric current.

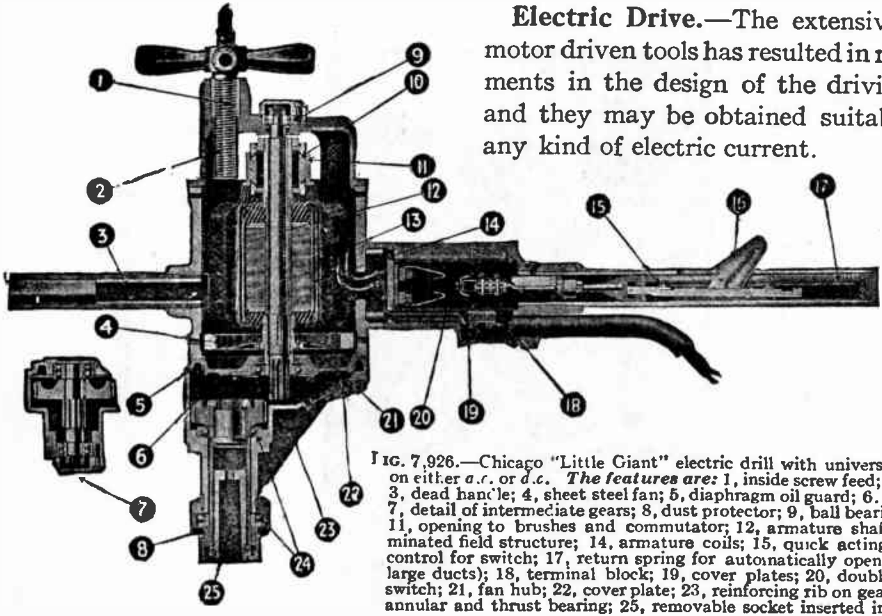


FIG. 7,926.—Chicago "Little Giant" electric drill with universal motor which runs on either *a.c.* or *d.c.* ***The features are:*** 1, inside screw feed; 2, protecting sheath; 3, dead handle; 4, sheet steel fan; 5, diaphragm oil guard; 6, grease compartment; 7, detail of intermediate gears; 8, dust protector; 9, ball bearing; 10, commutator; 11, opening to brushes and commutator; 12, armature shaft and pinion; 13, laminated field structure; 14, armature coils; 15, quick acting switch; 16, trigger control for switch; 17, return spring for automatically opening switch (used on large ducts); 18, terminal block; 19, cover plates; 20, double pole double break switch; 21, fan hub; 22, cover plate; 23, reinforcing rib on gear case; 24, combined annular and thrust bearing; 25, removable socket inserted in spindle.

The "Universal" motors will operate on either direct or alternating current, some being suitable for frequencies ranging from 20 to 125 cycles single phase, and for pressures ranging from 110 to 600 volts. The universal feature is of value to contractors or others who may have occasion to do work in various localities and find in some place only direct current available and in others only alternating current.

In addition to the universal line, tools may be obtained with motors designed for direct, or for alternating

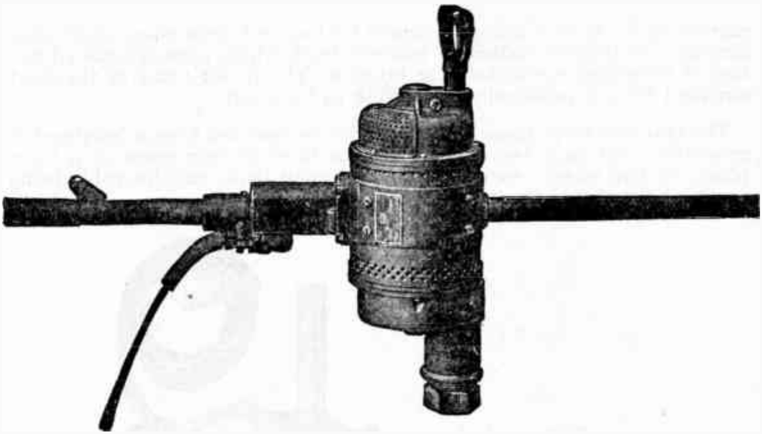


FIG. 7,927.—Chicago "Little Giant" screw spike driver (for 110, 220 or 600 volt *d.c.*). It is a powerful electric rotary tool which operates in conjunction with a special circuit breaker designed to open the circuit when the spike is screwed home. It requires an operator and a helper to take care of the heavy torque developed at the instant of maximum effect when the head of the spike is forced against the base of the rail. At this instant the circuit breaker opens the circuit and the tool stops turning. On electric roads the circuit is taken from the trolley or third rail.

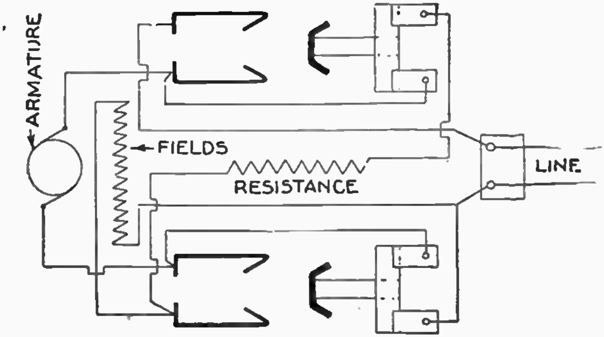


FIG. 7,928.—Osborn safety device for electric drills. *It consists of* a special switch with connections including a small armature resistance mounted directly on the switch case. When the operator's hand is removed from the trigger shown at the right of the cut, a spring opens the main circuit from the line, thereby cutting off the line current from the drill. Immediately after the line circuit is open, a circuit is made through the armature and field windings, causing the motor to become a generator, the armature being practically short circuited through the resistance. The load thus produced on the armature causes it to stop almost immediately, thus effectively destroying the torque or pull on the handles of the tool. The tool cannot become unmanageable, as upon releasing the switch the electric braking takes place, thus acting as a safety device for the operator.

current only. Some tools are designed for two and three phase alternating current. In these an induction motor is used, which possesses the advantage of having no commutator or brushes. The motor being of the short circuited type is practically impossible to burn out.

The two and three phase motors cannot be operated from a lamp socket connection, but must be connected to the three or four wires of a three phase, or two phase circuit as the case may be, a suitable cable being provided for this purpose.

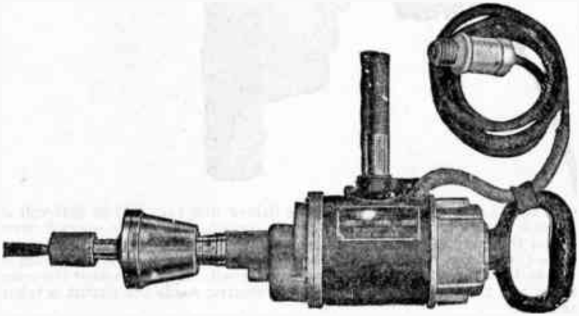


FIG. 7,929.—U. S. electric tool driver designed for driving wood screws. The large size tool may be used for driving large screws or tightening up nuts and bolts, using a socket wrench. *In operation*, when a screw has been driven as far as desired, the screw driver bit remains stationary, motor still revolves, this being accomplished by a friction clutch with spring release which forms a part of the tool.

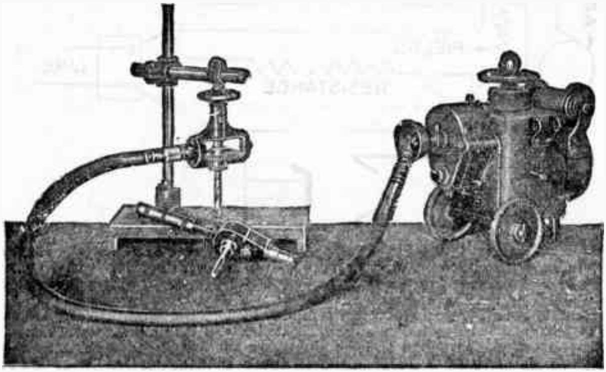
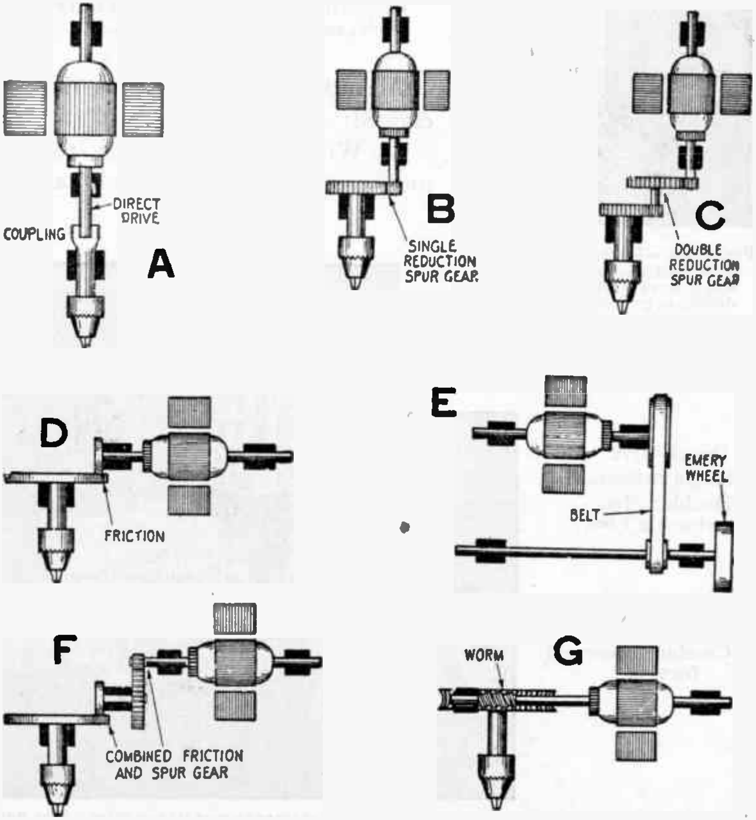


FIG. 7,930.—Stow combination of flexible shaft and enclosed multi-speed *d.c.* motor.

The Transmission.—The term transmission here means *the mechanism between the motor and the tool shaft through which the power is applied.* Its object is to "transmit" the power of the motor to the tool shaft altering if necessary the velocity of these parts in any desired ratio to properly perform the work.



FIGS. 7,931 to 7,937.—Various electric rotary tool transmissions. **A**, direct drive; **B**, single reduction spur gear; **C**, double reduction spur gear; **D**, friction; **E**, belt; **F**, combined friction and spur gear; **G**, worm gear.

FIG. 7,938.—Electro electric *direct drive* drill adapted to light high speed work such as light wood drilling in preparation for screws, piano, cabinet and furniture work, also small holes in the softer metals. Speed 8,000 *r.p.m.*; universal motor for either *d.c.* or *a.c.*

As the speed of a motor or turbine must be very high to develop a given power, because of the weakness of the torque, it must be evident that some form of gearing is necessary between the motor or turbine and the tool shaft to slow down the speed of the latter so as to develop sufficient torque to perform the required operation, except in the case of very light duty operations, such as light duty drills.

Accordingly transmissions may be classed:

1. With respect to the relative movements of motor and tool shaft, as:

a Direct drive
b Single reduction
c Double reduction { gears / belt

d Worm
e Friction
Combined gear and friction.

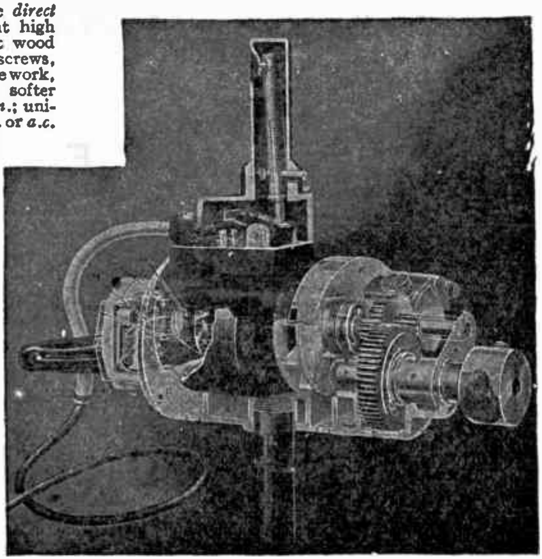
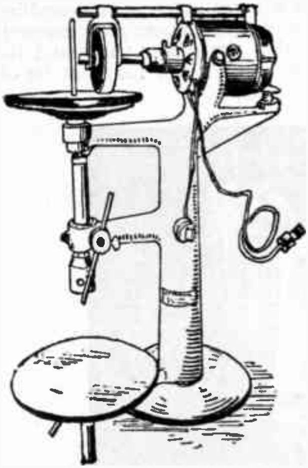


FIG. 7,939.—Van Dorn electric drill with double reduction spur gear transmission. *The parts are:* A, cable connection; B, switch; C, armature bearings; D, gear case; E, bearings; F, drive spindle; G, drive spindle thrust; H, brushes; I, commutator; J, motor; K, casing; L, side handle.



2. With respect to the direction of rotation, as:

a Non-reversible
b Reversible

The direct drive is suitable for light wood drilling, in preparation for screws, piano, cabinet and furniture work, also for drilling small holes in the softer metals.

A single or double reduction gear may be interposed between the driver and driven shafts according to the desired degree of speed reduction, adapting the machine respectively to medium or heavy duty work.

FIG. 7,940.—U. S. friction drive electric bench drill for drilling and light tapping.

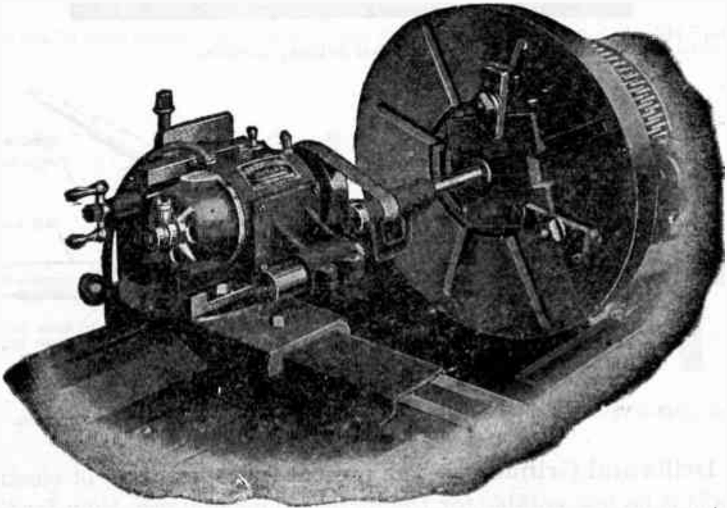


FIG. 7,941.—U. S. combination grinder on a lathe, set for *internal grinding operations*. The grinder can be raised, lowered or swivelled to any angle.

Where a very high degree of speed reduction is required, as in a combination of high speed motor and slow speed tool shaft, a worm gear transmission is desirable, however, with worm gearing the motor shaft and tool shaft must be at right angles to each other; this may or may not be objectionable, depending upon the service required.

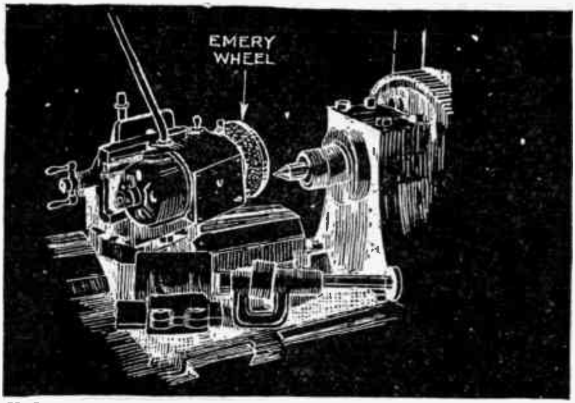


Fig. 7,942.—U. S. combination grinder with internal grinding attachment taken off and every wheel put on in place of pulley for *external grinding operation.*

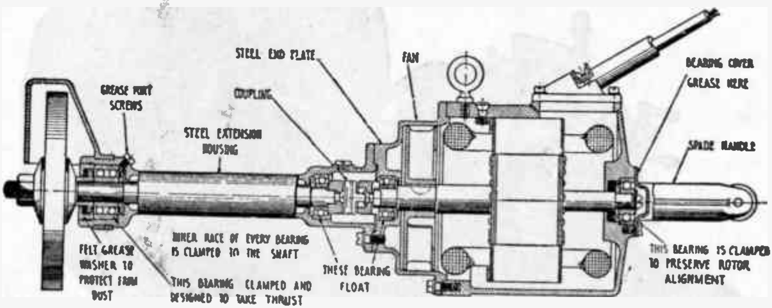


Fig. 7,943.—Van Dom direct drive electric grinder; sectional view showing construction.

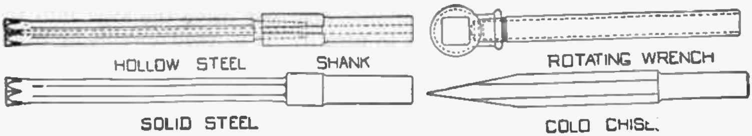
Drills and Grinders.—The present widespread use of electric tools is no less notable for the increased general use than for the many important variations of applications.

FIG. 7,944.—Chicago "Little Giant" electric hammer drill with universal motor adapted to concrete and soft stone, also for light chipping of metals. *In operation*, the hammer blow which is delivered by a piston on the dull steel or chisel, is produced by pneumatic impact and is very effective. At the instant the blow is struck, the piston is running free of all mechanical parts, and hence no shock or vibration is transmitted to the electrical parts of the tool. There is a live air device for cleaning hole of powdered cuttings when drilling in downward direction.

Drills, formerly, were thought to be valuable only for drilling; grinders found little use outside of foundries. New uses for these tools are frequently being discovered, many effecting great economy in production, maintenance, or construction methods.

The use of a drill for screwing insulator holders into cross arms is a typical example. Notable among the varied applications of grinders is rail grinding on railroad track work.

Hammers.—There are many operations such as chipping, caulking, tube beating, light rivetting, etc., that can be performed by a motor driven hammer with considerable saving of labor.



FIGS. 7,945 to 7,948.—Steels for Chicago hammer drill.

These hammers can be obtained in various types, so designed that the blows delivered per minute range from a few hundred heavy blows to 3,000 or more light blows adapting them to all kinds of uses. An important feature in hammer designs, is a provision against it being overworked, that is, it is so constructed that the strength of blow is constant.

In the electric drive a simple magnetic cushion is interposed between the hammer element and the motor, which prevents excessive vibration and breakage.

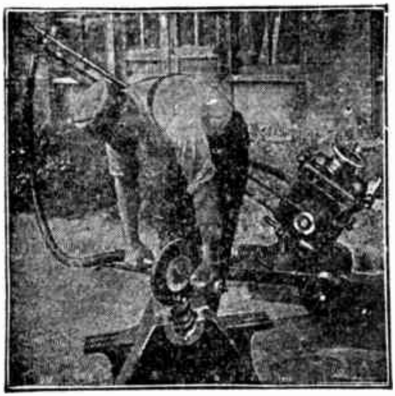


FIG. 7,949.—Slow adjustable flexible grinder for use in foundries and steel working industries. The motor shaft combination is mounted on a truck making it easily transportable to any part of the shop, eliminating the necessity of taking the work to the tool, thus saving time and cutting cost. By means of the swivel suspension the work can be carried on over an extensive area.

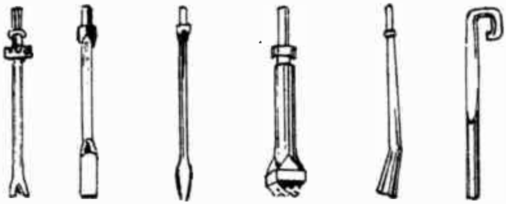
The pneumatic drive lends itself to hammers of the long stroke type which are well adapted to bridge, structural, and boiler rivetting being regularly designed for driving hot rivets of sizes ranging from ¼ to ⅞ in. in diameter.

Hammer Steels.—The efficiency of hammers is due to the number of blows struck per minute. These blows are comparatively light and the action in drilling is a crumbling or very minute chipping process.

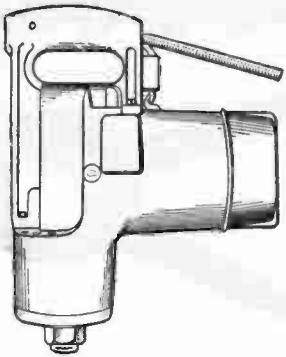
For this reason the type of drills selected depends largely on the nature of the material to be drilled.

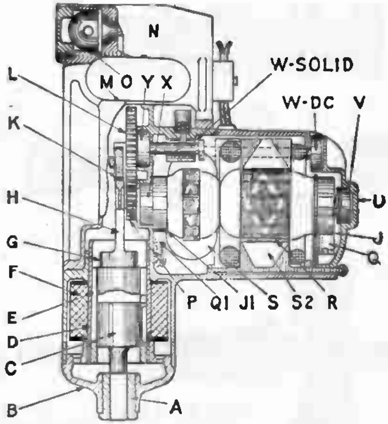
Star drills are recommended for ordinary drilling in concrete, ordinary brick, soft lime and Bedford stone.

Diamond drills used in hard rocks, granite, marble, vitrified brick and hard concrete. These are single point drills and may be used satisfactorily in places where the hammer does not drive the steel into the material so far that it is difficult to turn it. It is more difficult to drill a true hole with a diamond drill than with a star drill, unless care be taken to rotate the tool rather rapidly at the start, giving it a full ¾ swing.



FIGS 7,950 to 7,955.—Various Electro hammer steels. Fig. 7,950, hollow drill; fig. 7,951, chisel; fig. 7,952, bull point; fig. 7,953, bush hammer; fig. 7,954, channelling tool; fig. 7,955 wrench.





FIGS. 7,956 and 7,957.—Exterior and sectional views of Electro hammer. The control is by a switch mounted in the handle. A simple magnetic cushion is placed between the hammer element and motor to prevent excessive vibration and breakage. The strength of blow is constant.

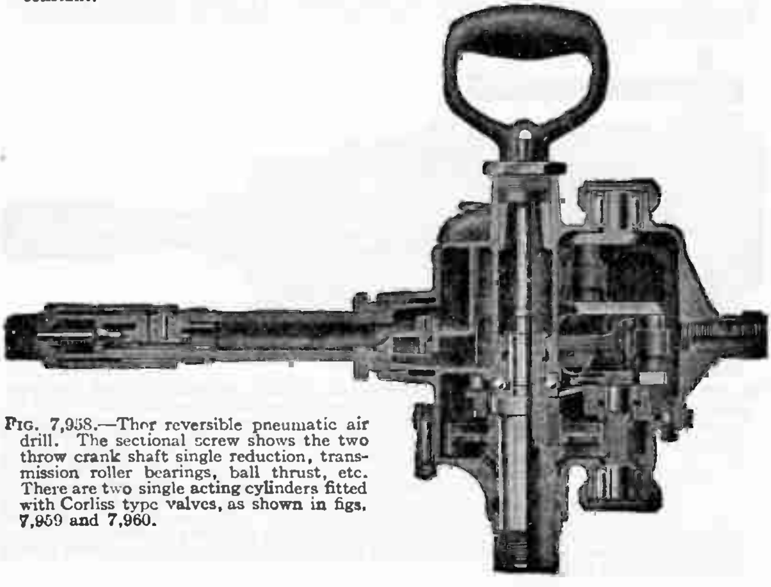
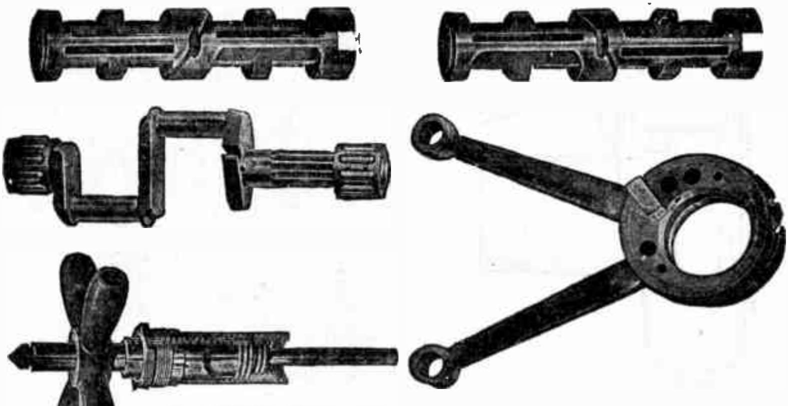


FIG. 7,958.—Thor reversible pneumatic air drill. The sectional screw shows the two throw crank shaft single reduction, transmission roller bearings, ball thrust, etc. There are two single acting cylinders fitted with Corliss type valves, as shown in figs. 7,959 and 7,960.



FIGS. 7,959 to 7,963.—Thor single acting piston air drill parts. Fig. 7,959 and fig. 7,960, Corliss valves; fig. 7,961, crank shaft and roller bearing; fig. 7,962, eccentrics; fig. 7,963, telescopic feed screw. The valves are so placed that the live air, which is magazined in the large chamber to the rear of the valves, is admitted over the full width of the edge, which is a distance of but the thickness of the valve bushing and cylinder wall from the piston. The exhaust slots cut into the hollow valve allows the air to be exhausted into the atmosphere.

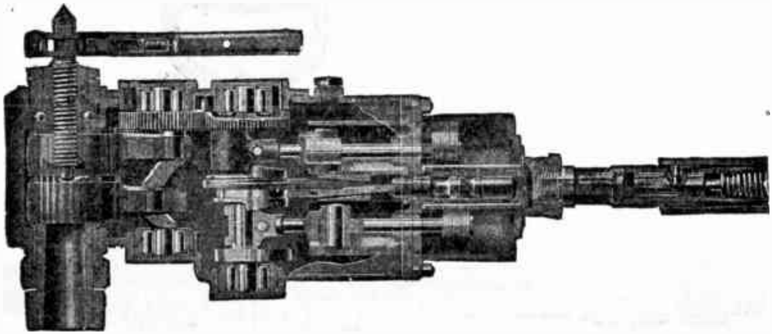


FIG. 7,964.—Thor close quarter double acting piston air drill, with piston valves. *In construction and operation:* There are two double acting cylinders, with valves located between the cylinders. Air is taken in centrally between the cylinders and there is as little clearance as possible. Geared to the crank shaft is another two throw crank diametrically opposed. This crank operates directly on two oscillating levers centered on the drill spindle proper and having the bearings around same. These levers are provided with pawls of practically the whole thickness of the lever. The pawls operate on ratchet teeth sunk in the spindle, the outer circumference, or point of teeth leaving ample slack for bearings of the levers. The motion of the drill spindle is continuous. The engine cranks are at an angle of 135° which allows the two pistons to pull together when the position of the levers requires the greatest power. The drill has a reversible ratchet feed and a poppet shuttle controls the speed and power.

Both star and diamond drills are made with square shanks to keep the cuttings loose in the hole and to prevent packing around the tool.

The relation of the square shank to the cutting size is important and has been established by a large amount of experience. The life of drill steels depends upon the material.

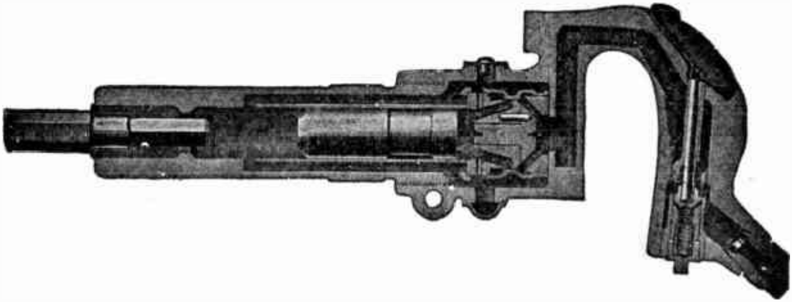


FIG. 7,965.—Thor *short stroke* pneumatic hammer for chipping, caulking and tube beading, etc. A feature is the valve mechanism. The valve block consists of two solid cylindrical parts. The exhaust passes below and above the valve.

In granite or vitrified brick frequently a drill dulls in from 2 to 5 ins. of drilling, while in soft stones the same steel will run over 60″ before it needs resharpening.

Drills of all types drill first upon the outside edges and when these edges become dull and rounded the drilling efficiency is rapidly lost.

Steels may be resharpened on a wheel, but after being touched up a few

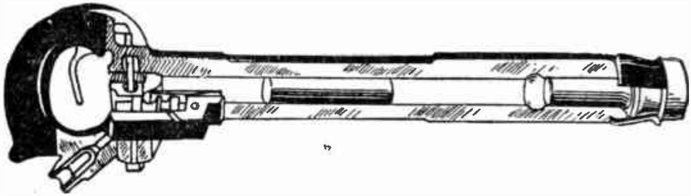


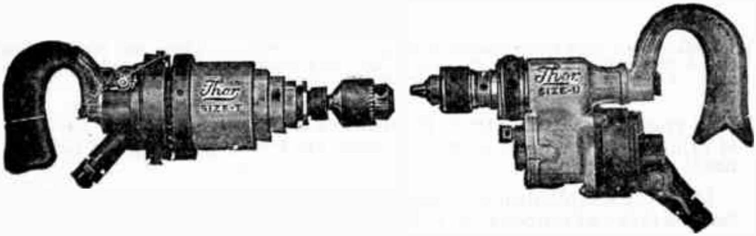
FIG. 7,966.—Thor *long stroke* pneumatic riveting hammer. The main valve lies parallel with the main bore, but is not directly operated with the air in the downward stroke. When the piston returns, it opens what is termed the auxiliary valve, the purpose of which is to admit a slight amount of air, which lightly starts the piston downward, and also supplies air for the power stroke. After short travel in the downward direction, the main valve opens and admits the full volume of air direct and very close to the piston. The piston, therefore, from a gentle start gets an extremely forceful and quick acting blow and quicker return, with practically no vibration. The throttle valve is arranged so that a light or heavy blow can be given.

times they lose their size. This is important where holes are being drilled for expansion bolts and the like. When the sizes are lost the steel may be redressed by a blacksmith and this redressing process may be repeated many times until the whole shank of the tool is used up.

Pneumatic Drive.—Compressed air is extensively employed as the power medium for motor driven tools. These tools are usually designed to operate on 80 lbs. air pressure. There are two general types of motor used:

1. Piston
2. Turbine.

They are made non-reversible or reversible, according to the requirements of the service for which they are intended.



FIGS. 7,967 and 7,968.—Thor reversible *turbine* air drills. Fig. 7,967, direct drive speed 220 *r.p.m.*, adapted to drilling in steel up to ¼ inch, and boring in wood up to ⅜ in. in diameter. These drills are intended for light drilling and are equipped with roller bearings. In the gear type two sets of drive gears are between the turbine shaft pinion and spindle. The air chamber encircles the turbine, the air jets passing through the wall in diametrically opposed position have no tendency to side or end pressure. The air is cut off by pushing trigger to neutral point, and by throwing it over the neutral point the air is reversed and quickly stops spindle.

The piston or reciprocation drills have two cylinders and cranks at right angles, thus avoiding dead centers.

The turbine drive is inherently suitable for high speed work as it turns at a high rate without appreciable vibration; hence it is adapted to light duty service, as for insulated light drilling, and when sufficiently geared down heavy duty work may be performed.

On account of the free running qualities of all the parts, the spindle would continue to turn over for a long time after the pressure is cut off, but by momentarily reversing a reversible machine the moving parts are quickly brought to rest.

CHAPTER 40

Ignition

It is a good plan before tinkering for ignition (or carburetor) troubles ***to see*** *if there be any gasoline in the tank, and if the cock in the pipe between the tank and carbureter be turned on.*

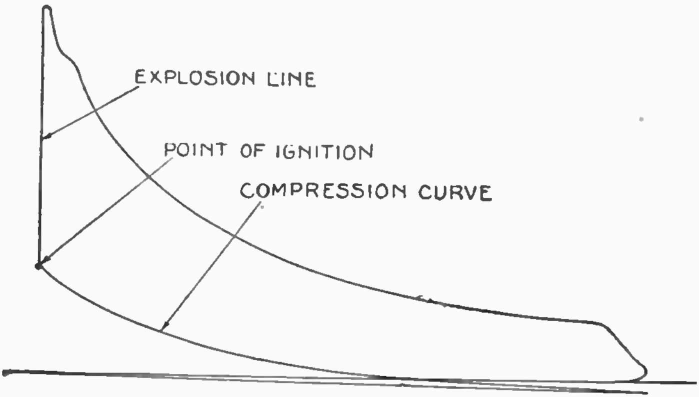
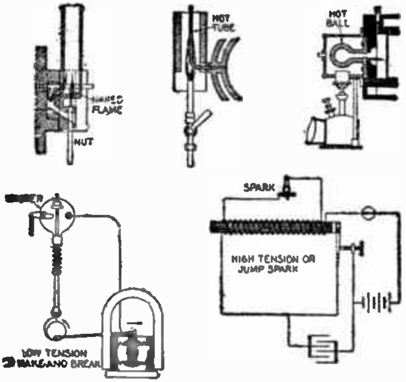


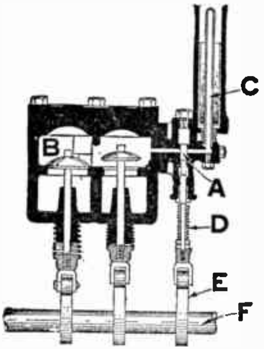
FIG. 7,969.—Indicator card for gas engine illustrating the ***"point of ignition."*** It will be noted that compression continued to the end of the stroke, before the compression curve made an abrupt change into a nearly vertical line, the point of ignition, that is, the piston position at the instant of the spark, the nearly vertical "explosion" line with the high peak coming almost to a point, denotes a strong mixture and a quick explosion.

Point of Ignition.—The "timing" or selection of the point of the stroke at which ignition shall take place is an important factor in the application of any method.

Since there is an appreciable time interval between the spark and the



FIGS. 7,970 to 7,974.—Various methods of ignition. Numerous devices have been tried to fire the charge in gas engines. In the early days, a flame behind a shutter was used, the latter being opened at the proper moment (fig. 7,970). Sometimes the flame was blown out by a too violent explosion. so this method gave way to a porcelain tube that was kept at white heat by an interior flame (fig. 7,971). Tube being subject to breakage, spongy platinum, heated by compression, was next tried and found to work, if not too moist from watery vapor in the gas mixture, or if the engine speed were not too high. Another method consists in heating a spherical projection (hot ball) of the cylinder head (fig. 7,972). Electricity is now universally used. Hence, in order to gain an understanding of ignition principles, it is necessary to have at least an elementary knowledge of electricity. Figs. 7,973 and 7,974 show ***make and break*** and jump spark methods of electric ignition.



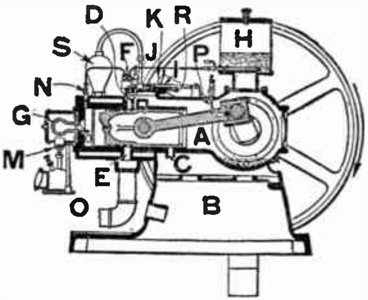


FIG. 7,975.—Hot tube ignition. ***In construction,*** a valve A, commonly called the timing valve, is provided, and which is interposed between the admission valve chamber B (communicating with the clearance space of the cylinder) and the interior of the hot tube C. This valve is normally held closed by the spring D. When the piston reaches its inner dead point at the end of the compression stroke, a cam E, on the secondary shaft, opens the valve und allows a portion of the compressed charge to pass into the hot tube where it ignites. The timing valve is held open throughout the power and exhaust strokes, thus permitting the products of combustion to be carried out of the tube with the exhaust.

FIG. 7,976.—Meitz and Weiss two cycle oil engine with hot ball igniter. ***In operation*** the charge is automatically ignited on the compression stroke by contact with the heated walls of the hollow igniter ball G. ***Before starting,*** the igniter ball is heated for a few minutes by a small oil burner M. The oil jet from the injection nozzle N, strikes the projection O, extending from the igniter ball and is sprayed, vaporized and mixed with the air and steam in the compression space. The igniter ball is maintained at a dull red heat by the heat of the explosions. A, crank chamber; B, base; C,D, ports; E, exhaust put; F, pump; G, igniter ball; H, resevoir; I, plunger guide; J, dome pipe; K, pin; M, oil burner; N, injection nozzle; O, projection; P, projecting tube; R, pump plate; S, dome.

maximum pressure of combustion, it is clear that the spark should occur earlier for an engine running at high speed than for one running at low speed. *In general* the *spark should be advanced as much as possible, consistent with smooth running and economy, in order that the temperature at release, or when exhaust begins, should not be high enough to injure the exhaust valves.*

Methods of Ignition.—The charge in the cylinder of a gas engine may be ignited in several ways, as

1. By means of a naked flame;

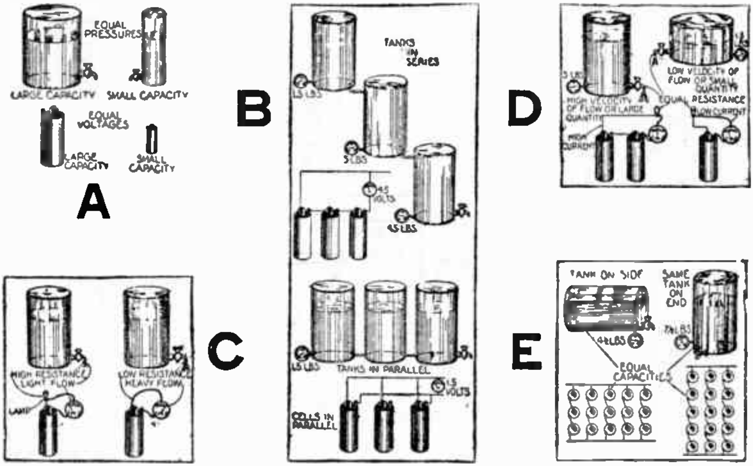
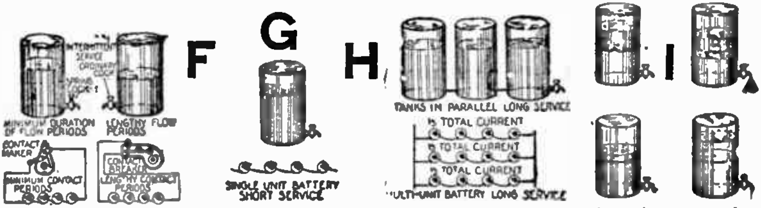


FIG. 7,977 to 7,981.—*Hydraulic analogies:* Figs. A, *capacity;* figs. B, *pressure;* figs. C, *resistance;* figs. D, *current;* figs. E, equal capacities at different pressuses.



FIGS. 7,982 to 7,985.—Hydraulic analogies. Figs. F, *useful service;* figs. G, series cconection; fiigs, H, *parallel connection;* figs. I, *recuperation.*

2. By means of a highly heated metallic surface;
3. By an electric spark,
4. By the heat of very high compression.

The naked flame is practically obsolete, and the hot surface or hot tube is used to a very limited extent, except in the case of some types of oil engine. Many builders of standard engine, however, are prepared to furnish hot tube ignition. ***Electric ignition is now the prevailing method***

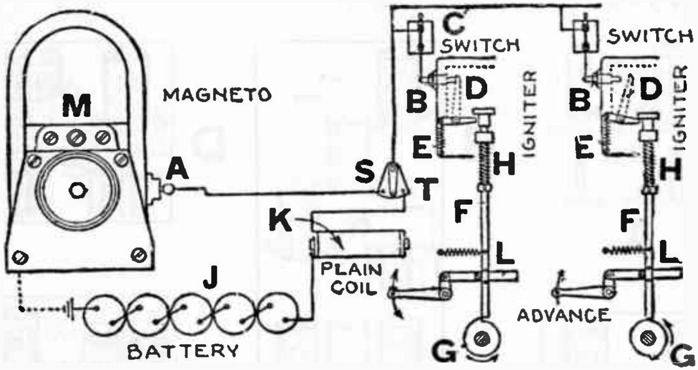
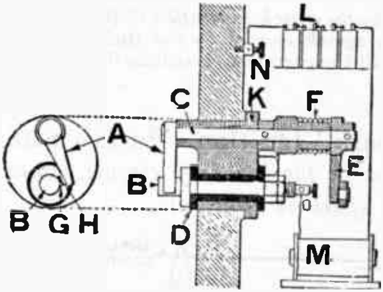


FIG. 7,986.—Low tension or make and break ignition. ***In starting, say on the battery***, the arm of the two way switch is turned upon point T. The movable electrode D, of the first cylinder being in contact with the insulated electrode B, by the spring E, the current will flow from the battery J, through the coil K, thence through the two way switch and the single throw switch to the insulated electrode B. The movable electrode D, being in contact with the insulated electrode B, the current returns to the battery through D and the metal of the engine, thus completing the circuit. As the cam G, revolves in the direction indicated by the arrow, its nose passes from under the lower end of F, the latter drops with great rapidity by the action of spring H, and in so doing a shoulder at the upper end of F, strikes the external arm of D, a blow causing the contact point of D, to be ***quickly snapped*** apart from B, producing an arc which ignites the charge. This cycle of operations is repeated by the ignition mechanism of each cylinder in rotation.

Low Tension or "Make and Break" Ignition.—In this system there is a device known as an ***igniter***, ***placed in the combustion space of the engine cylinder.***

This consists of two electrodes, one of which is stationary and the other movable. The stationary electrode is insulated, while the other, having an arm within the cylinder and placed conveniently near, is capable of being moved from the outside so that the arm may come in contact with the stationary electrode and be separated from the latter with great rapidity.



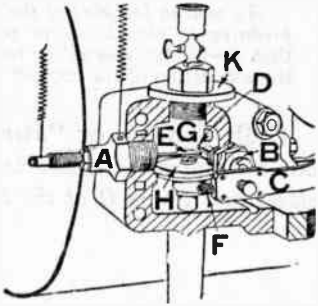
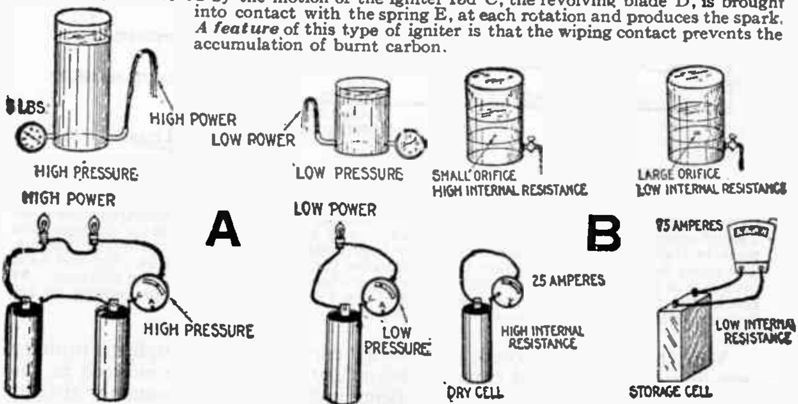


FIG. 7,987.—Hammer break igniter. *It consists of* two metallic terminals A and B. The terminal A, is mounted on a movable shaft C, while B, is stationary and *insulated* from the cylinder wall by the lava bushing D. A suitable cam rod, attached to the crank E, provides the means for rocking the terminal A, so as to bring it in contact with the terminal B, *and then quickly separate* the terminals to produce the spark. The helical spring F, provides a semi-flexible connection between the shaft C, and the crank E. The contact points of the two terminals are tipped with two small pieces of platinum G and H, and both terminals are mounted in the removable plug K, which is usually inserted through the wall of the cylinder head, so that the igniter points extend into the compression space of the cylinder. In the circuit is a battery L, and primary spark coil M.

FIG. 7,988.—Wipe contact igniter. *It consists of* two independent electrodes, the stationary electrode A, and the movable electrode B. The igniter is located in the inlet chamber G, directly over the head of the admission valve H, and either one of the electrodes can be reached for inspection or removal independently by removing the cap K. *In operation,* when B, is revolved by the motion of the igniter rod C, the revolving blade D, is brought into contact with the spring E, at each rotation and produces the spark. *A feature* of this type of igniter is that the wiping contact prevents the accumulation of burnt carbon.



FIGS. 7,989 to 7,996.—Hydraulic analogies. Figs. A, *power;* figs. B, *internal resistance.*

The circuit includes a ***primary induction coil.*** Current may be derived from either a primary battery, storage battery, or low tension magneto.

The *sudden breaking of the circuit by the **quick separation of the electrodes** produces an electric arc or **primary spark*** caused *by the **inductance***—that is—by the "inertia" or tendency of the current to continue flowing after the separation of the contact points.

High Tension or "Jump Spark" Ignition.—In this method, *an automatic device is placed in the primary circuit. which closes and opens it at the time a spark is required.*

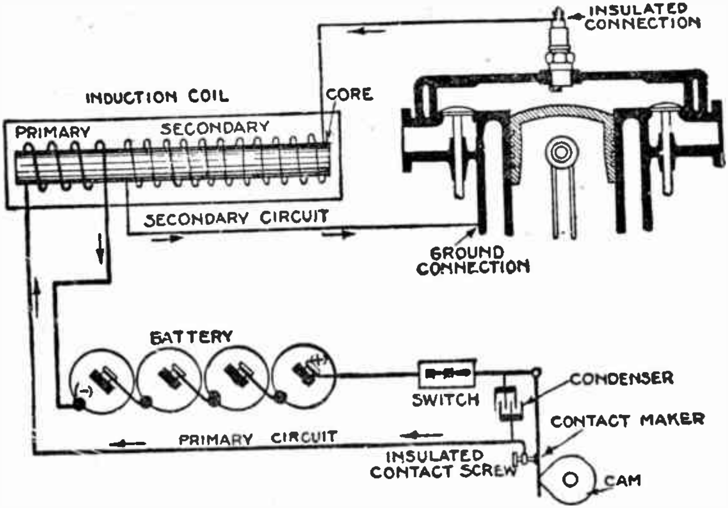


FIG. 7,997.—High tension or jump spark ignition. ***In operation,*** the nose of the cam in revolving engages the contact maker which completes the primary circuit and allows current to flow from the battery through the primary winding of the coil; this magnetizes the core. The primary circuit is now broken by the action of the cam and magnetic changes take place in the coil which induce a momentary high tension current in the secondary circuit. The great pressure of this current forces it across the air gap of the spark plug and as it bridges the gap a spark is produced. The arrows indicate the paths of the currents. At break, the primary current is "slowed down" by the condenser, thus preventing an arc between contact breaker contacts.

When the circuit is closed, the primary current flows through the primary winding of the coil and causes a secondary current to be induced in the secondary winding. A spark plug being included in the secondary circuit, opposes the flow of the current by the high resistance of its air gap. Since

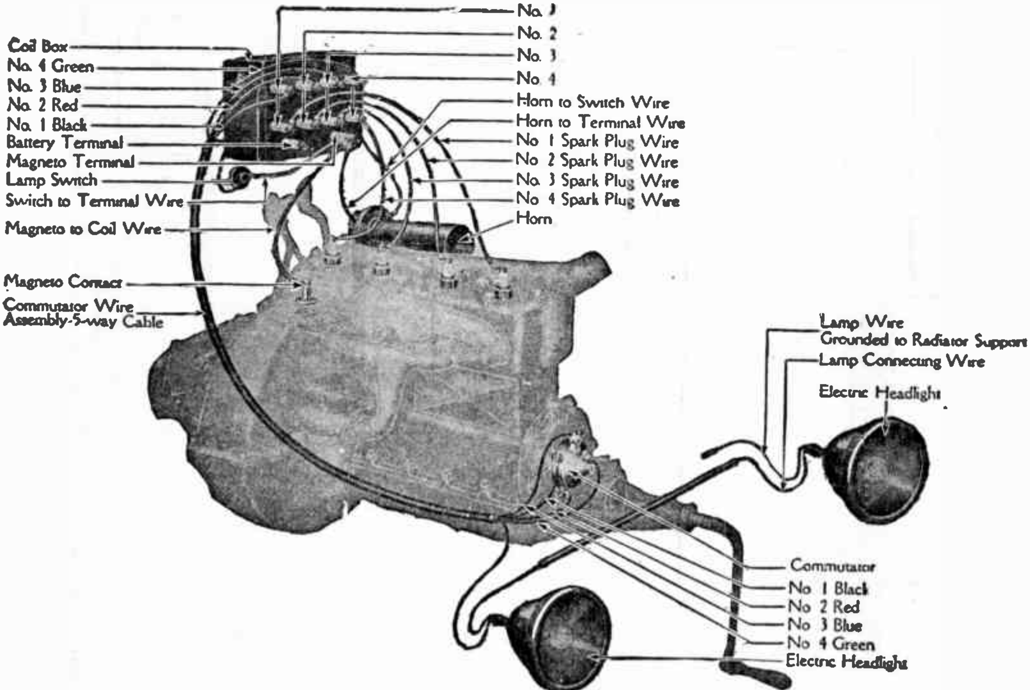


FIG. 7,998.—Wiring of Ford, horn, ignition and lighting systems showing commutator, spark coils, etc. The engine is started with current from storage battery and operated with the magneto, the latter being built onto the fly wheel.

the pressure of the secondary current is sufficient to overcome this resistance, it flows or "jumps" across the gap, and in so doing, intense heat is produced, resulting in a spark.

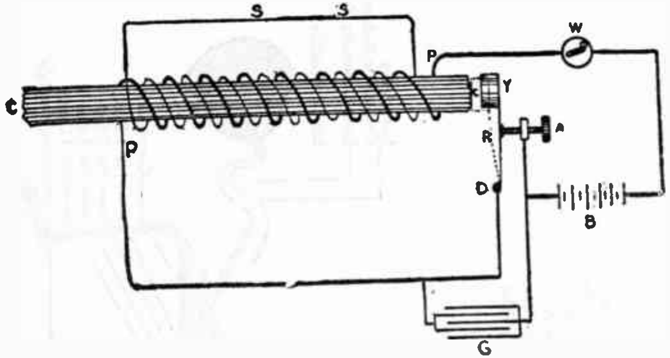
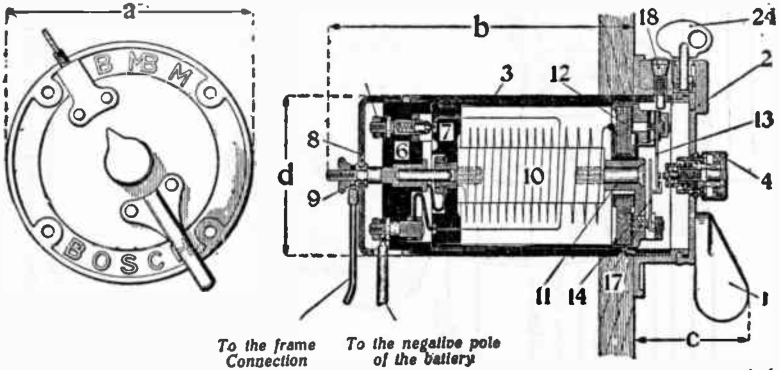


FIG. 7,999.—Secondary vibrator type induction coil. ***The parts are:*** A, contact screw, B, battery; C, core; D, vibrator terminal; G, condenser; P, primary winding; S, secondary winding; W, switch; Y, vibrator. ***In operation,*** when the switch is closed, the following cycle of action takes place: ***a,*** *the primary current flows and magnetizes core;* ***b,*** *magnetized core attracts the vibrator and breaks primary circuit;* ***c,*** *the magnetism vanishes, inducing a momentary high tension current in the secondary winding, producing a spark at the air gap;* ***d,*** *magnetic attraction of the core having ceased, vibrator spring re-establishes contact;* ***e.*** *primary circuit is again completed and the cycle begins anew.*



FIGS. 8,000 and 8,001.—Bosch type C horizontal secondary coil. ***The parts are:*** 1, switch handle; 2, movable cover; 3, coil housing; 4, starting press button; 6, fixed connection plate; 7, movable switch plate; 8, cable cover; 9, milled edged nut; 10, iron core; 11, plate carrying the starting arrangement and the condenser; 12, condenser; 13, contact spring; 14, vibrator; 15-16, auxiliary contact breaker; 17, vibrator spring; 18, stop screw for switch handle; 24, locking key.

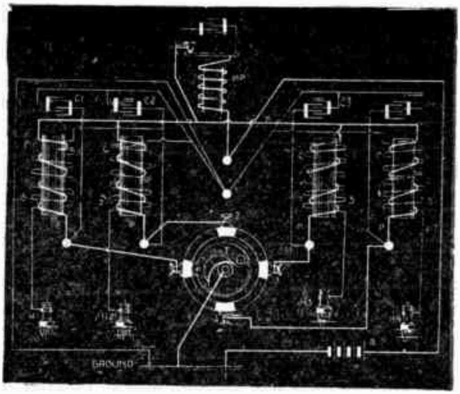
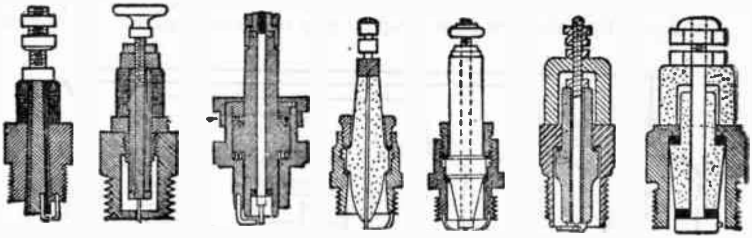
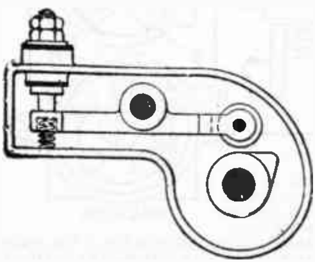


FIG. 8,002.—Circuit diagram of a master vibrator coil. B, is the battery; C, the unit coils; C1, C2, etc., the condensers; P, the primary windings and S, the secondary windings; H1, H2, etc., the spark plugs; T, the timer; MP, the master primary; V, the vibrator; W, the common primary connection; 1, 2, etc., the stationary contacts of the timer.



FIGS. 8,003 to 8,009.—Sections of well known spark plugs. The first five have procelain insulation; the last two, mica.



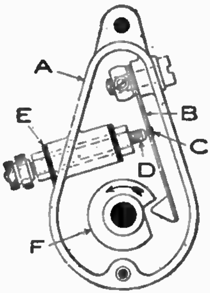


FIG. 8,010. — Contact maker and mechanical vibrator. *In operation,* as cam F, the weight on the end of blade, B, drops into the recess no the cam causing the blade to vibrate and make a number of contacts with D, thus producing a series of sparks when in operation.

FIG. 8,011.—Contact breaker. This device keeps the circuit closed at all times except during the brief interval necessary for the passage of the spark at the plug points. It is used to advantage on engines running at very high speeds, as it allows time for the magnetic flux in the core of the coil to attain a density sufficient to produce a good spark.

A form of high tension ignition called *synchronous ignition*, employs a *distributer* and a single coil for the several cylinders of a multi-cylinder engine.

Magnetos.—There are many types of magneto in use for ignition. They may be classified,

1. With respect to the armature, as
   - *a.* Stationary;
   - *b.* Oscillating;
   - *c.* Rotating.

2. With respect to the kind of current generated, as
   - *a.* Low tension;
   - *b.* So-called high tension { with separate coil; with self-contained coil
   - *c.* True high tension.

Inductor Magnetos.—In this class of magneto, *the armature is fixed* so that it does not revolve and is located with the sector shaped heads of the core at right angles to the line joining the field poles. This position of the core furnishes the least magnetically conducting path. An annular

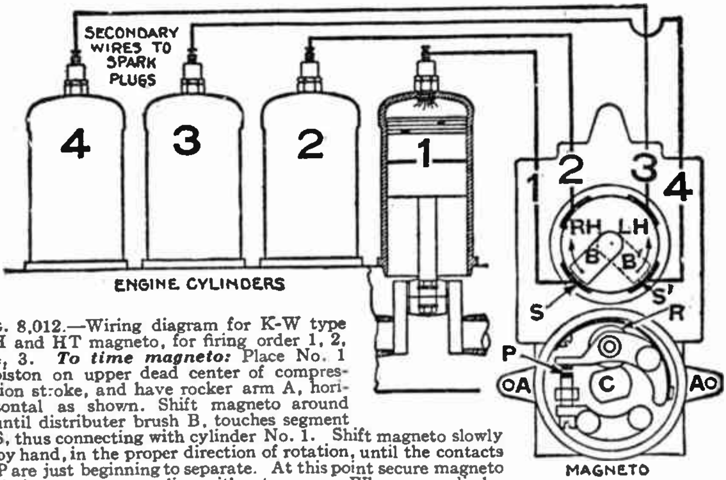
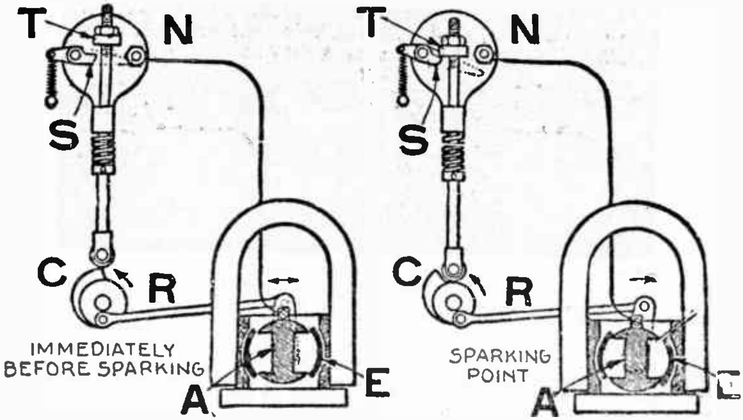


FIG. 8,012.—Wiring diagram for K-W type H and HT magneto, for firing order 1, 2, 4, 3. ***To time magneto:*** Place No. 1 piston on upper dead center of compression stroke, and have rocker arm A, horizontal as shown. Shift magneto around until distributer brush B, touches segment S, thus connecting with cylinder No. 1. Shift magneto slowly by hand, in the proper direction of rotation, until the contacts P are just beginning to separate. At this point secure magneto shaft to gear or coupling with set screws. When one cylinder is timed, proceed to connect the others as follows: Ascertain the firing order of the engine, then crank engine slowly and connect plug cable from next cylinder that fires to distributer segment No. 2 and so on until all the plug cables are connected. The secondary connections on the hard rubber distributer block are numbered in consecutive order, 1, 2, 3, 4. etc. These numbers do not refer to the engine cylinders, and it is necessary to determine the order in which the cylinders fire and connect secondary cables accordingly.

space between the armature and the field poles is provided for the rotation of an *inductor*.

The magnetic condition of the armature core depends entirely upon the position of the inductor. The latter is arranged, 1, to revolve continuously with a gear drive from the engine, or 2, to rotate to and fro through a small arc by link connection to the half time shaft.

Low Tension Magnetos.—Generators of this class may be used to supply a current of low voltage for, 1, make and break ignition or for, 2, high tension ignition with induction coils or coil spark plugs. A low tension magneto has an armature winding consisting of about 150 to 200 turns of fairly thick wire, covered with a double layer of insulating material.



FIGS. 8,013 and 8,014.—Low tension ignition with inductor magneto. *In operation,* the cam C, on the half time shaft, makes a contact just before sparking, and immediately breaks it again by permitting the hammer T, to fall on the cam S. A spark is produced at the instant of break of the ignition contacts. The winding of the armature A, has one end grounded through the base of the magneto, the current returning through the engine to the point S; the other end of the winding is led through an insulated post to the nut N, by which it is connected with a stud brought through the cylinder wall, where a wiper, indicated by dotted outline, normally rests against it by means of a spring. *In make and break ignition the quicker the break the better and spark,* which means that *the spring operating hammer T, should be amply strong.*

One end of the winding is grounded to the armature core and the other, brought to a single insulated terminal. When this terminal is connected to any metal part of the magneto or engine (since the latter is in metallic contact with the base of the magneto), the circuit is complete. The wiring therefore is very simple, which is one of the advantages of the system.

The "live end" of the armature winding is brought out by means of a metallic rod passing lengthways through the shaft of the armature; a hard rubber bushing is provided as insulation between the shaft and the rod. The live end of the winding is located at one end of the armature shaft.

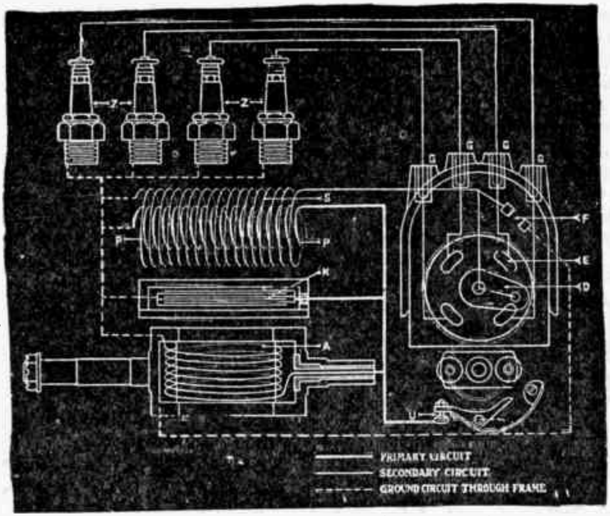


FIG. 8,015.—Circuit diagram of a magneto with self contained coil. A is the armature winding; P, primary of transformer; S, secondary of transformer; D, distributing brush carrier; E, contact segments; F, safety spark gap; G, terminals to plugs; U, interrupter; Z, spark plugs. *In operation,* alternating current flows from the armature having two points of maximum pressure in each armature revolution. As the current leaves the armature, it is offered two paths: 1, the shorter through the interrupter U to the ground, and 2, the longer through the primary P of the induction coil to the ground. A third path through the condenser K is only apparently available; it is obstructed by the refusal of the condenser to permit the passage of the current, as the condenser will merely absorb a certain amount of current at the proper moment, that is at the instant of the opening of the interrupter. The interrupter being closed the greater part of the time, allows the primary current to avail itself of the short path it offers. At the instant at which the greatest current intensity exists in the armature, the interrupter is opened mechanically so that the primary current has no choice but must take the path through the primary P of the induction coil. A certain amount of current is at this instant also absorbed by the condenser K. This sudden rush of current into the primary P of the induction coil, induces a high tension current in the secondary winding S of the coil which has sufficient pressure to bridge the air gap of the spark plug. The sharper the rush of current into the primary winding P, the more easily will the necessary intensity of current for a jump spark be induced in the secondary winding S. *The distribution of the current* in proper sequence to the various engine cylinders is accomplished as follows: the high tension current induced in the secondary S of the induction coil is delivered to a distributing brush carrier D that rotates in the magneto at half the speed of the crank shaft of the engine. This brush carrier slides over insulated metal segments E—there being one for each cylinder. Each of these segments E connects with one of the terminal sockets that are connected by cable with the spark plugs as shown. *At the instant of interruption* of the primary current, the distributing brush is in contact with one of the metal segments E and so completes a circuit to that spark plug connected with this segment. Should the circuit between the terminal G and its spark plug be broken, or the resistance of the spark plug be too great to permit a spark to jump, then the current might rise to an intensity sufficient to destroy the induction coil. To prevent this what is known as a safety spark gap is introduced. This will allow the current to rise only to a certain maximum, after which discharges will take place through this gap. *In construction* the spark discharges over this gap are visible through a small glass window conveniently located.

from which the current flows to an insulated terminal by means of a metal contact which is pressed against the revolving rod by a spring.

High Tension Magnetos.—These are *erroneously* divided into three classes, viz.: 1, those in which the induction secondary wiring is wound directly on the armature; 2, those having a secondary induction coil contained within the magneto; and 3, those having the coil in a separate box usually placed on the dash. Strictly speaking the first mentioned type is the only real high tension magneto. Forming part of a high tension magneto is a *distributer* which delivers current to the cylinders in proper sequence.

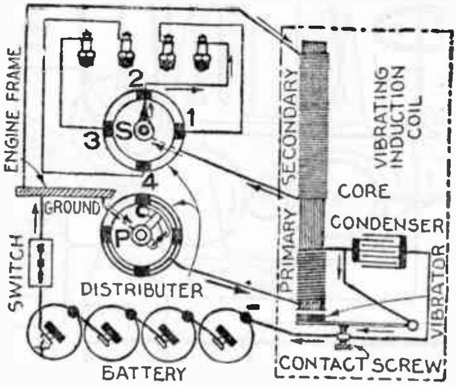


FIG. 8,016.—Synchronous high tension ignition. Here a single coil in combination with a *distributer* is used for any number of cylinders.

Synchronous Drive for Magnetos.—In order that the periods when a spark is desired shall coincide with the periods when the voltage is at or near a maximum, it is ***necessary** that a magneto be driven synchronously*, that is at a speed in a definite rate to that of the engine, as otherwise the sparking periods might occur with a zero point of electrical generation, and no spark would be produced.

To meet these conditions the drive is made positive and usually consists of toothed wheel gears.

Dual Ignition.—As defined, a dual ignition system is *one having two separate current sources with some **parts** of the ignition apparatus **in** common.*

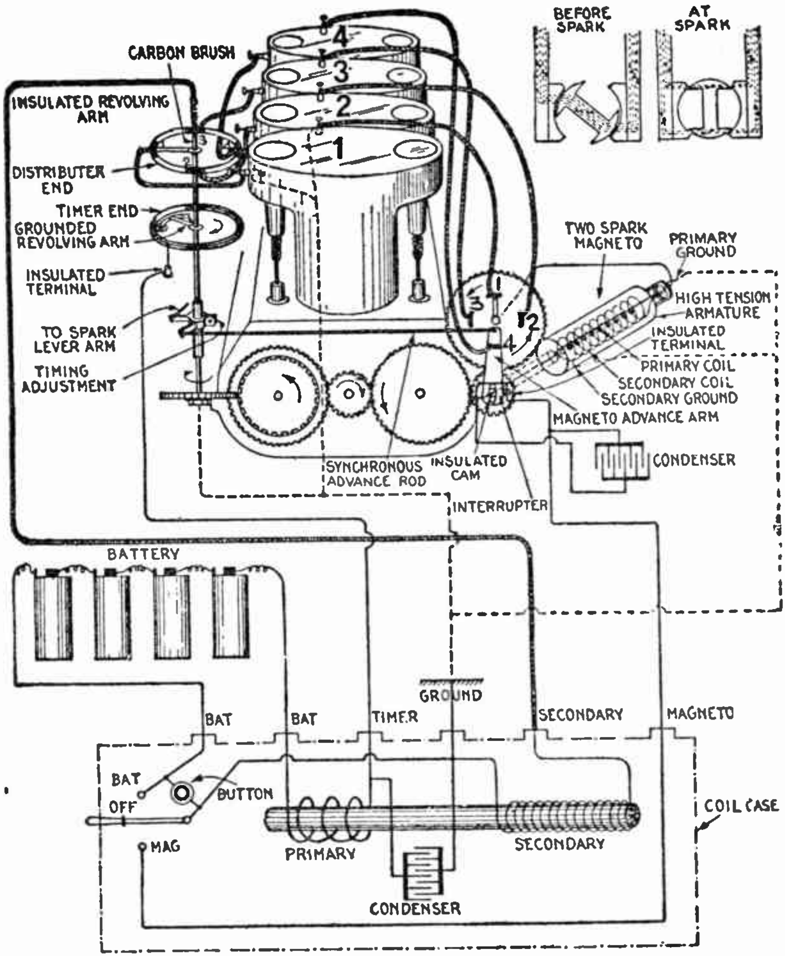


FIG. 8,017 to 8,019.—Double ignition consisting of a two spark high tension magneto system and a battery synchronous ignition system with engine driven distributer. Fig. 8,017, elementary diagram of connections; fig. 8,018, position of magneto armature just before time of spark; fig. 8,019, position of armature at time of spark.

Most magneto systems are examples of dual ignition, that is the distributer which forms a part of the magneto is used to distribute the current from either the magneto or a battery. Thus, if a short circuit occur in the armature, by turning a switch, current may be *furnished* by the battery and *distributed* by the magneto. Moreover, because of the difficulty of cranking an engine fast enough to start on the magneto, the battery is usually used for starting and the magneto for running.

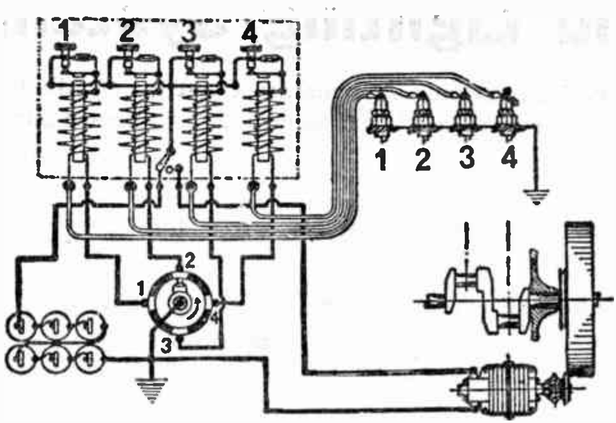


FIG. 8,020.—Dual jump spark ignition for a four cylinder four cycle engine. Current is supplied by the battery when the switch is in the position shown in the figure. By turning the switch to the right, a current from the magneto will be furnished. *Operation* with the battery in the circuit and the timer in the position shown, current flows from the positive terminal of the battery, to the switch, thence, to the contact screw of coil number two. From here, it flows through the vibrator blade, primary winding of the coil timer and the metal of the engine, and returns to the battery. The primary circuit is alternately opened and closed with great rapidity by the vibrator so long as the rotor of the timer is in contact with terminal 2. During this interval, a series of high tension current is induced in the secondary circuit producing a series of spark. The current which flows through the secondary winding is in a direction opposite to that of the primary current. At each interruption of the primary current, an induced high tension current flows through the secondary winding, to the spark plug, across the gap, producing a spark and returns through the metal of the engine, timer, and back to the coil,

Double Ignition.—An extreme provision against failure in operation consists in ***providing*** *two entirely independent ignition systems*.

For some installations both make and break and jump spark systems are provided, in others, two high tension systems.

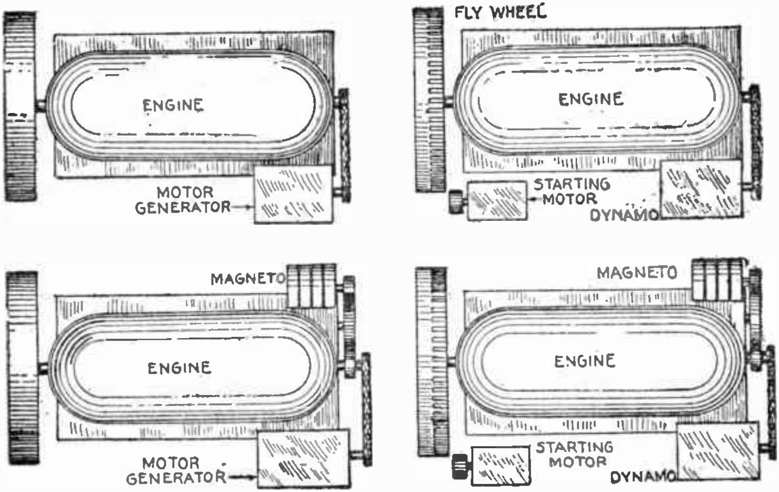
CHAPTER 41

Auto Starters and Lighting Systems

The various starting systems are classed, according to the kind of power used, as: 1, mechanical; 2, compressed air; 3, gas; and 4, electric.

The employment of electricity for gas engine starters has the advantage of also supplying current for lighting and ignition as well, and this has led to the development of systems involving various combinations.

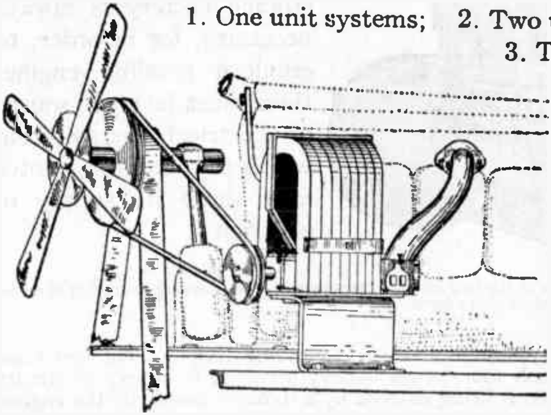
Classes of Electric Starter.—There are numerous electric



FIGS. 8,021 to 8,024.—Classes of starter systems. Fig. 8,021, one unit system; fig. 8,022, two unit system; fig. 8,023 so called two unit system; fig. 8,024, so called three unit system.

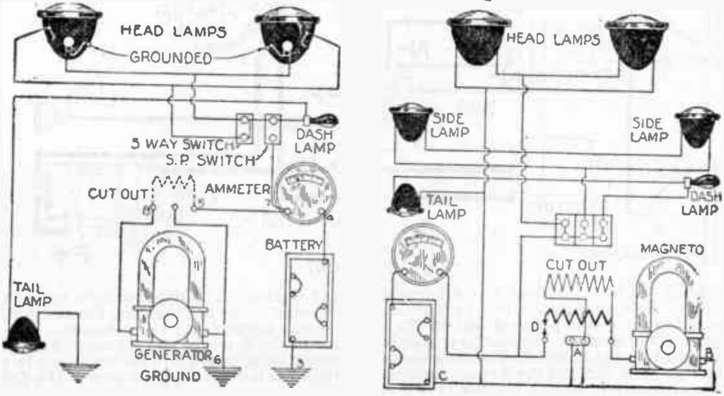
starting systems, and they may be classified according to the methods of obtaining current for starting and ignition, and the power element of the starter, as:

1. One unit systems; 2. Two unit systems; 3. Three unit systems.



These several systems comprise respectively: 1. A motor-dynamo; 2. A motor and a dynamo; 3. A motor, a dynamo, and magneto all separate.

FIG. 8,025.—Holzer-Cabot lighting magneto as installed on model T Ford car. A 60 ampere hour storage battery, if fully charged, will operate the side and tail lamps (6 candle power total) for approximately 50 hours, or the head and tail lamps (34 candle power) for approximately 10 hours. Turn off head lights when car is standing.



FIGS. 8,026 and 8,027.—Holzer-Cabot lighting magneto outfit installation. Fig. 8,026, one wire system as applied to double bulb or turn down head lamps: fig. 8,027, two wire system, suitable also as a general guide for motor boat wiring.

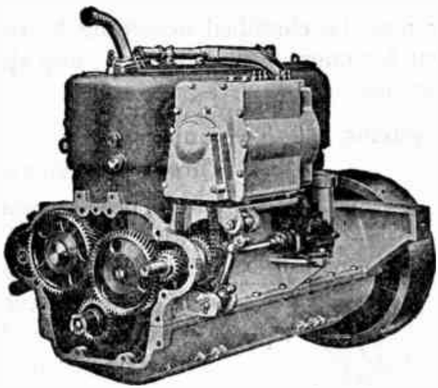


FIG. 8,028.—Entz single unit starting and lighting system; view showing mounting of motor dynamo on engine and silent chain drive.

Electric Starters Require a Storage Battery.—In any electric system a storage battery is always necessary, for in order, to crank a gasoline engine, there must be some source of electrical energy from which the cranking motor may draw its supply of electricity.

Without it there would be no electric cranking devices. The first function, therefore, which the storage battery serves is to supply electricity for starting purposes, it being charged by a dynamo driven by the engine.

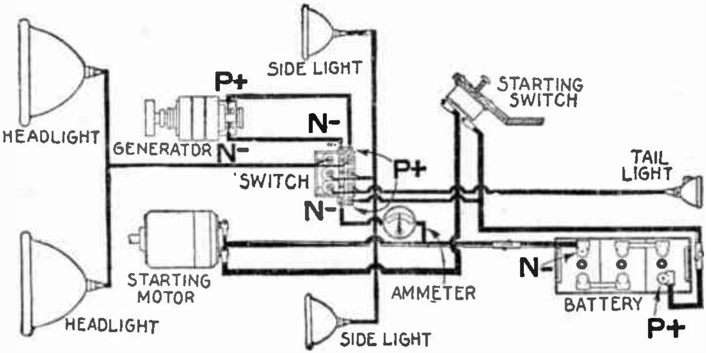


FIG. 8,029.—Autolite two unit starting and lighting system. The dynamo is driven by the engine. *In operation*, during such time as the electric lamps are burning, the current for operating them is supplied direct by the dynamo, any surplus, not being consumed, being stored in the battery. When the engine is running in the day time and no current is being consumed by the lamps, the entire amount of current being produced is being stored in the battery. The dynamo has a speed governor contained in a drum that is a part of the drive. A reverse current circuit breaker is placed between the dynamo and battery to break the circuit when the battery pressure exceeds that of the dynamo. The circuit breaker is housed between the magnets of the dynamo and is a part thereof. An ammeter reading in both directions for zero is mounted on the dash. The capacity of battery is 120 ampere hours.

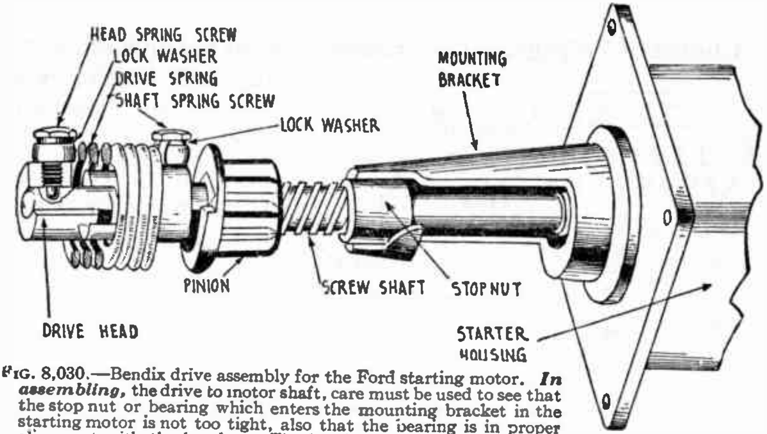
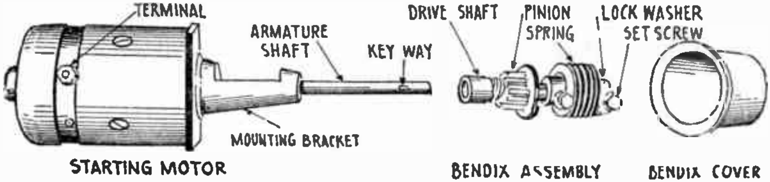
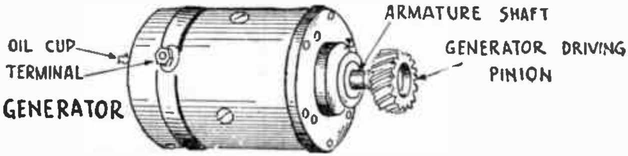


FIG. 8,030.—Bendix drive assembly for the Ford starting motor. ***In assembling,*** the drive to motor shaft, care must be used to see that the stop nut or bearing which enters the mounting bracket in the starting motor is not too tight, also that the bearing is in proper alignment with the bracket. The bearing should be oiled and then fitted so that it can be turned readily with the fingers. If the bearing be too tight, it should be dressed down with an oil stone. Too tight a fit will cause the bearing to freeze to the bracket, resulting in serious damage to the starter.





FIGS. 8,031 to 8,034.—Starter and dynamo assembly. ***To remove dynamo,*** first take out the three cap screws holding it to the front end cover and by placing the point of a screw driver between the dynamo and front end cover, the dynamo may be forced off the engine assembly. Always start at the top and face dynamo backward and downward at the same time. Plates may be obtained from nearest dealer if car is to be operated with dynamo removed. ***In replacing dynamo,*** the drive pointer must be properly meshed with the large time gear. The bracket to which the dynamo is bolted is separate from the cylinder block and the meshing of the generator driving pinion with the large time gear can be regulated by the use of one or more paper gaskets between the bracket and the cylinder block. The bracket should rest tightly on the crank case gasket and line up with the face of the time gear case. If these gears be meshed too tightly, a humming noise will result, also the dynamo shaft will be thrown out of alignment.

Choice of Voltage.—The pressure used on the different lighting and ignition systems is six volts, and were it not for the problem of cranking, there probably would not be any reason to change.

The advantage of low voltage is that the circuits are easily protected from electrical leakage. Low pressure lamps are manufactured with less difficulty than those designed for higher pressure

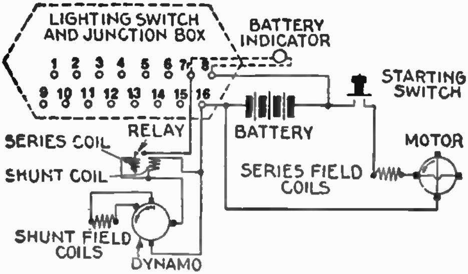


FIG. 8,035.—Wiring diagram of *Wagner* two unit starting and lighting system. The connections shown in dotted lines are put on by the automobile manufacturer, and they may or may not be correct for all cars using the *Wagner* system of starting and lighting. However, they are correct for a Studebaker car.

Voltage of Units.—The weight of six volt batteries is less than that of the higher voltage type. Were it not for these considerations, starting motors would be designed for high pressure, as they are smaller and consequently lighter. High voltage for the motor does not necessarily mean high voltage for the dynamo and lights.

There are three general combinations:

1. All one voltage, either 6, 12, 16, or 18 volts;

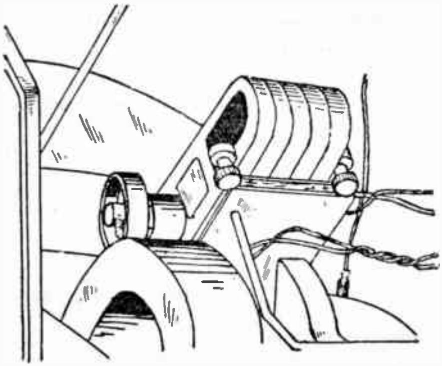


FIG. 8,036.—Method of driving a generator direct from engine fly wheel by friction pulley with spring or cushion base; the latter relieves the stress on the shaft from excessive vibration. The governor regulates the speed of the machine and prevents burning out of the lamps. The illustration shows a K-W magneto installed on an early Maxwell car.

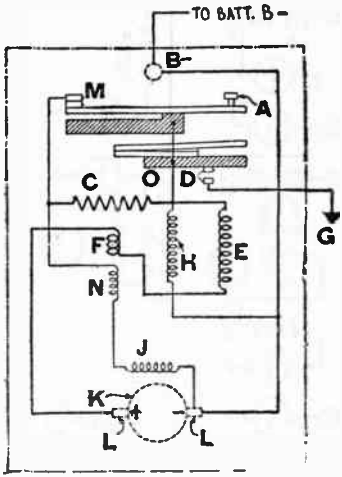
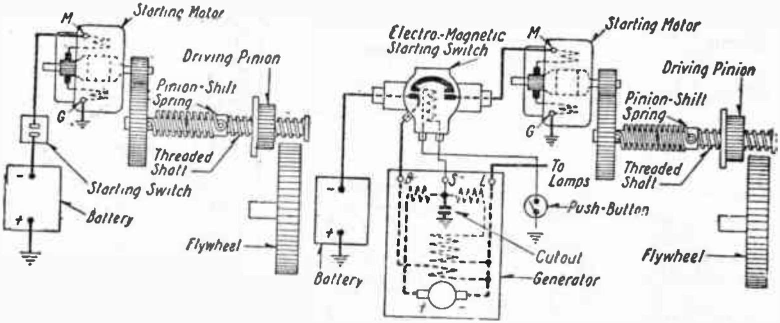
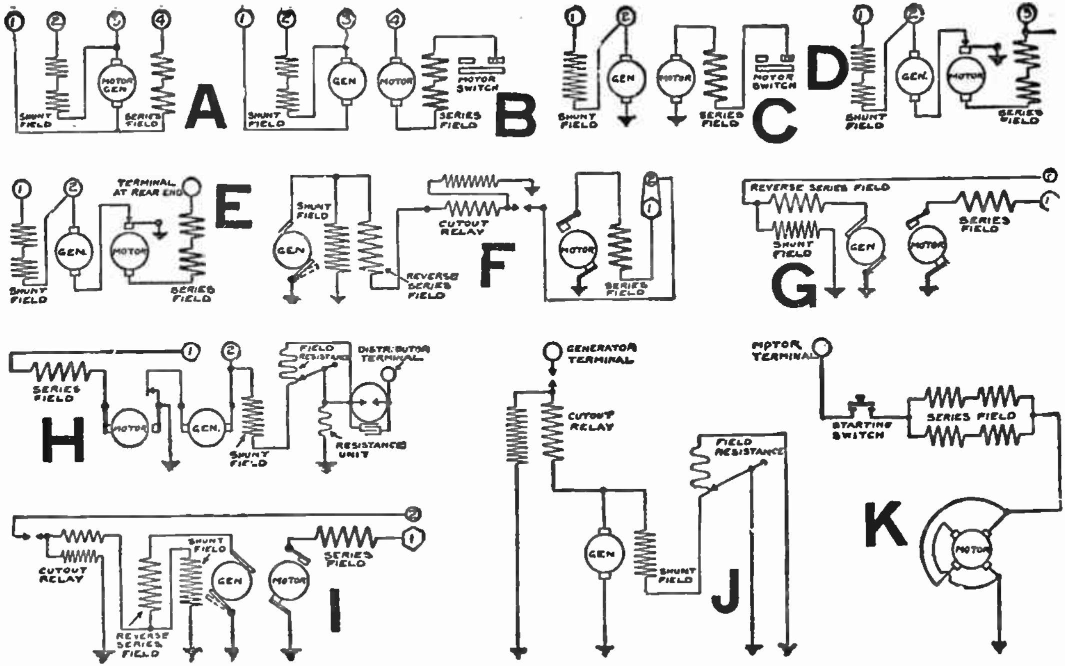


FIG. 8,037.—Diagram of connections of Westinghouse dynamo with self-contained regulator. The regulator performs two functions: 1, that of a cut out, and 2, that of a voltage regulator. Each function is performed by its individual element but the operation of the second function depends upon that of the first. When the dynamo is being operated at a speed below the predetermined "cut in" speed, the contacts of the cut out are open, and *vice versa*. The cut in speed var es from five to ten miles per hour on high gear, depending upon the gear ratio and wheel diameter of the car. ***For voltage regulation,*** the shunt fields of the dynamo are so designed that a voltage in excess of normal would be regularly generated when dynamo is operated at high speed and no load. This excess voltage is prevented and the voltage is held constant by the automatic voltage regulator. When the dynamo is operating below cut in speed, the regulator contacts are closed, and remain closed till there is a voltage in excess of the predetermined value. This voltage is fixed by the setting of the voltage regulating screw. When, due to increased speed of dynamo, the voltage tends to exceed the value for which the regulator is set, the regulating contacts open, opening the direct shunt field circuit and cutting in the regulating resistance. This causes a momentary drop in voltage so that the contacts close again. This opening and closing of the contacts is repeated so rapidly as to be imperceptible to the eye, and holds the voltage constant. **A**, voltage regulating screw; **B**, battery terminal; **C**, regulating resistor; **D**, cut out contacts; **E**, series coils; **F**, series compensating coils; **G**, ground; **H**, regulator shunt coil; **J**, dynamo shunt coil; **K**, commutator; **L**, brushes; **M**, regulating contacts; **N**, shunt compensating coil; **O**, cut out armature.



FIGS. 8,038 and 8,039.—Diagrams of Westinghouse electrical and mechanical connections of double reduction motor and switch for automatic screw pinion shaft. Fig. 8,038, with hand or foot operated starting switch; fig. 8,039, with electro-magnetically operated starting switch controlled by push button. In the figures, when the starting switch is closed, the full battery voltage is impressed on the motor and it starts immediately. The pinion, when the motor is at rest, is within the screw shift housing and entirely away from the fly wheel gear.



FIGS. 8,040 to 8,050.—Internal circuits of motors, generators, and motor generators in Delco Systems (Phillips and Copland diagrams). *A*, 1912 Cadillac, 1913 Cole, Hudson, Oakland and Oldsmobile. *B*, 1913 Cadillac and Packard 13-38. *C*, Buick 14-54, 55, Oldsmobile 6-54, Oakland 43, 48, 62, Cole 4-40, 4-50, 6-60, Moon 4-42, 6-50. *D*, 1914 Cadillac. *E*, 1914 Hudson 6-54. *F*, 1914 Buick 24, 25, 36, 37, Cartercar 7, Paterson, Oakland 36, Hudson 6-40. *G*, 1915 Buick, 24, 25, Cartercar, 9. *H*, Buick 36, 37, 54, 55, Cadillac 8, Cole 6-50, Hudson 6-40, Moon 6-40, 6-60, Oakland 37, 49, Oldsmobile 42, Paterson and Westcott Model U. *I*. 1915 Westcott 4. *J* and *K*, 1915 Cole 8.

2. Generating and starting at 12, 16, or 18 volts, and lighting at 6, 8, and 16 volts respectively.

3. Generating and lighting at 6 volts, and starting at 24 or 30 volts.

One Unit Systems.—The term "one unit" as applied to an electric starting system means that *there is a motor and dynamo* ***combined*** *in one machine*, or motor dynamo, as it is called, the dynamo furnishing current for the starter, and for charging the storage battery.

Two Unit Systems.—This classification indicates that the *motor and dynamo are* ***separate units***, as distinguished from the one unit system.

There is another system, ill advisedly called two unit, consisting of a *motor dynamo, and a magneto.* The reason for this confusion is because some dynamos are arranged to furnish current for ignition when not charging the battery, thus ignition has to be considered in the classification to distinguish the last mentioned system from the arrangement of three independent units.

Three Unit Systems.—This division comprises those systems which have a *motor, dynamo, and magneto* ***each separate.***

Here, each unit has a single function and is only electrically associated with the rest of the apparatus in the system. Thus, the dynamo supplies current for charging the battery, which in turn delivers current to the motor and ignition system at starting, and also to the lighting system, the magneto furnishing current for the ignition system, when the engine is running.

The term three unit system applies only to "starting, lighting and ignition systems," as distinguished from "starting and lighting systems."

Control.—In any electric system where there is a dynamo and a storage battery, two control elements are necessary for the proper working of the system:

1. Means for preventing reversal of current when the dynamo is charging the battery; 2. Means for limiting dynamo voltage.

When the engine is slowed down the speed of dynamo is also reduced, which causes the pressure induced in the armature to become less than the battery pressure against which it must force the current in charging, and accordingly, unless some automatic device be provided to break the circuit when such condition obtains, the current will reverse and flow out of the battery. This automatic device is called a *discriminating cut out* or *reverse current circuit breaker*, and consists of an electromagnet connected in the dynano circuit, which, when the dynamo generates sufficient pressure to charge the battery, will attract an armature and close the circuit between the dynamo and battery, and which will also open the circuit when the battery pressure becomes greater than that induced in the dynamo.

Again when the engine speeds up, the voltage increases and some form of regulator must be provided to prevent undue rise of voltage otherwise the battery would be charged at too high a rate. This regulation may be effected : 1, mechanically; 2, electrically, or 3, thermally.

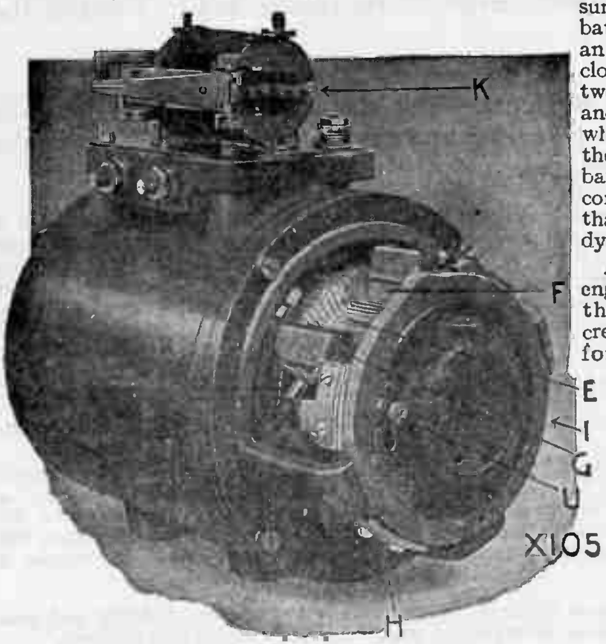


FIG. 8,051.—Wagner dynamo of two unit starting and lighting system. The drive is through a train of gear or equivalent. The windings and internal connections are of such character that no regulating devices are required except a cut out. ***In construction,*** the commutator E, and brushes F,G,H, and I, are located under the cover which in this cut is removed. The brushes H and I, collect the current from the commutator and furnish this current for charging the battery through the cut out K. The brushes F and G, collect the current from the commutator and furnish this current for exciting the fields.

CHAPTER 42

Electric Vehicles

Vehicles propelled by electric motors supplied with current for storage batteries have a travel capacity ranging from 75 to 100 miles per charge, with controller arrangements for providing speeds varying from 6 to 25 miles per hour. In these cases the number of cell in each battery may vary from 10 to 30 according to the make and number of plates in each cell. The number of plates in each cell may vary to suit special conditions.

Gasoline-Electric Vehicles.—A not altogether successful attempt has been made to eliminate the shortcomings of each by combining the gas engine with a dynamo connected to a storage battery, for supplying the power required by the electric motors.

Such a combination will operate at practically constant speed at all loads, as the dynamo with the storage battery serves to furnish the necessary overload, or consumes that portion of the energy which is not needed.

Motors for Electric Vehicles.—These are of the enclosed type of construction, which of necessity they must be, in order to protect them from dust, etc., in their exposed positions under the car. They are designed for overloads of 200% or more.

Drive or Transmission.—Because of the relatively high speed of the motor as compared with that of the rear wheels of the car, a system of gearing is necessary between the motor and

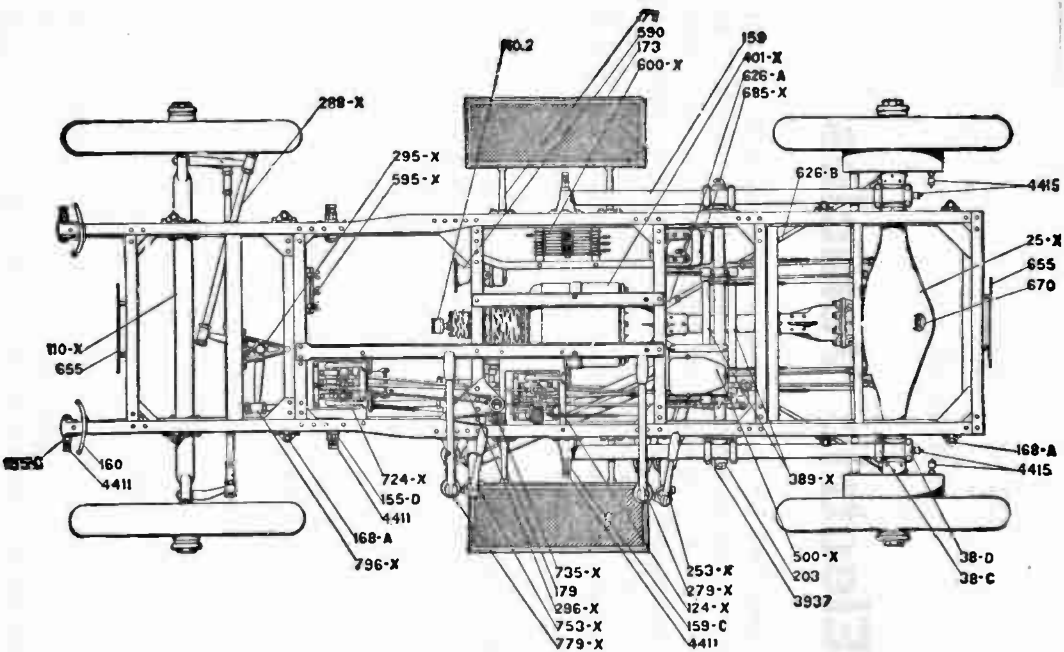
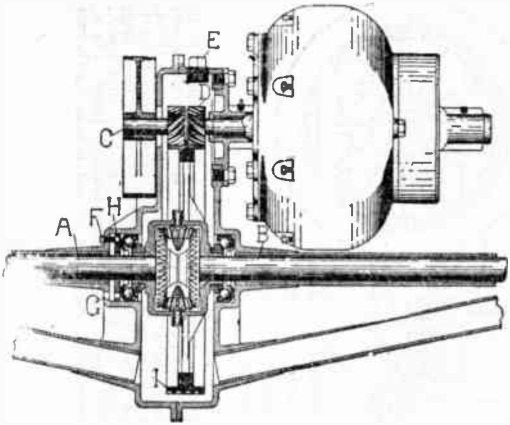


FIG. 8,052.—Plan view of Baker electric chassis. The parts are: 25-X, rear axle; 38-C, rear spring yoke front; 38-D, rear spring yoke rear; 110-X, front axle; 124-X, front levers, rear; 155-C, front spring bolt, front; 155-D, front spring bolt, rear, 159, rear spring; 159-C, rear spring bolt; 160, head lamp bracket; 168, A, fender bracket; 173, step pad; 179, step bracket; 203, rear spring seat, center; 253-X, rear control mast; 279-X, steering mast, rear; 288-X, lower steering rod, bell crank to spindle; 295-X, bell crank; 296-X, lower steering rod, mast to mast; 389-X, brake shaft; 401-X, motor; 500-X, controller; 590, horn; 595-X, fuse box; 600-X, resistance; 626-A, brace rod clevis; 626-B, brace rod; 655, license bracket; 670, oil inlet; 685-X, contactor ;724-X, foot levers, front; 735-X, interlock, 753-X, front control mast; 779-X, steering mast, front; 796-X, lower steering rod, mast to bell crank; 3,937, rear spring clip; 4,411, 4,415, No. 2 grease cups.



rear axle to obtain the necessary velocity reduction. Moreover, in some cases, other gears must be provided so that the power may be applied to the rear shaft when the motor shaft and rear shaft are at right angles to each other.

FIG. 8,053.—Single motor attached to rear axle through *herringbone* single reduction gears

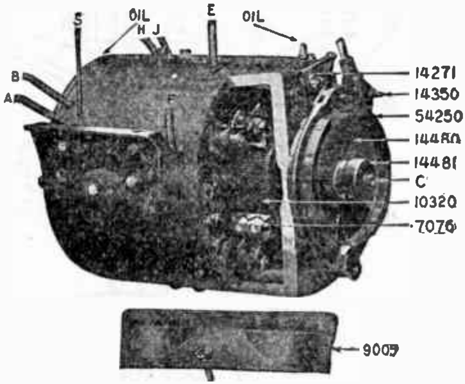


FIG. 8,054 and 8,055.—Rauch and Lang vehicle motor. ***Instructions for care of motor:*** The two oil covers lead to the ball bearings in the motor yokes. A good grade of light cylinder oil is recommended for these bearings. The commutator, 10,320, should be at all times kept clean, free from any gummy or gritty substance. The carbon brushes 7,076 should make perfect contact with the surface of the commutator and should be replaced with new ones when worn out. These brushes are originally 1⅝ inches long and should be replaced with new ones as soon as the measurement is reduced to 1¼ inches. It is safer to replace these brushes often, rather than allow them to become too short. Very serious damage may result from using brushes that are too short or ones that make poor contact with the commutator. Brushes that are too short or that are making poor contact will pit, burn and blacken the surface of the commutator. Replacement of brushes should be made only by an experienced person. The motor leads are lead out of motor through insulated holes. These holes, lettered J,H,B,A,S,E and F, correspond to the letter contacts on the controller into which they are connected. The motor brake may be adjusted for wear by means of the winged nut 14,350. Clearance between brake jaws and wheel may be adjusted by means of the screw 14,271. To remove brake wheel from armature shaft, take the 5/16 screw C, out of the cap 14,481. A ½ inch, 12 pitch bolt, 3 inches or longer, or a cap screw may then be screwed through the threads in the cap and up against the end of the armature shaft. Continue to turn this screw and the pulley will be drawn off the shaft.

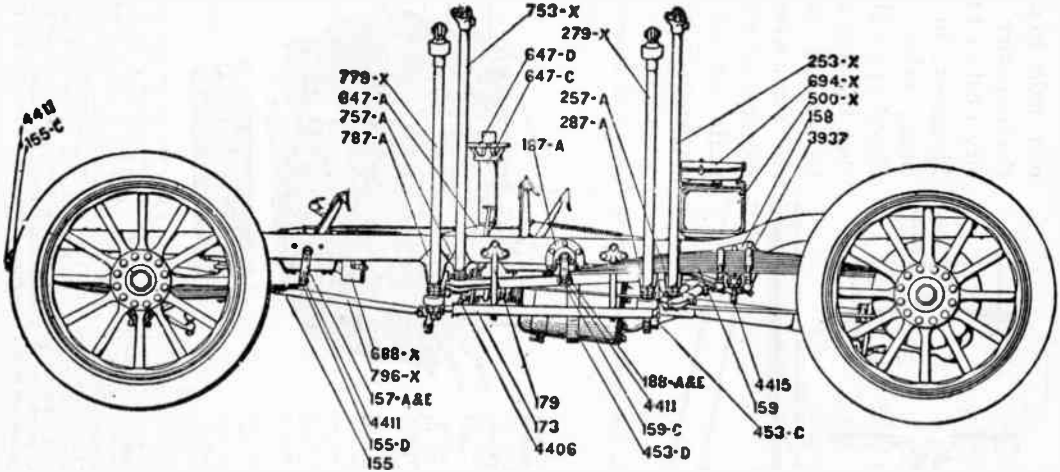
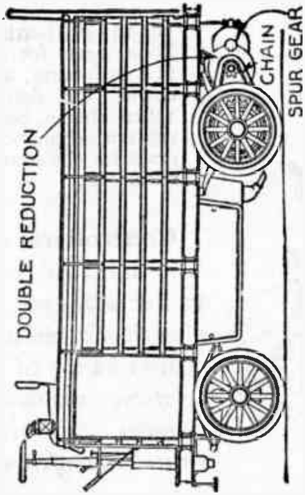


Fig. 8,056.—Side view of Baker electric chassis. The parts are: 155, front spring; 155-C, front spring bolt, front; 155-D, front spring bolt rear; 157-A, front spring shackle; 157-E, front spring shackle lock plate; 158, rear spring bracket center; 159, rear spring; 159-C, rear spring bolt; 173, step pad; 179, step bracket; 187-A, front hanger for rear spring; 188-A, rear spring shackle; 188-E, rear spring shackle lock plate; 253-X, rear control mast; 257-A, rear control mast bracket, lower; 279-X, steering mast, rear; 287-A, steering mast bracket, rear; 453-C, safety loop, short; 453-D, safety loop, long; 500-X, controller; 647-A, seat pedestal bracket, left; 647-C, seat pedestal tube, left; 647-D, seat pedestal stop cup; 688-X, opening switch; 694-X, closing switch; 753-X, front control mast; 757-A, front control mast bracket, lower; 779-X, steering mast, front; 787-A, steering mast bracket, front; 796-X, lower steering rod, mast to bell crank; 3,937, rear spring clip, 4,406, 4,411, 4,415, grease cups.



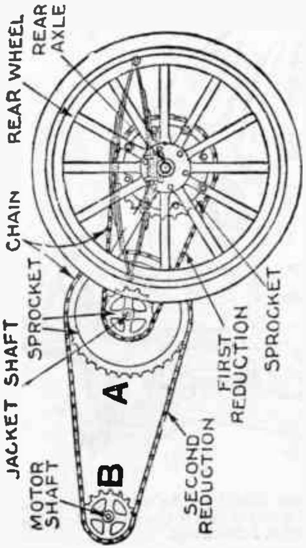


FIG. 8,057.—Double chain drive. The rear axle is of the "dead" type and each rear wheel has a sprocket with which the chains mesh. The jack shaft is parallel to the rear axle and upon the maintenance of parallelism between the two axles depends the satisfactory working of the chain. The cut illustrates single and double reduction chain drive. For single reduction the motor would be located at A, and for double reduction, at B.

FIG. 8,058.—Chain and sprocket double reduction gear for heavy trucks. As here shown, the motor is hung above the springs, missing the jars of travel.

There are several forms of drive, as by 1. Herringbone gear; 2. chain gear; 3. worm gear.

Herringbone drive.—This drive is extensively used because of its freedom from noise, its simplicity and durability owing to the parts being enclosed.

Chain Drive. — This form of drive is desirable for heavy service, as on very large trucks. It is a noisy and dirty mode of power transmission, and when not enclosed is subject to rapid wear. A very objectionable feature of chain drive is the fact that the chain sometimes climbs the teeth due to considerable wear or to too little clearance.

Combination Chain and Gear Drive.—For very heavy trucks where a considerable reduction in speed is required between the motor and wheels, a double reduction is sometimes used. The motor is usually hung above the springs, thus being protected from the jars of travel.

There are several forms of double reduction using light high speed motors by means of various combinations of gear and chain, with silent, roller

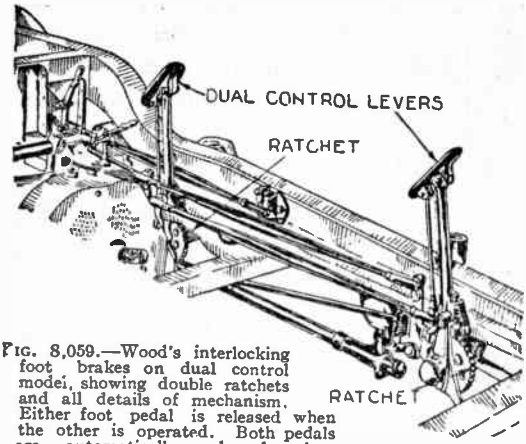


FIG. 8,059.—Wood's interlocking foot brakes on dual control model, showing double ratchets and all details of mechanism. Either foot pedal is released when the other is operated. Both pedals are automatically released when controller is moved to first speed.

chains or herring-bone gears for the first reduction, and single or double roller chains, bevel gears or herringbone gears for the second reduction.

Controllers — The form of controller adapted to electric vehicle use consists of *a rotatable insulated cylinder carrying on its circumference a number of contact, arranged to make the desired connections with the terminals of the various apparatus in the circuit through a wide range of variation*

Some controllers are constructed with a cylindrical surface, upon which bear single leaf springs, the desired electrical connections being

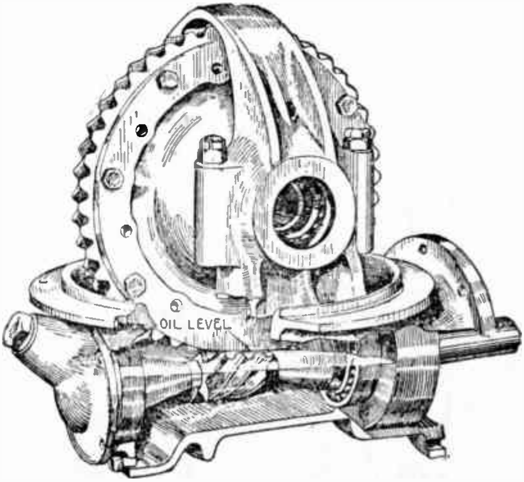
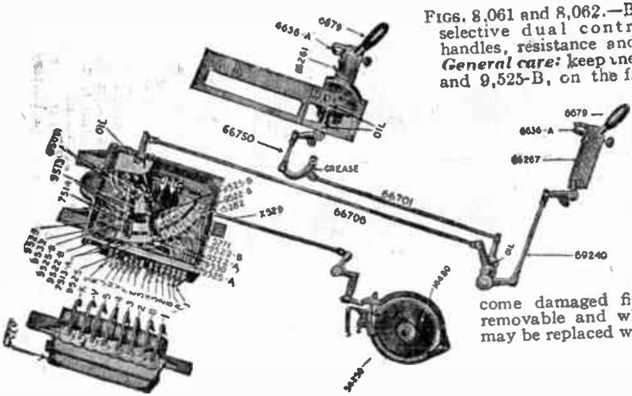


FIG. 8,060.—Lancaster type of worm drive as used on some electrics. An advantage claimed for this form of worm drive is the fact that mounting the worm below the ring gear permits it to be placed in a bath of oil, assuring constant and ample lubrication.



Figs. 8,061 and 8,062.—Baker R and L, selective dual controller, control handles, resistance and motor brake. *General care:* keep the plates, 9522-B and 9,525-B, on the face of the controller and the shoes 7,513-A on the movable arm clean and free from burned and rough edges. The contact plates 9,522-B and 9,525-B, and the shoes 7513-A, are the ones that become damaged first. They are removable and when badly worn may be replaced with new ones.

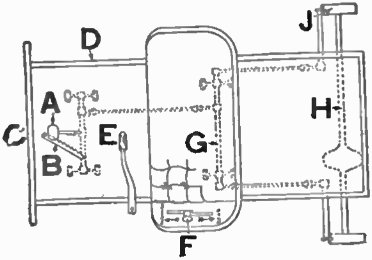
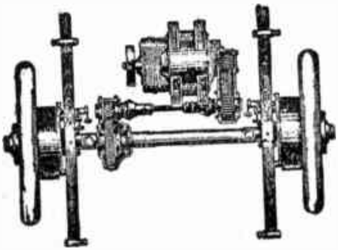


Fig. 8,063.— Diagram of the controlling apparatus of a light electric vehicle. A, brake pedal; B, ratchet retaining pedal in place, operated by left foot; C, dash board; D, body sill; E, steering handle; F, controller handle; G, rocker shaft for setting hub brakes; J, brake band on wheel hub; H, rear axle.



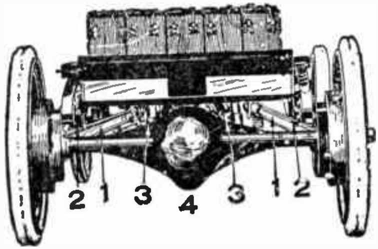
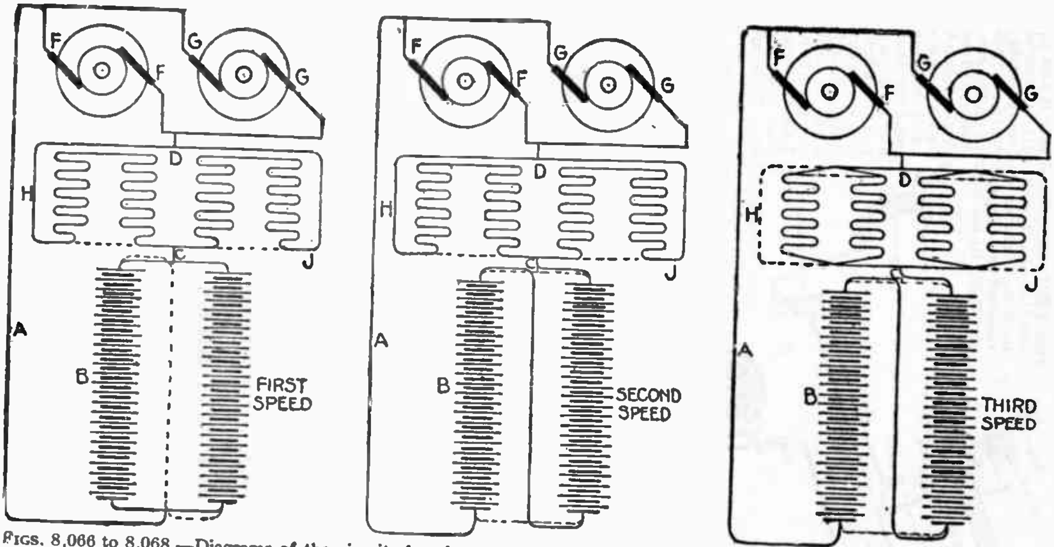
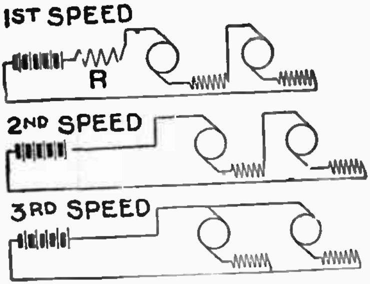


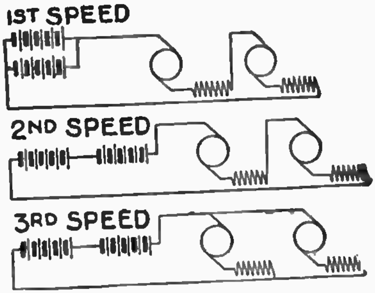
Fig. 8,064.—Waverly double reduction gear or combination herringbone and so called "silent" chain.

Fig. 8,065.—Rear view of Wood's chassis with battery showing the following *features of construction:* 1, radius rods extending from rear axle to sub-chassis frame; 2, rear springs rest on radius rods, instead of on rear axle; 3, motor, showing ball and socket spring suspension; 4, worm drive, showing location of worm below rear axle.



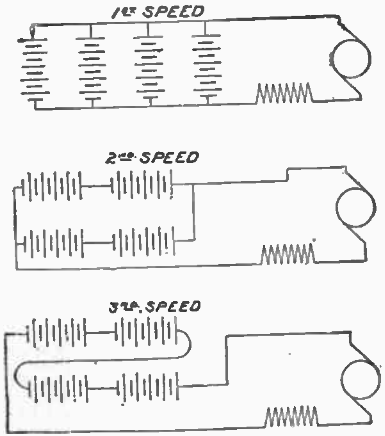
FIGS. 8,066 to 8,068.—Diagrams of the circuit changing arrangements of a typical electrical vehicle. The full lines in these diagrams indicate the closed or active circuits; the dotted lines the open, or inactive circuits. As may be readily understood, the whole scheme of the circuit changing depends on employing several different circuit connections between battery and motor, which may be opened and closed, as desired. Here A and C are the lead wires between battery, B, and motor brushes, FF and GG, and the field windings H and J, and the wire D. Fig. 8,066 shows first speed; two units of the battery B are connected in parallel, which means that the voltage is reduced to the lowest point. The wire C, connected to the bridge between the positive poles of the battery, leads the current to the field windings, H and J, which, in this figure, are connected in series-parallel, which gives the lowest speed and power efficiency of the motors. By the wire, D, the current is carried to the brushes, FF and GG, which, according to this scheme, are permanently connected in parallel, the return path to the negative pole of the battery being through the wire A. In fig. 8,067. the circuit is varied so as to connect the two units, so as to give its highest pressure efficiency. But, since the field windings of the motors are also connected in series, or in series parallel, as in this case, the efficiency in speed and power is reduced nearly one-half. In fig. 8,068. the two units of the battery are connected in series, which, as in the former case, indicates the greatest efficiency in power output; but the field windings are connected in parallel, which means that the voltage generated by their operation is equivalent to the voltage of only one motor, with the result that the speed and power efficiency is raised to its highest point.





FIGS. 8,069 to 8,071.—Diagrams showing methods of speed changing in a typical one battery unit, two motor circuit. ***The first speed*** shows the two motors in series, with a resistance coil interposed; ***the second,*** the motors in series, without the resistance; ***the third,*** the motors in parallel.

FIGS. 8,072 to 8,074.—Diagram showing methods of speed changing in a two battery unit, two motor circuit, showing combinations for three speeds. ***The first speed*** is obtained with the battery units in parallel, and the motors in series, ***the second,*** with the battery units in series and the motors in series; ***the third,*** with the battery units in series and the motors in parallel.



made by suitably connected conducting surfaces on the cylinder circumference, and cut outs being similarly accomplished by insulating surfaces, bearing against the spring contacts at the desired points. This type of controller is one of the most usual forms for motor vehicle purposes.

Troubles.—In order to properly cope with the numerous disorders and mishaps likely to be encountered, the following points relating to troubles may be found helpful:

FIGS. 8,075 to 8,077.—Diagrams showing combinations for three speeds in a typical four battery unit, single motor circuit. The only changes made in these circuits are in the battery connections. ***For the first speed*** the battery units are in parallel; ***for the second,*** in series parallel; ***for the third,*** in series. The motor connections are not varied.

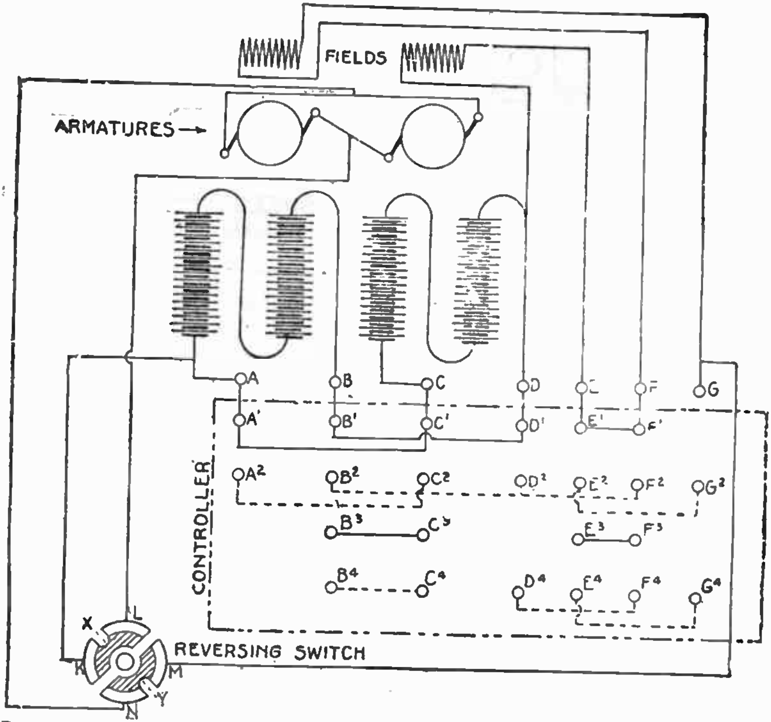


FIG. 8,078.—Diagram plan of the several parts of an electric vehicle driving circuit. The field windings and armatures are shown projected, the proper wiring connections being indicated. The periphery of the controller is laid out within the broken line rectangle, the contacts and connections through it for varying the circuits through four speeds being shown. *For first speed* the controller is rotated so that the row of terminal points, A, B, C, D, E, F, G, are brought into electrical contact with the row of terminal points, on the controller, A′, B′, C′, D′, E′, F′, G′; this connects the two unit battery in parallel and the field windings of the two motors in series. A further movement of the controller, bringing the points, A, B, C, etc., into contact with A², B², C², etc., ***gives second speed***, the batteries now being in parallel and the fields in series parallel. *For third speed*, the points B and C are brought into contact with B³ and C³, and E and F with E³ and F³, which means that the batteries are connected in series, and the fields in series. Similarly, for fourth speed, the points B and C are brought into contact with B⁴ and C⁴, and D, E, F, G, with D⁴, E⁴, F⁴, G⁴, which means that the batteries are in series and the fields in parallel. The connections between the battery, the armature brushes, and the motor fields, are made as indicated through the rotary reversing switch by the terminals, K, L, M, N. The switch may effect the reversal of the motors by giving a quarter turn to its spindle, which means that the contacts of segment X, will be shifted from L and K to K and N, and the contacts of segment Y, shifted from M and N to L and M, thus reversing the direction of the current.

1. If vehicle run too slow, look for the following:

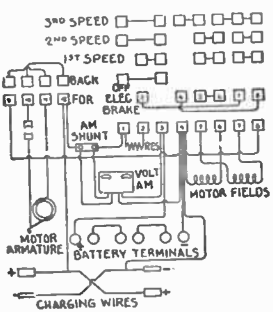
a. Deflated tires. *b.* Slow tires, due to other makes having been substituted for those furnished by the manufacturer of the vehicle. *c.* Broken bearings in wheels, countershaft or motor. *d.* Shoes not making perfect contact on face of controller. *e.* Brushes not making perfect contact on commutator due to being too short, or commutator being dirty. *f.* Broken battery jar, solution having partly leaked out. *g.* Brakes rubbing when they are supposed to be thrown off. *h.* Battery exhausted.

2. If the current be higher than usual when running on the level, look for the following:

a. Tight bearings. *b.* Brakes rubbing. *c.* Silent chains too tight. *d.* Front wheels out of alignment. *e.* Tires deflated.

3. If needle on ammeter vibrate more than usual, moving up and down very rapidly, look for the following:

a. Blackened commutator. *b.* Commutator brushes worn too short. *c.* Loose connections at battery terminals or at connections on controller. *d.* Broken wire leading to meter.



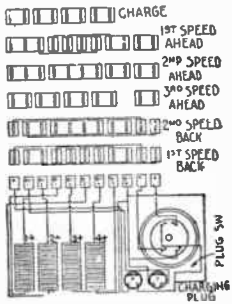


FIG. 8,079.—Diagram of controller connections of one unit, one motor circuit, with variable fields.

FIG. 8,080.—Diagram of controller connections of a four unit one motor circuit, with constant series connections for fields and armatures in forward and backward speeds.

4. If vehicle refuse to run, look for the following:

a. Broken jar in battery. *b.* Broken connections between cells. *c.* Broken terminals. *d.* Open motor leads. *e.* Broken connections on any part of vehicle.

5. In case vehicle do not run on any of the speeds, first examine those connections that are easiest to get at, viz:

a. Those at the end of the batteries. *b.* The connecting straps, connecting one cell to another. *c.* The wires going into the circuit closing switch. *d.* The springs on the controller arm and the copper shoes. Be sure that they make contact with plates on the controller face. *e.* See that there are no wires hanging loose, that appear to belong in the controller. *f.* If the trouble be not found in some one of these points, it would be best to have an expert examine the machine.

CHAPTER 43

Electric Railways

The extensive development of the electric railway has given rise to numerous systems, which may be classified in several ways, thus

1. With respect to the current, as
   - *a.* Direct;
   - *b.* Alternating;

2. With respect to the method of current generation, as
   - *a.* Mechanical {steam; hydraulic; gas engine.
   - *b.* Chemical {storage battery.

3. With respect to the power system, as
   - *a.* *D. c.* transmission and distribution;
   - *b.* *A. c.* transmission, *d.c.* distribution;
   - *c.* *A. c.* transmission and distribution

4. With respect to the current collecting devices, as
   - *a.* Trolley;
   - *b.* Surface contact;
   - *c.* Third rail;
   - *d.* Conduit.

5. With respect to the location of the electrical source, as
   - *a.* External {power station.
   - *b.* On the car {storage battery; gas-electric plant.

6. With respect to the distribution pressure, as
   - *a.* Low tension {pressures up to 600 volts.
   - *b.* High tension {pressures above 600 volts.

7. With respect to the service, as
   - *a.* City lines {elevated; surface; subway.
   - *b.* Interurban or suburban;
   - *c.* Long distance lines;
   - *d.* Industrial short lines.

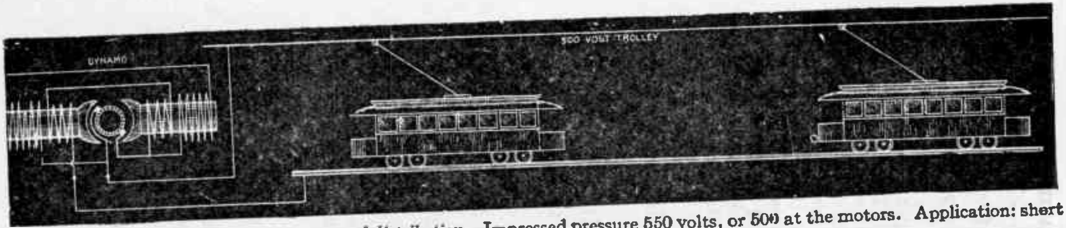


Fig. 8,081.—*Direct current transmission and distribution.* Impressed pressure 550 volts, or 500 at the motors. Application: short lines of radius 5 to 8 miles from power house; greater radii necessitate the use of boosters.

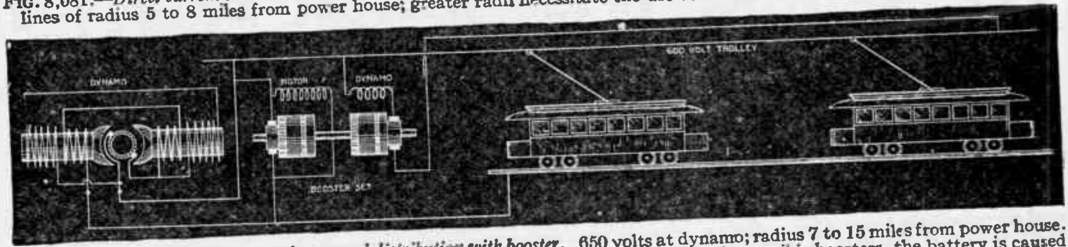


Fig. 8,082.—*Direct current transmission and distribution with booster.* 650 volts at dynamo; radius 7 to 15 miles from power house. Some stations employ storage batteries to take care of the peak loads. By means of reversible boosters, the battery is caused to take current from the power house feeder at time when the power demand is low on the section supplied for the sub-station, thus storing up current which it subsequently delivers to the line when the power demand is heavy. In some cases the batteries are simply *floated* on the line and tend to equalize the demand and the voltage. By these means the radius of successful operation of direct current systems is extended to about 15 miles from the power house.

D.C. Transmission and Distribution.—This system is especially adapted *for densely populated sections as in large cities.*

It is not well adapted to the operation of roads covering large areas and is becoming obsolete, owing to the great amount of feeder copper required to transmit large amounts of energy at 600 volts, which is the usual pressure used.

The standard pressures are 600, 1,200, 1,500 and 2,400 volts; 600 and 1,200 volt motors are used.

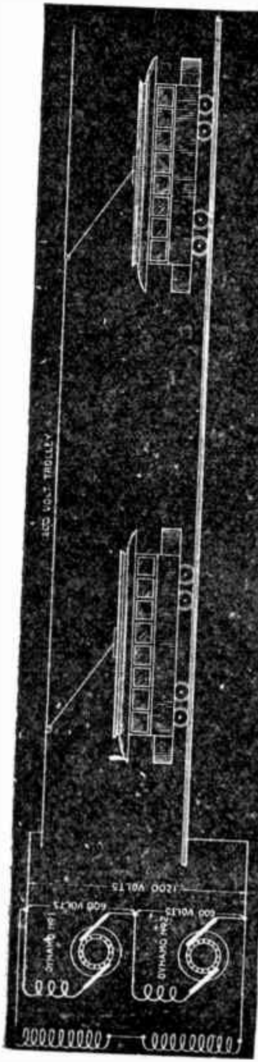


FIG. 8,083.—*Direct current transmission and distribution.* 1,200 volt two stage generator; radius 10 to 20 miles from power house. Either one 1,200 volt, or two 600 volt motors (connected in series) may be used. With 600 volt for motor equipment, the pairs are connected in series and parallel to give the excellent result obtained by series parallel control.

A. C. Transmission, D. C. Distribution.—This system is in general use *for suburban roads and the larger city systems.*

The advantages accruing from the use of both alternating and direct current must be evident, thus, a large amount of power can be transmitted by alternating current at high voltage reducing the cost of copper to a minimum, and by means of rotary converters, converted into direct current of suitable working voltage for the motors at the distribution points.

A.C. Transmission and Distribution.—For current supply, a single phase alternator may be used, or one leg of a three phase machine.

For short lines the alternator may be wound for the trolley voltage, but for long lines a high pressure machine is used with step down transformer substations, or a medium pressure machine with step up and step down transformers. Trolley voltages of 3,300, 6,600, 11,000 and as high as 13,000 are in use.

Overhead Trolley System.—In this arrangement which is largely used in towns and cities, the current for the motors ***is taken*** *from an overhead wire by means of a "trolley"* with grooved wheels, which is held up against the wire by a flexible pole.

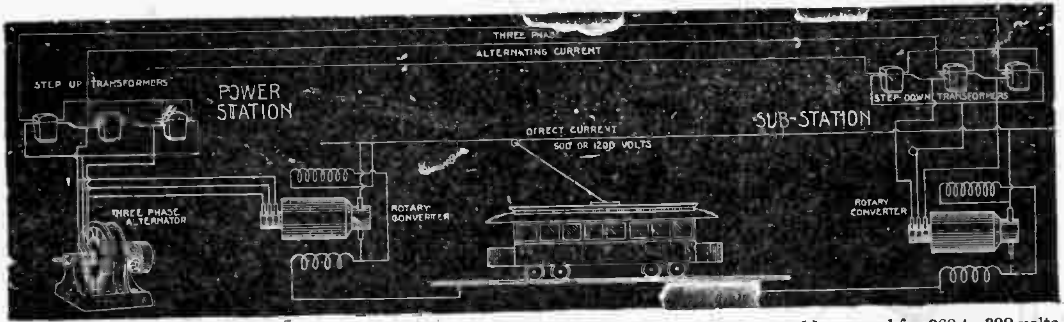


FIG. 8,084.—*A.c. transmission, and d.c. distribution.* The three phase alternator is a 25 cycle machine wound for 360 to 390 volts. Transmission pressure 13,500 volts ***This system may be varied in several ways*** to satisfy special conditions, for example; 60 cycles may be used where the general lighting circuits are supplied from the same power house, and storage batteries may be installed in the sub-stations for equalizing the demand and reducing the rotary converter capacity necessary.

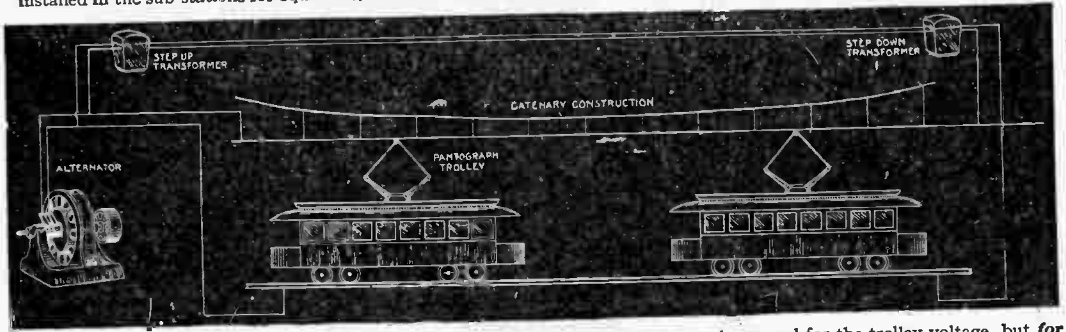


FIG. 8,085.—*A.c. transmission and distribution.* ***For short lines*** the alternator may be wound for the trolley voltage, but ***for long lines*** a high pressure machine must be used in connection with step down transformer sub-stations or a medium pressure machine with step up and step down transformer as here shown. Trolley voltages of 3,300, 6,600, 11,000, and as high as 13,000 are in use, but the usual pressure is 6,600 volts ordinarily, and 11,000 for the electrification of existing steam railways

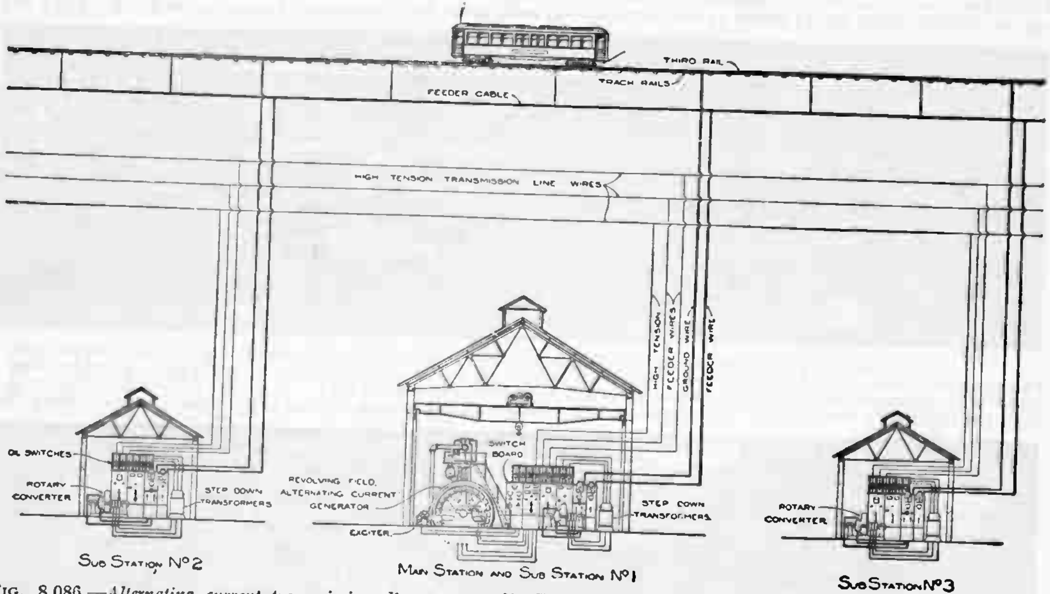
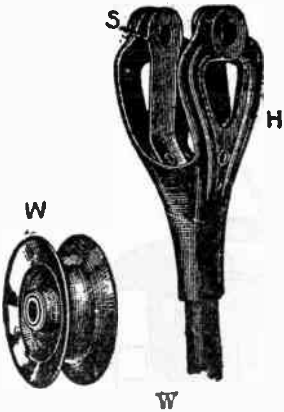
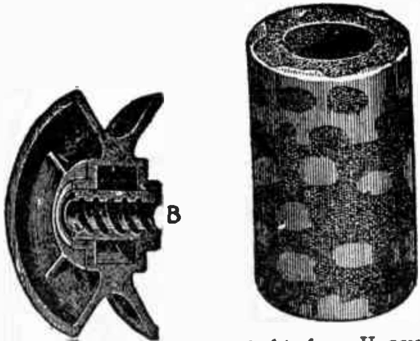


FIG. 8,086.—*Alternating current transmission, direct current distribution.* The diagram shows the main station and two sub-stations with apparatus and connections to the line. ***In the system*** here shown, three phase current is generated at the main station, where it passes to *step up* transformers to increase the pressure a suitable amount for economical transmission. At various points along the railway line are *sub-stations*, where the three phase current is reduced in pressure to 500 or 600 volts by *step down* transformers, and converted into direct current by rotary converters. The relatively low pressure direct current is then conveyed by ***feeders*** to the rails, resulting in a considerable saving in copper in moderate and long distance lines.

The wires from the contact wheels pass down the pole to the car controller and thence to the motor, the return circuit usually being through the rails.

Surface Contact System.—This system may be advantageously used in some *industrial works where an overhead trolley is objectionable, and a third rail is not permissible.*





FIGS. 8,087 and 8,088.—Trolley wheel and harp. The spring S, attached to frame H, pressing against the side of the trolley W, maintains good electrical contact.

FIGS. 8,089 and 8,090.—Section through trolley showing lubricating bushing B, and view of bushing removed from trolley.

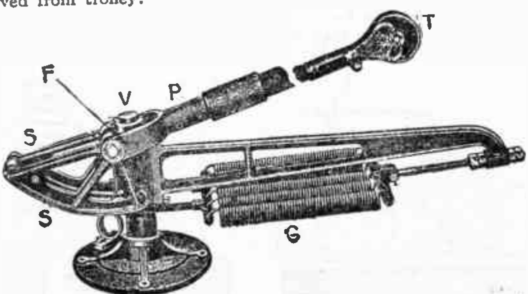


FIG. 8,091.—Trolley base. *As shown,* the pole P, terminates in a fork F, attached to a pair or sector S,S, forming a frame, capable of revolving about a vertical axis V, so as to accommodate the pole and trolley to turns or curves in the track and trolley wire. The spiral springs G, maintain a tension upon these sectors tending to force the pole P, upward.

The Westinghouse surface contact system requires no poles or overhead wires and leaves yards and buildings free of all obstructions. The current is supplied to the motors through contact buttons which are connected to a feeder cable laid along the track, through electromagnetic switches; the buttons are "dead" except those directly under the motor cars or locomotives.

Third Rail System.—In this system a rail called the "third rail" is laid outside the track rails. The current is taken by

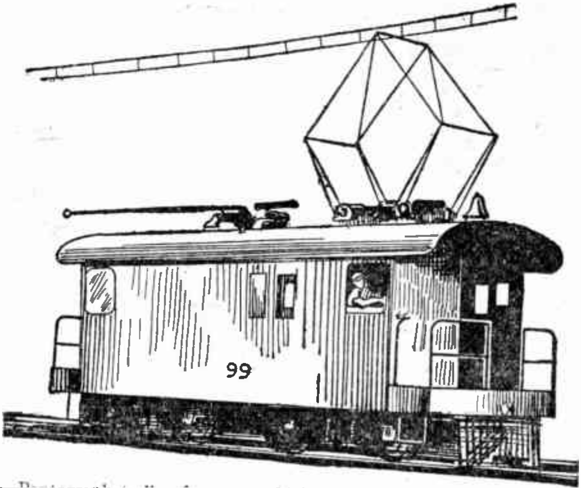
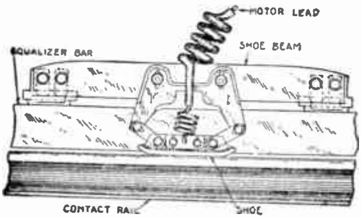
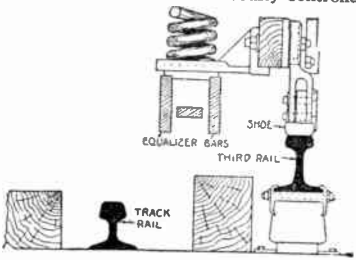


FIG. 8,092.—Pantograph trolley for use on high speed, high pressure lines. It is nominally held in contact by a spring and may be raised or lowered by compressed air control in the motorman's cab. The trolleys on the entire train may be thus simultaneously controlled from any one point.





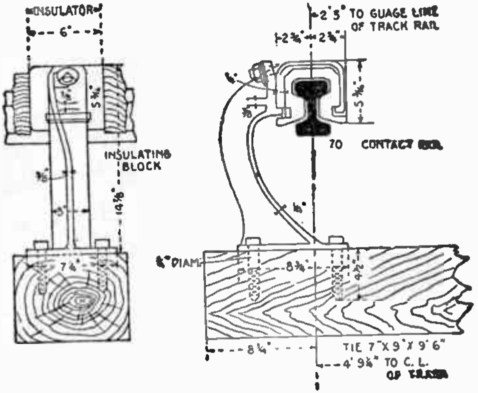
FIGS. 8,093 and 8,094.—Details of third rail and contact shoe as used on the Manhattan Elevated Railway, New York City.

means of a suitable contact shoe which slides along the rail, and the car is controlled by the motorman as in the case of a trolley car. This system is extensively used on elevated railways and subway systems.

Underground Trolley or Conduit System.—This is a metallic circuit system, there being two insulated conductors supported in a conduit.

The current is taken by a trolley which extends from the car into the conduit through a central slot and makes sliding contact with the conductor.

This system is used in the streets of large cities where the use of overhead trolley wires are objectionable, but the cost of construction is very great.



FIGS. 8,095 and 8,096.—Details of New York Central Railroad inverted third rail.

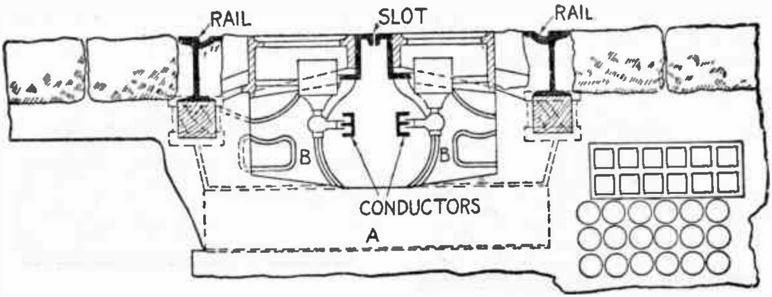
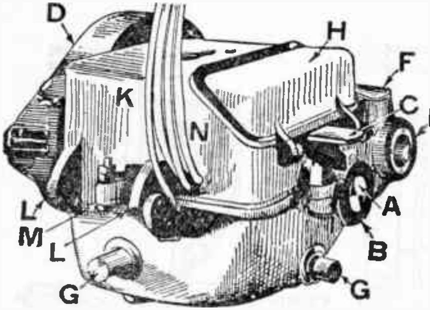


FIG. 8,097.—Sectional view of conduit system of the Third Ave. street railway, New York City.

Motor Types Employed.—There are three types of motor in use for electric railways; the direct current motor, the single phase commutator motor, and the three phase induction motor.

Motors.—The severe operating conditions of railway service demand *a motor differing in many respects from the ordinary machine.*



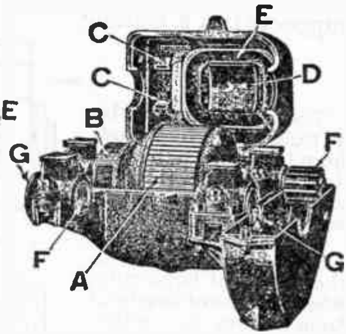
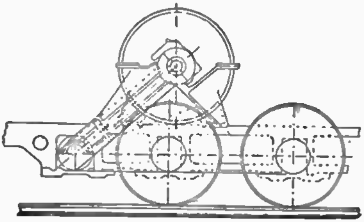
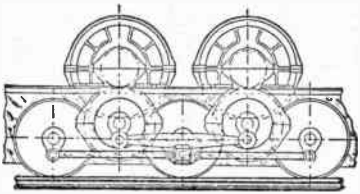


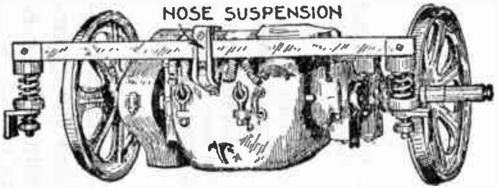
FIG. 8,098.—*D.c.* railway motor, casing closed. *As shown,* the armature shaft A, projects through its bearing B, lubricated by the grease box C, and is connected with the car axle by gear wheels enclosed in the gear cover D. The gears serve to reduce the speed of the car, and also to increase the effective pull of the motor. The car axle passes through the bearing E, lubricated by the grease box F. The motor is supported on the truck by the lugs G,G. The commutator door H gives access to the brushes, while a more complete inspection of the working parts may be obtained by throwing back the upper half of the casing K upon the hinge L,L, after unscrewing two bolts, one of which is shown at M. The insulated cables shown at N, pass through the casing and supply current to the motor.

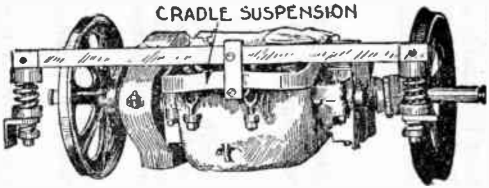
FIG. 8,099.—*D.c.* railway motor casing open. *As shown,* A, is the armature; B, commutator; C,C brushes; D, upper pole; E, upper field. The pinion F, secured to one end of the armature shaft engages with a gear wheel on the car axle, which passes through the bearings G,G, corresponding to the bearings designated E, in fig. 3,514.

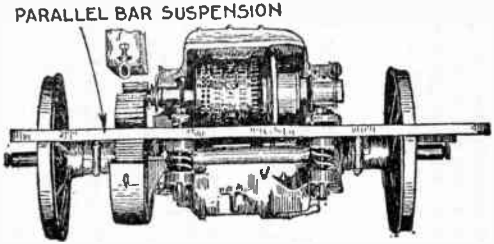




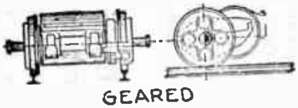
FIGS. 8,100 and 8,101.—Various motor suspensions. Fig. 3,532, Pennsylvania gearless motor with connecting rods; fig. 3,533, geared motors with yoke, or erroneously called Scotch yoke.

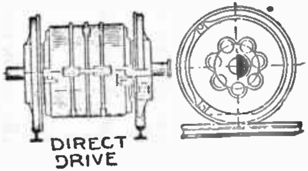


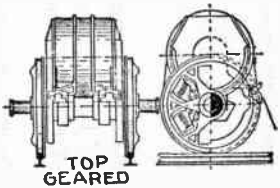




FIGS. 8,102 and 8,104.—Various motor suspensions. Fig. 8,102, nose suspension; fig. 8,103, cradle suspension; fig. 8,104 parallel bar suspension.







FIGS. 8,105 to 8,107.—Various motor suspensions. Fig. 8,105, New Haven geared motor; fig. 8,106, New Haven gearless motor; fig. 8,107, New Haven top geared motor.

The principal requirements are: 1, that it shall be dust and water proof because of its exposed location beneath the car; 2, it must be capable of very heavy overloads to secure quick acceleration at starting; 3, it must be compact because of the limited space available; 4, large bearings with efficient self-oiling devices must be provided to secure long operating periods without attention.

Motor Suspension.—Usually the motor is constructed with a set of bearings on one side of the frame, in which bearings the axle of the car wheels rotate.

Mounted upon this axle is a large gear which meshes with the pinion gear on the end of the armature shaft, the gears being protected from dust, etc., by a casing. The side of the motor opposite to that containing the car axle is usually fastened to a bar, which in turn is mounted upon springs connecting it to the car truck.

There are numerous forms of suspension, and these may be classed as: 1, cradle suspension; 2, nose suspension; 3, yoke suspension; 4, parallel bar or side suspension; 5, twin motor suspension.

The ***cradle suspension*** consists of a U shaped bar fastened to the truck at the middle of the U. It is intended to relieve the bearings of the weight of the motor, and is now semi-obsolete.

Nose suspension consists in casting a projection or nose on the motor frame and fastening it to the motor truck by means of a heavy link, the object being to distribute the weight of the motor between the car axle and the truck. It is the prevailing method.

Yoke suspension consists in rigidly bolting a cross bar to seats cast on the motor casing, the ends of these bars being spring supported to the truck frame.

In ***parallel bar*** or ***side suspension*** there are two parallel bars fastened to the car truck, supporting the motor on springs at its center of gravity.

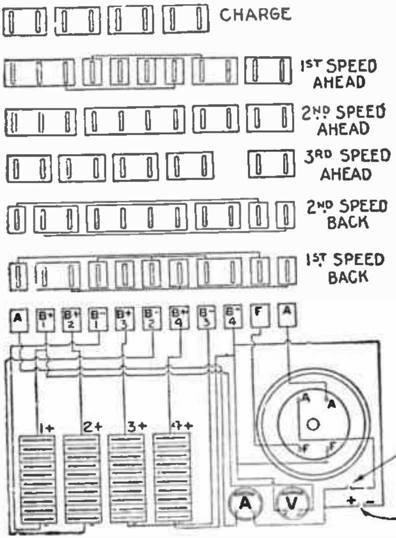
With ***twin motors,*** two motors of equal capacity are mounted above each axle. Each motor is provided with a pinion and the two pinions of the pair of motor mesh with a single gear which is mounted on a quill surrounding the driving axle.

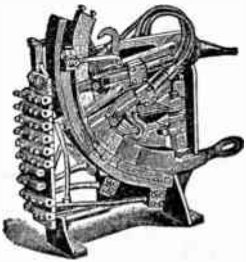
Motor Control Systems.—The speed requirements for traction motors give rise to several control systems, and the apparatus employed to effect the proper sequence of connection corresponding to the system of control adopted is known as a controller. A comprehensive classification would divide the various systems

1. With respect to the method of operation, as
   - *a*. Hand control;
   - *b*. Automatic control; *c*. Master control.

2. With respect to the current, as
   - *a*. Direct;
   - *b*. Alternating.

3. With respect to character and sequence of connections, as





FIGS. 8,108 to 8,115.—Controller of the Rauch and Lang electric vehicles. It is of the flat radial type. Two movable copper leaf contacts of ample size make all commutations necessary to obtain the various speeds. Five speeds forward and reverse are provided.

FIG. 8,116.—Diagram of controller connections of a four unit one motor circuit, with constant series connections for fields and armatures in forward and backward speeds.

- *a*. Direct current
  - rheostatic;
  - field;
  - series parallel;
  - multi-unit (master control).

- *b*. Alternating current
  - single phase
    - rheostatic;
    - compensator;
    - induction regulator;
  - three phase
    - rheostatic;
    - changeable pole;
    - cascade
      - single;
      - parallel single;
    - combined changeable pole and cascade.

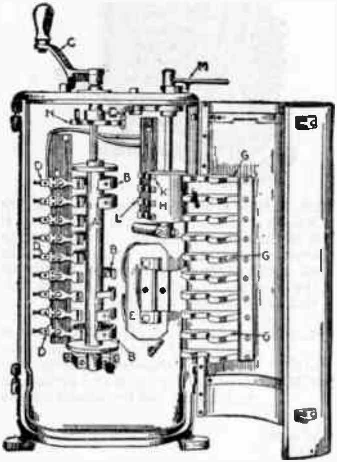
4. With respect to the method of transition, as

a. With power off;
b. With series resistance;
c. Bridge.

With ***hand control*** the motorman, by moving the controller handle can vary the current value without any time limit device.

Automatic control includes certain automatic devices which prevent the motorman applying to the motors a current greater than a predetermined value.

The master or ***multi-unit control*** system, ill advisedly called multiple unit control, is one in which the motors on each car of a train of several cars are controlled from one master controller.



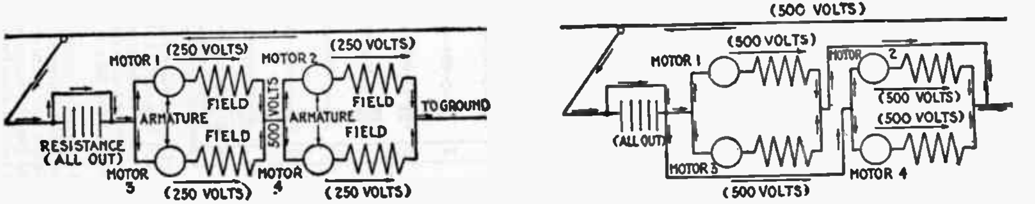
Rheostatic control consists in progressively cutting out sections of a resistance connected in series with the motor.

The method of ***field control*** consists in varying the intensity of the motor field magnets, by dividing the coils into two sections and arranging the controller to give a proper sequence of connection.

The ***series parallel control*** is used with two or four motor equipments. The sequence of connection for a two motor car during the control period is as follows: 1, both motors connected in series with control resistance, 2, control resistance progressively reduced, 3,

FIG. 8,117.—Ordinary rheostatic controller. ***In operation,*** the current passing through the motor passes through the coils of the magnet E, and converts its core into an electro-magnet which produces a powerful magnetic flux around the contact surfaces of the springs D,D,D. At the instant the circuit is broken either in changing connections or when the current is entirely shut off, the influence of this powerful magnetic flux prevents the severe sparking which would naturally occur otherwise by blowing out the arcs as soon as they are formed. The reversing cylinder H, carries four conducting segments K, and a corresponding number of contact spring L. By moving the handle M, through an arc of about 60 degrees, the segments in contact with the springs L, can be changed and the direction of the current through the armature of the motor reversed, thereby causing it to rotate in the opposite direction and back the car. As the reversing operation cannot be safely accomplished while the motor is running, the handles C and M, are made interlocking so that the latter cannot be moved unless the former be in the "off position." The proper operation of a controller requires that all the successive contacts be made and none omitted. This is insured by the action of the star wheel located at N.

FIGS. 8,118 and 8,119.—Diagrams of series parallel two motor control. Fig. 8,118, series running position, all resistance cut out; fig. 8;119, parallel running position, all resistance cut out.



FIGS. 8,120 and 8,121.—Diagrams of series parallel four motor control. Fig. 8,120, series running position, all resistance cut out; fig. 8,121, parallel running position, all resistance cut out.

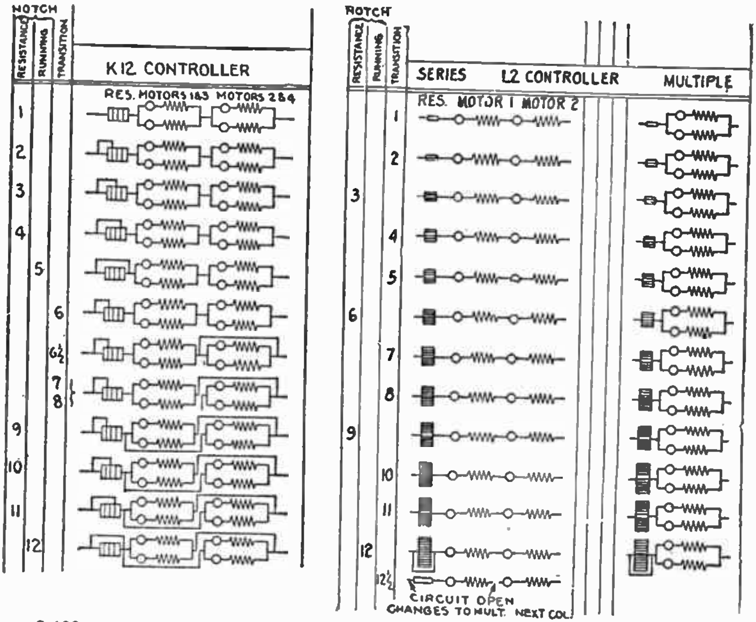
in circuit in series with parallel connection of motors. 4, control resistance progressively reduced, 5, both motors in parallel with control, no resistance.

The mode of transition divides the series parallel control into several types, as 1, power off, 2, series resistance, and 3, bridge transition. In the power off method of transition, the controller is so arranged that the power is cut off from both motors in changing the motor connections from series to parallel. Now semi-obsolete.

In series resistance transition, during the transition from series to parallel, a resistance is placed in series with one motor and the other motor is first short circuited, then disconnected from the main circuit, and finally placed in parallel with the other motor. The bridge method of transition consists in grouping the motors and their resistances like the arms of a ***Christie***, or erroneously called Wheatstone bridge.

bridge, so that after the two motors are in full series position, the resistances may be placed in circuit again in parallel with the motors without opening the circuit. The two motors are then connected in parallel with each other and each in series with its own resistance.

A.C. Control Systems.—In the compensator method, the impressed pressure *is gradually increased by progressively cutting out sections of the compensator or auto-transformer.*

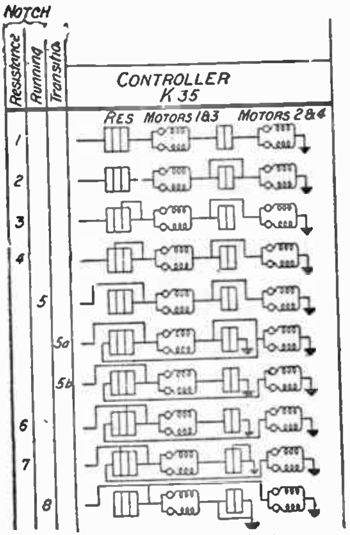


FIGS. 8,122 to 8,133.—Westinghouse type K-12c ontroller connections. In changing the motor connections from series to parallel, it will be noted that the controller short circuits one pair of motor, but the current continues to flow to the other pair. The *series method* here employed consists in connecting the total amount of resistance in series and then progressively short circuiting the various connections until all are cut out.

FIGS. 8,134 to 8,157.—Westinghouse type L-2 controller connections. This type controller opens the circuits to both motors before making the change from series to parallel. In this parallel method additional sections of resistance are connected in parallel with the first section on each successive step. The value of the resistance in circuit is decreased as each new section is added in parallel with the first section and, finally on the last step the entire group is short circuited.

The induction regulator method employs an induction regulator which consists of two coils: a primary, and a secondary, which are wound upon separate cores and are capable of angular adjustment for changing the direction of the flux from the primary through the secondary so that the voltage generated in the secondary increases or decreases the voltage supplied to the motors by the auto-transformer according to the relative angular position of the secondary to the primary.

Three Phase Induction Motor Control.—Rheostatic control is applied to three phase induction motors *by arranging a variable resistance in series with the armature winding and progressively reducing it as the motor speeds up*, till at full speed or the last step of the control all the resistance is cut out.



FIGS. 8,159 to 8,168.—Westinghouse type K-35 controller connections.

With this control the slip ring or external resistance motor is used. In the changeable pole method the number of pole may be altered to secure variable torque either by providing the motor with independent field windings, or by regrouping the field coils.

Cascade operation consists in the various combinations of two motors. The armature of the two motors are mechanically connected, the field of the first is connected to the supply and the armature to the field of the second motor; the armature of the second motor is connected to the external resistance at start. As the motors speed up, the external resistance is cut out till armature of second motor is short circuited. For motors of equal number of pole, after reaching maximum speed, they may be separated and each, having resistance inserted in its armature circuit, may have its field connected to the supply. For maximum effort the external resistances may now be progressively cut out resulting in full parallel operation.

In the single control cascade method the second motor is cut out after the period of concatenation. In parallel single cascade control, motors are employed having a different number of pole, or different gear ratios.

In operation, when the motor with the greater number of pole reaches synchronism, it is cut out. If the motor with the lesser number of pole be cut out instead, the train will operate at a speed between that corresponding to concatenation and that for the free running of the motor with the lesser number of pole with armature short circuited.

The changeable pole and cascade methods are combined by first making the sequence of pole change and then applying either of the cascade methods, thus giving several speeds.

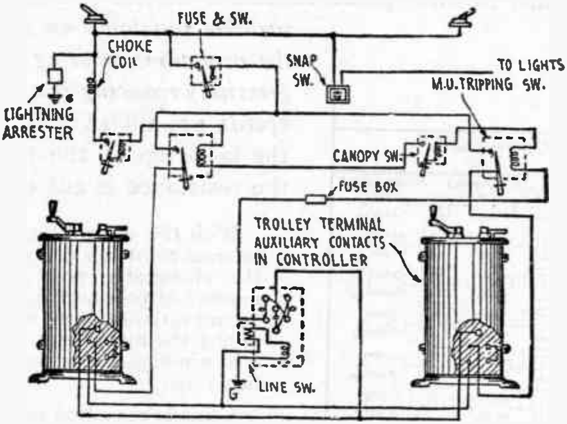


FIG. 8,169.—Westinghouse auxiliary contactor equipment. A contactor equipment consists of a powerful pneumatically operated switch, or "contactor," mounted beneath the car and connected to the main reservoir of the air brake system. The switch is controlled by means of a magnet valve, which is operated by current from the trolley. The circuit of this magnet valve is carried through a pair of auxiliary contacts located on the drum of the controller. When the handle is moved toward the off position, the circuit of the auxiliary contacts, and hence the circuit of the magnet valve is broken before the main power circuits are broken, and thus the main power circuit is always opened by the pneumatically operated switch beneath the car rather than by the controller contacts.

Combined D.C. and A.C. Control.—In changing from *a.c.* to *d.c.* (or from direct to alternating) it is ***necessary** to guard against the possibility of wrong connections* upon the car for the current received, that is, to prevent disaster should connections be made for 600 volts direct current operation and accidental contact be made with 6,600 volts alternating current trolley.

To guard against this, the main switch of the direct current and alternating current car equipment is provided with a retaining coil so designed that it will open when the motor current is interrupted.

Where *a.c.* and *d.c.* trolley sections adjoin, a dead section is left between the two for a length not exceeding a car length, so that a car may pass from

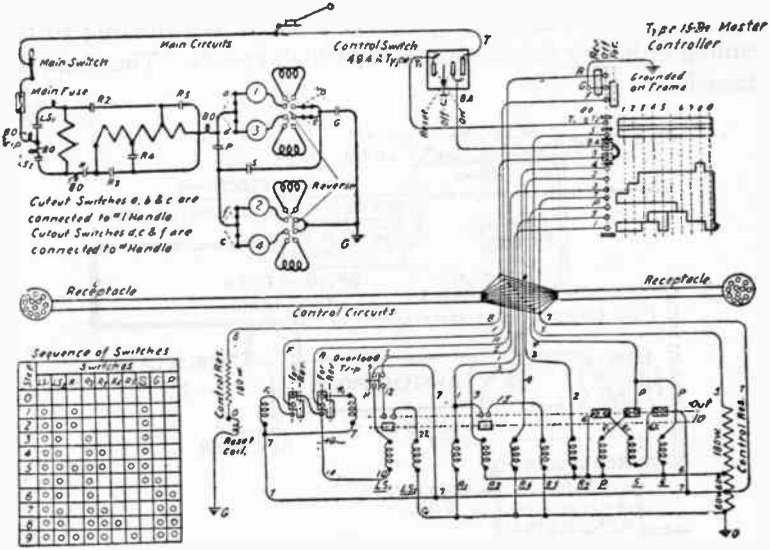


FIG. 8,170.—Diagram of connections Westinghouse unit switch control (type HL) for quadruple equipment of 75 horse power motors or less. In type HL control the various main circuit connections between trolley, starting resistors and motors (which, in drum type control, are made by the overhead circuit breaker and the power drum and contact fingers of the controller) are made by pneumatically operated switches assembled in a common frame designated as a switch group, which is located underneath the car. Each switch is closed when desired by compressed air from the brake system, acting on a piston. The reversing connections ordinarily made by the reverse drum of the platform controller are made by a reverse drum similar to that of the controller, but of more substantial construction, pneumatically operated and mounted in a separate case underneath the car. The complete reverse drum with its operating mechanism is termed a *reverser*. The admission or release of compressed air to the pistons for operation of the switches and reverser is regulated by means of electrically operated magnet valves, one of which is attached to each piston cylinder. The circuits from the various magnet valves are controlled by a master controller on either car platform through a control train line, which extends the length of the car and terminates at each end in a twelve conductor train line receptacle. By moving the handle of the master controller from notch to notch, the various switches in the switch group are operated and the proper motor connections are established. If the adjacent train line receptacles on two or more cars be connected by suitable train line jumpers, the operation of either master controller on any car will cause the various switches on all of the cars to close or open simultaneously for train operation.

one section to the other at full speed, in which case the main car switch opens on the dead section through lack of power to operate the retaining coil, and will reset automatically for alternating or direct current operation as the case may be, after leaving the dead section.

Locomotives.—Numerous types of electric locomotive have been built for a variety of purpose, from yard switching to the hauling of heavy passenger trains at high speeds. They may be classed

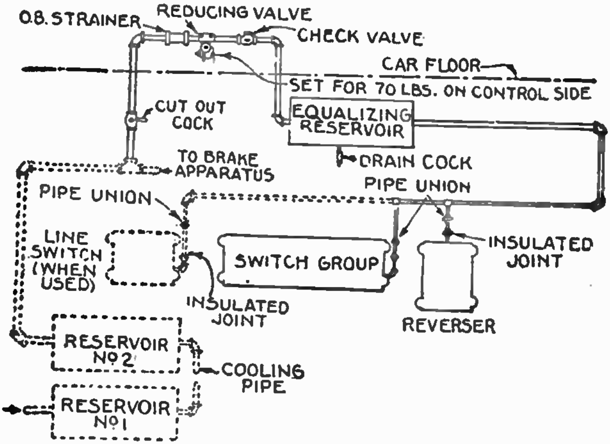


FIG. 8,171.—Arrangement of piping of Westinghouse unit switch control, type HL. The piping here shown is for the compressed air which operates the control apparatus, the air supply being taken from the brake system. The amount of air required for operating the switches is so small compared to that required by the brakes and whistle that it is practically negligible.

1. With respect to the power source, as

   a. External;
   b. Storage battery:
   c. Steam-electric.
   d. Gas-electric.

2. With respect to the transmission, as

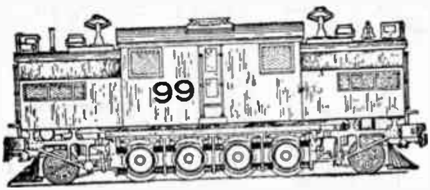
   a. Gearless;
   b. Geared;
   c. Connecting rods;
   d. Scotch yoke;
   e. Combination gear and connecting rods.

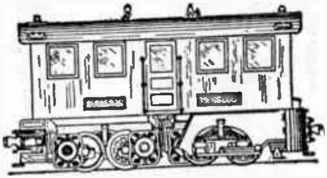
A gearless locomotive is one having the armatures built on the axles of the driving wheels; a geared locomotive has speed reducing gears between the motor and axle.

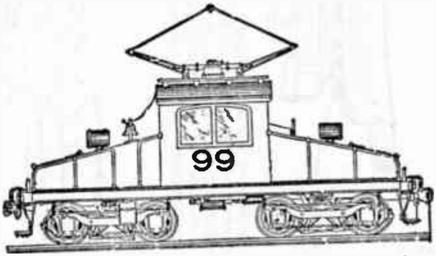
In the side rod driven type the motors are placed in the cab and the driving torque communicated to the drivers by means of connecting rods.

In the Scotch yoke arrangement, the yoke drives one axle through a sliding block and the others through rods connected to the yoke by knuckle pins.

The combination gear and connecting rod drive comprises motors geared to jack shafts which in turn transmit the power to the drivers by means of connecting rods.

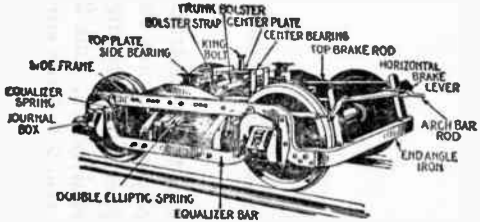






FIGS. 8,172 to 8,174.—Various electric locomotives. Fig. 8,172, New York Central 1-4-1 locomotive; fig. 8,173, ordinary form of locomotive, fig. 8,174, Baltimore and Ohio, 160,000 lbs., 0-4-0 locomotive.

The Running Gear.—There are two general types of truck for electric cars: 1, those in which the car body rests upon the truck bolster or side bearings which are supported by springs for the side frames carried by the axle journal boxes, and 2, those in which the car body rests upon the truck bolster supported from the truck frame which rests upon springs carried by equalizer bars resting on the axle journal boxes.



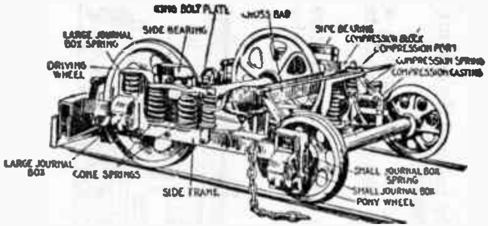
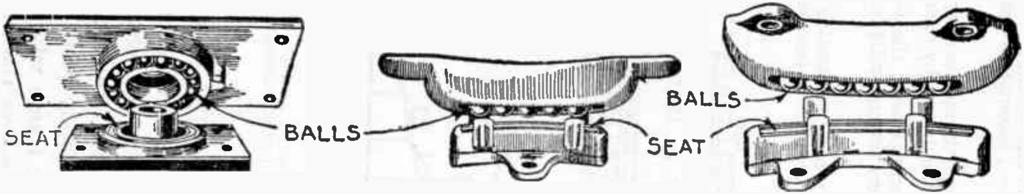


FIG. 8,175.—Standard motor Co. M.C.B. type high speed truck.

FIG. 8,176.—Brill maximum traction truck. On tangent track 75 per cent. of the weight of this truck comes on the motor axle which has the large wheels. When on a curve, part of this weight is shifted to the trailing wheels. This type is used extensively in city street car service and is not adapted to high speed. One motor is used on each truck.



FIGS. 8,177 to 8,179.—Center and side bearings of a truck. These form the contact points between itself and the car body. The car body is practically carried on the center plates on the truck bolster and comes in contact with the truck only at this point; but in order to prevent more than a slight displacement of the car body from the vertical, side bearings are placed over the side frames of the trucks, and so adjusted as to leave sufficient space between side bearing top plate and the plate on the car to take up the maximum compression of the springs when the car is fully loaded.

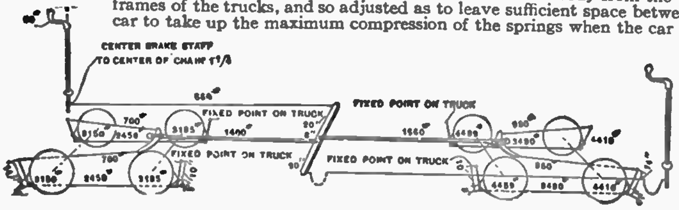


FIG. 8,180.—Hand brake system. One of the objectionable features of this arrangement is the use of a single *sway, bar* and *floating lever*, which results in the application of the greater braking pressure to the rear wheels or truck instead of to the front wheels or trucks where it should be capplied to secure the most effective braking.

Brakes.—The several types of brake used are classed as: 1, hand brakes; and 2, air brakes.

The familiar hand brake needs no description, and air brakes have been described at great length in Guide No. 3.

Car Lighting.—There are several systems in general use and the following descriptions give the essential features.

Stone System.—The equipment consists of a dynamo, a storage battery

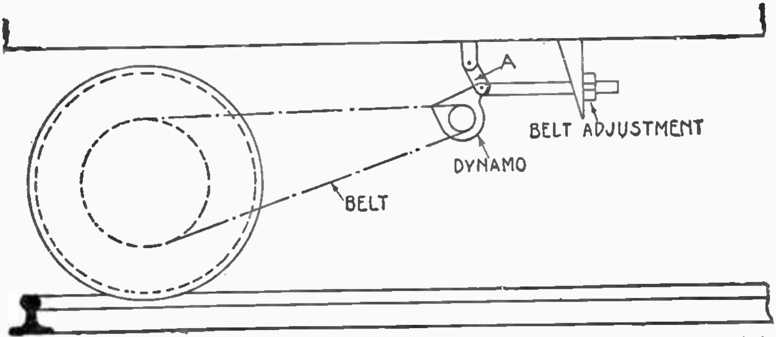


FIG. 8,181.—Method of suspending Stone system car lighting dynamo. *As hung,* the belt draws the dynamo out of the diagonal position in which it would naturally hang, thus putting a definite tension on the belt, just sufficient to absorb the power required. It is obvious that when the pull on the belt exceeds that due to the offset suspension of the dynamo that the dynamo will be drawn toward the axle and the belt allowed to slip. Thus the dynamo will run at practically constant speed for all values of train speed above the critical value. A mechanical governor automatically closes the dynamo circuit when critical speed has been reached. A storage battery is suspended underneath the car to act as auxiliary in lighting the lights when the dynamo is inoperative. Another function of the storage battery is that it acts as a ballast or regulator to keep the lights constant, absorbing the variations of dynamo output.

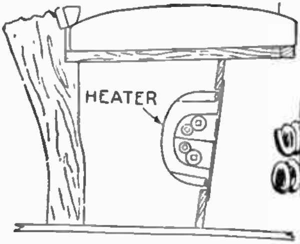
to act as auxiliary when the dynamo is inoperative, and an automatic switch to close the dynamo circuit when the critical speed has been attained.

The principle underlying the operation of this equipment is that regulation is obtained by allowing the belt to slip. As the speed of the train rises the dynamo voltage will tend to rise proportionally, this causing a great battery charging current to flow, thus increasing the dynamo output and belt pull.

McElroy System.—In this system the dynamo is mounted directly on the trucks and is driven by a gear and pinion similar to those used on the motors of trolley cars; these being enclosed in a wrought iron gear case which is made dust proof with leather packing.

"Axle" Lighting of Cars.—This is the prevailing method and consists of a dynamo belted to the truck axle, storage battery, and necessary auxiliaries for proper control.

Car Heating.—The amount of power consumed by electric



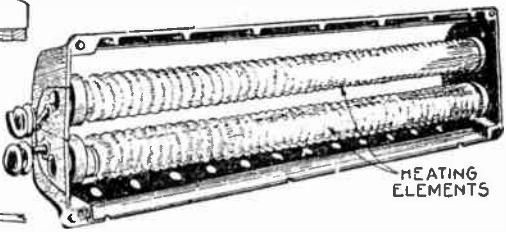
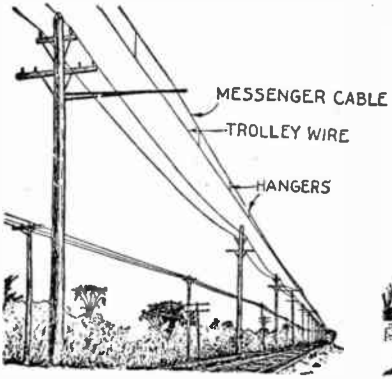


FIG. 8,182.—Section through car seat, showing location of panel heater.
FIG. 8,183.—Two unit coil of panel heater. The front is provided with a wire grating, to protect passengers' clothing from contact with the coil which in operation reaches a temperature above ordinary ignition point.



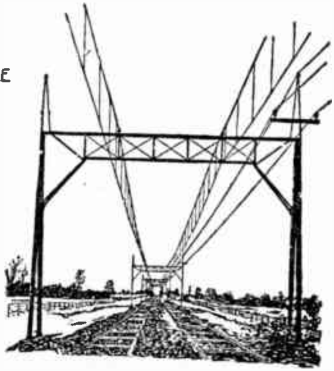
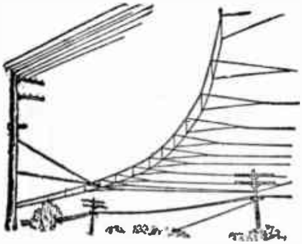


FIG. 8,184.—Eleven point bracket catenary construction for single track, suitable for ordinary interurban service.
FIG. 8,185.—Bridge type single catenary construction for double track, suitable for heaviest class of service, such as electrified steam railroads, and substantial interurban roads handling heavy freight traffic as well as heavy passenger traffic.

heaters naturally varies with the climatic condition, but for cars ranging from 24 to 34 feet in length the power consumption for average and severe weather conditions varies from 5 to 7 kilowatts, respectively, so that the electric heater loads on both street railway and interurban systems compose a very large part of the total energy consumed.



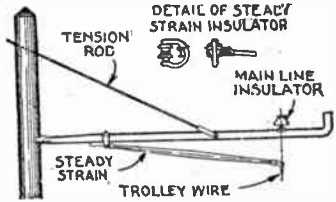
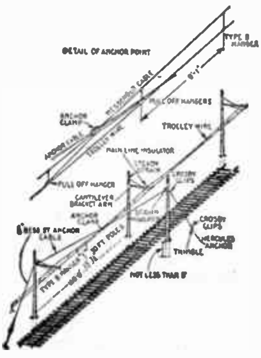


FIG. 8,186.—Single catenary curve construction. ***In locating*** the bracket arms on poles and the poles on curves, the effect of super-elevation and the lateral overhang of the cars or locomotives must be allowed for. as well as the position of the current collector. *Anchor spans* should be placed at the ends of curves and at frequent intervals on tangents.

FIG. 8,187.—Detail of bracket arm with steady strain.



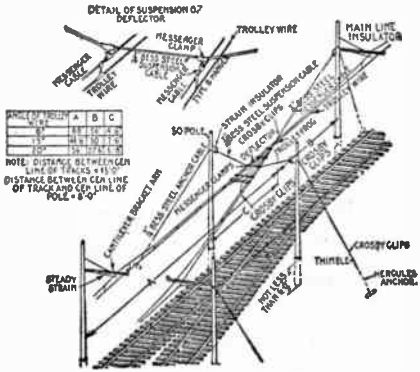


FIG. 8,188.—Catenary construction at anchor span.

FIG. 8,189.—Trolley deflector construction at switch. ***The method of construction*** employed at turn outs and sidings depends upon the type of current collector used.

Track.—This varies with the service and method of power transmission employed.

The track construction for overhead trolley line systems differs but little from other forms of railway construction, with the exception of the *bonding* of the rail joints. With the use of a track return this is absolutely necessary to secure a continuous metallic path, thereby reducing the resistance which would otherwise be introduced into the circuit.

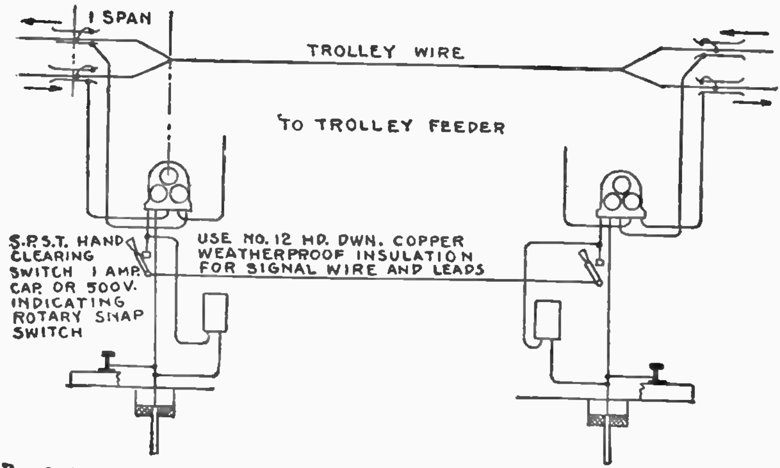


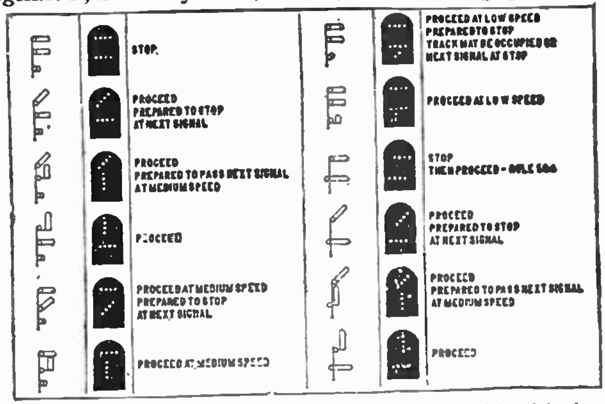
FIG. 8,190.—Automatic block signal system. The boxes are located at the end of each block and are provided with white and red semaphore discs operated automatically by trolley switches.

Trolley Line Construction.—The various methods of trolley line construction may be divided into two classes: 1, bracket construction, and 2, span wire or *catenary* construction.

There are two general classes of catenary construction: the single catenary, and the double catenary. In both of these the principal object aimed at is the maintenance of the trolley wire at a constant distance from the top of the rails.

In the single catenary construction the cable is carried by the brackets, spans, or bridges.

Signal Apparatus.—There are two general classes of railway signal: 1, block system, and 2, interlocking system.



FIGS. 8,191 to 8,202.—Corresponding aspects of semaphore and position light signals with their indications.

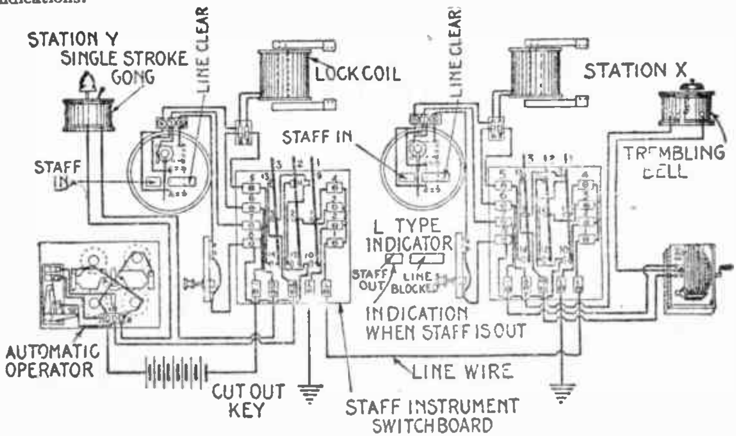


FIG. 8,203.—Automatic operator system. *In operation,* when current is passed through the line, the armature is rotated in a direction to cause it to lift the weight on which the normally closed contact is fixed. When current through the line is broken, this weight causes the armature to rotate in the opposite direction a sufficient distance to close the other contact and cut in a local battery. Current from this battery passes through a pair of coil holding the armature in this position, and releases the staff at opposite ends of the block. When the circuit is again broken, battery is cut out of the line.

Block signaling has to do with keeping trains which are running on the same track, at a proper distance apart. Inter-locking signaling is for the control of trains over tracks which intersect at points of crossing or divergence, and has for its object the prevention of conflicting movements, the proper routing of trains, and the insurance that the movable parts of the track are in their right positions before the signals governing movement over them can be made to give a proceed indication.

Railway Signals.—These consist of colored lights, colored flags or by metal signal banners. Some roads use a green signal for precaution while others use a yellow signal. Red is the danger signal.

The caution, stop, and proceed signals are in general use.

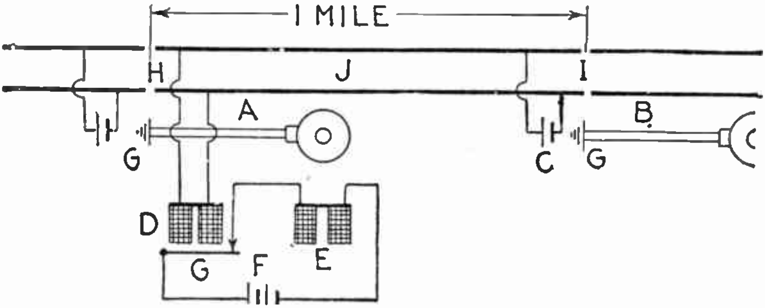
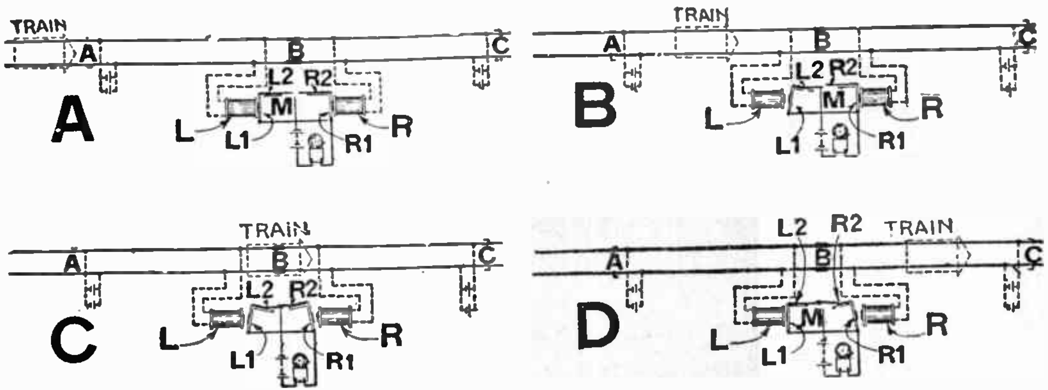


FIG. 8,204.—Simple track circuit whereby a signal is operated by a train in a block.

Flags or metal signals are used during the day and lights of various color at night.

Disc signals are displayed by movable shutters or discs in front of a fixed background; semaphore signals, by the position of a movable arm in a plane at right angles to the track and mounted on a high pole. The semaphore arms of distant signals have notched ends while the home signals have straight ends. When a home semaphore signal is *up* it means to stop; danger ahead. When a distant semaphore signal is up it means to proceed with caution and the next home station signal will indicate if the block be clear. Whether or not a relay be used in the track circuit, a bell is generally rung. At distant crossings only the bell is used, but near stations the relay is used to not only ring a bell but to throw a home signal.

Trolley Car Operation.—To start the car, see that the



FIGS. 8,205 to 8,208.—Diagrammatic sketches illustrating the interlocking feature of universal crossing bell relay. Fig. **A**, track circuit AB and BC, unoccupied, bell circuit open; fig. **B**, train has entered track circuit. AB, relay magnet L. De-energized armature L1, causes contact finger L2, to make contact with M, bell circuit closed; fig. **C**, train in track circuit AB and BC, (at crossing) relay magnet R, de-energized contact finger R2, resting on L2, bell circuit closed; fig. **D**, train in track circuit BC relay magnet L, energized contact finger R2, resting on L2, bell circuit open. When train passes out of track circuit BC, all parts normal as in fig. **A**, operation similar in either direction.

brakes are off, the canopy switches closed; then move the controller handle to the first notch.

After the car is well started, move to the second notch, and after a short time to the third, and so on to the last. Don't stop the handle between notches, and don't move it too slowly. On the other hand, do not move too rapidly from the first notch to the second.

In shutting off the current the handle may be moved around as rapidly as desired to "off" from whatever position it may happen to be on. When stopping at any point, the reverse lever is sometimes used to make the car go backward. Never reverse while the car is running, unless to avoid an accident. But if it be absolutely necessary to stop the car quickly, pull the brake on with the right hand and shut off the current with the left at the same time; then with the right hand free, throw the reverse lever and turn on a very little current.

After bringing the car into the car house, have the controller at "off," take off the controller handles, pull down the trolley and tie it a few inches below the trolley wire.

Car Does Not Start.—If the car fail to start when the controller is "on" and both overhead switches are closed, the trouble is due to an open circuit, and probably to one of the following causes:

1. The fuse may have blown or melted. Open an overhead switch o

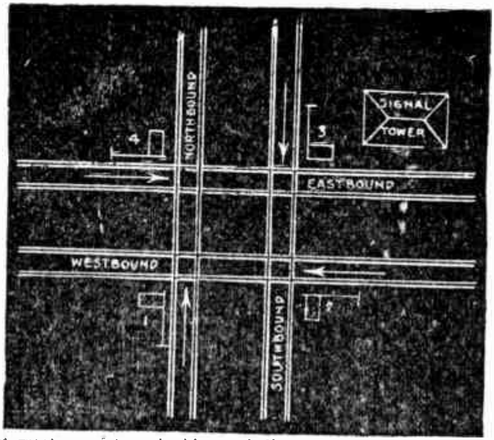


FIG. 8,209.—Intersection of two double track lines, with their respective signals. If these be *automatic* track relays properly interconnected, they can be readily arranged to give the protection desired. If they be *semi-automatic*, electric interlocking will be introduced to prevent confliction of routes. Thus, when signal 3, is at clear, to allow a south bound train to pass, 2, and 4, must be locked in the normal or stop position when electric locking or interlocking is used and prevented moving to clear if the ordinary automatic system be employed.

pull off the trolley and put in a new fuse, removing the burned ends from under the binding posts before doing so. Never put in a heavier fuse than that specified by the company, as it might result in damage by allowing too large a current to flow.

2. On a dry summer day, when there is much fine dust on the track, it happens that the car wheels do not make proper contact with the rail and the car fails to start. In such a case try to establish contact by rocking the car body. Should this fail to work, the conductor should take the

switch bar or a piece of wire and, holding one end firmly on a clean place on the rail, hold the other against the wheel or truck. This will make temporary connection until the car has started. The conductor should be sure *to make his rail contact first and keep it firm during this operation* or he may receive a shock.

3. If the track conditions be apparently good, it may be that the car stands on a piece of dead rail, a piece of rail on which the bonding has been destroyed. In that case the car conductor would have to go to the next rail section with a piece of wire to connect the two rails and then order the motorman to start his car.

4. A brush or two may not have been placed, or, if placed, may fit too tightly in the brush holder, so that the springs do not establish contact between the brush and the commutator. If this be the case, remove the brushes and sandpaper them until they go into the brush holder easily.

5. The contact fingers on a controller are rough, burnt, and perhaps bent so that the drum cannot make contact. It may also be due to wear on both the contact surfaces of the drum and the finger, which may have been burnt and worn away to such an extent that contact is not established when the controller handle is placed in the first notch. Try to smooth the burnt surface with sandpaper and bend the fingers or contacts into their proper position. Should this fail, then operate the car with the other controller. In this case the conductor should be on the front platform to handle the brake and give orders to the motorman when to start and stop, as the occasion requires. Under these conditions the car should never be allowed to travel at a high speed.

6. A loose or broken cable connection. This can be located and placed and fastened in its position. It is, in most instances, a cable connected to one of the motors, rheostat or lightning arrester, and very seldom in the controller stand.

7. A burnt rheostat. A rheostat may have received too great a current for some time and the first contact terminal may be broken. In such a case, if temporary connection cannot be conveniently established, the car will not start at the first notch, but at the second it will start with a jerk.

8. If the car refuse to start on the first contact, but start all right on the second and acts normal thereafter, then there is an open circuit in the rheostat, either internally, or the first cable connection is broken.

Abnormal Starting.—Sometimes a car will start with a jerk, but afterwards run smooth and normal.

This indicates a short circuit in the rheostat. Examine the rheostat terminals, as the trouble may be due to the crossing of the cables or a loose cable touching another terminal of the rheostat; do not touch it but run car back to barn

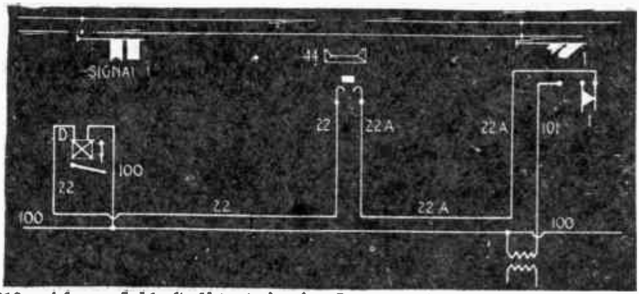


FIG. 8,210.—Advanced block distant signal. ***In operation*** when the towerman pulls a lever numbered the same as the distant signal he desires to operate, he completes a circuit between the two springs which causes the distant signal blade to clear.

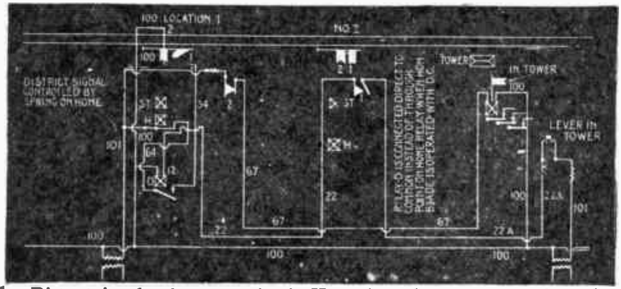


FIG. 8,211.—Distant signal and repeater circuit. Here, through a lever connection, when the lever is pulled out in the tower, current is allowed to flow to and complete a circuit through a contact spring operated by the signal mechanism. As soon as the distant blade clears, according to this circuit, a repeater located in the tower is de-energized and drops its armature, which shows the position of the blade whose action governs its source of energy.

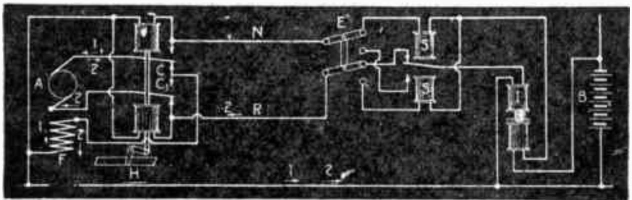


FIG. 8,212.—Diagram illustrating electric interlocking. A switch and lock movement is driven by a direct current motor, the shaft of which is connected by a magnetic clutch to an extension working a cam drum which operates the switch and lock. When the drum is revolved by the motor, first the lock rod and then the switch move in proper operation. After the switch has been moved against the stock rail it is automatically locked and a knife switch throws open the control circuits and closes the indication circuit. The direction of rotation for reversing the switch is controlled by a double field winding in the motor, one part of which is cut out while the other is in circuit.

Troubles.—Heavy flashing and smoking in the controller is due to dirt, moisture, metal dust in the controller, or the too slow turning off of the controller.

Open the overhead switch and blow out the dust from the ring terminals, also remove all dust at the lower ends of the controller and see that it is dry.

Should the lamps not light upon turning the lamp switch examine lamp circuit fuse.

If fuse be not blown, either a lamp is not screwed up or one is burned out. In either case none will burn because they are connected in series.

Motor Troubles.—A few motor troubles often met with are given here:

A sharp rattling noise when the car is traveling at high speed is the consequence of an uneven commutator.

A commutator that is flat in places, or a few bars that have become loose and project slightly, cause the brushes to be quickly forced away from the commutator by the high bars, and to be forced back onto the lower ones by the brush holder spring as soon as a high bar has passed. This causes heavy sparking at the brushes and excessive heating of the commutator segments, besides the rapid wearing down of the brushes. The rapid succession of these changes causes the noise, and this can be remedied only in the repair shop. It should be reported.

A dull thumping noise, also connected with sparking at the brushes, may be due to the armature striking or rubbing against the pole pieces. If this be due to loose bearings the cap bolts should be tightened, but if, on account of worn out boxes, the car should be taken to the barn at a reduced speed.

Abnormal heating of one of the motor armatures may be due to its striking the field poles when rotating.

Heating of the motor may also be due to a defective brake, caused by weak release springs or too short a brake chain.

Again, heating may be due to the oil or grease used which does not melt properly, if at all.

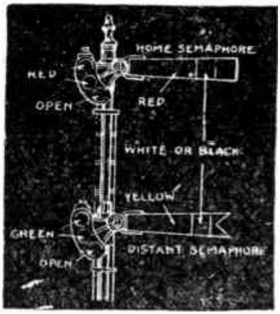
A full grease or oil cup is no sign of proper lubrication.

If it be found that bearings heat, in spite of full grease cups, take a clean stick, make a hole through the grease down to the shaft, pour in soft oil and go ahead.

It may be well occasionally to feel the car axle bearings, which get pretty warm when insufficiently supplied with oil.

Before Starting.—When the train is turned over to the motorman he should:

1. Pass along the outside and carefully examine the bus line and cable jumpers between cars, to assure himself that all connections are properly made and that the main switches are closed;



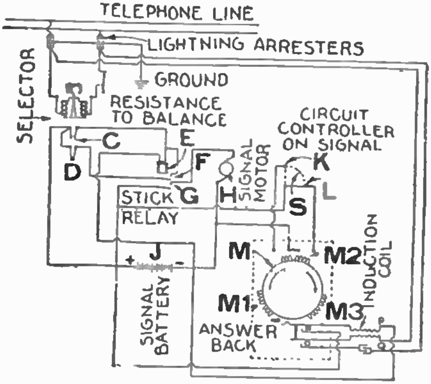


FIG. 8,213.—Standard home and distant semaphore signals. *In operation*, until either blade has reached a position approximately 30 degrees from the vertical it will indicate the same as though at the full horizontal position. This is effected by using several spectacles, each held in place by independent bezel rings, semaphores vary in length from 4 to 5 feet, about 4½ being regarded as standard.

FIG. 8,214.—Train dispatcher's selector system. *This is used* to indicate to the train engineer whether he is to proceed on the main line or to take a side track. When the indicator signal is turned from the normal to the reverse position a special "answer back" device is also operated, which makes an audible noise and informs the dispatcher that the signal has operated properly. To display a "take siding" signal the dispatcher turns a switch or depresses a key which operates the selector by closing the normally open contacts marked C. The "stick relay" throws signal battery current into a motor which operates the signal. To restore the signal to normal position the dispatcher operates the selector in the reverse direction, which opens the contacts marked C. This causes the "stick relay" to restore to normal position and throws a reverse signal back to the dispatcher. This system is semi-automatic.

2. Pass through the train, closing air compressor and third rail switches in each car, and opening master control switches in all cars except head car or car from which train is to be operated;

3. Pass along outside the train again and satisfy himself that the air compressors are working properly;

4. Take position in the motorman's compartment at forward end of train and note the brake pipe pressure, and close master controller switch;

5. Set circuit breakers by moving the circuit breaker switch over the master controller to the on position, holding it there about one second to allow time for all circuit breakers to set;

6. Test the air brakes, and if same work satisfactorily, the train is ready to start.

Train Fails to Start.—If, when all the connections are made and the controlling handle operated properly, the train do not start, the fault may be due to various causes, as: 1, failure of power; 2, fault in master control circuit; 3, fault in motor control circuit; 4, non-release of air brakes.

To detect failure of power, try the lights. Some faults liable to occur in the master control circuit are: loose cable jumper; grounded train cable; poor contact in master controller; master control fuse blown.

A loose cable jumper is detected by noting if the contactors on each car be working while the train is accelerating.

A grounded cable is detected by operating the master controller; if the master controller fuse blow, it indicates that one or more wires of the train cable are grounded.

To locate a ground in the train cable, disconnect train cable on operating car from rest of train by removing train cable jumper from its socket on second car. If the fuse now blow, when the controller handle is operated, it indicates that the ground is either in the operating car or its train cable jumper.

To determine which be grounded, remove jumper, if fuse blow when the controller handle is operated, the ground is in the car; if it do not blow, the ground is in the jumper.

To detect poor contact in the master controller, open master controller switch, remove cover from the controller and turn the handle slowly, noting if each finger make good contact with the drive.

A blown master controller fuse is indicated if, in turning the master controller handle to the first notch and thus opening the master controller switch, no arcing occur, the fuse is blown or is imperfect.

Fault liable to occur in the motor control circuit are: main fuse blown; shoe or trolley fuses blown; bus fuses blown; loose or disconnected bus jumper; circuit breakers open.

The blowing of the main fuses should not occur often. It is caused by short circuit or grounding in the motor circuit. Before renewing main fuse, open the main switch.

The grounding or short circuiting of the wiring on a car or truck may cause the trolley fuse to blow. The trolley or trolleys should be pulled down and trolley switch opened before replacing trolley fuse.

A shoe fuse may blow for short circuit, grounding of the car wiring on some part of the car or truck, or may be caused by a contact shoe on the car or train grounding. In replacing fuse, first open the third rail switch and insert the wooden paddles, provided for that purpose between all shoes on that car that are in contact with the third rail.

A loose or disconnected bus jumper may be detected when the train is at a crossover and current cannot be obtained on operating cars, although other cars of the train have current, thus indicating blown fuse or fuses, or that a bus line jumper is loose or disconnected between the operating and adjacent cars.

CHAPTER 44

Electric Ship Drive

The object of the electric drive is to ***overcome the inherent defects or limitations of the turbine***, that is, its function is similar to the so-called "transmission" of an automobile in that it gives flexibility of control and permits the turbine to run at its most economical speed.

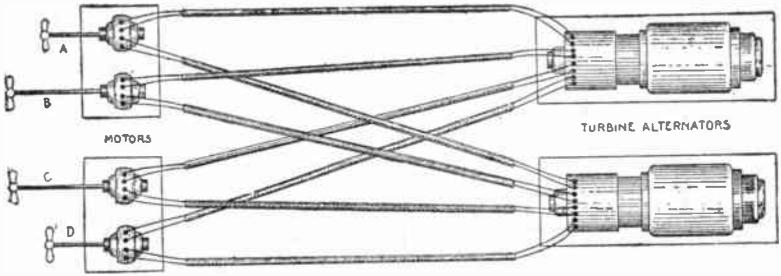


FIG. 8,215.—Elementary diagram illustrating the essentials of electric ship propulsion. Two turbine alternator units are shown on the right which are wired for various connections with the motors; the latter operates the propellers A,B,C and D.

Fig. 8,215 will make clear the plan of the driving mechanism. The generating plant is composed of two independent turbine alternators, each of which is capable of delivering one-half of the total power necessary to run the ship at maximum speed. The driving motors are of the three phase variety and each motor is equipped with two sets of pole piece—one of twenty-four poles and the other of thirty-six. By operating the motors on one or the other set of pole, the speed is changed without impairing the efficiency in any way. The plan of operation is to drive the motors at the lower speed for cruising with only one turbine alternator in operation, while for the greater speed the two alternators would be operated

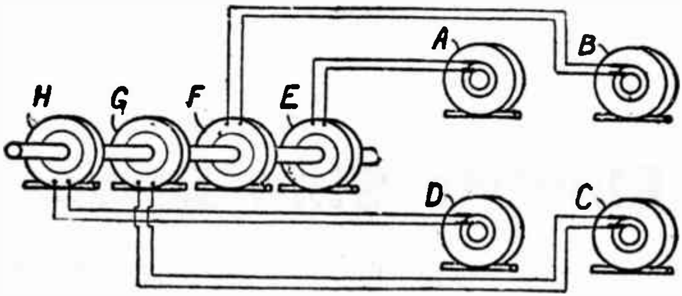


FIG. 8,216.—Hobart's alter-cycle control or induction motors for electric ship propulsion There are four motors E,F,G and H, wound respectively for 24,36,48, and 72 poles. The maximum speed of the propeller shaft is 100 *r.p.m.* with full power of all the motors. To run the motors at 100 *r.p.m.* requires frequencies of 20 cycles for the 24 pole motor, 30, for the 36 pole motor, 40, for the 48 pole motor, and 60 for the 72 pole motor. Thus to obtain equal *r.p.m.* the frequencies of the four alternators A,B C,D are respectively made 20,30,40 and 60. To obtain these frequencies when the alternators are down say to 600 *r.p.m.* requires respectively 4,6,8, and 12 poles for the alternators A,B,C and D. To drive the ship at two-thirds speed, motors F and H, are connected to alternators A and C, which provide respectively ⅔ of the frequencies of B and D, to which F and H, were connected for full speed running. Since for the lower speed only about ³/₁₀ as much power is required as for top speed, alternators B and D, and motor E and G, are shut down. For half speed a single motor is sufficient; this can be provided by operating motor H, from alternator D, or G, from A. One-third speed is obtained by operating H, from A.

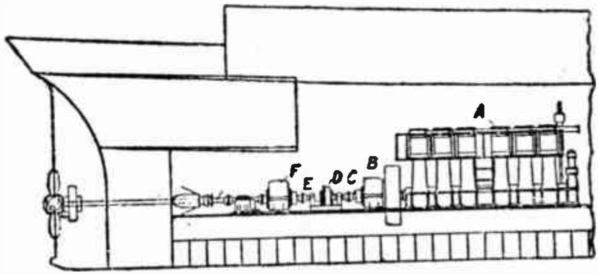


FIG. 8,217.—The ***Menlees system*** of propelling ships by gas engines. In the figure A, is a six cylinder gas engine coupled to a dynamo B. The shaft C, of the dynamo and engine is adapted to be connected by a clutch D, with the shaft E, of the electric motor F, which is connected with the propeller shaft. ***In operation*** at all ahead ship speeds direct driving may be employed, but, for speeds less than half, the electrical transmission may be used, the motor F, receiving electrical energy from the dynamo B. The drive may also be employed for reversing the astern speed by not greater than half the full ahead speed, suitable switches and gear being provided.

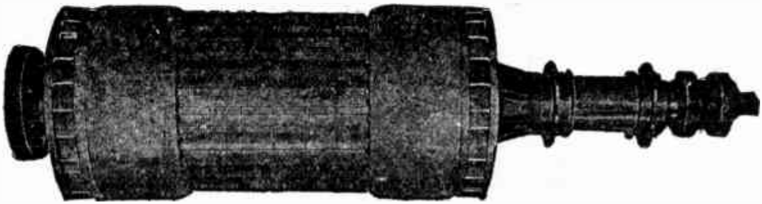


FIG. 8 218.—General Electric revolving field of alternator of the turbine driven unit shown in fig. 8,223.

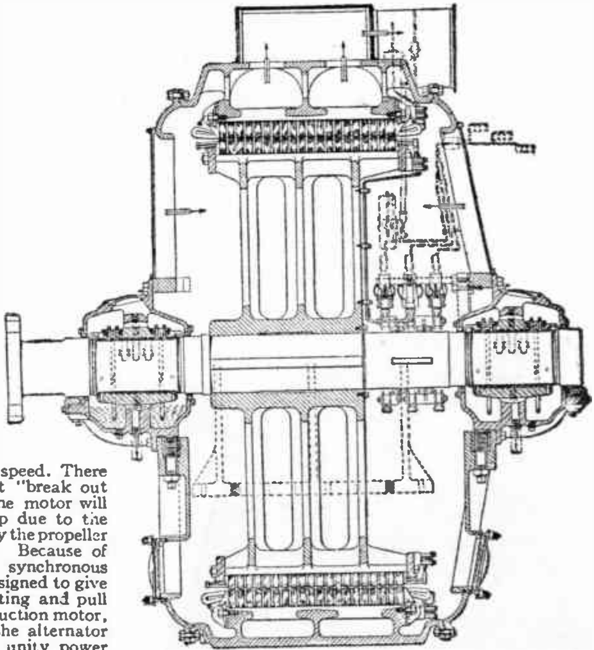


FIG. 8,219.—General Electric synchronous motor as designed for four new cutters for the coast guard service. Motors designed for ship propulsion must be capable of operating successfully under normal load and speed conditions and also of quickly reversing the propeller at full speed. There should be sufficient "break out capacity" so that the motor will not fall out of step due to the overloads imposed by the propeller in rough weather. Because of the fact that the synchronous motor cannot be designed to give quite as much starting and pull in torque as an induction motor, and also because the alternator being designed for unity power factor, is small, it is not possible to obtain sufficient reversing torque without over-exciting the alternator field. It is also necessary when reversing at full speed to reduce the alternator speed until the motor has been synchronized, after which motor and alternator are brought up to speed together. Where very high torque is required to brake the propeller down to zero speed against the action of the water tending to drive it as a tu bine, the motor may be operated as a short circuited alternator by reversing the phase rotation between motor and alternator, then establishing field on the motor but with no excitation on the alternator field. After the propeller has been brought to rest, the motor may be started as an induction motor, brought up to speed, and synchronized.

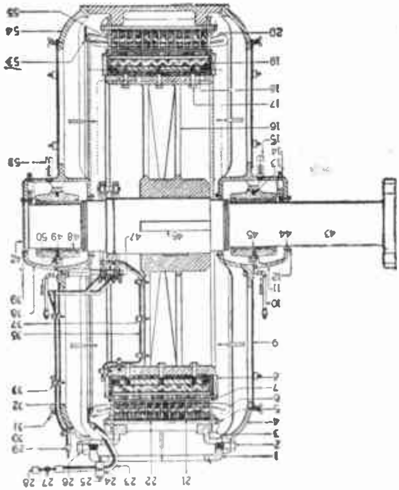


FIG. 8,220.—General Electric induction motor for merchant marine propulsion. The reliability of an induction motor on shipboard is greatly enhanced by the ease with which temporary repairs can be made in case of an electrical break down at sea, without disassembling the motor, so that the boat may continue at full or slightly reduced speed to port.

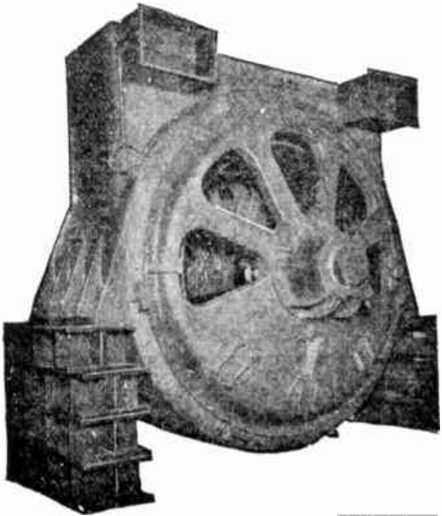


FIG. 8,221.—Exterior view of General Electric induction motor shown in section in fig. 8,220.

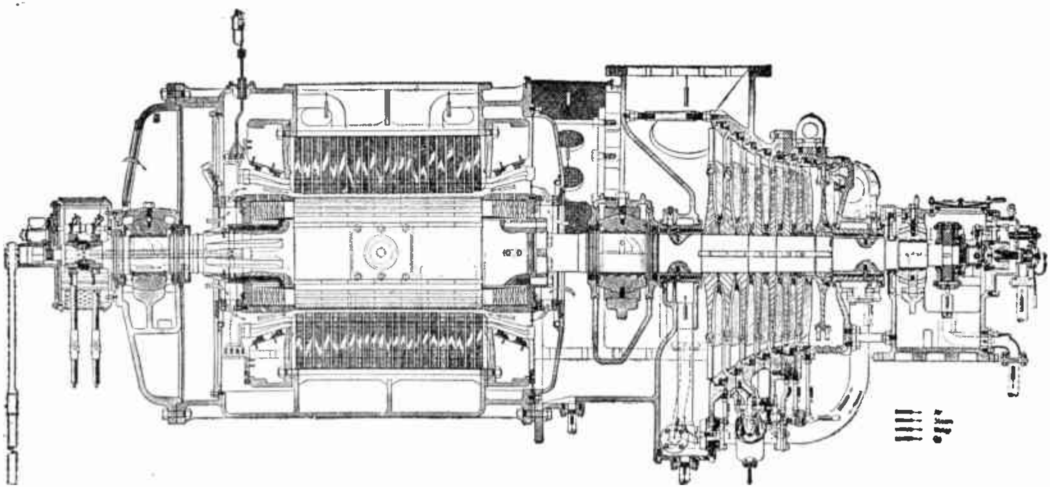


FIG. 8,222.—General Electric turbine driven alternator in which end bearing is carried by end shield.

in tandem with the motors arranged to run at their maximum speed. Thus it will be seen that when cruising, the one alternator is running at its full efficiency as are also the motors, while the second alternator is idle. Likewise, when full speed is required, the second alternator is started and run also at its peak of efficiency.

The author believes the time and money spent in devising such complication of machinery to secure flexibility of control and to obtain the necessary speed reduction between high speed turbines and low speed propellers could have been employed more profitably in perfecting a two speed and reverse gear, or more especially in seeking a commercially successful method of generating steam at considerably higher pressures and degrees of superheat than are common at present, for use in quadruple and quintuple expansion engines.

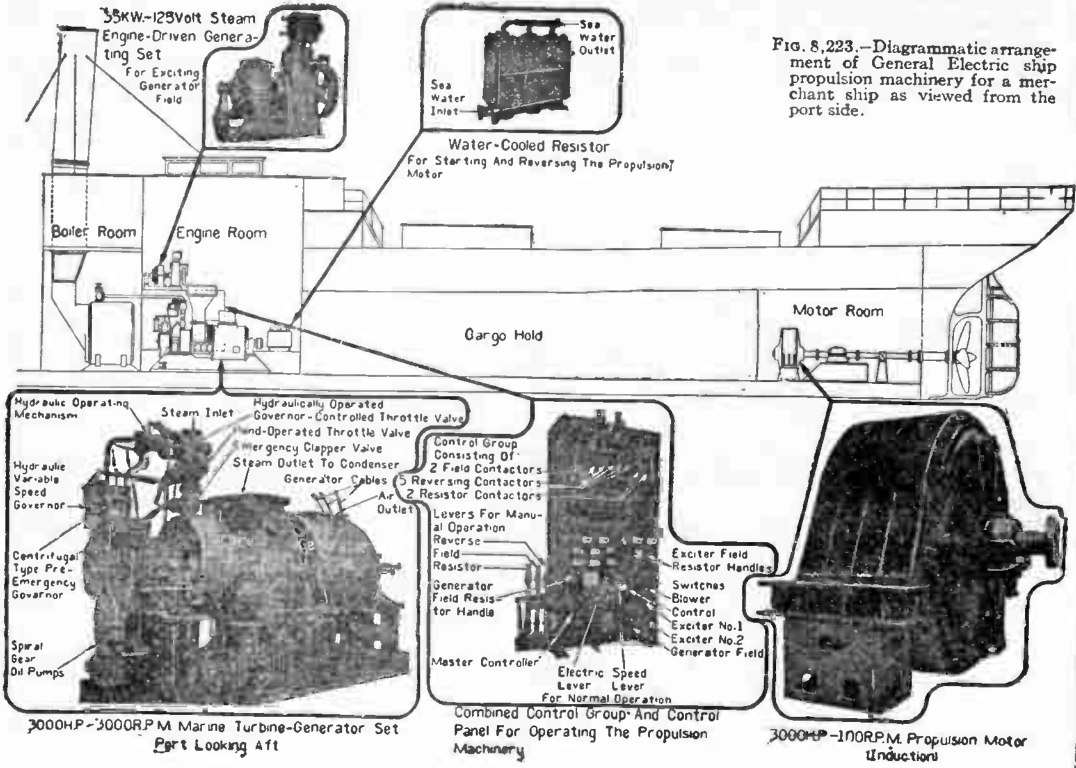


FIG. 8,223.—Diagrammatic arrangement of General Electric ship propulsion machinery for a merchant ship as viewed from the port side.

Table of Electrical Instruments on Control Panel

1. Excitation indicator
2. Generator ammeter
3. Propeller speed indicator.
4. Generator field ammeter
5. Generator volt meter
6. Turbine speed indicator
7. Indicating wattmeter
8. Temperature indicator
9. Exciter voltmeter
10. Exciter ammeter
11. Integrating wattmeter

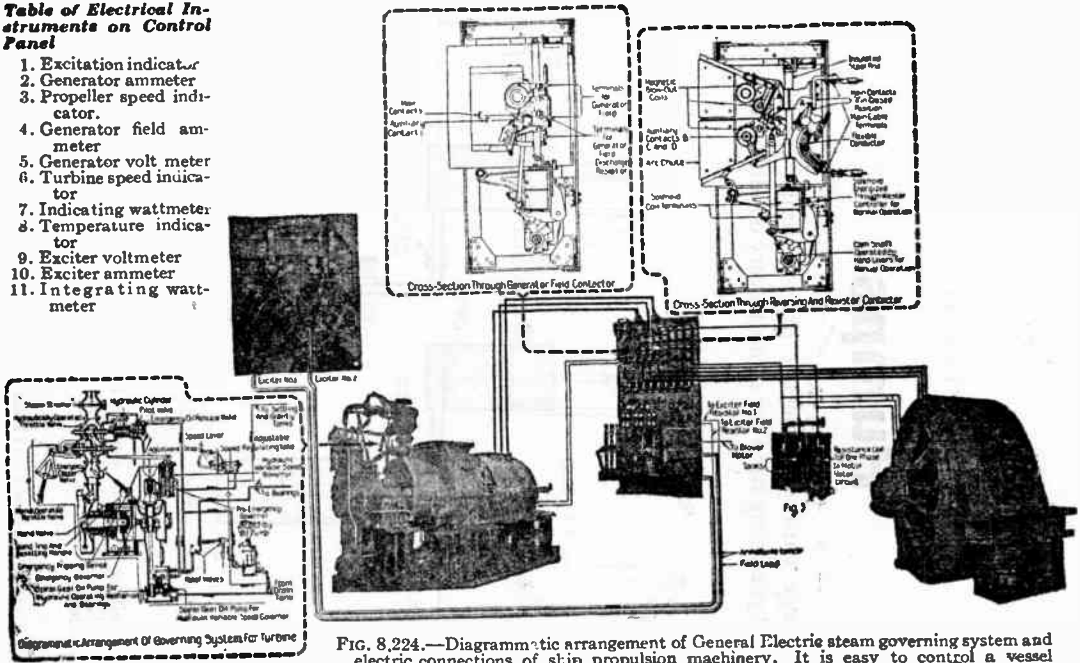
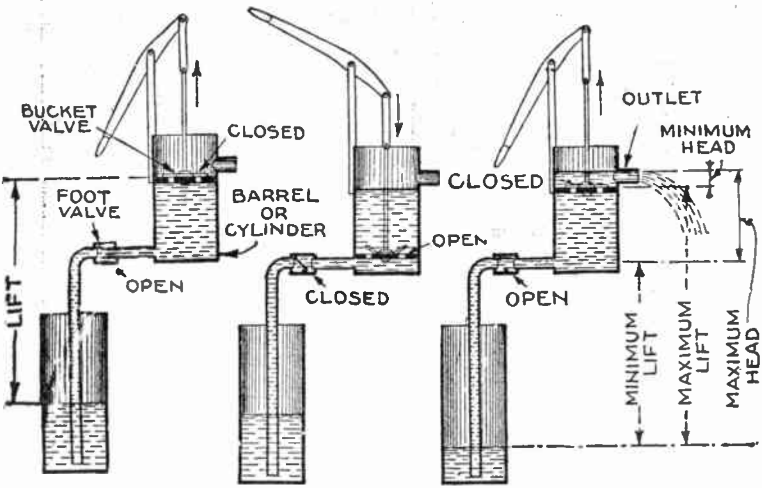


FIG. 8,224.—Diagrammatic arrangement of General Electric steam governing system and electric connections of ship propulsion machinery. It is easy to control a vessel equipped with a turbine driven alternator and propelled by a three phase induction motor mounted on a single driving shaft. Starting, stopping, and reversing are accomplished by means of an easily operated lever which serves to close, open, or reverse the electrical connections between the alternator and the driving motor on the propeller shaft. The speed of the propeller shaft is regulated through a range from one-third to full speed by means of a second lever which changes the speed of the alternator, the efficient driving of the propeller, under varying conditions in a sea voyage is gauged by a set of electrical instruments and governed by a third handle attached to a resistor in the alternator field circuit. This handle adjusts the excitation of the alternator.

CHAPTER 45

Pumps

A very large variety of electric driven pumps are of the reciprocating type being used for almost every condition of service.

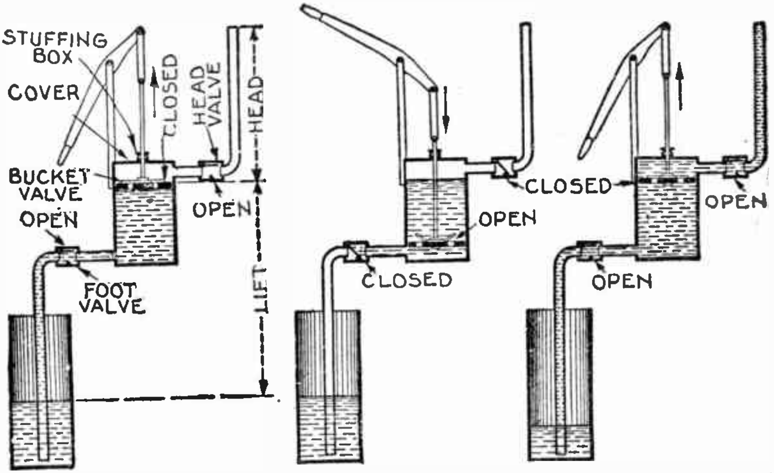


FIGS. 8,225 to 8,227.—Elementary single acting lift pump showing essential features and cycle of operation.

They are either single or double acting, single or multi-cylinder, vertical or horizontal, piston or plunger, etc., as may be best suited to any particular installation.

Motors for Reciprocating Pumps.—When *d. c.* motors are used, the *compound wound type is generally selected* for single acting pumps, on account of the rather pulsating load, but for double and triplex pumps having steadier load characteristics, *the shunt wound type is used to advantage.*

Both squirrel cage and phase wound induction motors are suitable, the latter as a rule being selected where it is desirable to reduce the starting current to a minimum, or where a somewhat variable speed is required.

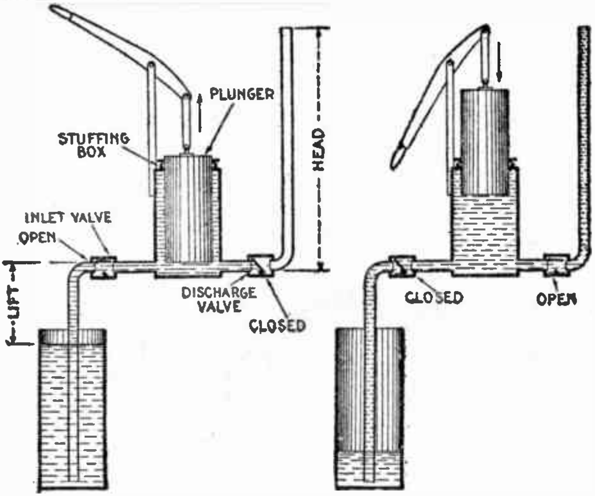


FIGS. 8,228 to 8,230.—Elementary single acting force pump showing distinguishing feature of closed cylinder.

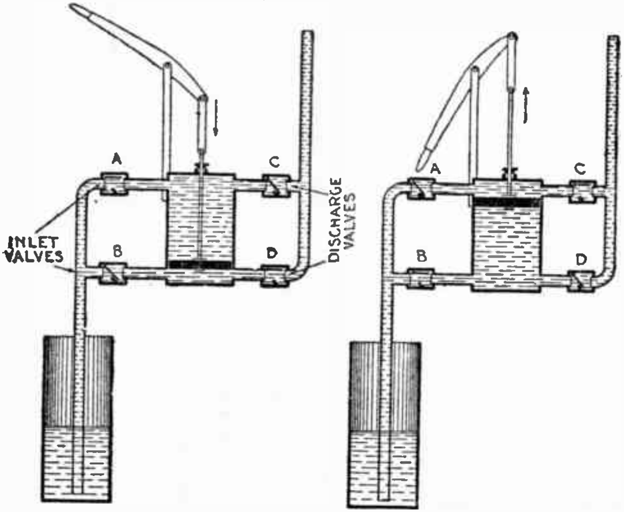
Synchronous motors may be, and are frequently used for driving large pumps. By pass valves must then, however, be provided for reducing the torque at starting.

Motors for Centrifugal Pumps.—On account of the peculiar characteristics of the centrifugal pump, *special care is required in selecting the type of motor best suited.*

With a reciprocating pump operating at constant speed an increase of the resistance increases the pressure and therefore the load on the motor,



Figs. 8,231 and 8,232.—Elementary single acting plunger pump showing essential parts. *The distinction* between a plunger and a piston should be carefully noted.



Figs. 8,233 and 8,234.—Elementary double acting piston force pump. *It is a conbination* of two single acting pumps and gives a nearer uniform flow than the single acting pump.

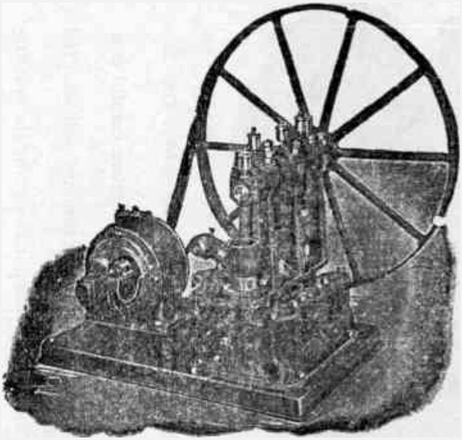


FIG. 8,235.—Deming single acting plunger triplex pump with ***single reduction belt drive.*** This type has the desirable feature of quiet running in addition to its compact arrangement. It makes a desirable arrangement for light service such as tank pumping in residences, apartment houses, hotels, or wherever noise is objectionable. It requires, however, a large pulley and is subject to slippage.

but with a centrifugal pump, an increase of the resistance reduces the load.

The volume of water delivered by a reciprocating pump is not affected by the reduction of the head, but the required power is reduced. A reduction of the head with a centrifugal pump, however, increases the volume of water, and as the efficiency at the same time goes down rapidly, the load increases. It is accordingly of importance to know what this overload, caused by a reduction of the head, amounts to—the duration of this overload. The capacity of the motor should as a rule be governed

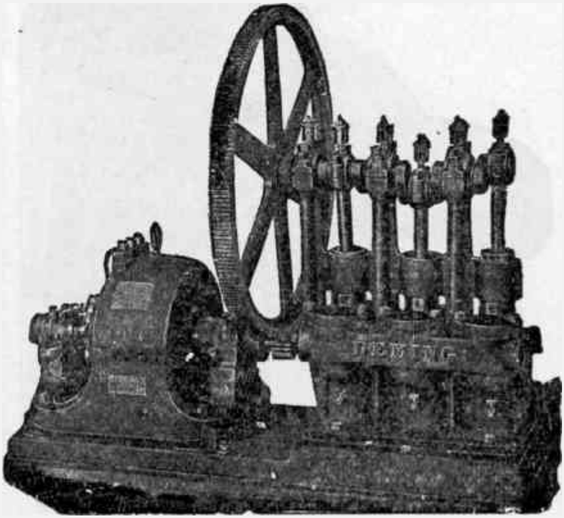
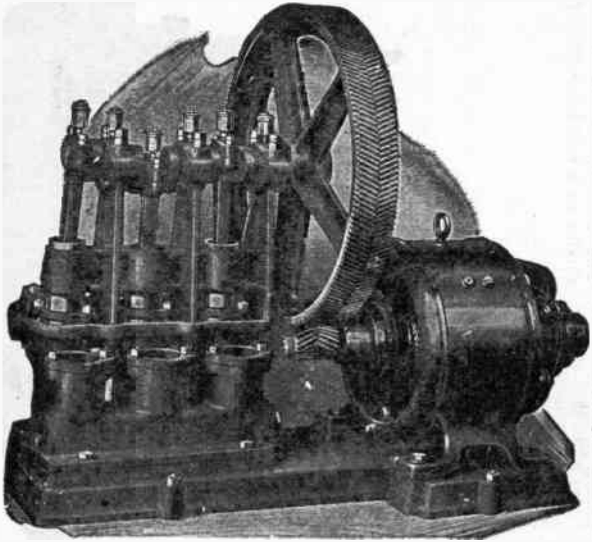


FIG. 8,236.—Deming single acting plunger triplex pump with ***single reduction spur drive,*** with rawhide pinion This type avoids the large pulley and gives a *positive* connection between motor and pump. This is a compact drive and is suitable for light service where space is limited and where some noise is not objectionable.



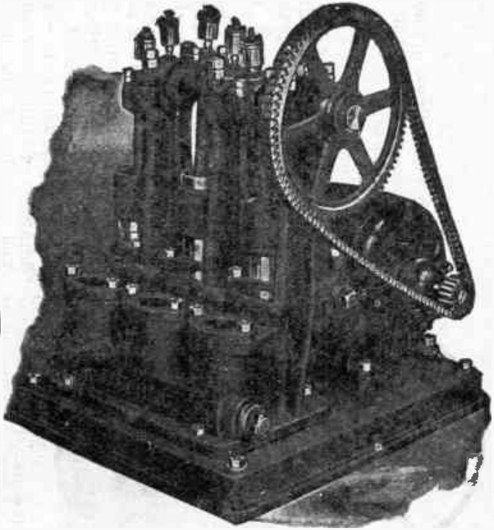


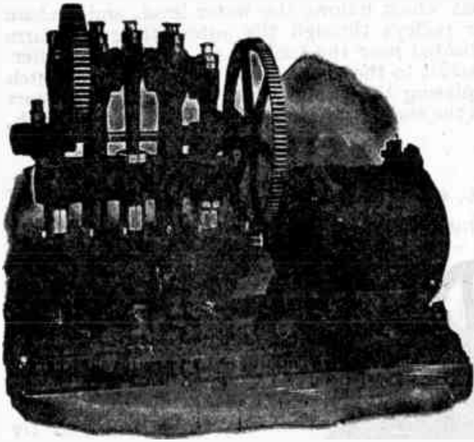
FIG. 8,237.—Deming single acting plunger triplex pump with ***single reduction herringbone drive.*** The features of the herring-bone gears are continuous and smooth action, elimination of shock, and reduced wear.

FIG. 8,238.—Deming single acting plunger triplex pump with ***single reduction, so called silent chain drive.*** This drive is desirable where quiet running is essential and space limited.

by the low and not the high head conditions. The condition of starting must also be given careful consideration in selecting the motor.

Shunt wound *d.c.* motors and either squirrel cage or phase wound induction motors are well adapted for centrifugal pumps and will readily meet the above conditions.

A synchronous motor may lead to difficulties unless proper precautions are taken in designing the starting winding and auxiliary starting equipment.



The Drive.—The reciprocating pump, because of the necessarily low speed at which it must operate ***requires a high velocity reduction between the motor and pump.***

Accordingly some form of gearing which constitutes the "drive" must be interposed between the two machines. The various types of drive are shown in the accompanying cuts.

FIG. 8,239.—Deming single acting plunger triplex pump with ***double reduction spur gear drive.*** As is evident, a large speed reduction between motor and pump is obtained in a small space. The arrangement permits the use of a high speed motor with a heavy duty pump.

Control Devices; Power End.—There are various devices for automatically starting and stopping the motor when predetermined conditions of pumping are reached. These consist of pressure regulators, float switches, etc.

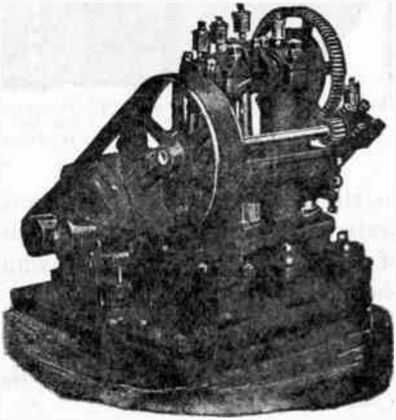


Fig. 8,247 illustrates the method of automatically controlling an electric house pump when the open tank pumping system is used. The pump is usually placed in the basement, the discharge pipe passing up through the building to the open tank in the attic, where it is generally located.

FIG. 8,240.—Deming single acting plunger triplex pump with ***double reduction combination short belt and spur gear drive.*** This type has the desirable features of quiet running and compactness. When a rawhide pinion is used practically all noise is eliminated.

In the tank is placed a float which follows the water level, and a chain from the float passes over pulleys through the automatic switch arm (the switch being usually located near the tank), and then to a counter-weight. Small buttons attached to the chain above and below the switch arm afford a means of regulating the points where the motor will start and stop. The figure shows the starting rheostat, fuse block, main switch, and wiring.

In place of a tank float, control may be effected by means of the varying pressure of the water due to the head.

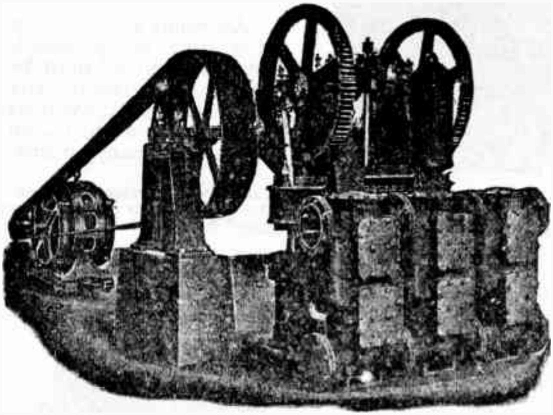


FIG.—8,241.—Gould double acting piston triplex pump with *double reduction combination long belt and spur gear drive.* The belt renders the drive less noisy than when both reductions are by spur gear, and yet retaining a high degree of compactness.

How to Figure the Cost of Electric Pumping.—The number of watt required by the motor of an electric pump must be sufficient to furnish power for: 1, lifting the water; 2, loss due to slip; 3, overcoming the friction of water in traversing the system from intake to point of delivery; 4, overcoming the friction of pump and gearing; 5, overcoming the friction of the motor; 6, electrical losses in motor.

Accordingly, as must be evident, the actual power to be supplied to the motor is considerably greater than the theoretical power required to lift the water.

For illustration, assuming that a certain pump have an efficiency of 85 per cent. and the motor which runs it, 88 per cent., then the combined

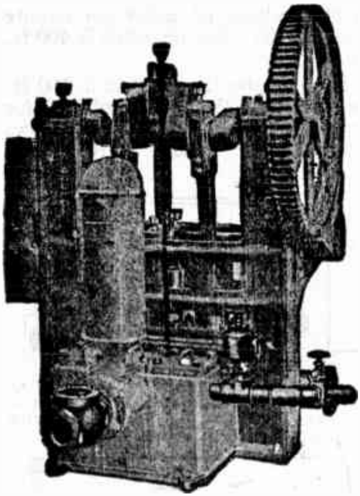


Fig. 8,242.—Goulds type L automatic pressure regulator and by pass.

efficiency, or efficiency of the system is .85 × .88 = .75. That is to say, if the electrical power delivered to the motor be 100 horse power and the efficiency of the system be 75 per cent., then only

100 × .75 = 75 horse power

is available for elevating the water.

To get the actual electrical power required, first, the theoretical head should be increased by the loss of head in feet due to friction in the pipe line, as determined from hydraulic tables. The result determined in this way must then be considered for the power loss in the pumping unit. This is determined by dividing the theoretical horse power by the efficiency of the system expressed as a decimal, thus:

$$\left.\begin{array}{c}\text{H.P. required}\\ \text{by motor}\end{array}\right\} = \frac{W \times H}{33{,}000 \times E} \quad \ldots (1)$$

in which

W = weight of water pumped per minute in pounds;
H = total dynamic head;
E = efficiency of the system comprising pump, motor, and gearing connecting them.

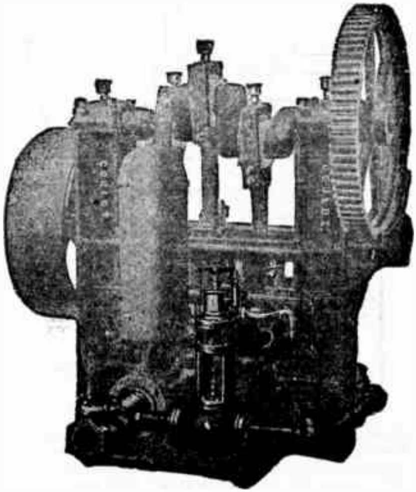
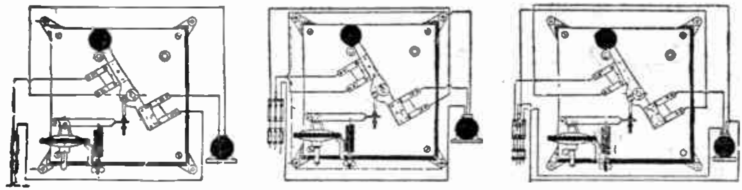


Fig. 8,243.—Goulds type K by pass control consisting of gate valve, discharge check valve and relief valve.

Example.—It is required to pump 300 gallons of water per minute against a combined static lift and head of 200 ft. The pipe line is 400 ft. long and contains 5 ninety degree elbows.

From table showing friction of water in pipes the friction loss in 100 ft. of 5 in. pipe, discharging 300 gals. per min. is 2.25 ft. Accordingly for 400 ft. it is $4 \times 2.25 = 9$ ft. From table showing friction of water in elbows one 5 in. 90° elbow, discharging 300 gals. per min. = .36 ft. Five elbows $= 5 \times .36 = 1.8$ ft.



FIGS. 8,244 to 8,246.—Wiring diagrams for Hill double pole automatic pressure tank switch. Fig. 8,244, direct, or alternating current, single phase, two wires; fig. 8,245, alternating current, three phase, three wire; fig. 8,246, alternating current, two phase, four wire.

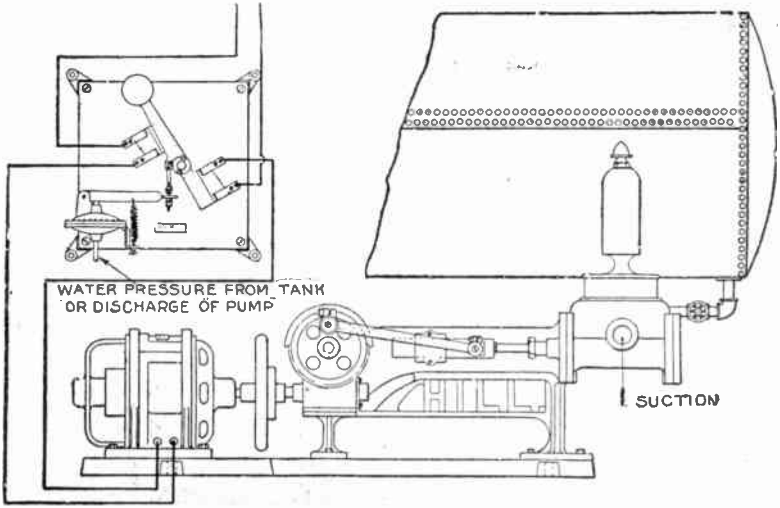


FIG. 8,247.—Hill double acting single cylinder piston tank pump with ***single reduction worm drive and pressure control apparatus.*** ***In operation*** of the control, as pressure rises, diaphragm moves lever until ball falls across center, throwing switch open suddenly. When pressure in tank decreases, on account of lowering of the water level, lever is moved until ball falls to the opposite side, closing switch and again starting motor and pump. The apparatus is set for different pressures by adjusting the thumb nut.

CHAPTER 46

Elevators

There are numerous kinds of electric elevator designed to meet the varied conditions of service. They may be classified with respect to the control, as:

a. Non-reversible;
b. Reversible;
c. Mechanical;
d. Semi-mechanical;
e. Semi-magnet;
f. Full magnet;
g. Push button;
h. One speed;
i. Two speed, etc.

The various methods of applying the power and other mechanical details have been described at length in Guide No. 7.

Elevator Motors.—Either *d.c.* or *a.c.* motors may be used but *d.c.* is preferable, because of the high starting torque of the *d.c.* motor.

The chief difficulty experienced with alternating current motors is this lack of ability to start under heavy loads, and for this reason proportionally larger sizes must be used, the increase in horse power required being fully 33 per cent.

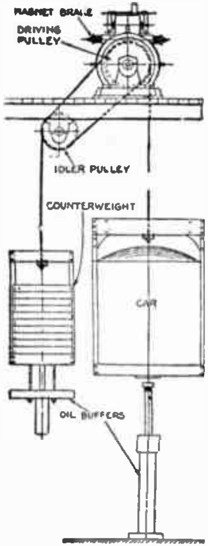
The adjustable speed *d.c.* motor having a small percentage of compound winding is the type giving the best control.

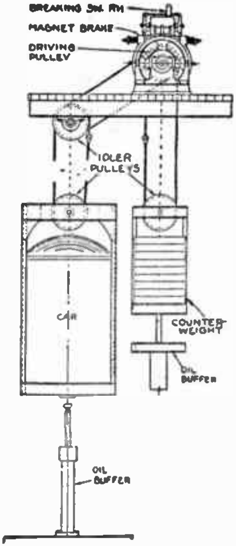
The squirrel cage induction motor should be used only for slow and constant speed freight elevators where the impairment of the line regulation, caused by the high starting current, is not important.

It is not possible to vary the speed of the ordinary induction motor under all conditions of load, nor is it ever possible to employ with it the dynamic brake used with the direct current motor.

Elevator squirrel cage motors, when thrown across the line, should not take more than 2½ to 3 times the normal current.

The polyphase slip ring, or external resistance motor is the type of *a.c.* motor suitable for high speed elevators.





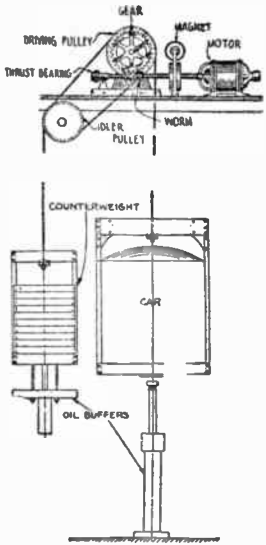


FIG. 8,248.—Overmounted 1 to 1 traction elevator. The control is full magnet, that is, the controller is actuated by a master switch in the car.

FIG. 8,249.—Overmounted 2 to 1 traction elevator. The motor is compound wound and runs usually at about eight hundred revolutions per minute at full car speed and load. The series field is used only at starting to obtain a highly saturated field in the shortest possible time, and this is then short circuited, allowing the motor to run as a plain shunt wound type. *In stopping* a comparatively low resistance field is thrown across the armature, providing a dynamic brake action and a gentle slowing down of the car, the brake being called upon only to effect the final stop and to hold the load at rest.

FIG. 8,250.—Overmounted traction elevator with multi-reduction or worm drive. Clearly, the worm gives a large velocity reduction permitting the use of a high speed motor. The magnetic brake being located to act on a brake pulley attached to the fast revolving motor shaft gives considerable braking power light grip on the brake pulley.

Controllers.—The controller performs a number of functions, *such as releasing the brake, starting, accelerating, slowing, and quickly starting the car.* Its control may be classified:

1. With respect to the rotation of the motor, as

   a. Non-reversible; *b.* Reversible.

2. With respect to the current, as

   a. Direct; *b.* Alternating.

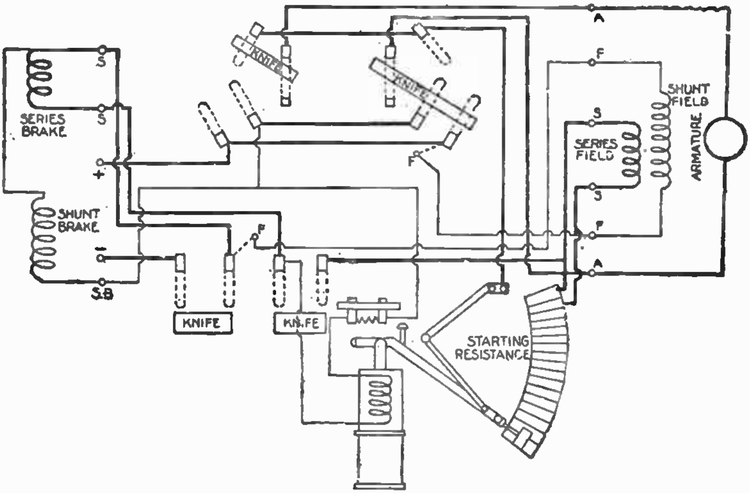
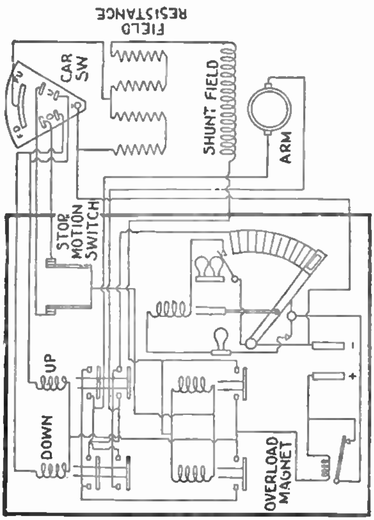


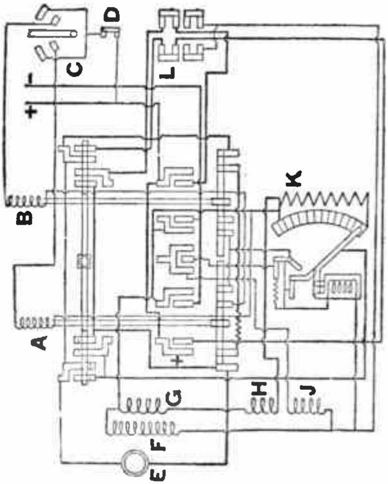
FIG. 8,251.—Diagram of A. B. See No. 4 mechanical controller.

3. With respect to construction, as

   a. Full mechanical; *c.* Semi-magnet;
   b. Semi-mechanical; *d.* Full magnet.

The simplest way in which a motor can be installed to drive an elevator, is to arrange it so as to drive a counter-shaft continuously, in which case the elevator is stopped and started by throwing belts on the tight or loose pulley.





FIGS. 8,252 and 8,253.—Diagram of A. B. See No. 4 magnet controller. Diagram of Cutler-Hammer, two speed magnet controller.

This system may be fully classified as a continuous operating non-reversible full mechanical control system. Obviously the term non-reversible refers to the motor which always runs in one direction as distinguished from motors which reverse their rotation to reverse the motion of the car.

The distinction between the various classes of controller, known as non-reversible, reversible, mechanical, semi-mechanical, semi-magnet, full magnet, and push button is illustrated in the accompanying cuts.

Full Magnet D. C. Controllers.—A typical direct current control apparatus of the full magnet type consists of several slate panels, mounted on an angle iron frame with all the connections made on the back of the board.

The solenoid switches mounted on the slate panels are arranged to perform the following functions:

1. To disconnect in the off position both sides of the line from the armature, series field, resistance, and brake magnet

Shaft limit switches may be installed so as to be operated either by the car or by the counter-weight, or by both.

The Safety Switch.—In order to insure the stopping of the elevator, even should some accident render the regular control from the car switch inoperative, a safety switch should be provided. This consists usually of a single pole switch enclosed in a cast iron box, the handle of the switch projecting through a slot in the enclosing case.

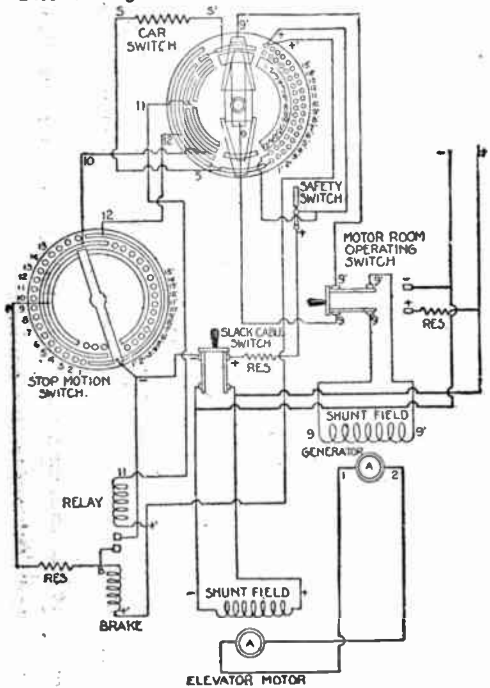


FIG. 8,254.—Diagram of Otis mechanical reversing control with type B reversing switch.

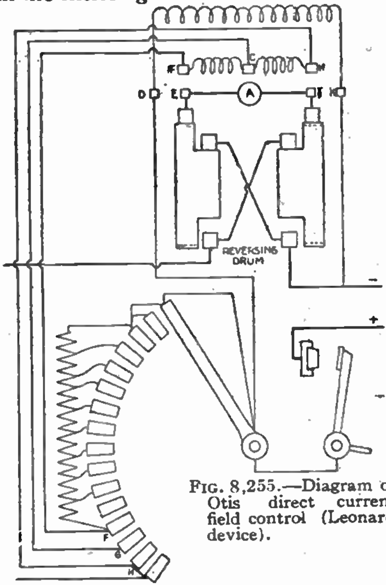


FIG. 8,255.—Diagram of Otis direct current field control (Leonard device).

This safety switch is designed to be connected, by means of a separate three wire cable, to that part of the control circuit which is in the side of the line opposite to that in which the car switch is connected. The third wire in this cable is desirable as a spare. The opening of the safety switch will therefore entirely disconnect one side of the control system from the line, and this switch, in connection with the car switch, makes it impossible for any combination of ground or short circuit to prevent the operator stopping the car at will.

2. To accelerate the motor automatically by cutting out the armature starting resistance step by step, and also the series field with the last step of armature resistance (this by means of individual series relay control) giving smooth acceleration under all load conditions.

3. To control the speed of the elevator by cutting resistance in or out of the shunt field circuit of the motor, affording positive speed control under widely varying loads.

4. To bring the elevator quickly, but smoothly, from high to low speeds, regardless of load, making accurate stops at landings an easy matter.

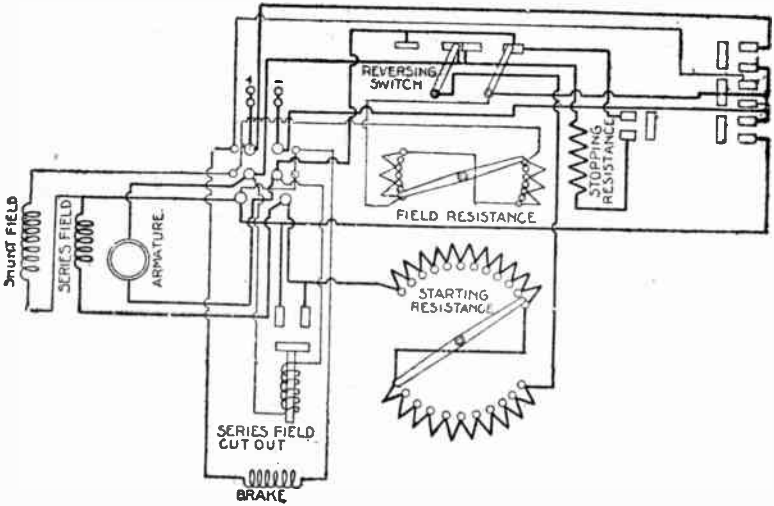


FIG. 8,256.—Diagram of Electron direct current mechanical controller.

5. To open the circuit to the motor should an overload current flow.

6. To apply the dynamic brake in the off position.

7. To operate the elevator at normal speed from the switchboard for test purposes.

To these seven functions may be added, as a modification of the standard controller equipment:

8. To open the shunt field circuit in the off position of the controller.

The Mechanical Brake.—The proper functioning of the mechanical brake is rendered positive by disconnecting both terminals of the brake magnet winding from the line and from the motor armature in the off position of the controller. This makes it certain that no possible combination of grounds or short circuits can keep the brake magnet energized and the brake released when the car switch is thrown to the off position. So long as the brake mechanism is in good working order mechanically, the positive application of the brake is assured.

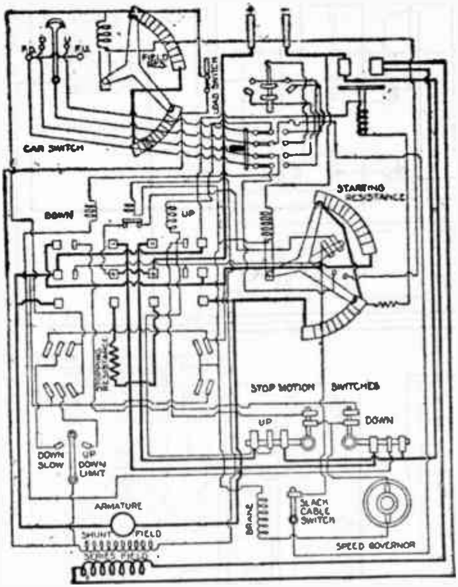


FIG. 8,257.—Diagram of Electron direct current two speed magnet controller.

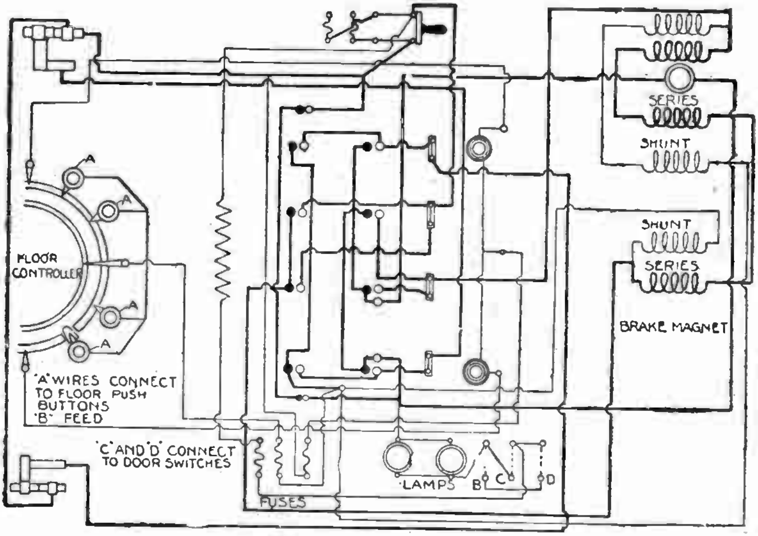
The Dynamic Brake.—Power for the operation of the dynamic brake switch is taken from the motor armature and the brake resistance is applied directly across the armature terminals.

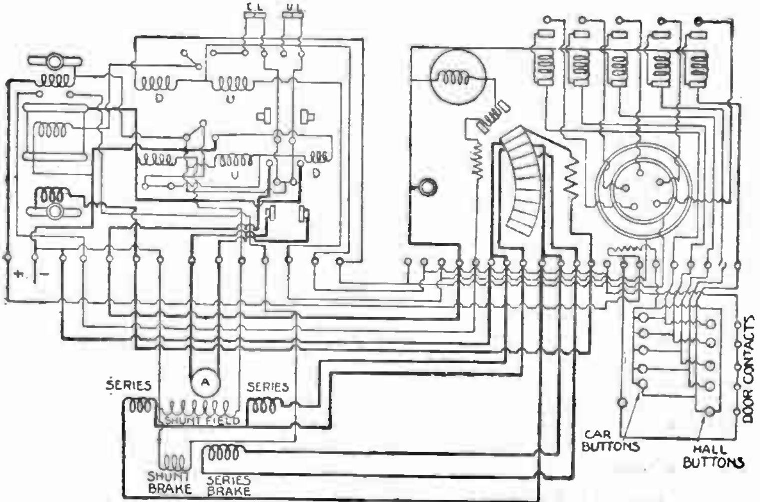
The application of this brake depends, therefore, not on the line voltage but solely on the motion of the armature.

In any form of elevator braking, mechanical or electric, the energy represented by the inertia of the moving parts must be dissipated in the form of heat in order to stop the motor.

In mechanical braking this energy is transformed into heat by the friction of the brake shoe; in electric braking it is transformed into heat by causing the motor to generate current and dissipating this energy in a resistance provided for that purpose—the dynamic brake resistance. Accordingly, when the dynamic brake is used in connection with the mechanical brake, the effectiveness of the latter is increased since it is not called upon to arrest a full powered motor, but one which has already been deprived of a portion of its energy by having a resistance shunted across its armature terminals.

The Try Out Switch.—Operators are usually instructed to go to the switch board every morning before entering the car and to test the





FIGS. 8,258 and 8,259.—Push button controllers. Fig. 8,258, Burdett and Roundtree dumb-waiter type; fig. 8,259, Darrin automatic type.

operation of the elevator by means of a *try out switch*, so as to ascertain that every part of the installation is operating properly. In this way the car may be run up and down the shaft several times each morning, testing not only the control apparatus, but also the motor, limit switches, brake solenoids, etc.

The try out switch consists of a single lever normally locked in the central position, and in the position completing the circuit to the car switch.

It is, therefore, not possible to operate the elevator from the car while the try out switch is in use, this fact enabling the try out switch to be used also as a safeguard against the operation of the elevator while the regular operator is absent from the car.

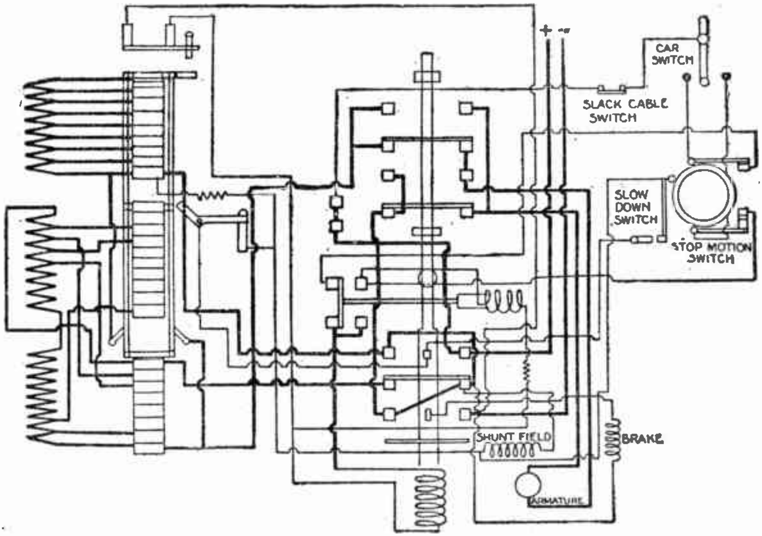


FIG. 8,260.—Diagram of National direct current type A, one speed gravity rheostat controller.

The Service Switch.—It sometimes happens that the main line knife switch ordinarily used as a service switch cannot be so located that it may be conveniently opened at night, or at other times when the elevator is idle for considerable periods. This condition is frequently met with in over mounted installations, and unless some provision be made for opening the circuit to the motor from the car, or from one of the lower floors of the building, the operator will be obliged to leave the elevator at the top of the shaft each night, walking down stairs every evening and up stairs every morning.

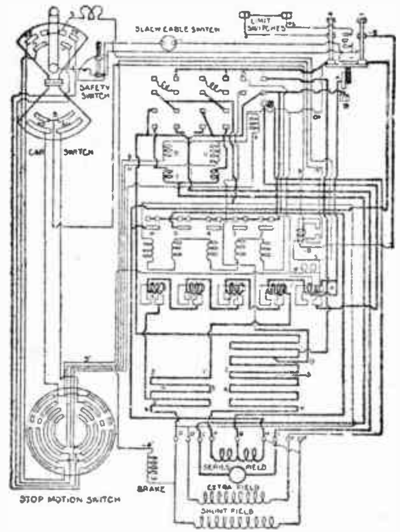


FIG. 8,261.—Diagram of Otis style B, direct current, two speed magnet controller.

The service switch remains closed normally while the elevator is in operation, not being connected in any way to the car switch or other speed regulating portion of the apparatus. Connection to the single pole service switch may be either through the safety switch, installed in the car, or through any other suitable pilot switch installed on the landing at which the operator usually leaves the elevator for the night. The opening of the switch disconnects one side of the line from the controller switchboard, enabling the operator or janitor of the building to open the circuit to the motor without going to the main line switch. The service switch controls, from one set of contact, the continuity of both the armature and shunt field circuits. This arrangement is necessary for safety, so that it will not be possible to open or close the armature circuit without also opening or closing the shunt field circuit.

Machine Type Limit Switch.—This switch is intended to insure the slowing down of the car from any speed not exceeding 300 feet per minute, and its stoppage at the predetermined limits of elevator travel. The slow down is accomplished by means of single pole switches in the control circuit, while the complete stoppage of the car is

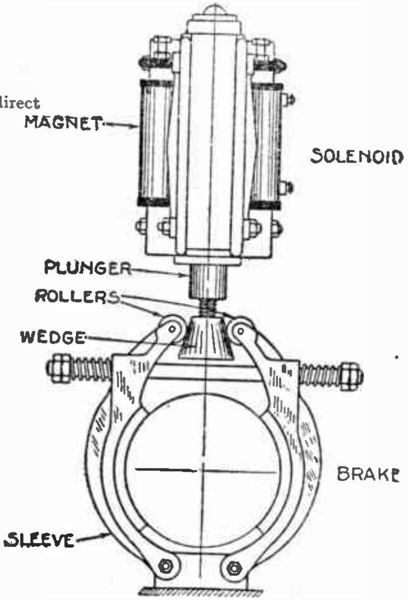


FIG. 8,262.—Typical arrangement of brake magnet having a wedge acting between rollers to release the brake.

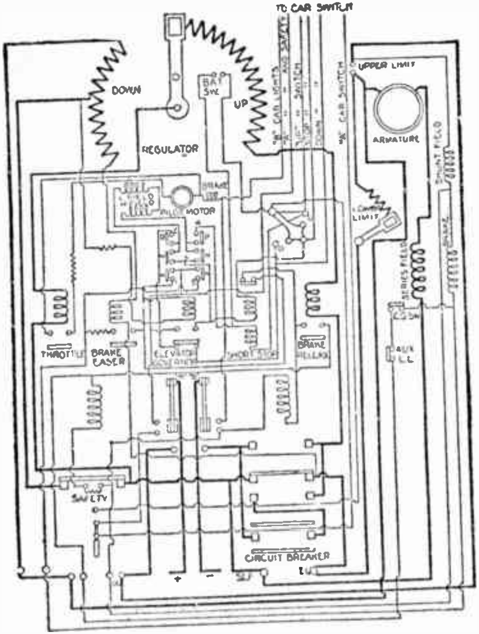


FIG. 8,623.—Diagram of Otis style GS direct current, two sweed controller.

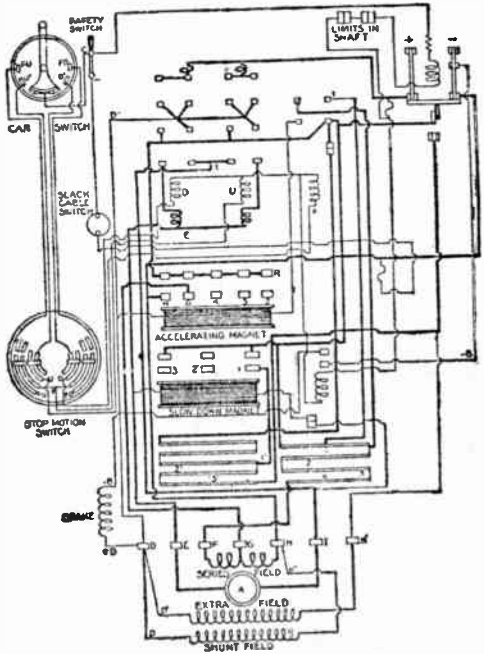


FIG. 8,624.—Diagram of Sprague direct current pilot motor controller for type A, Sprague elevator.

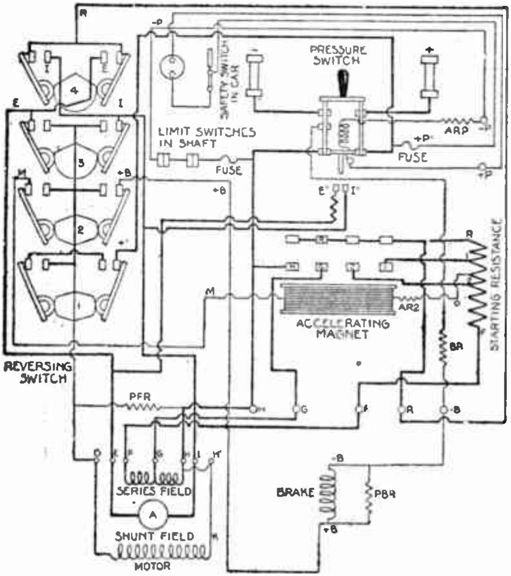


FIG. 8,265.—Diagram of Otis style 2H mechanical reversing switch.

brought about by double pole switches which disconnect both sides of the lines from the control system, thus insuring that the motor will be stopped even under conditions which might otherwise tend to impair the control of the car, such for instance, as grounds or short circuits in some part of the control system.

Connections to the limit switches are so designed that after the car has been stopped automatically at either limit of elevator travel it is possible for the operator to start and immediately accelerate to full speed in the opposite direction.

Shaft Limit Switches. — In addition to the machine type limit switches just referred to, over travel switches should be installed in the elevator shaft as an extra precaution. These shaft limit switches are arranged to be operated by the car which, on passing a given point, opens the switch thus introducing an additional break in the

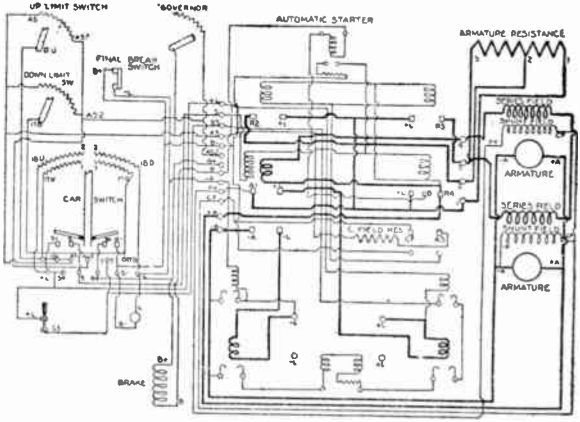


FIG. 8,266.—Diagram of Fraser direct current duplex motor controller.

control circuit and insuring the stopping of the elevator through the opening of the line and reverse switch.

Shaft limit switches, when used as over travel switches, should be so arranged that it is impossible for the operator to move the car after the switch has opened without first going to the elevator machine, thus insuring attention to the defect which caused the shaft limit switch to operate. These switches are sometimes installed alone in preference to the machine type of limit switch on drum type elevator machines.

On traction type elevator machines they obviously have to be used for both the automatic limits and over travel. For automatically slowing down and stopping the car three single pole shaft switches at either limit

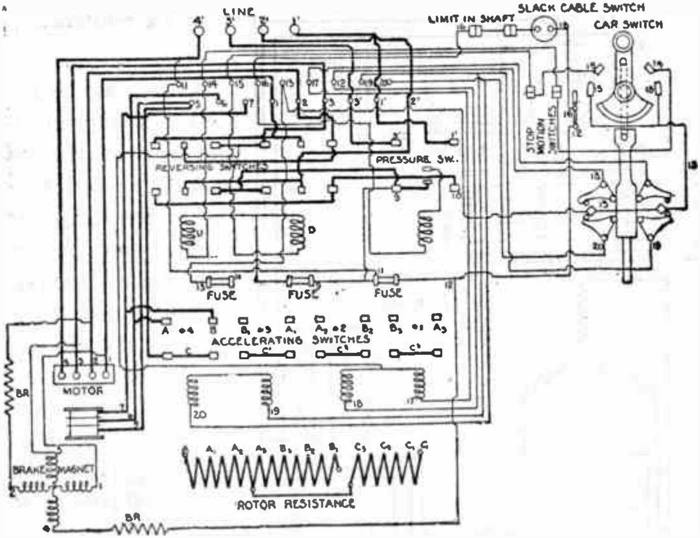


FIG. 8,267.—Diagram of Otis-type VAS alternating current, two phase magnet controller.

of elevator travel should be used, making a total of six switches in all. One switch in each of the two sets of three is used to slow down the car while the other two operate in unison as a double pole switch to bring the car to a standstill.

In addition two single pole shaft limit switches should be used for protection against over travel.

Alternating Current Controllers.—Since *a. c.* should preferably be limited to moderate speeds, because it is not feasible to employ dynamic braking.

This means that the car must be slowed down and stopped by the application of the solenoid brake alone, and the speed must therefore be one that will permit this being done with safety and comfort under all the widely varying conditions met with in elevator service.

A typical alternating current full magnet controller consists of several slate panels mounted on an angle iron frame which serves also as a support for the resistance.

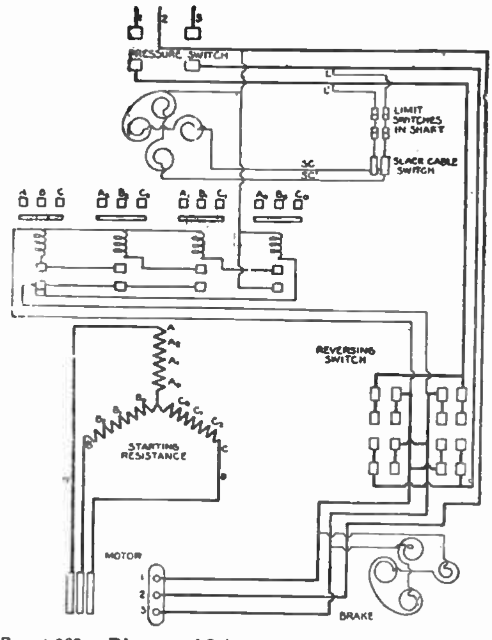


FIG. 8,268.—Diagram of Otis-type alternating current two or three phase mechanical controller.

A. c. solenoid switches mounted on the face of the panel and connected to the resistance (all connections being made at the back of the board) are arranged to perform the following functions:

1. To disconnect the primary wires from the motor and brake solenoid in the off position of the controller.

2. To accelerate the motor automatically by cutting the starting resistance out of the rotor circuit step by step (using series relay control) and giving smooth acceleration at all loads.

3. To operate the elevator from the switchboard for test purposes.

Current Relay Acceleration.—The acceleration of the motor is accomplished by a parallel solenoid self-starter with secondary starting

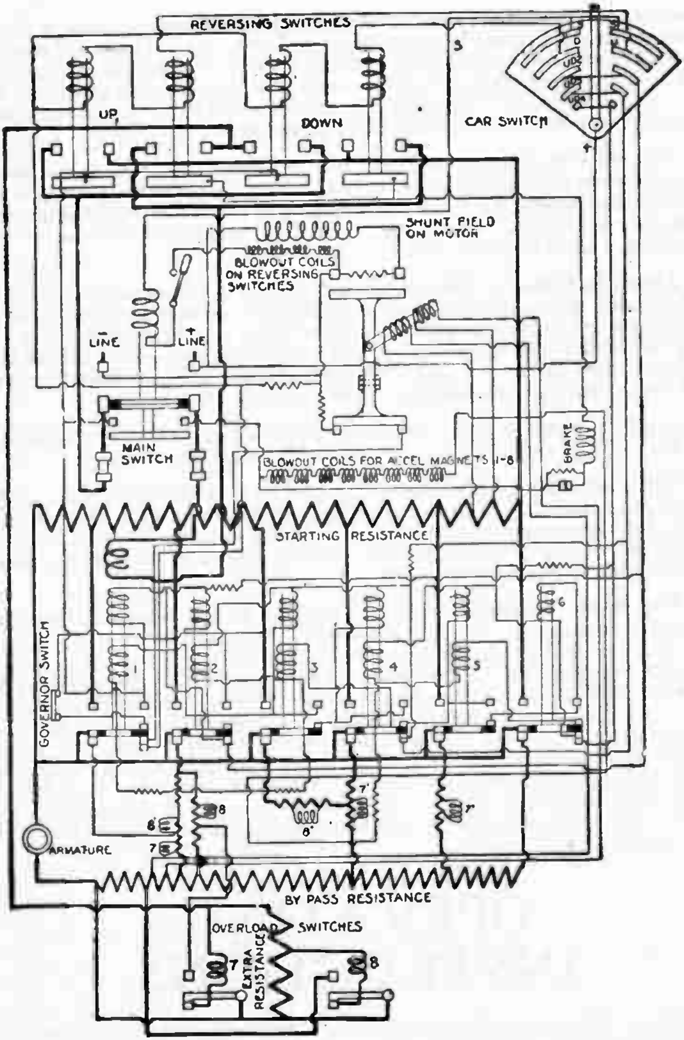


FIG. 8,269.—Diagram of A.B.See traction controller.

resistance. A suitable number of double pole alternating current solenoid switch are used, these being so connected as to cut a section of resistance out of each of the three phases of the rotor circuit simultaneously, the rate of acceleration being governed automatically by a number of current relay in the rotor circuit. By suitable adjustment of these relays the starting current is limited to a predetermined maximum.

The office of the relay is to lift and open the circuit to the succeeding switch when the starting current rises as each switch in turn is closed, thus preventing the cutting out of the next step of resistance until the motor has properly accelerated and the surge of current incident to the closing of the previous switch has died down.

Limit Switches.—The automatic stopping of the car at the two limits of elevator travel, in the case of a drum type elevator machine, is usually accomplished by a limit switch of the rotating cam or traveling cam type. These switches are designed to open both sides of the control circuit to the solenoid switches on the controller switch board, thus insuring the stopping of the car through the opening of the motor circuit.

Shaft limit switches may be used in place of the cam type limit switches, if desired, and should be used in the case of traction machines.

Two shaft limit switches should be used as over travel switches, in both cases, and should be so connected in the control circuit as to make it impossible for the operator to move the car in the reverse direction after over traveling without first going to the winding machine. This insures protection against phase reversal.

The Brake Solenoid.—This is designed to be connected directly to the motor terminals. When the circuit to the motor is closed, the solenoid is energized and the brake released. Upon the opening of the main line circuit (whether this be done intentionally in operating the elevator, or is the result of accident) the solenoid is de-energized and the brake applied. The operation of the brake solenoid is very rapid, and the force applied to the brake considerable. It is recommended, therefore, that the parts of the brake mechanism used with these solenoids, be of rugged construction, a simple toggle or wedge mechanism being most desirable. It is desirable also that the brake itself be so designed as to permit of the gradual, rather than a sudden braking effect, so as to avoid jarring the car by stopping it too quickly.

OPERATING INSTRUCTIONS

Before Starting.—The main switch connecting the motor with the supply circuit must be closed. This switch should not be closed, however.

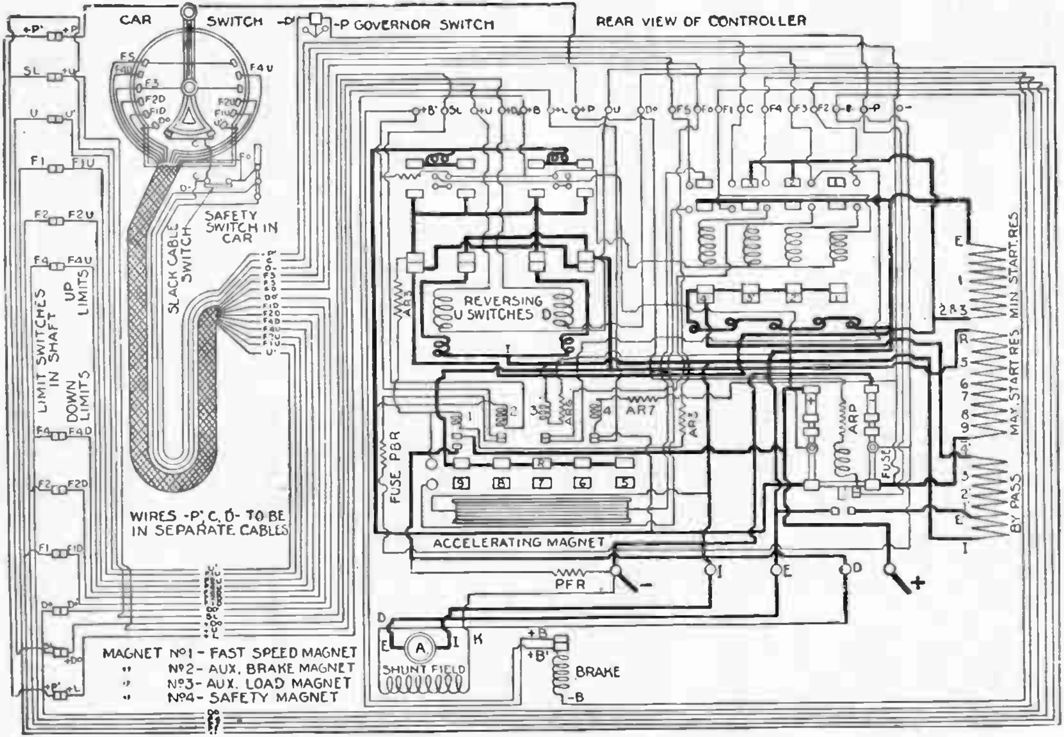


FIG. 8,270.—Diagram of Otis type MF4 direct current magnet controller for traction elevator.

until it is positively known that the hand rope, pilot wheel, lever, or switch of the operating device in the car is in its off position.

Motor Starter Contacts.—These contacts should always be kept smooth and bright. A piece of fine sand paper rubbed over them is the best means of producing the desired result After sand papering, the loose particles should be blown out with a bellows.

The bearings and cams of the motor starter should be kept clean and well oiled, and if a dash pot be provided to prevent the contact arm moving over the contacts faster than is necessary to secure the proper acceleration of the motor, this should be adjusted so that the arm will descend in from five to seven seconds.

As the retarding action of the dash pot may be overcome by gravity, a spring, magnetic attraction, or by the motion imparted from the motor, the shafting, or the elevator machine, the method of adjustment will depend upon which form of motor starter be used.

Caution in Adjusting.—An important point to remember in connection with the cleaning, oiling, or adjusting of the motor starter, and in fact in connection with the cleaning, oiling, or adjusting of any parts of the elevator equipment, is to open the main switch connecting the motor to the supply circuit before commencing these operations; this will tend to prevent accidents of an electrical or a mechanical nature.

Car Stops.—If, in the operation of an elevator, the car stop for some unknown reason, the operator should at once shift his controlling device in the car to the off position. If, then, upon shifting the controlling device again to start, the car refuse to move in either direction, some one of the following occurrences has probably taken place: It may be that the car or counter weight has met with some obstruction and the slack cable device has operated; that there is a poor contact in the switch or connections; that the fuse or circuit breaker has opened the motor circuit; or that the current has been turned off the supply wires. In any case, the motor should be examined before starting, to see that no damage has been done to it.

Car Stops between Landings.—When this happens, owing to a failure in supply of power, an effort should be made to have the main switch opened, the brake released, and the worm shaft turned either by pulling on the brake pulley or with a wrench on the end of the armature shaft so as to bring the car to a floor landing and allow the passengers to get out.

In some elevator motors, the free end of the armature shaft is purposely made square to facilitate turning the shaft with a wrench as just mentioned.

Car Beyond Control.—If the operator find he has lost control of the car and cannot stop it, he should not become frightened out allow it to make the full run, relying on the limit stops to automatically bring the car to a standstill at either end of its travel.

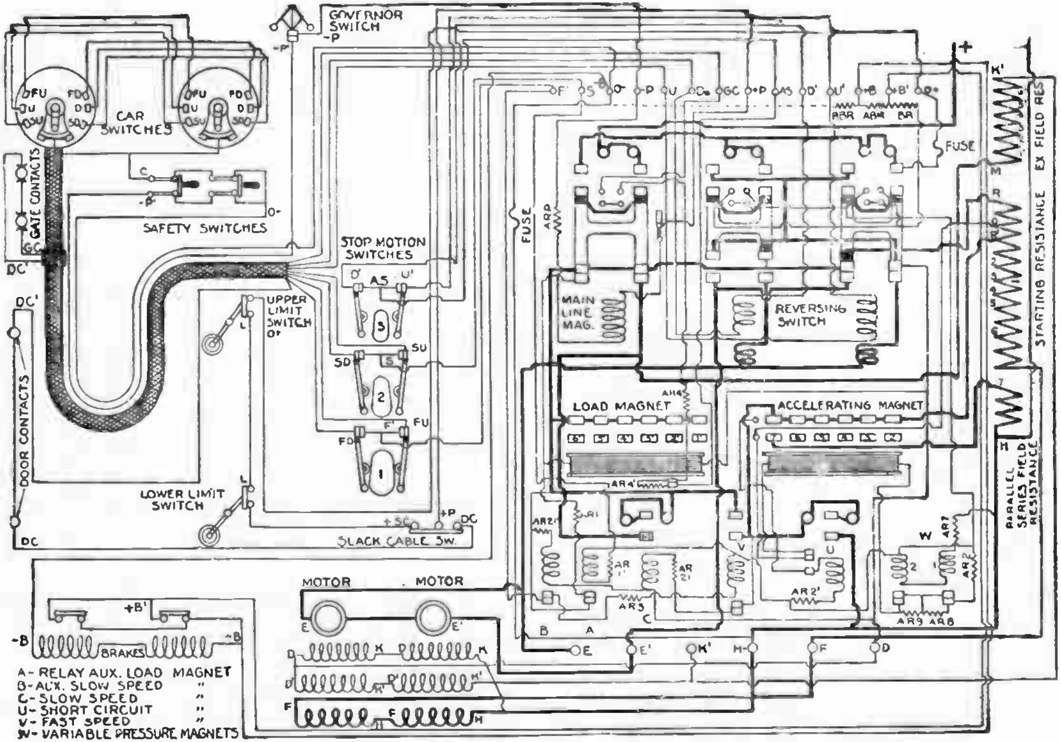


FIG. 8,271.—Diagram of Otis style 7 direct current duplex controller.

Limit Stops.—The operator should not rely on the limit stops to make a top or bottom landing, but should operate the controlling device in the car as he would to make any intermediate landing. It is advisable, however, to test the adjustment of the limit stops and determine if they remain in proper working order by trying them once daily by means of the car.

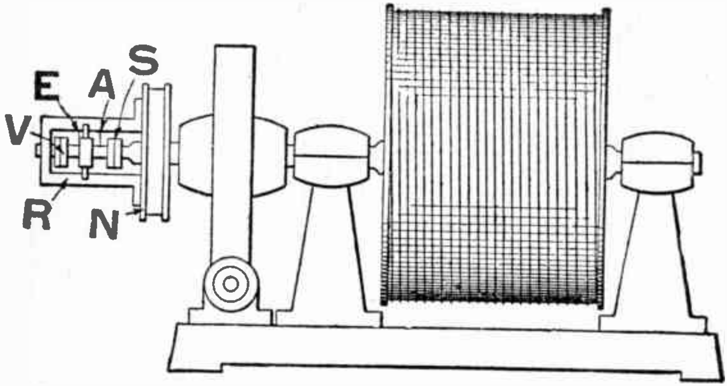


FIG. 8,272.—Machine limit stop or safety device placed on the machine to prevent over travel in case the stops on the shipper rope become inactive by the breaking of the rope. *It consists of* a threaded extension A, on the drum shaft upon which a traveling nut E, moves in a fixed ratio to the movement of the car. The shipper rope pulley N, is on that portion of the drum shaft which is not threaded, and carries a bracket R, that extends over the threaded portion. Owing to two lugs on the nut E, which fit in slots in the bracket, the nut can move only parallel with the shaft when the drum rotates unless the shipper rope sheave N, moves also. On each side of the nut E, there are claws that engage with similar claws on the inner sides of the nuts V, and S, when E, and V, or E, and S, come together. Check nuts on the outer sides of the nuts V, and S,securely clamp the latter to the drum shaft, so that when the nut E, engages either with V, or S, it will, by means of the bracket S, shift the shipper rope sheave N, thus cutting off the current from the motor and applying the brake. If the nuts V, and S, be located ont he threaded portion of the shaft so that contact is made between them and the nut E, when the car reaches its limits of travel, the operation of the device will stop the car automatically at both these points.

Leaving Car for the Night.—When the elevator is left for the night, the car should be brought to the lowest landing and allowed to remain there. Care must be taken to open the main switch connecting the motor to the supply circuit, before leaving the premises. In fact, whenever the car is to be left idle for any length of time, this switch should be opened to prevent any possibility of the motor starting up and causing damage.

CHAPTER 47

Cranes

By definition, a crane is *a machine for lifting, lowering, and moving a load in a horizontal direction*, as distinguished from a hoist which simply lifts and lowers a load.

With respect to range of movement, cranes may be classed as: 1, rotary: 2, rectilinear; and 3, combined rotary and rectilinear.

In addition to the ordinary forms coming under these heads, there are some miscellaneous types known as

1. Sheer legs;
2. Transporters;
3. Telphers {cableways; mono-rail systems.

Rotary Cranes.—In this type of crane, the construction is such as will permit the load *to be lifted, lowered, and moved radially*.

It is usual for the framing to be capable of making a complete circle. To reach a given point a radial and an angular movement are necessary.

Rectilinear Cranes.—This form of crane differs from the preceding type in that the load is *moved linearly instead of radially*.

To reach a given point, a longitudinal and a transverse movement are necessary.

Combined Rotary and Rectilinear Cranes.—A modification of the traveling crane, which *combines the functions of the two classes, rotary and rectilinear*, consists in pivoting one end of the bridge of a traveling crane and supporting the other end on a circular gantry. Most of the mechanism is identical with that of the traveling crane.

Transporters.—By definition a transporter is *a lifting and transporting machine designed to carry loads between two fixed points.*

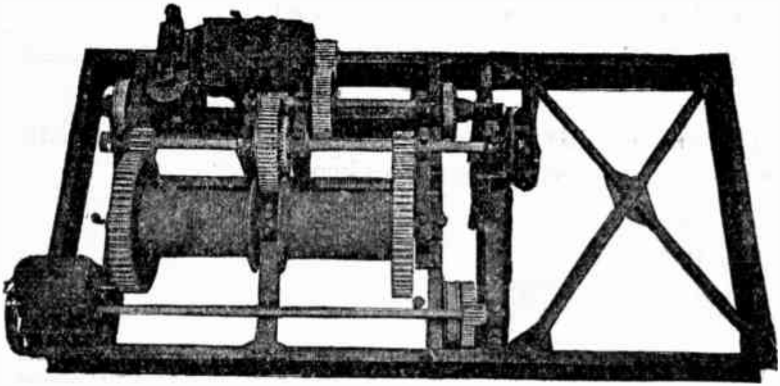


FIG. 8,273.—Niles crane construction: Standard grab bucket trolley suitable for operation with a two rope grab bucket, one rope being attached to bail of bucket and the other attached to the opening mechanism. The trolley framing consists of heavy steel channels securely riveted together, making a self-contained and rigid construction to which the mechanism is attached. The trolley is of the double drum type, each drum being operated independently of the other or in unison through the medium of one train of compensating gears. The hoisting drums are finished all over, and have grooves cut so that the bucket is lifted vertically without twisting, and the load is distributed equally to both bridge girders. One drum is fitted with a foot brake of the post type, balanced and positively withheld from contact with the brake wheel, except when applied by the operator for the purpose of opening the bucket The brake is operated by a foot lever conveniently located in the cage. The bucket is held by two sets of rope, the tension in which is always equalized through the compensating gears, avoiding the possibility of slack ropes and insuring the retention of the bucket by one of the ropes should the other break. The hoisting mechanism is controlled by powerful brakes preventing the dropping of the bucket or running down by gravity under any condition of service. The opening of the bucket or dumping of the load is by the simple application of the foot brake. When the open bucket comes in contact with the material to be handled, the controller is moved to the hoisting position. This closes and thereby fills the bucket, which, without further manipulation, is hoisted to the desired dumping point.

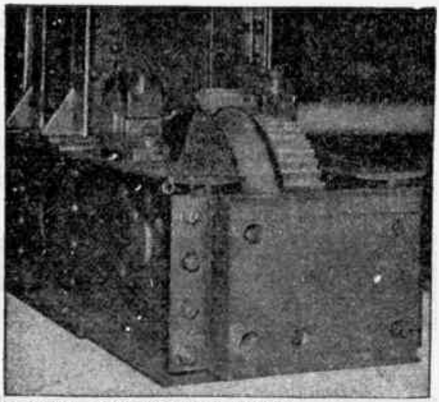
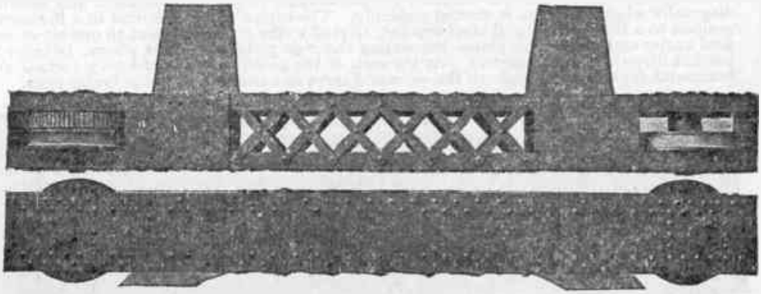


FIG. 8,274.—Niles crane construction; Bridge end trucks showing the two bearings for bridge drive shaft and the steel plate with bumper block at end of truck.

It is used chiefly for handling comparatively light loads at quick speeds and employed largely for the conveyance of materials such as coal in bulk. For the latter service it is provided with an automatic grab instead of a hook.

Crane Motors.—For driving the traveling, traversing, and slewing motions of crane, *series wound motors of a generally similar type to those used for electric traction give satisfactory results*, this work being in fact a simple class of electric traction.

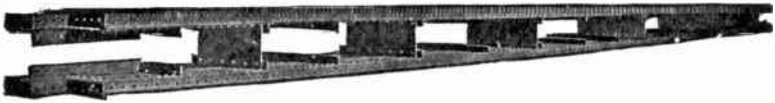


FIGS. 8,275 and 8,276.—Niles crane construction: bridge ends or trucks. The bridge ends are built up of plates and angles, as illustrated, or of heavy steel channels or I beams, depending upon the type and capacity of the crane. Heavy gusset plates connect the girders and bridge ends, and prevent the girders getting out of square. The bridge ends extend beyond the wheel and are capped at the ends with a removable steel plate, provision being made for attaching wooden bumper blocks, which prevent the wheels and gears of two cranes coming in contact when several cranes are on the same runway. The truck wheels may be easily removed by taking off the steel caps, jacking up the bridge ends just enough to remove the weight from the wheel, withdrawing the axle and rolling the wheel out. Lubrication of the truck wheels is provided by internal oiling through the center of the axle. The bridge drive shaft is carried at the ends by self-oiling cap bearings, so located as to eliminate overhung gears or pinions.

The driving of the hoisting motion presents a more difficult problem, for though it is easy to lift the load up, it is not always so easy to get it down again in a satisfactory manner.

Automatic Electro-magnetic Brakes.—It is customary to fit the hoisting motion with an electro-magnetic brake.

This may consist of a band brake which is normally kept on by a spring or weight and released by an ironclad solenoid, or it may be a disc brake



Figs. 8,277 and 8,278.—Niles crane construction: Box section bridge girders. The standard box section girders are built up of two web plates, four heavy angles and universal mill top and bottom cover plates. The web plates are reinforced at frequent intervals by heavy vertical angles and connected together by diaphragms to prevent vibration and skewing diagonally when the crane is started suddenly. The bridge motor is bolted in a horizontal position to a heavy structural steel bracket, riveted to the girder adjacent to one set of vertical angles and diaphragm plates connecting the web plates described above, in order to prevent distortion of the girders. At the ends of the girders are placed heavy vertical and horizontal angles which reinforce the webs and serve as a connection to the bridge ends.

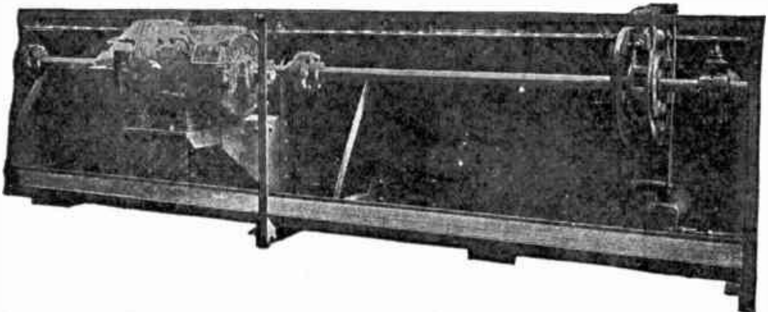
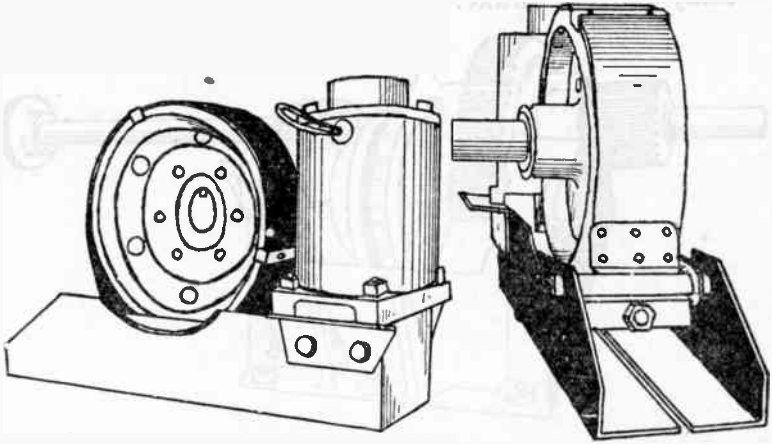


Fig. 8,279.—Niles crane construction: Bridge drive for box section girders. The web plates of the box section girders are reinforced by heavy stiffening angles, placed near the bridge drive motor and are connected by diaphragms, preventing distortion of the girders by motor or gears. A substantial platform with angle iron hand rail extends along the girder on the bridge drive side, providing easy access to the bridge motor, gears and bearings.

in which the discs are normally pressed together by a spring, an electro-magnet being provided to pull back the pressure plate and release the discs.

The coil of the solenoid or electro-magnet is in circuit with the hoisting motor, so that when current is switched on to the motor, the brake is released, and when it is switched off, the brake is applied. This makes an excellent safety device, but as it can only be off or full on, it cannot be used to regulate the descent of the load when lowering.

In cases where the driver has access to the gear, as in locomotive jib cranes and derricks, an addition may be made to the electro-magnetic brake in the form of a hand or foot release lever, by which the brake can



FIGS. 8,280 and 8,281.—Niles crane construction: Electric brake. It is of the ironclad solenoid type and is fitted with a removable brake band which engages almost the entire circumference of a turned and balanced wheel. The band is of special steel and lined with a renewable friction wearing surface. The brake is always on when there is no current flowing through the motor and is always off when motor is running.

be released or its pressure regulated. Loads are then hoisted by the motor, and are allowed to run down by their own weight, the speed of descent being regulated by the brake.

Where the driver operates the gear from a distance, the arrangement just described is not practicable, and some automatic or electrically controlled arrangement must be used to check the speed of descent of the load.

Automatic Mechanical Brake.—This type of brake is usually of the disc type, and is arranged *to allow the gear to run freely* *in the direction of hoisting, but holds it from running in the opposite direction*, being applied by a screw, or it can be arranged to be operated automatically by the load.

The brake is released by running the motor in the direction of lowering. As the motor releases the brake, the load tends to put it on again; consequently the speed of descent depends upon the speed of the motor, and this can, of course, be regulated by the driver by means of the controller.

Eddy Current Brake.—This type of brake is only used to

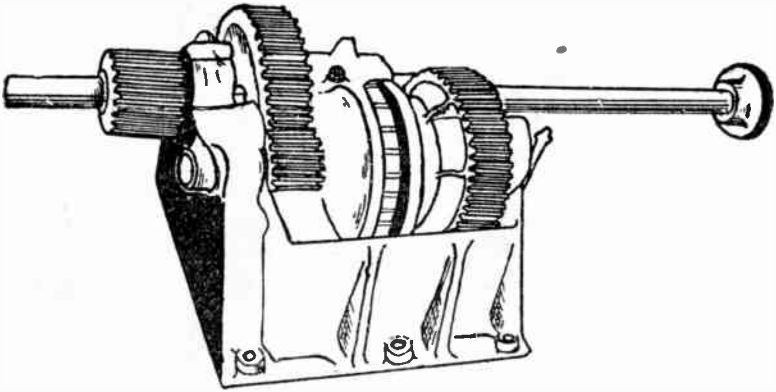


FIG. 8,282.—Niles crane construction: Mechanical load brake. It is of the double disc type with hard bronze wearing surfaces. It is automatic in action and self-contained, all thrusts being taken up within itself. The brake will not permit the load to run down unless the motor is revolved by power in the lowering direction.

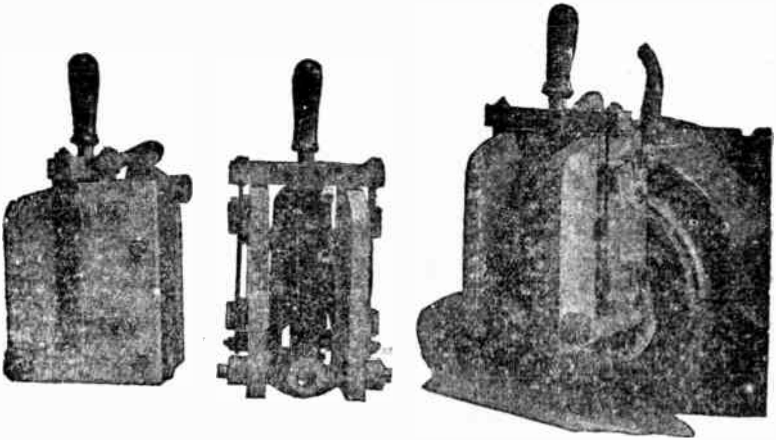
a limited extent. It consists of a wheel, generally of copper or other metal of low electrical resistance, which is arranged to rotate between the poles of an electromagnet.

The wheel is driven by the descending load, and eddy currents are generated in it, which give rise to a retarding torque. The eddy currents and the consequent torque are regulated by varying the strength of the magnet by means of a regulating switch and resistance.

Rheostatic Brake.—For this form of braking, the controller is provided with several positions on the lowering side, called *brake points*.

In these positions the controller alters the connections of the motor to those of a series dynamo, so that it generates current when driven by the descending load, the energy being absorbed by the controller resistance. The speed of lowering is regulated by varying the resistance.

Regenerative Control.—Instead of a series motor, a *shunt wound motor may be used* to drive the hoisting motion.



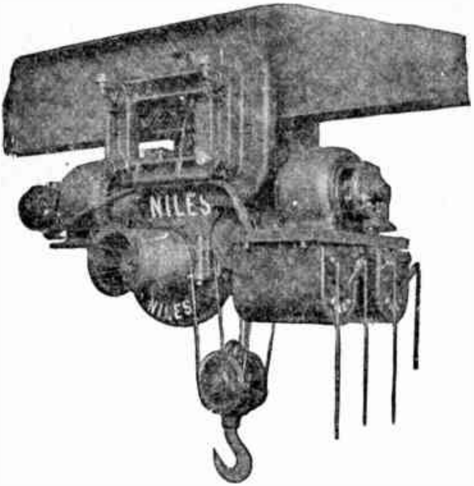
FIGS. 8,283 to 8,285.—Niles crane construction: Contact type limit switch. *It consists of* a worm wheel with machined teeth actuated by a turned steel worm which is attached directly to the hoisting drum shaft. The release mechanism is operated by a positive stop on the worm wheel with a by pass attachment which prevents damage to the switch by over hoisting. The switch blades are of a quick break type operated by a powerful spring. When the switch is open the motor cannot be operated until the switch is set by hand, after which the hook can be hoisted to the maximum height in the danger zone. When the hook is out of the danger zone, the release stop is automatically reset.

A shunt motor has the advantage that its speed can be efficiently regulated over a fairly wide range by inserting resistance in its field circuit. By this means considerable variation of speed in lifting and lowering may be obtained without the necessity of having variable speed gear in the hoisting train, and when lowering, the shunt motor, if overhauled by a load, becomes a dynamo and feeds current back to the circuit, thus automatically controlling the speed of lowering.

Collector Gear.—For overhead cranes copper wires about one-quarter to three-eighths inches diameter are stretched along the gantry, being supported at the ends by globe strain insulators. Trolley wheels or slides, mounted on the end carriage, make contact with these wires.

Controllers.—The drum type is generally used, *the various combinations of connection for hoisting, lowering, etc.*, being obtained by rotating this drum into different positions

Telpherage.—This word is defined as: *Automatic aerial transportation as by the aid of electricity, especially that system in which carriages having independent motors are run on a stout wire conducting an electric current.*



Telpherage properly includes those systems employing a wire or cable for a track, but the term is erroneously applied to systems using a rail. There are two divisions of telphers: 1, automatic; and 2, non-automatic.

The control of the automatic type is remote from the telpher,

FIG. 8,286.—Niles electric mono-rail hoist, built in capacities from three-quarters to six tons. They will run on straight and curved tracks, and are generally provided with a separate motor for traversing. The hoist is self-contained in one heavy cast iron frame to which the motors are attached end on, and the power is transmitted directly from the armature shaft to the drum shaft through worm and worm wheel. The traversing mechanism is also driven by worm and worm wheel, similarly to the hoisting mechanism except that, when the trolley is arranged to run on a single I beam, a double set of transmission gears is used. The worm gear mechanism is enclosed in oil and dust proof casings, and is noiseless in operation. In addition to the braking effect obtained by use of the worm and worm wheel, a powerful electric brake is attached to the hoist motor.

the non-automatic type being controlled by an operator who travels with the load who operates both the telpher and hoists from a cab or case which is attached to the telpher or carriage.

Telpher Motors.—The sizes of motor for telphers and hoists will depend upon the class of work to be done; the motors for telpher tractors vary from 5 to 15 *h.p.* and for the hoists, from 3 to 75 *h.p.*, the loads being from 500 lb. to 30,000 lb. The driving wheels and the motors may be connected by gears or by chain drive. Slow or medium speed motors are used.

Brakes.—The mechanical type of telpher brake is used and the hoist brake is of either the electro-mechanical or electro-dynamic types.

Spur gears and chain drive on the tractor transmit the power from motor to track wheels, and either spur or worm gear is used to transmit power to the hoisting drum.

Trackage.—Telphers either run in one direction on a closed track circuit, or to and fro over a single line.

On the single line and automatic telphers reverse themselves on completing their trips.

The spacing between the cars is regulated automatically by a block system.

Cableways.—The term cableway may be defined as a rectilinear *hoisting and conveying apparatus supported by a cable.*

A cableway will take up and deposit loads anywhere along a line directly underneath the main cable, and by means of switch blocks it may be made to serve an area having a width of about 15 feet or so each side of the cable.

CHAPTER 48

Electric Bells

The great multiplicity of bells may be classified

1 With respect to the ringing feature, as

a. Trembling or vibrating;
b. Single stroke;
c. Combination vibrating and single stroke;
d. Continuous ringing;
e. Buzzers.

2. With respect to the magnet winding, as

a. Series winding;
b. Shunt winding;
c. Differential winding;
d. Combined differential and and alternate winding;
e. High voltage winding;
f. Alternating current winding (polarized).

3. With respect to the form of of the interrupter, as

a. Contact breaker;
b. Contact maker.

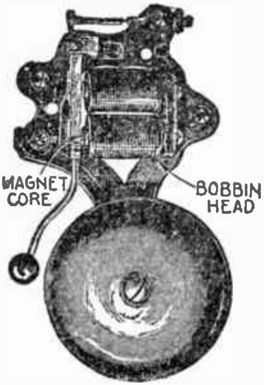


TABLE SHOWING PROPORTION OF PARTS OF ELECTRIC BELLS

Diameter of bell	Length of magnet cores	Diameter of magnet cores	Length of bobbin	Diameter of bobbin head	B. W. G. of wire on bobbin
2½"	2"	5/16"	1¾"	¾"	24
3	2¼	⅜	2	⅞	24
3½	2½	7/16	2¼	1	22
4	2¾	½	2½	1⅛	22
4½	3	9/16	2¾	1¼	20
5	3¼	⅝	3	1⅜	18
5½	3½	11/16	3¼	1½	16
6	3¾	¾	3½	1⅝	16
6½	4	13/16	3¾	1¾	16
7	4¼	⅞	4	1⅞	16
7½	4½	15/16	4¼	2	14
8	4¾	1	4½	2⅛	14
8½	5	1 1/16	4¾	2¼	14
9	5¼	1⅛	5	2⅜	14
9½	5½	1 3/16	5¼	2½	14
10	5¾	1¼	5½	2⅝	14
10½	6	1 5/16	5¾	2¾	12
11	6¼	1⅜	6	2⅞	12
11½	6½	1 7/16	6¼	3	10
12	6¾	1½	6½	3⅛	10

FIG. 8,287.—Bunnell vibrating bell. It has a skeleton type frame, pivoted armature, cast gong, and platinum contacts. Made in sizes 2½ inch to 12 inch.

4 With respect to the magnet, as

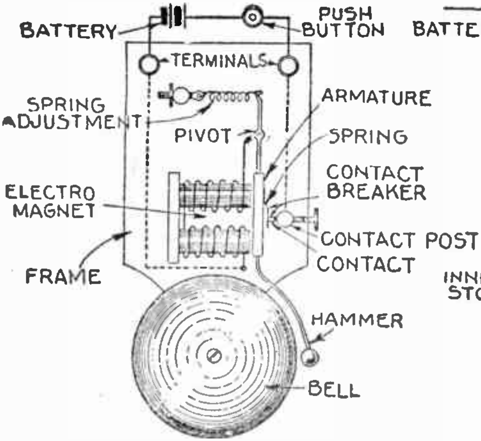
a. Single magnet;
b. Double magnet;
c. Four magnet (double acting).

5. With respect to the frame, as

a. Skeleton;
b. Iron box;
c. Wooden box.

6. With respect to the mode of operation, as

a. Single acting;
b. Double acting;
c. Electrical-mechanical;
d. Relay.



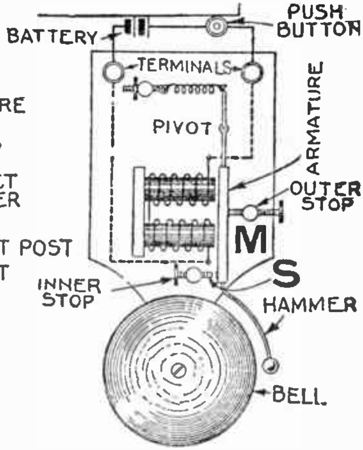


FIG. 8,288.—Elementary series vibrating bell. It consists of an electro-magnet, armature, contact breaker, pivoted hammer, bell, and frame. *In operation*, when the push button is pressed, the current energizes the magnet which attracts the armature causing the hammer to strike the bell, but before it reaches the end of the stroke, the contact breaker breaks the circuit and the hammer, influenced by the tension of the armature spring rapidly moves back to its initial position thus completing the cycle.

FIG. 8,289.—Elementary single stroke bell. *In operation*, when the push button is pressed, the current energizes the magnet and attracts the armature causing the hammer to strike the bell. The armature remains in the attracted position so long as the current flows through the magnet. When connection with the battery is broken, the hammer spring pulls the armature back against M. A stop S, averts the motion of the armature, momentum springing the lever and causing the hammer to strike the bell.

Trembling or Vibrating Bells.—This form of bell is perhaps more extensively used than any other. It consists, essentially,

NOTE.—The series of cuts representing various elementary bells are intended to illustrate *principles*, metallic circuits being shown for simplicity. *It should be noted that in construction*, the metal frame of the bell is used as a "ground" or return instead of a separate wire.

of: 1, an electromagnet; 2, pivoted armature; 3, hammer; 4, contact breaker; 5, bell; and 6, frame, as shown in fig. 8,288.

Single Stroke Bells.—This type of bell is one which *gives only a single tap each time the battery is connected in circuit.* Such operation is often desirable, as in signalling with a code.

Combination, Vibrating and Single Stroke Bells.—This type of bell is simply a *combination of the two bells just described*, as the classification indicates.

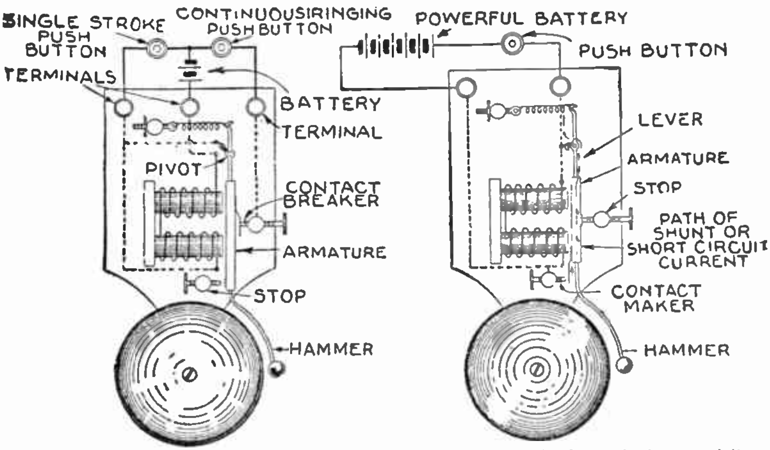


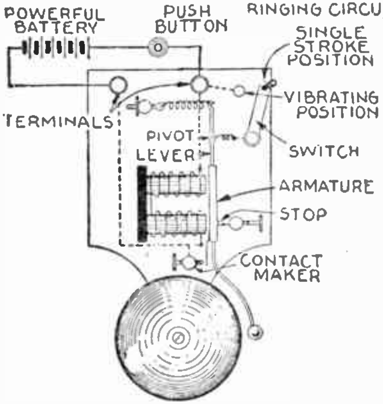
FIG. 8,290.—Elementary combination vibrating and single stroke bell. It is essentially a vibrating bell as shown in fig. 8,288, with a third terminal, and a stop to prevent continued contact of the hammer with the bell when working single stroke.

FIG. 8,291.—Elementary shunt or short circuit, combination vibrating and single stroke bell. This is simply an ordinary shunt bell with a switch arranged so that the short circuit through the contact maker, armature, and lever may be cut out, thus restricting the current to the magnet winding.

Any vibrating bell may be made single stroke by bringing out a third connection so that the current may pass through the magnet without traversing the interrupter.

A vibrating bell may be made single stroke by adjusting the contact breaker spring so that it does not open the circuit.

Shunt, or "Short Circuit" Bells.—In this form of bell the current, during operation, is not broken, but *as the magnet attracts the armature, the current is shunted or short circuited*, and thus being offered a path of very little resistance as compared with that of the magnet winding, most of the current flows through the short circuit.



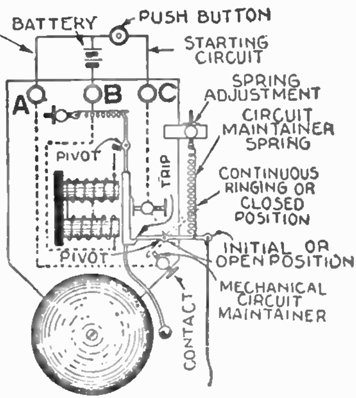


FIG. 8,292.—Elementary shunt bell with single stroke switch. ***Shunt*** cycle when the push button is pressed: 1, Current magnetizes the electro-magnet; 2, magnet attracts armature; 3, contact maker short circuits the current; 4, magnet loses practically all of its magnetism; 5, momentum acquired by moving element causes hammer to strike bell; 6, tension of the hammer spring overcomes weak magnetism of magnets and pulls armature away from magnet; 7, near end of outward swing, contact maker breaks circuit; 8, current again magnetizes the magnet; 9, momentum acquired by the moving element causes it to continue its outward swing (against the attraction of the magnet) to the stop.

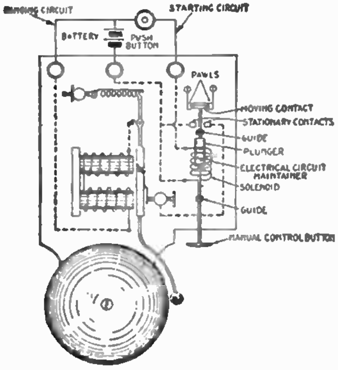
FIG. 8,293.—Elementary continuous ringing bell with ***mechanical circuit maintainer. It is essentially*** an ordinary vibrating bell fitted with a mechanical circuit maintainer and connections as shown. ***In operation,*** when the battery circuit is closed momentarily, the path of the current is via terminals B and C. On the swing of the armature toward the magnet the circuit maintainer trips and its spring causes it to move to the continuous ringing position, thus switching terminal A, wire to contact breaker via trip lever. With this circuit it is evident that the bell will continue ringing irrespective of whether the push button be held down or released, and also that the ringing will continue until the circuit maintainer is reset in its initial or open position by a pull on the manual control cord. ***This type*** bell is useful for burglar alarms.

Since this reduces the magnetism to such a small amount that the attraction of the magnet becomes less than the pull of the hammer spring, the hammer swings back to its initial position.

Continuous Ringing Bells.—This classification represents a form of vibrating bell, provided with *a suitable attachment for maintaining the circuit after it has been once established by pressing the push center*, regardless of the fact that the latter may be only momentarily held in the closed position.

There are three types of continuous ringing bell, classified with respect to the circuit maintaining device, as those with

1. Mechanical circuit maintainer;
2. Electrical circuit maintainer;
3. Combination mechanical and electrical circuit maintainer.



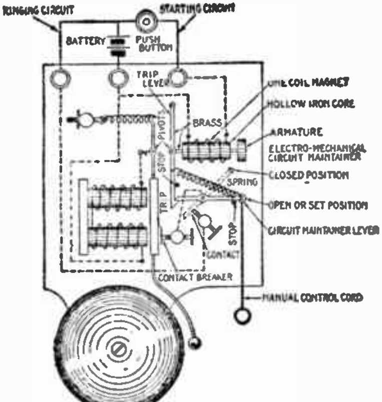
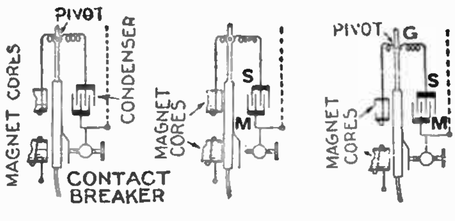
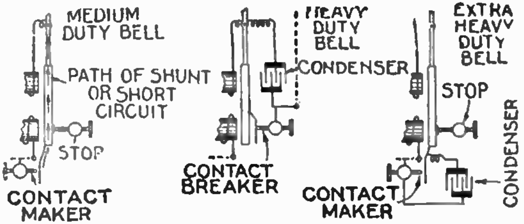


FIG. 8,294.—Elementary continuous ringing bell with electrical circuit maintainer. ***In operation***, when the *starting circuit* is *closed* by depressing the push button, current flows through the solenoid and draws down the plunger, thus *closing the ringing circuit*. The bell will now ring until the ringing circuit is broken by pushing upon the manual control button. To reset the circuit maintainer the manual control button is pushed upward until the moving contact rises above the pawls and the latter spring back to their normal (vertical) position, then the weight of the moving element is held by the pawls.

FIG. 8,295.—Elementary continuous ringing bell with *electro-mechanical circuit maintainer*. ***In operation***, when the starting circuit is closed by depressing the push button, current energizes this one coil electromagnet attracting the armature which disengages the trip. The spring snaps the circuit maintainer lever over to the closed position as shown by the dotted lines, the trip lever being drawn back by the spring against the stop when the push button is released. The bell beginning to ring as soon as the circuit maintainer lever closes the circuit through the contact breaker and bell magnet. ***To reset***, the manual control is pulled down until the circuit maintainer lever strikes the stop, the trip end will then engage with the claw of the trip lever.

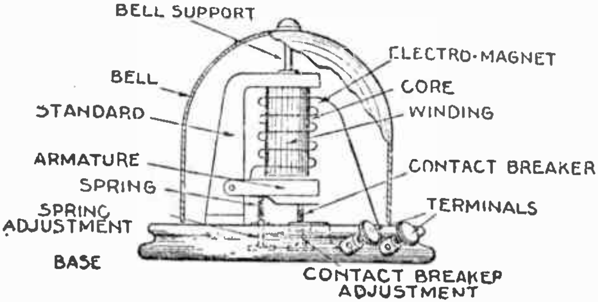
Buzzers.—A buzzer may be defined as *an electric call signal*





FIGS. 8,296 to 8,298.—Detail showing part of the elementary heavy duty high voltage bell (fig. 8,296) and illustrating the action of the condenser in preventing sparking. In fig. 8,296, current has just begun to flow, to energize the magnets. Fig. 8,297 shows the circuit broken by the contact breaker. Since an electric current cannot be *instantly* stopped, it will, when its path is suddenly interrupted, as here shown, jump the air gap resulting in a spark, unless another path be provided to gradually bring it to rest. This is accomplished by the condenser as indicated in the diagrams—electricity "piling up" on one set of plate M, increasing the pressure thereon, and leaving the other set of plate S, reducing the pressure thereon. When contact is again made by the contact breaker, as in fig. 8,298, the excess pressure on plates M, assists the battery pressure in starting the electricity, the current thus started dividing at the junction G, part flowing back into the plates S, until the pressure is equalized, that is to say the outflow at M, and inflow at S, reduces the difference of pressure between M and S, to zero.

FIGS. 8,299 to 8,301.—Suggestions for the prevention of sparking on special bells. Fig. 8,299 contact maker and shunt circuit for medium duty bell; fig. 8,300 contact breaker and condenser for heavy duty bell; fig. 8,301, contact maker and condenser for extra heavy duty bell.



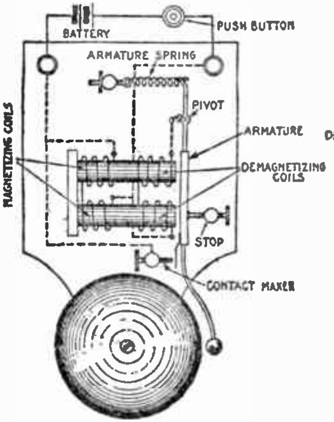
which makes a buzzing noise caused by the rapid vibrations of a contact breaker.

It operates on the same principle as the electric bell and can be adjusted to emit a pleasing musical hum.

FIG. 8,302.—Sectional view of a buzzer.

Differential Bells.—This type of bell represents one of the numerous schemes to eliminate sparking at the contacts of the interrupter.

The electro-magnet is provided with two windings which, for convenience to distinguish their function, may be spoken of as: 1, the magnetizing winding; 2, the demagnetizing winding.



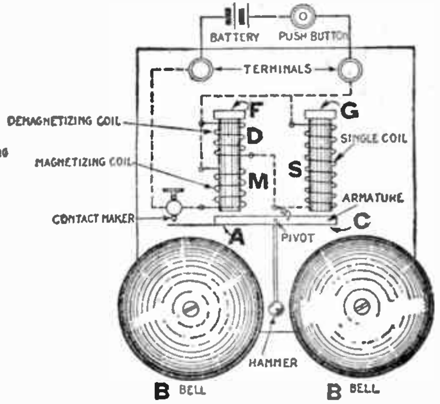


FIG. 8,303.—Elementary differentially wound vibrating bell. *In operation,* when the battery circuit is closed: 1, Current flows through the magnetizing winding and energizes magnet; 2, magnet attracts the armature; 3, contact maker closes circuit through demagnetizing coils; 4, demagnetizing coils demagnetize the magnet; 5, armature spring pulls armature back against the stop, while, 6, the contact maker breaks the circuit through demagnetizing coils.

FIG. 8,304.—Elementary differential and alternate bell. *In operation,* when the battery circuit is closed: 1, current flows through the magnetizing winding M, and energizes magnet F; 2, magnet F, attracts end A, of the armature; 3, contact maker closes circuit through demagnetizing coil D, and single coil S, (of magnet G); 4, demagnetizing coil demagnetizes F, and 5, magnet G, attracts end C, of the armature; 6, contact maker breaks the circuit through demagnetizing coil D, and single coil S. (of magnet G).

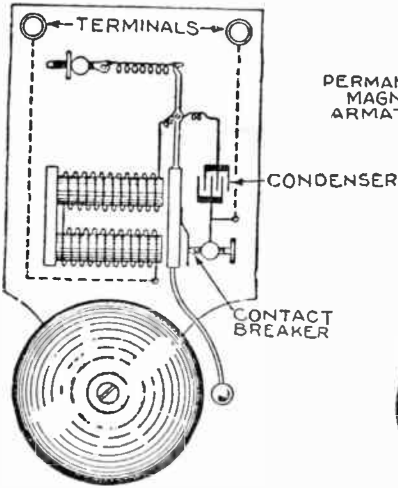
In order to get the desired effect, a *contact maker* is used instead of a *contact breaker;* it operates to control the current in the demagnetizing winding only.

Combined Differential and Alternate Bells.—In this type of bell *there are two separate electro-magnets, and an armature pivoted centrally between them,* so that it is alternately attracted, first by one magnet, then by the other as in fig. 8,304

High Voltage Bells.—In designing a bell for operation on high voltage currents, that is, on circuits of voltages higher than is usual in ordinary battery installations, provision must be made:

1. To limit the current to the proper value;
2. To secure the proper working conditions at the interrupter.

The first requirement is met by proportioning the magnet winding so



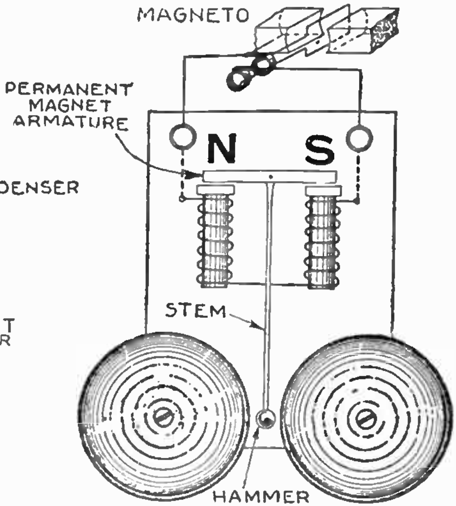
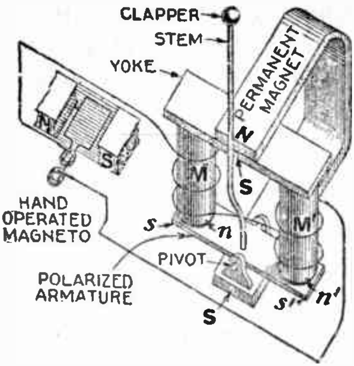


FIG. 8,305.—Elementary heavy duty high voltage bell. The winding is of fine wire to secure enough resistance to keep down the current to proper value. Sparking is avoided by connecting a condenser across the contact breaker as shown.

FIG. 8,306.—Elementary alternating current bell with permanent magnet armature. In construction the electro-magnets are wound similarly, that is, *in the same direction*, so as to produce like poles which simultaneously repel and attract the armature ends.

as to avoid an undue amount of current. Sparking at the interrupter may be prevented by the use of a condenser.

Alternating Current Bells.—A type of bell used extensively



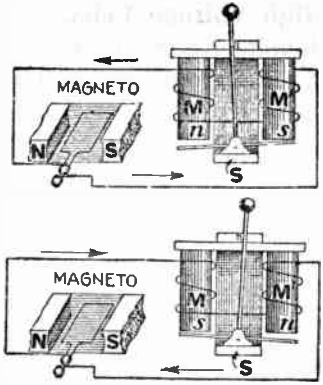
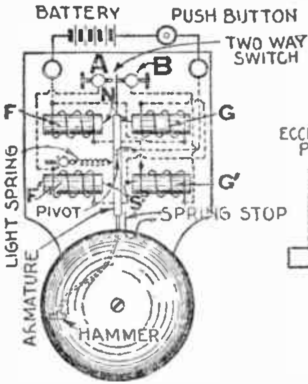


FIG. 8,307.—Elementary *a,c,* bell polarized by magnetic induction. N and S, are permanent magnet poles, and *n* and *s*, poles *induced* by the permanent magnet.

FIGS. 8,308 and 8,309.—Operation of the elementary *a.c.* bell of fig. 8,307. The figures show the induced poles and movement of the armature during one cycle of the low frequency *a.c.* supplied by the hand operated magneto.



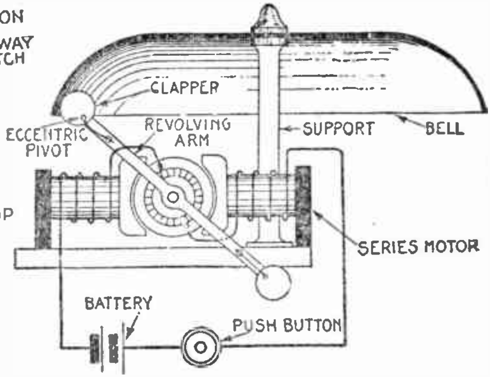


FIG. 8,310.—Elementary double acting bell. ***In operation***, magnets F,G′, and F′,G, are alternately energized. Assuming the current to flow first through F,G′ and then through G F′, F and G′, will have N and S poles, and G and F′,S and N poles; these will induce unlike poles in the ends of the armature attracting it at both ends.

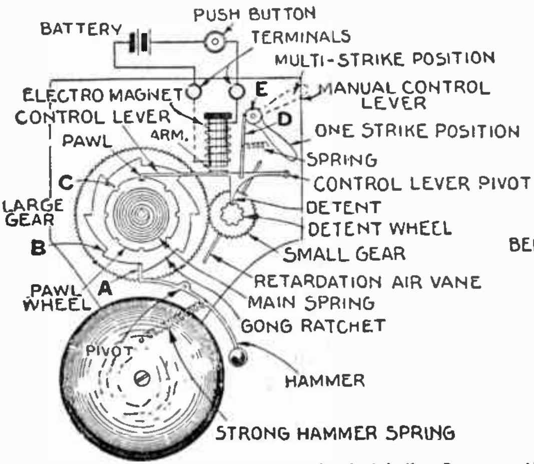
FIG. 8,311.—Elementary motor driven, or revolving strike bell. ***In construction***, the motor has a revolving member attached to the shaft and an eccentrically pivoted clapper at either end, which in operation delivers two blows to the bell at each revolution of the motor. A desirable type of bell for use where a very loud ringing alarm is required.

in telephone work, to operate on the alternating current furnished by the magneto is shown in fig. 8,306, and its operation illustrated in figs. 8,308 and 8,309.

Double Acting Bells.—This type of bell is desirable *for railroad signals or any place where an extra loud alarm is desirable.*

Motor Driven Bells.—This type of bell is desirable *for use where a loud ringing alarm or signal bell is required.*

It consists essentially of a motor having a double striker mounted at



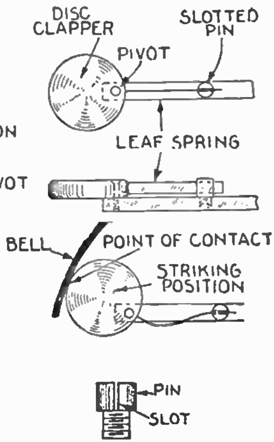


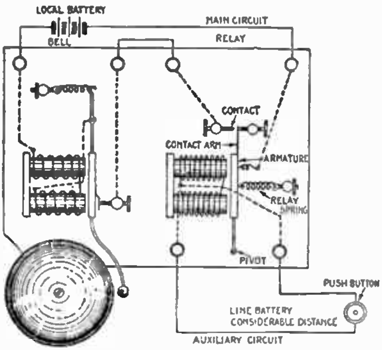
FIG. 8,312.—Elementary electro-mechanical bell. ***In operation,*** the main spring having been wound up, a momentary push on the push button will energize the electro-magnet, attracting the control lever and raising the pawl out of engagement with the pawl wheel and also the detent clear of the detent wheel, allowing the gears to revolve. If the push button be now released, the pawl will ride on the pawl wheel, keeping the detent out of engagement with the detent wheel. As the large gear turns counter-clockwise, the finger A, rides on the ratchet, gradually drawing the hammer away from the bell against the tension of the hammer spring. As the finger rides off the point B, the hammer is suddenly released and strikes the bell a powerful blow. At the same instant the pawl falls into the depression C, on the pawl wheel and the detent engages with one of the numerous depressions in the detent wheel, thus stopping the mechanism. A moderate velocity of rotation of the gears is obtained by means of the retardation air vane.

FIGS. 8,313 to 8,316.—Construction details of clapper for motor driven bell, and view showing action of clapper on striking the bell.

the armature shaft as shown in fig. 8,311, giving two strikes to each revolution.

Electro-Mechanical Bells.—Where a very powerful bell is required to operate at a distance with little battery capacity, the electro-mechanical bell is well suited.

In this type of bell, *the electric current is used simply to control a spring operated mechanism which supplies the energy to ring the bell.*



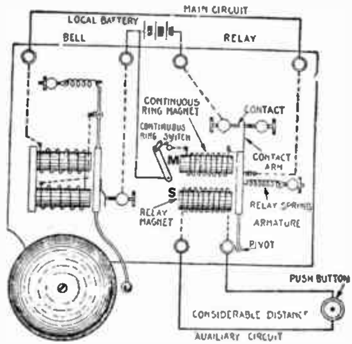
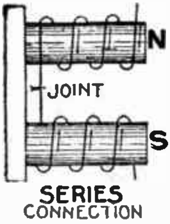


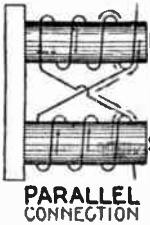
FIG. 8,317.—Elementary relay bell and connections. The relay here shown is in principle identical with the telegraph relay. ***In operation,*** when the push button is depressed current for the line battery in the auxiliary circuit energizes the relay magnets which attract the armature, moving the contact arm against the contact, thus closing the main circuit and ringing the bell. Clearly the operation continues until the push button is released, that is, when current ceases to flow in the auxiliary circuit, the relay magnets loose their magnetism, the relay spring pulls the armature to the right moving the contact arm against the stop, thus breaking the main circuit.

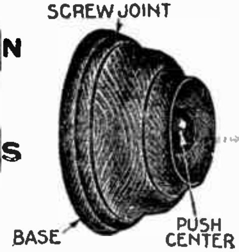
FIG. 8,318.—Elementary relay bell having *continuous ring device.* ***In operation,*** when the push button is depressed, magnet S, is energized and the same action takes place as in fig. 8,317. Now it the continuous ring switch be closed, magnet M, also becomes energized as soon as the main circuit is closed by magnet S. Since M, is now connected with the battery, it will hold the contact arm in the closed position, irrespective of whether the pushed button be depressed or released, causing a continuous ringing of the bell until the continuous ring switch is opened by hand.

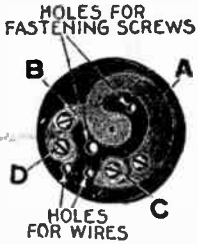
Relay Bells.—Where bells are to be operated *at a considerable distance a relay is usually employed*, especially in the case of large heavy duty bells requiring considerable energy to operate them.

Bell Wiring.—Always start to wire at the push, and run the wires from the push to the bell, and to the battery.





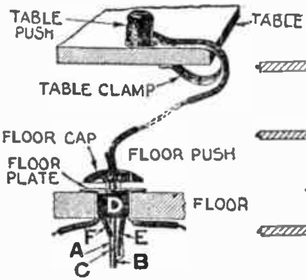




FIGS. 8,319 and 8,320.—Reducing resistance of bell coils. When connected in parallel (fig. 8,320) the resistance is reduced one half, allowing more current to flow through the coils for a given voltage.

FIGS. 8,321 and 8,322.—General construction of an ordinary push button. Fig. 8,321 exterior view; fig. 8,322 interior view.

FIG. 8,323.—Special push button with indicating buzzer inside, useful for any system where the caller desires to know positively that the bell has given the signal.



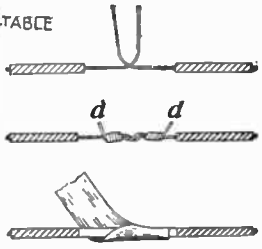
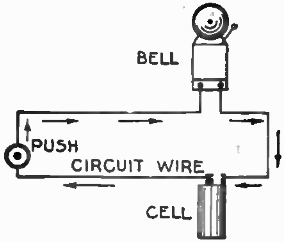


FIG. 8,324.—Paper weight type of multi-push button, suitable for desk use.

FIG. 8,325.—Combination floor and table push button suitable for dining room. The table clamp renders the push portable, permitting it to be moved at any time.

FIGS. 8,326 to 8,328.—Proper method of making a joint in covered wires. First scrape off about 3 ins. of the insulating covering on the end of each wire; scrape the bared copper wire until it is bright and clean; bend these wires into the position shown in fig. 8,326; and then firmly twist them around each other as shown in fig. 8,327. Second, cut off the projecting pieces *d*, *d*, close to the joint, and then solder the latter to prevent corrosion. This corresponds to a Western Union splice. Third, wrap a piece of adhesion or friction tape around the joint over about half an inch of the insulating covering of each wire, as in fig. 8,328.



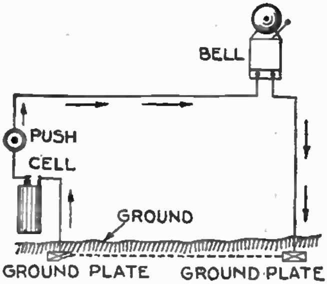
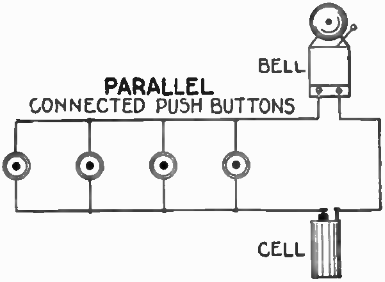


FIG. 8,329.—Simple bell, metallic circuit.

FIG. 8,330.—Simple bell circuit with *ground* return. Instead of using ground plates, a more convenient method consists of connecting the ground wires to a gas or water pipe.



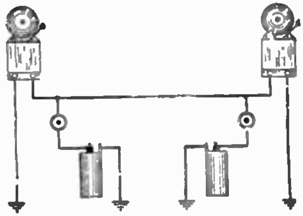
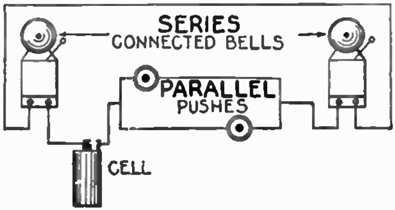


FIG. 8,331.—Parallel connected push buttons for ringing one bell from several points. It is obvious that if the push button were connected in series, all would have to be closed to complete the circuit.

FIG. 8,332.—Series circuit connections for ringing two bells from either one or two push buttons. In this diagram the bells are in series, and one of them must be arranged for single stroke.



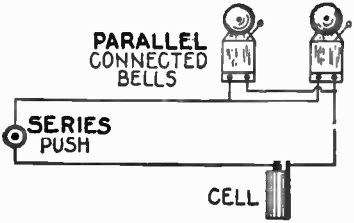
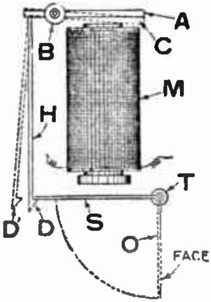


FIG. 8,333.—Series connected bells for ringing two bells from either one or two pushes.

FIG. 8,334.—Parallel connected bells for ringing two bells from either one or two pushes



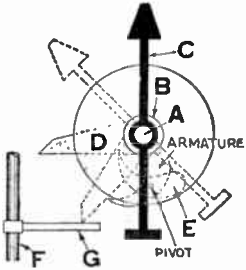
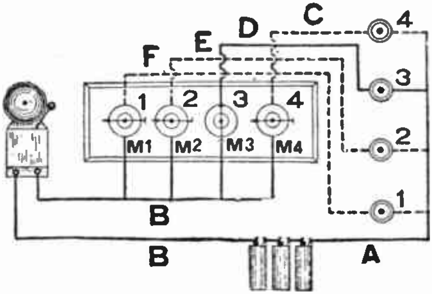


FIG. 8,335.—Gravity drop annunciator. *In operation,* the shutters are reset by turning the knob seen on the side of the case.

FIG. 8,336.—Shutter or gravity annunciator drop. *In operation,* when the circuit is completed by the depression of a push center, the current flows through the coils of the electromagnet M, and energizes its core, and the latter attracts the armature A, pivoted at B. When the armature is drawn to the position C, the claw D, is thrown to the position D', thereby releasing the shutter S, pivoted at T, allowing it to drop by gravity to the position O, thus displaying the number marked upon its face.

FIG. 8,337.—Arrow or needle annunciator drop. *In operation,* when the current flows through the coils of the electromagnet, the armature E, turns on its pivot towards the magnet core A, thereby releasing the arm D, which in falling rotates the arrow to the position shown in dotted lines. The arrow is reset by pressing a button, which raises the rod F carrying the arm G.



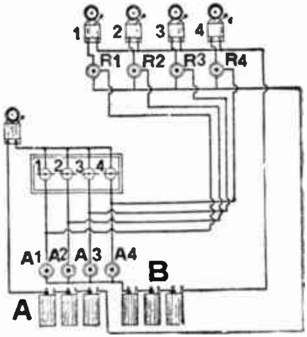


FIG. 8,338.—Method of wiring an annunciator.

FIG. 8,339.—Western Electric return or fire call annunciator system. *In operation,* when one of the annunciator pushes A1, A2, etc., is pressed, battery B, becomes connected in series with the bell 1 or 2, etc., as the case may be. When one of the room pushes R1 R2, etc., is pressed, its corresponding bell is cut out and the circuit becomes similar to an ordinary annunciator circuit.

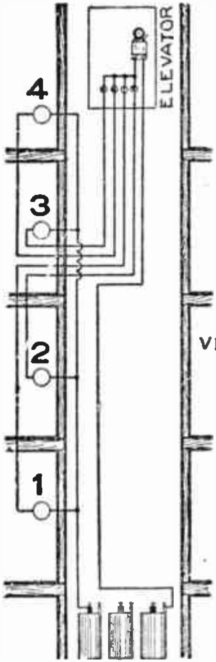


FIG. 8,340.—Annunciator circuit for single elevator.

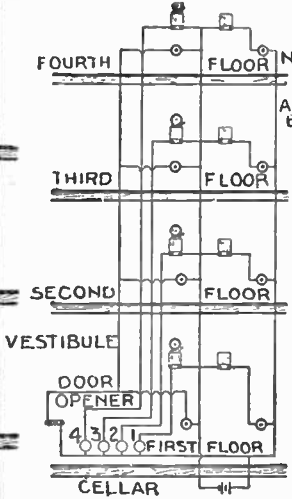


FIG. 8,341.—Bell and buzzer circuits for an apartment house.

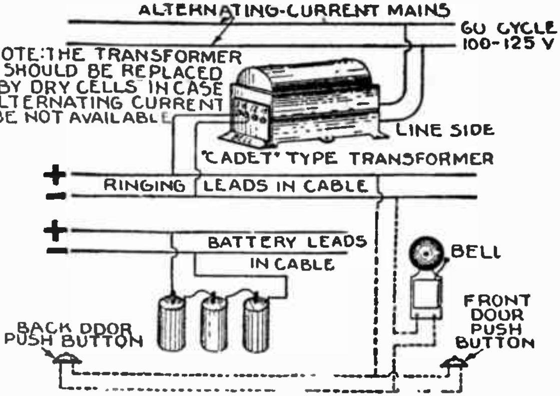
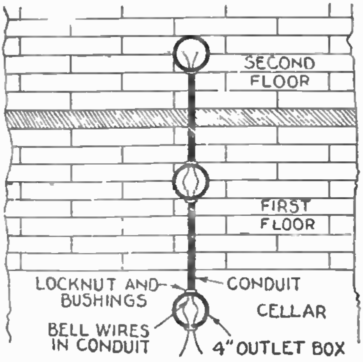


FIG. 8,342.—Method of connecting a bell ringing transformer for ringing inter-phone bells and door bells. Dotted lines show wiring for door bell using same source of ringing current.

fasten each wire lightly to the woodwork with staples or double pointed tacks.

The wire from the push to the battery may be run through holes bored in the floor directly under the push, but inside the front door, then along the cellar beams to the battery. In many houses the wire from the push to the bell may also be run along the cellar beams. In such cases, a second hole should be bored in the floor by the side of the one accommodating the wire from the push to the battery, for the wire from the push to the bell



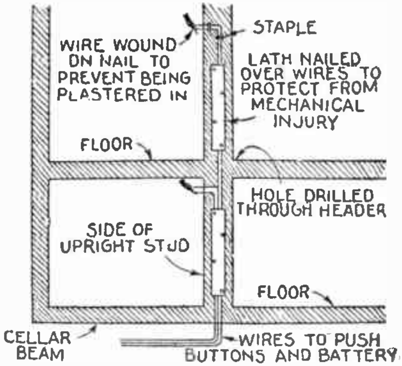


FIG. 8,343.—Method of installing bell wires in brick house.

FIG. 8,344.—Method of installing bell wires in unfinished house of wood construction.

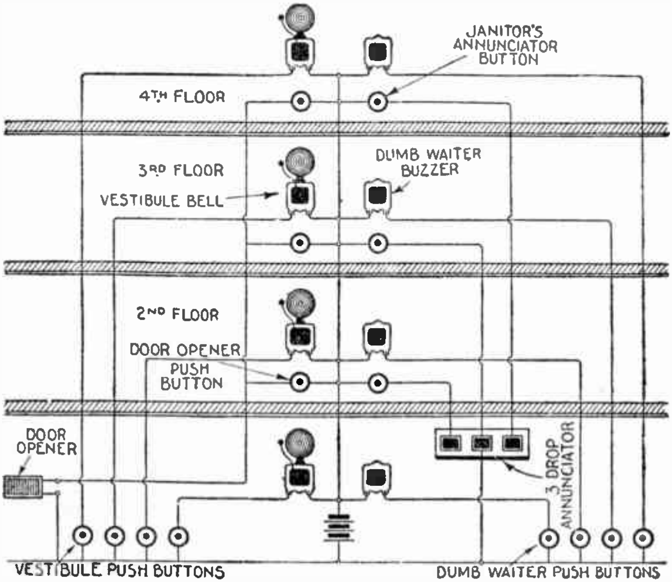


FIG. 8,345.—Wiring diagram for bells, door opener, janitor's annunciator and dumb waiter buzzer of a four story apartment house.

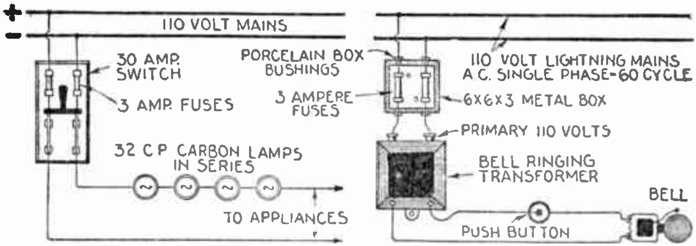


FIG. 8,346 —Connections for reducing lighting main voltage. If voltage be too strong, add more lamps.

FIG. 8,347.—Method of connecting bell ringing transformer.

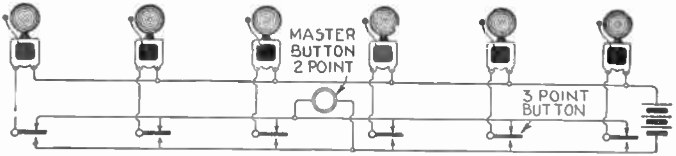


FIG. 8,348.—Selective and master button system; master button rings all bells simultaneously.

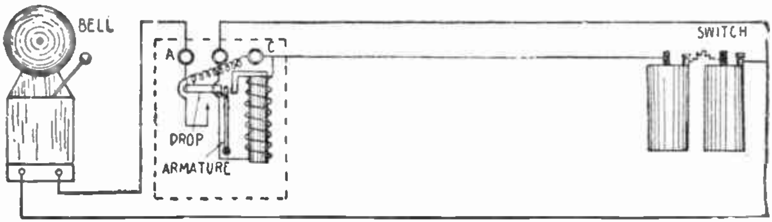
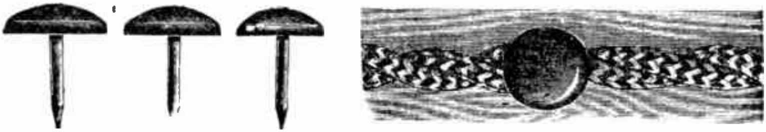


FIG. 8,349.—Automatic burglar circuit with gravity drop circuit maintainer to give continuous ringing. *In operation*, when the switch is closed, the circuit maintainer magnet winding is connected in series with the battery and the armature is drawn up against the core of the magnet so that the drop is released and allowed to fall against the contact point connected with the A, binding post. The drop, which is connected with C, binding post, thereby closes the bell circuit and allows the bell to ring until the drop is again raised to its normal position.

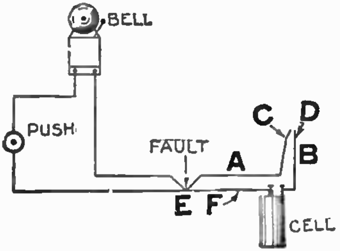


FIGS. 8,350 to 8,353.—Milonite nails and method of tacking two insulated wires. The heads are colored to match insulation and the wires can be tacked down without cutting or injuring the insulation.

Bell Troubles.—These are due to a variety of cause, which may be easily rectified.

When the armature sticks to the magnet cores and fails to make contact with the screw, the trouble is generally due to weak spring, or to the loss of brass pieces, which are inserted in the ends of the cores to prevent actual contact with the armature. A piece of paper stuck over the ends of the cores will often serve as a satisfactory remedy.

When the bell makes a screeching sound, the trouble may be due to a too rapid vibration of the armature; too much battery power; or to the fact that the contact screw is too far forward. If the excessively rapid vibration is caused by too little play, or too much battery power, the fact will be indicated by violent sparking.



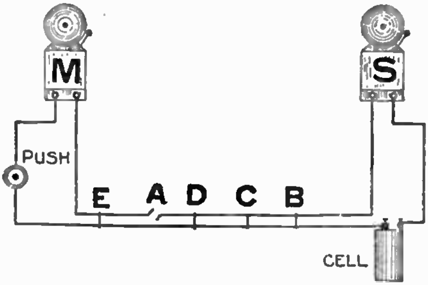
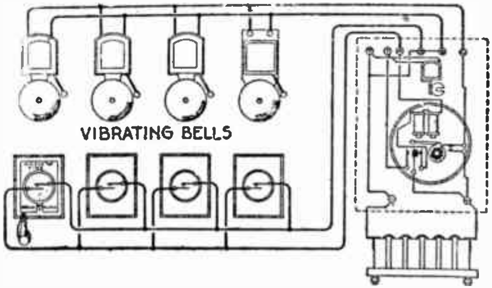


FIG. 8,354.—Test for crossed wire in bell circuit. E, represents short circuit. *In testing,* disconnect the wire from one terminal of the battery, connect a short piece of wire B, to that terminal, and place the two ends C and D, on the tongue. If the circuit wires be touching each other at some bare spot E, the current will flow from the battery along F, to the point of contact E, thence along A, to the tongue, and along B, to the battery. The flow of current will be indicated by a metallic taste upon the tongue, or by connecting a telephone receiver between C and D, the diaphragm will be made to vibrate. Without this indication, or the absence of the metallic taste on the tongue, it is probable that the trouble is due to a break.

FIG. 8,355.—Test for break in bell circuit. A, represents the break. *In testing,* take a bell to the battery and connect it between the circuit wires and the battery at the points B,C,D, and E, working towards the push. At each of the points cut away a little of the insulating covering of the wires, and short circuit the latter, beyond the bell and the battery with a knife blade. If the bell ring at the points B,C, and D, but fail to ring at the point E, the break will be located at A, somewhere between D and E.

Dirty contacts and loose contact screws increase the resistance of the circuit, tend to decrease the current allowed to pass through the magnet coils, and often prevent the bell ringing at all. It should be noted that the contacts are of platinum, as German silver and other similar metals are soon corroded away by the sparking. The contact screws should not be readjusted unless it be found necessary to do so because of loosened screws.



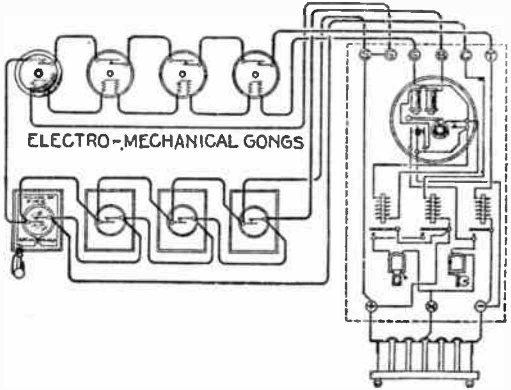


FIG. 8,356.—*Open* circuit fire alarm system. *In operation,* when the glass is broken at any of the boxes, it causes a small electro-magnet in the code relay to trip a clock mechanism which is equipped with a wheel upon which are mounted a number of contacts arranged so that that circuit is open and closed a number of times successively until the spring of the clock mechanism is unwound. Which takes at least three minutes which is ample time to give sufficient alarm.

FIG. 8,357.—*Closed* circuit fire alarm system. *In operation,* this system is the same as the open circuit code system, except that a closed circuit relay is installed in the master box.

Bell Circuits Troubles.—Faults, other than those caused by weak push and bell springs, dirty and loose contacts, and run down battery are generally due to crossed wires, or broken wires.

Fig. 8,354 shows the method of making a simple test for a cross, and fig. 8,355, for determining location of a break. Short circuits are often caused by double pointed tacks or small staples cutting through the insulation and injuring the wire. This is often the result of carelessness and too much haste in tacking up the wires. ***No more than one wire should be placed under one staple.***

CHAPTER 49

The Telegraph

The simplest form of telegraph system consists of: 1, live wire; 2, battery or other source of electricity; 3, a transmitting instrument or *key* 1 and 4, receiver or *sounder*.

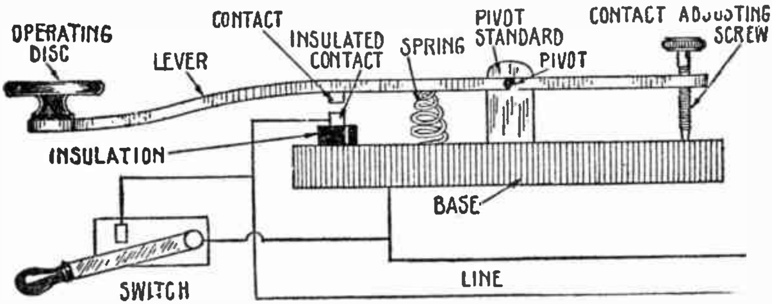


FIG. 8,358.—Elementary transmitter or *key*. ***It consists of*** a pivoted lever provided with a contact and adjusting screw, and carried on a base having an insulated contact and a spring to keep the lever normally in the open position. A switch is provided to close the circuit when the key is not in use. ***In operation,*** the disc is grasped by the 1st, 2nd, and 3rd fingers; depressing the disc causes the two contacts to touch the circuit. Closing the circuit for a short period corresponds to a "dot" and, for a longer period, to a dash. The periods in which the circuit is closed are indicated audibly by the "sounder."

Classification.—The telegraph, like other inventions, has been considerably developed, resulting in numerous systems. A classification of these various systems, to be comprehensive must be made from several points of view, as with respect to:

1. The kind of circuit, as
   - *a*. Ground return;
   - *b*. Metallic.

2. The method of operating the circuit, as
   - *a*. Closed;
   - *b*. Open.

3. The transmitting capacity
   - a. Single Morse line;
   - b. Diplex;
   - c. Duplex;
   - d. Quadruplex;
   - e. Multiplex;
   - f. Phantoplex.

4. Method of receiving as
   - a. Non-recording;
   - b. Recording { by perforations; by printing.

Morse Single Line System.—This ordinarily includes a *battery for supplying a low tension current and a line wire connecting two or more stations serving to establish a circuit between them;* a return connection to the battery, formed either by another wire or by the earth to a transmitting key, and a sounder or recording apparatus at each station.

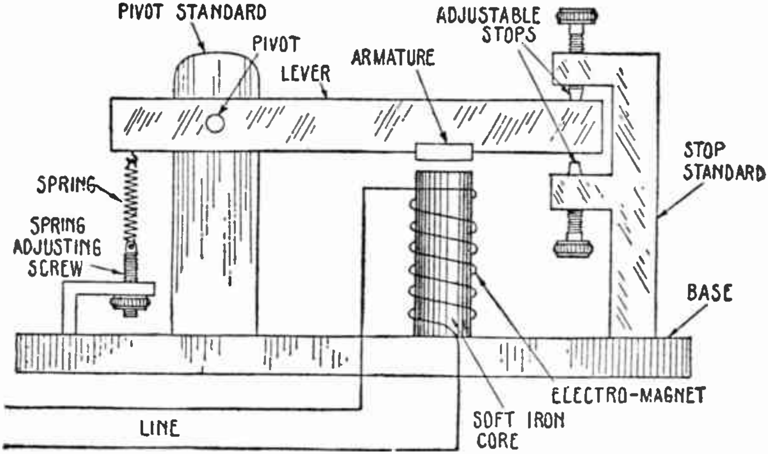


FIG. 8,359.—Elementary sounder. *It consists of* a heavy pivoted lever arranged to vibrate between two stops and held normally against one of these stops by the action of a spring, there being an electromagnet which when energized acts on an armature attached to the lever causing the latter to move from the upper stop to the lower stop, the blow thus produced, owing to the heavy construction of the lever, being distinctly audible.

Ques. On what does the operation of the telegraph depend?

Ans. An electromagnet can be magnetized and demagnetized with great rapidity on respectively making and breaking the magnet circuit, the magnetic action thus obtained being used to operate a sound producing mechanism so that the various combinations of "dots" and "dashes" representing the letters of the alphabet are indicated audibly.

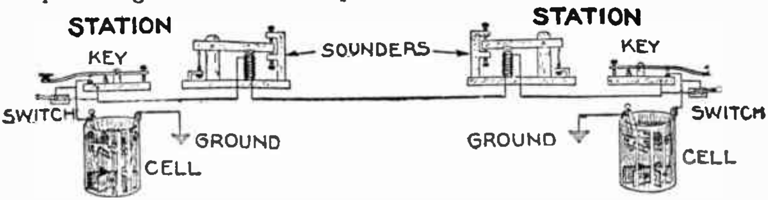


FIG. 8,360.—Elementary short line *closed circuit* system. When not in operation the switches are closed and current flows which energizes the magnets and holds the instrument armatures in the down position. This necessitates the use of a closed circuit cell as for example the crow foot gravity type which is capable of supplying a very weak current for a long duration of time.

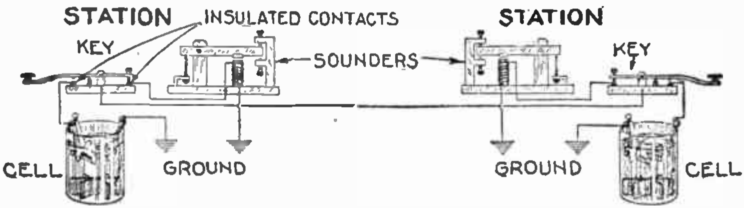


FIG. 8,361.—Elementary short line *open circuit* (European) system. *As arranged,* the battery is in operation only when a message is being sent. A main battery is necessary at each station, whereas in the *closed system*, employed in America, main batteries are required only at the terminal stations.

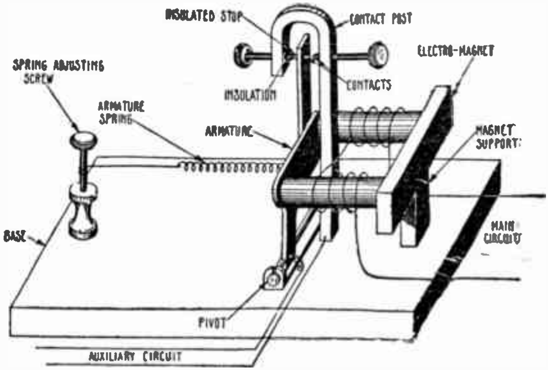


FIG. 8,362.—Elementary relay. Note the delicate armature construction as compared with sounder, thus requiring very little energy to operate. A relay is virtually a very delicate sounder with a contact maker at the end of the armature lever.

Relays.—In general, a relay is *a device which opens or closes an* **auxiliary circuit** *under predetermined electrical conditions in the* **main circuit.**

Its function is to act as a sort of ***electrical multiplier,*** that is to say, ***it enables a comparatively weak current to bring into operation a much stronger current,*** thus reducing considerably the battery capacity required.

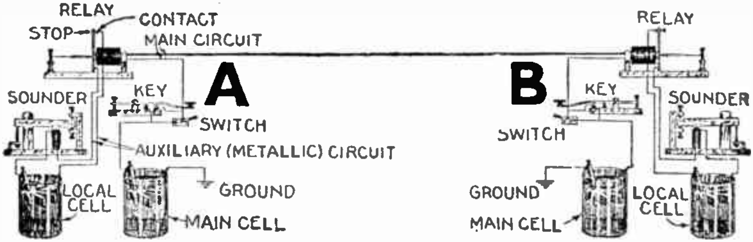


FIG. 8,363.—Elementary short line with relays. Normally both switches are closed; this energizes the relay magnets and keeps the auxiliary circuits closed by holding the relay contacts together. *In operation,* the sender opens his switch and with the key sends the message by successively making and breaking the main circuit in proper sequence. This causes the relay armature to move back and forth against the contact and stop, thus making and breaking the auxiliary circuit in synchronism with the movements of the key. In this way, the very weak main current is enabled to bring into action the much stronger current of the auxiliary or local circuit, thus, the movements of the delicate relay armature are reproduced by the heavy armature of the sounder.

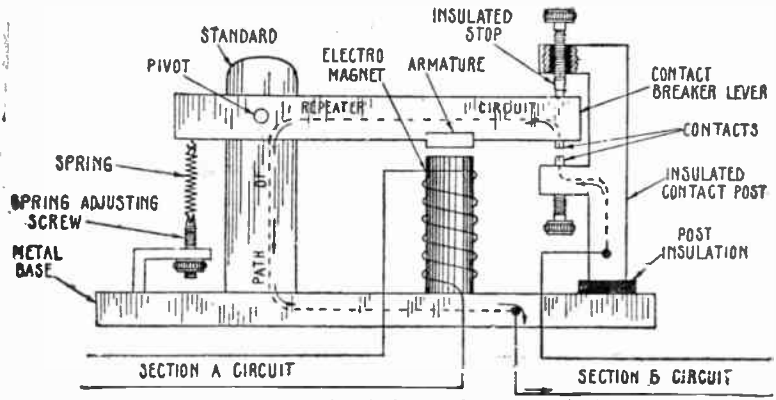


FIG. 8,364.—Elementary repeater showing the insulated parts essential for the contact maker, and path of the current through the repeater portion of the instrument. The insulated stop on the upper arm of the contact post is shown in sectional view to clearly indicate the insulation at this point. Compare this instrument with the elementary sounder fig. 8,359 and note the essential points of difference.

Repeaters. — When the length of a telegraphic circuit exceeds a certain limit, the working margin becomes so small that satisfactory signals cannot be transmitted even by the aid of increased battery capacity.

This limit under existing conditions is much less in wet weather than in dry weather. Under such conditions it was formerly necessary to retransmit all communications at some intermediate station, but this duty is now performed by an instrument called a *repeater*.

By definition a repeater is a *sounder provided with a circuit maker, for synchronously controlling a second circuit.*

It repeats a message from one section to a second section of a line by aid of a separate battery.

Diplex Telegraphy. — By definition this is *a system which permits* ***two messages*** *to be transmitted in the same* ***direction*** *at the* ***same time*** *over a single wire.*

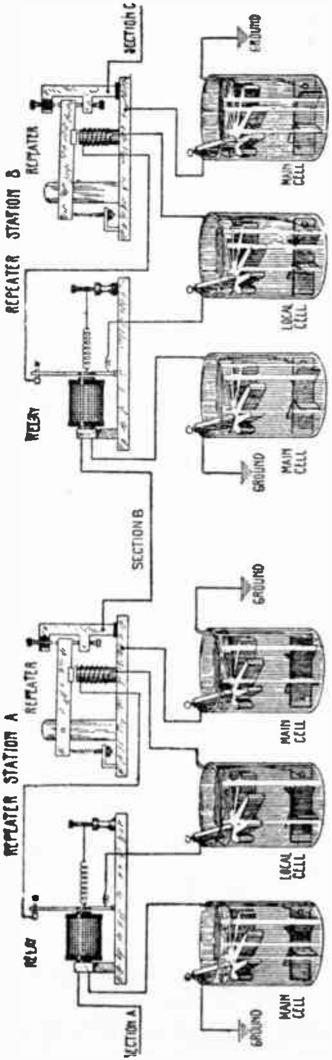


FIG. 8,365.—Elementary repeaters as connected in a circuit. *In operation*, if the home station or beginning of section A, line send a message, the movements of the relay at station A, will cause similar movements of the repeater, this in turn is repeated at station B, and all other stations on the line.

In principle the receiving instrument at the home station, while free *to respond to the signals of the key at the distant station, shall not respond to the signals of its associate key.*

Duplex Telegraph.—This system is one which permits the

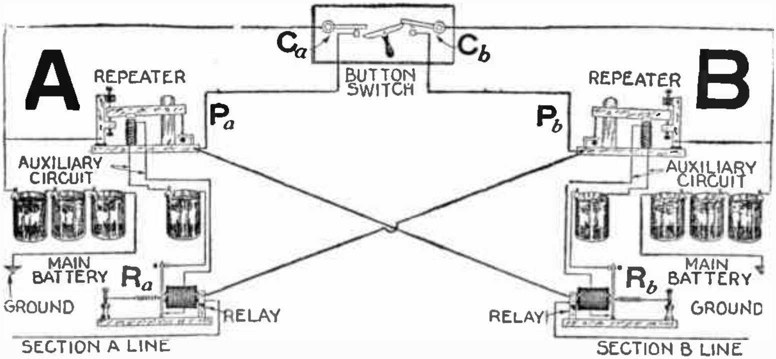


FIG. 8,366.—Elementary so-called "button" repeater (properly called repeater system with button switch). ***In operation,*** if say section B line be opened by the key of the operator, the armature of section B relay will open, which in turn opens section B repeater, whose circuit breaker breaks the circuit of section A. This causes the armature of section A relay to open, followed by that of section A repeater, the circuit breaker of the latter also breaking the circuit of section A. The operator of section B line cannot now close the circuit, because it is still open in another place, viz., at the circuit breaker of section A repeater. The button switch eliminates this difficulty, for when it is swung to the left, it closes a spring contact C_a, forming a connection between the circuit breaker of section A repeater, enabling the operator of section B to open and close its circuit, at pleasure, while his signals are repeated into section A by the action of the circuit breaker of section A repeater.

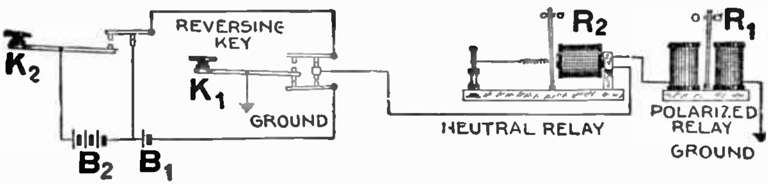
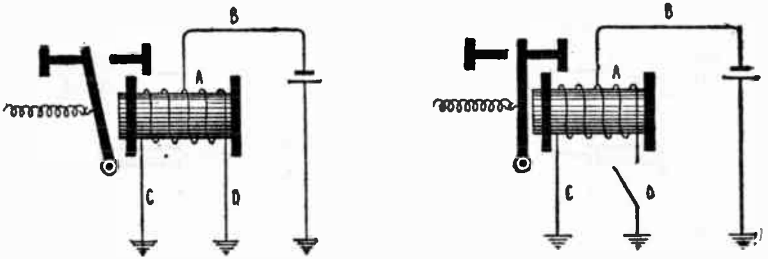


FIG. 8,367.—Elementary duplex system. ***In operation,*** if the sender depress key K_2, this brings both sections of the battery in circuit on the line, causing the armature of the neutral relay R, to be attracted. If now another signal be sent by the depression of key K_1, the full strength of the current traversing the neutral relay R_2, will be reversed. If the armature spring of the neutral relay R_2, be adjusted so that it cannot respond to the weak current of battery B_1, it is evident that signals may be sent by reversing the smaller battery B_1, by means of K_1, which will operate R_1, but not R_2.

sending of two messages simultaneously in opposite directions over a single wire.

There are several systems of duplex telegraphy, namely:

1. Differential; 2. Polar {with battery; with dynamo; 3. Bridge.



FIGS. 8,368 and 8,369.—Detail of the differentially wound third spool of relay of the Weiny-Phillips system. In fig. 8,368, one terminal of the battery is shown grounded while the other terminal is shown connected differentially with two equal windings of the magnet. The current divides at A, half going through each coil. It may be observed that the direction of the winding of one coil is opposite to that of the other. Thus, when current flows through the wire B, the magnetization of the core due to the action of current in the coil A-C is neutralized by the presence of current in the coil A-D, and as a result the core is not magnetized at all; so that the retractile spring attached to the armature holds the latter in the "open" position as shown in fig. 8,368. If, however, while the coil A-C remains closed, the coil A-D be opened, as in fig. 8,369, the core will be magnetized due to the presence of current in the coil A-C while no current exists in coil A-D, the latter no longer neutralizing the magnetic effect of the former. The armature, therefore, is attracted and held in the "closed" position as shown in fig. 8,369.

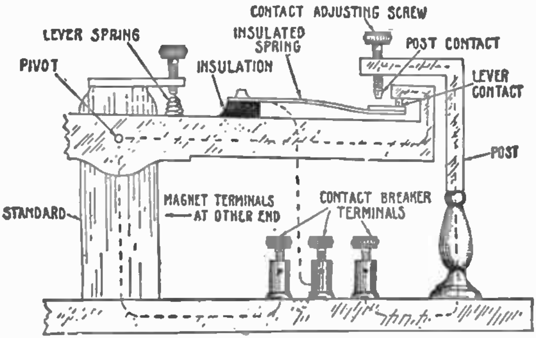


FIG. 8,370.—Detail of contact breaker end of a transmitter showing the three contacts, method of mounting the spring contact, and the circuits from the contacts to terminals. The duration of contact, or portions of the stroke of lever during which the circuit through the post contact and spring contact remains closed is regulated by the contact adjusting screw.

Differential Duplex System.—This method *employs a relay wound with two sets of coil, in each of which the current flows in a different direction.*

Consequently when two currents of equal intensity are passed through the relay at the same time, they neutralize each other, and the relay does not become magnetized.

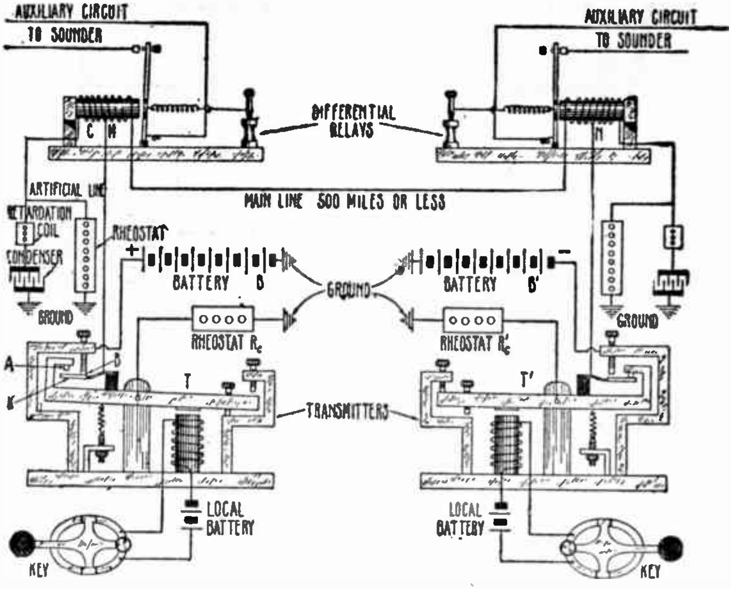
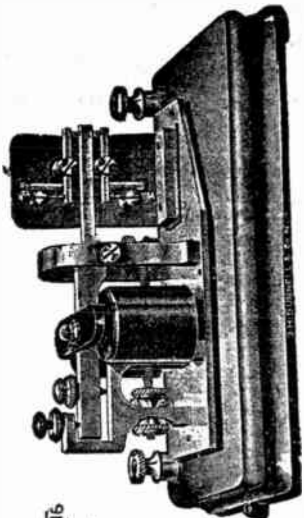


FIG. 8,371.—Stearn's differential duplex system. The circuit can be traced from the tongue contact K, to the point of division M, known as the "split." At this point one branch goes through the right portion of the relay winding to the main line, and the other through the left portion of the relay, the artificial line and to ground. When K, is in contact with B, the circuit is through battery B, to ground, and when in contact with A, it is through the transmitter lever, and rheostat R_c to ground. The purpose of the rheostat R_c is to divide the current passing through the relay coils equally between the main and artificial lines. When this condition is established, the current will pass through the relay with no appreciable effect upon it and the duplex is said to be "*balanced*."

Each station is provided with a differential relay, and there are two complete circuits, one including the line wire, and the other consisting of resistance coils having a resistance equivalent to that of the line and known as the *artificial line.*



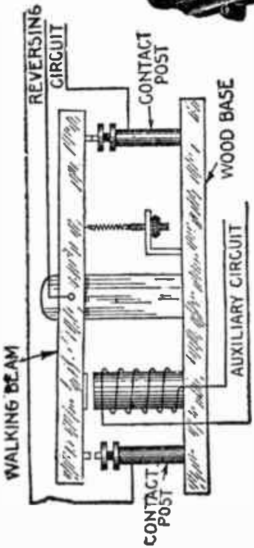


FIG. 8,372.—Elementary "walking beam" pole changer. *As can be seen*, it is impossible for all three wires of the reversing circuit to be connected at any instant, that is before each reversal, the circuit is broken, thus interposing an air gap; this is an undesirable condition where dynamos are used for current supply, because, their very small internal resistance would otherwise permit considerable sparking.

FIG. 8,373.—Bunnell pole changing transmitter or circuit continuity preserving reverser, suitable for battery current.

The key and battery at each station are common to both circuits, the points of divergence being at the relay and at the ground plate.

When the key at one station which may be called the *home station* is depressed, the current flows through both sets of coil of the relay at that station without producing any magnetizing effect. Consequently, the relay and sounder at the home station remain unresponsive, but at the distant station, the current will flow through only one set of coil at that station and will cause it to operate the local sounder. The same effect, of course, is produced when the key of the distant station is depressed.

Polar Duplex System.—Each station is *provided with two batteries or dynamos, which are arranged in such a manner that the direction of the current in the line depends on whether the key is in its raised or depressed position.*

As in the case of the differential method, the current divides at the relay, which instead of being of the differential type is known as a *polarized relay.*

The Bridge Duplex System.—This method is based on the principle of the

Christie or so-called Wheatstone bridge*. It is used in the operation of submarine telegraph cables.

In this method, the relay is placed in the cross wire of a Christie bridge and the key is so arranged that connection is made with

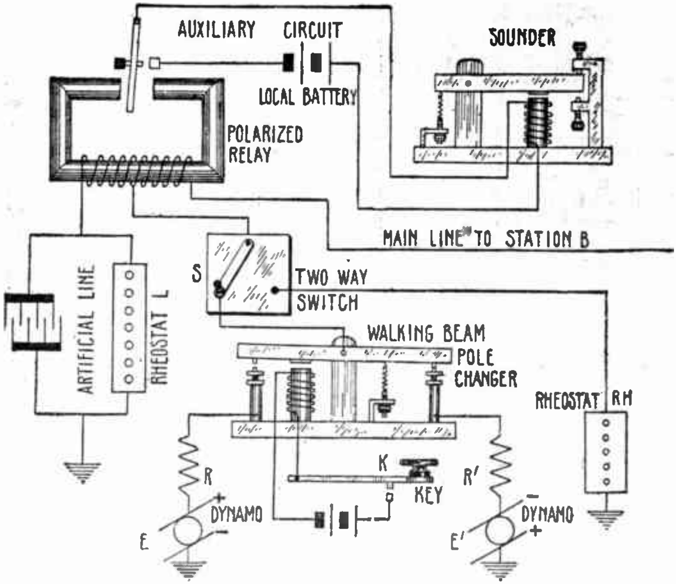
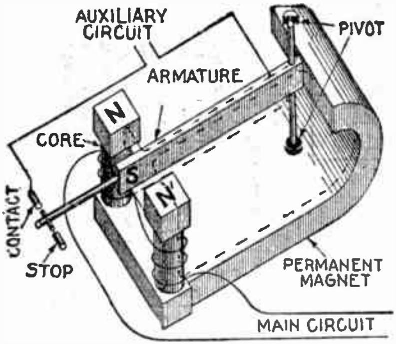


FIG. 8,374.—Dynamo polar duplex system. E and E', are the dynamos, E, for the positive and E', for the negative current. These supply their currents through resistance coils R R', either of German silver wire or of incandescent lamps. K, is the key which closes the local circuit of the walking beam pole changer. The position of the lever of the pole changer determines which current is being sent to line through the pivot of the lever. The two way switch S, is for changing from duplex to ground connection through a rheostat RH, for the purpose of enabling the distant station to obtain a balance. From the switch the current goes to the junction of the two coils of the relay where it divides, one-half going to the main line, if the line circuit be closed at the distant station, and the other half through the artificial line to ground. The resistance in the artifical line is made equal to the resistance of the line and relay coils at the distant station. This is adjusted, not by measurement, but by trial. The operator at the distant station turns his switch to the ground position and signals are then sent by the operator at the home station.

*NOTE.—The author desires to emphatically protest against appplying the name Wheatstone to this bridge. This ingenious and useful system of electrical measurement was first described by ***Samuel Hunter Christie***, in *Phil. Trans. R. S.*, 1833, 95-142. Wheatstone simply directed attention to it and although *full credit was accorded to **Christie** by Wheatstone for his admirable device*, electricians have ever since persisted in calling it the *Wheatstone Bridge*, and it seems probable that it will always continue to be known by that name, despite the injustice of such error.



the battery before the line leading to the earth is broken. Adjustable resistance coils are placed in the arms of the bridge and a wire connects the key with one arm of the bridge, which is completed at the opposite end by a suitable arrangement. If the resistances be equal, the relays will not operate when the

FIG. 8,375.—Elementary polarized relay. *In operation,* when no current flows through the electromagnet, the armature (having no spring), when placed midway between the poles of the electromagnet will be attracted equally by each and accordingly will approach neither. When, however, the electromagnet is energized, the magnetism thus reduced in its cores either increases or overcomes that due to the permanent magnet, producing unlike poles according to the direction of the current. Thus the armature is attracted by one and repelled by the other. The magnetism of the electromagnet of the polarized relay changes in response to the reversals of the distant battery and the armature vibrates to and fro between its front and back stops in accordance with those changes.

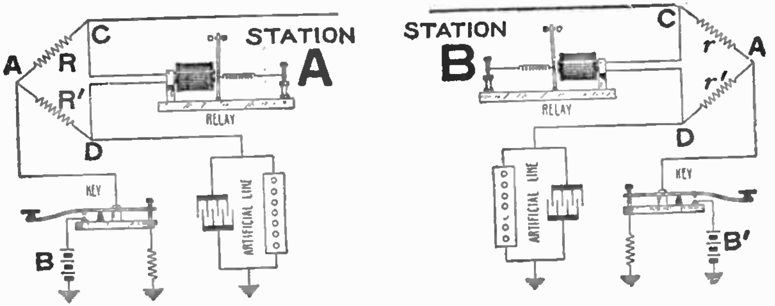


FIG. 8,376.—Diagram illustrating the operation of the bridge duplex system. In the figure, B and B', are the main line batteries, one at each station. R, R', and *r*, *r'* are the bridge resistances at each station. The various connections are clearly shown in the diagram. *In operation,* closing station A key sends out a current which divides at A, half passing over the main line to station B, and reaches earth via the apparatus at that end of the line, while the other half passes through the artificial line at station A, reaching the earth at that end of the circuit. Since the resistance between C and D, is the same as R or R', the pressures at C and D, are equal, and no current will flow through station A relay. This holds only when the resistance of station A artificial line is made equal to the resistance of the actual line to ground at the distant end. The relay at **A** is accordingly not affected when **A** sends to **B**. The same condition obtains when **B** alone sends to **A**. Signals from **A** operate the relay at **B** because the incoming signals have a joint path made up of the branches CD and CA, thus setting up a difference of pressure between the points C and D sufficient to operate the relay.

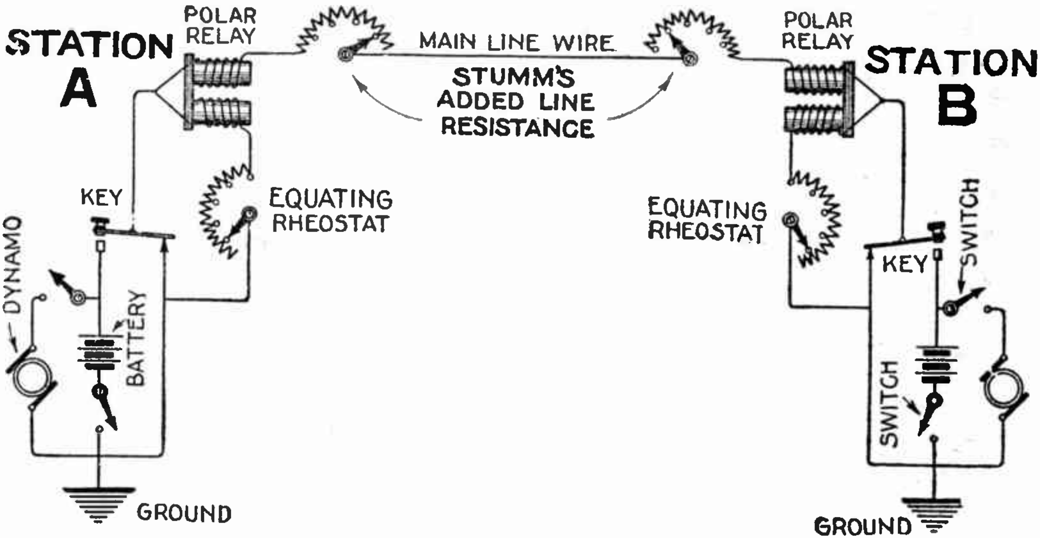


FIG. 8,377.—Stumm's added adjustable line resistance. It is a feature in duplex and all other multiplex office equipment. Formerly all balancing against wet weather line leakage was done on the artificial line rheostat and was always very unsatisfactory and often entirely ineffectual so that quite frequently such circuits had to be abandoned until the weather resumed normality—that is, became dry. The Stumm method leaves the artificial rheostat stand unchanged at normal ohmage, *i.e.*, equal to the actual line resistance in dry weather and when the wet storm begins to cause leakage, line resistance is looped in between the relay and line sufficient to balance the artificial ohmage, and by being added to sufficiently as required maintains a steady working balance reversing the procedure as the storm recedes. This method not only secures a good and continuous working balance but also prevents heating of instrument and other office wires and cables because the resistances in the main and artificial lines remain the same in stormy wet weather as during fair and dry. In other words the actual and artificial lines have flowing in them the proper battery strength for the resistances traversed. The value of the Stumm line resistance is very great as it prevents damaging delay to tens if not hundreds of thousands of telegrams during every general rain storm which inevitably occurred under the old method of wet weather balancing. The relays used may be differential, if preferred.

current is transmitted, but since the earth is employed to complete the circuit, they will respond to the received current, thus enabling each operator to send and receive signals at the same time.

Quadruplex System.—This method of telegraphy ***permits the simultaneous sending of two messages in either direction over a single wire.***

Theoretically it consists of an arrangement of two duplex systems, which differ from each other so greatly in their principles of operation that they are capable of being used in combination.

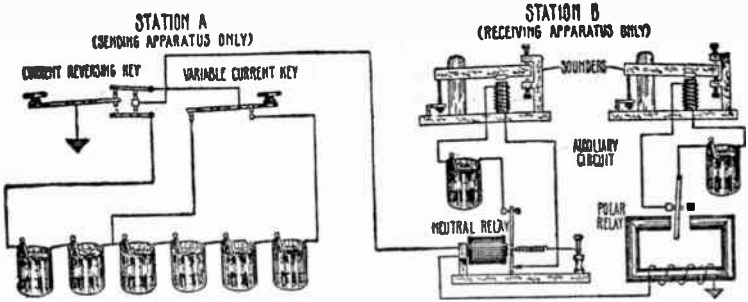


FIG. 8,378.—Elements of the quadruplex system. For simplicity, the receiving apparatus is omitted at station A and the sending apparatus at station B, the complete installation being shown in fig. 3,089. Because of the fact that a polar relay responds solely to changes in direction of the current, and a neutral relay to changes in strength of the current, it must be evident that, if the two relays be connected in series as shown, signals may be produced by the polar relay by operating the current reversing key, and with a sufficiently weak current the neutral relay will not respond; also, if the *direction* of the current be maintained constant by using the variable current key signals will be produced on the neutral relay but not on the polar. Hence, with this arrangement, two messages may be sent from station A to station B simultaneously, and by extension, if the reader imagine each station fitted with both sending and receiving apparatus, four messages may be sent at one time, thus giving quadruplex operation.

The sending apparatus consists of a reversing key and a variable current key (or equivalent), and the receiving apparatus consists of a neutral relay and a polar relay, batteries and connections.

Telegraph Codes.—There are three *codes* or systems of signals used for general telegraphic purposes.

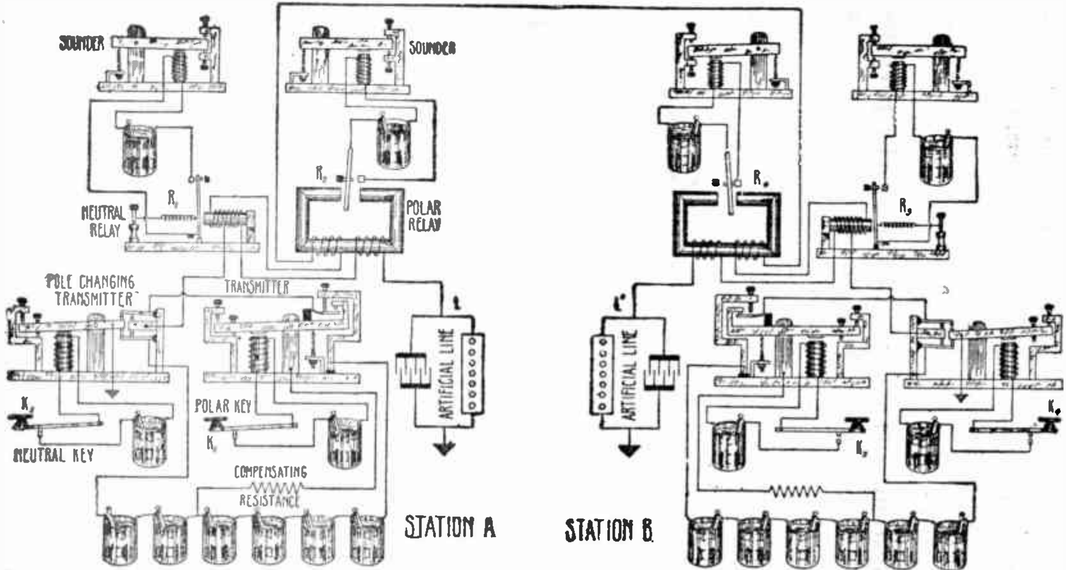


FIG. 8,379.—Quadruplex system with battery current supply. The apparatus employed in operating the polar system of the duplex is generally called the "No. 1 side of the system," or the polar side. It consists of the polar key and the polar relay at either station. The apparatus employed in operating the other system of the diplex is called the "No. 2 side of the system," or the neutral side. It consists of the neutral key and of the neutral relay. In operation, when none of the keys are depressed, no current flows through the line, but a comparatively feeble current flows through the artificial lines L and L′, insufficient to operate the neutral relays, and to maintain the polarized relay tongues on the dead stops. Consequently, none of the sounders respond. If now K_1, be depressed, a strong positive current is sent to line at station A. This does not affect the relays at A, since it passes through them in opposite directions but on arriving at B, it tends to keep the polarized relay tongue R_4, on the dead stop, while it has sufficient power to operate the neutral relay R_3. In the same way if K_3 alone be depressed, relay R_1 alone will respond. If K_2 alone be depressed, a feeble negative current will flow to line, in a direction which will actuate R_4, but it will not have sufficient power to actuate R_3. If K_4 alone be depressed R_2 alone will similarly respond alone. The depression of any key will cause its corresponding relay to close its local circuit at the distant end of the line, regardless of the condition of the keys at that end. In practice the reversed position of neutral relay stop requires a repeater with contact on the upstroke between each neutral relay and sounder, or the equivalent secured by transposition of battery, for synchronous operation: these modifications are here omitted for simplicity.

The Codes

LETTERS

Morse	Continental	†Navy	*Bain
A •—	A •—	A ——	A •—
B —•••	B —•••	B —••—	B •—•
C •• •	C —•—•	C •—•	C •••
D —••	D —••	D ———	D ••—
E •	E •	E •—	E •
F •—•	F ••—•	F ———•	F •———
G ——•	G ——•	G ——••	G •—••
H ••••	H ••••	H •——	H •——
I ••	I ••	I •	I ••
J —•—•	J •———	J •——	J •••—
K —•—	K —•—	K —•—•	K •——•
L ⸺	L •—••	L ——•	L ••••
M ——	M ——	M •——•	M •— •—
N —•	N —•	N ••	N ••——
O • •	O ———	O —•	O —
P •••••	P •——•	P •—•—	P —•—
Q ••—•	Q ——•—	Q •—••	Q —•—•
R • ••	R •—•	R —••	R ——•
S •••	S •••	S —•—	S —••
T —	T —	T —	T —•••
U ••—	U ••—	U ••—	U —•
V •••—	V •••—	V •———	V ———•
W •——	W •——	W ••—•	W ——••
X •—••	X —••—	X —••—	X —••—
Y •• ••	Y —•——	Y •••	Y ——
Z ••• •	Z ——••	Z ————	Z ———
& • •••	&	&	& ————

NUMBERS

Morse	Continental	†Navy	*Bain
1 •——•	1 •————	1 ••••	1 •————
2 ••—••	2 ••———	2 ——•—	2 ••———
3 •••—•	3 •••——	3 •••—	3 •••——
4 ••••—	4 ••••—	4 ———•	4 ••••—
5 ———	5 •••••	5 ••——	5 •••••
6 ••••••	6 —••••	6 ——••	6 ————•
7 ——••	7 ——•••	7 •———	7 ———••
8 —••••	8 ———••	8 —•••	8 ——•••
9 —••—	9 ————•	9 •——•	9 —••••
0 ⸺	0 —————	0 —••—	0 ——•——

PUNCTUATION MARKS

	Morse	Continental	Phillips
Period	••——••	•• •• ••	••——••
Colon	—•— • •	———•••	—•— • •
Colon Dash	—•— •—••	—•— —•	—•— •—••
Semi-colon	••• ••	—•—•—•	••• ••
Comma	•—•—	•—•—•—	•—•—
Interrogation	—••—•	••——••	—••—•
Exclamation	———•	——••——	———•
Fraction Line	•	——	•
Dash	—•• •—••	—•• —••—	—•• •—••
Hyphen	•••• •—••	—••••—	•••• •—••
Apostrophe	••—• •—••	•————•	••—• •—••
Dollar Mark	••• •—••	••• —••—	••• •—••
Pound Sterling	••••• •—••	—•—••	••••• •—••
Shilling Mark	••— —	—•• —•	••——
Pence Mark	•••••	—••	—••
Capital Letter	•• • •—••	—•—• —••—	•• • •—••
Colon Followed by Quotation	—•— ••—•	—•— —••—	—•— ••—•
Cents	•• •	—•—•	•• •
Decimal Point	—•• • • —	•———•	—•——
Paragraph	————	•—•—••	————
Italics or Underline	••— •—••	••——•—	••— •—••
Parenthesis	••••• —•	—•— —•—	•••••—• ••••••—•
Brackets	—••• •—••	—••• —••—	—••• •—•• —••• •—••
Quotation	••—• —•	•—•—•—•—	••—• —• ••—• —•
Quotation in Quotation	••—• •—••	•—••—•	••—• •—•• ••—• •—••
Per Cent	—•—	———•••———	——••——

Learning a Code.—The student should first thoroughly commit to memory the groups of signs representing the letters of the alphabet, the numerals and the principal punctuation points, viz., the period, comma, and point of interrogation; the remaining characters can be learned afterwards, as they will be little needed by the beginner. By constant drill the habit of making dots with regularity, uniformity, and precision must first be acquired; then dashes, and lastly in order, group of dots and dashes, letters and words. If possible for the student to obtain a register, he should by all means employ it in his practice, for he will then be more easily enabled to observe and correct the faults in his own manipulation. The student should learn to form the conventional characters accurately and perfectly; speed will come in good time, but only as the result of constant and persistent practice.

†NOTE.—The Navy code is now obsolete, being discontinued Nov. 18, 1912; the Navy at present uses the Morse.

*NOTE.—The Bain code was at one time in use in parts of America and Europe in connection with the Bain chemical telegraph system, but is now obsolete, though of historical interest.

The Morse code is exclusively used in the United States and Canada; ***the Continental code*** in all European and other countries, and in all submarine telegraphy by international agreement; ***the Phillips code*** is used for "press" work in the United States.

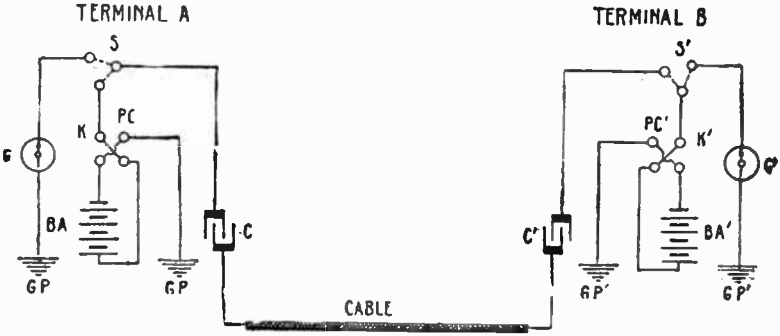


FIG. 8,380.—Diagram of a simple submarine telegraph cable circuit. The equipments of both terminals A and B, are exactly the same, consisting of the transmitting keys K,K', the pole changing switches PC, PC', line switches S,S', galvanometers G,G', condensers C,C', batteries BA, BA', and the necessary ground plates GP, GP'. By means of the switches S and S', the current may be allowed to pass either to the earth through the galvanometers or other recorders, or to the transmitting keys K and K', thence through the batteries BA, and BA', to the earth, depending on whether the signals are being sent or received at the respective terminals. By means of the pole changing switches PC and PC', operated by the keys K and K', either pole of the battery can be connected to the condensers C and C', and thereby to the line at the will of the respective operators, and the cables charged inductively, the corresponding signals being reproduced at the distant terminals by connecting the galvanometer with the line by means of the switches S or S', as the case may be.

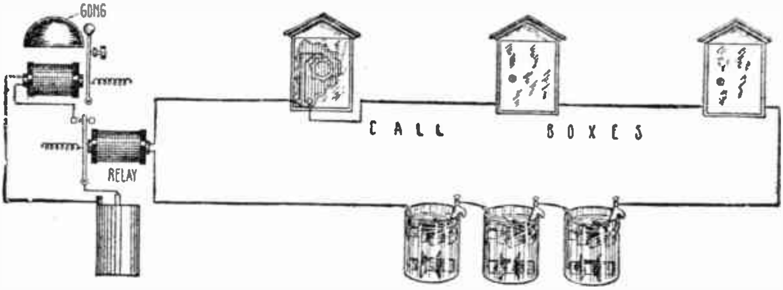


FIG. 8,381.—Diagram of elementary fire alarm circuit. Fire alarm apparatus forms that element of the system depended upon to announce to the fire fighting force the existence of and location of a fire. The equipment consists of gongs and indicators located in the fire department houses, and where volunteers form part of the fire department, public alarms are given by means of devices for automatically striking large bells or blowing whistles.

CHAPTER 50

Telephones

In the electric telephone, *the vibrations of the diaphragm of the transmitter are transmitted to that of the receiver by means of electric currents sent out in the form of electric waves along the conducting wires connecting the two instruments.*

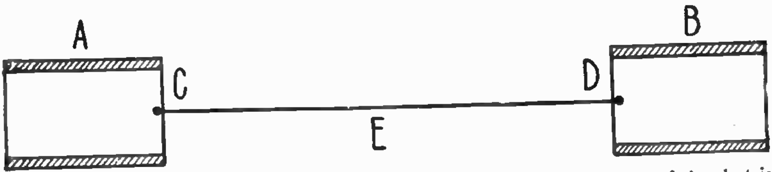


FIG. 8,382.—Simple toy telephone, whose working principle is similar to that of the electric telephone. ***In operation,*** when the open end of the tube A. is placed before the mouth, the vibrations of the membrane C, caused by the varying sound waves constituting articulate human speech, are transmitted with mechanical action by the string E, to the membrane D, and set up in the latter vibrations corresponding to those of C. The vibrations of C, cause sound waves in the air which are propagated according to the principles of acoustics, to the ear, placed at the open end of the cylinder B.

The current used for this purpose is of vibrating or alternating character and its strength at any instant has direct relation to the sound vibrations transmitted by the voice.

A telephone set usually comprises: 1, a *source of electric current supply*; 2, a *transmitter*; 3, a *receiver*; 4, an *induction coil* consisting of primary and secondary windings; 5, a *receiver hook* or automatic switch; 6, a *bell* or ringer consisting of two magnets and an armature and two bell gongs, and 7, a *condenser* with common battery sets.

Current Source.—This varies according to the system used at the exchanges.

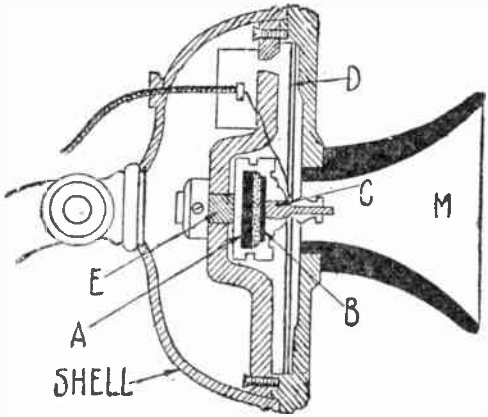
The "common battery system" does away with the use of primary cells.

The *d.c.* required for the talking and for the switch board indicating signals is obtained from storage batteries charged from power driven dynamos and the *a.c.* for operating the subscriber's polarized bell or ringer is obtained from alternators.

Transmitter.—Fig. 8,383, shows a form of transmitter largely used.

The speaker talks into the mouth piece M, and the sound waves caused by his voice impinge on the metal diaphragm D, producing corresponding vibrations therein. Attached to the center of the diaphragm is a button and cup of hard carbon B, opposite to which and fastened to the frame is a second brass button E, and carbon cup A.

The space between the two cups is filled with coarse granules of carbon C. The buttons A and B, constitute the electrodes of the transmitter. The electric current from the battery passes from one to the other of the electrodes, through the carbon granules which form a conducting path consisting of an indefinite number of loose contacts. The resistance of the circuit, and consequently the strength of the current, can be regulated by varying the rate of vibration of the carbon granules. The button B, communicates the vibrations of the diaphragm D, to the carbon granules: therefore the voice of the speaker, characterized by the inflections and articulations of human speech, is reproduced in the varying strength of the electric current.

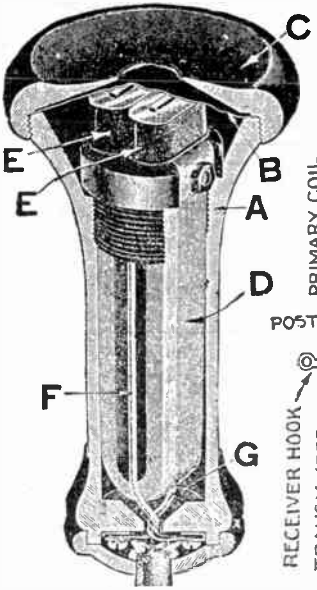


Receiver. — There are numerous forms of receiver, the Bell receiver being the form now generally used, as in fig. 8,384.

FIG. 8,383.—White solid back transmitter. *In construction,* the carbon chamber is formed by two mica diaphragms supporting the electrodes and brass ring collar. Each electrode is fastened to a brass disc. The use of two mica diaphragms provides for any vibration of the front electrode, which is transmitted through the granular carbon to the rear electrode. The whole chamber is caused to vibrate, which keeps the carbon granules alive and precludes their becoming packed.

In operation the varying strength of the electric current produced by the vibrations of the diaphragm of the transmitter causes corresponding variations in the magnetic state of the electromagnet D, making it act upon the diaphragm B, with different degrees of intensity so that the listener's ear placed close to the receiver cap readily recognizes the characteristics of the speaker's voice.

Call Bells.—These devices, for attracting the attention of the party desired, usually consist of a *polarized bell operated by current from a magneto located in a box.*



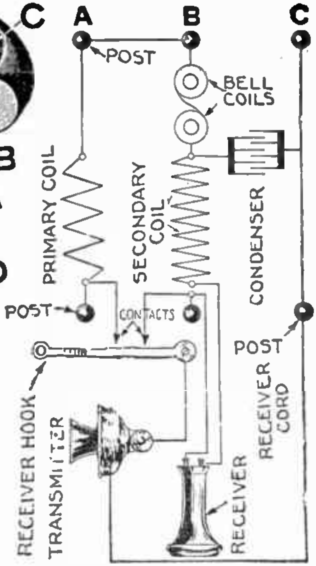


FIG. 8,384.—Bell Standard bi-polar receiver. ***It consists of*** a hard rubber case A, hollowed out at its upper extremity, and containing the thin, soft iron diaphragm B. Cap C, which screws on case A, is capable of vibrating freely. D, is a permanent magnet of the horse shoe type and E, E, an electromagnet located directly under the diaphragm B, which is in close proximity, but not in contact with, the poles of the magnet. These coils have soft iron cores screwed fast to the ends of the steel magnet so that when heavy alternating currents traverse through their windings the permanent magnetism of the horse shoe magnet is not disturbed. These coils are connected in series and terminate at the wires F and G.

FIG. 8,385.—Inside connections of telephone bell box. ***In operation,*** when the receiver is off the hook the contacts there are closed by the upward spring of the hook and the circuits are closed for operation. The line is always connected to the two outer posts A and C, the middle post B, often stamped G, is used for ground connection on party line instruments.

Inter-Communicating Switching Device.—For small systems such as those of hotels, the inter-communicating switching device is often combined with the telephone set.

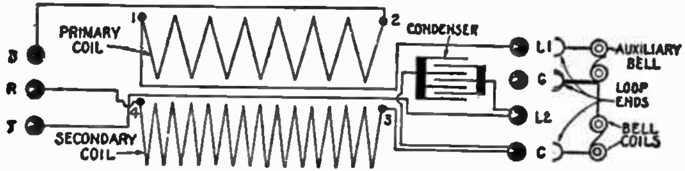


FIG. 8,386.—Improved wiring of bell box by N. Y. Telephone Co. If an auxiliary bell be wired in, the two sets of coil are connected in series and the post G, is used to connect the loops; otherwise the G, post is not used unless for ground connection in party wires. Post marked L1, corresponds to post A in fig. 8,385, post C, corresponds to post B, and post L2, corresponds to post C, in fig. 8,385, C referring to the condenser in each case. Post S, is connected to switch contact, post R, to receiver cord and post T, to transmitter.

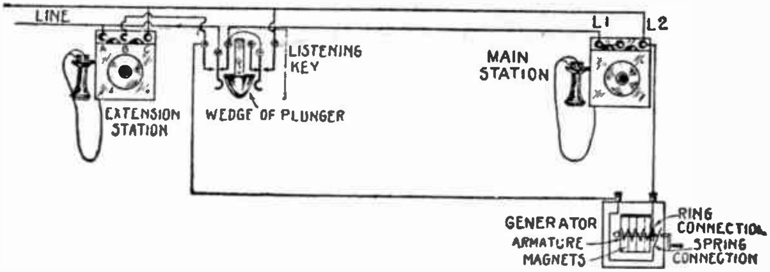


FIG. 8,387.—Two common battery instruments wired so that only one bell at a time can be rung by Central (plan 3 N. Y. Tel. Co.). *In operation,* with the listening key normal (as shown) central can ring only the main station bell but the extension can talk, and by throwing the listening key, the main is completely cut out and allows only the extension to ring and talk. The ringing key must be thrown to ring the extension station from the main, which makes the system intercommunicating.

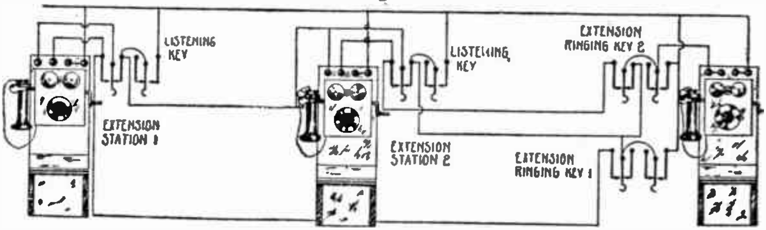
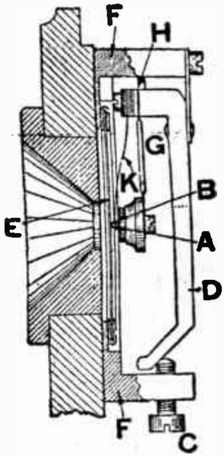


FIG. 8,388.—Three magnetos wired so that only one bell at a time can be rung by central (according to which listening key is thrown, permitting talk for any telephone with keys normal.



When there are a large number of subscribers, an exchange or central station is necessary, where the wires connecting the various subscribers or other small stations can be joined at will by the central operators.

Switch Boards.—These are made in sections, called *positions*, for central offices.

FIG. 8,389.—The Blake microphone transmitter. In this instrument a single contact is maintained between the platinum point A, and the polished carbon button B, by means of the adjusting screw C, acting against the strip of iron D, called the anvil. The vibrations of the diaphragm thus affecting the current which passes from the battery through the iron frame ring F, the anvil D, the connection G, the carbon button B, the platinum point A, and out again from the contact H, of the spring K. At one time the Blake transmitter formed a part of the standard equipment of almost every telephone in the United States and was also largely used abroad. No transmitter has ever exceeded it for clearness of articulation but it is decidedly deficient in power in comparison with the modern transmitters. The latter are composed of granulated carbon.

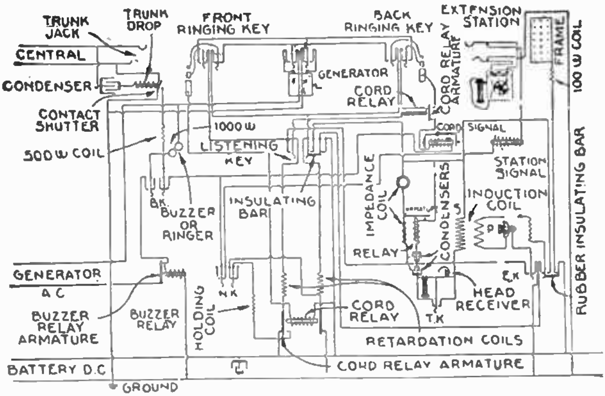


FIG. 8,390.—Positive supervision type of P.B.X. switch board adopted by N. Y. Telephone Co. *With this type,* each pair of cord is supervised by the positive supervision relay which controls the bull's eye cord signal. There are as many station jacks and station signals as there are extension stations and as many central jacks and drops as there are central (trunk) lines coming into switch board. There is only one buzzer key B.K., one night key N.K., one generator key G.K., one emergency key E.K., and one telephone receiver key T.K. mounted on each switch board.

The requirements of such exchanges are satisfactorily met by the use of various forms of multiple switch board in which each subscriber's line, instead of terminating in only one jack, connects with several, equal to the number of "positions."

This arrangement enables each operator to make any desired connection of the many thousands registered in the exchange, either by inserting

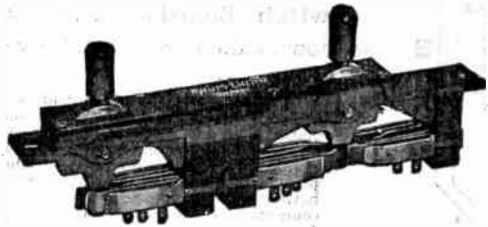


FIG. 8,391.—Modern ringing keys. In order to meet the needs of every calling subscriber, the operator must perform several different acts in shifting and changing circuits and to facilitate this work, devices to simplify it as much as possible have been developed. The modern ringing keys have greatly helped in the saving of the operators' time. By throwing the little levers a hard rubber bushing makes or breaks the contacts at the springs and throws alternating current ringing power into the line. When the finger pressure is released, the levers fly back again into normal position.

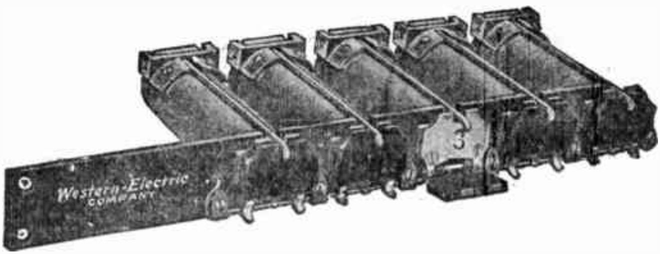


FIG. 8,392.—Mounted trunk drops. Tubular trunk drops are mounted on a metal strip each being held by two small screws underneath the drop shutter. The tubular casing of each drop is soft iron inside of which is the drop winding, the ends of the coil wires terminating at lugs which protrude from the casing and are insulated therefrom. The drop shutters are then screwed fast to the metal strip and adjusted so that they may fall easily when the armature is held up by the magnet.

the plug in the jack on her own panel or by reaching with the cord of her calling plug to the panel or position on either side of her.

The Common Battery Telephone System.—This is sometimes called a central energy arrangement. A dynamo at the central office charges storage batteries over night with electricity which supplies current to all subscribers, thus affecting a cost saving.

A feature of this system is that the removal of the subscriber's receiver informs central of the subscriber's presence at the telephone.

The operator's equipment consists of a regular head or hand receiver

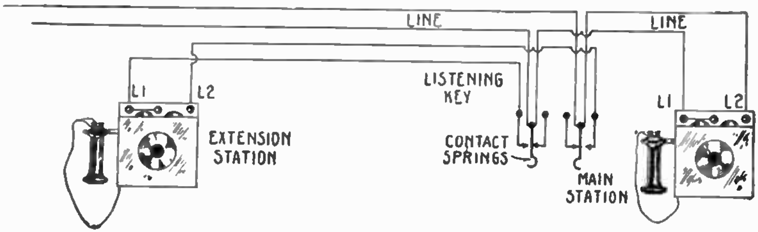


FIG. 8,393.—Wiring diagram showing two telephones with a listening key at the main instrument to cut off the extension-station. This key can be placed at either instrument and the extension wired to either inner or outer contacts. As shown, the key is at the main station and the extension is on the outer contacts. This is called plan 10.

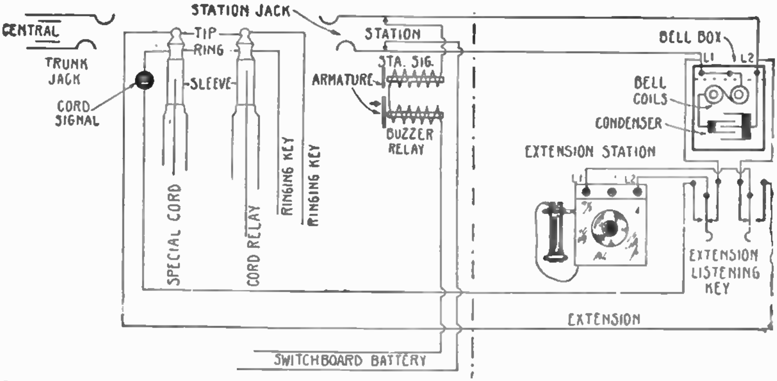
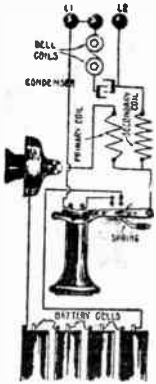
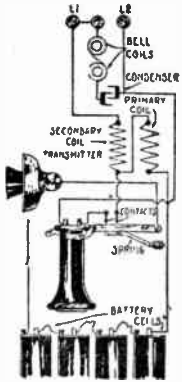


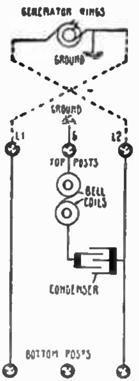
FIG. 8,394.—Private line extension station current from P.B.X. switch board, whereby absolute secrecy with outside exchanges is obtained. When extension listening key is normal, extension signals operator in same way as do all other extensions. After asking for private connection special cord, without listening key being plugged in central (trunk) jack by operator, subscriber throws extension listening key and conversation ensues. If P.B.X. operator's attention be again desired, listening key is thrown normal. Operator calls extension in usual way on any cord except special and rings extension special bell no matter how listening key be thrown. Since there is no listening key on special cord, operator must use any other cord for connection between P.B.X. and extension station.

and a switchboard transmitter supported on an adjustable transmitter arm with cords, or a breast plate transmitter and receiver with head band, cord, and cut in plug, also the necessary condensers, induction coils, and retardation coils, all of which are connected to the listening key circuits.

Central Office Exchange Equipment.—This consists of the necessary apparatus for transmission and signalling between private branch exchange (P.B.X.) switchboards and the exchange.







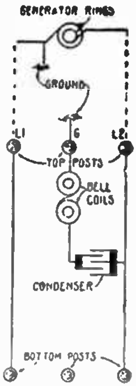


FIG. 8,395.—Booster set with battery connected in the circuit to strengthen transmitting and receiving power of common battery instrument.

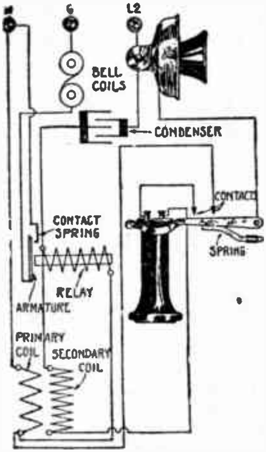
FIG. 8,396.—Independent telephone station wired for local battery talking and common battery ringing.

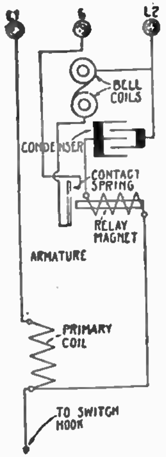
FIG. 8,397.—Wiring diagram of two party line R, bell station with G, post represented as connected to ground and negative side of alternating current generator also grounded. When bell is rung, ringing key throws positive current in instrument at L2, across condenser and through bell and out at G, to negative side of generator through ground.

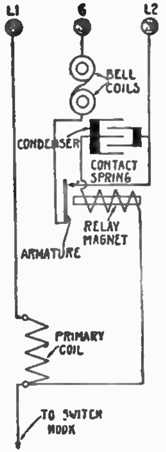
FIG. 8,398.—Wiring diagram of two party line J, bell station with G, post represented as connected to ground and negative side of alternating current generator also grounded. When bell is rung, ringing key throws positive current in instrument at L2, across condenser and through bell and out at G, to negative side of generator through ground.

The operators sit at the various "positions" of the switchboards, there being two types called the A and B boards. When a subscriber lifts the receiver, an electric light burns in a jack and the B, operator answers with the answering or back cord and throws her listening key and says number please.

When the subscriber gives the number she gives the B, operator the number by going into the B, operator's ear over a call circuit button on the A, board, the B, operator then sets the ringing key and gives the A, operator the assignment of a trunk and the A, operator plugs the calling or front cord in the outgoing trunk multiple in the jack which has been given her. The A, operator completes the connection when the subscriber who is connected through the B, board answers, the light or drop on the cord circuit goes out, and stays out until the parties hang up and then the light opens on the A, cord circuit and the A operator takes down the cords







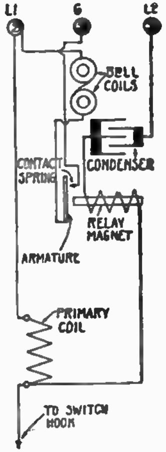


FIG. 8,399.—Four party line R, station showing the primary and secondary of the induction coil and the receiver and transmitter all of which are connected as shown in all party wire instruments. ***In operation,*** when the relay armature is held up against its contact spring, the bell circuit is complete to L1, post and rings through ground.

FIG. 8,400.—Wiring diagram of four party line J, bell station showing the primary of the induction coil, the selective ringing relay, and the condenser connected in series across the line. One end of the bell coil connects with post G, to ground and the other connects with the relay armature. When this armature is held up against its contact spring the bell circuit is complete to L2, post and rings through ground.

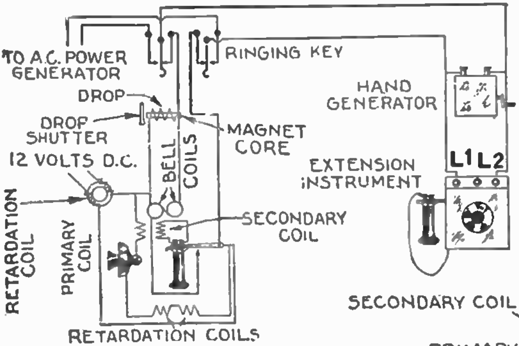
FIG. 8,401.—Wiring diagram of four party line M, bell station showing the primary of the induction coil, the selective ringing relay and the condenser connected in series across the line. One end of the bell coil connects with L2, post and the other end connects with the relay armature. When this armature is held up against its contact spring, the bell circuit is complete to G, post, and rings through ground.

FIG. 8,402.—Wiring diagram of four party line W, bell station showing the primary of the induction coil, the selective ringing relay, and the condenser connected in series across the line. One end of the bell coil connects with L1, post and the other end with the relay armature. When this armature is held up against its contact spring, the bell circuit is complete to ground, and rings through ground.

and as soon as the calling cord or front cord is taken out of the outgoing trunk jack the B, operator gets the disconnect signal and she disconnects the cord from the number in the subscriber's multiple. In all cases A, boards are connected to B, boards by call circuit buttons and the B, operator does not talk to the subscriber.

P.B.X. systems extension stations are arranged to terminate on jacks of the size suitable for the reception of the cord connecting plugs.

Party Lines.—These are so arranged, that the telephones of a number of subscribers may be connected on one circuit so that all have a common drop and jack at the exchange switch board. Systems of this type are frequently adopted where the business is small in proportion to the length of the line.



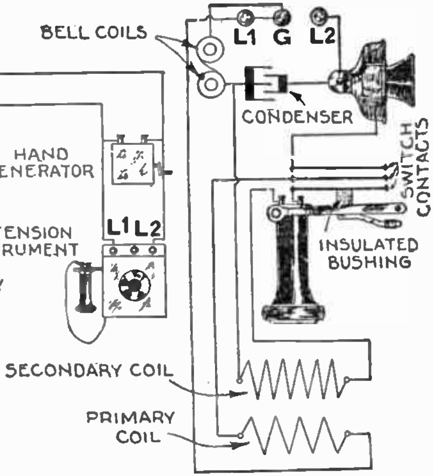


FIG. 8,403.—Stock Exchange extension station as installed in New York City. *In operation*, when main wants extension, the ringing key is used with ringing power. The extension bell is not connected but one can talk from the instrument.

FIG. 8,404.—Police signal box, showing the bell and condenser connected as usual across the line between L2 and G posts. *In construction*, the switch hook is insulated from the instrument by hard rubber bushings.

90 TELEPHONE TROUBLES

Subscribers' Troubles

1. Open bell. 2. Open condenser. 3. Open bell strap wire.
4. Bell out of adjustment. 5. Open auxiliary bell.

Effect: Can call central but central cannot ring subscriber although both can talk.

6. Open receiver. 7. Open receiver cord. 8. Open secondary coil.
9. Open switch hook contact. 10. Receiver diaphragm missing.

Effect: Can hear central ring but cannot hear talking with receiver.

11. Open primary coil. 12. Open switch hook contact.
13. Open transmitter. 14. Open transmitter cord.

Effect: Can hear central ring and talk but cannot talk back.

15. Dented receiver diaphragm.
16. Swinging open (cut out) receiver cord.
17. Short circuited induction coil.
18. Reversed secondary connections.

Effect: Can hear bell ring but can hear talking only faintly.

19. Packed carbon granules in transmitter.
20. Cut out transmitter cord.
21. Primary coil reversed.

Effect: Can hear central ring and talk but cannot be heard clearly.

22. Swinging ground on ring side of line.
23. Line crossed with other lines.
24. Party wire biasing spring out of adjustment.

Effect: Bell rings occasionally without cause.

25. Loose connection at one or both sides of line.
26. Cut out desk stand cord.

Effect: Noisy line.

27. Open line wire. 28. Open inside wire.
29. Badly corroded inside or outside wire.

Effect: Subscriber cannot call or be called. ***Test:*** Strap out opens with test receiver. Disconnect short circuited lines and then test by strapping in test receiver. Shake cut out cords to locate trouble.

Private Branch Exchange (P.B.X.) Troubles

30. Generator feeder not correctly poled.

Effect: Pressing ringing key while plugging cord into any station jack, all extension bells will ring or tap. Clear by reversing connections.

31. Generator feeder open.
32. Buzzer ringer coils open.
33. Buzzer relay contact does not make.

Effect: Central cannot ring P.B.X. operator on any drop. ***Test*** by following out circuit with test receiver.

34. Battery feed open.

Effect: Buzzer relay vibrates while plugging trunk jack until E, key is thrown. ***Test*** by following up battery with test receiver.

35. Short circuited or grounded ring of battery feed.

Effect: Battery of insufficient strength to talk and extensions cannot get switch board. ***Test*** by first removing wires from binding posts at cross connecting box and tapping with test receiver or 24 volt lamp strapped across wires of incoming feed. If lamp light bright or receiver click loud, battery is coming in O. K. Reconnect the tip side of feed, connect one side of a test receiver to ring binding post and tap the other side several times on end of loose wire. If receiver click, trouble must be toward switch board. Then at back of switch board open ring side of battery and tap as before at cable end of wires. If click be heard, trouble is in switch board cable; if no click be heard, trouble is in switch board.

36. Short circuited cord plug.

Effect: Cord plugs are hot or plugs emit smoke when dampness has crept in bushings separating the three parts of plug. ***Test*** by throwing up all listening keys and placing operator's receiver to the ear, start from first and depress each ringing key separately. Clicking noise in receiver indicates short circuit. Turn down each cord where clicking noise is heard and disconnect each cord so turned down at cord lug connections.

37. Cord circuit at relay contacts short circuited.
38. Cord circuit shortened by touching of keyboard wires.
39. Ringing key contacts crossed.

Effect: Clicking still heard in operator's receiver when turned down cords are disconnected and ringing keys are again depressed. If ringing key contacts be thought to short circuit because the inner contact spring makes contact with the outer before breaking from the inner, the G, key can be thrown, which will temporarily clear the trouble. Then the contacts must be adjusted.

40. Positive supervision relay sticks.

41. Bull's eye cord signal sticks.

Effect** (**of 41**)**: Operator cannot tell when parties have finished talking. ***Test*** by jarring relay and clear by making good adjustment.

42. Open trunk jack springs.

43. Open trunk line condenser. 44. Open trunk drop winding.

Effect: Central cannot ring local P.B.X. trunk drop.

45. Buzzer relay open. 46. Buzzer contact spring does not make.

47. 500 ohm resistance coil open.

48. Ring or ground side of battery open.

49. Ground wire open where springs make contact in falling.

Effect** (**of 49**)**: Drop shutters fall when central rings but buzzer does not ring or buzz.

50. Broken wire at trunk jack common to all jacks.

51. Open 100 ohm resistance coil.

Effect: Banging noise is heard when local operator plugs into central jack.

52. Cut out hand receiver cord. 53. Cut out head receiver cord.

54. Cut out transmitter cord.

Effect** (**of 54**)**: Breaking of circuit is noticeable by occasional breaks in the conversation. The conversation may be carried on O.K. if all cords be kept perfectly motionless, but as soon as moved or shaken there are noticeable cut outs in the conversation.

Test: Throw any listening key and place tip of either plug of that pair of cord on first one binding post and then on another of the receivers, at the same time shaking the cords. The trouble is generally located at the cord tips or connections.

55. Transmitter open.

56. Primary coil of operator's set open.

57. Transmitter cord open. 58. Listening key contacts open.

Effect (of 58): Central cannot hear local operator on any cords, nor can P.B.X. operator hear central.

59. Receiver open. 60. Secondary coil open.
61. Receiver cord open.

Effect: P.B.X. operator cannot hear central operator but central can hear P.B.X.

62. Short circuited trunk line condenser. 63. Short circuited jack springs. 64. Drop winding crossed with frame.

Effect (of 64): Central gets steady light from P.B.X.

65. Open station signal. 66. Open station jack contacts.
67. Open wire between jack and signal.

Effect: One extension station cannot get local operator.

68. Open common wire to jacks.
69. Open common wire to signals.

Effect: All extension stations fail to get local operator.

70. Open plug or cord. 71. Open contact at ringing key.
72. Open positive supervision relay. Open cord relay contacts

Effect: Cord in question cannot be used.

73. Open condenser at operator's set.

Effect: Operator cannot hear but can be heard O.K.

74. Open between battery feed and listening key. 75. Open between listening key and E, key. 76. Open between battery feed and E, key. 77. Short circuited induction coil.

Effect (of 71): Throwing of listening keys does not give usual side tone (live sound heard by tapping on transmitter) until E, key is thrown.

78. Open holding coil. 79. Open N, key contacts.
80. Open upper relay contact.

Effect: When an extension station is connected through to central and receiver is hung up (such as a night connection) the central disconnecting signal shows. The holding coil should prevent this with its high resistance shunted across the line when N, key is thrown.

Plan Troubles

81. Hand generator turns hard.

82. On plan 3 or 5, listening key contacts are crossed.

Effect: System is short circuited.

83. Plan 3 or plan 5 generator handle sticks.

84. Short circuited condenser.

85. Wet desk stand cord.

86. Ringing key contacts on plan 5 are crossed because plunger sticks.

Effect: Both extension station bells will ring when one listening key is thrown.

87. Desk stand cord short circuited on plan 3 or 5 extension.

Effect: That extension bell will ring or tingle at same time that main bell rings.

88. Desk stand cord connected wrong on either extension.

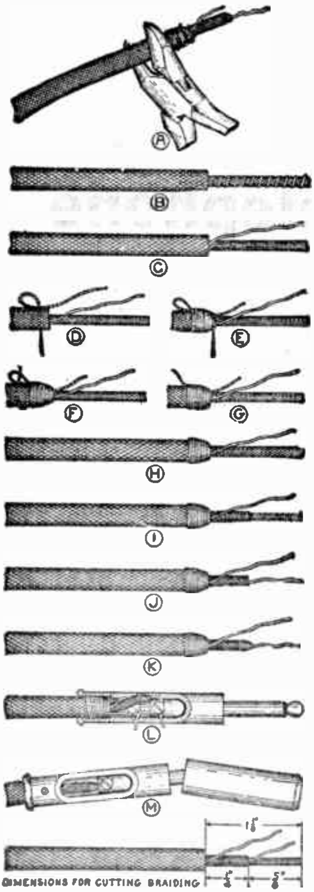
Effect: Plan will become confused and appear to be wired wrong, according to how the cord is wired.

89. Open strap wire at plan 3 or 5 listening key.

Effect: In any case the main instrument would be cut off by an open line and not by a short circuit for which the strap is used.

90. Listening key contacts open on plan 8 key.

Effect: Main station can ring extension but cannot talk. If key be not down normal for ringing and thrown for talking main, cannot get extension station.



FIGS. 8,405 to 8,418.—*Repairing Western Electric Steel Cords.* A, remove the plug from the cord and cut off the worn end of cord; B, cut back outer braiding and sewing with a pair of snips about $1\frac{1}{8}$" leaving sleeve conductor bare; C, pull out spiral sleeve conductor with a pair of pliers and cut to about 1" in length; D,E,F,G, and H, bind outer braiding $\frac{5}{16}$" back with W.E. three ply gilling thread; I, cut back inner braiding $\frac{1}{2}$" leaving tip conductor bare; J, pull out tip conductor and trim inner core to length; K, bind inner braiding with gilling thread about $\frac{5}{16}$" back from end, the operation in accomplishing this being the same as outlined under D,E,F,G, and H; L, screw into plug; M, fasten sleeve and tip conductors under screws and replace shell.

CHAPTER 51

The Automatic Telephone

The term automatic telephone means *a telephone system fitted with automatic electric devices such that the user, by means of a* **numerical dial** *attached to the instrument can:* **1,** *establish a connection in a large public exchange*, in from three to five seconds; **2,** *be sure that he gets the number he dialed;* **3,** *receive a positive signal, if the line be busy*, and **4,** *break the connection when he desires*—all without the aid of an operator in the central station.

Clearly then the automatic telephone does away with the large force of central station operators, and as the connection is made electrically, instead of by a second person, mistakes are largely avoided, and connections more quickly made. Accordingly, from the standpoint of the user, the appeal of the automatic telephone is due to its speed, accuracy, directness, impersonality and secrecy.

The transmitter, receiver, ringer, and hook switch for an automatic telephone may be of any standard type. The only part of the instrument that is peculiar to the automatic system is the calling device or *dial*. At the central office, the machines which make the connections between subscribers' lines are divided into the following classes:

1. Line switches;
2. Selector switches;
3. Connector switches.

According to the size of the installations the automatic telephone system may be classed as:

1. Single office exchange;
2. Multi-office exchange;
3. Private automatic exchange (P.A.X.).

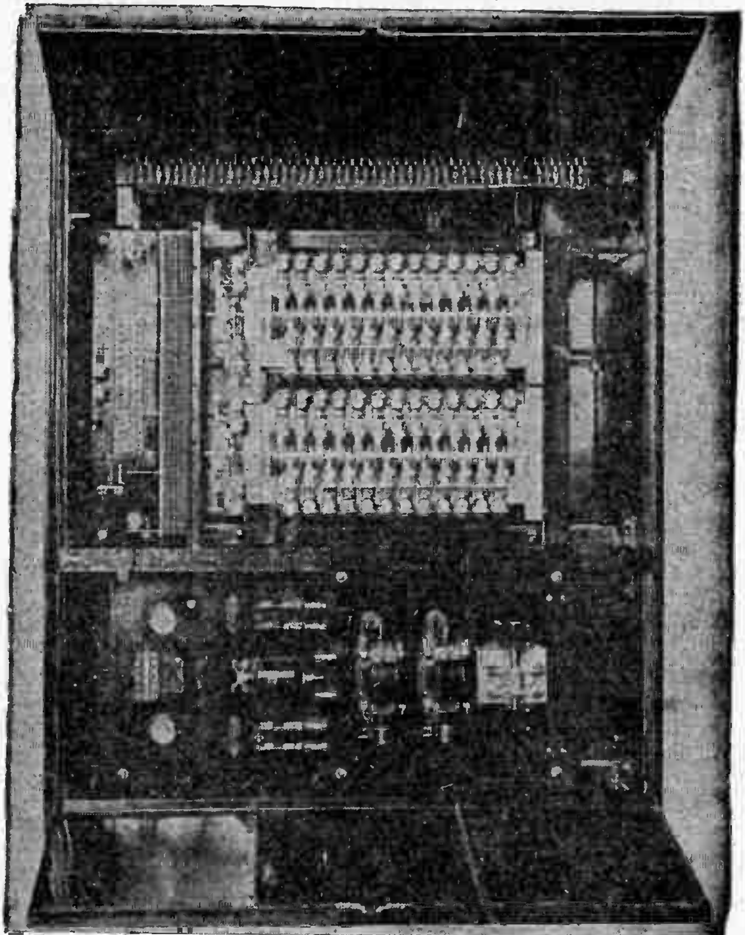


FIG. 8,419—A 50 line private automatic exchange (P.A.X.) equipped for 25 telephones.

The second system is simply a collection of groups of subscribers, each group having its central station and arranged for inter-communication between the several groups.

The private automatic exchange (P. A. X.) is something entirely apart from public exchange operation, being, in fact, a system of automatic electric services designed for private ownership by business or industrial institutions.

1. SINGLE OFFICE EXCHANGE

General Working of the Automatic Telephone.—This can be most clearly illustrated by considering the private auto-

FIG. 8,420.—Automatic telephone wall type showing *dial* by which the subscriber makes calls without the aid of a central office operator.

FIG. 8,421.—Automatic telephone, desk type.

matic exchange system. The exchange consists of the automatic switch board, current supply, terminals, etc

The telephone lines (two wires each) entering the room, pass through a main distributing frame and thence to line switches. The line switch is a device for enabling a large number of telephones to use a smaller number of automatic switches, based upon the well-known fact that only a small percentage of the telephones are in use at any one time. Thus fifty subscribers' lines require only seven switches, because no more than seven connections are needed at any one time.

From the line switches wires run to the connector switches, whose function it is to make the connections,

The current is supplied to the automatic switches by a 24-cell lead storage battery, with a controlled pressure of from 46 to 49 volts.

When a user takes the receiver from the hook, the line switch associated with his line extends the latter to an idle connector switch and prevents anyone else using the same switch.

While the first figure of the call number is being dialed, a magnet in the connector lifts the shaft and wiper springs with a step by step ratchet action to a certain row of contacts.

When the second digit is dialed, another magnet rotates the shaft and wiper springs until the latter rest on the pair of contacts to which the desired line is attached. The connector switch then tests the line to see if it be busy. If the line be busy, the connector prevents the completion of the connection and sends a distinctive tone to the calling station, so that the calling person knows the conditions.

The busy tone is created by the rapid interruption of direct current through the primary of an induction coil. Mounted on the converter shaft is a commutator with many segments. The 48-volt battery current is led through this in series with the primary of the induction coil and a pair of interrupter springs. The latter makes the tone come and go periodically, causing it to be recognized clearly as a "busy tone." The secondary of the induction coil is led to the connector switches.

If the line be not busy, the connector switch protects the called line from being seized by anyone else, clears it of attachments and rings the bell of the desired station. The calling person can hear that the ringing is actually taking place. When the desired station answers, the ringing is stopped, and conversation proceeds as in any common battery system.

When the conversation is completed and the receivers are hung on their hooks, the connector switch and the line switch both restore to normal, and are at once ready for another call.

Essential Elements of the Automatic Telephone.—The various devices comprising the automatic system by which telephone connections are made without the aid of an operator at central office are:

1. Subscriber's dial;
2. Line switch;
3. Connector switch.

The relay group is considered a part of the connector.

Subscriber's Dial.—The function of this device is *to alter the electrical condition of the line in such a way as to cause the apparatus at the central office to complete the desired connection.*

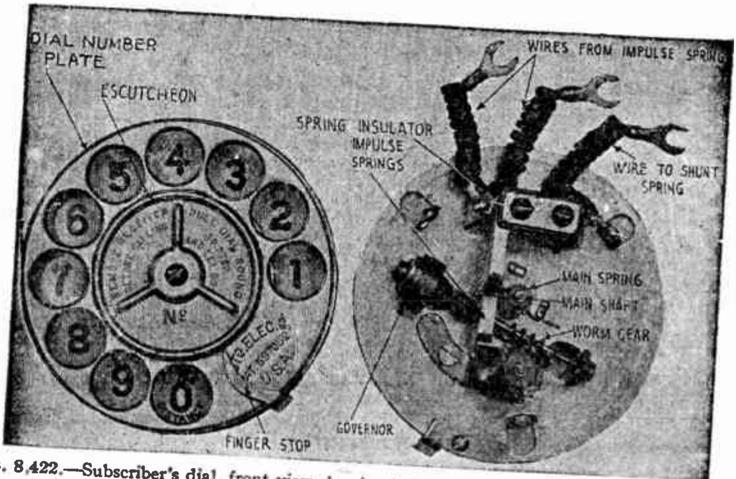


FIG. 8,422.—Subscriber's dial, front view showing holes in disc, numeral sand finger stops.
FIG. 8,423.—Subscriber's dial, rear view showing mechanism.

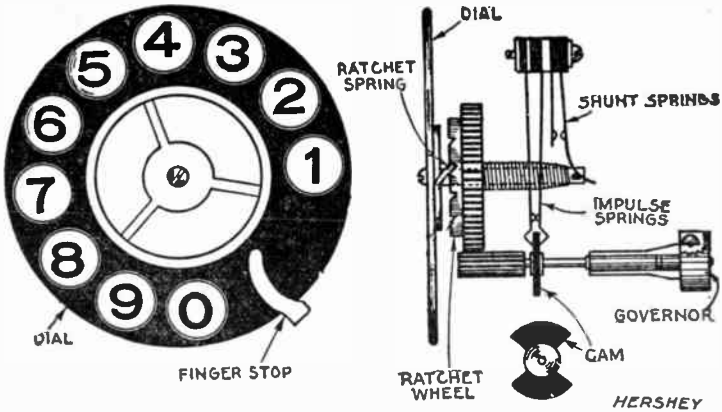
It consists of a dial pivoted at the center and arranged so that it may be turned in a clockwise direction.

As shown in fig. 8,422 it is perforated with ten finger holes, through which appear the numbers 1,2,3,4,5,6,7,8,9,0.

To call the number, say 53, the subscriber places the tip of his finger in the hole through which 5 appears and turns the dial to the right until his finger strikes the stop; he then removes his finger whereupon a spring causes the dial to return to its normal position. Similarly the second number, 3, is "dialed," thus completing the manual operations of calling the number 53.

The mechanism of the dial is such that each time the dial is moved, as just described, an electric circuit is opened a number of times corresponding to the number dialed. Thus when the number 5 is dialed the circuit is opened 5 times. This mechanism is shown in figs. 8,424 and 8,425, and in diagram in fig. 8,426.

Subscriber's Circuit.—Included in this is the receiver, transmitter, shunt and impulse springs of the dial mechanism, line and release relays, as shown in fig. 8,426.



FIGS. 8,424 and 8,425.—Front and sectional side view of subscriber's dial, showing mechanism and end view of cam. *In operation*, as the dial is rotated by the finger clockwise, a coiled spring is wound, which, after removing the finger on reading the *stop* causes the dial to return to its initial position. This is a ratchet which transmits the return movement to gears and a governor. The gears are in mesh with a pinion on which is a cam which is so geared that when say No. 1 is "dialed," the cam will make one half revolution, opening the impulse spring once. Similarly the impulse spring will be opened a number of times corresponding to the number dialed.

When the subscriber dials a number, *the circuit will be opened a number of times corresponding to the number called* and this is the principle upon which the apparatus at the central station depends to make the connection.

When the dial is moved from the initial position, the shunt springs close contact, maintaining a shunt around the transmitter and receiver until such time as the dial returns to its initial position. This prevents variation of resistace in the subscriber's loop and irregular operation of the central office mechanism.

Connector Switch.—At the central station *the impulses* sent from the subscriber's station by the dial mechanism *act upon a connector switch which makes the connection*

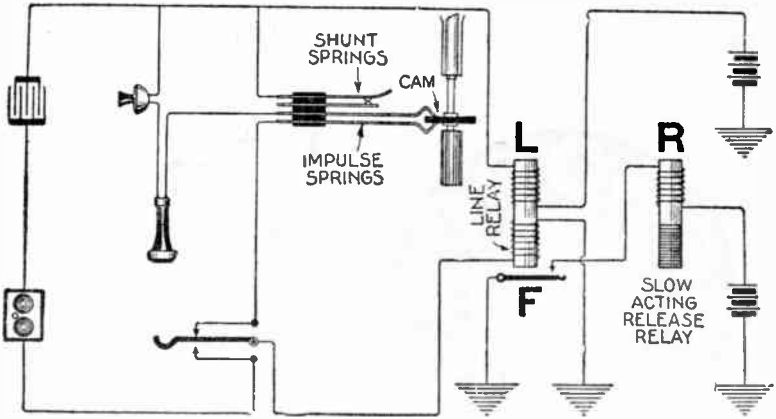
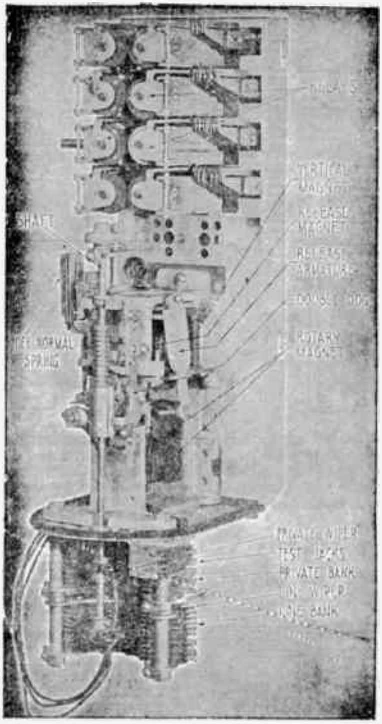


FIG. 8,426.—Subscriber's circuit. *In operation,* when the receiver is lifted from the hook, the circuit is through the upper winding of line relay L, transmitter, receiver, impulse spring, upper contact of switch hook, lower winding of L, to ground. When thus, line relay become energized and closes the release line relay, whose circuit is from battery through release relay, contact maker F, to ground. When a number, say 1, is dialed, and the dial released, the cam is given one half turn as it returns to initial position, and one of the cam wings momentarily opens the impulse spring as it passes between them. This momentarily opens the circuit of line relay L, which causes L, to disenergize for an instant, and in turn opens the circuit of relay R. The latter being slow acting remains closed even though its circuit was momentarily opened.

There are two principal differences between the work of an operator on a multiple switchboard and that of an automatic connector. The first lies in the difference in the number of lines to which they have access. The operator has within her reach a multiple jack for every line in the switchboard, be the number of lines 1,000 or 10,000. She may therefore make a connection to any line entering the office, but a connector switch has access



to but 100 lines. Secondly, a subscriber's operator takes the orders of and makes the connections for certain predetermined subscribers only. The number she serves seldom exceeds 200 and is often less than 100, but a connector switch is, when idle, ready to handle the order of any subscriber who may wish to connect to any one of the 100 lines to which it has access.

Fig. 8,427 shows a connector switch with cover removed. The lower part of the machine supports two curved banks of contact plates or strips. The under bank, called the line bank, contains 100 pairs of these contact plates arranged in 10 horizontal rows, 10 pairs to the row. These pairs of bank contacts correspond to the line springs in the multiple jacks of a manual board, and may be multipled before any desired number of connector switches.

The upper bank contains 100 single contacts which correspond to the sleeves of multiple jacks. This is the busy test bank, commonly called the "private" bank. The cord and plug of the manual board are represented by the "wipers" on the shaft of the machine.

FIG. 8,427.—Strowger type connector with banks. The connector is the final switch of a series used in making a call. *It consists of* a shaft carrying three wiper springs, which by means of a step by step vertical and rotary motion, may be caused to rest on any desired set of contacts in the bank. The relays at the top are used to control the action of the magnets, the busy signal, ringing current, transmission currents, etc.

The lower or line wiper consists, as shown, of a pair of long flexible springs insulated from each other and each soldered to a flexible cord, while the upper or private wiper is a pair of springs connected together to a third cord.

The movement of the wipers, corresponding to those of an operator raising a plug and inserting it into the proper multiple jack, are performed

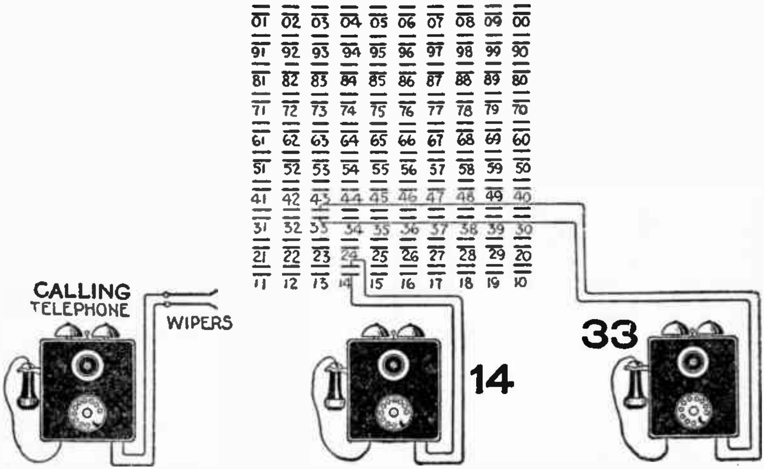


FIG. 8,428.—Diagram of line bank contacts, associated with each connector and numbering system of the telephone lines of which they are the terminals. The number of any set of terminals can be determined by noting the number of vertical and sidewise steps the wipers must be given to reach that set, remembering that ten steps is always represented by zero. Thus six vertical steps and ten rotary steps would cause the wipers to reach contact No. 60.

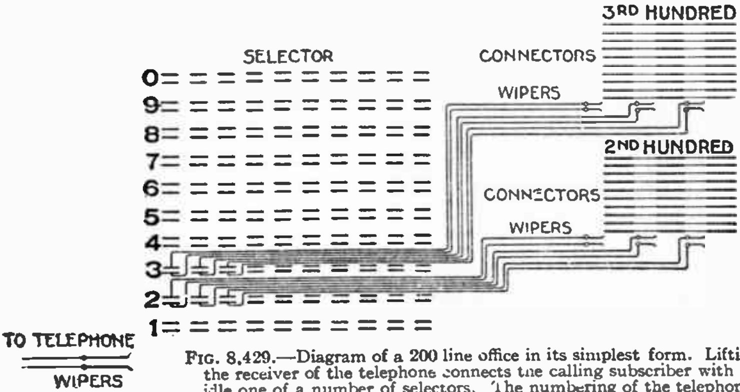
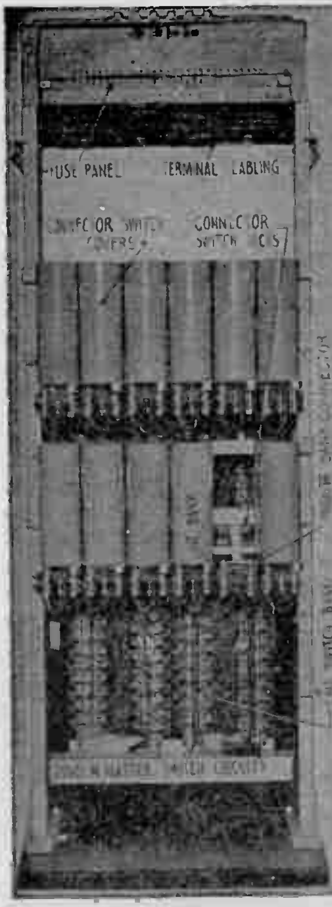


FIG. 8,429.—Diagram of a 200 line office in its simplest form. Lifting the receiver of the telephone connects the calling subscriber with an idle one of a number of selectors. The numbering of the telephones in this office is from 200 to 300 inclusive, since the second and third levels of the selectors are used. Dialing the first figure (a 2 or a 3) steps the selector up to the second or third level and thereby chooses the 200 or 300 group of lines. Immediately the vertical motion of the selector shaft is complete, the shaft and wipers automatically rotate to select an idle connector serving that 100 line group. This action is independent of the calling device. The last two figures dialed cause the connector to pick out the desired line.



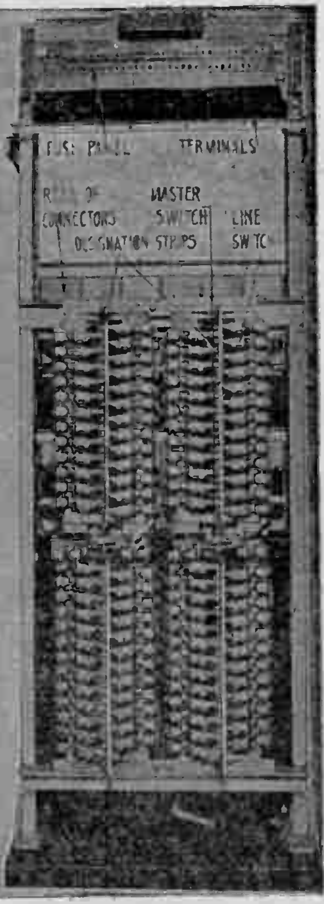
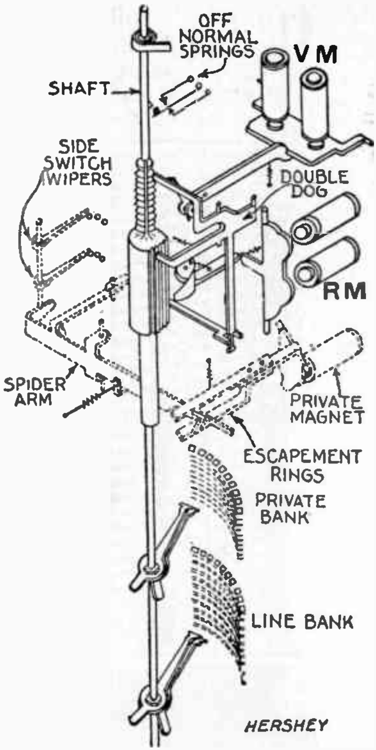


FIG. 8,430.—100 line switch board *front view.* Here are shown 100 subscribers' line switches mounted on a steel frame in four sections of 25. Two sections of 25 are mounted on each swinging shelf and each shelf of 50 are controlled by a master switch. Above the switches may be seen the power panel and terminal assembly.

FIG. 8,431.—100 line switch board *rear view.* On the rear of a line switch unit are mounted the connectors which serve that 100 lines. The incoming subscriber's lines, besides being connected to the line switches are also connected to the connector bank contacts. The capacity of a unit is usually 24 or 28 connectors, although it is seldom necessary to install more than 15 except for party lines.

by the shaft which has a step-by-step vertical movement and a step-by-step rotary movement. These movements are actuated by pawls and ratchets operated by electromagnets controlled by the subscriber from the calling device on his telephone, and are always in accordance with the last two digits of the number he calls.



For example, if he call a number ending in 43, the shaft is raised four steps and then rotated three steps, thus raising each wiper opposite the fourth row of contacts from the bottom of its respective bank and then sliding it over to the third contact in the row.

The machine is then ready to close the circuit of the calling subscriber through to the circuit of the called party, but before doing this it first closes the private wiper circuit only and thus makes an automatic busy test.

If it find the desired line busy, it keeps the connection open and immediately transmits the busy signal back to the calling subscriber.

If the desired line be not engaged, the connector switch immediately

FIG. 8,432.—Diagram of connector switch, and the two banks of contact. The switch consists of a shaft arranged to make under control of magnets, a step by step vertical movement, and a step by step rotary movement. Attached to the shaft near its lower end are two wipers, the lower (double) wiper makes contact with the *line bank*, and the upper (single) wiper makes contact with the *private bank*. Further up on the shaft are vertical teeth by which the shaft is raised step by step, and just below which is a pinion or hub of rotary teeth by which the shaft is rotated step by step. The coiled spring at the top of the shaft causes it to return to its initial position when released. Gravity is utilized to lower the shaft to its initial vertical position.

begins to ring the called party's telephone bell automatically and intermittently. When he answers, the ringing stops and the two subscribers' lines are closed together for conversation.

Talking current is supplied to the transmitters of both telephones from the central office battery through the relay coils of this connector switch, just as in manual practice it is supplied through the relay coils of the cord circuit.

The diagram fig. 8,432 shows clearly the mechanism of the connector switch.

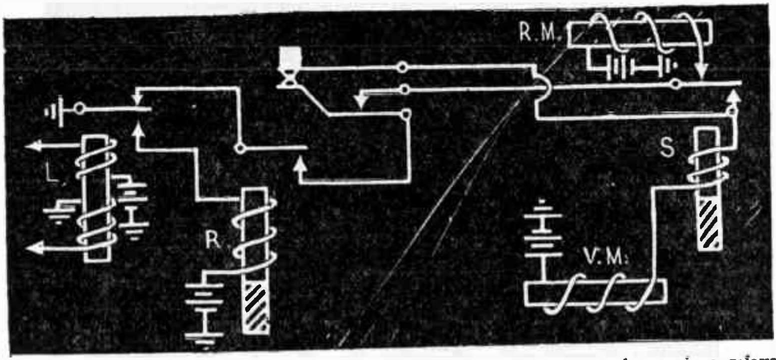


FIG. 8,433.—Connector switch circuit. When the subscriber removes the receiver, relays L and R, are closed as explained in fig. 8,426. Suppose the first number dialed by the subscriber be 4, then the circuit of relay L, is momentarily opened 4 times; which in turn each time opens the circuit of relay R. Since R, is slow acting it does not open. The first time relay L, armature opens a circuit may be traced *from ground, break springs relay L, make springs relay R, break contact "off normal spring" relay S, through vertical magnet to battery.* The current in the circuit causes relay S, and the vertical magnet to operate. S, being slow acting remains in position for fraction of a second. When relay and armature again opens the same circuit is closed, except that since the shaft has already been raised one step, the circuit will pass through the *make contacts of the "off normal spring" and the make contacts of relay S.* Shortly after the last impulse of current has passed through S, it will open and cannot again close because of the open circuit at the off normal springs: When the subscriber dials the second number, each time relay L, opens, a circuit may be braced from *ground break springs relay L, make springs relay R, make off normal springs, break springs relay S, through rotary magnet to battery.* The current in this circuit causes the rotary magnet to close a number of times corresponding to the number dialed, thus rotating the switch to the proper contact.

Connector Switch Circuit.—This circuit includes *the vertical and rotary magnets, which operate the switch.*

Fig. 8,433 shows the circuit, which it should be noted, is a continuation of the subscriber's circuit shown in fig. 8,426, the two relays L and R, of fig. 8,433 being the same relays at L and R, of fig. 8,426.

Private and Line Banks.—As shown in fig. 8,432 these form a part of the connector switch. The diagram fig. 8,434 shows 100 single contacts in the private bank and 100 double contacts in the line bank.

Each telephone is connected to a certain pair of contacts in the line bank. For each pair of contacts in the line bank, there is a corresponding contact in the private bank associated with it.

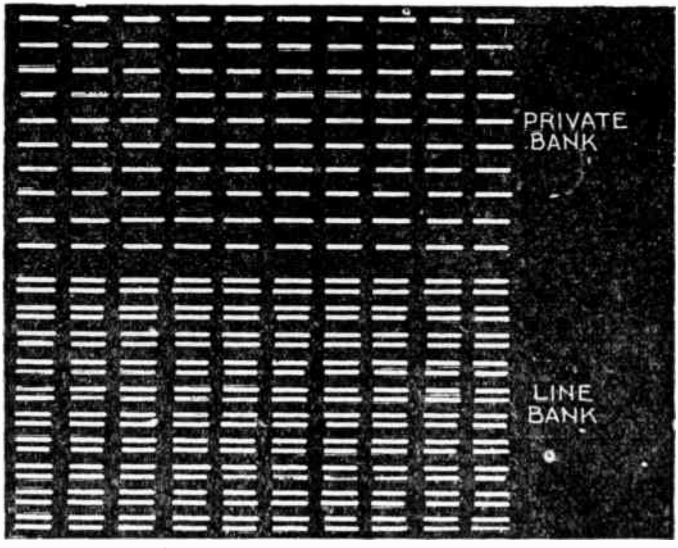


FIG. 8,434.—Diagram showing contacts of line and private banks of a 100 line system. These banks form a part of the connector switch.

The object of the private bank is *to protect a line against intrusion when that line is in use;* it is in other words, a busy test bank and in operation, whenever a telephone is in use the corresponding private bank is grounded.

Private Bank or Busy Test Circuit.—This is shown in fig. 8,435. The spring assembly on relays A, and W, are what are called *make before break* springs.

When current flows through the relay, the make spring strikes the movable spring and causes it to break contact with the stationary spring.

When relay B, is once energized it is independent of the private bank contact ground, hence the busy tone is continued even though the called line becomes idle.

When a busy line is called, the wiper cut off relay W, does not cut the connection through the wipers, hence there will be no interference with those already using the line.

The circuit of the rotary magnet is taken through a pair of break springs on relay B, so that a subscriber, while receiving the busy tone cannot again operate the rotary magnet by interfering with the dial.

The make springs on relay A, prevent opening of the rotary magnets, due

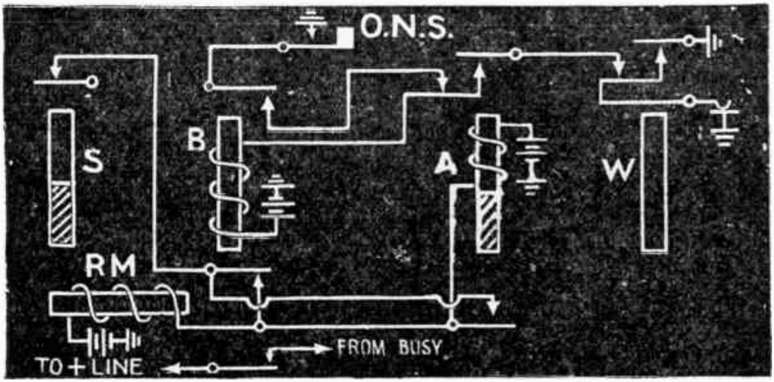


FIG. 8,435.—Private bank or busy test circuit. Assuming a telephone in use and its private bank grounded, relay A, being slow acting, will remain energized momentarily after the completion of the rotary movement. Now a circuit may be traced *from ground at private bank contact, through private wiper, break springs relay W, make springs relay A, through busy relay B, to negative battery.* The current in this circuit will cause relay B, to close forming a locking circuit for itself independent of the ground from the private bank contact. This circuit may be traced from "*off normal spring ground,*" *make springs relay B. break springs relay A* (which by this time has opened) *through relay B, to battery.* Further relay B closes a pan of contact which places the busy time on the line indicating to calling subscriber that the line is busy.

to the tendency of relay B, to operate should the private wiper pass over one or more busy contacts.

If the called line be idle, there will be no guarding ground on the associated private bank contact. After relay A, opens a circuit is closed through the wiper cut off (or ringing) relay W, which grounds the private bank contact, so that any one calling this number will receive the busy tone, thus protecting the busy line against intrusion.

Disconnection of Connector Switch.—After the completion of a telephone conversation means must be provided *for returning*

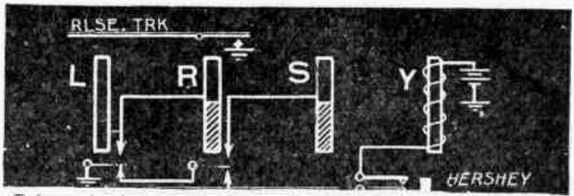


FIG. 8,436.—Release circuit by which the connector switch double dog is operated to restore connector switch to normal. Since during conversation, the line relay remains closed the connector switch release circuit remains open. Now when the receiver is hung on the hook (at the calling station) the line relay opens and a moment after the release relay opens. This completes a circuit *from ground, break springs of line relay, break springs of release relay, off normal springs, through release magnet Y, to battery and ground.* This energizes the release magnet which removes the double dog allowing connector shaft to return to normal position, the release circuit being opened at the off normal springs when the shaft reaches the normal position. On the release relay is a pair of make springs, by which ground is placed upon the release trunk.

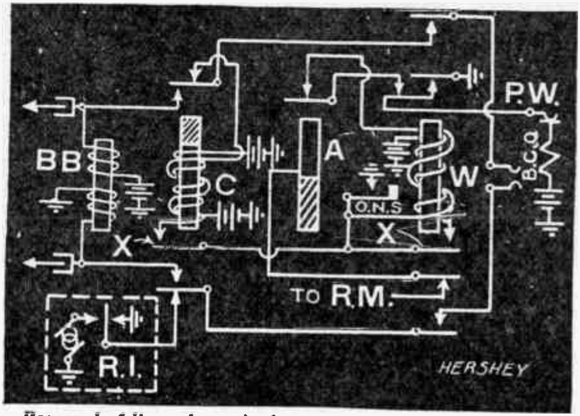


FIG. 8,435a.—***Removal of line wipers during rotation.*** When the second number dialed requires several steps of rotation, the line wipers during the rotation make contact with the contacts rotated over. Hence, if any of the lines rotated over be busy an unpleasant sound would be heard as the wipers passed over the contacts unless they be disconnected from the connector during the rotary movement. Assume number 65 has been called and that the line and private wipers are now resting upon the bank contacts associated with telephone number 65. When relay A, de-energizes, following the last rotary impulse, a circuit may be traced from "off normal spring ground," low winding relay W, break springs relay A, break springs relay W, private wiper, private bank contact, through the B.C.O. to negative battery. The lower winding of relay W, will energize sufficiently to close the springs X, thus forming a locking circuit which may be traced *from "off normal spring ground" springs X, through the high winding of relay W, to battery.* The current in the circuit will cause relay W. to fully operate so that the line wipers are cut through to the connector and ground is placed on the private wiper.

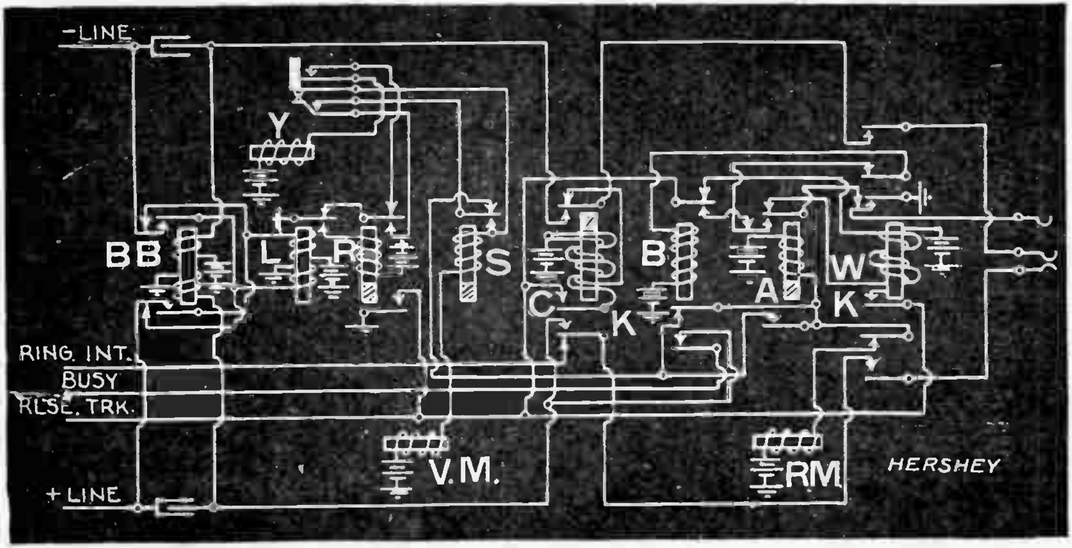


FIG. 8,437.—Diagram of complete connector circuit.

the connector switch to its normal position, when the subscriber hangs up the receiver, thus disconnecting the line.

This is done by a part of the connector switch mechanism called a *double dog* operated by a *release magnet.* The circuit which controls the release magnet, called the release circuit is shown in fig. 8,436.

Complete Connector Circuit.—Connections in this circuit are shown in fig. 8,437.

Included in the diagram are the familiar line and release relays, also, series relay, instantaneous ring cut off relay, busy relay, back bridge relay, wiper cut off relay, release magnet, vertical magnets, rotary magnets, and slow acting rotary control relay. The duties of these various relays are here briefly given.

Line Relay—Receives the dial impulses and repeats the same to the vertical and rotary magnets; also feeds talking battery to calling subscriber.

Slow-Acting Release Relay—Prepares circuit of the vertical and rotary magnet, and maintains the release magnet circuit open until such time as the conversation is completed.

Slow Acting Series Relay—Used to operate the vertical magnets.

Busy Relay—Used to give a calling subscriber a busy tone in case the line called be busy. It also prevents undue rotation of the shaft by the rotary magnets.

Ring Cut Off Relay—Feeds ringing circuit to the called line and releases ringing circuit when the subscriber answers.

Back Bridge Relay—Feeds talking battery to the called subscriber, and reverses polarity of the calling line.

Wiper Cut Off Relay—Cuts connector through to the wipers when an idle line is reached.

Vertical Magnets—Gives vertical movement to connector shaft when first number is dialed.

Rotary Magnets—Gives rotary movement to connector shaft when second number is dialed.

Release Magnet—Removes double dog to restore connector shaft to normal position when receiver is hung on hook at completion of conversation.

Rotary Control Relay—Operates in parallel with the rotary magnets, and closes the circuit through to the busy relay.

Line Switch.—As must be evident the complicated connector switch is a very costly part of the apparatus, and if, as has been assumed in the previous explanation that each line is provided with one of these connectors, the cost of the installation would be prohibitive. Now since only a small number of lines are in use at one time, it will suffice *to employ only a few connectors in* *proportion to the number of lines, if there be provided means by which when a subscriber removes his receiver from the hook, his line will be connected to an idle connector switch.* This is accomplished by what is called the *line switch.*

With this device, it has been found in practice that only ten connector switches are needed for each 100 line installation.

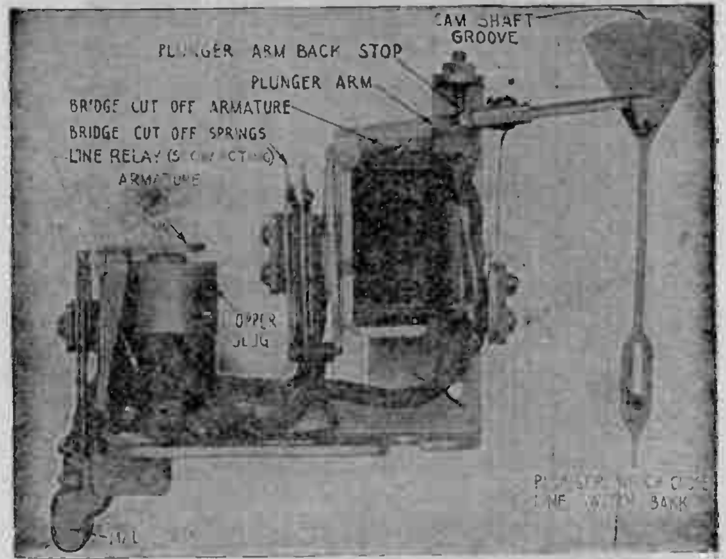


FIG. 8,438.—Line switch. ***It consists of*** a line relay and a combination "pull down coil" and "holding coil" carrying two armatures. The larger armature carries a plunger, which is pivoted so that its point may be swung by the master switch in front of a bank of contacts. The bank consists of 10 sets of contact springs with which are associated ten trunks. Line switches are mounted in groups of 25, four groups being provided for each 100 line unit. One master switch may be provided for any number of groups of line switches depending upon the trunking capacity desired, since each master switch controls ten trunks. Normally the plungers are at rest poised over bank contacts multiplied to an idle trunk. When a subscriber removes his receiver from his telephone switch hook preparatory to making a call, a circuit is thereby closed which causes the plunger arm of his line switch to be at once pulled down, carrying its plunger out of engagement with the master shaft and thrusting it into the bank. The effect of this is to connect the subscriber's line to a trunk leading to an idle first selector switch, as shown diagrammatically in the right hand portion of the figure. The instant that one line switch thrusts its plunger into the bank, thus occupying the trunk over whose multiple all idle plungers have been poised, the master switch operates and swings the remaining idle plungers forward over the next multiple of bank contacts. If this trunk should be busy, the movement proceeds until an idle trunk is found. It is to be noted that a line switch always uses a pre-selected idle trunk instead of making a selection after a subscriber starts to call.

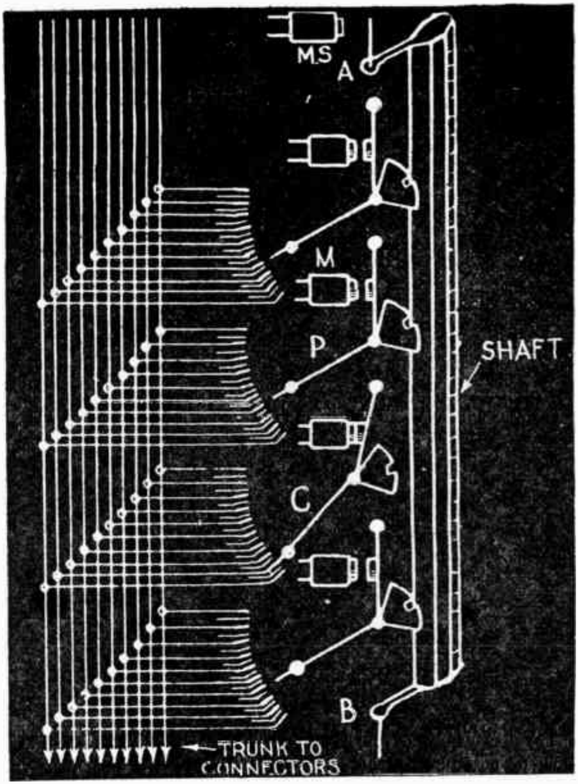


FIG. 8,439.—Diagram of line switch and connections. The switch *consists of*, a magnet M, and plunger P, whose head or wing is slotted so that it may engage a projecting edge of the shaft. The shaft is pivoted at A and B, and is capable of a rotary motion of about 40 degrees under control of a master switch MS. The rotary motion causes the plungers of the various line switches to oscillate in front of the terminal of the trunks to the connector switches. Under control of the master switch the shaft comes to rest *only* opposite an idle trunk. If the shaft be holding all the plungers opposite, sav the second trunk, and a subscriber remove his receiver, the corresponding plunger will *plunge in* and extend the connection to the connector associated with trunk number two. The plunger when *plunged in* is now free of the shaft as shown at C. The master switch, by means of the shaft moves the remaining plungers opposite an idle trunk, giving what is called *pre-selection of trunks*. When the subscriber who plunged in on trunk No. 2, hangs up his receiver, his plunger will come out of the bank but the slot in the wing of the plunger will not engage the shaft at this time. Hence this plunger will remain opposite trunk No. 2, until the shaft again swings in front of this trunk and picks it up. To prevent a caller connecting on a busy trunk, a plunger must not plunge in while the master switch is seeking an idle trunk. This requirement is met by what is called the *open main battery feed*.

In making a connection, after the line switch (also called the *non-numerical switch*) connects the line with an idle connector, the connection is completed by the connector switch as already described.

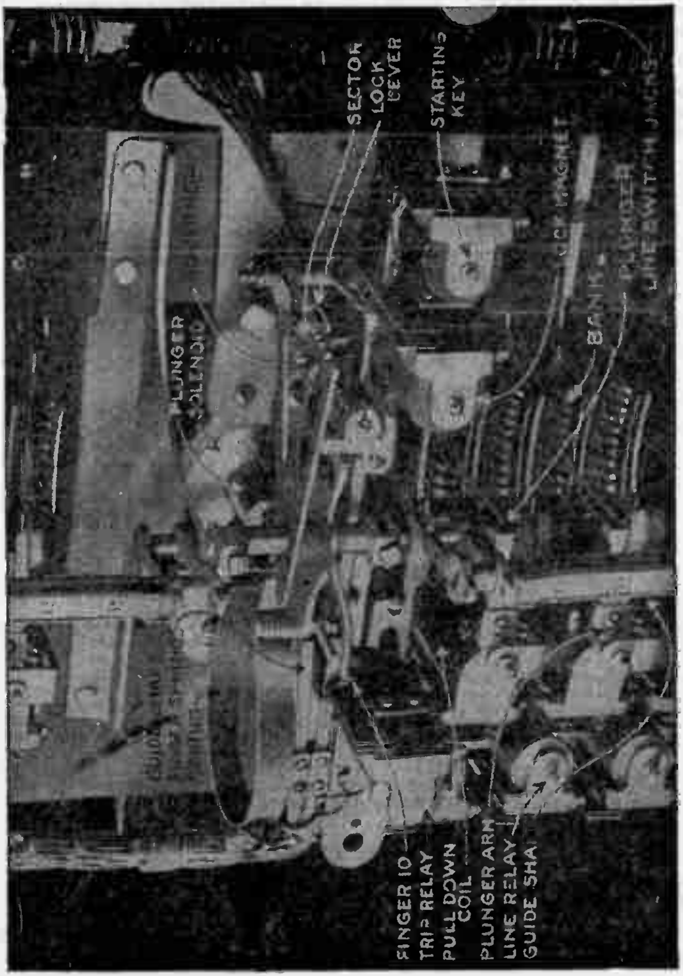


FIG. 8,440.—Mechanism of line switchboard.

Fig. 8,439, shows the working of the line switch, and fig. 8,440, its general appearance.

An important part of the line switch is the solenoid, which operates the shaft of the line switch in seeking trunks and the locking mechanism. This part of the mechanism with its circuit is shown in fig. 8,442.

The shaft of the line switch is moved counter clockwise by a spring, and clockwise by the solenoid. One arm of the locking segment L, is arranged to face springs Y, into contact when the switch is standing opposite the first trunk.

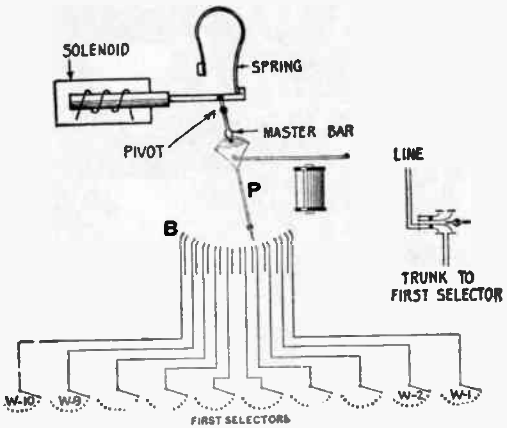


FIG. 8,441.—Master switch mechanism of line switch and diagram of trunks to first selectors. In the line switch, the notch in the head of each plunger meshes with a rocking bar or "master shaft" as it is called. A step by step device called a master switch (seen in the upper part of the figure) is connected to each pair or to each four master shafts and by means of them can swing the plungers back and forth, step by step over the banks of contact springs. The plungers are normally held in position by the master bar, which carries a feather fitted into the slots at the rear of the plunger. When the line switch operates, the plunger point is thrust into the bank, connecting the line to the connector or selector trunk, and at the same time disengaging itself from the master bar. The master switch is now automatically unlocked and begins to move under the action of the curved spring until an idle trunk is reached. When the master switch reaches the end of its stroke, the solenoid is energized and this pulls the shaft back in the opposite direction against the action of the spring.

The trip relay T, has a mechanical locking feature, which after it is once energized, will hold the springs in an operated position until mechanically released.

A section of L, is so formed as to release the springs of the trip relay T, when the master switch comes opposite the tenth trunk.

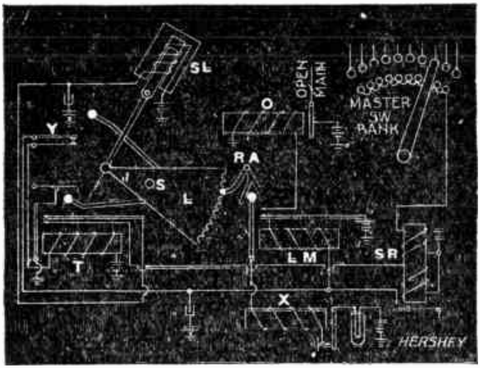


FIG. 8,442.—Solenoid control of line switch shaft, locking mechanism and circuit. If the line switch be standing opposite, say trunk No. 8, and a plunger plunges in on the trunk, a circuit can be traced from *release trunk ground, through master switch wiper and starting relay SR, to battery and ground.* SR, will energize and close a circuit *from ground through springs of relay SR, locking magnet ML, to battery and ground.* The locking magnet will operate to remove the retaining air from the locking segment, which now being free, to move, under the action of the spring will swing switch wiper and plungers in front of trunk No. 7. If this trunk be idle, the associated bank contact will not be provided and relay SR, will open and break the locking magnet circuit allowing the retaining arm to drop into the seventh slot of the locking segment. This arrests the rotation of the line switch shaft and holds the plungers opposite the seventh trunk until that trunk becomes busy. If this trunk had been busy the circuit of relay SR, would not have been opened, and the rotation would have continued until an idle trunk was reached. A plunger cannot plunge in while the master switch is moving for during the motion the open main circuit is open at the springs of relay O. The springs of the locking magnet, when in an operated position, also close a circuit through the supervisory relay X.

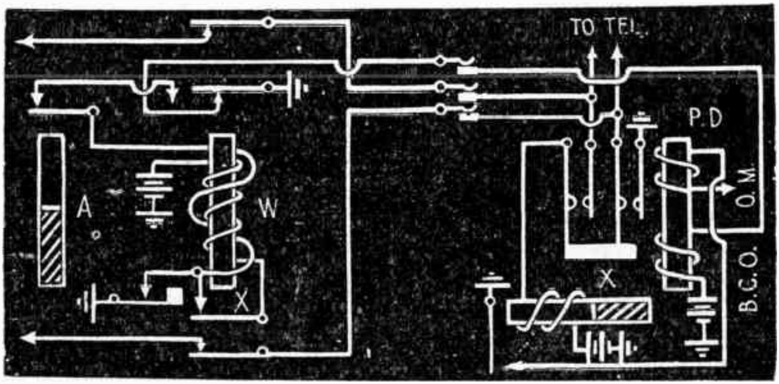


FIG. 8,443.—Diagram of portion of a connector switch circuit illustrating *clearing the called line of attachment.* Suppose a called line found to be idle and relay W, cut the connector

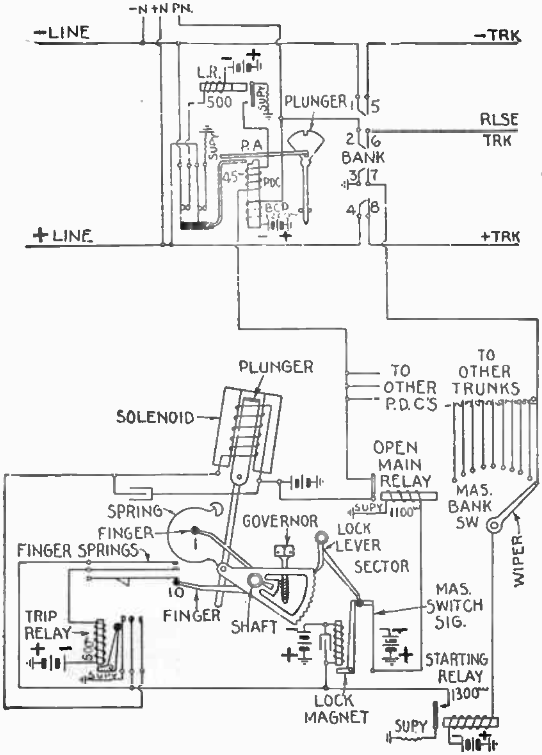


FIG. 8,444.—Line relay and master switch circuits.

There are ten sets of double contacts in the master switch bank, the lower contact being multiplied together. Each contact of the upper row is associated with one of the line switch trunks.

The switch wiper short circuits the upper and lower bank contact associated with the trunk upon which it happens to be standing.

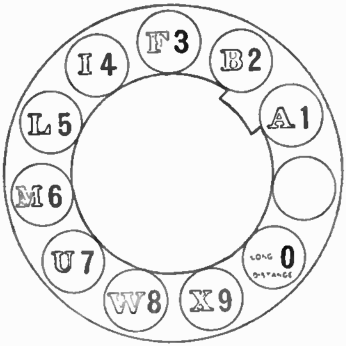
The locking magnet LM, operates to force its springs together and draw retaining arm RA, from locking segment L. Again if the retaining arm be resting against locking segment L, but has not yet fallen into a slot, it will hold the springs of relay LM, in contact. The operation of the solenoid control is explained in fig. 8,442.

FIG. 8,443.—*Text continued.*

through to the wipers. A part of the plunger circuit associated with the called line is shown at the right. When relay A, releases after dialing, a circuit may be traced from *"off normal spring ground", low winding of relay W, break springs relay A, break springs relay W, private wiper, through the B.C.O. of the called plunger to battery and ground.* The B.C.O. of the called plunger will clear the called line of attachments, and relay W, will operate sufficiently to close springs X. When this condition obtains, a circuit may be traced from *"off normal spring ground," make springs relay W, high winding of relay W, to battery and ground.* The current in this circuit fully operates relay W. Direct ground is now placed on the private bank contact by springs of relay W, *so slowly* that the B.C.O. of the called plunger will have sufficient time to clear the called line of attachments before W, cuts the connector through to the wipers. The springs of W, are of the *make before break* type so that the B.C.O. will not be opened.

Clearing the Called Line.—When a telephone is called it is necessary that the line be cleared from battery and ground feed. This is called "clearing the line of attachments" and is illustrated and explained in fig. 8,443.

2. MULTI OFFICE SYSTEMS



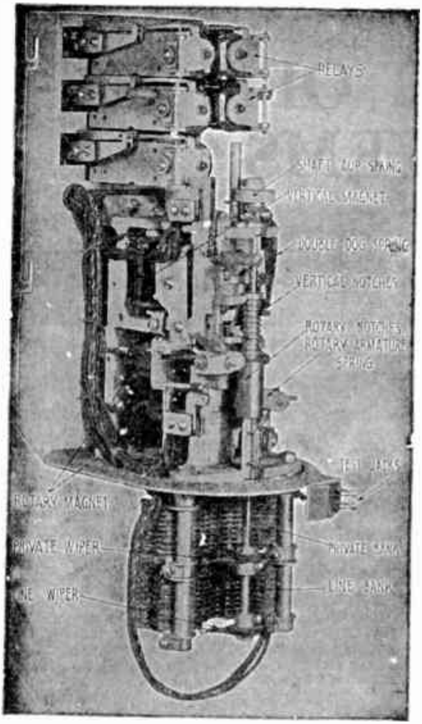
Up to this point only a 100 line, single office exchange system with 10 connector switches has been considered However, in practice, a single office may contain any number of lines. There is no limit either way. A recent single office installation at Norfolk, Va., of 11,500 lines is at the present, the largest single office in existence.

FIG. 8,445.—Multi-central station dial. On all 100,000 line systems the numbers are made up of a letter and four figures instead of five figures. With this method of numbering 26,187 would, for instance appear in the telephone directory as B-2187. When operating the calling device many subscribers will remember a letter and four figures more clearly than they will five figures.

The grouping of lines in multi-office exchange system is, with respect to the exchanges strictly according to number.

Thus, assuming 100 line units, telephones numbered 1 to 99 are wired to exchange A, those numbered 100 to 199, to exchange B, etc. At each of these exchanges is a set of *connector switches, through which connection is made with any subscriber's line which terminates at the same exchange.*

Now if a subscriber whose line terminates at exchange A, desire to talk with a subscriber where line terminals at exchange B, *he must first obtain connection to an idle connector switch in exchange B*, and in order to do this a new piece of apparatus *called a* ***selector switch*** *is necessary*, as shown in fig. 8,446.



It looks, and is very much like a connector switch; in fact the mechanism and banks are the same. Its mechanism gives the familiar vertical and rotary motion to a shaft and wipers and differs from the selector switch in the circuits and relays only.

In any multi-exchange system, the selectors *are divided into a number of classes according to the size of the group they are to choose.*

For example, in a 10,000 line system first selectors would choose the 1,000 line group, and second selectors the 100 line unit.

FIG. 8,446.—Stronger type selector with banks. ***It consists of*** a group and trunk choosing switch. Like the connector it comprises the usual shaft, bank, and wipers, and a mechanism whereby the shaft can be lifted and rotated step by step. Unlike the connector, however, it is a one digit switch. The vertical motion is controlled from the calling device and serves to pick out a certain group of lines. The rotary motion is automatic and picks out an idle trunk leading to that group.

The bank contacts of the selector switches are terminals of trunk lines instead of subscribers' lines

The first or lower row of first selector bank contacts constitutes the terminals for a group of 10 trunk lines leading to second selector switches in the **1,000** section of the plant.

The second row represents another group of 10 trunk lines to second selectors in the **2,000** section of the plant, the third row represents a group of trunks leading to second selectors in the **3,000** section of the plant, etc., so that through the 10 rows of bank contacts the first selector has access to 10 second selectors in each of the 10 sections of 1,000 lines which make up a 10,000 line office.

The first selector switch used by a calling subscriber is operated *in accordance with the first digit of the number he calls.*

Suppose, for example, he is calling the number **2,543**. The impulses sent in by the first movement of his calling device will raise the shaft, and accordingly the wipers of the first selector switch two steps, placing each wiper opposite the row of bank contacts second from the bottom in its respective bank.

Now the selector switch unlike a connector switch, does not wait for the subscriber to make another turn of his dial before rotating its shaft, but the rotation is automatic and beyond the subscriber's control.

The rotation starts the instant the vertical movement is completed, and, in the particular case which is here used as an example, sweeps the wipers step by step over the row of bank contacts connected to trunks leading to the **2,000** section.

At each step of the rotation, the bank contacts on which the wipers then rest are given the busy test, and as soon as a disengaged trunk line is found the rotary movement stops and the connection is completed to an idle second selector. This is all accomplished in a fraction of a second, so that the second selector is operated by the subscriber's calling device impulses corresponding to the second digit **5**, of the number **2,543** which he is calling.

The wipers of the ***second selector*** are accordingly raised five steps and are then automatically rotated just as the first selector wipers were. The bank contacts of this second selector are the terminals of the trunks to the 10 sets of connectors which complete the connections to the line groups making up the **2,000** section of the plant. Consequently when the second selector wipers stop on an idle trunk in the fifth multiple, the calling subscriber is placed in connection with an idle connector in the **2,500** group; that is, a connector which has access to the desired subscriber's line No. **2,543**. This connector is then operated by the last two movements of the subscriber's calling device, and performs the functions of an operator in the manner already described at some length.

Fig. 8,447 illustrates this grouping arrangement and shows the connection just described from the calling telephone to a first selector, then from the second row of first-selector bank contacts to a second selector in the **2,000** section of the exchange, then from the fifth level of this second selector's bank contacts to a connector switch in the **500** group of the **2,000** section, and then through the fourth row of the bank contacts of this connector to the called telephone.

It is readily understood that by thus using a first selector to

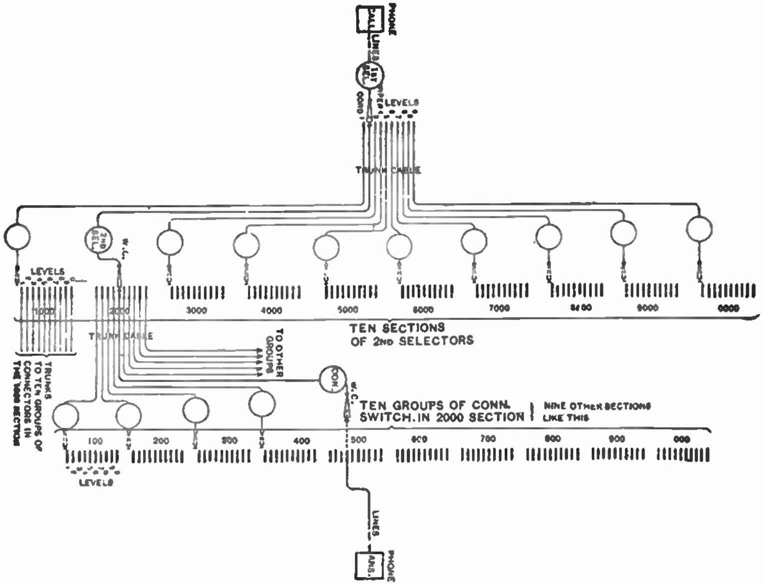


FIG. 8,447.—Diagram illustrating working of the multi-exchange system *by means of selector switches.* As shown, connection has been made by a subscriber with phone No. 2,543, by means of *first* and *second selector switches* and a connector switch, the latter located at the central station at which the line of the subscriber called terminates.

pick out a trunk to any one of ten different **1,000** sections, second selectors in each section to pick out trunks to any **100** group in each **1,000**, and then by using the connectors to complete calls to individual lines in each **100**, that connection may be made by the use of three switches from any calling telephone to any number from **0000** to **9,999** or in other words to **10,000** different numbers.

It will also be readily understood that by using a fourth switch, called a third-selector switch, and using numbers with five digits instead of four, that the capacity of the system will be multiplied by ten and will be 100,000 lines instead of 10,000.

In a system of 100,000 lines, **10,000** numbers are generally set aside for

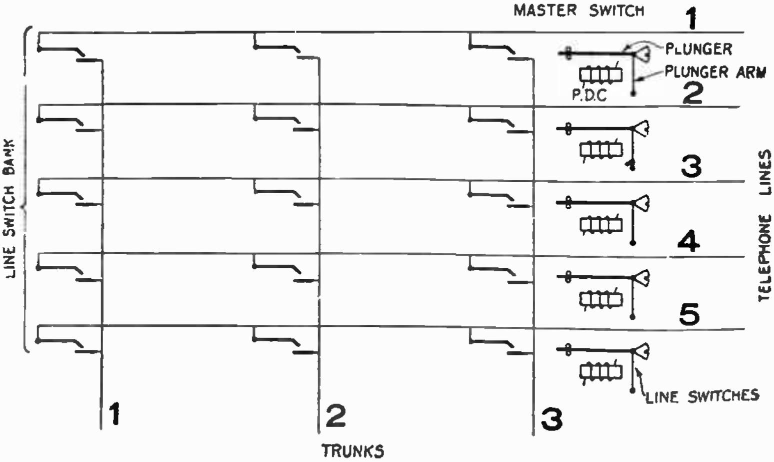


FIG. 8,448.—Diagram showing relation between the lines and the trunks at the line switch banks. Although only three trunks are shown, it must be understood that there are always ten, and the number of lines may be anywhere from 25 to 100. Assume that the position of the master switch is such that each line switch plunger is pointing opposite its set of contacts belonging to trunk No. 3. If a call be originated on say line No. 3, the plunger of that line switch will operate to close its pair of contacts on trunk No. 3, thus connecting the line with the trunk. At the same time the master switch operates to move the remaining plungers until they are resting opposite the contacts of line No. 2, (assuming that trunk to be idle). The next line switch being used will take trunk No. 2 and the rest of the plungers will take up a position opposite the next idle trunk. It must be understood that the trunk finding movement takes place from No. 10 to No. 1. The master switch does not preselect trunks in moving from No. 1 to No. 10, but passes over them without stopping.

each main central office. Consequently on each call the first selector picks a trunk to the desired office, the second selector picks a trunk to the desired **1,000** in that office, the third selector picks a trunk to the desired **100** and the connector completes the connection to the desired line.

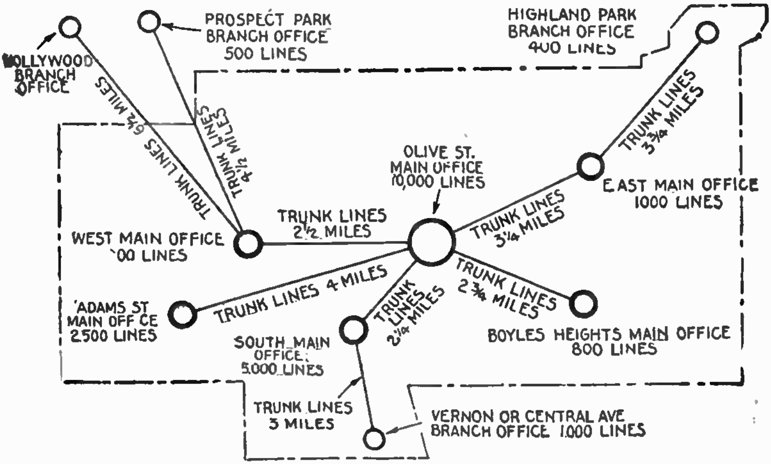
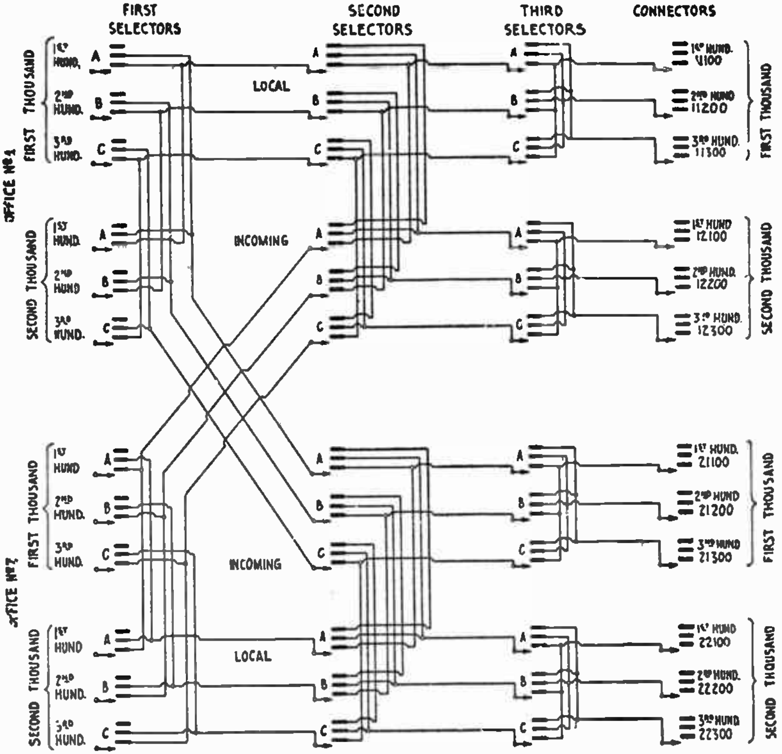


FIG 8,449.—Diagram of automatic telephone system installed at Los Angeles, Cal. As shown there are six main offices, each with an ultimate capacity of 10,000 lines. The Olive Street main office is now equipped for 10,000 lines, West for 4,000 lines, Adams for 2,500 lines, South for 5,000 lines, Boyles for 800 lines and East for 1,000 lines. The numbers in the South Office all commence with **29,000**. Those in Olive Street Office all commence with **60,000** etc. South office has a branch office called Vernon; West office has two branches which are called Prospect Park and Hollywood; East office has a branch called Highland Park. The numbers in each branch office commence with the same digit as the numbers in the main office to which it connects. That is: one of the sections of **1,000** numbers are taken from the main office and are set aside for use in the branch. For example: the lines now equipped in South office are numbered from **21,000 to 25,000** and the numbers in its branch Vernon run from **29,000 to 29,999**. It is of course, unnecessary for a calling subscriber to know to which office he is connected or to which office the party he desires to call is connected. The trunking between offices is all automatic. A subscriber, for instance, in the South office, who, on the first move of his dial turns it from the number **2**, will automatically select a local trunk line to a second selector in South office. If he make the first turn from the number **3**, a first selector at South office will automatically connect him to a trunk line terminating in a second selector at East office. Or, if he make the first turn from the number **6**, the first selector at South Office will automatically select an idle trunk to Olive Street office, etc. Suppose, a subscriber connected to the South Office wish to call **62,127**, which is an Olive Street office number. The first movement of the dial operates a first selector at South office, and extends the connection over an idle trunk to a second selector switch in the Olive Street office. The second digit **2** will operate the second selector at Olive Street office, and extend the connection to a third selector in the **2,000** section of the Olive Street switchboard. The third digit **1** will extend the connection to an idle connector switch in the **100** group of the **2,000** section. The last two digits will operate this connector switch and complete the connection to **27** in this particular **100**. Suppose, again, that a South office subscriber is calling **39,143** which is in the Highland Park branch office. The first movement of the dial operates a first selector in the South office and selects a trunk to a second selector in the East Main office. The second movement of the dial raises the shaft of this second selector nine steps, and selects an idle trunk to a third selector in the Highland Park branch office. The third movement extends the connection through a local trunk in the Highland Park branch office, to an idle connector in the **100** group, and the last two motions of the dial result in the completion of the connection to **43** in that particular hundred. The time required to complete a connection and the number of machines used is independent of the number of offices through which a connection may be trunked.



INTER OFFICE TRUNKING (100,000 LINE SYSTEM)

FIG. 8,450.—100,000 line automatic telephone system. Such a system is necessarily divided up into several offices, because it is too large to be placed in one. The ideal distribution would have 10 offices of 10,000 lines each. The details of switch connections may be illustrated by using only two offices. Each office is somewhat like an ordinary 10,000 line exchange. There are 10 connectors for each 100 lines and there are 100 selectors which deliver traffic in a given thousand, consisting of 10 hundreds. These selectors are now called third selectors, although their function is exactly the same as that of the second selectors in a 10,000 line system. Back of the third selectors are other selectors whose duty it is to choose thousands. The banks of the first selectors in the 100,000 line system distribute traffic to the offices of levels. One level will be the local level, because it runs to second selectors in the same office. All the rest of the levels trunk out to other offices. All the trunks from the given level of first selector banks run to a given office and any trunk serves as well as any other. They can all be formed into one group by means of secondary line switches. This is common practice. The incoming trunks end on incoming second selectors. Their banks are multiplied to the banks of the local second selectors in such a manner as to mingle the traffic as uniformly as may be done.

Systems of 100,000 lines capacity have been installed in a number of different cities. One of the most notable is that in Los Angeles, as shown in fig. 8,449.

In multi-central installations, each line terminates at a line switch. The line switch is not under the control of the subscriber, but connects him automatically to an idle first-selector switch the instant he removes hi receiver from his switch hook preparatory to making a call. The first selector is, therefore, operated by the first impulses transmitted from the subscriber's calling device just as in the older systems. When the line switches are used, 10 first selectors for each 100 lines are generally sufficient to handle the traffic.

Each line switch (fig. 8,438) includes the line and cut off relays with which each line is equipped just as in manual practice.

Ordinarily the banks of 100 line switches are multiplied together and connected to 10 first selector trunks, but for four-party line service or extra heavy traffic, the number in one multiple is often reduced to fifty. Fig. 8,430 shows a front view of a complete line switch unit with 100 line switches and two master switches mounted. Only one master switch is used at a time the other being held in reserve. Fig. 8,431 is a rear view of the same unit showing how the 10 connector switches used for handling calls incoming to any 100 lines are mounted on the same upright as the line switches handling their outgoing calls.

While the primary object of the line switches was to reduce the cost of the switch board by eliminating 90 per cent of the comparatively expensive first selector switches, they have also simplified the central office equipment and have reduced the space required for it. Further, they have resulted in several new and somewhat radical departures in the art of building automatic telephone systems. The most important of these is the line switch district station which enables very considerable savings to be made in underground and aerial cable.

A district station is installed by placing one or more line switch units complete with connector switches in a small building at the telephonic center of a district, generally a mile or more distant from the nearest central office. The lines of all telephones in the district are brought to the district station and are there connected to the line switches. The first selectors to which these line switches are trunked remain at the nearest large central office, consequently when a district station subscriber removes his receiver from his switch hook preparatory to making a call, his line switch instantly puts him into connection by means of a trunk with a first selector switch at central office. The connector switches for handling the calls to the district station telephones are mounted in their usual places on the back of the line switch units, and are connected by trunks to the banks of second selectors, also located at the nearest central office. Thus all calls from and to the district are handled over trunks instead of over subscribers' lines.

CHAPTER 52

Motion Picture Projectors

The function of a moving picture machine or *projector* is *to project motion pictures upon a screen*. The machine not only projects pictures on the screen, but is usually provided with apparatus for reproducing *synchronized sound*.

The projector proper consists essentially of:

1. An optical system, comprising

   a. Source of light;

   b. Lens { condenser; objective.

2. Intermittent film feed-system, comprising

   a. Upper reel;
   b. Upper steady feed sprocket;
   c. Steady drum;
   d. Film gate;
   e. Intermittent sprocket;
   f. Intermittent movement;
   g. Shutter;
   h. Lower steady feed sprocket;
   i. Lower reel;
   j. Lower reel drive;
   k. Operating crank and drive;
   l. Numerous presser rollers.

Besides these various essential parts, safety devices such as, fire shutter, fire valves, film shields, etc., are provided.

How a Projector Works.—The elementary diagram fig. 7,790 has been prepared to show in a very clear manner the operation of a projector. If the reader imagine the crank A, turned

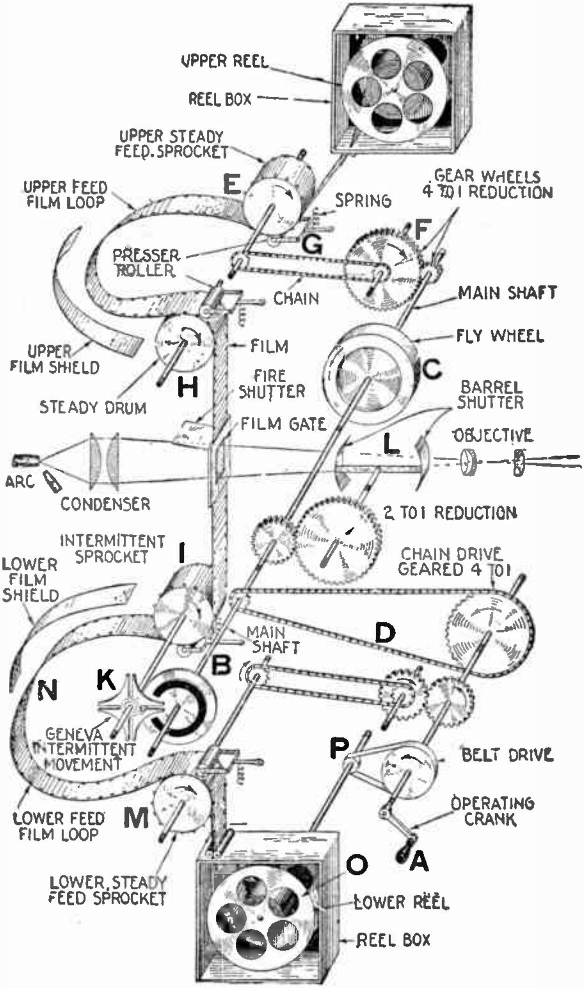


Fig. 7,790.—Elementary moving picture machine without case showing essential parts arranged to illustrate plainly the motion system.

counter clockwise he will have no difficulty in tracing the movements of the various parts.

The diagram does not represent any particular machine but is intended to give a clear idea of how the film is fed across the film gate intermittently and the synchronous operation of the shutter whereby the light is cut off from the screen during each movement of the film, with alternate "on" intervals while the film is at rest.

The operation of the projector is briefly as follows:

By turning crank A, in fig. 7,790, counter clockwise, the main shaft B, is driven through the 4 to 1 reduction chain drive D, a steady turning motion being caused by the fly wheel C, this in turn operates the upper steady feed sprocket E, through the 4 to 1 reduction gear F, thus the teeth of E sprocket which mesh with the perforations in the film, feed the film at a constant rate, the film being held against E by pressure roller G. A film loop or length of loose film is thus maintained between E and the steady drum H.

The film is fed past the film gate intermittently by the intermittent sprocket I, operated by the Geneva movement K, the latter producing a quick quarter turn of I, followed by a relatively long rest during which the main shaft B, makes one revolution.

The barrel shutter L, by a 2 to 1 gear with the main shaft and proper timing, operates to cut off the light rays from the screen during each movement of the intermittent sprocket I, and to admit the light during the intervals that I remains stationary. The synchronous operation of the intermittent sprocket and the shutter is very clearly shown in the diagram.

A lower steady feed sprocket M, which operates at the same speed as the upper sprocket E, maintains a lower feed film loop N, and feeds the film to the lower reel O. Because of the increasing diameter of the roll of film due to winding the film on reel O, the velocity of rotation of O must be allowed to vary; this is accomplished by means of the belt drive P, the belt permitting slippage below the maximum speed. *It should be carefully noted* that the total revolutions made by each of the three sprockets E, I, and M, is the same, the only difference being that the *motion of* E *and* M *is constant while that of* I *is intermittent*.

The object of the upper and lower feed loops is to lessen the inertia of the film by reducing the length of film subject to the sudden intermittent motion.

The film gate guides the film so as to prevent any lateral motion, flattens the film and by frictional resistance prevents the momentum of the film causing any up and down vibration.

The Intermittent Movement.—Various devices have been introduced for producing the intermittent movement necessary in projecting motion pictures. The movement consists essentially of an intermittent sprocket and intermittent gear.

The sprocket is a cylinder with teeth at each end, or for very light construction, it may consist of two hubs provided with teeth and properly

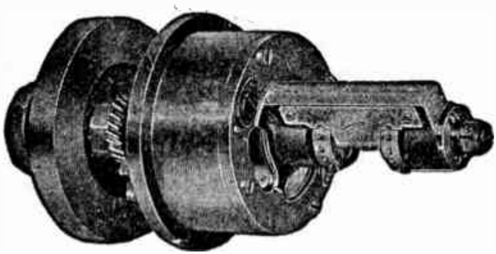
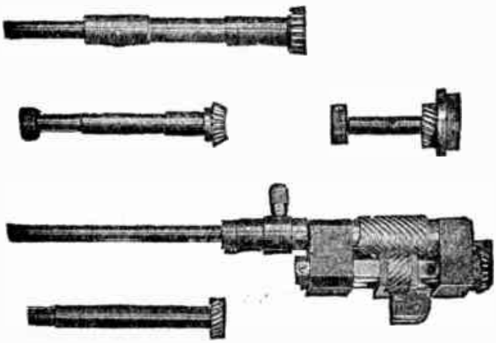


FIG. 7,791.—Simplex Geneva type intermittent movement.



FIGS. 7,792 to 7,796.—Simplex gears. The bevel and intermediate gears are made of tormica, which material absorbs noise and damps the ring of metal gears.

spaced on a shaft to take the film. The teeth mesh with perforations in the film and thus secure a positive movement.

Of the various intermittent movements, the Geneva is extensively used and easily understood. Its operation is shown progressively in figs. 7,799 to 7,804.

The nature of the motion is as follows:

1. Begins slowly (fig. 7,800),

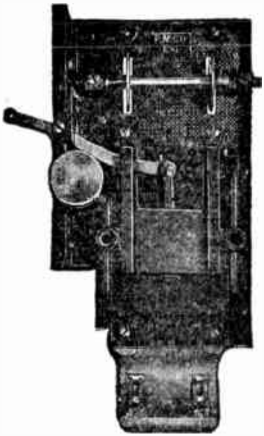


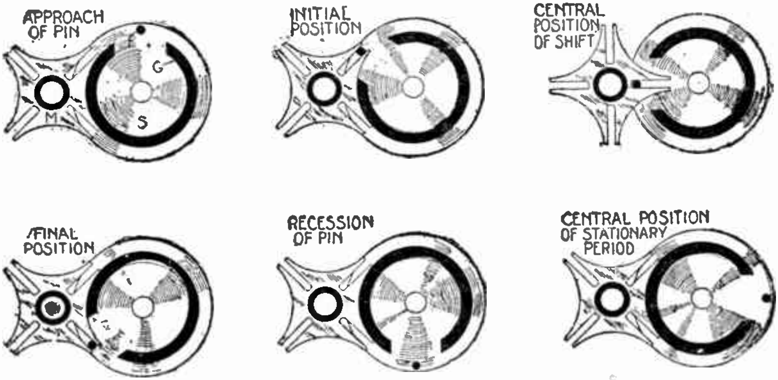
FIG. 7,797.—Simplex film trap. It has a felt runner type of tension shoe. The film guide may be removed from the mechanism by giving it a slight upward thrust; this permits ease and free access to all parts of the trap and door for the purpose of cleaning away emulsion, dust or dirt. Film trap is equipped with a slide in mask which eliminates the projection of the sound track to the screen. By slipping this mask in or out as desired, silent, sound on disc, or sound on film prints may be properly projected at will. A gate locking device also forms part of this assembly. This assures the projectionist that once the gate is closed it will remain locked in position during the projection of pictures. The gate may be released by a slight pressure of the finger when pressing on the opening device to which the lock is attached. The fire shutter is of the gravity type.

FIG. 7,798.—Simplex center frame.

2. Accelerates to a maximum at the mid position (fig. 7,801) and

3. Gradually slows down to zero (fig. 7,802).

Light for Projectors.—Both arc and incandescent lamps are used to produce illumination for motion picture projection.



FIGS. 7,799 to 7,804.—Operation of Geneva movement shown progressively. *It consists of* a maltese cross M, and a disc S, provided with a pin F, and circular guide G. *In operation*, the pin disc S, is in continuous motion and the pin is so located that it enters one slot of the cross M and carries it along with it, thus causing one-quarter revolution. The circular guide G, is cut away sufficiently to allow the cross to make a quarter revolution, but when it registers with the cross it holds the latter securely until the pin rotates around to the next slot.

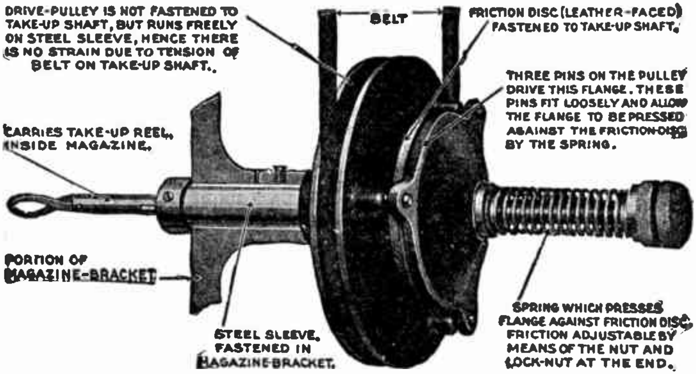
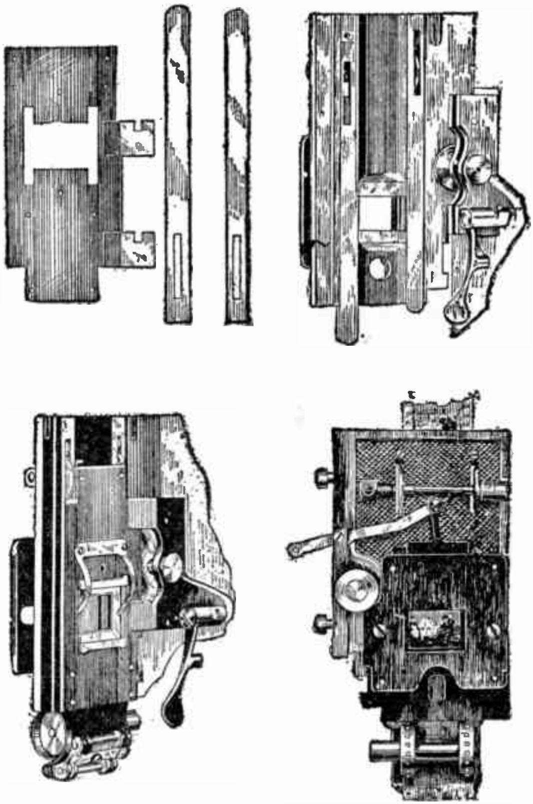


FIG. 7,805.—Simplex take-up device. *It is driven* from the main driving gear, thus balancing the entire mechanism and equalizing the strain on the main driving shaft. The unit is adjustable for any desired tension. Two grooved pulleys are furnished permitting the use of reels with either 2 in. or 5 in. hubs.



Figs. 7,806 to 7,811.—Construction details of Simplex film gate. It is made of machine steel; the lugs securing the gate to the holder being electrically welded. Fig. 7,806 represents milled surfaces. The film trap shoes (figs. 7,806, 7,810), are of steel ground on both sides and beveled (fig. 7,806) to permit sliding into the dovetail slots (fig. 7,809). The lateral guide rollers (fig. 7,810 and 7,811) are of steel hardened and ground; the film cannot pass the guide rollers unless it be set between the two. If it should not be, it automatically rights itself. The distance between the rollers is adjustable by a set collar (fig. 7,811). The gate (fig. 7,810) is opened for threading by a light inward pressure on a thimble (fig. 7,811), and is closed by releasing the film trap door trip lever (fig. 7,810). Thus, in threading, there are only two operations: one to open, and one to close the gate. The intermittent sprocket tension shoe is made of ten pieces of hardened tool steel. The two inside shoes are offset and do not touch the film. The cooling plate (fig. 7,811) is made of two pieces of sheet steel separated ¼ inch, which arrests the heat by radiation and protects the fire shutter and aperture side of the film trap. The air space between the film trap is ⅛ inch.

In the old type arc, light is produced by passing an electric current across an air gap between two carbon electrodes, thereby heating the tip of one of the carbons, the positive, to bright incandescence. The resulting, slightly concave, bright spot constitutes the principal light source.

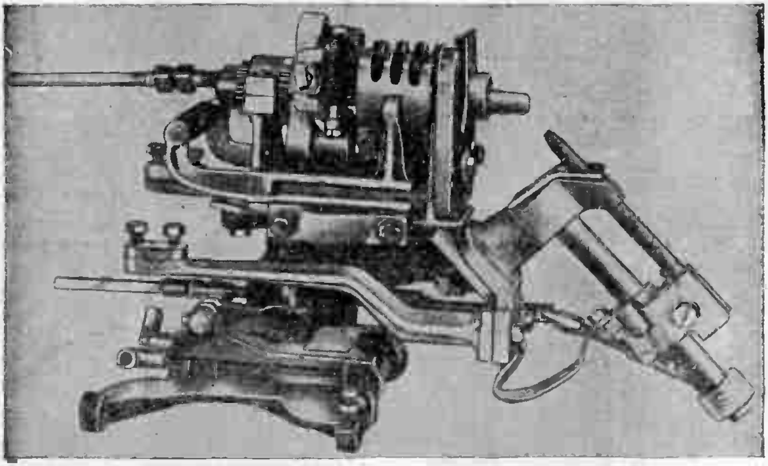
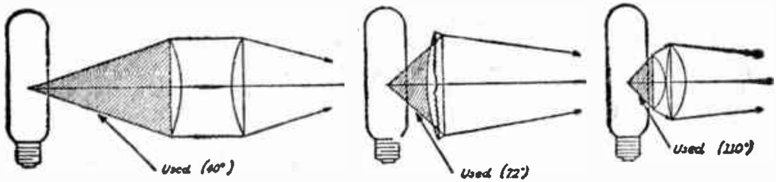


FIG. 7,812.—Hall and Connolly high intensity arc burner. *It consists* essentially of a combination tilting and swiveling stand upon which, but electrically insulated therefrom, is mounted an upright bracket casting carrying the lamp frame proper. The lamp frame carries a long spline shaft and a threaded shaft along which ride the positive carbon holder carriage with its rotating gears and carbon clamp. The threaded shaft advances the carbon carriage at the same time that the carbon holder and clamp are being revolved in the carriage. At the front of the lamp frame is a locating V recess in which rests loosely a half round carbon contact of ample surface and weight. In this contact the carbon slides and rotates under pressure from another contact resting on top of the carbon held down by a spring and lever. The carbon carriage is provided with a quick release from the worm drive for quick retrimming of the carbon. The length of travel of the carriage is sufficient to give 22 minutes of continuous burning at normal amperage. The positive carbon contacts are shaded from the heat of the arc flame by means of insulated, laminated shields made of heat resisting non-corrosive metal. The negative carbon unit consists of a pivoted self-aligning carbon clamp carriage sliding on two substantial rods or guides, the upper ends of which are rigidly attached to the guide head casting, which in turn is attached to, but properly insulated from, the same bracket casting carrying the positive unit. The guide head casting has a V recess into which the carbon is held and slides under tension of a tungsten spring located underneath the pivoted carbon holder carriage. The pivoted carbon holder and the V shaped guide head insure constant and correct alignment with the positive carbon and at the same time give to the copper coated negative a good wiping contact. Feeding motion is imparted to the negative carbon through a connecting rod coupled to a nut traveling on a long threaded shaft located on the back of the burner away from the direct heat of the arc.

In the high intensity arc, light is similarly produced by passing a heavy current across an air gap between two electrodes, but the position and composition of these electrodes are different.



FIGS. 7,813 to 7,815.—Comparison of arc and incandescent lights. The crater of the arc emits light only forward. With such a distribution the 10 in. or 12. focus plano condensers and a 1½ in. diameter projection lens collect and utilize practically all of the light. The incandescent lamp emits light very nearly equally in all directions. Obviously, if the incandescent lamp be simply substituted for the arc, only a small portion of the total light emitted will be used as in fig. 7,813. Accordingly, in order to intercept more light, a much shorter focus condenser must be used. At first, a single piece corrugated condenser was used as in fig. 7,814 and later a triple lens aspheric condenser as in fig. 7,815. Such condensers pick up a solid angle of light of about 110°, as against 40° for the old plano condensers. In order to utilize the light which is given off to the rear of the lamp, a spherical mirror is placed behind the bulb, and so adjusted as to reflect an image of the filament coils back between the coils themselves. Thus instead of the 60° picked up in the arc system, we are utilizing the equivalent of 220° of solid angle. It is very important that the spherical mirror be accurately adjusted, in order to secure the best results.

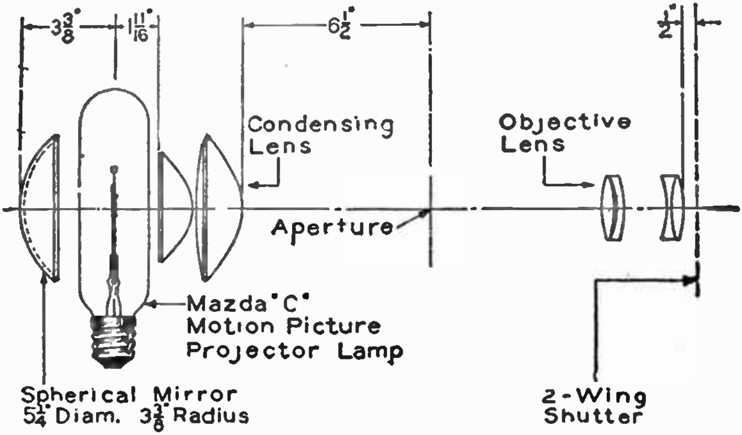
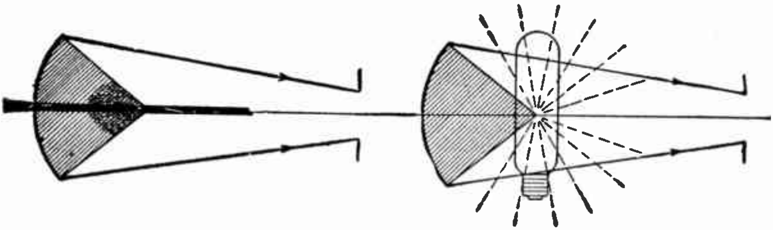


FIG. 7,816.—Optical train with incandescent lamp using Bausch & Lomb Cinephor condenser.

The positive is made up of rare earths, the principal one of which is cerium fluoride, and this rod of luminescent, arc sustaining material is encased in a thin shell of carbon. The negative consists of a copper coated heavy carbon shell surrounding a flame sustaining core. *The negative electrode* is positioned at an angle varying from 20 to 45 degrees according to the service for which the particular burner is intended

The current in passing across the air gap is concentrated in the core of the positive, causing great current density at this point. The core burns away more rapidly at first than the carbon shell, thus forming a cup shaped cavity more than ⅜ of an inch in depth, tapering down from about ¾ the



FIGS. 7,817 and 7,818.—The standard arc lamp reflector, when used with an incandescent lamp, redirects but a small part of the available light through the condenser. Good results with incandescent lamp projection necessitate not only the proper equipment, but also very accurate adjustment of the various elements of the optical system.

diameter of the shell at the rim to about the diameter of the core at the bottom. In this cup or crater the luminescent gases from the core are generated and superheated, giving rise to tremendous temperature. *These gases are the light source* in the high intensity arc. This method of producing light is made possible by using sufficient current density, a special positive electrode of suitable structure and composition, by placing the negative electrode so that the arc stream is projected against the face of the crater to confine the positive gases, and revolving the positive carbon in order to prevent the rim of the crater burning away unevenly and letting the gases escape too rapidly.

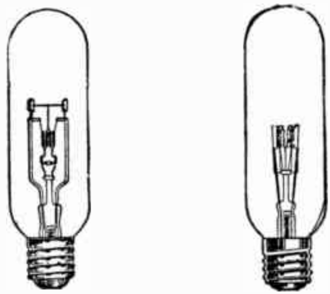
The brightness of the old type arc is about 140 candle power per square millimeter of crater surface.

The brightness of the new high intensity arc may be forced to well above 900 candle power per square millimeter of crater surface

Fig. 7,812 shows the gear and mounting of a high intensity arc lamp.

The construction and operation of a modern projector is shown in fig. 7,821.

Referring to illustration, the pedestal, carriage, adjustable support and base, constitute a single symmetrical unit. The stand rests on six leveling points and the projector is not attached to the floor or fastened to the building.



Figs. 7,819 and 7,820.—Comparison of Mazda lamps. Fig. 7,819 shows a 28-32 volt, 900 watt, and fig. 7,820 a 1,000 watt Mazda projection lamp. The lower voltage lamp, on account of the shorter length of filament and its lesser liability to squirm when heated, has the desirable factor of greater filament concentration. *Reason for low voltage:* It is characteristic of tungsten filament that the higher the voltage, the smaller in diameter the wire must be, and the more it will squirm when it is heated and cooled. If 110 volt lamps were used the filament could not be concentrated into so small an area nor could it be run at quite so high a temperature. The greatest filament concentration possible, with the low voltage high current lamp is, therefore, the prime reason for its use. The useful size of light source is limited by the optics of the projector. The lens system will pick up light from a limited area and any light outside of this area is of no avail.

The underslung motor table O, is close to the base and the motor is accessible for oiling or regulating. It can be raised or lowered on its supporting rod by loosening two wing screws. The position of the motor on the stand is an important factor in eliminating vibration.

To tilt the projector, release locking handle A, attached to rear adjustable support, by turning it to the left, loosen pedestal adjustment locking nuts B and C, and pedestal adjustment hand wheel D, can then be turned with either hand to give desired angle. Micrometer adjustment can be made by means of the hand wheel, and compression springs E, on rear adjustable support make this extremely comfortable. When A, B, and C, are again locked, the projector is held rigidly in the proper position.

The lamp house can be placed in position for slides by loosening knobs F and G, firmly grasping slide over arm handle H, and drawing it to the left for the correct placing. Lamp house carriage K, turns on lamp house pivot

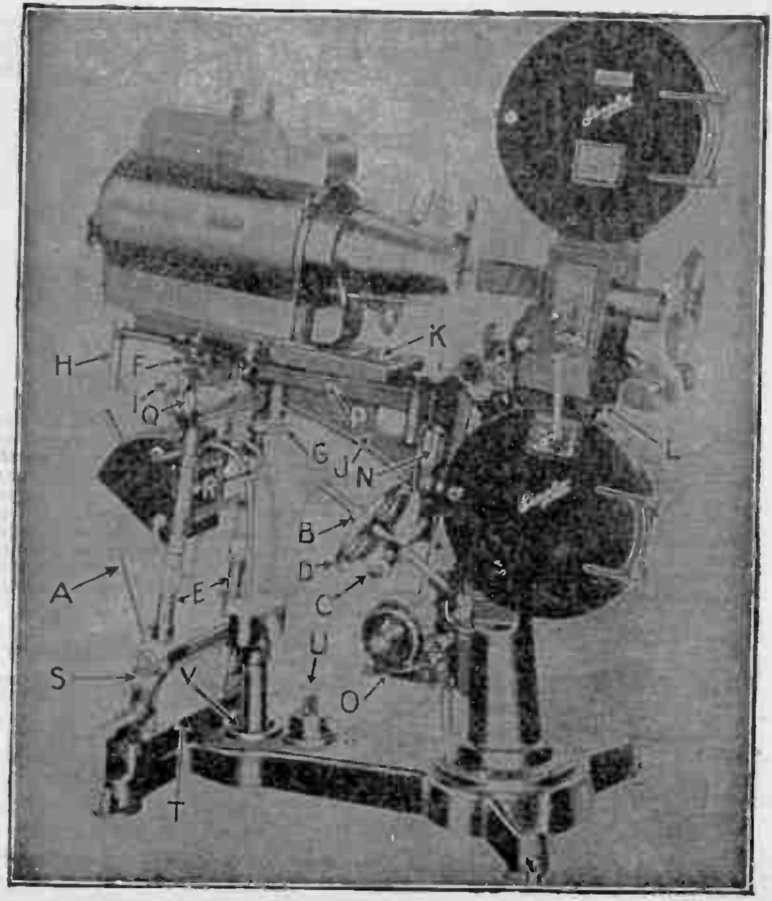


FIG. 7,321.—Model M, Simplex projector.

N, and at G, and slides over lamp house carriage rod I, and rear adjustable support. When F and G, are again locked, lamp house carriage K, is held rigidly in position.

The rear adjustable support consists of an upper fork Q, two rods R, and a lower fork S, swings on the pivot casting T. When the locking handle A, operates, it releases a powerful friction lock, and support rods R, are free to slip through the lower fork S. When the locking handle A, is released, the adjustable support ceases to act and hangs idle from the swinging table. When locked the rods and two forks constitute a structure that firmly connects the swinging table to the base. The 100 ampere switch and switch box are attached to the rear adjustable support. There is a foot motor switch U, for starting and stopping the projector and the 4 in. opening V, is provided in the base for installing a condulet.

TEST QUESTIONS

1. *What is the function of a motion picture machine or projector?*

2. *Of what does a motion picture projector consist?*

3. *Draw an elementary diagram illustrating how a projector works.*

4. *Describe the construction of the intermittent movement.*

5. *What is the nature of the motion due to the intermittent movement?*

6. *What is a take up device?*

7. *Give construction details of the film gate.*

8. *How does a high intensity arc burner work?*

9. *Give comparison of arc and incandescent lights.*

CHAPTER 53

Electric Welding

By definition electric welding is that branch of welding in which *an electric current is used to create the great heat required for jointing together into firm union two pieces of metal.*

Electric welding may be classified:

1. With respect to the method of applying the heat, as

   a. Arc;

   b. Flash;

   c. Resistance.

2. With respect to the kind of electrode used, as

   a. Carbon;

   b. Metallic.

3. With respect to the form of weld, as

   a. Spot;

   b. Butt;

   c. Line or seam;

   d. Tube;
   etc.

4. With respect to the method of bringing the metals together, as

   a. Compression;

   b. Autogenous.

5. With respect to the method of applying the "added metal" as by

   a. Carbon arc with welding rod;

   b. Metallic arc.

Source of Welding Current.—Any electric circuit of suitable voltage and amperage, either *a.c.* or *d.c.* may be used for electric welding. Usually in order to keep down the losses involved in reducing the voltage to that required by the arc, a special low voltage dynamo is used.

Two types of dynamos are generally used:

1. Constant voltage, flat compounded;
2. Variable voltage.

The constant voltage machine can be used to supply welding current to any number of welding circuits, while the variable voltage type supplies current for only one welding arc.

The constant voltage machine operates at 60 volts and the current in each arc is adjusted to the proper value by means of an adjustable resistor.

The windings of the variable voltage dynamo are so arranged that the terminal voltage of the machine automatically adjusts itself to that required to maintain the arc.

The open circuit voltage available for striking the arc in this type of dynamo, is usually slightly greater than the voltage of the constant voltage machine. Average values vary from 70 to 80 volts. Resistors are required only for very low welding currents. Any necessary adjustments are made either by shifting the dynamo brushes or by means of a rheostat in the dynamo field circuit. In this type of dynamo a high, open circuit voltage is available for striking the arc, after which it is automatically reduced to that required to maintain the arc.

For metallic arc welding by the hand method, the usual range of arc current is from 50 to 300 amperes at a voltage of approximately 20 volts. For automatic metallic arc welding, a current range of from 75 to 400 amperes is used with an arc voltage varying from 16 to 25 volts.

Carbon Arc Welding.—In this method of welding the electrode is of carbon or graphite and merely creates the arc and melts the metal.

Into this puddle of molten metal is inserted a rod or metallic stick which also melts and fills up the gap and fuses with the metal.

Carbon arc welding differs from metallic arc welding in that it is a puddling process and is somewhat similar to the gas welding process.

Metallic Arc Welding.—A metallic electrode is used in this method. The electrode forms a terminal for creating the arc, and also supplies the added or "filler" metal by melting.

When welding with the metallic electrode an arc is drawn between the parent metal or work and the welding rod, which causes the melted rod to flow across the arc into the molten pool of the parent metal. This deposition of metal is accomplished by contact made between the molten metal and the globules formed on the end of electrode filler wire.

The concentration of thermal energy at the terminal of the wire electrode causes a small part of the work being welded to melt almost instantaneously, and an intermittent flow of metal across the arc stream.

The metal in the arc stream is in both the liquid and gaseous form, the liquid metal being transferred across the arc by molecular attraction, adhesion, cohesion, surface tension or a combination of these.

The transfer of metal is not dependent on gravity since overhead welding indicates that the transfer of metal can be accomplished against the forces of gravity. The metal is melted at the point where the arc strikes the plate or work causing a crater to be formed, which also provides a means of observing the penetration and consequently good fusion while welding, by noting the depth of the arc crater. Metallic arc welding is a widely used method.

The Electric Welding Arc.—An arc is formed by *current flowing across a gap in an electric circuit.*

A small amount of the material, forming the terminals of the arc gap, is heated to an incandescent vapor. This vapor provides the conducting medium in the arc stream by which

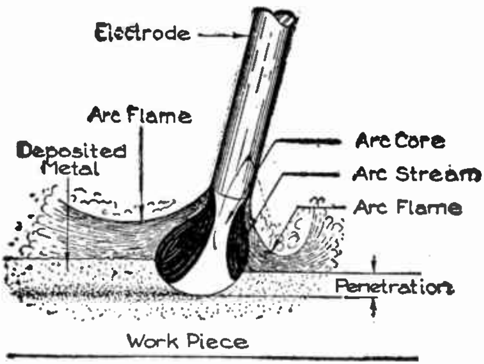


FIG. 7,973.—The welding arc. The terminal from which the current passes to the arc is termed the *positive electrode* or the *anode*, and the terminal to which the current passes from the arc is called the *negative electrode* or *cathode*. Although the exact distribution of heat in the arc between the two electrodes is still unknown, it is the generally accepted theory that approximately two-thirds of the heat is liberated at the positive terminal and one-third at the negative terminal. When *d.c.* is used, one terminal remains positive continuously and the greater portion of the total heat is liberated at this terminal. When *a.c.* is used, the terminals are alternately positive and negative so that approximately the same amount of heat is liberated at each terminal.

the current is carried from one terminal to the other, as shown in fig. 7,973. The temperature of the vapors in the arc and, consequently, the intensity of the light given out are so great that colored glass must be used in order to protect the eyes.

When suitable glass is used, the different portions of the arc can plainly be distinguished from one another. The center is usually referred to as the arc core, and some observers are able to see that this is divided into two portions designated as "arc core" and "arc stream." In general, this portion of the arc will usually be seen as greenish in color, of comparatively small diameter, and forming a direct line between the two terminals.

The point where the arc core strikes on either terminal is seen as a light red or yellowish spot considerably brighter and, therefore, hotter than the metal surrounding it. The metal around this spot is molten and is usually seen as a bright red area. This color gradually shades off into a darker red with lower temperatures, and finally becomes black at a short distance, not over ½ in. from the arc, except in the case of very heavy welding.

Slag, oxides, etc.. can be distinguished floating on the molten metal either as light or dark spots, depending upon the melting point of the impurity. Surrounding the arc core is the arc flame which is irregular in shape and in constant motion, being easily deflected by magnetic fields caused by the current in the electrode and in the plate, and also by drafts which may arise by reason of the heat in the arc, or by exposure to wind, etc.

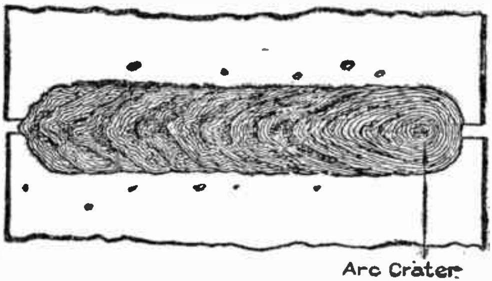
Polarity.—Since the mass of the work to be welded is generally large in comparison with the mass of the electrode, it is desirable to have more heat liberated in the work to bring its temperature to the fusing point at the same time that metal is fused and deposited from the electrode. For this reason, *d.c.* is much more satisfactory for arc welding, since the work can be supplied with a greater amount of heat from the electrode simply by using it as the positive terminal. However, in some cases involving the welding of certain alloy steels and a few other metals, it is sometimes desirable to reverse the polarity and make the electrode positive.

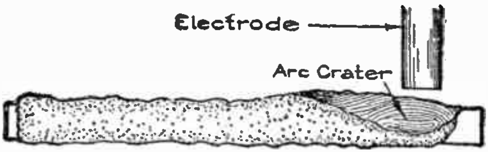
The *a.c.* arc is inherently unstable on account of the fact that both current and voltage pass through zero with each alternation. In order to make it possible to maintain an arc with any degree of certainty, it is necessary to insert a large amount of ballast, either in the form of resistance or reactance; that is, the open circuit or impressed voltage on the welding line must be of a relatively high value compared with that necessary if *d.c.* be used.

If resistance be used for the ballast, there is a great waste of power in the resistor. and if reactance be used, the excess voltage will be consumed as a reactance drop, resulting in low power factor for the equipment.

The polarity of a circuit can be determined in a number of ways.

The simplest and most positive way is to determine it by means of a volt meter. Another method is to draw an arc between either a bare metallic electrode or a carbon electrode and a steel plate. If the plate be positive and the electrode negative, the arc will be fairly stable. If, however, the circuit be reversed and the electrode be positive, the electrode will heat up very rapidly and the arc will become "wild" or it will flutter and be hard to





FIGS. 7,974 and 7,975.—Longitudinal section of deposited metal showing penetration and arc crater. Correct penetration will make certain that the metal of the plate is melted and in condition to receive the metal projected from the electrode, and also that the area of the crater will be sufficient to receive all of the metal from the electrode and not permit any of the deposited metal to overlap on the solid metal of the plate where it will not stick.

keep going. In welding low carbon steels with reversed polarity, the penetration with the metallic electrode is poor, and the deposited metal can often be easily knocked loose.

Penetration.—At the point where the arc strikes the plate, assuming that current, polarity and speed of travel are correct, the metal is melted and seems to be forced out of the pool by some sort of a blast from the arc, as shown in figs. 7,973 to 7,975.

This results in the metal piling up around the edges of a small depression in which the metal is in a molten state. This depression is referred to as the arc crater, and its depth provides a means of observing the penetration during welding, and, to a certain extent, of predicting the soundness of the weld, since one requirement of a weld is to obtain good penetration. The crater depth will depend upon the thickness of metal welded, but, in general, should be at least 1/16 in.

Length of the Arc.—While the correct arc length alone will not insure good welds, it is agreed that a long arc is almost certain to result in a poor weld.

With a short arc, the heat is concentrated on the plate, whereas, with a long arc, a great deal of it is lost into the surrounding space.

A long arc is not as stable as a short one. It tends to wander over a considerable area on the plate and the arc flame blows about very rapidly. This action, however, together with the greater length of the arc, affords considerable opportunity for the air to come in contact not only with the metal passing from the electrode to the plate, but also with the very hot metal in the arc pool or crater. This results in the absorption of oxygen and nitrogen, both of which are detrimental to the quality of the weld.

With a short arc, the flame, consisting of vapors coming out of the arc, acts as a protection and largely prevents the absorption of these outside gases. A short arc will deposit more metal in the weld, at the point needed, than a long arc.

The following table of arc lengths gives the approximate desirable gaps for different electrodes and voltages.

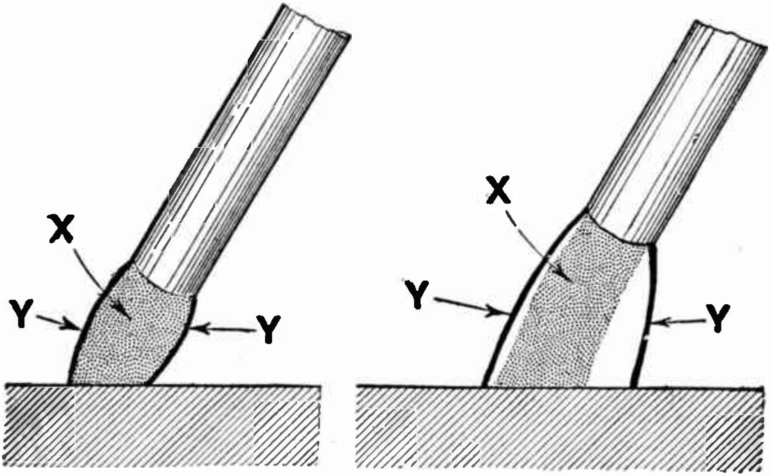
Table of Arc Lengths

Size of Electrode	Voltage across the Arc	Arc length
1/16	15 to 17	1/16
1/8, 5/32	17 to 20	1/8
3/16, 1/4	18 to 25	3/16

Advantages of the Short Arc

1. Maximum penetration;
2. Slight overlap;

3. Maximum strength;
4. Maximum ductility;
5. Minimum porosity;
6. Maximum amount of metal deposited at the point needed;
7. Makes it possible to use alloy electrodes.



FIGS. 7,976 and 7,977.—*Judging the arc length, 1. By appearance of arc.* If the arc be short it will appear as in fig. 7,976. Here the molten metal X, passing through the arc, will appear to be protected from the atmosphere by an enveloping neutral flame Y. If the arc be too long, the protecting neutral flame Y, will whirl around, exposing first one side and then the other side of the molten metal, as in fig. 7,977, allowing it to become oxidized, and it will have a burnt and porous appearance when deposited. The bead will not have the same appearance as one made with a short arc.

Disadvantages of the Long Arc

1. Minimum penetration;
2. Excessive overlap;
3. Minimum strength;
4. Minimum ductility;
5. Maximum porosity;
6. Uncontrolled deposit,

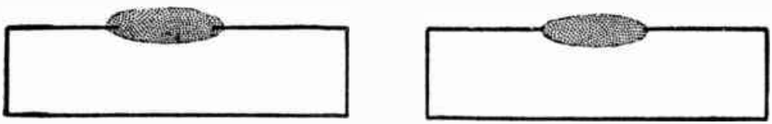
7. Excessive waste of electrode material;

8. Burns out all the alloys in a high grade electrode.

Experience will teach the operator to tell by observation when a short arc is being held.

It is possible to tell by sound, with low carbon steel electrodes, whether the arc be long or short. If the arc make a rapid crackling sound that is fairly steady in intensity, much like the frying of grease in a pan, the arc is short. If the arc make a hissing sound punctuated by explosions occurring at intervals of from ½ to 1½ seconds, the arc is too long.

A short arc throws a steady shower of small sparks, whereas each of the explosions caused by the long arc scatters many larger globules of metal.



Figs. 7,978 and 7,979.—*Judging the arc length, 2. By appearance of the weld.* Good penetration of the welding metal into the parent metal is not obtained with a long arc and there will be a bad overlap, as in fig. 7,978, while if the arc be short, there will be good penetration and a slight overlap, as in fig. 7,979. Another way to determine if the arc be too long is to examine the crater or depression in parent metal on breaking the arc, and see what the penetration looks like. If there be no penetration in the parent metal, then the arc is too long, providing of course, the proper electrode, current and correct polarity are used.

Figs. 8,024 to 8,031 will further assist in judging the length of the arc.

Metallic Electrodes.—In general, the metallic electrode for welding the commercial grades of wrought iron, plate, structural and cast steel, and to a considerable extent of cast iron, should be a high grade of low carbon steel wire which has a carbon content of .20% or less. Practically all commercial electric welding wire on the market meets this requirement, although there are a number of special electrodes containing greater amounts of carbon, which are used for special purposes.

The medium and high carbon steel electrodes are used where a hard deposit is required, but are not generally satisfactory where strength is necessary. In ordering, electric arc welding wire should be specified, since wire for acetylene welding is often treated in such a way as to render it unsuitable for electric arc welding.

The electrode wire should be cut into pieces convenient for the operation.

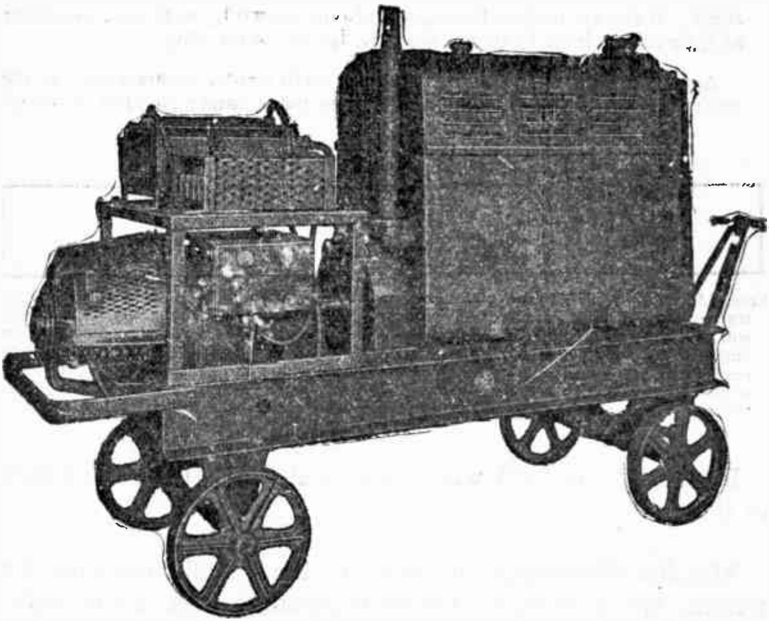


FIG. 7,980.—General Electric portable gas engine driven arc welder. The dynamo is self-excited. A self-adjusting stabilizing reactor automatically steadies the arc under all welding conditions, making the arc easy to start and maintain.

A length of 14 to 18 in. is satisfactory, since it is about the greatest length an operator can handle; at the same time it reduces the number of times the electrode is changed, and consequently the wastage.

With an electrode which is red hot, it is impossible either to start an arc or to maintain it.

The exact temperature varies with different electrodes, but it is advisable to keep the electrode cool. The passage of the welding current and the heat conducted back from the tip tend to heat that portion of the electrode wire carrying current. Accordingly, when the welding current is high for the electrode size, the wire should be gripped in the middle. By this means, the portion carrying current is all consumed before it has time to become too hot for use. With lower current values, the electrode is gripped at the end to save time and to minimize the number of times the arc is interrupted.

Welding Currents.—It is difficult to give universally applicable figures covering current, speed, etc., for electric arc welding because of the effect of conditions under which the work is done, the character of the work, and the varying skill of operators.

The following figures for bare metallic electrodes, are based on favorable working conditions and a skilled operator. However, they are approximations only and are given merely as a general guide.

Electrode Diameter in Inches	Amperes Hand Welding	Corresponding Plate Thickness in Inches
1/16	50–100	Up to 3/16
3/32	100–150	Up to 1/4
1/8	125–175	Above 1/8
5/32	150–200	Above 1/4
3/16	175–350	Above 3/8
1/4	225–400	Above 3/8

NOTE.—*Defective electrodes.*—Occasionally electrodes will be found that are not uniform as evidenced by the fact that, at intervals, the arc will suddenly become wild and erratic and the metal may pass from it in large drops without any apparent change in the electrical conditions or in the manipulation of the electrode by the welder. It is probable that at points in the weld where this action has taken place there will be weak spots with poor penetration. If a strong weld be desired, such an electrode should not be used, and metal deposited under these conditions should be chipped out before proceeding with the weld. Electrodes containing a considerable amount of carbon are generally erratic in this way.

Position of Work.—There are three general positions of work to be welded.

1. Flat;
2. Vertical;
3. Inclined.

Flat indicates that the surface on which the weld is made is horizontal; *vertical* that it is vertical; and *inclined* indicates an angle, not a right angle,

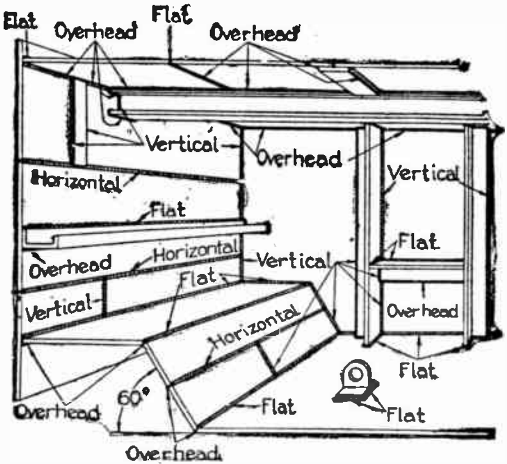
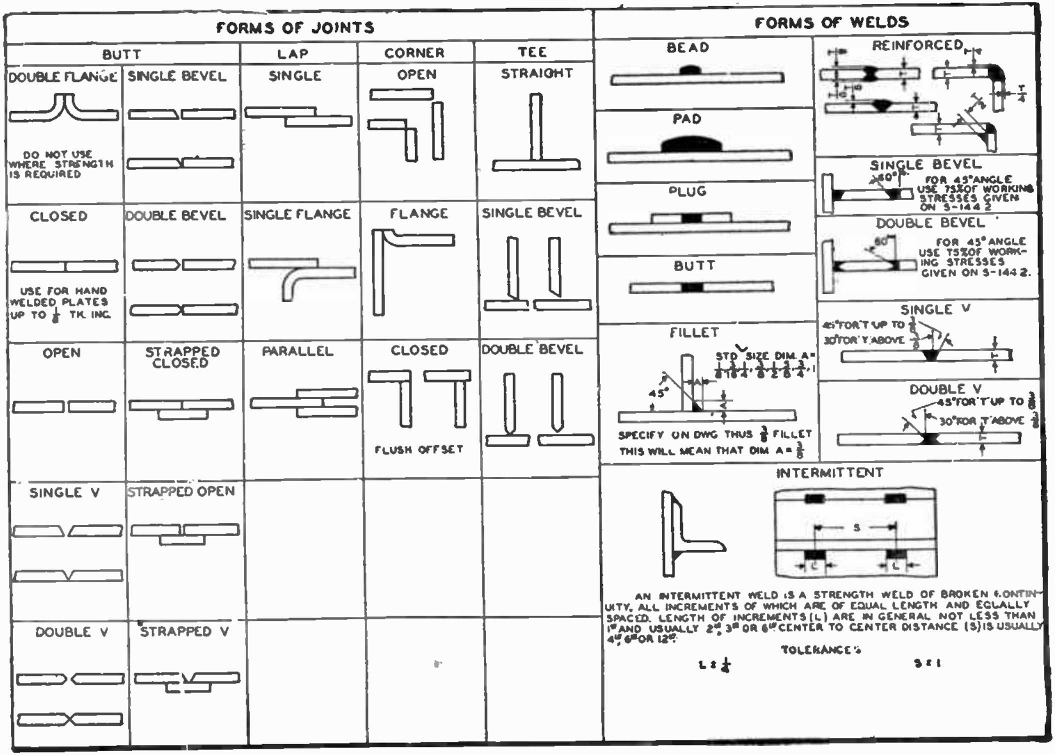


FIG. 7,981.—Various positions of weld.

to the horizontal. When inclined, the angle between the horizontal and the surface to be welded is usually specified.

Position of Weld.—There are four general positions of weld.

1. Flat;
2. Horizontal;
3. Vertical;
4. Overhead.



FIGS. 7,982 to 8,023.—Welding terms.

A *flat* position is one in which the welding material is applied in a generally downward direction.

A *horizontal* position is one in which the welding material is applied to a seam or opening in a plate, the plane of which is vertical or inclined 45°, or less, to the vertical, and the line of weld is horizontal. The electrode is held in horizontal position, or the welding end is inclined slightly downward.

A *vertical* position is one in which the welding material is applied to a vertical surface, or one inclined 45° or less to the vertical, so that the line of weld is vertical or inclined 45° or less to the vertical. The electrode is held horizontal, or the welding end is inclined slightly downward.

An *overhead* position is one in which the welding material is applied from the under side of any members whose plane is such that it necessitates the electrode being held with its welding end upward. These positions are shown in fig. 7,981.

Type of Weld.—In general, there are four kinds of welds.

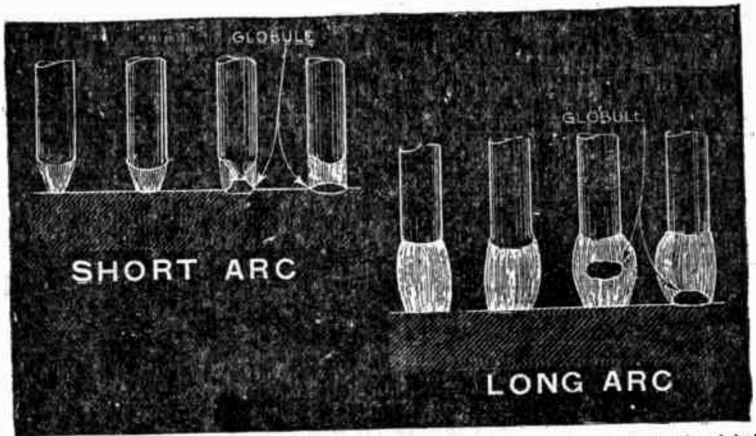
1. Tack;
2. Strength;
3. Caulking;
4. Composite.

Tack Weld.—In this weld the welding material is applied in small sections or spots to hold two edges together, and should always be specified by giving the space from center to center of welds and the length of each weld itself.

It is not necessary to consider the design of the weld. A tack is also used for temporarily holding in place material that is to be solidly welded, until the proper alignment and position are obtained. In this case, neither the length, space, nor design of weld need be specified.

Strength Weld.—This is one in which the sectional area of the weld is sufficient to give the joint the desired tensile strength. At least 80% of the strength of the surrounding material is the minimum. A good welder should always be able to attain at least 100% strength. The welding material may be applied in any number of layers.

Caulking Weld.—In this weld the deposited metal is used to close a seam or opening so that no leakage occurs under a water, oil or air pressure test of at least 25 lb. per sq. in. Neither the ultimate strength nor the design of the weld is of particular importance in a purely caulking weld.



FIGS. 8,024 to 8,027.—Short arc. From the globular formation it will be noted that the globule never is subjected to full heat of the arc, as it is in contact with molten metal in plate before it leaves tip of electrode. It will therefore be readily seen that the length of a short arc will vary with the diameter of electrode used, and what would be a long arc on ⅛ in. electrode might be too short for a ¼ in. electrode.

FIGS. 8,028 to 8,031.—Long arc. The illustrations show how the globule detaches from the end of electrode and in passing through a long arc to plate is subjected to full heat of arc, and of course the longer the arc the more burnt the globule will be when it reaches the plate.

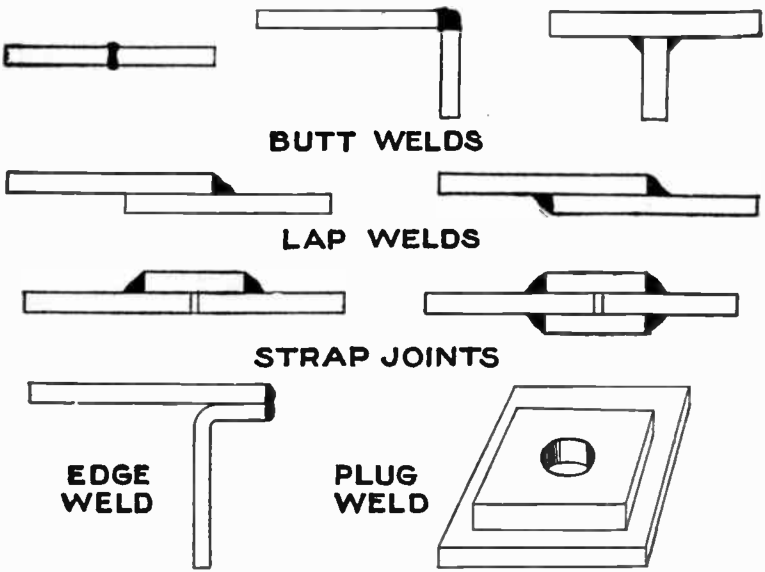
Composite Weld.—This weld is one in which both the strength and density are of vital importance.

The strength must be at least as specified for a strength weld, and the density must meet the requirements of a caulking weld; both as defined above.

Types of Welded Joints.—There are six general types of joints that are used in commercial welding. These may be designated by the manner in which the joint is made as:

1. Butt;
2. Lap;
3. T;
4. Strap;
5. Edge;
6. Plug.

Butt Weld.—The two plates to be joined are brought together, edge to edge, and welded along the seam thus formed.



FIGS. 8,032 to 8,040.—Various types of welded joints.

Two plates when so welded form a flat surface, or a corner, as shown in figs. 8,032 and 8,033.

Lap Weld.—In this weld the edges of two plates are overlapped, and the welding material is so applied as to bind the edge of one plate to the face of the other, as in figs. 8,035 and 8,036.

T Weld.—This occurs where plates are to be welded at right angles to each other, as in fig. 8,034.

Strap Joint.—This is where the junction of the ends of two surfaces is re-enforced by a plate or *strap* of metal covering the joint and fillet welded to each of the adjoining surfaces, as in figs. 8,037 and 8,038.

It is, in reality, a re-enforced butt joint. Two re-enforcing straps are used when a stronger joint is necessary.

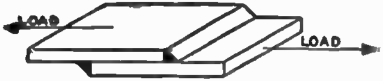
Edge Weld.—Where two comparatively thin, parallel pieces are joined by welding the edges together, the edge weld is used, as shown in fig. 8,039.

Plug Weld.—Used in joining two plates by welding through a hole in either one, or both of them, as shown in fig. 8,040. This type of joint is very seldom used.

The types of joint shown in figs. 8,032 to 8,040 may be made in a number of ways. The most useful and those most commonly found in commercial welding practice are shown in figs. 8,044 to 8,050.

Expansion and Contraction.—While expansion and contraction cannot be prevented, their effects can be minimized if certain methods be adopted in arranging the parts preparatory to welding, or by the order in which the deposited metal is applied.

For ductile materials, where the parts welded are free to come and go by reason of their ductility, extensive precautions to prevent contraction stresses are probably not advisable.



WELDING MATERIAL STRENGTH

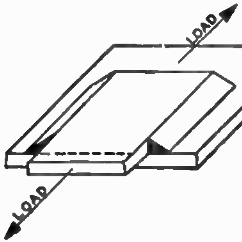
Dynamic, Vibration or Lifting Load } 5000 Lbs. Per Square Inch Maximun

Static Load—11,300 Lbs. per Square Inch Maximum for Throat of Fillet Welds

13,000 Lbs. per Square Inch Maximum for Tension in Butt Welds

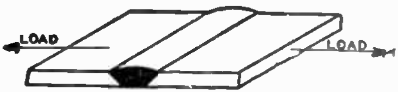
15,000 Lbs. per Square Inch Maximum for Compression in Butt Welds

Ultimate Strength—40000 Lbs. per Square Inch Maximum



STRENGTH OF FILLET WELDS

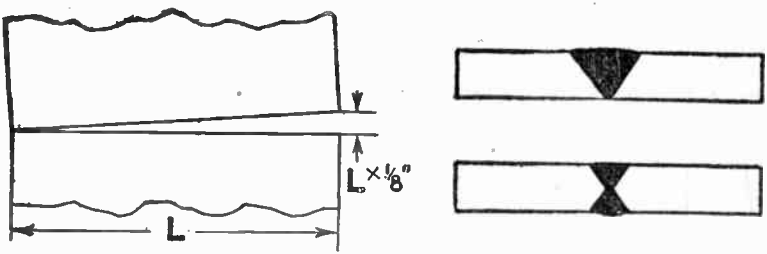
Size of Fillet	Allowable Load in Pounds Per Inch Length	
	At 5000 Pounds Per Square Inch	At 11300 Pounds Per Square Inch
⅛ x ⅛	440	1000
3/16 x 3/16	660	1500
¼ x ¼	890	2000
⅜ x ⅜	1330	3000
½ x ½	1770	4000
⅝ x ⅝	2210	5000
¾ x ¾	2650	6000
1 x 1	3540	8000



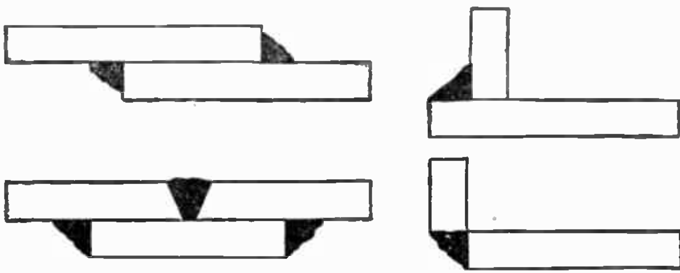
FIGS. 8,041 to 8,043.—Strength of welds. The table showing allowable strength of fillet welds applies to figs. 8,041 and 8,042. For figuring the strength of the butt weld shown in fig. 8,043, use the sectional area of the steel plate at a stress of 5,000 lbs. per sq. in. for dynamic or vibration load and 13,000 lbs. per sq. in. for static load in tension or 15,000 lbs. per sq. in. in compression.

In the case of non-ductile materials and castings or large structures, where the contraction effects are liable to be cumulative and to distort seriously the finished product, considerable attention must be paid to eradicating these harmful effects.

When welding joints formed by plate edges, if the welding be performed by starting at one end of the seam and continuing



FIGS. 8,044 to 8,046.—Various types of butt welds. For thin plates up to 1/8 in. in thickness, the plates are butted together at the end where the weld is to start and spaced apart a distance equal to 1/8 in. per ft. of weld at the other end as shown in fig. 8,044. This is to allow for the contraction stresses set up as the weld progresses. Plates 1/8 to 1/4 in. in thickness are spaced a small distance apart at the beginning of the weld. This spacing varies from 1/16 to 1/8 in. When butt welds are made on plates thicker than 1/4 in. some type of bevel or V. is necessary in order to obtain the proper penetration. Fig. 8,045, single V weld, the most common type; fig. 8,046 double V weld for heavy plate. L = length of weld.

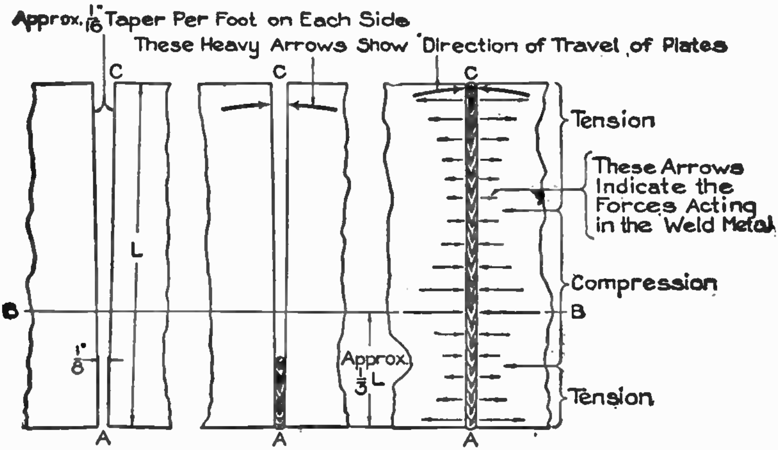


FIGS. 8,047 to 8,050.—Various examples of fillet welds. Lap welds may be made with either a single or a double fillet as shown in 8,035 and 8,036. The fillets may be either the full thickness of the plate, as in figs. 8,035 and 8,036, or they may be smaller as in fig. 8,047. The size of the fillet used will depend upon the strength needed in the joint. As in the case of lap welds, either the single or double fillet may be used for welding two plates together at right angles, as shown in figs. 8,034 and 8,048. The double fillet, fig. 8,034 is always used when strength is required. Fillet welds are used in making strap joints, as in figs. 8,037 and 8,038. In fig. 8,049, a strap joint using both a fillet and a V weld is shown. A corner joint, used when welding heavy steel plate, is shown in fig. 8,050.

until the other end is reached, as in figs. 8,051 to 8,053, the opening at C, will certainly be drawn together as the welding progresses from A to C.

As the welding continues from B to C, the contraction of the fused-in metal will produce stresses, as indicated by the arrows.

Fig. 8,054 shows a method of sequence of welding designed to distribute the heat and contraction stresses more evenly



FIGS. 8,051 to 8,053.—Locked-in stresses in a weld due to contraction. When the joint is completed, the transverse contraction stresses along the joints will be greatly concentrated at the ends A and C. The stresses impair the quality of the weld and, in many cases, develop a fracture on cooling. When a fracture develops where this method is used, it usually occurs at the end where the joint is finished.

throughout the joint, and thus reduce the amount of drawing and prevent concentration of contraction stresses. This order of welding is known as the *step back* method.

When the parts are rigid and no allowance can be made for contraction, or when it is desired to minimize the drawing of the plates, the joint is formed by welding in the order as shown in fig. 8,055.

When welding heavy sections, such as locomotive frame members and similar parts, it is advisable where possible, to spring the butting parts slightly preparatory to welding. Under exceptional conditions, an intermittent procedure may be adopted to prolong the operation and reduce the amount of heat developed in the object welded.

As the distortion caused by welding is due to localized or uneven heating, preheating may be employed to prevent this distortion, and thus reduce the difference in temperature developed between any two points of the parts affected by the welding.

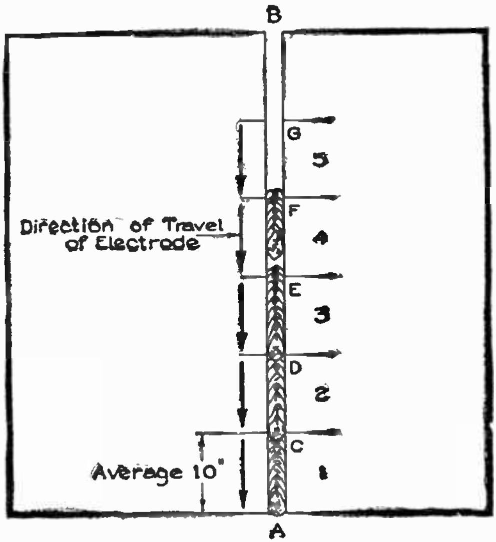


FIG. 3,054.—Step back method of welding to distribute contraction stresses. *As shown the* deposited metal is applied in sections. The sections 1, 2, 3, etc., are welded in numerical order and in the direction shown by arrows. By starting at **C**, section 1, progressing toward the end **A**, section 2 would best be welded in the same manner from **D** to **C**. Each section should be finished at least flush before starting another.

Cast Iron Welding.—A welder is frequently called upon to weld broken iron castings. Cast iron is difficult to weld by any process under the most favorable conditions and the results obtained are more or less inconsistent.

This is due to the brittleness and low tensile strength of cast iron. However, satisfactory welds can be made by the exercise of care in the selection of welding equipment, proper electrodes and preheating the casting. There is no means, however, by which the strength of the welded joint may be accurately predetermined and for this reason the work should never be undertaken unless the person responsible is thoroughly familiar with these facts.

Malleable castings are annealed gray iron castings.

The annealing usually affects the casting only to a small depth, which makes it possible for welding to be done in the annealed or softened section.

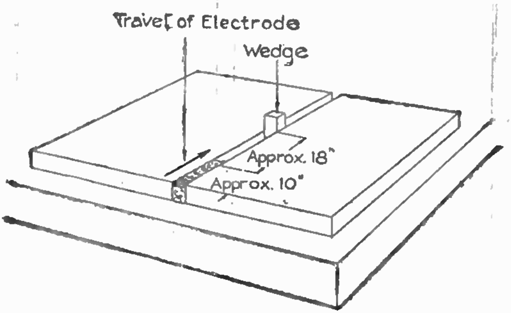


FIG. 8,055.—Method of reducing contraction by locking up the stresses produced. When welding long seams, the drawing may be reduced to almost nothing by the use of spacing blocks or wedges placed in the opening approximately 18 ins. from the section being welded, and toward the end of the seam to which the weld is progressing.

Consequently, the weld metal becomes similar in character to carbon cast steel.

If the casting be machined in the welded section, it must be re-annealed. In welding iron castings and castings similar in character, it is sometimes desirable to make the electrode rod the positive terminal in order to reduce the effective heat in the casting.

Welding Non-Ferrous Metals.—Non-ferrous metals as used commercially have been welded with varying degrees of success. Such metals are more or less difficult to weld with the electric arc. due principally to their low melting points.

Brass.—It is difficult to weld brass due to the vaporization of the zinc content when subjected to the temperature of the electric arc. The addition of metal to brass can be done successfully, but the metal from a brass electrode cannot be added to parent metal of the same composition.

Bronze.—This metal having a low percentage of zinc, can be welded without difficulty either by the metallic or carbon arc process, providing an electrode having a low percentage of tin and zinc is used.

Aluminum.—Great difficulty is experienced in welding aluminum by any process, for two reasons. 1, the metal has a great affinity for oxygen, therefore as it becomes heated a skin of oxide forms on the surface. 2, the metal has a very critical melting point and passes from the solid to the liquid state suddenly. It must be supported at the point to be heated to prevent the hot portion caving in. The only way to attempt the welding of aluminum is by the puddling process using either the metallic or carbon arc.

Copper.—Welding copper to copper or copper to mild steel can be done by either the metallic or carbon arc. It is recommended that a phosphor copper electrode be used in making such welds.

Preparation of the Work.—There are several factors which must be considered when preparing work for welding in order to get the best results.

Provision must be made for expansion and contraction wherever possible. The strength of the weld will depend on the correct beveling and spacing of parts to be welded. Uniform fusion is directly dependent on the proper beveling and spacing.

The cleaning of the surfaces is another important factor, which must not be overlooked and considerable stress should be given this point, so that the welding operator will realize that good welds can be expected only when the joints to be welded are kept clean.

In all cases the material should be cleaned of all rust, scale, paint, dirt or foreign matter. This is necessary in order to exclude the foreign matter from the weld and to help make the operation of welding as easy for the operator as possible. *Foreign matter is usually a poor conductor of electricity and interferes with the control and manipulation of the welding arc.*

The best possible fusion is obtained when welding in a downward horizontal plane position on a flat steel plate.

It follows, then, since this is the easiest and best position in which welding is done, that when possible and economical to do so, arc welding should be done in the downward, horizontal plane position.

When welding in this position the welding wire is held approximately perpendicular to the face of the plate. It is necessary to bevel the abutting edges of plates or sections, except on sections ¼ in. thick or less, to approach this position.

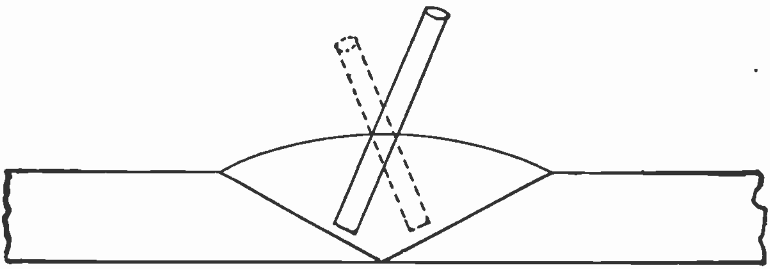


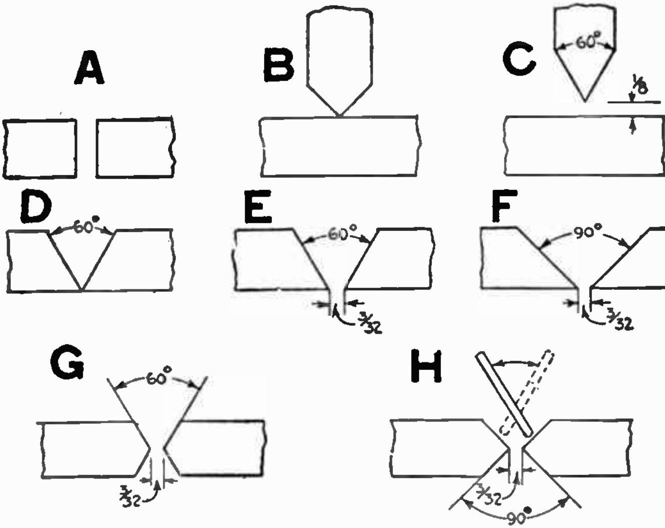
FIG. 8,056.—Best theoretical welding angle.

The best type of welding preparation would theoretically be one giving the greatest included angle if all other considerations be omitted, excepting the angle of the welding wire to the face of the work. A joint of this kind is shown in fig. 8,056. The expense of preparation and welding joints of this type would, however, be prohibitive. It is readily seen that a much smaller included angle will serve the requirements.

Another fundamental of good preparation or joint design is to keep the cross section of the added metal as small as practicable, so as to localize the effective heat in adjacent sections.

The accompanying examples figs. 8,057 to 8,064 illustrate the preparation of the most common joints of the butt type. The same principles of preparation apply to other types of joints.

Lessons in Metallic Arc Welding.—While learning to weld, the beginner will find it convenient to use a bench or table such



FIGS. 8,057 to 8,064.—Preparation of joints for welding. A, *very bad.* Except on sections of ¼ in. thickness or less, this is a very poor type of joint where strength of weld is important. The bad feature of this design is that the faces of the original metal are not presented for welding, and fusion to them cannot be obtained unless the arc can play upon them. Closing of the crack by fusion of the edges may look like a good weld but the strength is only equal to the strength of the weld section. However, this preparation is sometimes permissible, for carbon arc welding and for certain thicknesses of metals. B, *bad, except for work where a square corner is essential after welding.* When used, this joint should be prepared as shown in fig. C. This type of joint is better than that of fig. B. However, in this type of joint, great care must be exercised to obtain fusion at the apex of the angle and the vertical plate: D, *good, but can be improved* by adding a free distance between the two sections as shown in fig. E. This type of joint is good especially where more than one layer of metal is to be deposited; F, *better.* This type of joint satisfies all the requirements as to preparation for work welded on one side only; G, *very good.* This joint is better than the preceding one, and is applied on sections which are heavy enough to warrant beveling on both sides. The factors which influence the adoption of this type of joint are strength of weld required, thickness of the section, cost of preparation as compared with the reduced cost of welding and permissible warpage; H, *very best.* This type of joint satisfies the conditions as to arc manipulation and reduced section of weld. Warpage is also reduced, due to the fact that the force on either side is counteracted by the force of the opposite side.

NOTE.—***When repairing cracks in castings,*** it is often desirable to drill a hole at the termination of the crack to prevent further breaking. Also, care should be taken to bevel the work to the extreme depth of the crack or flaw, so that it will be a solid section after welded. If this be done the unwelded portion may cause the casting to re-crack, when the added metal cools and contracts.

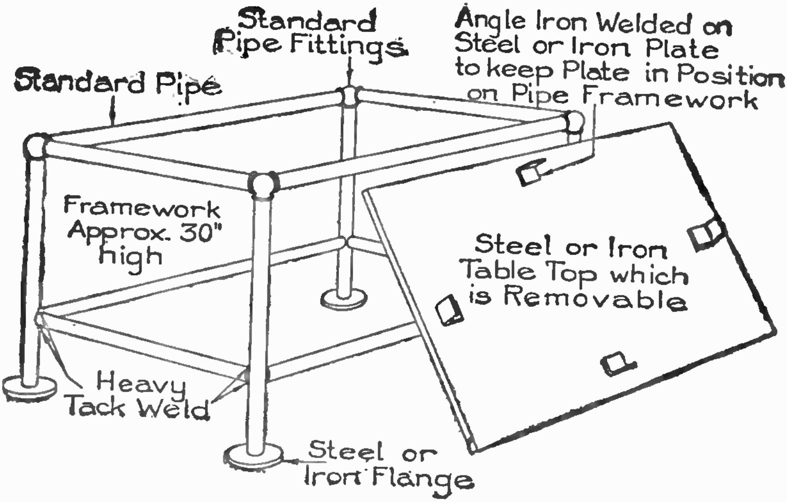
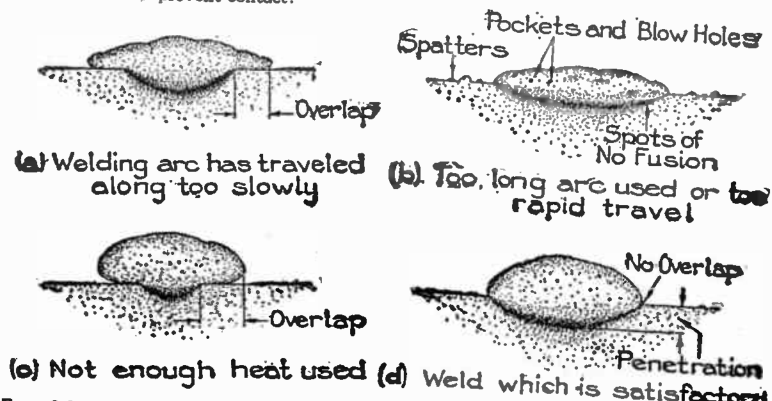


FIG 8,065.—Welding table with removable top suitable for small work which may be picked up and moved about by hand. It may be built of pipe and fittings with a steel plate top to which the positive lead is connected. The work may be set on this bench, the contact being sufficient to carry the current. In many cases, a vise mounted on the table will be found desirable. If the work be too large for the table, it may be set beside the table and a bar laid across to it. This will provide sufficient current carrying capacity, provided scale and rust do not entirely prevent contact.



FIGS. 8,066 to 8,069.—Cross section of beads deposited under different conditions.

as shown in fig. 8,065, with a steel plate top connected to the ground lead.

The welder can sit in a comfortable position, and by avoiding muscular strain, can better concentrate on the exercise. The steel top will catch many of the sparks and prevent burning the floor or bench.

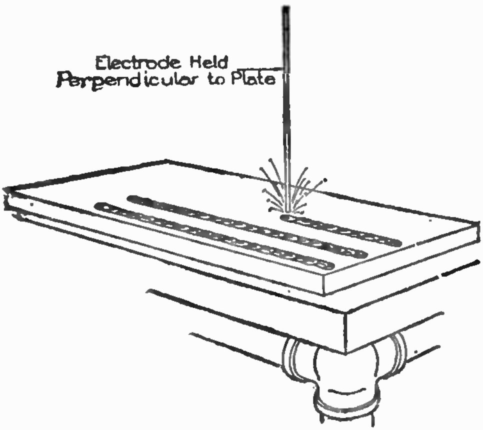


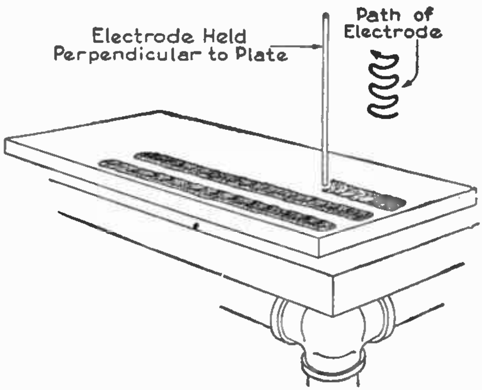
FIG. 8,070.—*Lesson 1. Laying single beads.* Run straight, continuous beads at least 12 in. long. Do not let the arc go out while the bead is being run, except to change electrodes. Uniform width and height of bead. Proper penetration and no overlap. No signs of porosity. Length of bead should equal the length of electrode wire used. *Instructions:* Take all the preliminary steps described before and strike the arc near the edge of the plate nearest the student. Move the electrode slowly and steadily across the plate away from the operator, keeping both arc length and rate of travel constant.

The exercise plates can be laid on the steel top, which will make the connection of the ground circuit.

For vertical and overhead welding, the plates can be attached to the bench top by short tack welds. A screen should be placed around the table to protect the eyes of others.

It is recommended that the beginner use a hand shield during the exercises on metallic electrode welding, since it keeps the left hand occupied and prevents using the left hand as a brace for the right hand. Also, the shield can be quickly moved before the face, allowing the operator to direct the

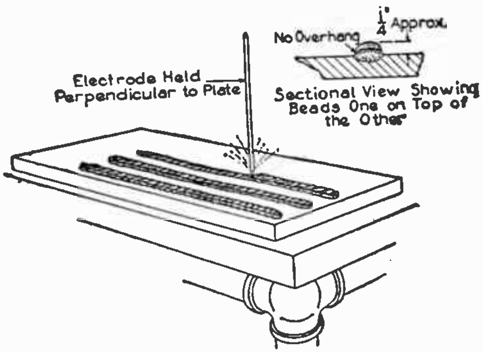
FIG. 8,071.—Position of welder when welding, showing shield, electrode, electrode lead and work table. The operator should try to assume an easy position in which the whole body is comfortable and braced so as to be steady without strain, leaving the right arm entirely free.



FIGS. 8,072 and 8,073.—*Lesson 2. Three parallel beads*. In this and all following lessons, the deposited metal should meet all the requirements of a good weld, uniformity of height and width, regularity of ripples, good penetration, and no overlap nor signs of porosity. These electrode visibly, until the instant before it makes contact and strikes the arc.

The beginner will profit greatly by watching for a time, an experienced welder.

He should closely observe the motions used in striking the arc and in moving along a weld. His ear will become accustomed to the sounds of the arc, both when it is too long and when it is of proper length. When at the



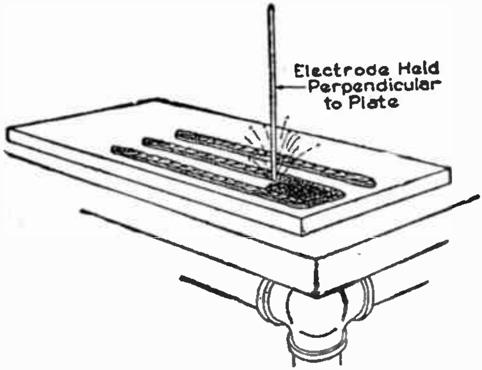
Figs. 8,074 and 8,075.—*Lesson 3. Three parallel beads in two layers.* Current in arc, 50 amperes. The reduction in current is because the conduction of heat into the plate is not as rapid, since the heat is applied to the top of a narrow ridge instead of the broad surface of the plate. A second layer deposited on each of the beads made in Lesson No. 2. Total height of completed beads, ¼ in. *Instructions:* Use for practice the plates from Lesson No. 2 that were not passable. Clean the surface of the preceding beads well with a scratch brush. When a good practice weld has been made, use the plate that passed the requirements of Lesson No. 2. Do not let the metal from the second layer run over the edges of the first layer.

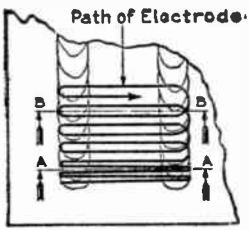
Figs. 8,072 and 8,073.—*Text continued.*

factors will not be mentioned again, but it should be understood that they are of the first importance, and it is assumed that the student will make welds that meet these requirements. The particular requirements of this lesson are: beads each 12 in. long, ⅜ in. wide and ⅛ in. high. *Instructions:* The same as Lesson No. 1 except that, in order to obtain the required width of bead, it will be necessary to spread the weld by weaving the electrode in a crescent motion from left to right and from right to left across the line of travel. The arc will follow a path similar to that shown in fig. 8,073. This cross motion should not be too rapid, or the weld will not penetrate. This movement of the electrode should be governed by the same conditions laid down in the preliminary instructions allowing for the different motion. Each time an electrode is changed, use the scratch brush to clean the surface where the bead is to be deposited and to seal the crater properly. In making this weld, it will be necessary to use more than one electrode per bead. Each time the arc is broken to change the electrode, the arc should be recommenced according to instructions given in the section on *depositing metal.*

proper distance of ⅛ in. the arc will have a very snappy sound like frying grease; a long arc will have a dead, sputtering sound.

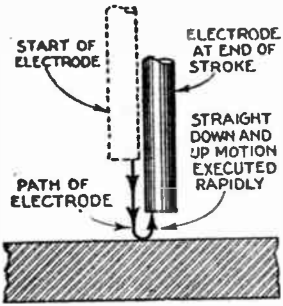
By using an electrode holder and electrode, but without any current, he can practice the motions of striking the arc. The hand shield should be used





FIGS. 8,076 to 8,079.—*Lesson 4.* Filling space between welds made in Lesson No. 3. Weld made in two layers. Same height as previous beads, leaving smooth surface. Weld must penetrate plate below and into beads at either side to form a solid mass of metal, as shown in fig. 8,076. *Instructions:* Clean the surfaces where the weld is to be made by means of the scratch brush and repeat each time an electrode is changed. Fig. 8,077 illustrates the manner in which the weld is made. The path of the electrode is as shown. At the start of the weld, the electrode is moved back and forth two or three times to build up the metal quickly to the desired height. A cross section of the weld at the start would have the appearance as shown in fig. 8,078. After building up the weld to the height of the two parallel beads at the start, the path of the electrode is that of an elongated spiral. The weld, from now on, is made in two layers, the bottom layer thoroughly penetrating both plate and parallel beads, and the top layer overlapping the bottom layer about two-thirds of its width. The top layer completes the fill to the top of the parallel beads and gives a smooth finish to the weld. The appearance of a section of the weld is shown in fig. 8,079. The type of bead described and used in this lesson is known as the *rope bead.*

just as though an arc were to be struck, since the operator should form the habit of always covering the eyes before striking the arc. Repeated flashes of the arc on the eyes, even though they are only momentary, will cause eyeburn.



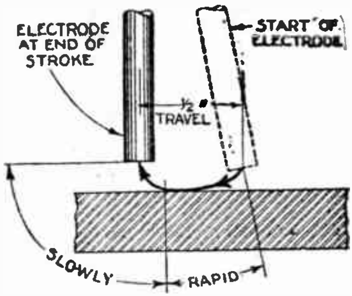


FIG. 8,080.—*Striking the arc, 1.* Insert an electrode wire in the holder, gripping it by the middle. Adjust the current for about 125 amperes dead short when welding. It is possible to determine the current with an ammeter by holding the electrode holder against the plate and reading the current. This value will be roughly about one-half more than when the arc is being held. Lay one of the exercise plates flat on the table. Take the welding position shown in fig. 8,071. Holding the electrode vertical, bring it to the point on the plate where the weld is to be started, but do not touch the plate until the hand shield is moved in front of the face. Touch the electrode very lightly and quickly to the work by a motion of the wrist. This is a quick, picking action. The movement in touching the plate and just freeing the electrode should be quick. Then bring the electrode away more slowly about ⅛ in. or until the arc has the proper snapping sound. Hold the arc a few seconds and then snap it out. If the electrode stick or freeze immediately, bend it from side to side with a steady pull which will probably free it. If this fail and the electrode become red hot, the circuit should be opened by opening the line switch, or by freeing the electrode from the holder, or by lifting the plate from the bench. On cooling, the electrode can be broken away with a hammer. The welder should practice starting the arc in this way, holding the arc a little longer time at each attempt, and moving it slowly over the plate until he is able to start and hold the arc consistently. Move the arc straight along; do not try to spread the bead or to weave or impart a zigzag motion to the electrode holder.

FIG. 8,081.—*Striking the arc, 2.* This method is to avoid sticking. It consists in "scratching" the electrode on the surface of the plate. The withdrawal of the electrode should be slower than the rest of the motion.

The accompanying illustrated lessons by courtesy of the ***General Electric Co.,*** will be found to comprise an excellent course for the welding student.

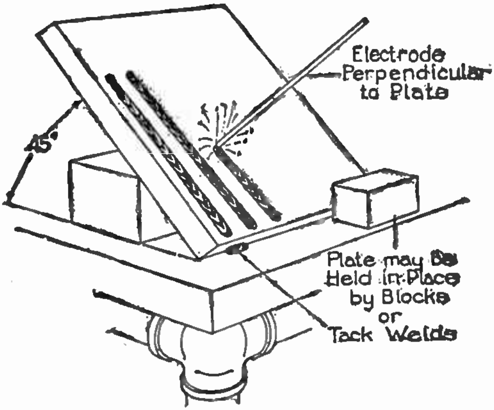
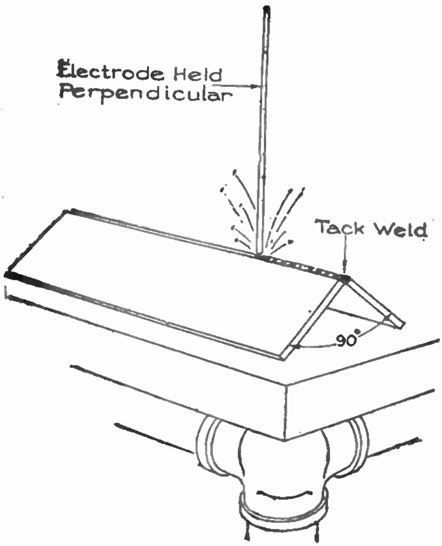
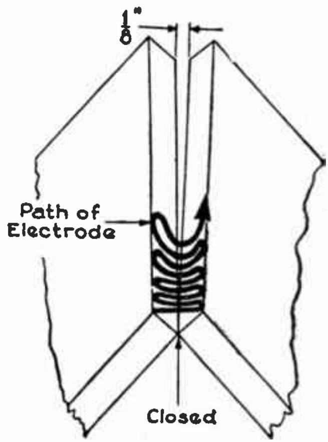


Fig. 8,082.—*Lesson 5. Laying three parallel beads, 45°.* ***Instructions:*** Similar to Lesson No. 1. The plate may be rested against a brace or welded to the bench top by a weld about ½ in. long, just enough to support it, as shown. Begin weld near bottom of plate. The arc must be kept short, or the metal will run, causing an uneven appearance.





Figs. 8,083 and 8,084.—*Lesson 6. Straight butt weld method of making right angle butt weld in horizontal position.* Good appearing weld, even across the top without bumps, craters, or

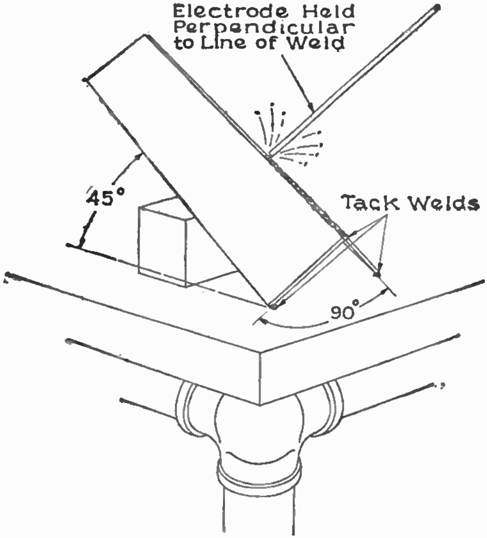


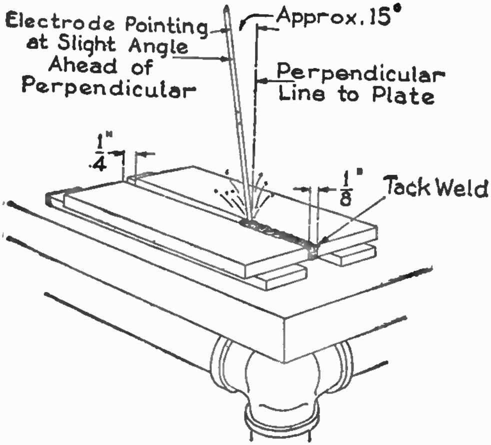
FIG. 8,085.—*Lesson 7.* Right angle butt weld inclined 45° to horizontal. This is the same as Lesson No. 6, except that, after tacking the plates as shown in fig. 8,083, they are placed so the weld makes an angle of 45° with the horizontal. The end having the ⅛ in. opening should be at the top. Begin at the lower end, and weld upward and away from the operator, as shown.

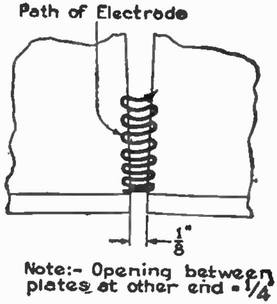
FIGS. 8,083 and 8,084.—*Text continued.*

dribbles over the edges. Weld must extend through bottom of groove, and show on under side. The break should, in general, follow the middle of the weld. The grain of the metal should be uniformly fine and of a dull gray color. *Instructions:* Place the plates at an angle of 90° as shown in fig. 8,083. Assuming that the plates are 12 ins. long, they will be spaced about ⅛ in. at one end, as in fig. 8,084. Tack the plates at the ends where the edges touch. Start the arc at this end and, as the weld advances, the shrinking of the deposited metal will gradually draw the plates together. Therefore, as the arc reaches any point along the weld, the plates at that point will be spaced a slight distance apart. The general rule for spacing the plates in welds of this type is ⅛ in. per ft. length of the weld. At the beginning, the path of the electrode will be a simple, spreading motion to distribute the heat evenly. As the plates become hot, the metal in the weld and at the bottom of the groove tends to fall or sag through. To prevent this, the amount of heat in the middle of the weld is reduced by moving the electrode farther up along the edge of the plates and making a more pronounced horseshoe-shaped path, the sides of the horseshoe being about ³⁄₁₆ in. long. The travel across the middle of the weld should be made faster, and that along the sides of the horseshoe, slower. In this way, the maximum heating is caused along the edges of the cold plate where good fusion is necessary. Do not run over the edges of the plates.

Striking the Arc.—The principal precaution to be observed when striking the arc is to prevent *freezing* or *sticking* the electrode to the work. This is caused in the following manner:

The electrode touches the work only on a small surface, a point, or sharp corner. The heavy current melts this and it sticks to the plate. More of the electrode melts and, as it is being pushed against the plate, the end of

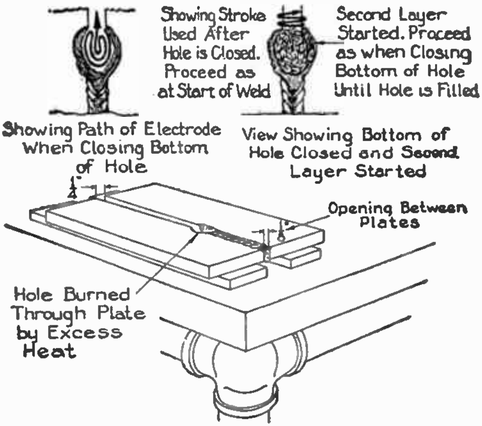




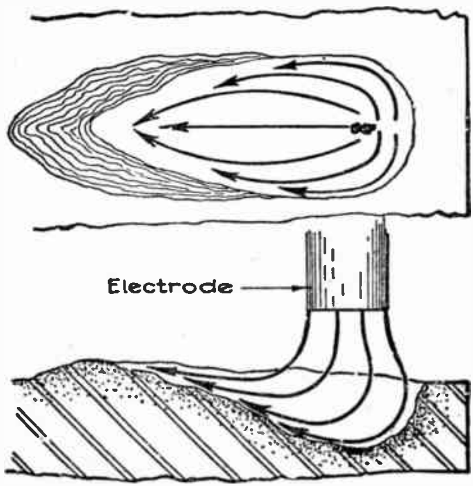
FIGS. 8,086 and 8,087.—*Lesson 8. Straight butt weld, plates in same plane.* Same as lesson 6, except position of plates is horizontal. ***Instructions:*** Place the plates as shown in fig. 8,086, with an opening of ⅛ in. at one end and ¼ in. at the other. Tack the end with the ⅛ in. opening. The path of the electrode will be similar to that in Lesson No. 6, except that the sides of the horseshoe are longer, about ¼ to 5/16 in. The path of the electrode is shown in fig. 8,087. This path must extend over the edges of the plates as shown, in order that the deposited metal will be thoroughly fused with the plate. Figs. 8,088 to 8,090 illustrate the method of filling a hole caused by the use of too great an amount of heat or too slow a feed of electrode.

the electrode will weld fast. The current then rapidly heats the rest of the electrode, unless it is broken away at once. This trouble is avoided by quickness in making the electrode touch the work and in bringing it back just away from the plate. The electrode should be drawn back to the arc length somewhat more slowly than the movement in the first part of the action, as in fig. 8,080.

Depositing Metal.—In advancing the arc, care should be taken not to move the electrode faster than it is possible for



Figs. 8,088 to 8,090.—Method of filling hole in butt weld caused by arc melting through.



Figs. 8,091 and 8,092.—Diagrams showing flow of welding metal when welding.

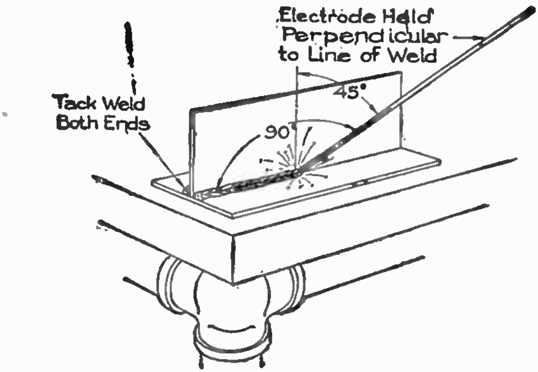
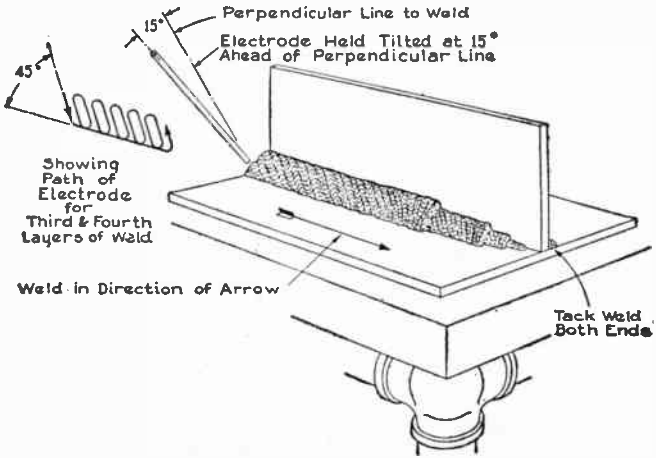


FIG. 8,093.—*Lesson 9. Single fillet T weld.* Clean and uniform surface, indicating penetration into plates at edges of weld. No signs of porosity. Surface of weld should be flat across, not re-enforced or concave. Clean surface of each layer with hammer and chisel, and brush before depositing a succeeding layer. *Instructions:* In making the first bead, the electrode should be moved slowly across the plate, advancing as fast as necessary to keep the proper height of the deposited metal, which should be approximately ¼ in. Since the weld is being made in the middle of the horizontal plate, the heat will be conducted away in both directions by this plate, and, therefore, at a greater rate than by the vertical plate. The crater should be established at the juncture of the two plates, with the greater portion on the bottom plate.



FIGS. 8,094 and 8,095.—*Lesson 10.* Method of making 4-layer T weld in horizontal position.

the arc to melt a place on the plate for receiving the deposited metal. If the arc be moved too fast, the metal will be merely laid on the plate with no penetration.

The operator should keep the arc traveling forward just fast enough to keep it at the forward edge of the crater, as in fig. 7,975.

This is the greatest speed of travel possible with the combination of plate thickness, electrode diameter, and current used. Advancing the arc less rapidly will result in a bead somewhat higher and wider.

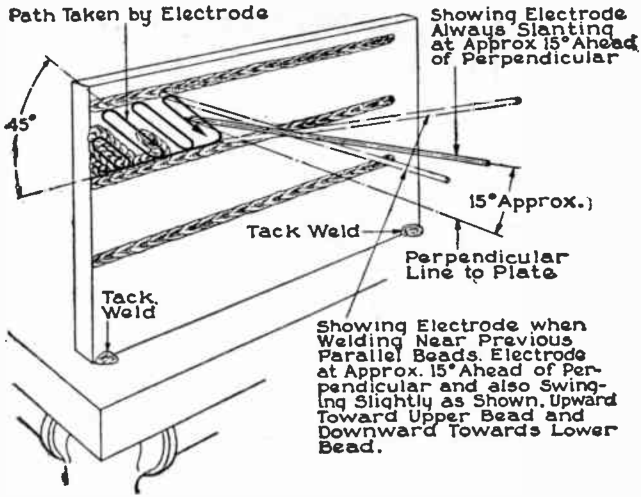


FIG. 8,096.—*Lesson 11.* Method of filling in between parallel, horizontal spread beads on vertical plate.

Too low a speed will result in overlap of the bead, and possibly in oxidized metal caused by the melting of a large crater and exposure of this hot metal to the air. The gases and vapors from the arc will protect the metal in a small crater to a certain extent.

These exercises should be continued until the operator is able to start the arc practically every time.

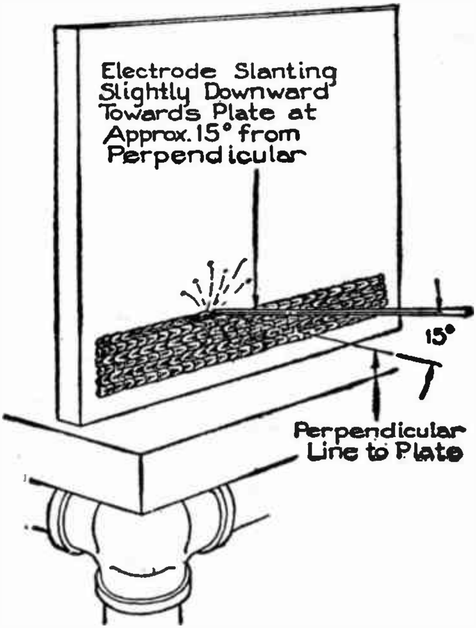
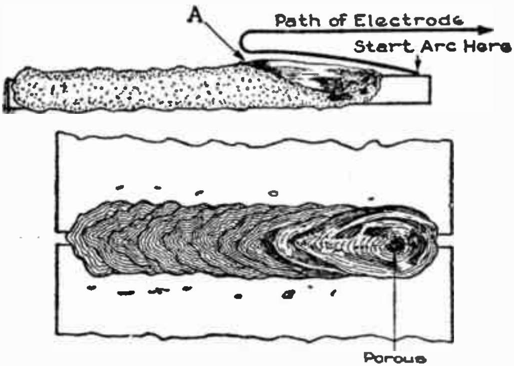


Fig. 8,097.—*Lesson 12.* Method of building up a patch on a vertical plate working upward.



Figs. 8,098 and 8,099.—Section of deposited metal showing penetration and crater.

Gradually increase the length of the bead and make curved lines, letters, etc., but do not weave.

Now, begin to examine the beads deposited while moving the arc along the plate, by comparing them with fig. 8,099.

The sound of the arc, and its appearance, both from the standpoint of length and size, and also the size and number of sparks, should be noted in connection with the appearance

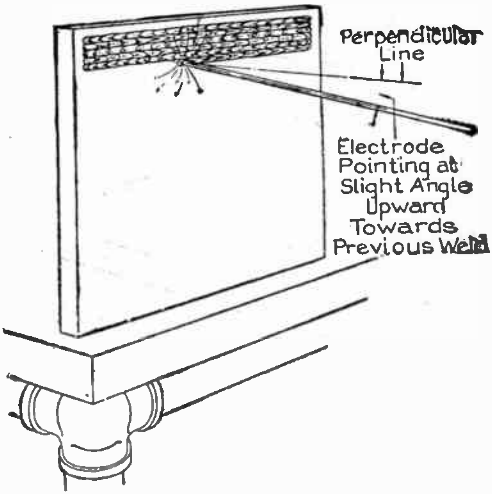


FIG. 8,100.—*Lesson 13.* Method of building up a patch on a vertical plate working downward.

of a bead. Chip off the bead, commencing at the end where the weld was begun, since this is usually the weakest point.

Continue making beads 3 or 4 ins. long until the bead has the appearance of a good weld; that is, even height, width, no overlap, and good penetration.

If a volt meter be connected to measure the arc voltage, it will aid to have someone watch this and report from time to time what the voltage is. It should be kept from 18 to 20 volts and the appearance under these conditions noted.

Now repeat the above exercises, first using a current of 100 amperes in the arc, and then of 75 or 80 amperes.

These currents will require increasingly greater steadiness of the hand, both in starting and in holding the arc after it is started. The observations above as to arc sound and appearance should be checked in each case against the appearance of the bead.

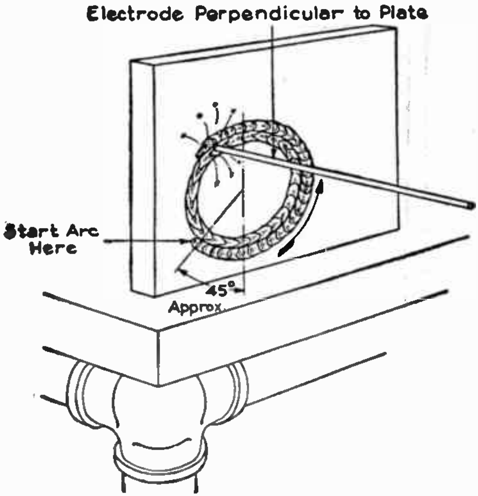


FIG. 8,101.—*Lesson 14. Welding around tubes.* The weld should be made continuously in one direction as shown, from start to finish. Particular attention should be given to obtaining a tight weld at the starting and finishing points, since such a weld under service conditions must be tight under high pressure.

The surface of the bead should consist of regularly spaced ripples with no holes or spongy places.

No large drops of metal should be outside the weld on the plate and, when the bead is chipped off, it should be necessary to cut it away the full width of the bead, thus showing that there is no overlap.

It will be noted that wherever the arc stops, there is a spongy, porous spot in the crater.

In the case of long welds, where it is necessary to use more than one electrode, such a spot will be found wherever the arc is stopped to change electrodes.

When an arc is broken, care should be taken in recommencing to close the gap in the deposited metal and also to guard against leaving a lump of metal on the bead.

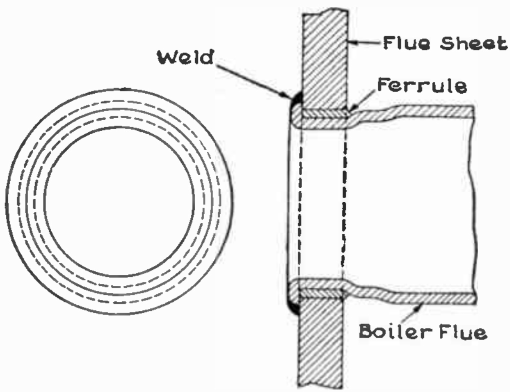


FIG. 8,102 and 8,103.—*Lesson 14. Continued.* Cross section of flue of locomotive showing method of welding tube to flue sheet.

Strike the arc about ¼ to ⅜ in. in front of the crater, and come back as shown in fig. 8,098, holding the arc very closely, and then proceeding in the direction of the weld. The path of the electrode is as indicated in figs. 8,098 and 8,099, the travel back to the point A, being faster than normal. From point A, the weld should be continued at the normal rate.

It can now be assumed that the welder is able to start an arc and to hold it uniformly for a short time.

From this point on, the exercises will take the form of lessons on carbon arc welding as given in the accompanying illustrations with certain conditions specified, and certain requirements which are to be met by the finished weld, before the student passes on to the next lesson.

Lessons in Carbon Arc Welding.—A source of welding current is required which will deliver from a maximum of 400 to 600 amperes down to a minimum of about 40. A carbon electrode holder and electrodes of various sizes are needed. While the hand shield may be used in cutting, it is necessary to use both hands for welding, and therefore, the helmet must be used for the latter operation.

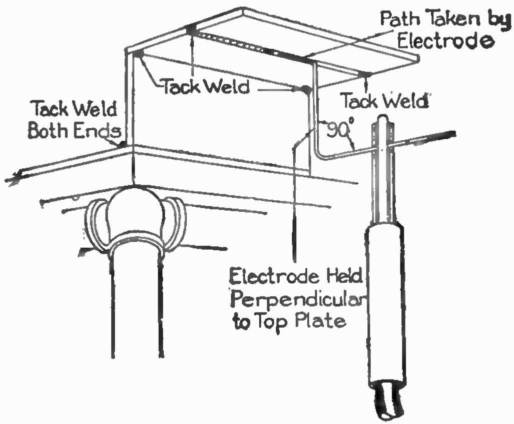


FIG. 8,104.—*Lesson 15.* Method of making an overhead straight butt weld.

Striking the Arc.—The carbon arc is very stable and easy to maintain. The length can be varied over wide limits without causing the arc to go out.

There is no tendency for the electrode to freeze or stick, as in the case of the metallic electrode. Accordingly, the arc can be struck without difficulty at any point, and rapidly moved over the surface of the work to the point where the weld is to be made.

Depositing Metal.—In welding with the carbon electrode, a molten pool should be formed on the work and the added metal deposited in this pool. The arc should be kept at this point until the added metal is thoroughly melted and mixed with the original metal before more material is added.

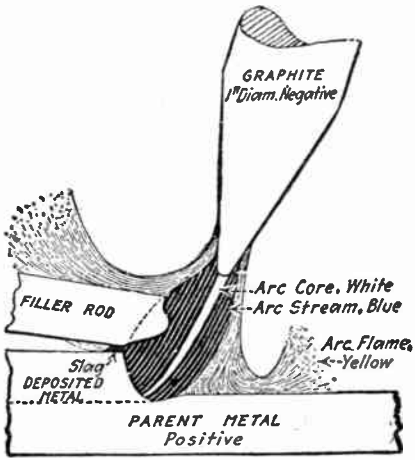


Fig. 8,105.—Correct position for graphite electrode and metal filler rod.

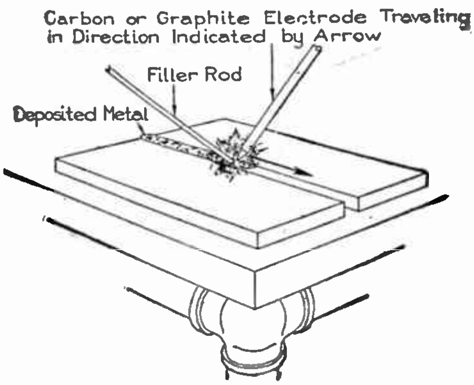


Fig. 8,106.—Direction of travel in making a carbon weld.

The added metal is usually in the form of a long stick of filler rod held in the welder's left hand. When the pool or the work is ready, the end of the filler rod is inserted in the pool, and the arc directed against the rod just above the surface of the molten metal. This will melt through the rod, and leave the end in the molten pool on the work.

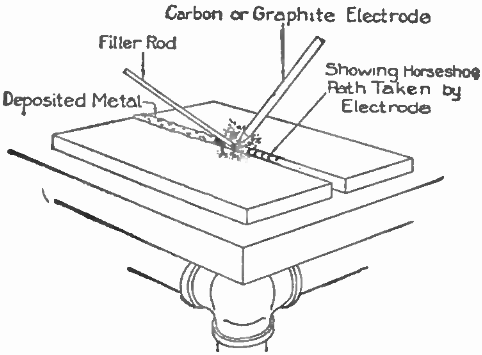


FIG. 8,107.—Electrode travel in making a butt weld with the carbon arc.

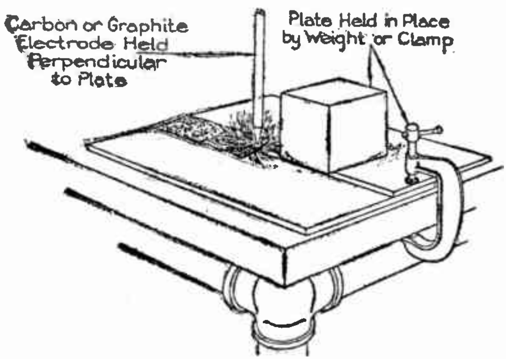
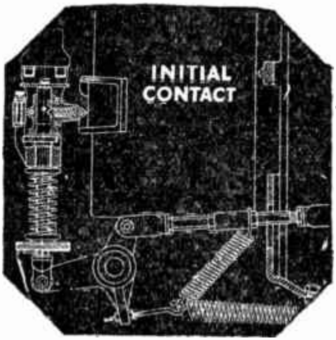
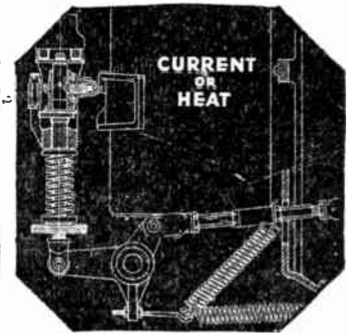
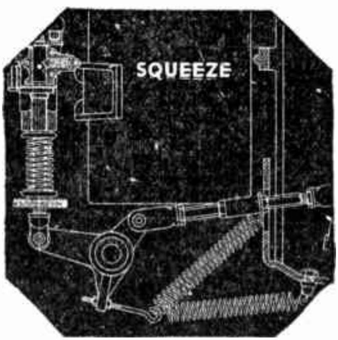


FIG. 8,108.—*Lesson 1. Lap weld of thin sheet metal. Instructions:* The line of weld will be along the middle of the overlapped portion. Strike the arc at one end, and move it slowly along the line of weld. The heat of the arc should fuse through the upper strip and into the lower. This depends on both the current and rate of travel of the electrode along the weld. Penetration can be increased by reducing the rate of travel until a point is reached where the heat spreads out too wide on the upper strip and causes the fusion of a wide area. When this condition is found, increase the current and advance the electrode faster. Experience will show the best combination to use.

The arc should be played about on the pool until the added metal is all melted down, when, because of the circulation caused by the heat, the molten metal will be well mixed. After this, the filler rod may be again inserted in the pool, and the process repeated, advancing along the line of weld.





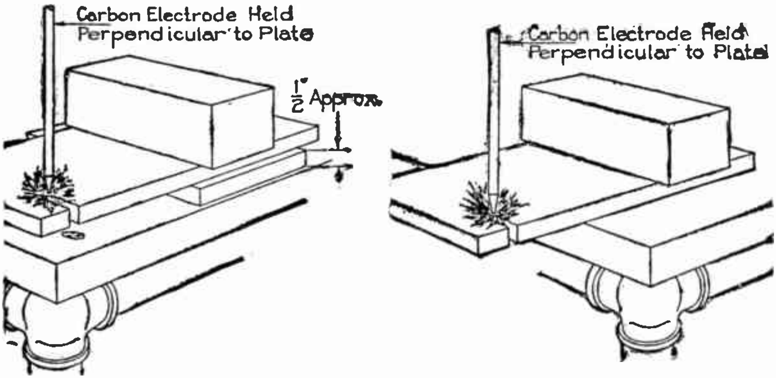


FIGS. 8,109 to 8,111.—A. E. F. spot welder diagrams showing operation. 1. Pressing down on treadle brings welding points on work. This initial contact must press lightly to assure high resistance and heat generation at point of weld, yet not too light to create air gaps. 2. Pressing further on treadle closes switch contact thus applying current. Switch remains closed, automatically opening with a quick break, cutting off current. 3. Treadle continued downward to end of stroke, applying pressure to the then plastic metals, setting the weld.

Position of Electrode.—In welding or building up, the electrode is generally held perpendicular to the surface of the plate, but is inclined ahead about 15° to the line of weld to direct the arc back into the weld.

Direction of Travel.—By welding from left to right, a right handed welder avoids awkward positions. The arc is directed backward into the weld, and the position of the arms and hands is comfortable.

Resistance Welding.—The art of resistance welding was discovered accidentally by Prof. Elihu Thompson in Philadelphia, in 1885. While experimenting with a spark coil operated from a bank of batteries he accidentally welded two steel rods of about ¼ in. diameter.



Figs. 8,112 and 8,113.—*Lesson 2. Cutting a steel plate with a carbon or graphite electrode. Instructions:* First, melt away the lower part of the plate, and then bring the arc toward the top. This undercutting makes it easier for the molten metal to run out. It is particularly beneficial in cutting heavy parts such as castings, shafts, etc. It is often necessary to follow the molten metal down with the arc to keep it fluid until it runs off. The width of the cut will depend on the size of the electrode used and on the skill of the operator in keeping to a straight line.

By definition, *resistance welding is that method in which a sufficiently strong electric current is sent through the two metals in contact to be welded which melts the metals by the resistance they offer to the passage of the electric current.*

There are several forms of resistance welding known as

1. Butt;
2. Flash;
3. Spot;
4. Seam;
5. Tube.

Each depends on the resistance offered by the metals in contact, to the passage of the current for the production of the

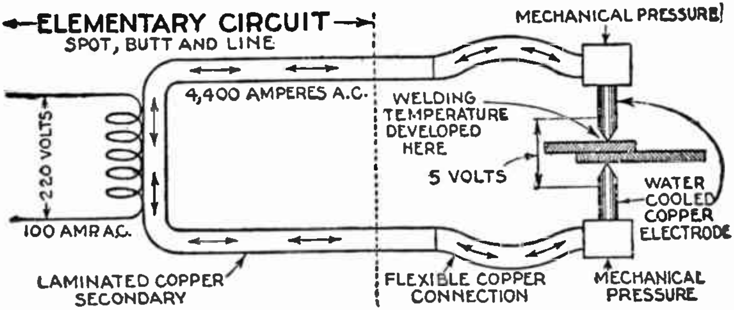
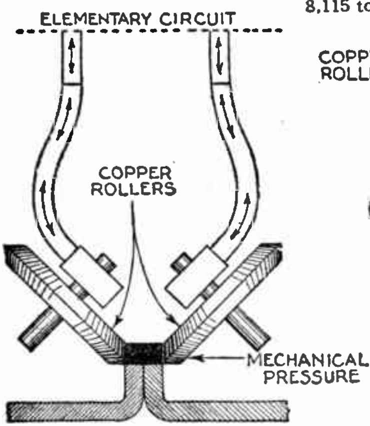
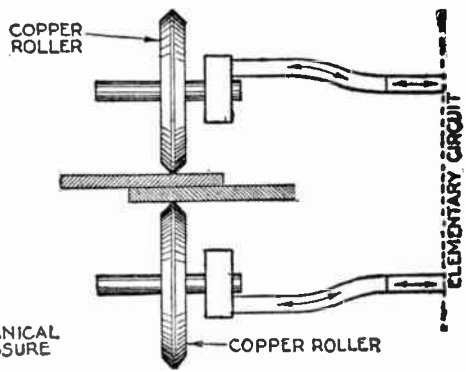


FIG. 8,114.—Circuit diagram for spot welding. Spot welding, for the most part, is used in place of riveting. It consists of 1, discharging an enormous current, at a fairly low voltage through two or more pieces of sheet metal or bar stock; 2, following up the discharge of current with sufficient pressure on the two or more pieces of metal so as to unite the molecules of the metal; 3, cutting off the current before the mechanical pressure is released, so as to prevent burning the die points. The spot welding process is also used largely in the manufacture of wire goods, such as lamp shades, wire cloth, screening, netting, fencing, and an endless variety of objects and utensils for various uses. Above elementary circuit indicated in figs. 8,115 to 8,117 by dotted line.





FIGS. 8,115 and 8,116.—Circuit diagrams for seam welding. *It consists of* passing two or more metal sheets or bars, between the rollers of a seam welder. The electric current passing from roller to roller through the work heats up the parts to be joined in the nature of a spot welder and the mechanical pressure on the roller electrodes consummates the weld.

heat to melt or soften the metal. Usually there is mechanical pressure applied to the soft or melted metal to force the parts together and aid in binding them.

In butt welding, the ends of the pieces to be joined are butted and current passed from one to the other until they become plastic and the pressure binds them.

A modification of butt welding is flash welding.

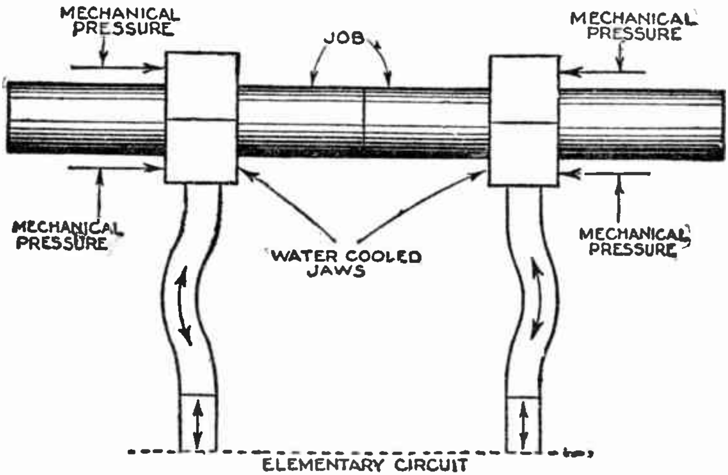


FIG. 8,117.—Circuit diagram for butt welding.

The difference being that current is applied to the parts before they are brought together so that when they meet arcing or flashing takes place and greater heat produced and projections burned away and thereby the surfaces brought closer together; the pressure completing the bond. The flash method has almost entirely superseded the butt weld method.

In spot welding, the parts or pieces are joined in spots.

The metals are brought together either butted or lapped and the electrodes connected to the metals both above and below the particular points where they are to be joined. This creates heat at these points and softens the metals within these restricted areas and by pressure completes the weld. The joining points being wherever the electrodes are connected.

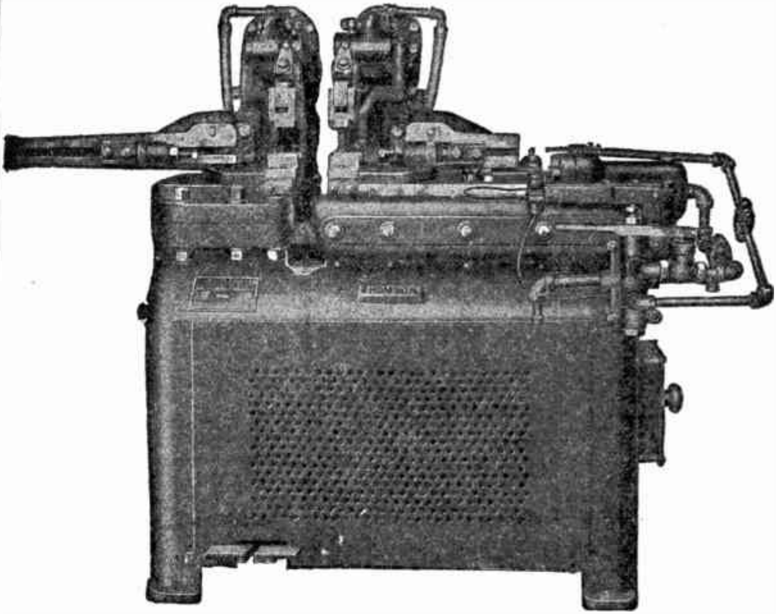


FIG. 8,118.—Thompson butt welder. *Capacity.*—Iron or steel. A cross section from .0123 minimum to a cross section of ¾ sq. in. maximum continuously, or 1 sq. in. at long intervals. Rims 2½ ins. wide by ¼ in. thick by 10½ ins. minimum diameter. Rims 1⅜ ins. wide or narrower and as small as 8 ins. diameter can be handled. Pipe or tubing up to 1 in. diameter extra strong; pipe or tubing 1¼ ins. diameter standard, can be welded by fitting contacts to size.

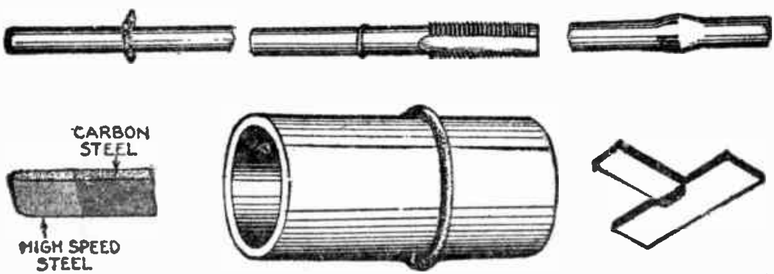


FIG. 8,119 to 8,124.—Various examples of butt welds. Fig. 8,119, flash weld; fig. 8,120, tool weld; fig. 8,121, upset weld; fig. 8,122, high speed steel weld; fig. 8,123, pipe weld; fig. 8,124, tee weld.

Butt Weld Data

(According to Thompson Electric Welding Co.)

Round Iron Diameter	Area in Square Inches	KW Required	Time in Seconds to Make Weld	Cost per Thousand Welds at 1¢ per KWH
1/4"	.05	2	3	.02
3/8"	.11	3.5	5	.05
1/2"	.20	5	5	.07
5/8"	.31	7.5	10	.21
3/4"	.44	12	15	.50
7/8"	.60	15	18	.75
1"	.79	18	20	1.00
1 1/8"	.99	25	25	1.73
1 1/4"	1.23	35	30	2.90
1 1/2"	1.37	50	40	3.55
1 3/4"	2.41	65	45	8.12
2"	3.14	75	50	10.42

In seam welding, the electrodes either in the form of wheels or rollers, move along the seam of work and weld it.

This is used for cylinders or other work of that kind and either the rollers move or the work moves. Pressure of course is applied the same as for the other welds.

The electric current passing from roller to roller through the work heats up the parts to be joined in the nature of a *spot* welder and the mechanical pressure on the roller electrodes consummates the weld.

CHAPTER 54

Soldering

A knowledge of soldering is useful to the electrician, and the acquirement of proficiency in it will be found of value.

Solder.—By definition, solder is *a fusible alloy*. There are a great many varieties of solder. In electrical engineering, the solder used in practically always *an alloy of tin and lead.*

As the electrical conductivity of such an alloy is usually about one-seventh that of copper, the best joint between copper conductors is made by bringing the copper surfaces as close together as possible and using a minimum of solder.

For jointing, especially where work has to be done in awkward positions, it is essential that the solder should have a plastic stage between its liquid and solid states.

There are two general classes of solder:

1. Soft;
2. Hard.

Soft solder is an alloy composed of lead and tin. Sometimes [illegible] metals are added to lower the melting point.

NOTE.—***The soldering amateur*** will agree that soldering is a distinct art in itself, and while it looks easy, it is not; moreover, skill cannot be acquired without considerable practice; however, the information to be obtained in books will be found helpful, not only to the beginner, but also to the experienced workman.

The following table gives the melting points and relative hardness of various *tin lead* solders.

Melting Points and Hardness of Tin Lead Solders

Percentage Tin	Percentage Lead	Melting Temp. Deg. F.	Brinell Hardness Test	Percentage Tin	Percentage Lead	Melting Temp. Deg. F.	Brinell Hardness Test
0	100	618.8	3.9	60	40	368.6	14.6
10	90	577.4	10.1	66	34	356.0	16.7
20	80	532.4	12.16	70	30	365.0	15.8
30	70	491.0	14.5	80	20	388.4	15.2
40	60	446.0	15.8	90	10	419.0	13.3
50	50	401.0	15.0	100	0	466.0	4.1

In the table which follows will be found the proper solder and flux to use with various metals.

Soft Solders and Fluxes for Various Metals

Metal to be Soldered	Flux	Soft Solder: Tin	Lead	Zinc	Aluminum	Phosphor tin	Bismuth
Aluminum	Stearin	70		25	3	2	
Brass	Chloride of zinc, rosin, or Chloride of ammonia	66	34				
Gun metal		63	37				
Copper		60	40				
Lead	Tallow or rosin	33	67				
Block tin	Chloride of zinc	99	1				
Tinned steel	Chloride of zinc or rosin	64	36				
Galvanized steel	Hydrochloric acid	58	42				
Zinc	Hydrochloric acid	55	45				
Pewter	Gallipoli oil	25	25				50
Iron and steel	Chloride of ammonia	50	50				
Gold	Chloride of zinc	67	33				
Silver	Chloride of zinc	67	33				
Bismuth	Chloride of zinc	33	33				34

Common or plumber's solder consists of one part of tin to two parts of lead, and melts at 441° Fahr. It is used by plumbers for ordinary work, and occasionally for electrical work where wiped joints are required, for instance, in large lead covered work.

Medium or fine solder consists of equal parts of tin and lead, or *half and half*, and melts at 370° Fahr. This solder is always used for soldering joints in copper conductors, and for soldering lead sleeves on lead covered wires.

Hard solder is an alloy composed of copper and zinc, or copper, zinc, and silver.

Hard solder in general is sometimes erroneously called ***spelter***.

The following table gives the various hard solders, proper flux, and metals for which they are suited.

Hard Solders and Fluxes for Various Metals

Metal to be soldered	Flux	HARD SOLDER			
		Copper	Zinc	Silver	Gold
Brass, soft	Borax	22	78		
Brass, hard	Borax	45	55		
Copper	Borax	50	50		
Gold	Borax	22		11	67
Silver	Borax	20	10	70	
Cast iron	Cuprous oxide	55	45		
Iron and steel	Borax	64	36		

As will be noted from the table, most of the hard solders are alloys of copper and zinc. An easily fusible hard solder may be made of one part copper to two parts zinc, this, however, makes a joint that will be weaker than when an alloy more difficult to melt is used.

A hard solder that is readily melted is made of 44% copper, 50% zinc, 4% tin, and 2% lead.

A hard solder for the richer alloy of copper and zinc may be produced from 53 parts copper and 47 parts zinc.

Solder must have a lower melting point than the metals to be joined to it.

NOTE.—*Solder containing much lead* makes a weak joint because the lead does not transfuse with brass.

NOTE.—*Solder containing much tin* is brittle.

The melting point should approach as nearly as possible that of the metals to be joined so that a more tenacious joint is effected.

The fusibility of a solder can be increased by the addition of a small portion of bismuth.

Soft solder melts at a low temperature compared with hard solder which melts at a red heat.

German Silver Solders.—German silver is a very hard alloy of copper (50 to 60%), nickel (15 to 25%), and zinc (15 to 20%). A German silver containing 1 to 2% of tungsten is called *platinoid*. These alloys have a high electrical resistance, platinoid being higher than the other varieties of German silver; the resistance increases uniformly between 32° and 212° Fahr.

German silver solders possess considerable strength, and are often used for soldering steel. The color is very similar to that of steel.

In preparing German silver solders, the copper is melted first, and then the zinc and nickel added simultaneously.

Hard German Silver Solders

These solders, sometimes called steel solders, contain a large proportion of nickel and are very strong. They require a very high heat for melting, and usually cannot be fused without the aid of a bellows or blast.

No. 1. Copper, 35 parts; zinc, 56.5 parts: nickel, 9.5 parts.

No. 2. Copper, 38 parts; zinc, 50 parts; nickel, 12 parts.

Soft German Silver Solders

No. 3. Copper, 4.5 parts; zinc, 7 parts; nickel, 1 part.

No. 4. Copper, 35 parts; zinc, 56.5 parts; nickel, 8.5 parts.

The following No. 5 formulae given by Kent is similar to No. 4:

No. 5. Copper, 38 parts; zinc, 54 parts; nickel, 8 parts.

Soldering Fluxes.—The word *flux*, means a *substance applied to a metal to make solder flow readily on its surface.*

The action of a flux is largely that of cleaning the surface, and of reducing any oxide on the surface to the metallic state.

If a piece of sheet copper be carefully cleaned by means of emery cloth and heated over a gas flame, the surface will be seen to tarnish rapidly and assume a dark brown appearance. A small piece of rosin dropped on the surface will melt, and when the liquid runs, the initial brightness of the surface will be found to reappear.

There are a number of fluxes suitable for various kinds of soldering, but pine amber rosin is the best for electrical work as it does not cause corrosion. A corrosive flux, such as zinc chloride solution (killed spirits) should be strictly excluded from any electrical work.

The Underwriters' code permits the use of a flux composed of chloride of zinc, alcohol, glycerine, and water.

This preparation is easily applied and remains in place. It permits the solder to flow freely and is not highly corrosive. This flux is made as follows: Zinc chloride, 5 parts; alcohol, 4 parts; glycerine, 3 parts. Anhydrous zinc chloride crystals should be used dissolved in alcohol.

The glycerine makes the flux adhesive. To prevent the alcohol igniting, the mixture may be diluted with water.

For electrical work, especially when very small wires are used, rosin should be insisted upon to avoid any corrosion.

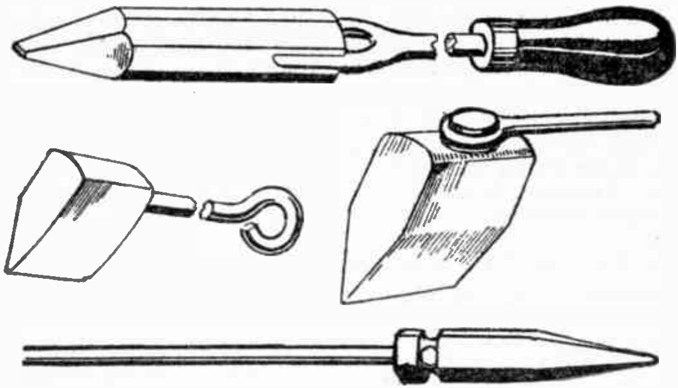
No one flux can be assigned to any one metal as being peculiarly adapted or fitted to that metal for all purposes. The nature of the solder often determines the flux.

The various fluxes and their use are given in tabular form in the accompanying tables. According to Haswell, the proper fluxes to use are as follows:

For iron, use borax
" tinned iron, use rosin
" copper and brass, use sal-ammoniac

For zinc, use chloride of zinc
" lead, use tallow or rosin
" lead and tin, use rosin and sweet oil

Soldering Bolts or Bits.—The erroneously called soldering "iron" or bit consists of a large piece of copper, drawn to a point or edge and fastened to an iron rod having a wooden handle as shown in fig. 8,194. There is a great variety of bits which may be classed:



FIGS. 8,194 to 8,197.—Various soldering bits, or so called "irons." Fig. 8,194, ordinary edge bit; figs. 8,195 and 8,196, hatchet bits; fig. 8,197, pointed bit.

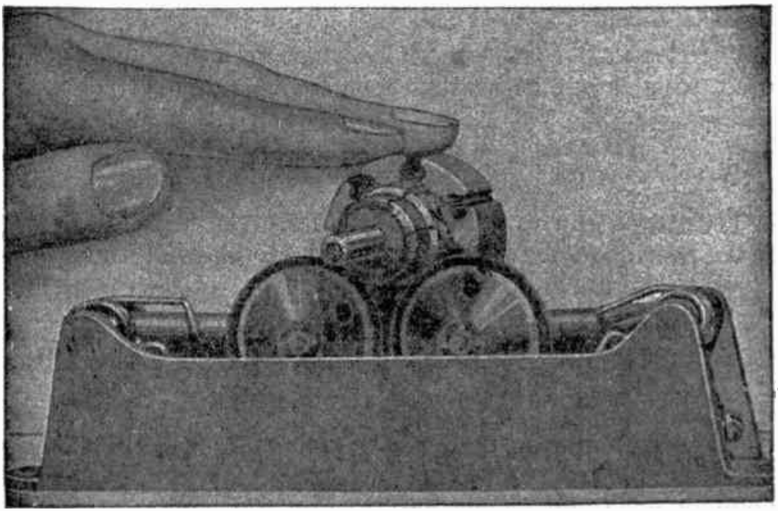
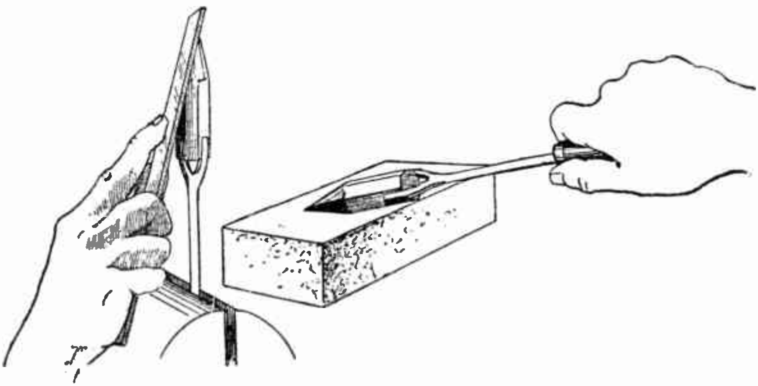


FIG. 8,198.—Chapman manual commutator fluxing machine. *In construction,* two cloth rollers carried by a spring actuated lever, dip into a trough of flux and press against commutator as armature is rolled by hand.

1. With respect to their shape, or construction as:
   a. Pointed;
   b. Grooved;
   c. Hatchet.

2. With respect to the method of heating, as:
   a. Externally heated; b. Internally heated {electrically, or by gasoline torch.

The various types of bit are shown in the accompanying cuts.



FIGS. 8,199 and 8,200.—Two methods of cleaning the bit. Fig. 8,199, filing; fig. 8,200, rubbing on soft brick.

A heavy bit is preferable for joining work, as one weighing less than two pounds does not retain the heat long enough.

Tinning the Bit.—Preliminary to soldering, the bit must be coated with solder, this operation being known as "tinning."

To tin a soldering bit, heat it in a fire or gas flame, until hot enough to melt a stick of solder rapidly when it is lightly pressed against it.

When the bit is at the right temperature, the heat can be felt when it is held close to the face. When hot enough clean up the surface of the copper with an *old* file.

If the temperature be too high, the copper surface will be found to tarnish immediately, in which case the soldering bit must be allowed to cool slightly and the cleaning repeated. When the surface only tarnishes slowly a little flux is sprinkled upon it, and then rubbed with a stick of solder.

After the molten metal has spread over the whole of the surface which it is desired to tin, the superfluous solder is wiped off with a clean damp rag.

The surface should then present a bright silvery appearance when properly tinned.

The operation of tinning the bit is shown in figs. 8,204 to 8,206. Once a soldering bit has been well tinned care should be taken not to overheat it. If the bit at any time reach a red heat it will be necessary to repeat the whole tinning process before it is fit to be used again. ***No good work can be done with an untinned or badly tinned bit.***

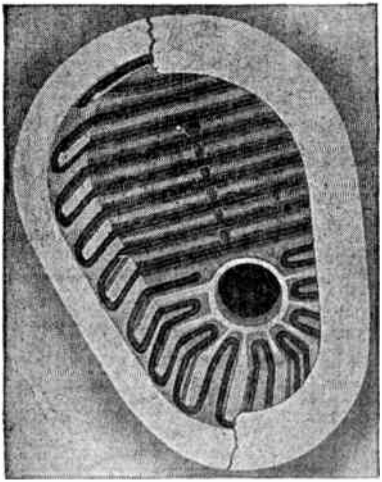
Soft Soldering.—The theory of soft soldering is that: *as the solder adheres to and unites with the surface of the copper when the bit is tinned, so will it adhere to and unite the surfaces of the metals to be soldered.*

FIG. 8,201.—Chapman "Allatonce" electrically heated commutator soldering machine. View showing general appearance of machine.

Soft soldering, as well as hard soldering, consists in welding together two or more pieces of similar or dissimilar metals by means of another metal of lower melting point.

In order to solder successfully wire joints, the following instructions should be followed:

1. Clean and tin the bit as shown in figs. 8,204 to 8,206.



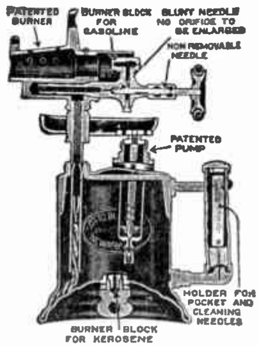


FIG. 8,202.—Electrical heating elements as used on Chapman "Allatonce" commutator soldering machine. Rating of heating elements 1600° to 2200° Fahr. but operated at only about 1200°.

FIG. 8,203.—Bernz gasoline torch with holder for heating soldering bits.

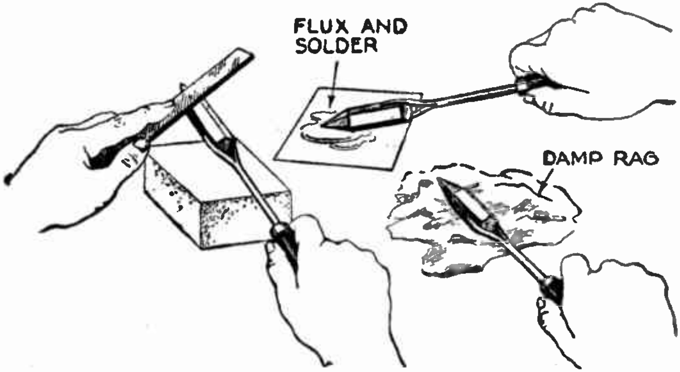
2. Heat the bit in the fire until it reaches the right temperature. Do not try to solder a joint with a bit so cool that it only melts the solder slowly, nor with one so hot that it gives dense clouds of smoke when in contact with rosin. Burned rosin must be regarded as dirt.

3. Remove the bit from the fire and hold it, or preferably support it on a brick or block of other material which does not conduct heat readily.

4. Wipe the surface clean with a rag. Apply solder until a pool remains on the flat surface, or in the groove, if a grooved bit be used.

5. Sprinkle with rosin, lay the joint in the pool of solder and again sprinkle with rosin.

6. Rub the joint with a stick of solder so that every crevice is thoroughly filled.



FIGS. 8,204 to 8,206.—"Tinning" the bit. Fig. 8,204, cleaning bit by filing working surfaces with an old file; fig. 8,205, rubbing the bit on the flux and solder, which may be conveniently placed on a piece of sheet tin as shown; fig. 8,206, removing surplus solder by giving each side of the bit a quick stroke over a damp rag.

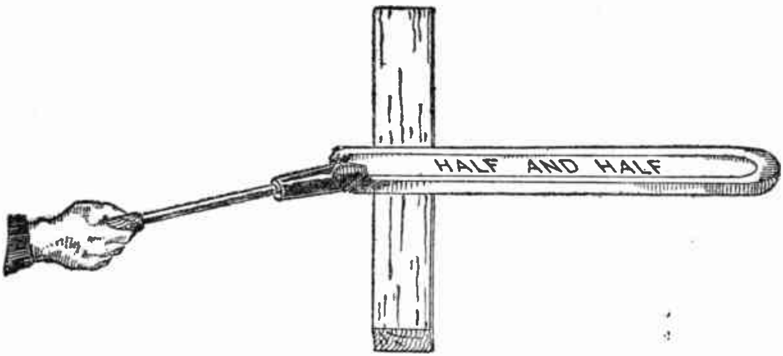


FIG. 8,207.—Picking up solder with a hot bit. This is the proper method for small work. Rest the bar of solder on some support as a brick or piece of wood and touch it with the end of the hot bit. Some of the solder will melt and remain on the bit. It is then transferred to the part to be soldered, and if the surfaces be in proper condition and fluxed when the bit touches the surfaces, the solder will leave the bit and cover the surfaces. *In picking up solder* from the stick, care should be taken not to leave the bit in contact with the solder too long or some of it will drop off. The larger the bit and area tinned, the more solder will the bit hold

7. Remove the bit, and lightly brush superfluous solder from the bottom of the joint. See that no sharp points of solder remain which may afterwards pierce the insulation.

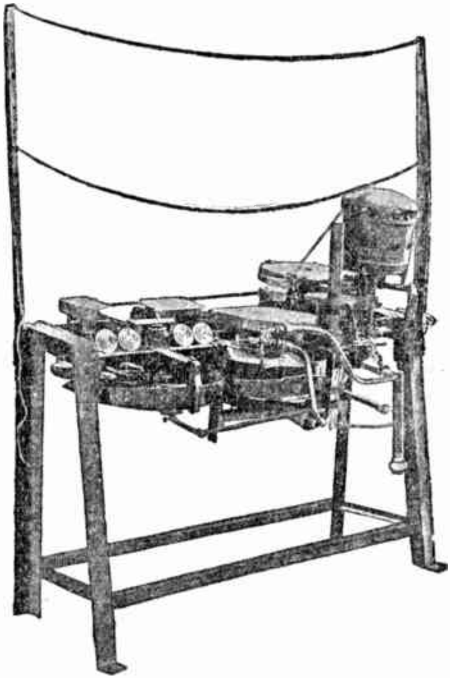


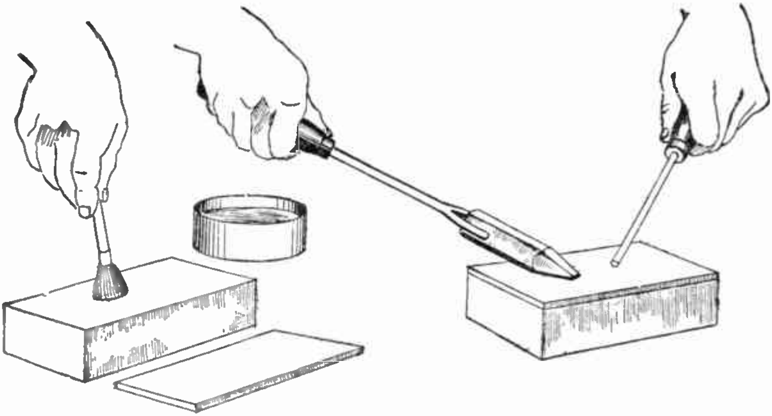
FIG. 8,208.—Chapman full automatic thermostatic wafer soldering machine. *In operation* automatic dial feed timing is arranged to take stock from a chute. Timed immersion in flux; four tests for sound stock and proper entry in machine; four throw outs for defective stock or entry. The machine does not stop but throws out the defective pieces and keeps on going. Solders by immersion, and a gentle removal from solder bath, then spun at 1800 *r.p.m.* to throw off excess solder. Cooled in a device to prevent sticking of sections together, and discharged through a non-denting device (not shown).

NOTE.—*If the bit be overheated or burned,* heat to redness and then plunge into cold water, when most of the hard oxidized surface will scale off.

NOTE.—*A soft coal fire* will quickly destroy the tinning on a bit.

When the bit is first placed on the joint, the solder should run up into the joint. This will occur only when the joint is well made and thoroughly cleaned, and if the workmanship be perfect it is even possible to fill the joint completely by feeding in solder below the joint as it melts and runs up into the joint.

A well soldered joint should present a smooth, bright appearance like polished silver. Wiping the joint before it cools destroys this appearance, and is also liable to produce roughness, which is detrimental to the insulation.



FIGS. 8,209 to 8,212.—*Sweating.* When two surfaces are to be united by sweating, first see that the surfaces are perfectly clean, then flux as in fig. 8,209. Put a piece of tinfoil over one surface and the other surface on top. They should be held firmly together by a clamp or other means and heated as in fig. 8,212 by a hot bit, or if the metal have considerable thickness by a torch, until the solder melts. When cool, the surfaces will be found to be firmly united.

NOTE.—42% tin 58% lead is the strongest of the tin lead alloy. It works good and has sufficient viscosity to fill commutator lead slots automatically. It is therefore not surprising that the nearest commercial composition 40% tin 60% lead (also known as "commercial") is the most popular composition for soldering commutators. It is cheap, works easily and does not throw out of hot commutators as readily as solders containing a higher proportion of tin.

NOTE.—*Soldering Temperature.* The correct temperature for soldering must be determined for each job and flux largely by experiment. It varies with the size of the work, the insulation of the commutator, the solder composition and the nature of the flux. Usual soldering ranges are between 500° Fahr. and 700° Fahr. Do not try to work around 800° Fahr. as about this temperature the drosses become soluble in the solder and the solder is said to be "burnt" and will behave badly.

In order to prevent the insulation on the wire near the joint being damaged, the process of soldering should be carried out as quickly as possible, and for this reason the tendency to burn the insulation is less with a *hot* bit (a quick bit) than with a cooler one.

FIGS. 8,213 to 8,215.—Airco-Davis-Bournonville lead burning torch designed for "burning" or welding lead. By attaching a proper mixing head and using City gas instead of acetylene, this torch may be used for soldering. The temperature with gas is about 3,500° Fahr.

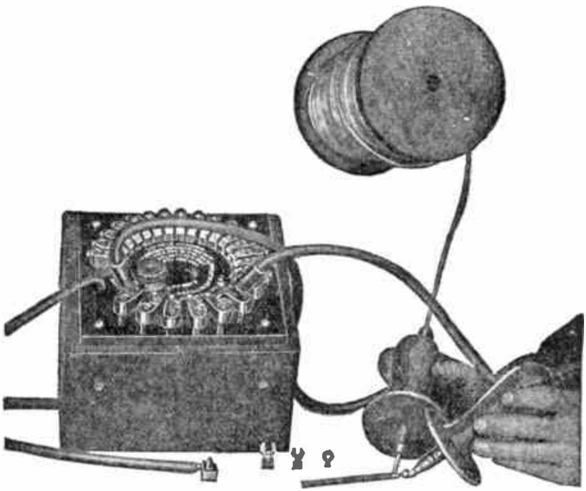


FIG. 8,216.—Chapman universal armeter used with carbon contact resistance soldering leads. Connect pair of No. 8 flexible leads to say O and 5V terminals.

NOTE.—***Block tin*** melts at 446° Fahr. and is used by many especially on very high speed and otherwise heavily worked commutators on account of its 88° higher melting point. Its viscosity is low, that is, it flows freely and it therefore may be necessary to fill the commutator lead slots by hand after it is soldered, but before it cools, using a piece of wire solder or fire block tin.

Sweating.—In this operation *the surfaces are cleaned, heated, and covered with a film of solder.* The soldered surfaces are then placed together and heated by passing the bit over the outside surface until the solder melts and unites the two surfaces.

Sweating is often employed for the temporary holding together of work which has to be turned or shaped, and which could not be so conveniently held by other methods. After having been turned or shaped, the separation of the parts is readily effected by the aid of heat.

TEST QUESTIONS

1. *What is solder?*
2. *Name the two general classes of solder.*
3. *What is the difference between soft and hard solder?*
4. *Of what does common or plumbers' solder consist?*
5. *What is the requirement with respect to the melting point of solder?*
6. *What is a soldering flux?*
7. *Why are some fluxes undesirable for electrical work?*
8. *What is the right name for a so-called soldering "iron"?*
9. *Why should the bit be tinned?*
10. *Describe the operation of tinning the bit.*
11. *What is the theory of soft solders?*
12. *Describe the operation of sweating.*

CHAPTER 55

Electric Heating

The application of electrical energy to domestic and industrial heating has numerous advantages.

For domestic and some industrial purposes, heat is produced by electricity *by forcing it through resistance wires*, raising the temperature of the latter, and applying the heat thus generated to the articles to be heated.

Heating Units.—By definition a heating unit or heating element sometimes called resistor, is *a length of resistance metal in the form of a strip, or coiled wire through which electric current is passed to give off heat.* The heating unit becomes hot on account of the resistance it offers to the current.

Selection of Heating Units.—The choice of material for a heating unit depends upon temperature conditions. All materials used deteriorate to some extent when heated, some will withstand higher temperatures than others. Accordingly in the manufacture of resistance wires there are several kinds to meet the different conditions of service.

Classification of Heating Units.—The numerous applications of heating units give rise to various types which may be classified:

1. With respect to form, as

   a. Wire;
   b. Strip.

2. With respect to service, as

   a. Stove;
   b. Immersion;
   c. Space, etc.

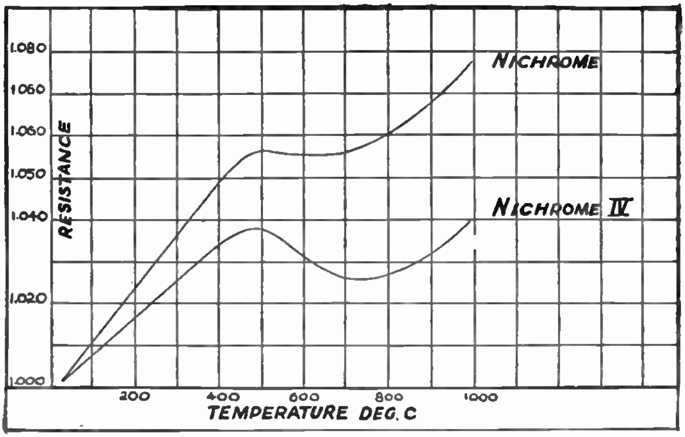


FIG. 8,217.—Temperature coefficient curves of "Nichrome" and "Nichrome" IV here shown represent wire slowly cooled from 1000° C. as specified by the American Society for Testing Materials. Slight variations from this curve may be expected due to variations in methods of annealing of different sizes of wire.

3. With respect to the general application, as

   a. Domestic;
   b. Industrial.

Design of Heating Units.—To obtain satisfactory and efficient results in electric heating the unit should be properly proportioned, located, placed and suitable for the service.

Refractory materials surrounding resistor elements should possess high thermal conductivities, otherwise the resistors will not be able to dissipate their heat as rapidly as it is generated, and will be subjected to undue temperature rise.

As the flow of heat through materials is inversely proportional to the length of the path, the refractory material surrounding resistors should be of minimum thickness consistent with safe mechanical and dielectric strength.

Selecting Nichrome IV resistance wire for illustration, the accompanying table gives size of this resistance wire suggested for a given number of watts at 110 volts. The sizes selected are those which will operate at approximately 1700° Fahr. in open coils and are suitable for radiant heaters, range units, etc.

Nichrome IV Wire, 110 Volt Circuit

Watts	Amperes	B. & S. Size	Ohms 75° F	Length	
300	2.72	25	37.6	19 Ft.	4 Ins.
325	2.95	24	34.7	22	5
350	3.2	24	31.6	20	5
375	3.4	24	30.1	19	6
400	3.64	23	28.1	22	10
425	3.87	23	26.4	21	5
450	4.10	22	25.0	25	7
475	4.32	22	23.7	24	4
500	4.55	22	22.5	23	0
525	4.77	22	21.5	22	0
550	5.0	21	20.5	26	7
575	5.23	21	19.6	25	6
600	5.46	21	18.7	24	4
625	5.67	21	18.0	23	5
650	5.91	20	17.3	28	5
675	6.15	20	16.6	27	3
700	6.36	20	16.1	26	5
725	6.58	20	15.6	25	7
750	6.82	20	15.0	24	7
775	7.04	19	14.5	30	0
800	7.26	19	14.1	29	0
850	7.72	19	13.3	27	5
900	8.17	19	12.5	25	10
950	8.63	19	11.9	24	6
1000	9.08	18	11.3	29	2

For other voltages divide the number of watts required at that voltage by the voltage factor (next table). Select nearest number of watts in the 110 volt table, multiply the length in 110 volt table by voltage factor. Suppose a device should require 550 watts and the supply voltage is 150. Factor for 150 volts is 1.36 and $\frac{550}{1.36}=405$ watts. Nearest value in 110 volt table is

400 and would require No. 23 wire. This size should be used on 150 volts but length should be 21 ft.×1.36 or 28 ft. 7 in.

Voltage Factors on Basis of 110 Volts

Voltage..........	100	120	150	200	220	240	32
Factor...........	91	1.09	1.36	1.82	2.0	2.18	0.29

Nichrome Wire—110 Volts

Watts	Amperes	B. & S. Size	Ohms 75° F	Length	
250	2.27	25	43.6	21 Ft.	2 Ins.
300	2.72	24	36.4	22	0
350	3.2	23	31.0	24	0
400	3.64	23	27.2	21	0
450	4.10	22	24.1	23	5
475	4.32	22	23.0	22	4
500	4.55	22	21.8	21	0
550	5.0	21	19.8	24	5
575	5.23	21	18.9	23	2
600	5.46	21	18.1	22	4
615	5.6	20	17.7	27	6
640	5.82	20	17.0	26	6
660	6.0	20	16.5	25	3
700	6.36	20	15.6	24	4
750	6.81	19	14.5	28	5

Nichrome Ribbon—110 Volts—1/16" Width

Watts	Amperes	Thickness	Ohms 75° F	Length	
400	3.64	.003	27.2	9 Ft.	10 Ins.
425	3.87	.0035	25.6	10	9
440	4.00	.0035	24.7	10	5
450	4.1	.004	24.1	11	7
475	4.32	.0045	22.9	12	5
500	4.55	.0045	21.8	11	8
525	4.77	.005	20.8	12	6
550	5.0	.005	19.8	11	11
575	5.23	.0056	18.9	12	10
600	5.46	.0056	18.1	12	3
625	5.68	.0063	17.4	12	11
650	5.91	.0071	16.7	14	11
660	6.00	.0071	16.5	13	10
675	6.15	.008	16.1	15	0
700	6.36	.008	15.6	14	[illegible]
750	6.82	.0089	14.5	15	1

Another example follows taking the alloy "Nichrome" which is suitable for electric irons, toasters, hot plate, space heater, etc.

The second and third tables on page 1,208 give size for a given number of watts at 110 volts.

For voltages other than 110 divide the number of watts required at the given voltage by the voltage factor page 1,208. Select nearest number of watts in the 110 volt table, multiply the length in 110 volt table by the voltage factor. Suppose an electric iron take 550 watts and the supply voltage is 100. Factor for 100 volts is .91 and $\frac{550}{.91} = 605$ watts.

Nearest value in 110 volt table is 600 watts which requires 12 ft. 3 ins. of $\frac{1}{16} \times .0056$ "Nichrome" ribbon. This gives the size to be used on 110 volts, but the length should be $.91 \times 12$ ft. 3 ins. or 11 ft. 2 ins. The winding for 550 watts, 110 volts would then be 11 ft. 2 ins. of $\frac{1}{16} \times .0056$ "Nichrome" ribbon.

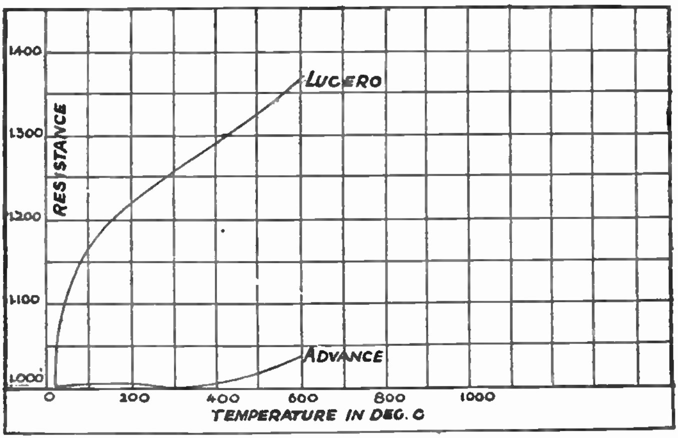


FIG. 8,218.—Temperature resistance curves for "Advance and Lucero" resistance wire showing change in resistance of one ohm of wire with increasing temperature.

Immersion Heaters.—These devices for heating liquids are made in a variety of forms to suit different conditions.

The various methods of heating water may be classed:

1. With respect to capacity, as

   a. Non-storing;

   b. Storing.

2. With respect to the heating element, as

   a. External element;

   b. Immersed element.

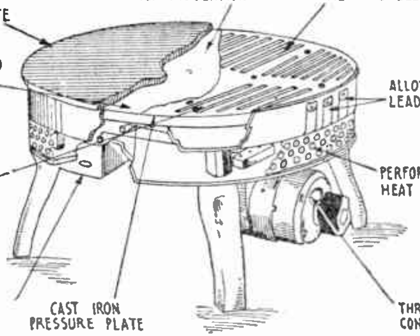


FIG. 8,219.—Electric disc stove. Adapted to laboratory and other industrial purposes. The maximum surface temperature is 750° Fahr.

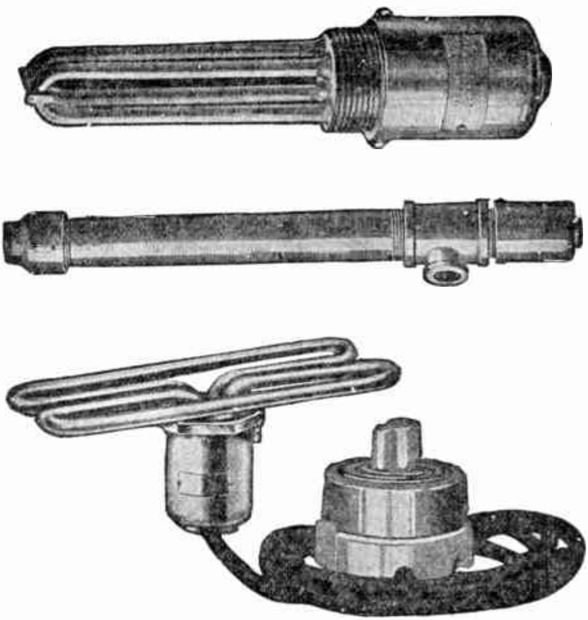
The so-called "instantaneous" is an example of the non-storing class and consists of a heating element and coil of pipe through which water passes, the rate of flow, and consequently the temperature being controlled by a valve. Nothing can be more ridiculous than to call these affairs "instantaneous" heaters, as no physical change takes place instantaneously.

The average use of water is from 20 to 125 gallons per family per day; temperature 104° Fahr. for bath purposes; 150° Fahr. for dish washing.

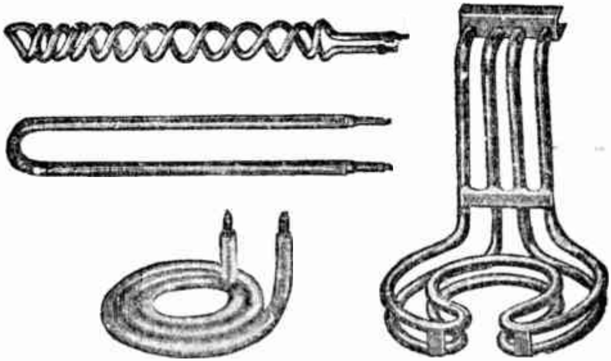
If water be heated as required for use, a large demand, 2 to 5 *k.w.* is created for a short time and under usual conditions, does not secure a sufficiently low energy rate to be economical.

The rate can be lowered by using a lower demand, .5 to 1 *k.w.* over a longer time or continuously, that is, heating the water in advance and storing it in a suitable heat insulated tank.

The demand can also be lowered by arranging a double throw switch to permit use of either range or water heater, but not both at same time. Effective heat insulation on the tank, to reduce heat loss into the room, is required where water is stored. Automatic temperature control aids in securing constant temperature of stored water, and automatically adjusts the average current consumption to the existing hot water requirements.



FIGS. 8,220 to 8,222.—Cutler-Hammer water immersion heaters, for *a.c.* or *d. c.* circuits. Fig. 8,220, pipe outlet type heater. Cord and switch removed; fig. 8,221, circulation type heater. Cord and switch removed; 8,222, bottom outlet heater complete with cord and switch. These heaters are adapted to applications such as water tanks, sterilizers, stills, vulcanizers, glue cookers and other industrial applications where it is necessary or advantageous to have the heater immersed directly in the water. This method of heating liquids results in highest heating efficiency since there is practically no direct loss of heat to the atmosphere, the heat is imparted directly to the water. In addition with the heater inside the tank, it is usually a simple matter to insulate the entire tank to prevent losses by radiation.



Figs. 8,223 to 8,226.—Cutler-Hammer tubular heater units of special shapes and sizes, showing the adaptability of these heater units.

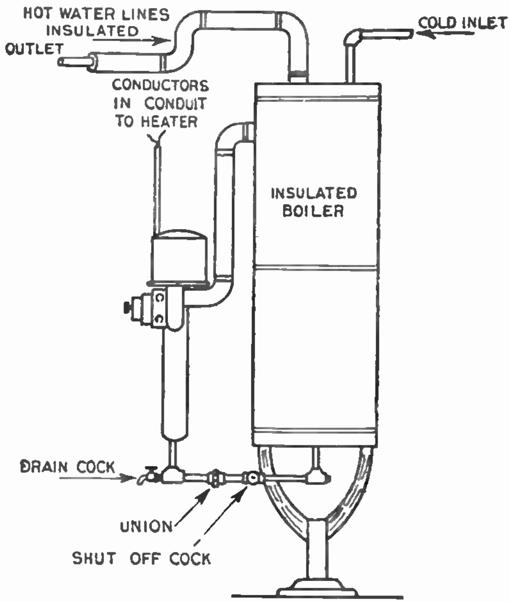


Fig. 8,227.—Wiegand "Chromalox," side arm type electric water heater attached to storage tank.

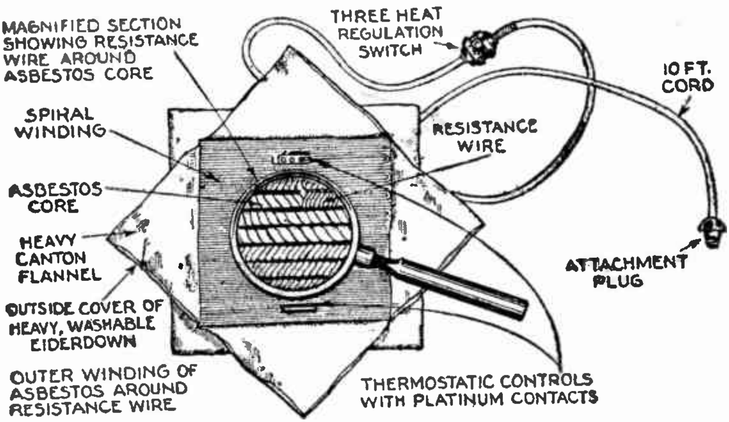


FIG. 8,228.—Electric warming pad. *It consists of* a flexible heating element with an outer cover of eiderdown which is removable and washable, so that the pad may always be kept in a sanitary condition. The pad is arranged for three heats, which are regulated by means of a switch so designed as to be easily operated in the dark, the sense of touch enabling the user to change from one heat to the other. It also contains two thermostats to prevent overheating. *Never* leave a pad applied to a patient unable to remove same.

Efficiency and Gallons per 24 Hours of Water Heated to 104° Fahr.

(36 gal. tank covered with 1 in. hair felt insulation on tank and 1 in. magnesia covering circulation piping. Cold water 39° Fahr. Faucet close to tank.)

Kind of system	Kind of equipment	Watts	Efficiency per cent.	No. gal. hot water available (at 104° Fahr. per 24 hrs.)
Storage	Outside circulation	600	82	75
Storage	Outside circulation	1,000	76	117
Storage	"Clamp on"	750	78	89
Intermittent	Outside circulation	3,000	73	330
Intermittent	Outside circulation	5,000	69	525

Space Heaters.—As its name implies a space heater is for diffused instead of concentrated heat, such as room heating.

For this purpose the unit is made from ribbon in the form of a strip.

The electric energy required to heat an ordinary sized room when the outside air is near the freezing point ranges from about 1 to 2 watts per cu. ft.

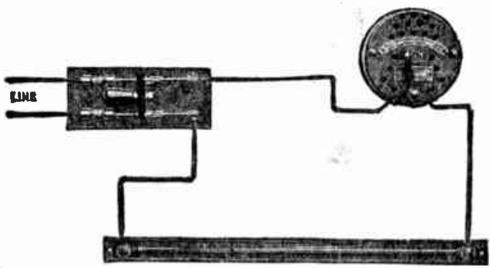


FIG. 8,229.—Cutler-Hammer space heater with rheostat heat control.

The following table shows the loss of heat per sq. ft. of window and wall surface, for one degree Fahr., difference of inside and outside temperature, the loss being expressed in heat units per hour.

Loss of Heat per Sq. Ft. of Surface

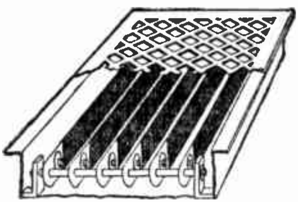
Kind of Surface	B. t. u. per hour	Kind of Surface	B. t. u. per hour
4 in. brick wall	68	Window, single glass....	.776
8 in. brick wall	46	Window, double glass...	.518
12 in. brick wall	32	Skylight, single glass....	1.118
16 in. brick wall	26	Skylight, double glass...	.621
20 in. brick wall	23	Ceilings, fire proof......	.145
Floors, fire proof	124	Ceilings, wooden beams.	.104
Floors. wooden beams..	683	Ordinary wooden wall, lathed and plastered..	.1

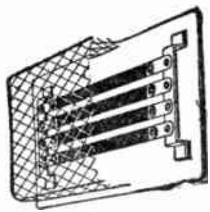
Example.—What will be the loss of heat per hour in a single room, wooden structure when the temperature inside is maintained at 70° Fahr., while the outside is at 32°. Size of room 10×10×10, having three 3×6 windows. Here all surfaces must be considered.

Area of windows $=3\ (3\times6)=54$ sq. ft.
Area of walls $=4\ (10\times10)-54=346$ sq. ft.
Area of floor $=10\times10=100$.
B.t.u. lost through windows $=(70-32)\times.776\times\ 54=1{,}592.4$
B.t.u. lost through walls $=(70-32)\times.1\ \ \ \times346=1{,}314.8$
B.t.u. lost through floor $=(70-32)\times.083\times100=\ \ 315.4$

Total loss of heat per hour.................. $=3{,}222.6$ *B.t.u.*

FIG. 8,230.—Cutler-Hammer space heater: view showing general appearance and size shown by a 2 ft. rule.





FIGS. 8,231 and 8,232.—Application of space heaters under floor and on wall.

Space heating units as made by Cutler-Hammer are two feet long and may be used singly or in groups. These units have a capacity of 500 watts each and may be connected to *d.c.* or *a.c.* circuits of proper capacity and for any voltage between 100 and 125, or 210 and 250. Each heater is stamped with the voltage for which it is designed and should not be used on systems of higher voltages. Being made up in the 500 watt capacity, they provide a very flexible scheme for heating. Only as many as are actually required need be installed, yet additions can be made easily. They can be mounted in groups, or singly at different locations. The mounting holes permit the use of ordinary screws for mounting. There is no assembly.

The number of heaters required depends on many factors. An outdoor crane cab in a northern state would require more heat than one in a locality where the winters are moderate. Also a cab of good construction will be warmed satisfactorily with fewer heaters than one of poor construction.

The watt rating of a heater is determined by three general considerations:

1. Safe heater temperature.

One that will insure a satisfactory length of life.

2. Desirable operating temperature for the service.

3. Fire risk.

FIG. 8,233.—Wiegand one inch wide, strip heater designed for use in building special machinery where heat is required at some local point on the machinery as is the case in package forming and sealing machines, marking machines, and other manufacturing process equipment These strip heaters are rated at comparatively high wattage per sq. in. They safely operate at red heat, not exceeding 1,300° Fahr. The single end strip heater shown has the usual advantage of bringing the terminals to one end which is often desirable in machine building

The maximum safe operating temperature of the space heater is between 700° and 800° Fahr.

This is the approximate operating temperature of the standard 500 watt space heater when used under the conditions for which it is primarily designed, that is, for heating air at atmospheric temperatures and with free ventilation. It is evident that if the heaters be mounted in an enclosure which is at a much higher temperature than atmospheric or living room temperatures, the temperatures of the heater will be increased and it will therefore be over-rated and its life will be shortened. It is also evident that if the heaters be crowded together so that there is an interchange of heat between them. one acting to heat its neighbor, the safe operating temperature will be exceeded and the heaters may burn out unless the rating be reduced.

Example.—Assume that a standard space heater is installed in a plate warmer for keeping plates or dinner service warm. It is evident that while a standard rating might be used, the temperature of 700 to 800° Fahr. in contact with or close to chinaware, would be very apt to cause breakage. Therefore, the plates should be spaced away from the heater and preferably shielded from direct radiation and convection, or a lower rated heater used. For example, a 220 volt heater on a 110 volt circuit, which will deliver 125 watts.

In the same way the temperature must be considered from the operation or service standpoint in many industrial processes. In a package sealing machine, for instance, while a standard rating might be safe so far as the heater is concerned, the high temperature might burn the glue or overheat the paraffin. Therefore, a lower rating would be called for, not on account of the life of the heater, but on account of operating conditions and results to be accomplished.

Building Heating, Thumb Rules.—As a rough approximation, a rule of thumb is as follows:

.35 watts per cu. ft. (See *A*)
Plus 3.5 watts per sq. ft. of wall area (See *B*)
Plus 35. watts per sq. ft. of glass area (See *C*).

A. This takes care of the heat required for raising the temperature of the air approximately one complete change of air per hour. For more frequent changes, increase the wattage proportionately.

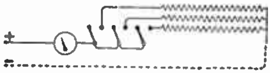
B. This takes care of the loss of heat through the walls. In figuring the wall area, the area of the four sides of the rooms and the ceiling and the floor are all included and a deduction is made for the glass area. The rule assumes good building construction, such as a good 12 in. brick wall or well made, double frame wall.

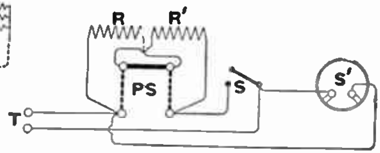
C. For measuring glass area, the overall area of the frame is measured and this area is deducted from the total wall area.

The above rule assumes a temperature elevation of 70° Fahr. or, in other words, external temperature of zero, room temperature of 70° Fahr. If the room adjoin other heated rooms, allowance must be made, based on the difference in temperature between the room under consideration and the adjoining rooms.

This thumb rule is for rough estimates only. It will agree quite closely with more complicated calculations in some cases, but on the other hand, there may sometimes be a considerable error so that it must be used cautiously. The following two examples will illustrate how the above rule is applied:

Example.—Small house 12 ft.×10 ft.×9 ft. high, good construction, 12 in. brick walls, with 3 windows each 3 ft.×5 ft., is to be heated to 70° Fahr. with zero temperature outdoors and one complete air change per hour.





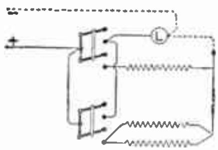


FIG. 8,234.—Arrangement of internal circuits for heaters in which each resistance section is controlled by a separate switch.

FIG. 8,235.—Internal connections of a cooker. T, terminals; PS, parallel or series switch; S, ordinary switch; S′, two pin socket for plug connection; R,R′, resistance sections. Current is turned on or off from R,R′ at S, while PS. puts R and R′ either in parallel or series. S′, allows of the attachment of an auxiliary heater. This arrangement is applicable to other types of heater, and S′, would then generally be omitted.

FIG. 8,236.—Arrangement of two circuit heater with pilot lamp L. When either switch is put on, L lights up. The top switch controls one-third of the heater resistance, and the bottom switch two-thirds.

$$.35\ (12\times10\times9)$$

$$\text{Plus } 3.5\left[(12\times10\times2)+(12\times9\times2)+(10\times9\times2)-(3\times5\times3)\right]$$

$$\text{Plus } 35(3\times5\times3)$$

Equals 4,022 watts. Eight 500 watt space heaters should be used, which will give a total of 4,000 watts.

Example.—Room 12 ft.×10 ft.×9 ft. high, good construction with well made, double frame walls, with two exposed walls containing 3 windows, each 3 ft.×5 ft. Room is on top floor, with ceiling (roof) exposed, with the room adjoining the 10 ft. wall heated to 70° Fahr. and that adjoining the 12 ft. wall 60° Fahr. The room beneath is heated to 70° Fahr. Two complete air changes per hour

$$.35\times2(12\times10\times9)$$

$$\text{Plus } 3.5\left[(12\times10\times1)+(12\times9\times1)+(10\times9\times1)\right.$$

$$\left.+\frac{70^\circ-60^\circ}{70^\circ}(12\times9\times1)-(3\times5\times3)\right]$$

$$\text{Plus } 35(3\times5\times3)$$

Equals 3,339 watts. Seven 500 watt space heaters should be used, which will give a total of 3,500 watts.

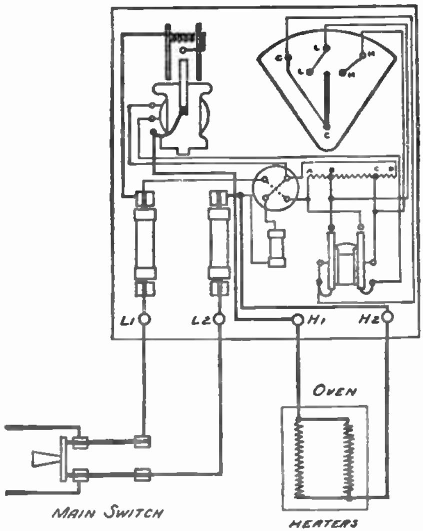


FIG. 8,237.—Control panel with switches, fuses and thermostat for the automatic regulation of heat.

Regulation of Heat.—To properly control the heat output, regulation of wattage may be required to:

1. Heat up rapidly from room to operating temperature; that is, to supply the heat of absorption and latent heat.

2. Provide for changes in operating temperature.

3. Provide for operation at uniform temperature where the heat requirements vary during operation.

The following methods of regulating wattage are in most common use:

1. By dividing the heater into sections and changing the voltage impressed on each section by connecting the sections in different combinations.

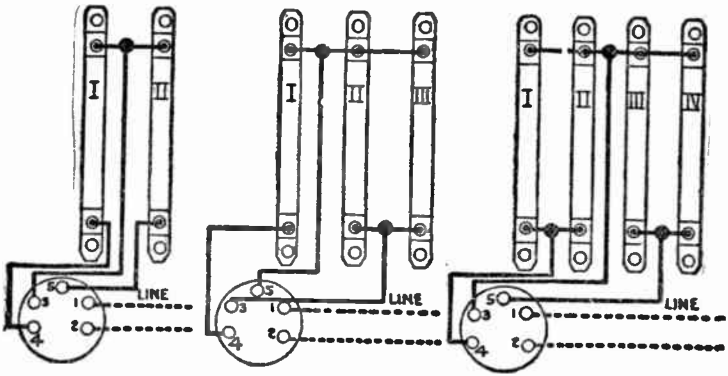


FIG. 8,238.—Two heaters and snap switch. *High,* full heat, heaters 1 and 2; *medium,* one-half heat, heater 2 only; *low,* one-quarter heat, heaters 1 and 2; *off.*

FIG. 8,239.—Three heaters and snap switch. *High,* full heat, heaters 1, 2 and 3; *medium,* two-thirds heat, heaters 2 and 3 only; *low,* one-third heat, heater 1 only; *off.*

FIG. 8,240.—Four heaters and snap switch. *High,* full heat, heaters 1, 2, 3 and 4; *medium* one-half heat, heaters 3 and 4 only; *low,* one-quarter heat, heaters 1, 2, 3, and 4; *off.*

2. By dividing the heater into sections each designed for line voltage, and providing each section with a switch.

3. By the use of a series rheostat. This gives closer regulation than methods 1 and 2, and does not complicate the heater by sectionalizing it. Rheostat control is particularly well suited to heaters developing small wattages.

4. By connecting the heater intermittently to the line, opening the circuit when the maximum operating temperature is reached and closing the circuit when minimum operating temperature is reached. This is the method generally employed in automatic temperature control. A thermostat or other

temperature responsive device is used and for low wattages, opens and closes the circuit directly, or for higher wattages actuates a suitable magnet switch.

5. By a time switch for connecting and disconnecting the heater at predetermined times.

Figs. 8,237 to 8,240 show how some of the methods of regulation just described are accomplished.

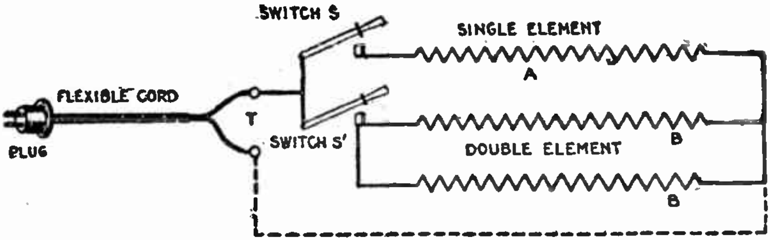


FIG. 8,241.—Arrangement of internal circuit for heaters giving three heating values. *In the diagram* A, represents one-third of the heating circuit; BB, two-thirds. With switch S, on, one-third of full heat is given; with S′, two-thirds, while with both S, and S′, on, the heater works with full power. At T, are two terminals to which the ends of the flexible cord from the plug are secured.

Non-Metallic Heating Units.—These are suitable for high temperature service such as applications in which the temperatures range from 1900° Fahr. (1038° C.) to 2750° Fahr. (1510° C.).

This temperature range covers the heat treatment of high speed steels, firing of ceramic ware and the heating of metals for forging. Non-metallic heating units are manufactured in cylindrical rods of carborundum brand silicon carbide. Silicon carbide has no known melting point; it is highly refractory and has a high specific resistance.

TEST QUESTIONS

1. *What are heating units?*
2. *Upon what does the choice of material for heating units depend?*
3. *Give classification of heating units.*

4. *Give calculation for heating units for electric irons, toasters, etc.*
5. *Describe an immersion heater.*
6. *How much electric energy is required to heat an ordinary sized room in freezing weather?*
7. *Give calculation for house heating.*
8. *What name is given to heating units used for house heating?*
9. *How is the watt rating of a heater determined?*
10. *What is the maximum safe operating temperature of a space heater?*
11. *Give building heating thumb rules.*
12. *Describe the regulation of heat.*

CHAPTER 56

Domestic Refrigeration

Domestic Refrigeration.—By definition, domestic refrigeration is *refrigeration on a small scale as accompanied by a self-contained unit with automatic control, fool proof and of suitable size for household use.*

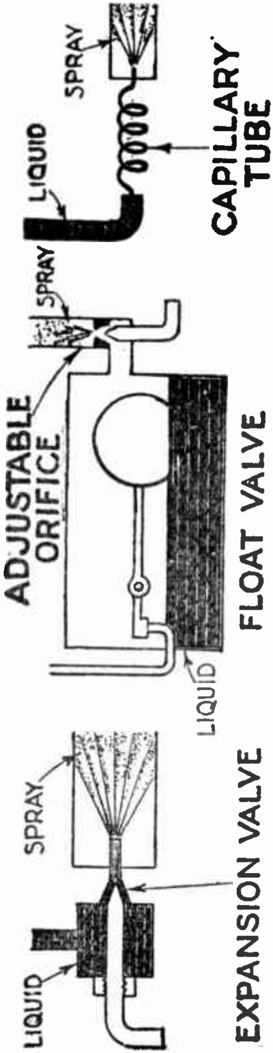
The term electric refrigeration is misleading.

Electricity has nothing to do with the refrigeration cycle, but is used to furnish the power to perform the cycle, that is, to drive the compressor.

Details of domestic refrigeration systems are given in the sections following.

Compression Systems.—There are two general type of compressor apparatus classed according to the method of expanding the refrigerant and known as

1. Dry system.
   a. Expansion valve;
   b. Capillary tube.
2. Flooded system.



Figs. 8,677 to 8,679.—Various methods of expanding the liquid. Fig. 8,677 by expansion valve; fig. 8,678, by combination float valve and adjustable orifice; fig. 8,679, by capillary tube.

In the *dry system*, the refrigerant *is admitted into the expansion coils of the evaporator in a semi-liquid or spray form, which is controlled by an expansion valve actuated by pressures.*

In the *flooded system, a relatively larger amount of liquid refrigerant is held in the evaporator and the proper operating level is maintained by means of a float valve actuated by gravity flow.*

Methods of Heat Transfer.—Two methods are employed to transfer heat from the interior of a cabinet to be cooled, namely,

1. By direct expansion;
2. By brine circulation.

These methods have been fully described and need no further explanation.

Compressors.—There are three types of compressors used:

1. Reciprocating;
2. Oscillating;
3. Rotary.

Reciprocating type compressors are generally either of *single* cylinder or *double* cylinder construction, having discharge and *intake* valves of varied differences of construction. The compressors may be *belt* driven, *gear* driven, or *directly connected to the motor.*

Condensers.—The condensing element is usually one of three types:

1. Water cooled;
2. Air cooled by *natural* air circulation.
3. Air cooled by means of a forced *fan* draft.

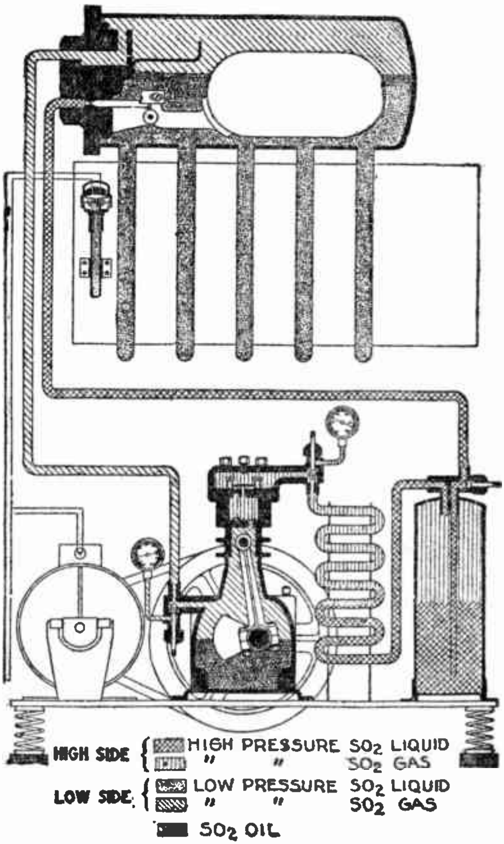


FIG. 8,680.—Kelvinator flooded system cycle.

Motors, Control Mechanism, Valves, Stuffing Box, Etc.—Motors of fractional horse power capacities to 1 *h.p.* and over of various industrial types are the *prime movers* of any electric refrigerator.

Control mechanisms are either of the following types:

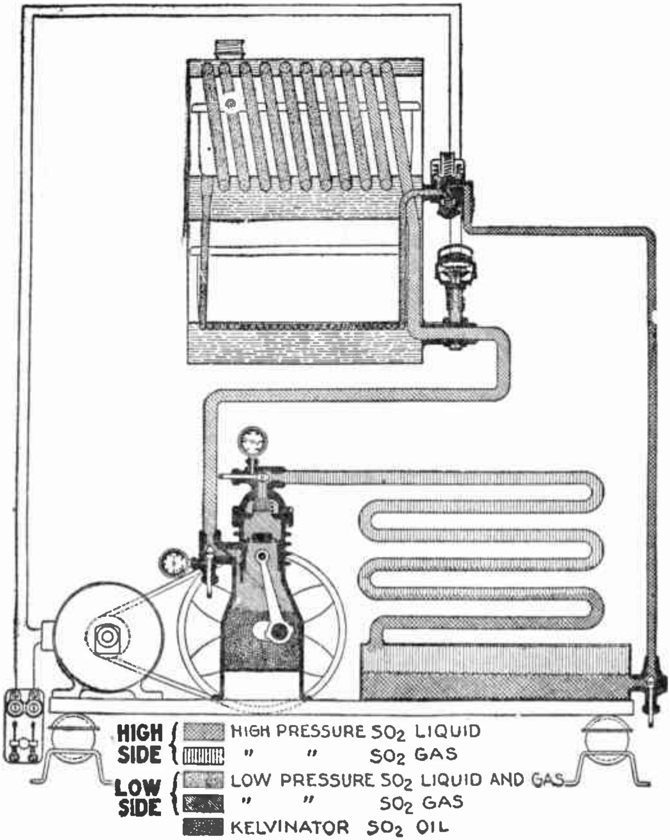


FIG. 8,681.—Kelvinator dry system cycle.

1. Pressure type;
2. Thermal type.

Servicc and shut off valves are usually required on the average refrigerating system. In many compression systems where the drive is by belt **or gear involving the use of a compressor drive shaft, a *stuffing box* is a primary element.**

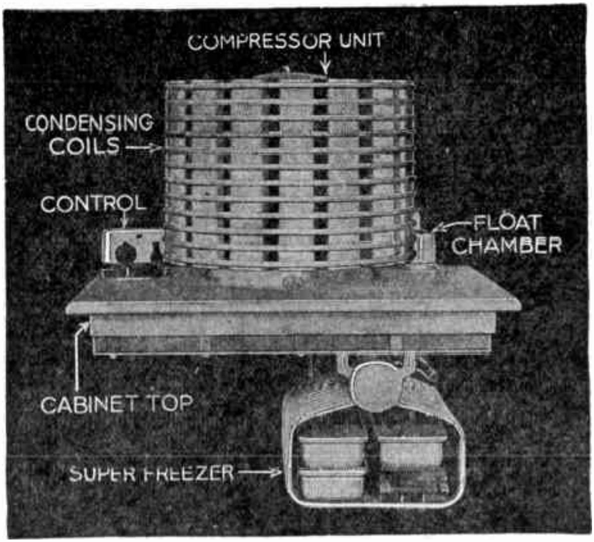


Fig. 8,682.—General electric domestic refrigerator unit. Exterior view showing general appearance. This unit fits on top of the refrigerator.

The function of the stuffing box is that of a packing gland to prevent leakage of the refrigerant by *sealing* the compressor drive shaft.

Typical Compression Type Domestic Refrigerator.—As an example of how the *compression cycle* is applied in a small unit for household duty the following brief description of the General Electric refrigerator is here given.

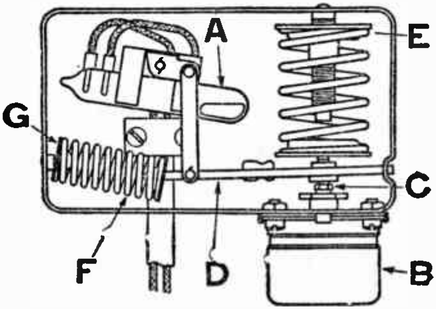


FIG. 8,683.—Rice automatic control by temperature. The electric circuit to the motor is opened and closed by the tilting of the mercoid switch A, which causes the mercury to flow from one end to the other, making or breaking contact with the terminals. The power element B, consists of a metal bellows containing a gas which quickly expands with a slight rise in temperature. When temperature increases, the power element exerts an upward push on the stem C, forcing up the lever D, which rocks the mercoid switch to the left closing the circuit. A decrease in temperature causes the power element to contract and the large adjusting spring at E, throws the switch back, opening the circuit. Spring F, gives the required snap action to the switch and is necessary for the proper operation of the control.

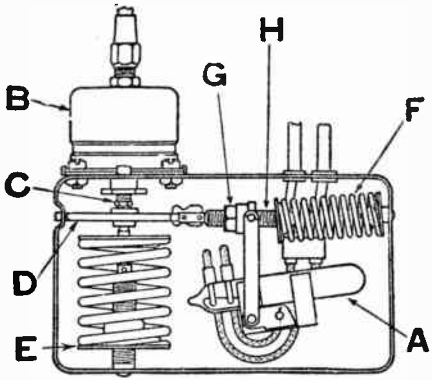


FIG. 8,684.—Rice automatic control by pressure. The electric circuit to the motor is opened and closed by the tilting of the mercoid switch A, which causes the mercury to flow from one end to the other, making or breaking contact with the terminals. The power element B, consists of a metal bellows to which is attached a stem C. The bellows within B, is connected direct to the refrigerant on the low pressure side. Experience has shown that there is a constant relation between the low side pressure and the temperature of the cooling unit. It is, therefore, possible to control temperature by controlling the low side pressure. As the low side pressure increases (unit closed down) the bellows power element expands pushing downward on stem C, and lever D, which rocks the mercoid switch to the right and closes the circuit. Running of the unit causes a decrease in low side pressure allowing the bellows element to contract. The adjusting spring at E, then throws the switch back, breaking the circuit.

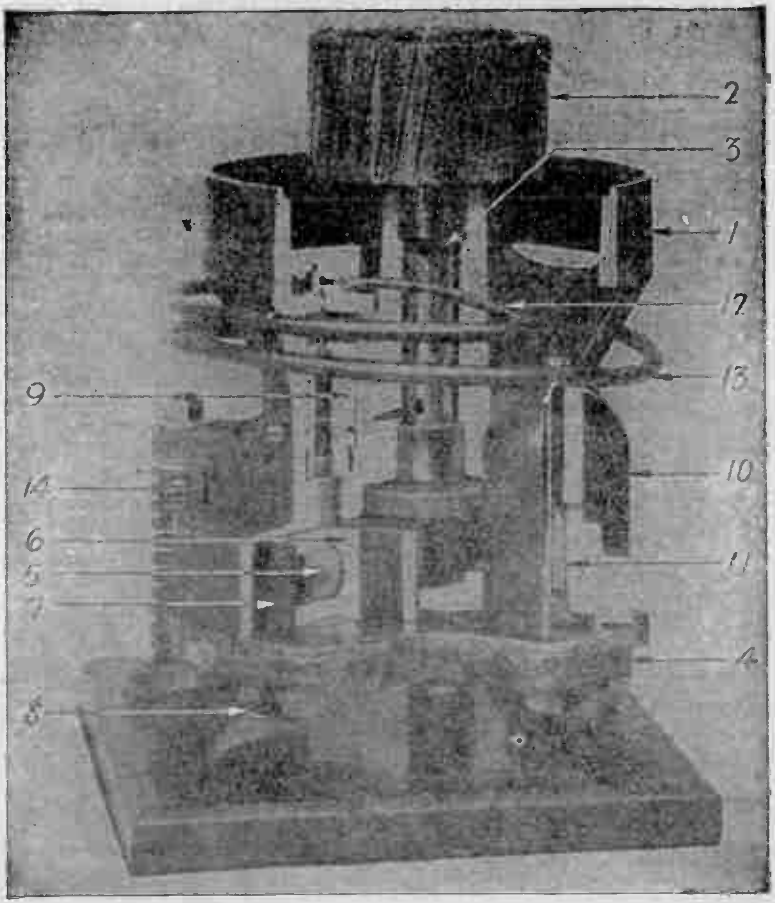


FIG. 8,685.—Cutaway section of General Electric refrigerator machine. The parts are: 1, main frame; 2, rotor; 3, main shaft; 4, bearing plate; 5, piston; 6, cylinder; 7, muffle box; 8, oil screen; 9, unloader; 10, surge chamber; 11, check valve plunger; 12, unloader tube; 13, suction tube; 14, supporting springs.

The General Electric compressor is of the oscillating type. The refrigerator consists in its entirety of two integral parts.

1. Refrigerating unit.
2. Cabinet.

The refrigerating unit consists of five principal parts.

1. Compressor.
2. Condenser.
3. Float chamber.
4. Evaporator (super-freezer).
5. Control.

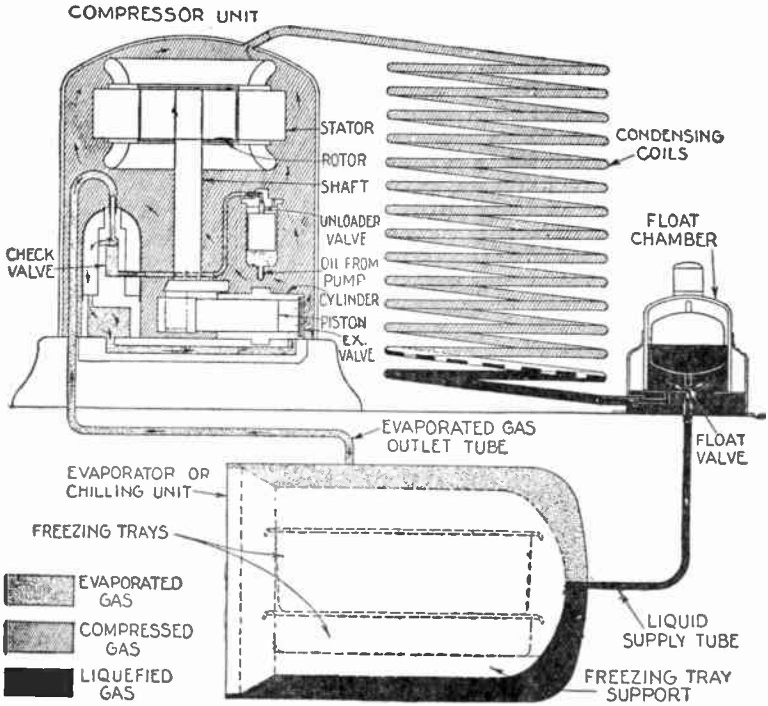
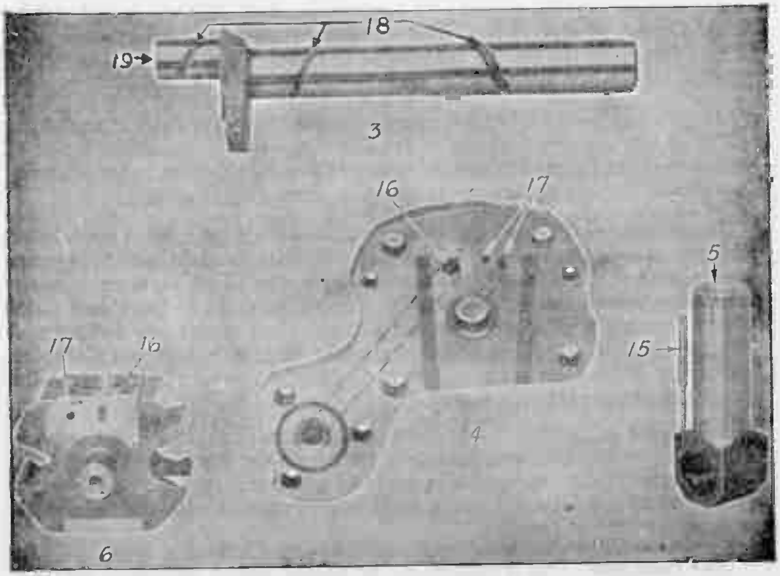


FIG. 8,686.—General Electric refrigerator unit. Diagram showing parts and cycle of operation.

Compressor unit.—This unit consists of the motor and compressor, together with the main frame on which they are mounted. The assembly is mounted on three vertical springs in order to reduce to a minimum the transfer of any noise or vibration to the outside casing.

The motor is of the single phase induction type.

The compressor is of the single oscillating cylinder type on the small units. As the piston is moved in and out by the action of the crank pin, the



FIGS. 8,687 to 8,690.—General Electric bearing plate, crank shaft, piston and compressor of refrigerator. The parts are: 3, crank shaft; 4, bearing plate; 5, piston; 6, compressor; 15, oil piston; 16, gas ports; 17, oil ports; 18, oil grooves; 19, crank pin.

cylinder is made to oscillate about its trunnions. The cylinder rides on the bearing plate and its oscillation opens and closes the suction port. This oscillation also operates the oil ports. The compressor operates at 1,750 revolutions per minute, which is the rated speed of the motor.

The base of the machine in which the mechanism is mounted is shaped like a bowl, which is filled with a permanent supply of high grade mineral oil up to the level of the bearing plate, thus forming an oil sump.

Positive forced feed lubrication is obtained by means of a plunger which is mounted beside the main compressor piston, and the cylinder in which it operates is in the same block as the main cylinder.

The oil plunger operates on the permanent oil supply in the same manner as the main piston operates on the vapor. Since the oil is never overheated, and it cannot become mixed with dirt, and it cannot oxidize or evaporate, there is therefore, no need to replace it.

Condenser.—This consists of circular copper coils, which are rigidly wound on sheet steel fins welded to the outside of the compressor case. These fins serve the double purpose of supporting the condenser coils and dissipating heat from the motor and condenser.

Float chamber.—The float chamber is located on the cabinet top to the right of the compressor case. Its function is to accumulate liquefied refrigerant until there is a sufficient supply to raise the float valve, allowing liquid, but no vapor to return to the evaporator as it is needed.

Evaporator.—This is located on the underside of the cabinet cover as an integral part of the whole refrigerating unit. Its function is to refrigerate the cabinet. It is made of two steel sheets, one of which is corrugated. These are folded into shape, with the upper part of the inner and outer sheets forming a cylindrical header and are then electrically welded and brazed together. This construction gives in effect a series of parallel tubes extending around the outer surface of the evaporator and opening into the header or refrigerant reservoir.

The liquid refrigerant is admitted from the float chamber into the evaporator where it evaporates, absorbing heat from the interior of the cabinet. The interior of the evaporator is made to accommodate ice freezing trays, two of which are set side by side and in direct contact with the floor of the evaporator for fast freezing.

The control.—This is located on the cabinet top at the left of the compressor case and consists of

1. A switch to throw the unit On or Off manually;

2. A thermostat to start and stop the motor in response to temperature changes in the evaporator when the manually controlled switch is On.

3. An overload protective device.

4. A starting relay.

Temperature control is accomplished by a metallic bellows, to which is attached a copper tube, the end of which is fastened to the evaporator. The bellows and tube contain a supply of sulphur dioxide to evaporate with a

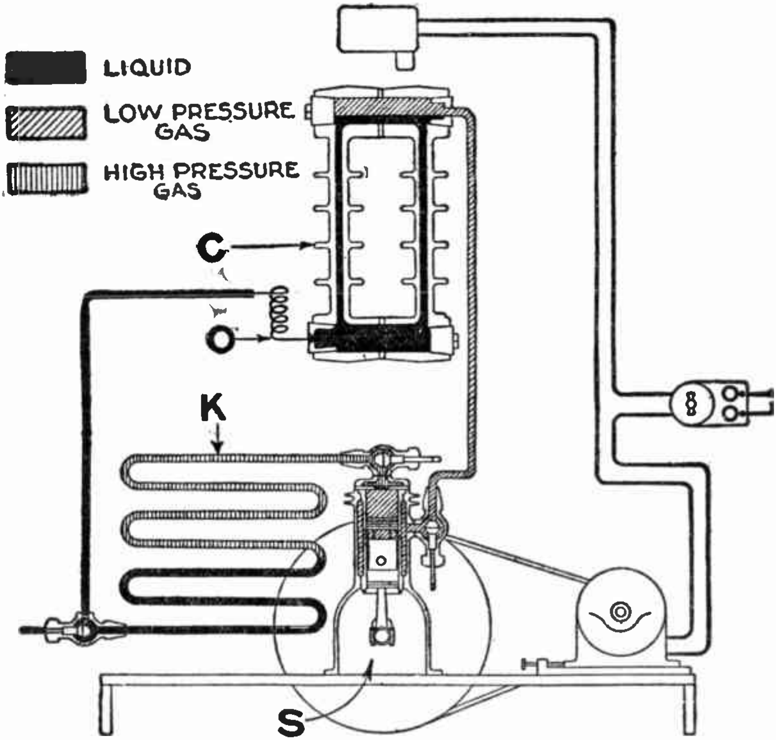


FIG. 8,691.—Operating cycle of Rice methyl chloride direct expansion refrigerating unit. The refrigerating effect is due to the latent heat of vaporization of the methyl chloride, that is, the amount of heat taken out of the surrounding air when the methyl chloride boils. The liquid methyl chloride starts vaporizing when released through the capillary tube O. It then boils or vaporizes in the cooling unit C, taking heat from the surrounding air inside the refrigerator. This vapor is conducted to the suction side of the compressor S, usually reaching it in a slightly superheated condition. The compressor then forces the vapor or gas into the condensing element K, where it is liquefied by cooling by a flow of air over the coils while the vapor inside is under pressure. It collects in liquid form in the bottom of the coils K, and is then allowed to return to the cooling unit C, through the capillary tube O. It should be noted that the resistance due to the constricted opening in the capillary tube O, causes it to act as an expansion valve. The tube builds up a back pressure in liquid feed line or high pressure side, and at the same time relieves it at low pressure into the low pressure side or cooling unit and suction pipe line.

resultant increase in the pressure. This increase in pressure actuates, through the metallic bellows, a switch which starts the motor.

Conversely, a decrease in temperature causes reduction in pressure, which opens the switch and stops the motor. The temperature may be adjusted by increasing or decreasing the tension on the temperature adjusting spring. This may be accomplished by means of the temperature adjusting dial which is on the front of the control. This allows the owner to adjust the cabinet temperature by a simple movement of the dial.

The motor is protected against overload by means of an overload trip which opens the circuit when an abnormal condition arises. The purpose of the starting relay is to close the starting contacts and thereby energize the starting winding, supplying the additional torque necessary to bring the motor up to speed.

In the case of the smaller units, a resistance, located in the control box, is in circuit with the starting winding. In the larger units one point of a capacitor is in circuit with the starting winding. Then when the motor has come up to speed, the starting winding is connected to another point on the capacitor unit and thereafter the motor runs as a polyphase motor. The capacitor on the larger units serves the purpose of increasing the power factor and decreasing the starting and running current.

Cycle of operation.—When the switch is closed and the motor is started, the pump begins to suck the sulphur dioxide vapor from the evaporator through the suction line. This reduces the pressure on the sulphur dioxide liquid and allows it to boil or evaporate freely.

As the sulphur dioxide changes from a liquid to a vapor, it absorbs heat from the interior of the refrigerator. The function of the rest of the refrigerator mechanism is then to reliquefy this vapor and feed it back to the evaporator. The pump, sucking the vapor from the evaporator, compresses it into the steel compressor case. From there the compressed refrigerant gas passes to the condenser coils, where it is cooled and as a result liquefies.

The liquid then drains down into the float chamber. When a sufficient quantity of liquid has accumulated to raise the float, the valve is opened, permitting some of the liquid to run back into the evaporator to complete the cycle.

The moving parts of the unit are liberally oiled by a forced feed system. A small piston plunger, attached beside the main piston, sucks oil from the sump in the base of the unit and forces it up around the piston and main bearings, from whence it drips back into the sump.

The oil pressure also operates an unloader, which equalizes the pressure on both sides of the main piston whenever the unit stops, thereby reducing the starting torque required and permitting the use of a smaller motor than would otherwise be required.

When the unit is running, the oil pressure forces the unloader plunger upward, thereby closing a small by-pass valve. As soon as the unit stops, the oil pressure decreases, allowing the unloader plunger to drop, and thereby opening the by-pass valve. This allows compressed vapor to enter the suction side of the pump. The rush of compressed vapor also closes the check valve, preventing this vapor returning into the super-freezer.

When the unit starts again, the by-pass valve is closed by the oil pressure, the check valve drops open and the unit resumes normal operation.

Multiple Refrigerating System.—Some apartment buildings have instead of individual refrigerating units, *a central plant located in the basement or other remote place, and furnishing refrigeration to each apartment by pipe line*. This is known as a *multiple refrigeration system* and it includes all systems in which the refrigerant is circulated from a common source to two or more separate refrigerator cabinets, each containing one or more evaporators or chilling units.

There are two general classes of these systems, namely

1. Brine piping systems.

2. Vapor piping systems.

The brine piping system comprises one or more commercial compressors placed in a machinery room which is generally located in the basement of the apartment building. A cold brine solution at a temperature of about 9° Fahr. is pumped through heavily insulated pipes into the refrigerator cabinet of each apartment kitchen.

The vapor piping system comprises one or more commercial compressors installed in the basement and a cabinet containing a *cooling coil* placed in each apartment kitchen refrigerator box.

Copper tubing and piping are used to connect the machines in the basement with the coils in the apartments. The refrigerant liquid is circulated through these tubes into the cooling coils of each cabinet, and the refrigerant gas returned to the compressor in the basement.

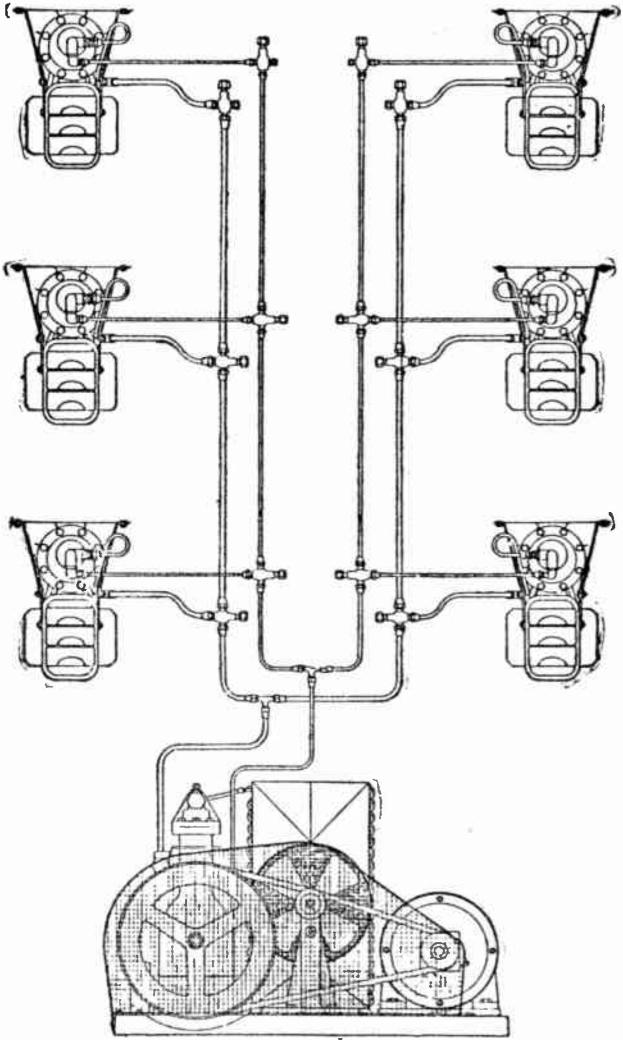


Fig. 8,692.—Servel apartment house installation with *header* and *riser* piping system.

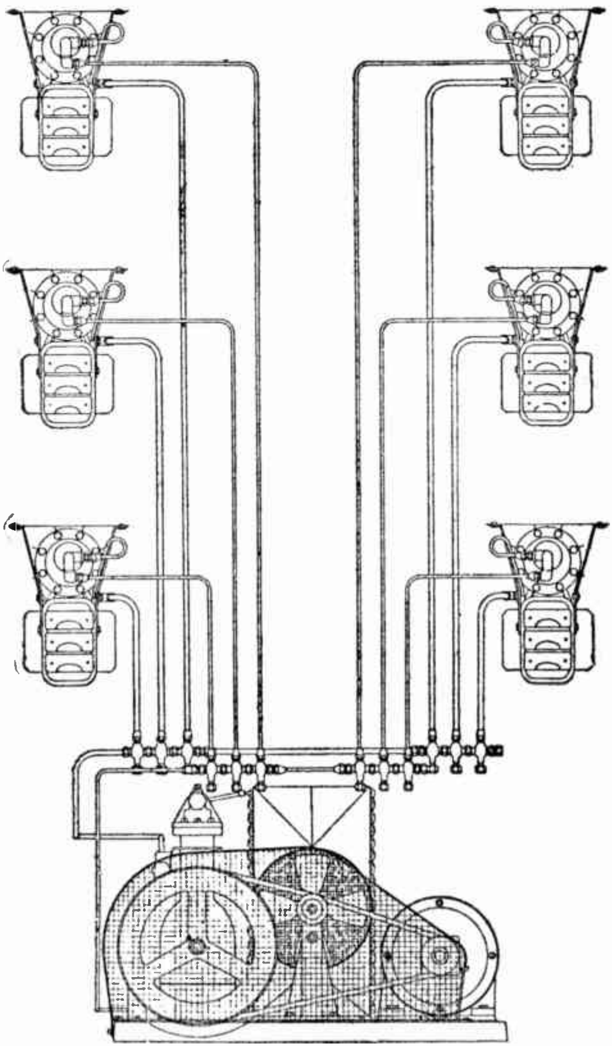


FIG. 8,693.—Servel apartment house installation using the manifold system.

There are two general methods of piping, known as

1. Header and riser system.
2. Manifold system.

These are shown in figs. 8,692 and 8,693.

Typical Absorption type Domestic Refrigerator.—As an example of how the *absorption cycle* is applied in a small unit for household duty, the following brief description of the Servel Electrolux refrigerator is here given.

The strong liquid (distilled water and ammonia only slightly stronger than household ammonia) is heated by the gas flame in the generator. The ammonia vaporizes and passes into the rectifier, where a constant temperature is maintained by the evaporation of ammonia from the previously liquefied ammonia in the bottom of the U tube. The ammonia then passes from the rectifier through the water cooled condenser, where it is cooled and liquified, the liquid ammonia flowing back into one leg of the rectifier.

When the level of the ammonia in the rectifier U tube becomes higher than the inlet pipe into the evaporator (located in the chilling compartment) the liquid ammonia flows from the rectifier through the heat exchanger into the evaporator where it evaporates and absorbs heat from the box.

A hydrogen gas atmosphere in the evaporator causes the ammonia to evaporate, maintaining a constant pressure in the system and requiring no valves or checks of any sort. As the ammonia evaporates into the hydrogen, the mixture being heavier than the hydrogen itself, sinks to the bottom of the evaporator, passes through the gas heat exchanger and into the absorber.

In the absorber the ammonia and hydrogen meet a stream of weak liquid which has been cooled in its passage from the generator. The liquid readily absorbs practically all the ammonia in the gas mixture. Heat is given off when the ammonia dissolves in water, so the absorber must be cooled.

The hydrogen being insoluble in water and being lighter than the incoming mixture of ammonia and hydrogen, rises and flows again to the evaporator, which is at a slightly higher level than the absorber.

The mixture of water and ammonia sinks in the absorber and passes by gravity back to the lower section of the generator. It is lifted from this point to the upper part by means of the thermo-siphon actuated by heat applied at this point. The heat supplied not only lifts the liquid from the lower level in the generator to the higher level in the generator, but also releases ammonia from the strong liquid to repeat its cycle.

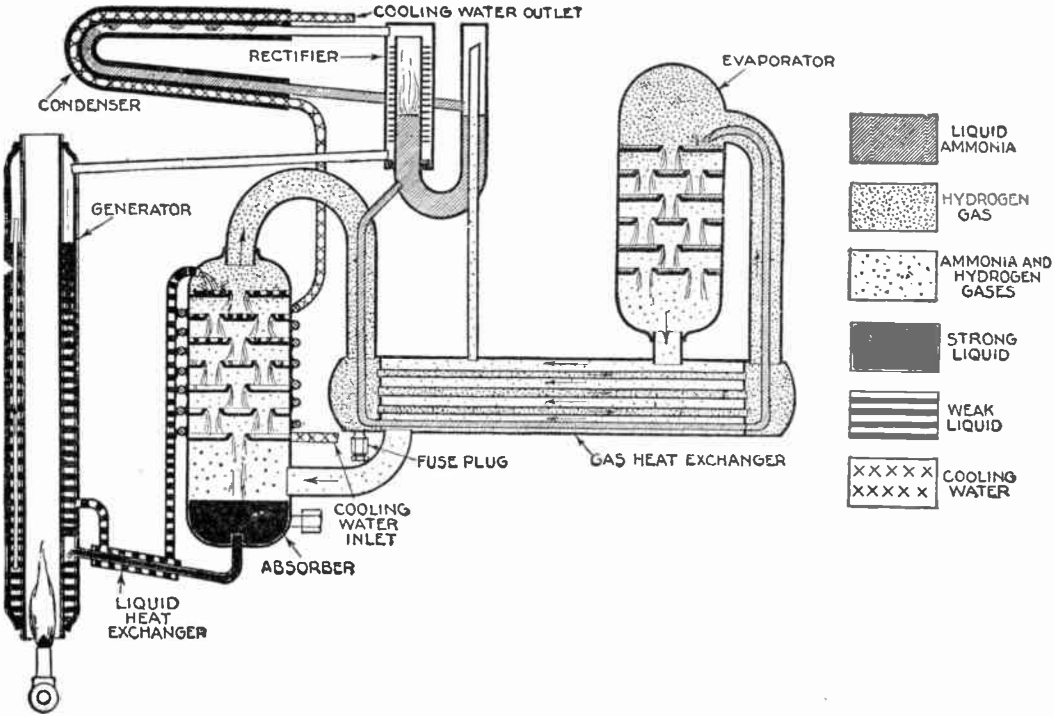


FIG. 8,694.—Sectional view of Electrolux absorption type domestic refrigerator, whose cycle of operation is explained in the accompanying text.

Service Instructions.—First try to locate the source of trouble before tinkering with the plant. By doing this much time and unnecessary labor will be saved. The following are the troubles ordinarily met with.

Frosting Back.—This is the term applied to any condition which frosts the suction line outside of the cabinet.

There are three causes, and they should be checked in the following order to save time:

First, the charge may be low allowing the float to stand in a half open position and a gas and liquid mixture blows through. This can be checked by opening the test cock on the receiver and bringing the reserve charge up to this point. This indicates a full charge and a reserve.

Second, the float may be stuck in an open position by a particle of dirt or scale, or the seat may be damaged. Stop the machine and listen attentively at the head of the float valve. If a continuous hissing be heard with the machine off, it is a clear indication that the needle is not seating. (Note that this test is unreliable unless there be adequate charge in the system.) In many cases, simply shaking or jarring the float valve will seat the needle, or it may be rapped lightly with a hardwood block. If these methods fail to close off the liquid supply, pump out the refrigerant, remove the float head and repair, clean or replace the needle and valve body. Before replacing the head on such a float valve, wipe the interior dry and *heat the head and valve mechanism* until they are too hot to hold in the hands so that no moisture will remain between the needle and valve body.

Third, the oil return orifice may be too small for the machine used on the job. This effect will be apparent as soon as the installation is made, and will persist whenever the machine operates. With an adjustable orifice in the float valve, the remedy is to remove the cap from the orifice body and turn the stem to the left just enough to prevent frosting outside the cabinet. If run out too far, the pull out and oil return will be killed and an oil bound float will result. A quarter turn in either direction near the break over point will make a great deal of difference.

Dead Chilling Units.—If this occur on an installation having only one cabinet on one machine with pressure control, the machine will operate very little or not at all.

If on a multiple system, it is possible to have one or more dead chilling units and yet have the machine operating on the others. Proceed to eliminate the possible causes in the following order:

No current to machine:

Check fuses and machine;
Closed liquid or suction valve.

Stuck float valve.

Treat this as described under "Frosting Back."

Oil Bound Float.—The simplest way to decide whether this is the trouble is to loosen the float or complete chilling unit, and rock it slightly forward and backward.

If the float release periodically due to the undulating motion of the oil, a hiss will be heard and the outlet line of the float will chill slightly due to the release of methyl. This effect is positive indication of excessive oil in the float chamber.

To remedy, loosen two or three of the lower cap screws at the lower part of the float head and drain the oil into a shallow pan. *This affords temporary relief only*. Before leaving the job, determine what caused the trouble and remedy it.

Short Cycle Operation of Machine.—Be sure the suction pressure control is set on a wide range.

Extremely Long Runs at Low Suction Pressure.—This will occur only on overloaded jobs or when sluggish thermostatic control is used instead of pressure control.

It can be overcome to some extent as explained under Improper Orifice Adjustment.

Short Cycling Due to Action of High Pressure Safety Switch.—This will occur only when the water supply is inadequate, or when the machine has an excess of reserve refrigerant in the condenser.

Incorrect Orifice Adjustment.—The smaller the gas orifice in the rear of the float shell body the more oil and refrigerant will be drawn through the oil return tube.

With float valve with adjustable orifice, the stem should be screwed in far enough to completely frost the vaporizer coil at a pressure near 18 lbs. on the suction gauge, for methyl chloride refrigerant, and one or two turns of the vaporizer should be frosting freely when the machine reaches cut off pressure. This means that some oil, methyl mixture will be drawn out all through the run, and under these circumstances, the float cannot *oil bind*. When near the correct adjustment a quarter turn left or right on the adjustment will make a great deal of difference in performance.

In domestic or apartment house chilling units, or submersion coils having the 7/32 in. fixed orifice the oil binding may be caused by too many chilling units on a given size machine. This lowers the velocity and consequently the oil pull out on these farthest away from the machine. The only remedy is to pump down the offending chilling unit, remove the head and substitute a 3/16 in. diameter orifice plug for the standard 7/32 in. plug.

With the new type automatic orifice in the domestic units, the condition cannot occur unless a large particle of scale or dirt should block the flapper disc in an open position and prevent it seating. Tapping will usually relieve such a condition in the remote possibility of its occurrence.

Clogged Oil Return Tube.—If tubing scale, filings or dirt collect in the oil return tube or strainer, so as to obstruct it, oil binding may result.

The only remedy is to remove the float head and clear the strainer or tube.

Plugged Line Filter.—In some cases it is remotely possible that the liquid line or the liquid filter may become plugged from an excess of dirt in the system. This will cause a dead chilling unit and the plug can be located by cracking connections successively until the joint is found where the liquid stops. Mashed or kinked tubing is the most frequent cause of this trouble.

Continuous Operation.—This may simply be a symptom of some of the troubles previously considered.

Severe frosting back due to any cause may force continuous operation. Correct as previously described. Overloaded machines may strike a balance point near cut off and may be unable to pull the chilling unit pressures down far enough to cut off. There are only two remedies. Either set the control to cut off at a higher temperature, or install a machine with enough capacity to pull the temperature down.

Compressor Not Pumping Full Capacity.—This may be caused by bad suction or discharge valves, worn rings, etc.

Chilling Unit Fails to Frost Fully During Run.—Sometimes on a chilling section installation, the first sections on the circuit will frost freely during the run while the latter sections near the return connections to the float valve will not frost.

Under these circumstances, the sections that do not film with frost are not doing their full share of work, and excessive machine operation will be necessary to keep the cabinet cold.

Under any circumstances, the section connected to the float outlet will be colder than the one at the opposite end of the circuit connected to the return inlet. This is true because the first section is fully flooded, and the last one carries a rather thin mixture of gas and liquid. It is not possible to have them at equal temperatures, but if properly regulated, all sections will operate to film with frost and be effectual in cooling the cabinet.

On float valve systems the flow of refrigerant through the section is governed by the frequency of lowering of the float ball.

This lowering is caused by drawing liquid out through the oil return tube.

The adjustable orifice permits drawing out enough liquid to take care of any normal set of sections.

The further the orifice is reduced by adjustment the greater the quantity of liquid drawn out, and consequently the more active the sections will be.

The best criterion for this adjustment is the condition of the line which returns gas and liquid from the sections to the float valve shell. If liquid be kept flowing in this line during the run the maximum effect will be obtained from the sections, and this line will frost freely.

The flow may be continuous with continuous frosting, or it may occur in even surges, as the float opens and closes, but for maximum results a frost film should be apparent on this line, clear to the end of the run.

If this line persist in defrosting near the end of the run, the sections are being starved, and the orifice must be run in further to increase the refrigerant flow. If, when this adjustment is secured, the frost line on the vaporizer has followed the suction line outside the cabinet or in extreme cases back to the machine, the only remedy is to add extra vaporizer surface. In any case, an excess of vaporizer coil will not have any unfavorable effect if extremes are avoided.

Cutting Off on High Pressure.—Any trouble that causes the head pressure to rise excessively may cause a machine to cut off and on at the high pressure mercoid.

The possibilities should be checked in the following order:

1. Insufficient water flowing.

   This may be due to misadjustment of water valve, line pressure, or mineral sediment plugging lines or valve.

2. Water supply warm.

   This can be caused by water backing up from hot water heaters or line running through boiler rooms.

Excess Charge.—This will cause cutting on and off by the high pressure control whenever the liquid floods the condenser tubing to such an extent that the surface in contact with warm gas is seriously decreased. Check by opening the test cock on the side of the condenser.

Ice Collecting on or Below Sections.—This trouble is caused by too low a cut on pressure.

The machine starts up before the last of the frost has melted off. It becomes harder to deal with when there is insufficient clearance between the bottom of the sections and the pan or deck. Keep the clearance wide and set on a high enough cut on to eliminate the last vestige of frost or ice before the machine starts up. Regulate the cabinet temperature by changing the cut off pressure.

Unbalanced Temperatures on Multiple Installation.—It will sometimes be found that the salesman or engineer on a job has underestimated the refrigeration demand on one cabinet, and overestimated the demand on another.

This results in equipment that gives temperatures below normal in one or above in another, with normal control settings. The best way to correct such a condition is to add one or more sections to the chilling unit whose cabinet is too warm. It can sometimes be remedied by removing one or more sections from the cabinet that is too cold, but this should not be done unless the machine has sufficient capacity to take care of the equipment at lowered suction pressures.

Chilling Units That Will Not Defrost During Idle Period.—This is caused by setting at too low a cut on pressure.

Occasionally temperatures are desired near or even below freezing. Under such circumstances, it is impossible to get a defrosting cycle.

If the cabinet temperature be below 32° it is a physical impossibility to melt the frost off the sections because frost only melts above 32°.

Float Valve Leaks (*Mayflower*).—If for some reason the float valve be prevented shutting off liquid supply at proper level, the refrigerant will be drawn through suction tube to crank case causing refrigeration and a formation of frost to take place at these points.

Sometimes there is insufficient liquid reserve in the receiver under compressor base to permit the liquid level in cooling unit to rise to a point where back frost will occur, and in this case only compressed vapor will be forced through float valve, causing a gurgling sound in cooling unit like air being blown under water. If this condition exist, compressor will be running at short intervals or continually, also a very low reading will be noticed if pressure gauge be attached to condenser shut off valve. To remedy this condition, first charge additional refrigerant into system.

If during this process frost should appear on suction tube, it is a sure sign that the float valve is not seating properly. This condition while rare, occurs shortly after a machine has been installed and is largely caused by careless handling of cooling unit in transportation. The trouble can usually be rectified by allowing system to remain idle for about 12 hours. (Refrigerator doors should be left open during this period.)

The rise in temperature in cooling unit causes the liquid to expand and its level to rise, thus forcing the float valve needle firmly into its seat.

If unsuccessful by this method, cooling unit hanger rod nuts may be loosened to permit unit to be rocked back and forth, which will agitate the liquid and thus cause the needle to move back and forth in its seat, having a tendency to properly seat float valve needle. If unable to correct trouble by above methods, it is possible that float valve is held open by a particle of foreign matter. Shut off liquid valve on compressor, block crank lever in switch housing, allowing compressor to run for about 30 minutes.

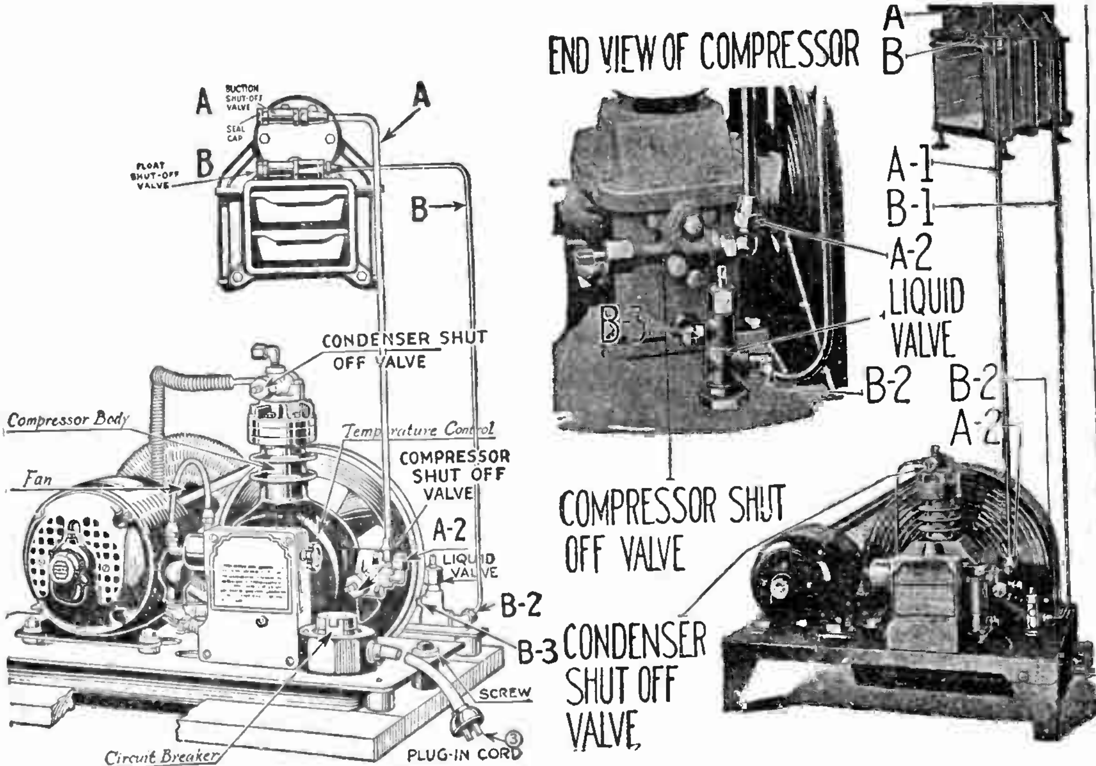
Stop compressor and apply blow torch to under side of receiver tank (move torch back and forth so as not to burn enamel) until gauge shows about 120 lbs. pressure.

Open liquid valve on compressor and allow liquid to rush under great velocity, through now wide open float valve. The general effect of this procedure is to wash out any foreign matter that may have become imbedded in float valve seat.

If, after all the methods just mentioned have been tried the system continue to back frost, it will be necessary to replace cooling unit.

Float Valve Stuck (*Mayflower*).—If float valve do not open, all the refrigerant in cooling unit will be pumped into receiver, causing little and eventually no refrigeration.

When this condition occurs, it is sometimes traceable to the needle point being wedged into its seat. To loosen, take a small piece of wood and place with end of grain against body of cooling unit directly above the float shut off valve and strike with short, sharp blows with small hammer. This procedure is usually successful in jarring needle out of its seat, permitting float ball to drop and liquid to flow into cooling unit until proper level is reached, at which point float valve will shut off.



FIGS. 8,695 to 8,697.—Mayflower domestic refrigeration unit.

If the proper results be not obtained by this method, it is possible that some foreign substance is lodged against outer orifice of float valve. To remove this obstruction, proceed as follows:

Remove plug from liquid valve and attach empty or partially empty service cylinder at B-3 (see fig. 8,695). Discharge liquid into service cylinder, thus relieving head pressure in compressor. Close valve on service cylinder.

Apply blow torch to tubing, leading from service cylinder to liquid valve, to drive liquid in tubing back to receiver.

Close charge valve and liquid valve and disconnect service cylinder. Turn compressor shut off valve to left as far as possible. Remove plug in shut off valve and insert half union coupling.

Complete a by-pass from this coupling to B-3, using short section of ¼ in. tubing with flare nuts on each end. Close compressor shut off valve by turning to right as far as possible. Start compressor by blocking switch with screw driver.

Now open charge valve. This will cause a vacuum to be drawn on liquid line and interior of float shut off valve on cooling unit, tending to withdraw obstruction.

During this procedure rap float shut off valve body above liquid valve with piece of wood and hammer.

Leaky Crank Shaft Seal.—This trouble is detected by methods depending on the kind of refrigerant employed. In an SO_2 machine a leak is detected by the smoke test.

Air in System.—A defective crank shaft seal, flare nut or tubing will cause air to enter through the suction or low pressure side.

Air, being a non-condensable gas, will cause a high head pressure in the condenser coils.

High head pressure indicates air in system or too much refrigerant.

If the compressor motor run in the wrong direction, the condenser will not get a sufficient blast of air. This results in overheating and high head pressure.

Purging System of Air. (*Mayflower*).—Shut off compressor and allow to remain idle for ten minutes.

Detach pressure gauge and turn stem on condenser shut off valve slightly to the right, allowing air to escape (air being lighter than SO_2 vapor rises to the top). If compressor be located in cabinet, or if a considerable amount of air is to be discharged, attach hose or piece of tubing and lead to out doors or in pail of lye water.

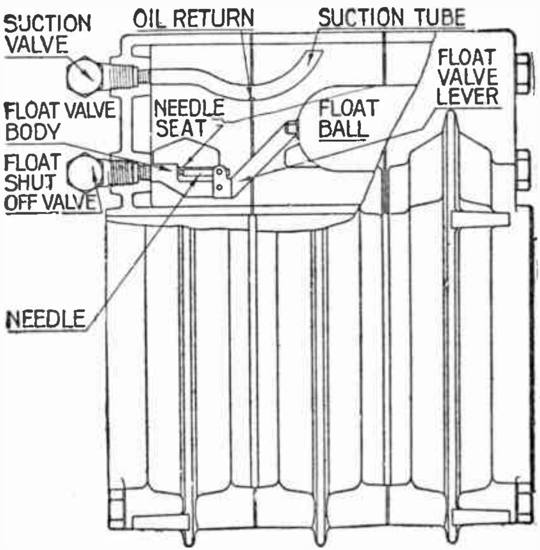


FIG. 8,698.—Mayflower float valve. The function of the float valve is to maintain a constant level of liquid sulphur dioxide in cooling unit, and if functioning properly, will shut off liquid supply before it reaches a point where it will be drawn back through small hole in suction tube marked oil return. This small hole is located at a point about a quarter inch above the normal liquid level in cooling unit and permits a certain amount of oil to float on top of liquid sulphur dioxide. (Oil being considerably lighter than sulphur dioxide.) If an excess of oil be pumped over by compressor, it will eventually reach this opening and be drawn back into the crank case, assuring lubrication of all moving parts.

Moisture in System.—If moisture come in contact with SO_2, sulphurous acid (H_2SO_3) will be formed.

This acid has a corrosive effect on the highly polished cylinder walls and causes the piston to stick. In mild cases it is sometimes possible to break compressor loose by a rocking motion of fan wheel and by drawing a small amount of oil, about ¼ pint in crank case.

If above method be not successful, it will be necessary to dismantle compressor, thoroughly clean, dry and evacuate same. This is best done at the factory.

This difficulty is rarely met with, but if it occur, it is invariably traceable to carelessness in installation, such as using tubing that has not been properly dried or sealed after it is dried, or by allowing air to enter system, especially in humid or rainy weather.

TEST QUESTIONS

1. *What is domestic refrigeration?*
2. *Name two types of compression system.*
3. *Name three methods of cooling the condensers.*
4. *Describe the motors, control mechanism, valves, stuffing box, etc.*
5. *Describe in detail a typical compression type machine.*
6. *What is the function of a stuffing box?*
7. *What are the five principal parts of a refrigerating unit?*
8. *Give the cycle of operation.*
9. *What is a multiple refrigeration system?*
10. *Name two general piping methods used in multiple systems.*
11. *Describe in detail a typical absorption system.*
12. *Give full instructions for operating and maintaining domestic refrigerators.*

CHAPTER 57

Domestic Oil Burners

Some knowledge of the fuel oils employed is essential to the intelligent operation of domestic oil burners. Fuels are derived from crude oils, obtained from different fields and vary considerably.

Oil fuels are now commercially known as domestic fuel oils Nos. 1 ,2, and 3; and industrial fuel oils, Nos. 4, 5, and 6. Sometimes the fuels are referred to as light, medium and heavy domestic oils; and light, medium and heavy industrial oils.

For most of the domestic burners, the manufacturers recommend fuel oil No. 3, while many burn either Nos. 1 or 2 fuel. The No. 4, a light industrial oil, is recommended for a small number of domestic burners now manufactured.

Effect of Grade of Oil on Economy.—The grade of fuel that can be used is usually fixed by the design of the burner with respect to the method of atomization, the type of ignition, etc.

The gravity feed burners invariably are designed to burn only the high grade distillates. The atomizing domestic burners use oil as heavy as No. 4. The grade of oil which can be burned determines to a considerable extent the cost of heating.

Oil Burners.—An oil burner is any device wherein *oil fuel is atomized or vaporized and mixed with air in proper proportion for combustion, previous to ignition.*

Oil burners may be classified:

1. With respect to operation, as

   a. Manually controlled:

   b. Automatic.

2. With respect to method of igniting, as

   a. Torch;

   b. Pilot light.

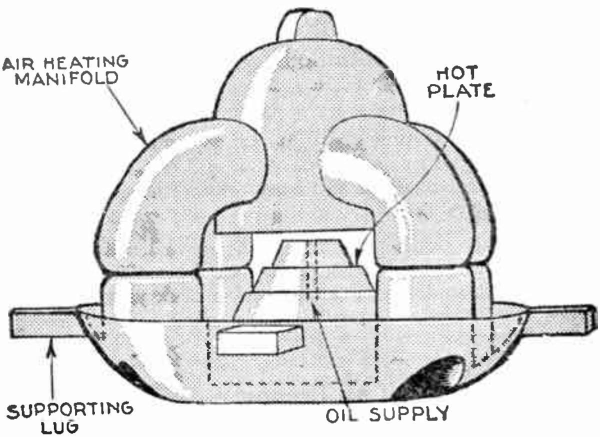


FIG. 8,699.—Casting which constitutes a simple gravity feed, vaporizing type burner.

3. With respect to the gasifying process, as

   a. Vaporizers;

   b. Atomizers.

4. With respect to the method of oil feed, a.

   a. Pressure;

   b. Gravity.

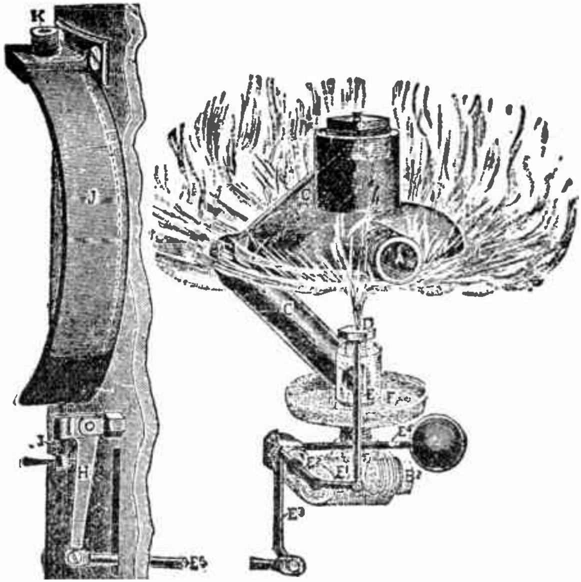


FIG. 8,700.—*Non-mixing* gravity feed *vaporizing* or *gas* type burner and automatic control. It is designed for gasoline or other light hydrocarbons or ordinary headlight oil, of 150° test. ***In operation,*** the oil is supplied through a pipe to the vaporizer indicated by the letter **A**, In its passage through the fire box and the vaporizer, it is converted into a vapor or gas which burns without odor, soot or residuum. From the top of the vaporizer **A**, the gas is conveyed through an elbow pipe **C**, as shown by arrows, to the mouth of the burner, where it escapes through a small opening **D** (made adjustable), and is ignited. The flame striking centrally upon the bottom of the vaporizer **A**, is spread in every direction, thus serving the double purpose of generating the gas in the vaporizer and distributing the heat equally to every portion of the boiler. The flame striking centrally upon the bottom of the vaporizer is spread radially and by heating the vaporizer converts the liquid fuel into gas. Working in this small opening **D**, is a shut off plunger **E**, which, raised or lowered, controls the flow of the gas. This plunger is connected by means of a rod **E**^{1}, counter-balanced rock shaft **E**^{2}, bell crank lever **E**^{3}, connecting rod **E**^{5}, to bell crank lever **H**, and to a hollow spring on the outside of the furnace. The weight of these rods is counterbalanced by the rod and ball **E**^{4}. The hollow spring is supplied with steam at boiler pressure through a small pipe at opening **K**. The saucer **F**, is for oil or alcohol used in raising the proper heat under vaporizer at starting, and until sufficient gas is generated for its own reproduction; a matter of three or four minutes. The burner is furnished with removable plugs **BB**^{1}, to facilitate cleaning. Rock shaft **E**^{2} is furnished with stuffing box **G**, to prevent leakage. ***In control,*** the straightening of the spring caused by an increase of pressure in the boiler, operates directly on the plunger by means of the adjusting screw **I**, bell crank lever **H**, and intermediate connections; thus establishing the relation between steam pressure and fire. Should the steam pressure rise, the plunger would close off the flow of gas correspondingly, and vice versa, thereby regulating the heat of the fire. The plunger cannot, however, shut off the flow of gas entirely; a small orifice is always left, enough to keep the burner and boiler hot; and in this way the trouble and annoyance of having to relight the fire after every stop is avoided.

Gravity Feed Vaporizing Burners.—This is the simplest type of burner, very often consisting merely of one or two rough castings which are set inside the furnace, and its initial cost is low.

There are two types of this burner, known as

1. Non-mixing;
2. Mixing.

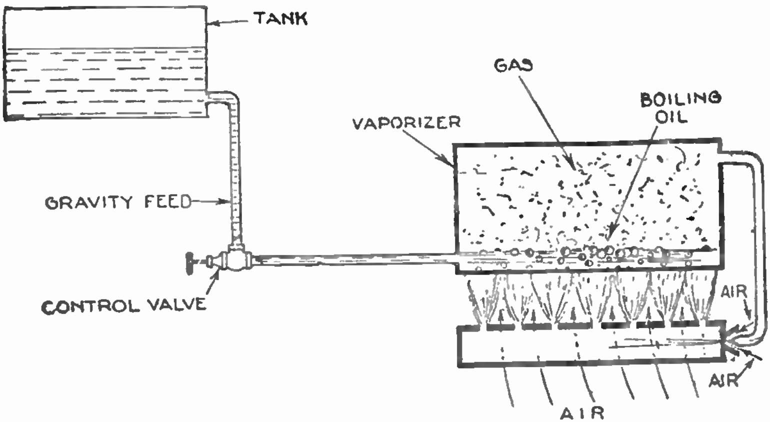


FIG. 8,701.—Elementary gravity feed *induction mixing vaporizing* burner. *In operation,* oil flows from tank to vaporizer, regulated by the control valve. The flame from the burner vaporizes the oil entering the vaporizer producing a gas which passes out to the mixer. The gas is injected through a nozzle into the *mixer* sucking in air, the mixture passing out and igniting at the top.

In the cheapest burners of this class the control is entirely manual; the burner is started by hand, and the control of temperature is effected in like manner. In some cases automatic control has been applied with apparent success.

The gravity feed non-mixing vaporizing burner is limited to the use of the relatively high priced fuels. Fig. 8,700 shows the construction of a burner of this type arranged for automatic control.

The principle upon which the non-mixing type operates is shown in fig. 8,700.

In this type the air to support combustion is brought into the furnace by the natural draft produced by the chimney. Some rather ingenious means are used to induce an intimate mingling of this air with the vaporized fuel, but in general, good combustion is not obtained by this method unless a highly volatile fuel be used.

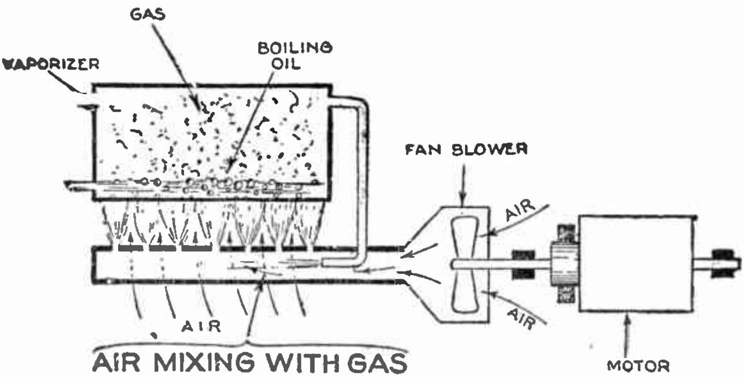


FIG. 8,702.—Elementary gravity feed *mixing*, vaporizing burner. Connected to the burner is a fan blower with outlet pipe surrounding the gas pipe as shown. *In operation*, air from the fan blower mixes *inside* the burner with the gas coming from the vaporizer. Thus the air is mixed with the gas before ignition, resulting in a blue flame and efficient combustion.

The principle of the mixing type vaporizing burner is shown in fig. 8,702.

Fig. 8,703 shows the construction and working of a well known *mixing vaporizing* burner. This burner is, strictly speaking, a mixing, *combined atomizing and vaporizing burner*. That is, the oil is atomized by the air at the intake to the fan blower and the fine spray carried by the air current to the vaporizer where vaporization takes place before ignition.

Another type of mixing vaporizing burner is the hot plate variety shown in fig. 8,714.

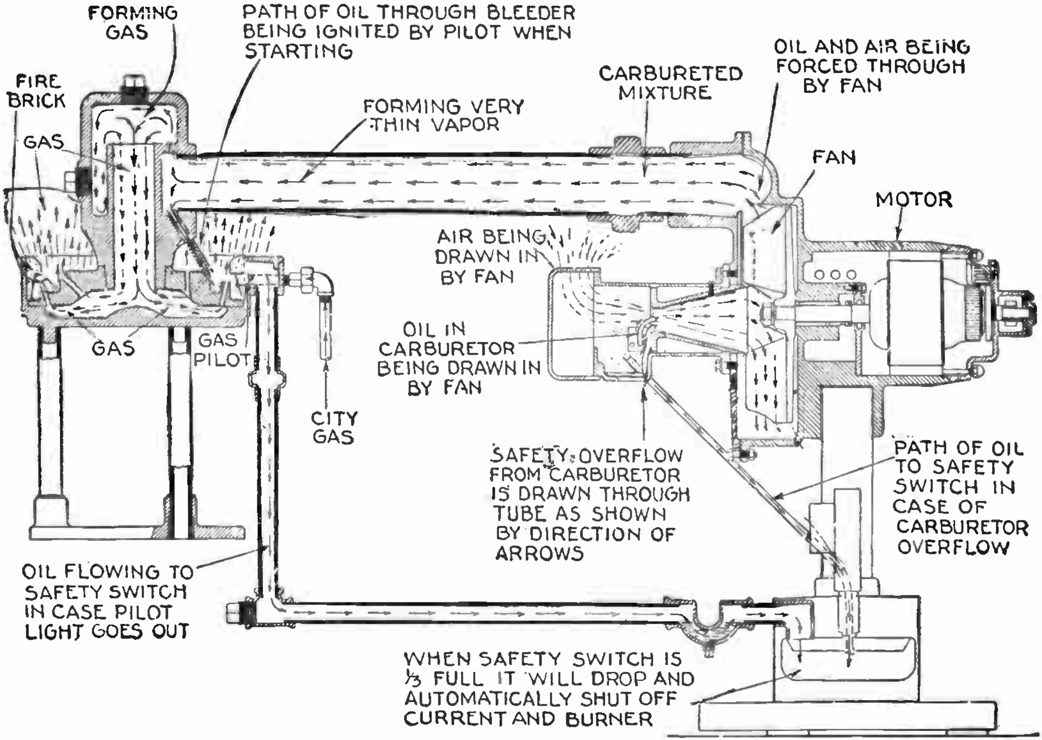


FIG. 8,703.—Crystal *mixing* vaporizing burner. Sectional view showing operation.

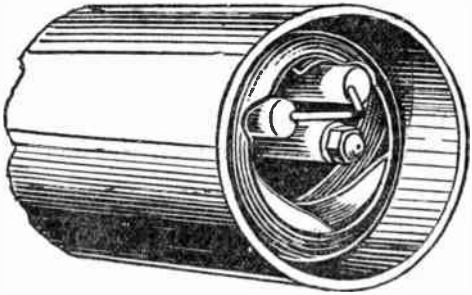


FIG. 8,704.—Oil-Electric draft tube, air diffuser and spray nozzle showing location of spark in relation to spray nozzle.

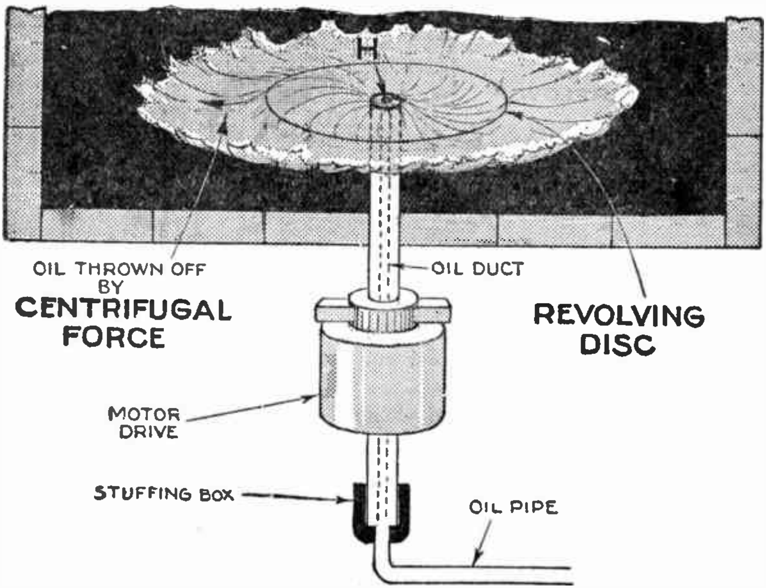


FIG. 8,705.—Elementary centrifugal force atomizing burner. The oil flows through the hollow spindle of a disc which is rotated at high speed by a motor. The oil overflowing at H, onto the disc at its center is hurled off the disc by *centrifugal force*, and ignited by a torch or pilot light, produces a ring of flame.

Here the vaporizer consists simply of a plate heated partly by a pilot flame as shown, ignition takes place at the plate, the plate being virtually a combined vaporizer and burner.

Atomizing Burners.—In this class of burner various methods are used for breaking up or atomizing the fuel. This is accomplished by:

1. Compressed air, or
2. Centrifugal force.

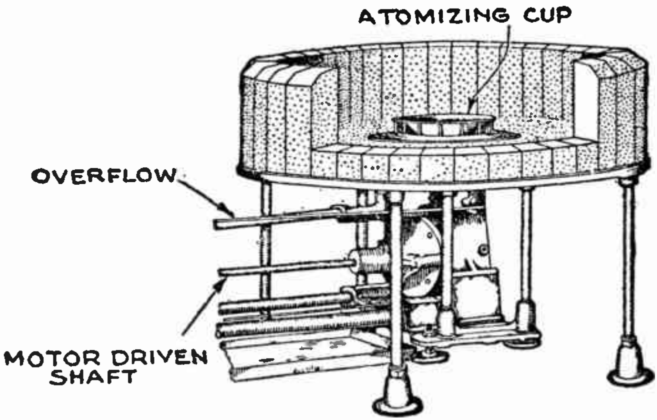


Fig. 8,706.—Motor driven centrifugal atomizing burner.

These two methods are shown in figs. 8,708 and 8,705 respectively. Fig. 8,706 shows a centrifugal force type burner as constructed.

Ignition.—Burners may be classified roughly with respect to the method of lighting, as

1. Wick;
2. Gas;

3. Electric;
4. Electric-gas;
5. Electric-oil.

With the manually controlled gravity burner, the hot plate is preheated by a wick which is saturated with oil and ignited by a torch.

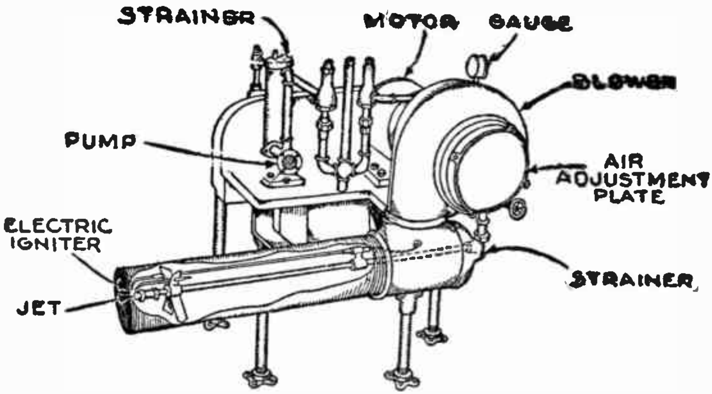


FIG. 8,707.—Motor driven atomizer burner of the electric ignition type.

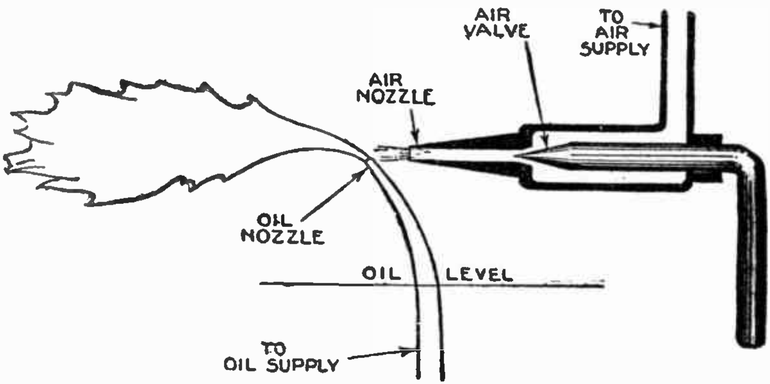


FIG. 8,708.—Atomizing oil by air jet or spray.

The plate must be heated to a temperature sufficient to vaporize the oil falling upon it. The heat of combustion is supposed to do this once the

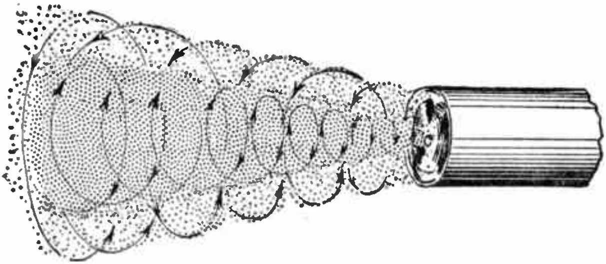


FIG. 8,709.—Method of commingling air and atomized oil by whirling each in contrary direction in conical streams. The oil stream comprises the inner cone, while the air stream comprises the outer.

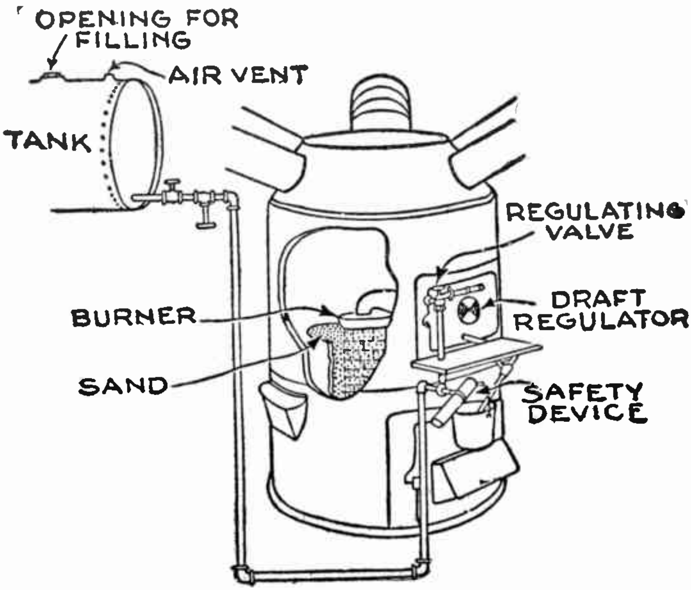


FIG. 8,710.—A simple manually controlled vaporizing burner installation in a warm air furnace.

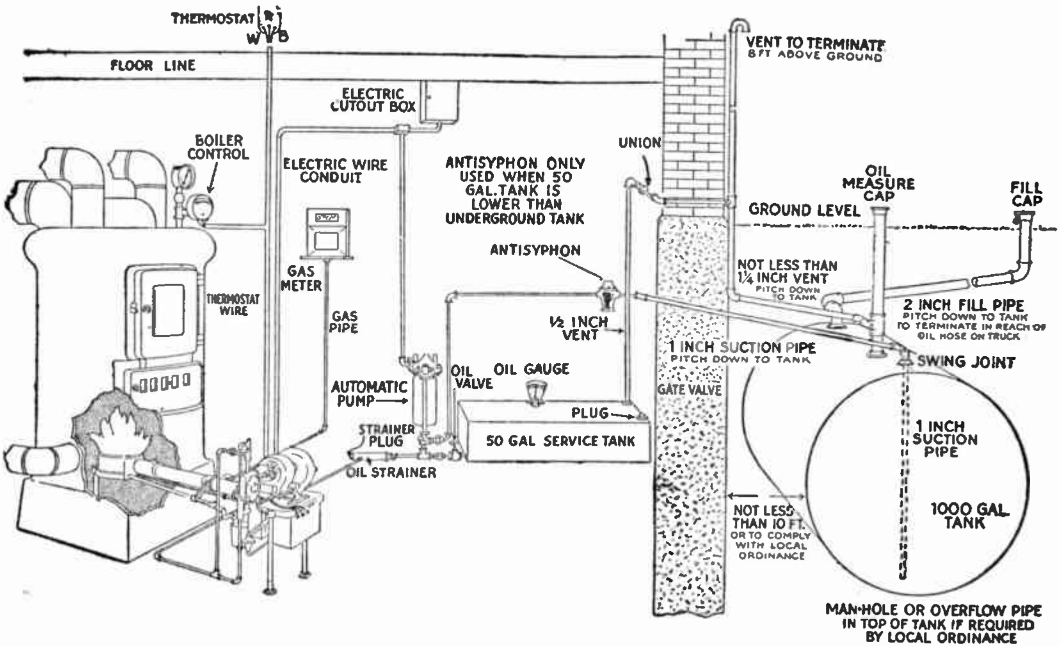


FIG. 8,711.—Berryman atomizer oil burner installation showing various connections, etc.

flame is started. The temperature of the house is maintained at a desired point by increasing or decreasing the intensity of the flame by means of a valve in the oil line, or the burner may be operated at a fixed intensity and then completely shut off as the condition may demand. Whenever the burner is off for a few minutes, the hot plate must be preheated again before the oil can again be vaporized and ignited.

In some automatically controlled vaporizing burners a gas flame is used for heating the hot plate and as a pilot light for igniting the fuel.

The gas flame burns continuously and keeps the hot plate at such a temperature as to cause the oil to vaporize when it is admitted to the apex of the plate and trickles down over the corrugations, fig. 8,713. At the same time the pilot flame licks through holes drilled in the hot plate and ignites the mixture of vaporized oil and air. The automatic device in this case merely shuts off or opens a valve in the oil line to the burner.

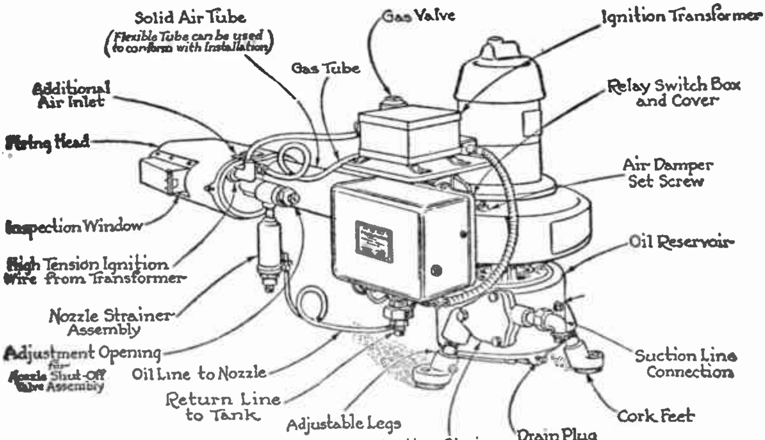


FIG. 8,712.—Wayne atomizer type burner. View showing parts.

The pilot flame is sometimes caused to expand at the time the burner comes on, and by this means the danger of extinguishing the pilot light is somewhat lessened and ignition is presumably hastened.

With the atomizing type of burner it is necessary to introduce a flame or electric arc within a region which is filled with an intimate mixture of oil and air in such proportions as to make it comparatively easy to ignite.

In the electric gas type, a gas pilot is turned on, the gas being ignited by a spark. The pilot light then ignites the charge. Still another device is the electric-oil ignition in which an independent atomized mixture is ignited by an electric arc and is utilized as a source of heat energy to ignite the charge of the burner proper.

In general, it should be noted that *the type of burner selected must conform to the particular igniting facilities present, whether gas or electricity, or both.*

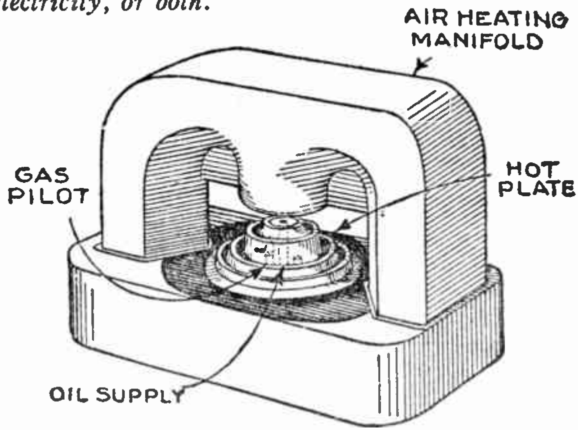


FIG. 8,713.—Casting of a vaporizing burner with which is incorporated the continuous burning gas pilot and plate heating flame.

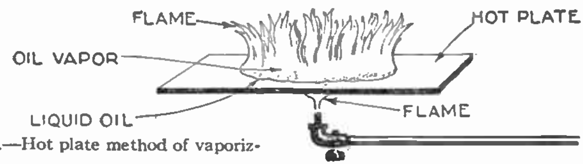


FIG. 8,714.—Hot plate method of vaporizing oil.

Combustion.—Oil fuel used by domestic oil burners contains principally hydrogen and carbon, with much smaller quantities of oxygen, nitrogen and sulphur. Of these elements, the carbon hydrogen and sulphur are the ones that burn or combine with oxygen.

Insufficient air supply is one cause of clouds of dense smoke and soot. This form of combustion is inefficient in that the fuel is not entirely consumed.

An excess of air is essential to insure that each subdivided bit of oil is provided with the amount of air necessary.

Furnace Design.—To obtain satisfactory results combustion must take place in a region of high temperature.

Note the following points on furnace design:

1. Practically all air must pass through the flame;

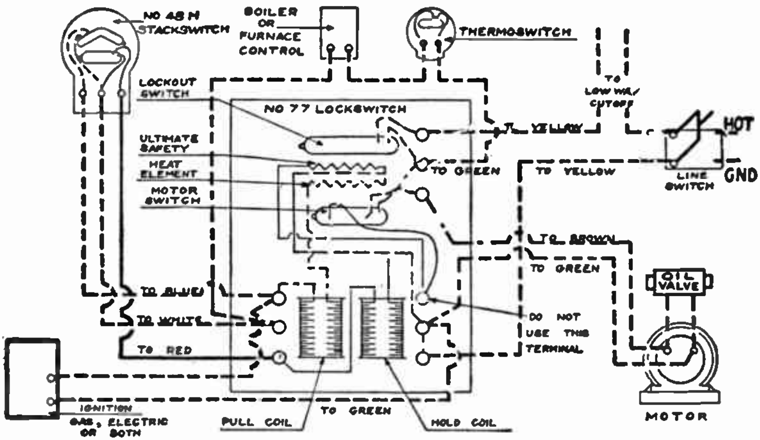


FIG. 8,715.—*Time-O-Stat control system, 1. Start or cold* position. In this position the mercury tubes are tipped downward toward the left. The current, therefore, cannot pass through the lower tube of the stack switch, but passes through the upper tube of the stack switch, returning over the blue wire to the blue terminal on the lower left hand board. At this point the current has two paths flowing outward to the ignition valve or spark transformer over one path and starting the ignition. The return line for the ignition circuit is connected to the green terminal on the lower right hand terminal board which is interconnected to the yellow terminal on the right hand terminal board and thus provides a return to the ground side of the line, completing the ignition circuit. The secondary path from the blue terminal on the lower left hand board leads the current to the pull coil and energizes this coil. This coil being energized rotates the motor switch to its on position and completes the circuit of the motor from the green terminal on the upper right hand board to the motor. The motor starts at this time. Its return line leads back to the ground connection through the green terminal on the lower right hand board. Connected in series with the pull coil is the heat element of the lockout mechanism through which, in the starting cycle, the current of the pull coil passes. The return line from the heat element leads back to the ground connection on the lower right hand terminal board at the green terminal. Upon completion of the current flow through the paths as outlined, the oil burner begins to run. Assuming entirely normal conditions, flame will result and the stack switch will be moved to its hot position, that is, both tubes tipped downward to the right.

2. The flame must not be allowed to impinge directly on either boiler sheets, tubes or brick work;

3. The flame produces better results when worked near hot brick;

4. The flame should be distributed over as large an area as possible to prevent localization of heat;

5. Every precaution must be taken to guard against excess air.

Automatic Control.—The oil flame is extremely rapid in heating and if not controlled in some manner will build up

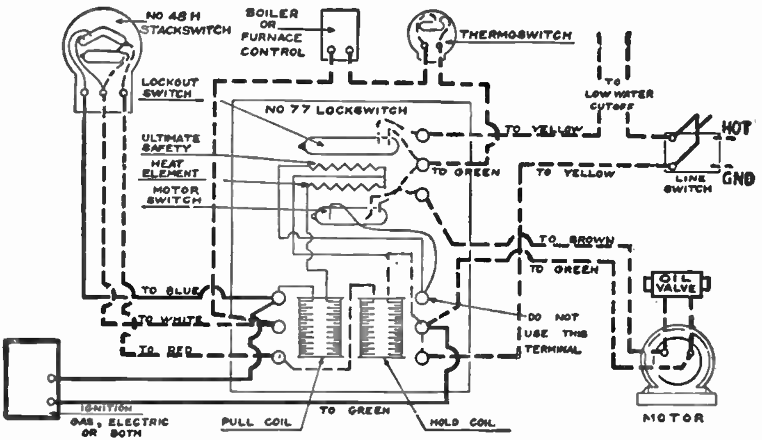


FIG. 8,716.—*Time-O-Stat control system, 2. Running position.* In this position the current enters as before through the line switch from the hot side of the line through the lockout switch to the green terminal on the upper right hand terminal board, then through the thermo-switch and limit control to the white terminal on the lower left hand terminal board. The current then passes out as before to the white terminal in the stack switch, but inasmuch as the stack switch is now in its hot position, the circuit through the blue terminal of the stack switch is open and thus the pull coil and the ignition have been de-energized and the ignition turned off. The current returns from the stack switch now on the hot side through the red terminal and to the red terminal on the lower left hand terminal board of the lock switch. From this terminal it is led through the hold coil, and from the hold coil it returns to the ground side of the line through the green terminal on the lower right hand terminal board. The hold coil being energized, the motor switch is maintained in the on position and the motor continues to run. Thus the flame and full operation of the oil burned is continued. The lockout switch heating element is of course taken out of the circuit as soon as the pull coil is de-energized and therefore the heat element cools off without opening the lockout switch. As soon as the thermo-switch limit control or low water cut off opens the circuit, current can no longer flow through either of the coils of the lock switch. therefore the motor switch returns to its off position and the burner is shut down.

temperatures and pressures in the heating system which may prove dangerous.

If the drafts of a coal furnace be inadvertently left open, the worst that can happen is to burn up the coal in the furnace. With the oil burner, however, overheating would go on as long as the oil supply lasted.

The power atomizing type of burner best lends itself to a variety of automatic controls, and it is in this type that such controls have been most successfully utilized.

The thermostat is the device on automatic burners *which renders the burner active or inactive in the process of maintaining desired room temperatures.*

In the thermostat there is a member, actuated by temperature changes, which operates to maintain a constant temperature by shutting off or starting the burner.

In automatic oil burner installations there are boiler controls in addition to the room thermostat.

The boiler controls are termed hydrostats, if it be a hot water system, and pressurestats if it be a steam system.

This boiler control is operated dually with the room thermostat and controls conditions at the boiler while the thermostat controls temperatures in the room. By the use of the hydrostat the temperature of the water in the boiler is kept within certain limits, and in the case of the pressurestat the steam pressure is kept within certain limits regardless of the temperature conditions in the rooms.

NOTE.—Time-O-Stat control system, 3. *Operation on ignition failure.* Should there be any failure of the ignition to start the fire properly when the thermo switch calls for heat, the stack switch will not go to the hot position during the starting cycle and the continued passage of heat through the heat element will warp the bimetal unit to which the lockout switch is attached and after a period of approximately a minute and a half the lock out switch will trip to the off position and shut down the oil burner by opening this switch. When this switch is open, current can no longer pass to any part of the lock switch system and in order to re-establish any operation in the lock switch system or the oil burner, it is necessary to reset the lockout switch by means of the manual reset in the lock switch. It has been demonstrated that a failure of ignition as the oil burner starts usually requires that some attention be provided for correction of the trouble, hence the opening of the lockout switch is made so that it will not reclose automatically.

In addition to the controls just mentioned, it is essential that precaution be taken *to cut off the burner in the event that ignition fails to take place.*

In such burners as permit, a drip bucket or sump is provided to catch the unburned fuel which flows to it when ignition fails. This device trips when a certain quantity has been delivered to it and either cuts off the oil supply or breaks the power circuit, in either case rendering the burner inoperative as to the generation of heat and flow of oil. The machine must then be reset by hand before operation can be resumed.

One of the chief objections to this control is the clogging of the line which delivers the unburned oil to the drip bucket or sump, owing to the accumulation of soot, scale, etc. Liberal passages offset this tendency to a great extent.

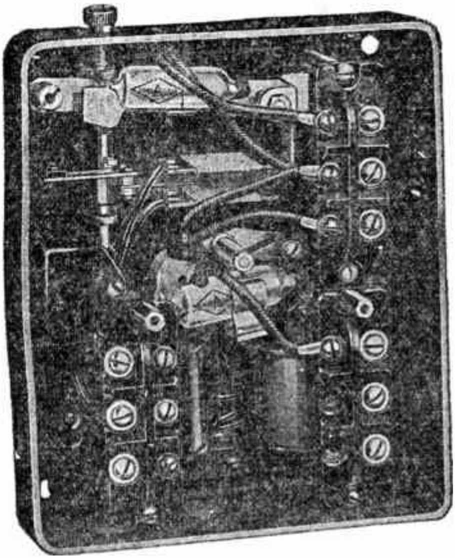
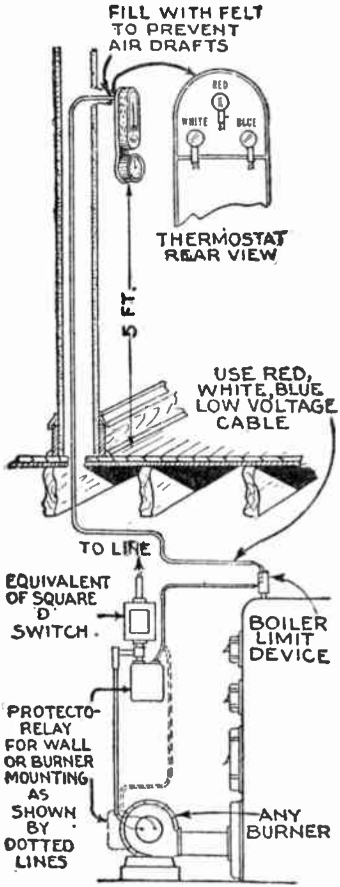


FIG. 8,717.—Time-O-Stat lock switch. This switch provides full automatic operation for oil burners of the power driven intermittent on and off type for either domestic or commercial use. The lock switch system is known as a high voltage system and all of the units of the system operate at the voltage of the electrical supply line.

Another emergency control is designed on the assumption that so long as the pilot light burns, the charge will be ignited and accordingly a thermostatic member which is exposed to the heat of the pilot light breaks the power circuit when the pilot light is extinguished.



FIGS. 8,718 and 8,719.—Installation diagram showing thermostat and connection. The thermostat or mechanical thermometer is the part of the device placed in one of the central rooms which is set for the degree of temperature desired.

When the general design of the burner is such as to make the catching of unburned oil and its subsequent delivery to a sump or drip bucket impracticable, the stack control is utilized.

A thermostatic member is placed in the stack and if, after a predetermined period, it do not become heated, indicating that the burner has failed to function, the thermostatic member breaks the power circuit and stops the motor and supply of oil.

Low water emergency controls are also applied in some installations and there are other devices, such as alarm bells, which are employed in conjunction with these emergency controls. Doubtless even more ingenuity will be manifested in this direction as design progresses.

Operation of Control System.—As an example of the methods employed in heating control a description of the operation of the Minneapolis-Honeywell system is here given.

This system consists of three separate units, so designed that they are integral parts and will not operate the burner except as a whole. These units are the recycling motor switch, combustion safety control, or protectostat with special relay, and room thermostat. A limiting device can be incorporated in the system and is highly desirable.

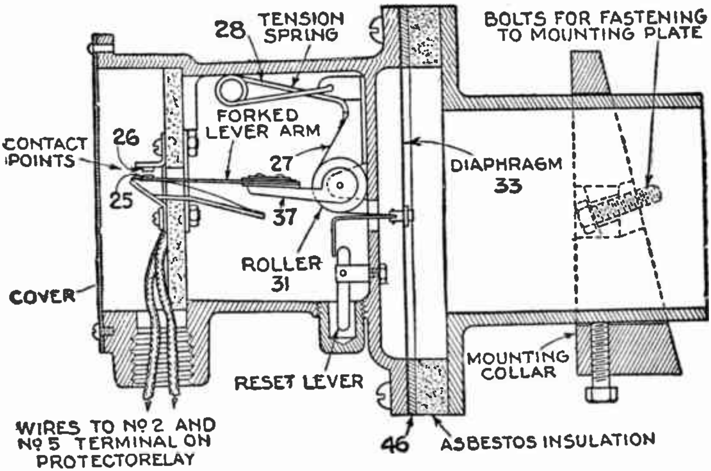
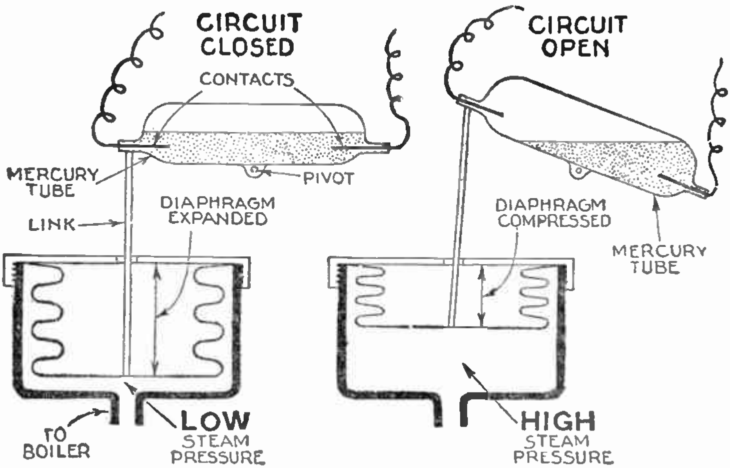


Fig. 8,720.—Minneapolis-Honeywell protectostat or combustion safety device. *It consists of* a main casting supporting an annular ring 46, to which a diaphragm 33, is attached. The diaphragm 33, and ring 46, expand and contract equally when subjected to the same temperature. This is the reason why the protectostat is not affected by changes in basement temperatures. If the diaphragm of the protectostat be subject to the radiant energy of an oil fire, the absorption of this energy will cause a temperature difference between diaphragm 33, and the ring 46. This causes the diaphragm 33, to expand rapidly and always buckle in the one direction as governed by strap 27, and spring 28, thus rotating roller 31, and raising arm 37, allowing contacts 25 and 26, to make. The closing of these contacts will close relay No. 2 of protectorelay. Evidently contacts 25 and 26, respond promptly to exposure to flame; also that the flame must be continued, for if it be not, the heat accumulated by the diaphragm is rapidly conducted to the ring 46 and housing, causing the diaphragm to cool and straighten out, separating the contacts 25 and 26.

The recycling motor switch provides low voltage current for the operation of the room thermostat and limiting device, and the low voltage side of the combustion safety control.

The maintaining switch and rotary line switch are of the rotary type and are always in definite relation to each other. They are integral parts of the motor switch, and in conjunction with the combustion safety control switch provide the safety features of the system.

The combustion safety control consists essentially of a thermostatic element of high temperature metal which is installed in the boiler or furnace smoke pipe and to which are connected suitable switches for both the line and low voltage circuits. These two switches are actuated by the expansion or contraction of the thermostatic element and prevent the continued operation of the oil burner under abnormal conditions. The combustion safety control closes the line circuit to the burner motor and opens the low voltage starting circuit as the burner goes into operation. When



FIGS. 8,721 and 8,722.—Elementary pressure switch illustrating principle. *In operation*, when the steam pressure is low the diaphragm or "bellows" will be expanded as in fig. 8,721, the link holding the mercury contact tube in horizontal position. In this position the mercury will cover both contacts closing the electric circuit which starts burner. As the steam pressure rises, the diaphragm is compressed which causes the mercury tube to tilt and open the circuit thus shutting off the burner as in fig. 8,722.

the burner is turned off by the motor switch these operations are reversed, and the controls are ready for a restart.

The system performs the following functions:

1. Starts and stops the oil burner at the command of the room thermostat, or when the temperature of the boiler or furnace has reached the predetermined maximum or minimum, if a limiting device be used.

2. Provides safety in the event of failure of ignition and premature extinguishment of the flame, thus preventing the abnormal discharge of oil in the fire box. It functions in from 15 to 45 seconds, depending upon local installation conditions.

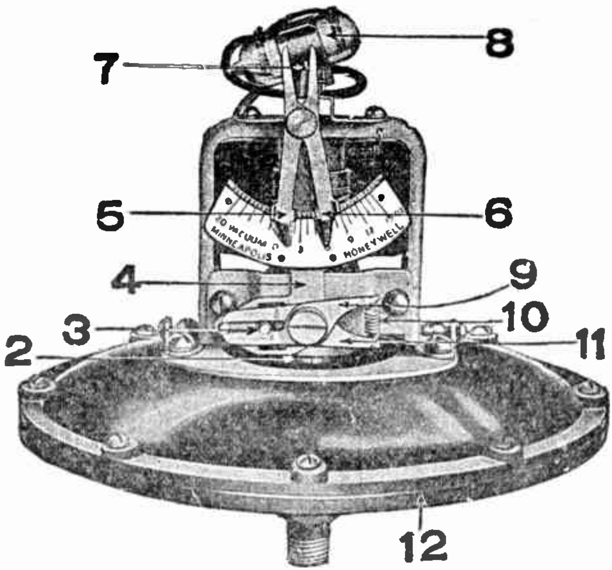


FIG. 8,723.—Minneapolis Honeywell vacuumstat or pressure switch for pressures lower than atmospheric as used on vacuum and so-called vapor systems. *It can be used* with systems employing a pump to maintain constant vacuum and both indicator hands may be set in the vacuum range. Within the base of the instrument is a flexible diaphragm that is forced upward as steam pressure is applied, carrying with it plunger 2, to which actuating pin 3 is attached. As the pressure increases pin 3, will cause arm 4, to which indicator hands 5 and 6, and the dial are attached, to move to the right. It will be noted that the upper half of the indicator hands extend and that pin 7, is attached to the mercury tube carrier and is located between the indicator hand extensions. As pressure is built up arm 4, assembly will move to the right until hand 6, extension meets pin 7, causing mercury tube 8, to tilt and stop the motor. As the pressure recedes, arm 4, assembly will move to the left until hand 5, extension meets pin 7, causing mercury tube to tilt and complete the circuit to the motor. Scissors 9, and 11, and spring 10, form the strain release.

3. In the event of a current failure, the motor switch will automatically recycle and start the burner again as current service is resumed.

In operation, when the room thermostat signals for heat, circuit is made to the maintaining switch, causing the motor switch to operate.

The rotary member of the line switch revolves, starts the burner motor, and carries the line circuit through the starting cycle. If ignition take place before the completion of the starting cycle, as it should, the heat of the stack will tilt the combustion safety control switch, and the line circuit to the burner motor will be carried through the line voltage tube thereof to continue the operation of the burner.

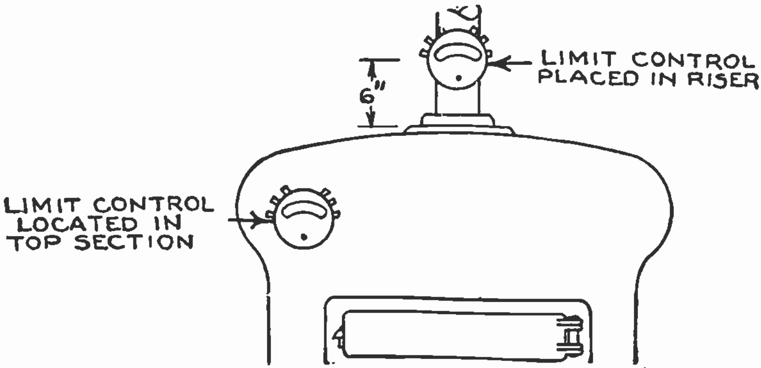
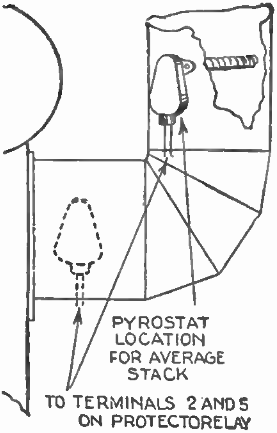
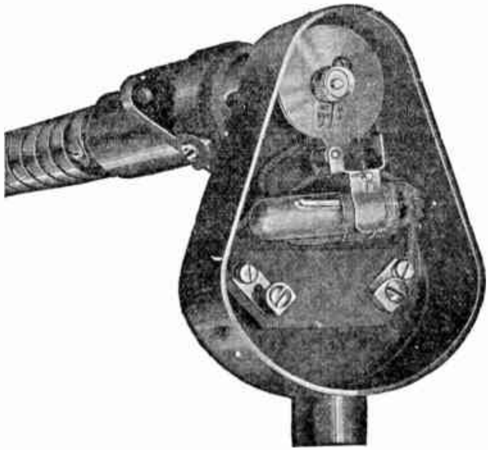


FIG. 8,724.—Minneapolis Honeywell aquastat or limit control showing placement. ***It is used*** to limit the water temperature in hot water heating plants. It may be used either independently to control the burner or in dual control with room thermostat. ***For example,*** with the room thermostat set at 70° and the aquastat at 160° the motor is shut off when the room temperature reaches 70° regardless of water temperature. However, if the water temperature reach 160° before the room temperature reaches 70° as might be the case when the boiler is being forced, the aquastat shuts down the burner. As soon as the boiler temperature has dropped a few degrees and should the room temperature still be below 70°, the aquastat will restart the motor. If the thermostat continue to call for heat, the aquastat will maintain the water temperature between 150° and 160° until the room temperature has reached 70°. This prevents overheating that at times may occur when only the room thermostat is used. Absolute control of the boiler at all times means more even and comfortable heating with a greater saving in fuel.

If ignition fail, no heat will be transmitted to the stack and at the completion of the starting cycle of the motor switch, the line circuit to the burner motor through the combustion safety control switch will be open, and the burner motor stopped. Both the burner motor and motor switch will be inoperative and in the dormant position until the release switch has been manually operated, which necessitates someone going to the basement to determine and remedy the cause of failure.

Should the fire be extinguished prematurely there will be an immediate drop in stack temperature which will tilt the combustion safety control switch and break the circuit to the burner motor. At the same time the circuit to the burner motor is broken through the line voltage mercury switch, contact is made in the low voltage mercury switch of the combustion safety control which closes the circuit to the motor switch and causes it to recycle.





FIGS. 8,725 and 8,726.—Minneapolis Honeywell stack switch or *pyrostat*. It is a combustion safety and operates on the change in stack temperatures. ***Its operation*** is caused by the tendency of the spirally wound bi-metallic strip to unwind with a rise in temperature. The spiral is so mounted as to project into the stack; one end is attached to the body of the pyrostat and the rotation of the free end as the temperature rises turns a shaft which passes back through the center of the spiral and into the body of the instrument. A ratchet toothed wheel is mounted on this shaft and turns with it. As the temperature rises, the ratchet wheel turns, carrying with it a phosphor bronze spring, which allows two contact points to come together completing the circuit to the protectorelay. As the ratchet wheel continues to turn with the continued rise in temperature, this spring passes from tooth to tooth without affecting the contact. If the stack temperature drop a predetermined amount, the ratchet wheel will engage the spring and separate the contact point, breaking the circuit to the protectorelay.

The burner will be put through the starting cycle again, but if ignition fail the combustion safety control will remain in the cold position and the burner will stop. It will then be necessary for someone to determine and remedy the cause of failure and depress the release switch button before the burner can again be started. In the event of current failure when the burner is in the on position, the motor switch will automatically recycle and start the burner again as current service is resumed.

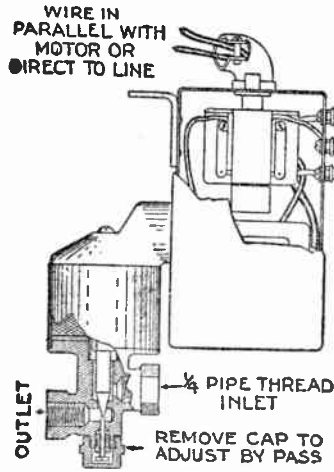


FIG. 8,727. — Minneapolis - Honeywell magnetic oil valve with relay. It is designed to control the high-low fire type oil burner directly from the room thermostat or limit control, or both. The valve is controlled by a small relay directly attached as shown. By this arrangement it is possible to operate a 110 volt valve by means of a low voltage thermostat. When the room thermostat calls for heat, a circuit is completed which energizes the valve, the plunger rises, allowing an increased amount of oil to flow and maintain the high fire. When the thermostat or limit control calls for less heat, the circuit to the valve is broken and the plunger falls to the low fire point.

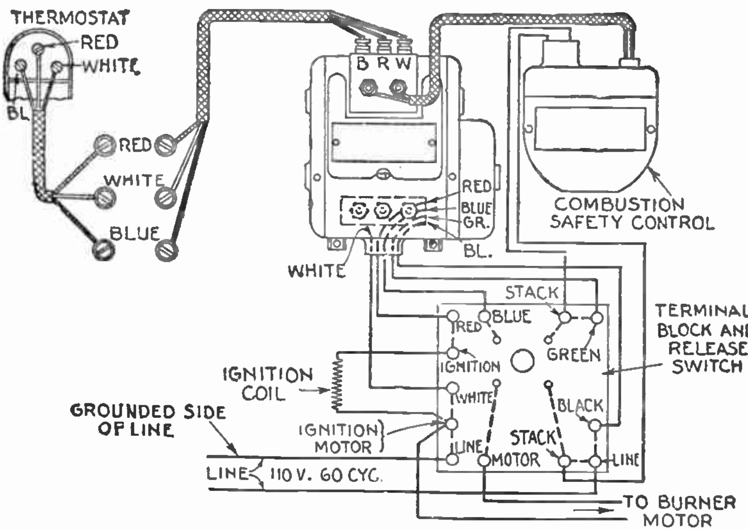
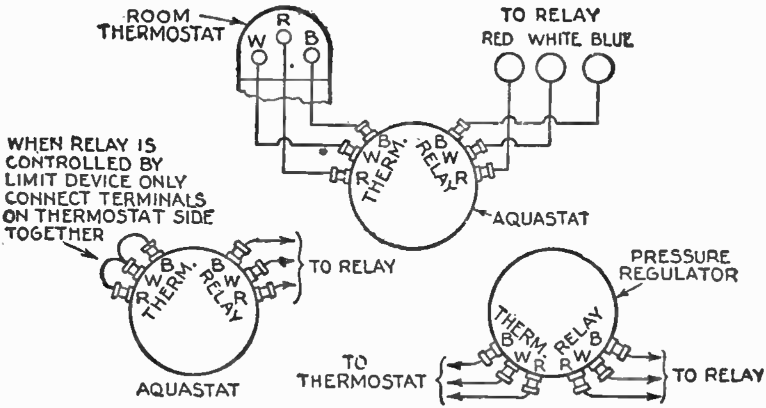


FIG. 8,728.—Minneapolis Honeywell connection diagram for motor switch; 110-220 volts, 60 cycle a.c.

Storage of Oil.—In contemplating the installation of an oil burner provision for storing fuel should be considered. For coal, the average home owner generally provides storage capacity ample to contain all the coal used during the heating season. With oil this is not usually the case. Aside from the added convenience of having a large supply of oil on hand, a more attractive price scale is offered to those consumers who buy oil in relatively large quantities.



Figs. 8,729 to 8,731.—Diagram showing Minneapolis Honeywell thermostat and controls Minneapolis limiting devices were primarily designed for limiting the amount of heat generated by the furnace or boiler in excess of that which could be absorbed by the system. Ordinarily the limiting device is used in dual control with the thermostat, but it can be used as the controlling means without a thermostat if that be desirable. Such a hook up is easily made with the six terminal post instrument by bridging or linking the three posts marked *from thermostat*, together and omitting the thermostat, wiring the balance of the circuit in the usual way.

Large storage tanks are installed in various ways and usually must conform to the ordinances which regulate such matters in the particular locality. From this tank the oil must be fed to the burner by suitable means, since regulations restrict the quantity of oil which may be stored above the burner level.

Installation Notes.—The following information will be found helpful:

1. Not only the furnace, but the chimney and the smoke pipe should be cleaned prior to the installation.

2. The damper in the stack should be removed or wired wide open.

3. All air leaks around the furnace, the ash pit opening, the stack and the chimney should be caulked with furnace cement.

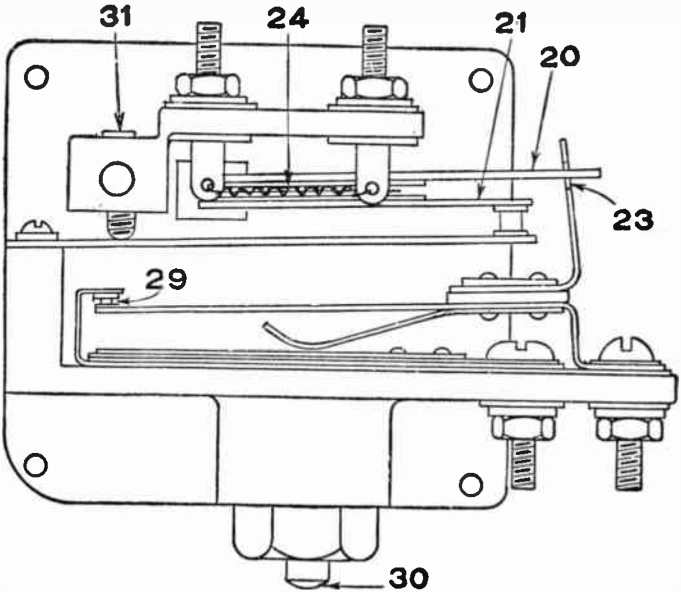


FIG. 8,732.—Minneapolis Honeywell thermal safety switch. *It acts* to provide a time element in the control system, allowing a sufficient ignition period, and affording a means of shutting down the burner as directed by the protectostat, preventing further operation until manually reset. *It consists of* the bimetallic strips 20 and 21, which when heated by the resistance wire grid 24, warp apart until the spring 23, is allowed to fall into the notched contacts 29, to snap open and latch, remaining so until blade 20 and 21, cool, when switch can be manually reset by push button 30. A bimetallic strip compensates for any movement of strips 20 and 21, due to rise and fall of the room temperature. The time required for the switch to operate can be varied by adjusting screw 31 to 30 seconds to 1½ minutes. Be very careful in making a change in adjustment, as a slight movement of screw will make a marked difference in time.

4. Local ordinances must be followed implicitly in regard to the installation of all electrical equipment.

5. All connections must be made tight. Oil leaks never take up. Clean all threads before putting on pipe joint cement and use a suitable cement. Red lead and similar dopes are not satisfactory, litharge and glycerine, *key paste*, or *pro tar* joint and gasket cement are best.

6. Pipe cement should be brushed on clean, dry male threads only.

7. Gasket unions must not be used. The brass seat ground joint type should be used.

8. Keep pipe line running absolutely parallel when running close together. All pipe must be straight without kinks and run in straight lines to give neat mechanical appearances.

9. Use all galvanized pipe and be sure it is clean inside. Rap and blow through it to remove all scale.

10. All electrical connections must be soldered.

11. See that the oil is of the proper grade to meet the needs of the burner and be careful to instruct the owner in regard to buying the right grade of oil to suit the requirements of the burner. This is an important detail.

12. See that the boiler is properly supplied with water.

13. See that the burner gets a fair start. Clean all flues of soot and dirt. Clean the boiler carefully. Remove all ashes and dirt.

14. Start burner and give it a thorough working test.

15. Leave the boiler or furnace room neat and clean.

TEST QUESTIONS

1. *What is the effect of grade of oil on economy?*
2. *What is an oil burner?*
3. *Give full classification of oil burners.*
4. *Describe a gravity feed vaporizing burner.*
5. *What is the difference between a mixing and a non-mixing burner?*

6. *Explain how a non-mixing burner operates.*
7. *State the principle of the mixing type burner.*
8. *How does a hot plate burner work?*
9. *How is the oil broken up in an atomizing burner?*
10. *How are burners classified with respect to ignition?*
11. *In a hot plate burner how hot must the plate be heated?*
12. *What must be provided for safety if ignition fail?*
13. *What kind of a pilot flame is used in some automatically controlled vaporizing burners?*
14. *What are the conditions for proper ignition?*
15. *What determines the type of burner to be used?*
16. *What is combustion?*
17. *What happens with insufficient air supply?*
18. *Give some points on furnace design.*
19. *What is a thermostat?*
20. *Name the various devices necessary for automatic control.*
21. *Describe in detail the operation of the Minneapolis Honeywell control system.*
22. *What are the points relating to the storage of oil?*
23. *Give a few points on installation.*

CHAPTER 58

Air Conditioning

Air is a mechanical mixture, chiefly of the gases, oxygen and nitrogen, about in the proportion of one to four. Air nearly always contains certain impurities, such as ammonia, sulphurous acid and carbon dioxide.

The latter being a product of exhalation from the lungs and of complete combustion, is so universally present (about in the same proportion everywhere, except where concentrated by some local condition), that it may be regarded as a normal constituent of the air.

Air Conditioning.—The term *air conditioning*, sometimes called *manufactured weather*, means in general *the treatment to which atmospheric air is subjected in order to regulate its temperature and humidity, and to make it pure.*

The effects of air upon comfort and health are due to the reactions of the human being to variations in air temperature, humidity and purity. The sense or feeling of warmth is dependent upon the moisture content of the air, and for this reason comfortable and healthful heating requires coincident regulation of humidity.

The purity of the air breathed by the human being is, of course, primarily important to his physical well being and personal efficiency is materially depressed by air that is contaminated with foreign matter, particularly in congested centers, manufacturing districts, or in proximity to any source of pollution.

Air conditioning is a sure and sane means of eliminating the personal inefficiencies resulting from improper air qualities in spaces enclosing human beings.

Humidity.—By definition humidity of the air is *the amount of water vapor it contains.* Humidity is stated as:

1. Absolute, or

2. Relative.

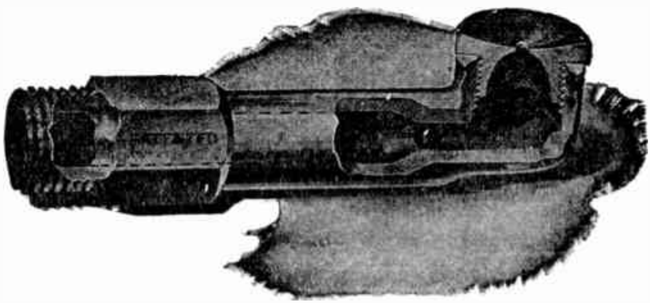


FIG 8,733.—Carrier spray nozzle. The water entering through the small circular chamber tangentially, acquires a whirling motion and is discharged through a small orifice in the center of the cap. The approach to the orifice is conical in shape, so that the rotation, or whirling speed of the water is greatly increased at the instant of discharge.

Absolute humidity is *the actual quantity of water in the air, usually expressed as so many grains of moisture in a cubic foot of air.*

A grain is 1/7,000 part of a pound. The amount of water the air is capable of holding is determined by the temperature, for *the warmer the air, the more moisture it can retain.* At 80° it can hold nearly twice as much moisture as at 60°.

Relative humidity denotes the relation between *the actual amount of water in the air and the maximum amount it is possible for the air to hold at the same temperature expressed in per cent.*

Air which is saturated has a relative humidity of 100%, while the air at the same temperature and holding but one-half of the saturation amount has a relative humidity of 50%.

It is the *relative humidity* and not the *absolute humidity*, that

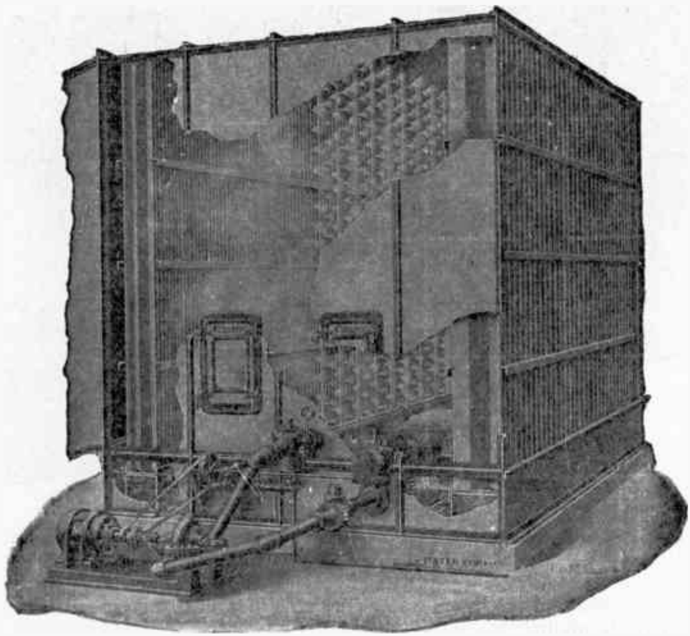


FIG. 8,734.—Carrier humidifier equipped with rotary strainer. *In operation,* air enters at right, through the baffle plates, passes through the spray chamber and leaves at the left through the washer eliminator plates. *The parts are,* R, rotary strainer; E, ejector heater P, pump; M, pump motor; S, pot strainer.

is important, for there exists a definite relation between the relative humidity and the moisture content of fibrous materials.

The higher the temperature of the air, the greater is its capacity to hold water. For example, air with a relative humidity of 70% at 90° contains

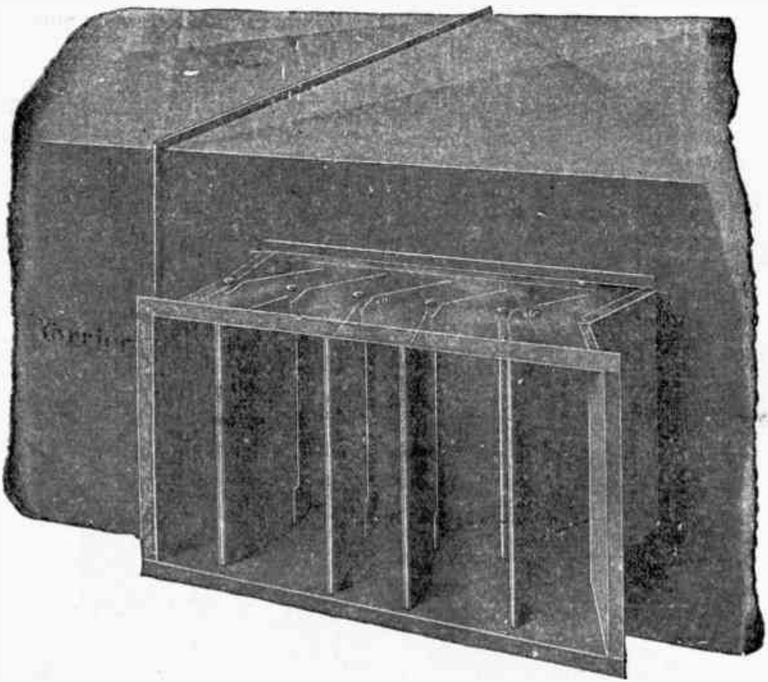


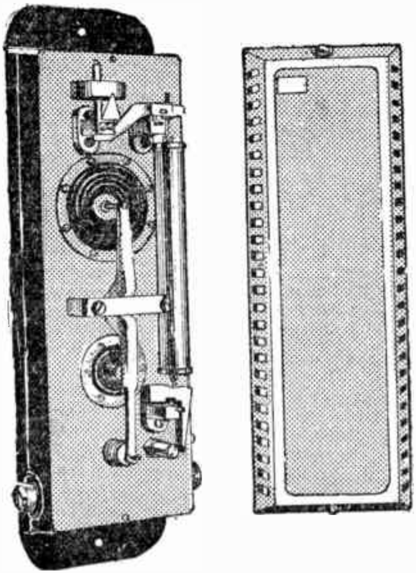
Fig. 8,735.—Carrier diffuser outlet (phantom view showing construction of the vanes).

about seven times as much water per cubic foot as air at 32° with the same relative humidity.

To put it another way, if air be heated without adding water vapor, the relative humidity decreases, and if it be cooled without taking out water vapor the relative humidity is increased.

The feeling as to whether the air is moist or dry *depends on relative and not absolute humidity.*

Since all substances which are affected by the presence of water vapor in the air absorb or give off water substantially in proportion to the relative humidity, this form of notation is the one most commonly used, and humidity is generally understood to mean relative humidity, or percentage of saturation.



FIGS. 8,736 and 8,737.—Carrier adjustable hygrostat with cover removed to show the hygroscopic mechanism. This instrument varies the humidity in accordance with variations in temperature, maintaining any desired relation between the two.

Dew Point.—By definition, this is *the temperature at which air becomes saturated with water vapor.*

NOTE.—*Relative humidity* is little understood by the average person, as indicated by the widespread (though now decreasing) use of radiator pans, and mechanical or electrically heated devices for the evaporation of moisture in homes or offices.

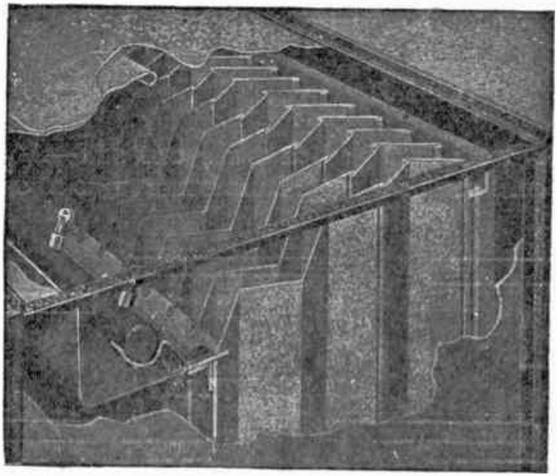


FIG. 8,738.—Buffalo air washer; part of casing removed showing *eliminator* in position. The eliminator which is integral with the scrubbing surface, is made up of a series of corrugated plates spaced and set in a vertical position across the discharge end of the spray chamber. The eliminator is made of a single sheet, the last three corrugations having projecting lips or gutters which remove the entrained water from the air. The plates are assembled in an angle iron frame demountably carried on clips on the sides of the casing. These angles are provided with slots into which the edges of the plates are slipped and held rigidly.

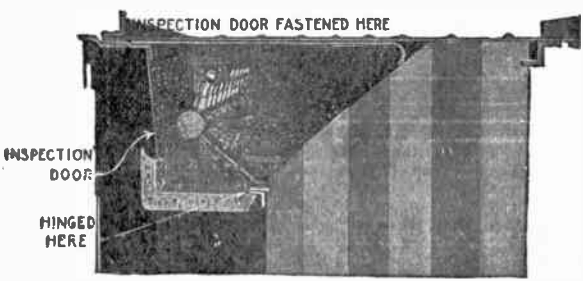
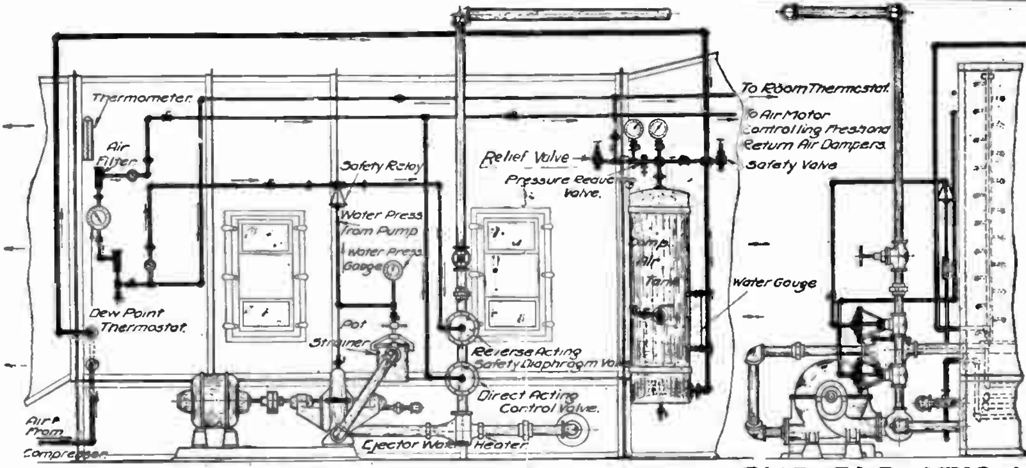
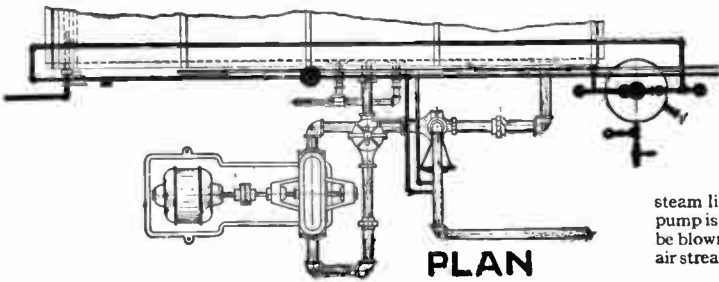


FIG. 8,739.—Buffalo flooding nozzles. The flooding of the eliminator, type A and B, washers, is done by an independent set of nozzles across the top. These nozzles distribute the water over the washing surface uniformly. The flooding is used continuously but provision is made for shutting off atomizing sprays in summer on very humid days. When the atomizing sprays are shut off. the increase in the humidity is so small that it practically amounts to nil.



FRONT ELEVATION

END ELEVATION



PLAN

FIGS. 8,740 to 8,742.—Carrier dew point control applied to a humidifier. This diagram shows all of the apparatus and the connections. ***In operation,*** the safety relay is held open by the pump water pressure, opening the reverse acting diaphragm valve, in the steam line to the ejector heater, only when the pump is operating properly. Thus steam cannot be blown through the ejector heater and into the air stream should the pump fail for any reason.

Since the capacity of air to hold water vapor decreases with lowering temperature, it is always possible by cooling the air to reduce its capacity to the point where the water vapor present just equals this capacity. The air is then said to be *saturated.*

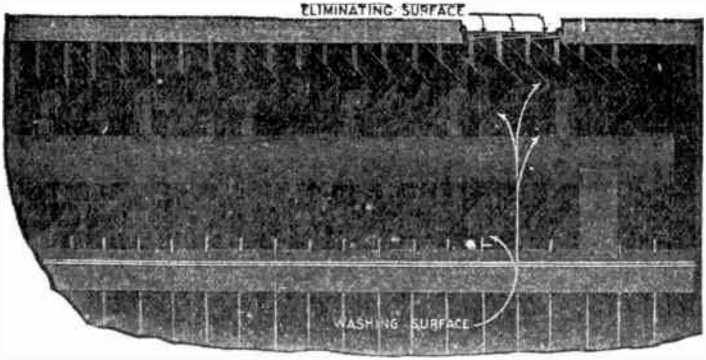


FIG. 8,743.—Buffalo eliminators; front view showing washing surface and narrow passages through which the air passes. The eliminators are so arranged that the first four corrugations are kept constantly flooded with a sheet of water which catches any solid matter, not already precipitated by the first set of sprays, and washes it to the settling tank. The wet surface exposed to the air thus obtained amounts to 19.5 sq. ft. of washing surface per 1,000 cu. ft. of air per minute, counting only the side of the corrugation against which the air impinges.

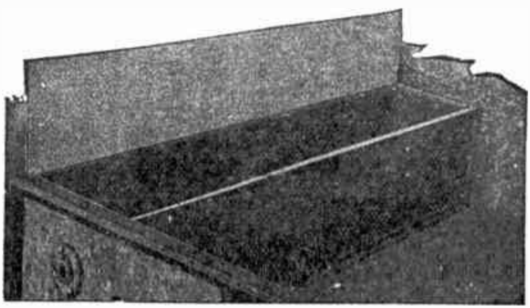


FIG. 8,744.—Buffalo suction compartment with screen cover. The settling tank is divided into two compartments by a brass wire cloth strainer, through which the water passes before entering the suction of the pump. This strainer offers a surface of more than one sq. ft. for each foot in width of the tank. The area of the strainer being many times the area of the suction pipe, provides a thorough filtering of the water at very low velocity.

If cooled below this saturation point, the capacity is still further decreased, the air cannot hold as vapor all of the water present, and the excess condenses into visible form as fog or dew. Accordingly, this condensation begins at the *dew point.** When the relative humidity is 100%, the air is fully saturated, and no more *invisible* vapor can be added without precipitation as dew, fog, or rain.

Wet and Dry Bulb Hygrometer.—This is a device *for measuring the relative humidity* or hygrometric state.

It consists of two thermometers mounted side by side, the bulb of one being kept moist by means of a loose cotton wick

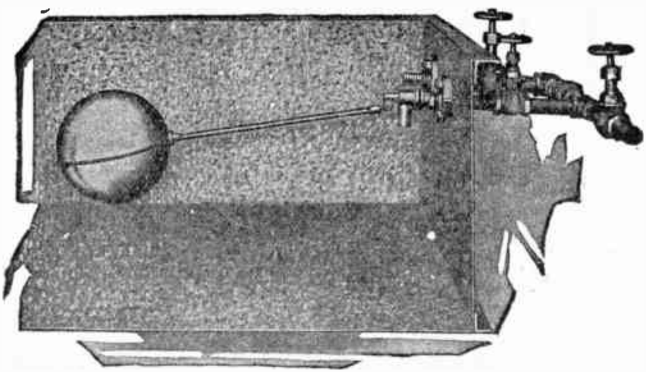


FIG. 8,745.—Buffalo automatic make up and quick filler. The required water level in the tank is automatically maintained by the float valve here shown. This allows constant operation of the pump at uniform suction head. It is also essential that provision be made for rapid filling of the tank after cleaning, and this is provided for by the extra flanged pipe inlet, which also serves as a hose connection.

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*NOTE.—*Example of dew point.*—A good illustration is the sweating of a vessel of ice water on a hot day. What really happens is that a thin film of air surrounding the vessel is cooled below the dew point, and the excess water is deposited as sweat. To put it in figures, if the air be at 72° with 60% relative humidity, it contains about 5 grains of water to the cubic foot. If the layer of air around the vessel be cooled to 42°, the air at this temperature can hold only 3 grains per cubic foot *when saturated*, and the extra two grains per cubic foot is precipitated or deposited on the vessel as sweat. The same thing happens in the formation of dew out of doors when the lowering of temperature at night brings the air near the ground below the dew point. Frost is formed whenever the dew point is below 32° or freezing temperature.

tied around it, the lower end of which dips into a vessel of water.

On account of evaporation from the bulb, this instrument is cooled, and indicates a lower temperature than the other, the difference depending upon

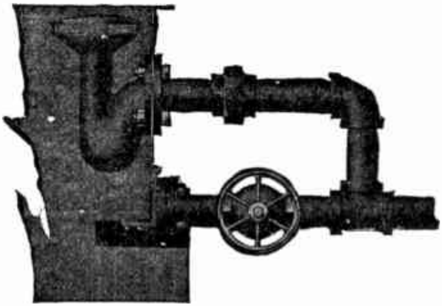


FIG. 8,746.—Buffalo water sealed overflow and drain. The water sealed overflow pipe is bolted to the side of the tank. Hooded construction prevents waste of the spray water. A drain box connection which can be easily cleaned is provided under the tank.

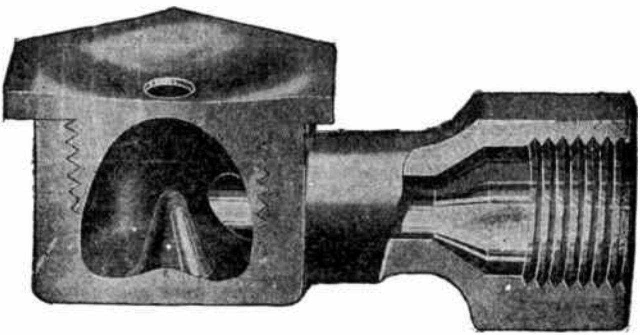


FIG. 8,747.—Sectional view of Buffalo spray nozzle. *In operation*, water enters a small circular chamber tangentially, which gives it a whirling or centrifugal action. The approach to the discharge opening is conical in shape, so the rotation, or whirling speed of the water, is greatly increased as it approaches the discharge. The effect of this arrangement is to give a most minutely divided or atomized spray, which offers an enormous amount of surface for washing and evaporation. The construction of the nozzle is such as to make it free from clogging with foreign material. The area of orifice of the nozzle is ample. In order to provide against clogging of the strainer, at least 12 sq. ins. of strainer screen is provided for each and every spray nozzle, giving a strainer surface 280 times the area of the nozzle orifice.

the rate of evaporation and hence upon the amount of aqueous vapor present in the air.

There is no simple relation between the readings and the hygrometric state; the latter is deduced therefore by reference to tables, although various empirical formulæ have been proposed.

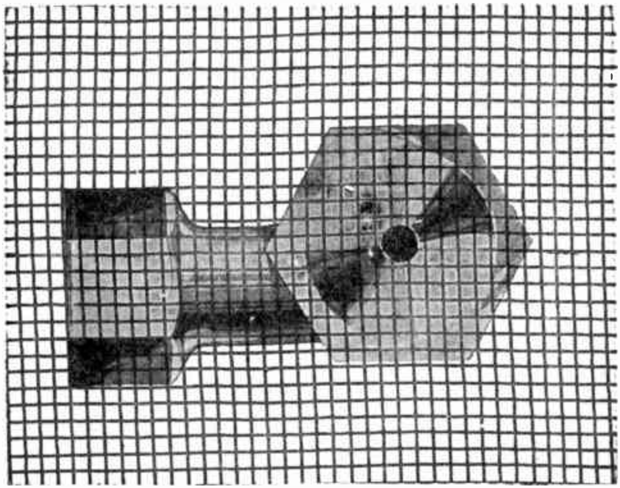


Fig. 8,748.—Buffalo spray nozzle under strainer screen, exact size.

The accompanying relative humidity tables are for use with wet and dry bulb thermometers. Directions are given under the tables.

Accurate readings can be obtained only when the air is caused to pass very rapidly over the moistened wick, either by means of a fan, aspiration, or by whirling the thermometer. The latter is the usual method, the instrument, comprising a dry bulb and a wet bulb thermometer mounted on a handle or chain for whirling, being known as a ***sling psychrometer.***

No stationary wet and dry bulb hygrometer mounted on a wall (unless in a strong air current) can indicate the true wet bulb temperature and such instruments are to be avoided.

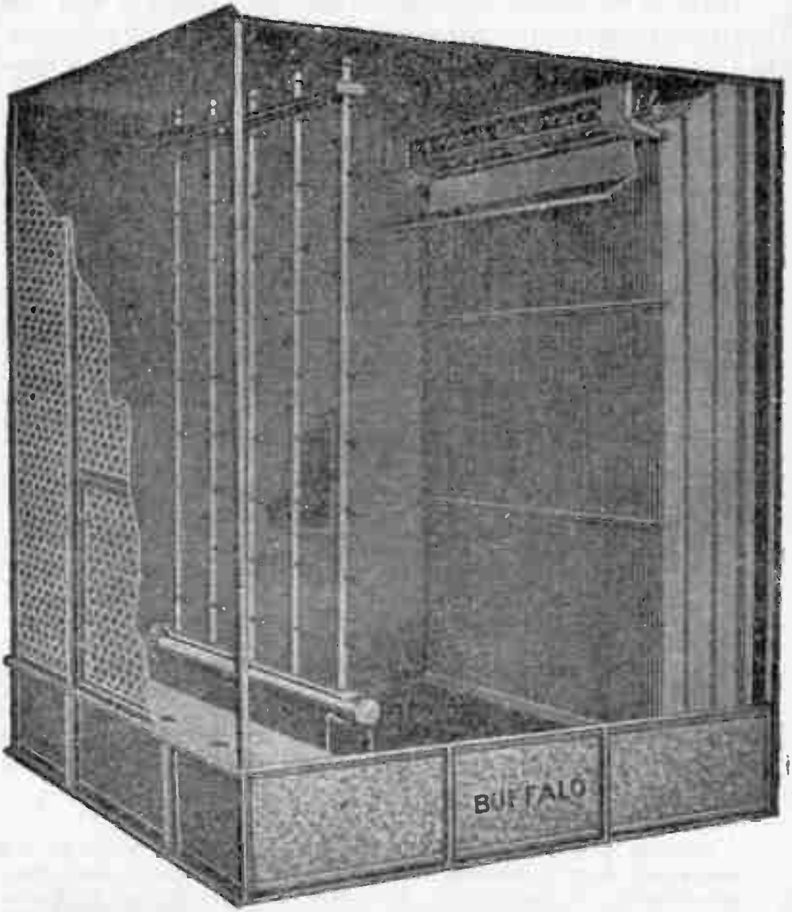


FIG. 8,749.—Buffalo type **A**, air washer with side and distributing plate removed to show interior construction.

RELATIVE HUMIDITY TABLES

FAHRENHEIT DEGREES. BAROMETER 29 INCHES.

Reading of Dry-Bulb Thermometer	Difference in Degrees Between Wet- and Dry-Bulb Thermometers											
	1	2	3	4	5	6	7	8	9	10	11	12
32	90	79	69	60	50	41	31	22	13	4		
33	90	80	71	61	52	42	33	24	16	7		
34	90	81	72	62	53	44	35	27	18	9	1	
35	91	82	73	64	55	46	37	29	20	12	4	
36	91	82	73	65	56	48	39	31	23	14	6	
37	91	83	74	66	58	49	41	33	25	17	9	1
38	91	83	75	67	59	51	43	35	27	19	12	4
39	92	84	76	68	60	52	44	37	29	21	14	7
40	92	84	76	68	61	53	46	38	31	23	16	9
41	92	84	77	69	62	54	47	40	33	26	18	11
42	92	85	77	70	62	55	48	41	34	28	21	14
43	92	85	78	70	63	56	49	43	36	29	23	16
44	93	85	78	71	64	57	51	44	37	31	24	18
45	93	86	79	71	65	58	52	45	39	33	26	20
46	93	86	79	72	65	59	53	46	40	34	28	22
47	93	86	79	73	66	60	54	47	41	35	29	23
48	93	87	80	73	67	60	54	48	42	36	31	25
49	93	87	80	74	67	61	55	49	43	37	32	26

Reading of Dry-Bulb Thermometer	Difference in Degrees Between Wet- and Dry-Bulb Thermometers																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
50	93	87	81	74	68	62	56	50	44	39	33	28	22	17	12	7	2
51	94	87	81	75	69	63	57	51	45	40	35	29	24	19	14	9	4
52	94	88	81	75	69	63	58	52	46	41	36	30	25	20	15	10	6
53	94	88	82	75	70	64	58	53	47	42	37	32	27	22	17	12	7
54	94	88	82	76	70	65	59	54	48	43	38	33	28	23	18	14	9
55	94	88	82	76	71	65	60	55	49	44	39	34	29	25	20	15	11
56	94	88	82	77	71	66	61	55	50	45	40	35	31	26	21	17	12
57	94	88	83	77	72	66	61	56	51	46	41	36	32	27	23	18	14
58	94	89	83	77	72	67	62	57	52	47	42	38	33	28	24	20	15
59	94	89	83	78	73	68	63	58	53	48	43	39	34	30	25	21	17
60	94	89	84	78	73	68	63	58	53	49	44	40	35	31	27	22	18
61	94	89	84	79	74	68	64	59	54	50	45	40	36	32	28	24	20
62	94	89	84	79	74	69	64	60	55	50	46	41	37	33	29	25	21
63	95	90	84	79	74	70	65	60	56	51	47	42	38	34	30	26	22
64	95	90	85	79	75	70	66	61	56	52	48	43	39	35	31	27	23
65	95	90	85	80	75	70	66	62	57	53	48	44	40	36	32	28	25
66	95	90	85	80	76	71	66	62	58	53	49	45	41	37	33	29	26
67	95	90	85	80	76	71	67	62	58	54	50	46	42	38	34	30	27
68	95	90	85	81	76	72	67	63	59	55	51	47	43	39	35	31	28
69	95	90	86	81	77	72	68	64	59	55	51	47	44	40	36	32	29

Reading of Dry-Bulb Thermometer	Difference in Degrees Between Wet- and Dry-Bulb Thermometers																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
70	95	90	86	81	77	72	68	64	60	56	52	48	44	40	37	33	30
71	95	90	86	82	77	73	69	64	60	56	53	49	45	41	38	34	31
72	95	91	86	82	78	73	69	65	61	57	53	49	46	42	39	35	32
73	95	91	86	82	78	73	69	65	61	58	54	50	46	43	40	36	33
74	95	91	86	82	78	74	70	66	62	58	54	51	47	44	40	37	34
75	96	91	87	82	78	74	70	66	63	59	55	51	48	44	41	38	34
76	96	91	87	83	78	74	70	67	63	59	55	52	48	45	42	38	36
77	96	91	87	83	79	75	71	67	63	60	56	52	49	46	42	39	36
78	96	91	87	83	79	75	71	67	64	60	57	53	50	46	43	40	37
79	96	91	87	83	79	75	71	68	64	60	57	54	50	47	44	41	37
80	96	91	87	83	79	76	72	68	64	61	57	54	51	47	44	41	38
82	96	92	88	84	80	76	72	69	65	62	58	55	52	49	46	43	40
84	96	92	88	84	80	77	73	70	66	63	59	56	53	50	47	44	41
86	96	92	88	85	81	77	74	70	67	63	60	57	54	51	48	45	42
88	96	92	88	85	81	78	74	71	67	64	61	58	55	52	49	46	43
90	96	92	89	85	81	78	75	71	68	65	62	59	56	53	50	47	44
92	96	92	89	85	82	78	75	72	69	65	62	59	57	54	51	48	45
94	96	93	89	86	82	79	75	72	69	66	63	60	57	54	52	49	46
96	96	93	89	86	82	79	76	73	70	67	64	61	58	55	53	50	47
98	96	93	89	86	83	79	76	73	70	67	64	61	59	56	53	51	48
100	96	93	90	86	83	80	77	74	71	68	65	62	59	57	54	52	49

To use tables, find difference in reading between dry- and wet-bulb thermometers. Under that figure, opposite dry-bulb reading, find per cent of Relative Humidity. *Example:* Dry bulb 75°, wet bulb 63°, difference 12. Under 12 and opposite 75 find 51% Relative Humidity.

Moistening Effect of Air.—*Air at high relative humidities (regardless of the absolute humidity) exerts a greater moistening effect than air at lower relative humidities.*

The moistening effect of the air varies approximately with its relative humidity, without regard to the actual weight of water vapor present.

In a textile mill, for instance, where one of the chief functions of air conditioning is to control the moisture in the yarns in course of manufacture, it should now be obvious that temperature control is equally as important as moisture control, since it is upon the relative humidity (water vapor

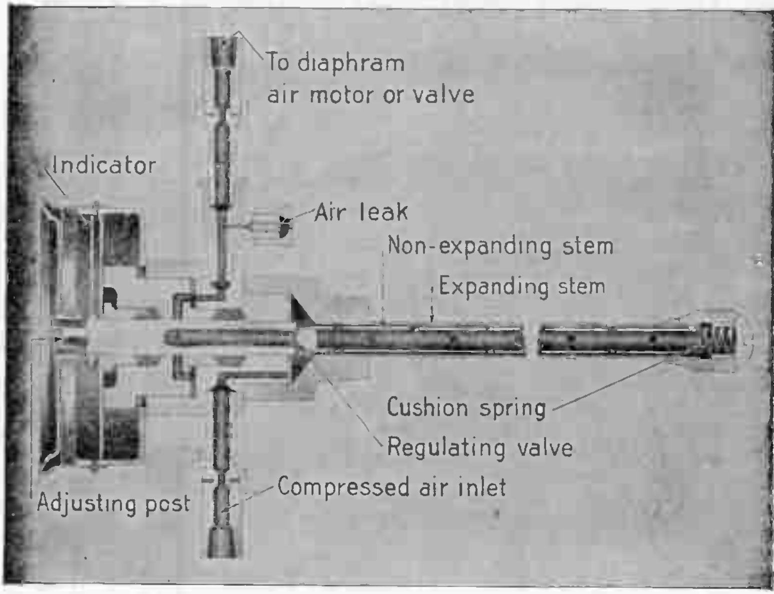


FIG. 3,750.—Carrier graduated thermostat; sectional view showing operating principle. ***It consists essentially of*** an outer expanding stem, usually of brass, and an inner non-expanding stem of nickel steel. These two members are rigidly connected at one end. The other end of the inner, non-expanding member, is provided with a bronze valve, ground to fit an adjustable valve seat. Between the inner and outer tubes there is an annular chamber. Compressed air, from a small auxiliary compressor, usually driven from the fan or pump shaft, is admitted to this annular space, and its passage through the instrument is regulated by the small valve attached to the non-expanding stem. As the temperature of the air surrounding the stem of the instrument rises, the outer member expands, the regulating valve recedes from its seat, and the compressed air passes through into the outlet chamber, from whence it goes to the diaphragm valve in the steam line to the spray water heater. Upon reaching this diaphragm valve, the compressed air moves it so as to decrease the amount of steam admitted to the ejector heater and thereby reduce the temperature of the spray water as required. When the temperature of the air leaving the conditioning machine falls below the point desired, the outer shell contracts and closes the compressed air supply to the diaphragm valve, whereupon the pressure upon the diaphragm of the valve is relieved through the air leak, as shown in the figure, and the valve opens, admitting steam to the spray water heater.

content as related to temperature) that the moistening effect of the air depends.

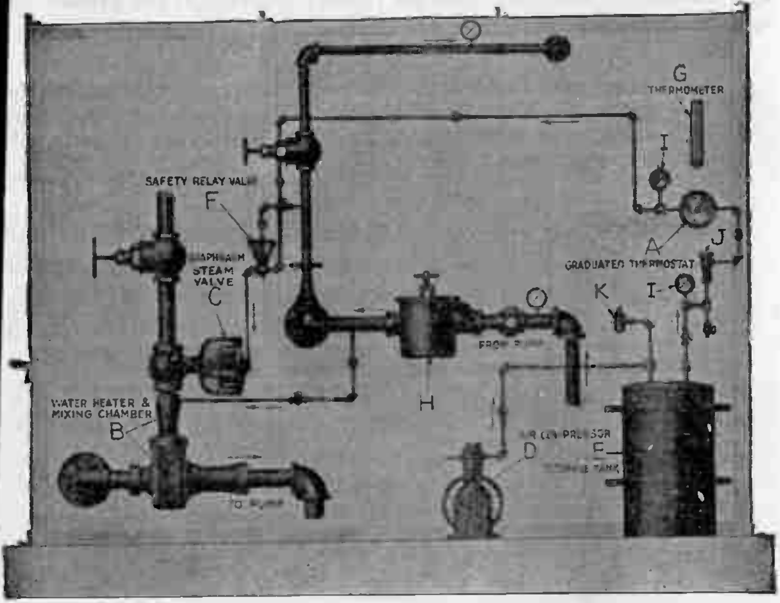


FIG. 8,751.—Buffalo ejector type dew point humidity control. ***In operation,*** saturation is produced by heating the spray water. This water supplies the latent heat of evaporation, and, in addition, raises the temperature of the incoming air to the desired dew point; that is, to the temperature necessary to hold the required amount of moisture. The water temperature is varied as may be necessary to maintain a constant dew point under variable conditions of entering air. The stem of a graduated thermostat **A**, is placed in the passage just beyond the eliminators, so that it is exposed to the temperature of the air leaving the washer. Any change in temperature causes a contraction or expansion of this thermostat and the temperature regulation is accomplished by contraction and expansion. A water heater and mixing chamber **B**, of the ejector type, is placed in the suction line to the pump. The diaphragm steam valve **C**, is placed in the steam line which supplies the water heater. This valve is operated by compressed air pressure from graduated thermostat **A**. The air compressor **D**, furnishes air at about 15 lbs. pressure to the storage tank **E**. The compressor is driven by the same motor that drives the spray water circulating pump. The diaphragm steam valve **C**, is normally closed. It only admits steam to the circulating water when air pressure is admitted to the diaphragm through the reverse acting thermostat **A**. This arrangement provides a safety feature in addition to a sensitive and accurate control, for if the air pressure should fail the steam would immediately be shut off. To provide for further safety from over humidification a safety relay valve **F**, is placed on the air line to the steam valve. This relay allows air to pass to the diaphragm steam valve **C**, only when the washer sprays are in operation.

Drying Effect of Air.—Briefly, *the drying effect of air varies approximately inversely with its relative humidity, the greater the relative humidity, the lesser the drying effect.*

It should be noted that it is the relative humidity which determines the effect and that, therefore, the effect depends upon both the temperature and the water vapor content of the air—since relative humidity depends upon both these factors.

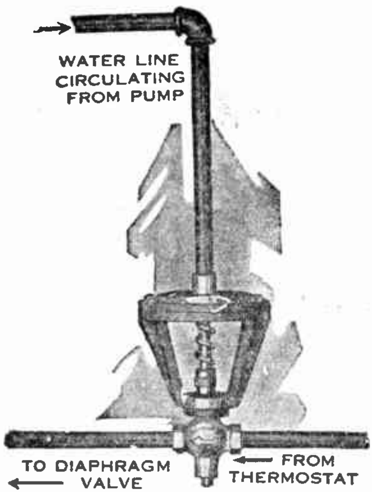
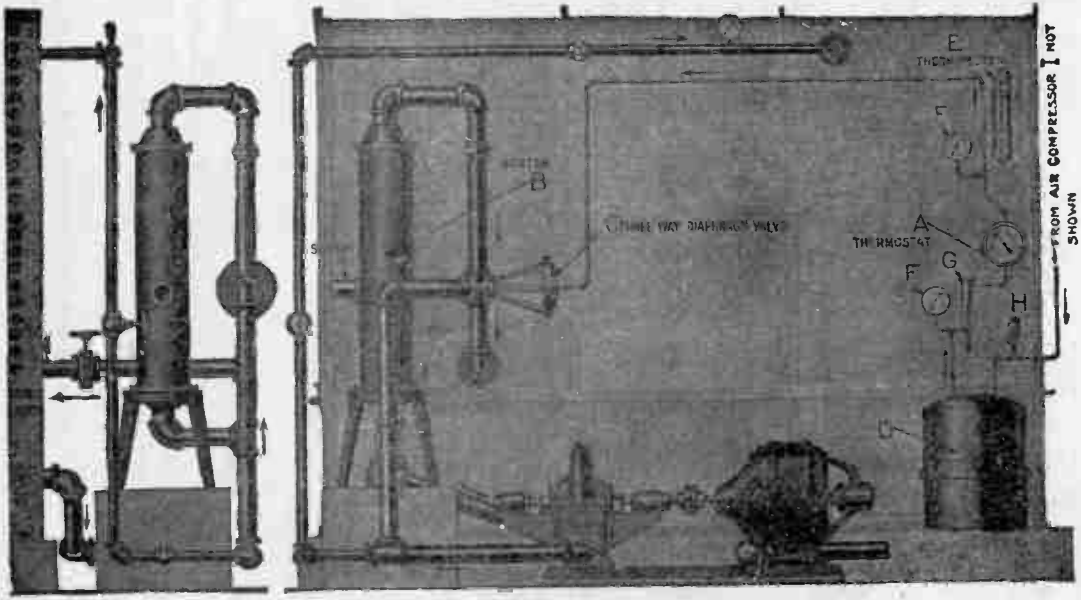


FIG. 8,752.—Buffalo safety relay valve.

Heating Effect of Air.—The quantity of heat which dry air contains is very small, because its specific heat is low, .2415 (for ordinary purposes) which means that one lb. of air falling one degree in temperature (Fahr.) will yield but .2415 of the heat which would be available from one lb. of water, reduced 1° in temperature. The presence of water vapor in the air materially increases the total heating capacity of the air because of the latent heat of the vapor itself.

Moist hygroscopic materials in the presence of dry air, even at high dry bulb temperatures, may actually be cooled, rather than heated. This occurs because the dry air immediately begins to evaporate moisture from the material and in so doing removes from the material, as well as from the air, the latent heat of evaporation.

Air Conditioning.—This operation (sometimes called "manufactured weather") involves four distinct air conditions upon



FIGS. 8,753 and 8,754.—Buffalo closed heater type dew point humidity control. Where steam is not available at a pressure of 3 lbs. or over, that is, where a vacuum steam heating system or hot water heating system is installed, an ejector heater cannot be depended upon for continuous and satisfactory service. In such plants a closed water heater is substituted for the ejector heater and safety device with the reverse acting diaphragm valve. The mixing valve *C*, is used with the closed water heater and is operated by the graduated action dew point thermostat. The seat of this valve takes intermediate positions to give the proper mixture of heated and by-passed water required.

the *relation of all* of which depend the comfort and health effects of indoor air.

These are:

1. Temperature;
2. Relative humidity;
3. Purity;
4. Motion.

Air conditioning accomplishes *the simultaneous control of the four conditions enumerated.*

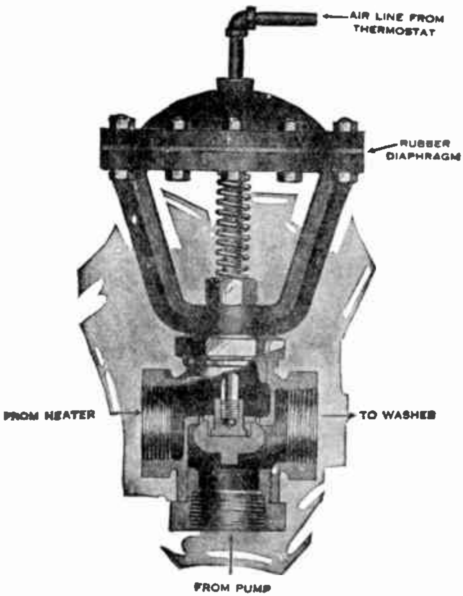


FIG. 8,755.—Carrier diaphragm valve. *It is located* in the steam line to the water heater, and is of the direct acting type, which means that it is held open by means of a spring, and closed when air pressure is admitted to its diaphragm motor.

Any system which neglects any *one* of these factors is not an air conditioning system. Hence a ventilating system or a fan heating system which merely moves unconditioned air, heated air, cooled air, filtered air or moistened air, is not an air conditioning system. Such systems have their legitimate applications, of course, but are too often confused with or miscalled air conditioning systems. hence this distinction.

Methods of Air Conditioning.—There are several methods employed for the automatic control of temperature and humidity and various standard forms of apparatus are used for accomplishing the required purposes. The Carrier dew point control is here given as an illustration.

With this control, the dew point, or saturation temperature of the air is automatically controlled by means of a simple expansion thermostat, exposed to the air at the instant of saturation in the air conditioning machine

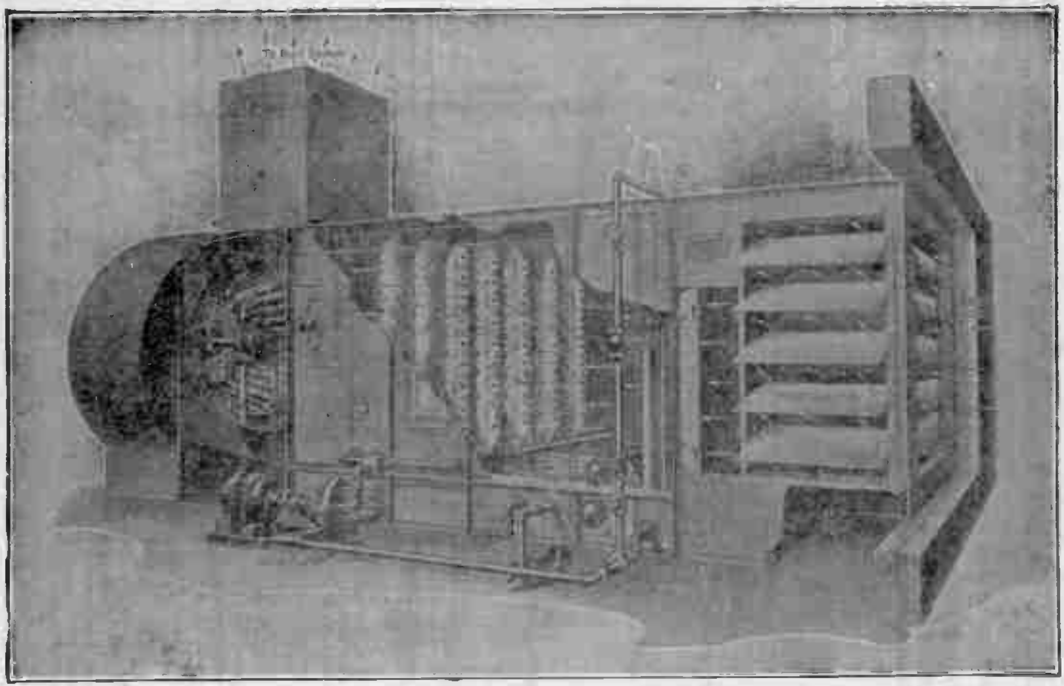


FIG. 8,756.—Carrier central station air conditioning unit showing the automatically controlled dampers, the spray chambers, the fan and the water circulation system. Within this chamber the air is completely cleansed, its moisture content adjusted, either increased or reduced. From the fan the air is delivered through the duct system to the rooms to be conditioned.

itself. Thus, the absolute humidity of the air is definitely fixed in the conditioning machine, because, as has been pointed out, where air is saturated at a given temperature, it contains a given quantity of water vapor corresponding to that temperature.

Obviously, any absolute humidity (*i. e.*, the number of grains of water vapor per cu. ft. of air) can be established by adjusting the thermostat to the corresponding temperature.

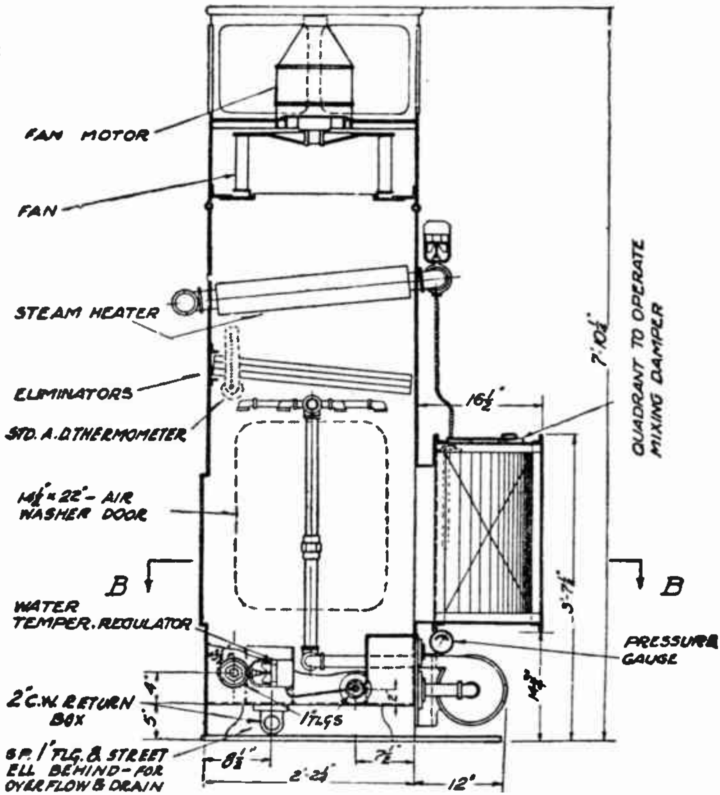


FIG. 8,757 —Carrier unit air conditioner, showing in detail its construction and operation.

The saturated air leaving the machine is heated by passage through suitable heaters, and its dry bulb temperature is increased sufficiently to establish the required dry bulb temperature in the space being conditioned.

The temperature of the air leaving the heaters is controlled by means of a second thermostat located in the room itself, and regulating the steam admitted to the heaters.

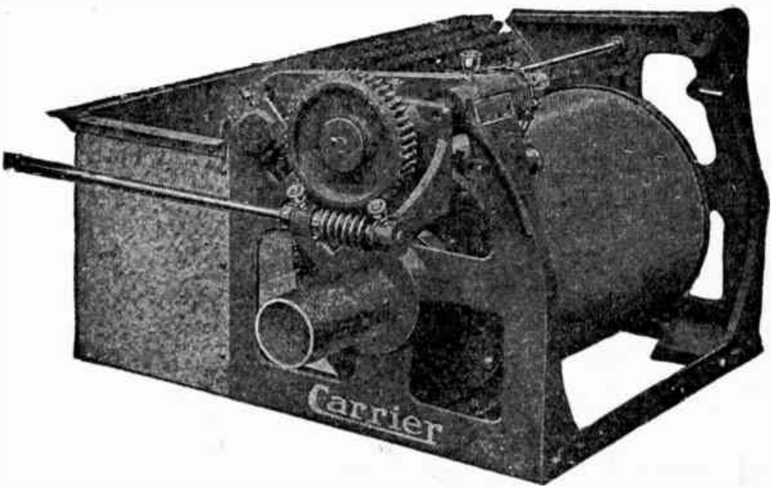


FIG. 8,758.—Carrier rotary strainer for removal of dirt or other foreign matter. The strainer is placed in the settling tank of the conditioning machine. The suction line to the pump is connected to a hollow trunnion, open to the interior of the revolving screen cylinder. A stiff cylindrical brush revolves against the surface of the revolving screen, sweeping it clear of accumulated dirt or fibrous matter. The dirt so collected by the brush is deposited in a small auxiliary tank, so that it does not again mingle with the water. The strainer tank requires cleaning about once a week, ordinarily, the operation takes not more than 15 minutes.

In certain instances it is permissible, during the summer season, for the dry bulb temperature to exceed that maintained in the winter, so long as the relative humidity is controlled at an approximately constant value. In such instances there is no provision for dehumidification, and the humidifier is used to effect as great a degree of cooling as possible by evaporation only. The dew point temperature of the air leaving the humidifier then becomes the same as the wet bulb temperature of the outdoor air, the dew point thermostat being inoperative.

The dry bulb temperature in the enclosure is regulated in accordance with the prevailing wet bulb temperature of the entering air and this regulation is accomplished by means of a hygrostat located within the enclosure, usually adjacent to the thermostat which is used for winter control. The shift from the room thermostat to the room hygrostat can be made either manual or automatic as required. In most cases it is automatic.

The hygrostat, which is sensitive to relative humidity, controls the dry bulb temperature of the enclosure by regulating the volume of air admitted. This avoids the use of heaters, and takes advantage of the available sun

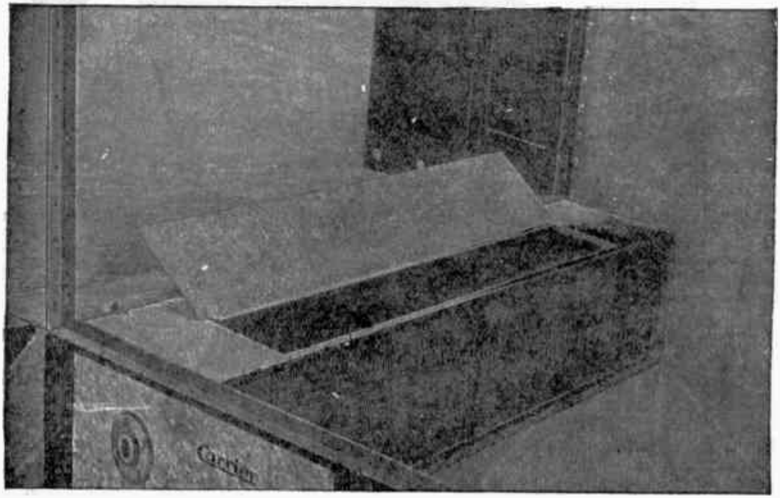


Fig. 8,759.—Carrier fixed suction strainer, the cover open. The pump connection shows in the lower left corner.

heat, or heat from sources within the room. If the dry bulb temperature of the enclosure be high, the hygrostat opens the volume dampers and admits a greater volume of cooler air from the humidifier.

If the dry bulb temperature be low, the hygrostat reduces the volume of cooler air and permits the sun's heat, or the heat from sources within the enclosure, to restore the desired condition.

If in summer, a dry bulb temperature lower than that of the atmosphere must be maintained, a dehumidifier is provided. In this case the dehumidifier acts, during the winter, as a humidifier, under dew point control, and during the summer, functions as a dehumidifier under the same dew point control, except that the dew point thermostat at the dehumidifier, instead of regulating the steam to the water heater, regulates the three way mixing valve in the pump suction line, controlling the temperature of the spray water by admixture of the warmer water from the spray chamber settling tank and cold water from the refrigerating coils, or other source; and the room thermostat, instead of regulating the steam to the heaters, regulates

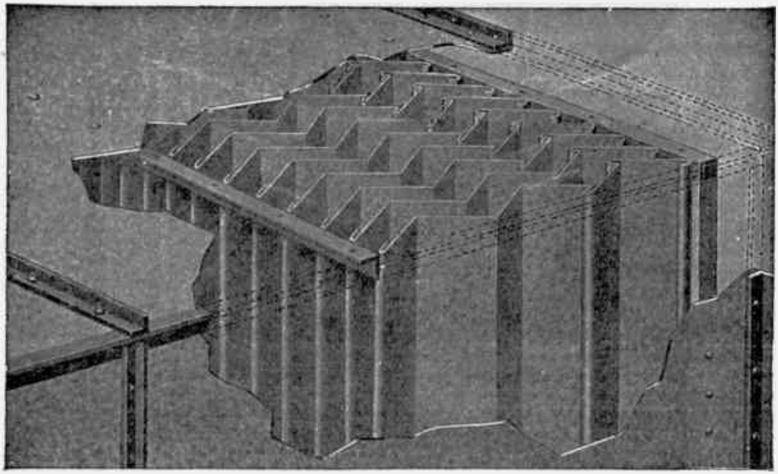


FIG. 8,760.—Carrier washer eliminator plates. *In operation*, as the air leaves the spray chamber it passes through a set of staggered washer eliminator plates which baffle the air from right to left, so that it is scrubbed against the wet surfaces of the plates. The cleansing action resulting is extremely effective, removing practically all of the solid foreign matter carried in the air, including those air borne organisms of disease, mold or decay with which the air may be contaminated. The latter three corrugations of the plates are provided with lips or gutters which trap the entrained free water carried in the air stream, remove it and return it to the settling tank.

the volume dampers in the supply ducts, controlling the temperature of the room by means of the volume of cold, dehumidified air permitted to enter.

The two control instruments, then, regulate the actual water vapor content of the air and its dry bulb temperature, thereby fixing its relative humidity.

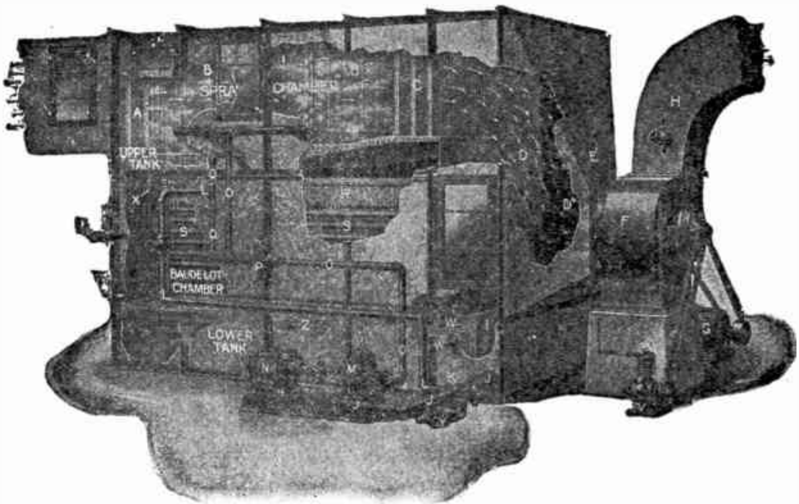


FIG. 8,761.—Carrier dehumidifier. A, distributor plates; B, sprays; C, eliminator plates; D, outlet; E, fan connection; F, fan, G, fan motor; H, fan outlet connection to duct system; I, pump suction screen; J, pump suction line; K, three-way mixing valve; L, line from upper tank to three-way valve; M, pump; N, pump motor; O, pump discharge line; P, pot strainer; Q, by-pass to upper tank for quick cooling at start; R, drip troughs over baudelot coils; S, baudelot cooling coils; T refrigerant connections; V, air compressor for automatic control; W, overflow from lower tank; X, upper tank drain; Y, lower tank drain to sewer; Z, fresh water connections for make up and cleaning.

There are many variations of this control, but to a general understanding of air conditioning practice, a knowledge of this control is sufficient.

In the complete conditioning of air, its purity must be maintained. Air conditioning machines, humidifiers and dehumidifiers, thoroughly wash and cleanse the air, removing practically all of the solid or soluble gas impurities, and most of the aerobic organisms of disease and decay.

The cleansing effect of the Carrier air conditioning machine is produced by the finely divided and uniformly dense water spray and the staggered washer eliminator plates against which the air is baffled as it leaves the

FIGS. 8,762 to 8,764.—Webster spiral mist nozzle disassembled to show construction.

chamber. These plates are flooded with water, so that their wet surfaces accomplish an extremely effective cleansing action.

Addition of Moisture to Air.—The addition of moisture to the air is termed *humidification*, and the conditioning machine, when functioning to add moisture to the air, is termed a *humidifier*. A humidifier is, in reality, *a low pressure, low temperature boiler in which the water is evaporated into vapor and then caused to mix with the air.*

In a humidifier, the water acts as the medium which conveys heat to the air, and as the source of the water vapor required to saturate the heated air. When the temperature of the spray water is above that at which the moisture in the air will condense, the conditioning machine is functioning as a humidifier.

Removal of Moisture from Air.—When the conditioning machine is functioning to remove moisture from the air, it is called a *dehumidifier*, and the process of removing moisture from the air is termed *dehumidification*.

The removal of moisture from the air is accomplished by condensation, the temperature of the air being lowered below its dew point, thereby causing the excess water to condense and fall into the tank of the conditioning machine.

In this case the water acts solely as a conveyor of heat from the air (besides its cleansing action) and, as such, the finely divided mist is extraordinarily effective (practically 100%).

In the Carrier system the dehumidifier functions either as a humidifier or as a dehumidifier, without alteration or rearrangement, except that the valves in the control line from the dew point thermostat are adjusted to connect the steam control to the water heater for winter operation, and to connect the three way mixing valve for summer operation.

Whether the requirement is humidification or dehumidification, the apparatus always operates under accurate automatic control, maintaining the required indoor conditions winter and summer, regardless of the outdoor weather.

Air Movement.—The effectiveness of any air conditioning apparatus depends as much upon the proper distribution of the air as upon the efficiency of the conditioning machine itself.

It may be said that an air conditioning installation is no better than its duct system. To be effective, the conditioned air must be uniformly distributed over the entire area of the enclosure, and, especially in closed or dry rooms, processing rooms, the circulation must not only be uniform, but vigorous.

Evaporative Cooling.—Since outdoor summer air is rarely fully saturated, there is usually a considerable difference between its dry bulb and its wet bulb temperature.

This difference is called the wet bulb depression. Due to the higher dry bulb temperature of summer, the wet bulb depression is greatest during the summer season.

As has been explained, the wet bulb temperature is that temperature to which air would be cooled, by evaporation, if the air were brought into contact with water and allowed to absorb sufficient water vapor to become saturated.

Thus, if outdoor summer air be drawn through a humidifier, wherein it will be completely saturated, its dry bulb temperature will be reduced to its wet bulb temperature, and the air will leave the humidifier at the outdoor wet bulb temperature. This cooling is accomplished entirely by evaporation, and is due to the latent heat required to convert the liquid water into water vapor, such conversion occurring the instant the air is brought into contact with the mist in the spray chamber of the humidifier, the heat being taken from the air.

The spray water in the humidifier is used over and over, only that quantity being added which is actually absorbed by the air. Thus, without any additional operating expense, a humidifier will, in summer, perform the function of cooling the air through the wet bulb depression.

The wet bulb depression is often, in some localities as much as 25° or even 30°, and quite commonly from 10° to 15°, even in localities adjacent to great bodies of water, where the humidity is high and the wet bulb depression, therefore, correspondingly low. In the vicinity of New York, for instance, the maximum outdoor wet bulb temperature is about 78°.

On such a day the dry bulb temperature would probably be about 90°, the wet bulb depression being $90° - 78° = 12°$. In Denver, where the maximum wet bulb is usually less than 78°, the coincident dry bulb is usually much higher than 90°, resulting in a greater wet bulb depression, which means that more cooling can be accomplished by evaporation.

Precautions in Using the Sling Psychrometer.—This instrument, shown in fig. 8,772, consists of *two accurately graduated mercury thermometers mounted on a metal strip and equipped with a swivel handle or a chain to permit whirling.* The thermometers are known as the wet and dry bulb.

The wet bulb is provided with a closely fitting fabric cover, usually silk, which serves to retain liquid and keep the bulb wet during observations. The dry bulb is set somewhat higher on the metal strip than the wet bulb, to avoid the influence of evaporative cooling.

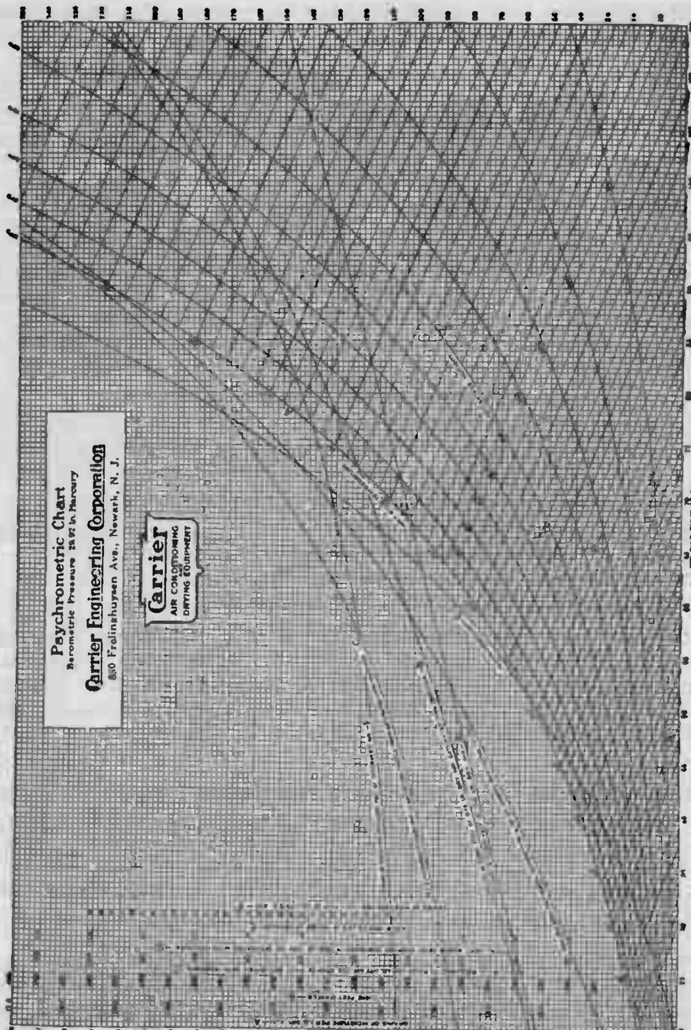


FIG. 8,765.—Psychrometric chart.

To observe the wet and dry bulb temperatures of the air, the wet bulb is thoroughly saturated with clean water, preferably distilled. The instrument is then whirled at a rate of 100 or more *r.p.m.*

The whirling should be continued for a half or three-quarters of a minute, then stopped and read quickly, the wet bulb first. Record the wet and dry bulb readings and make, immediately, one or more subsequent observations to check.

The following precautions should be observed:

1. The wet bulb covering should be of clean, closely fitting fabric free from sizing or other foreign matter.

2. Do not touch wet bulb covering with oily fingers.

3. Use clean water, preferably distilled.

4. If air be in motion, face the breeze while making the observation.

5. Step from side to side, while whirling, to prevent body influence.

6. If observations be made out of doors, it is well to seek shade from direct sunlight.

7. Be sure the wet bulb has been cooled to the minimum.

8. The stationary wet and dry bulb hygrometer is frequently subject to an error greater than 20% of the wet bulb depression, and is not a reliable instrument.

How to Use Psychrometric Chart.—On the chart, fig. 8,765, the *dry bulb temperatures* are shown by vertical lines, with the values indicated on the base line of the chart.

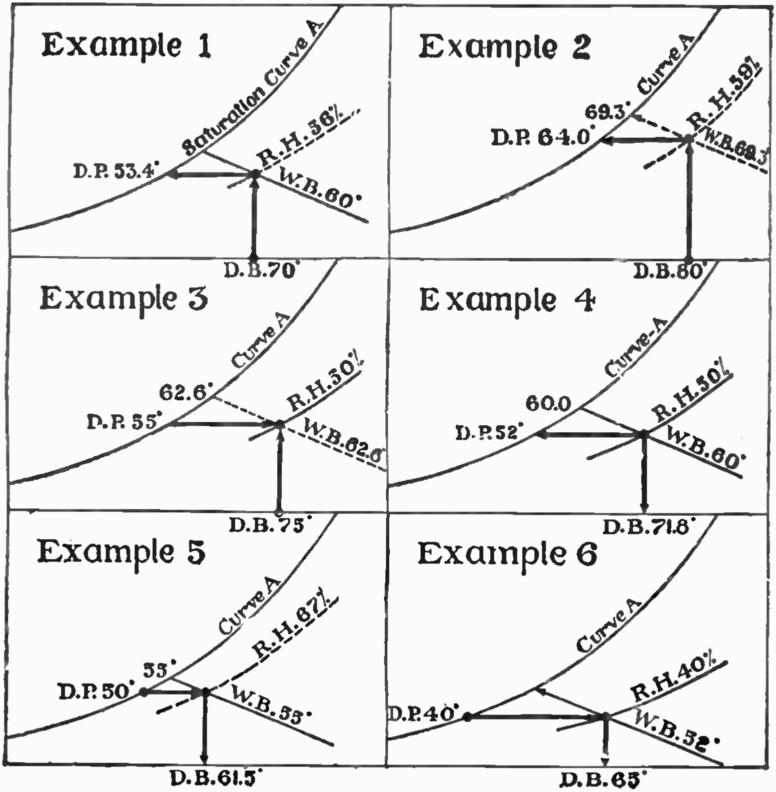
The *wet bulb temperatures* are represented by the oblique lines with values indicated at their intersection with the curved line A, marked "Dew point or saturation temperatures."

Dew point temperatures are represented by horizontal lines with values indicated at their intersections with the curved line A, marked "Dew point or saturation temperatures."

NOTE.—*The Draper recording hygrometer* gives a permanent and continuous record of relative humidity over a period of one week.

The percentages of relative humidity are represented by converging curved lines with values indicated thereon.

Any two of the above properties may be found, if the other two are known. The following examples and diagrams indicate the methods of using the chart.



FIGS. 8,766 to 8,771.—Diagrams to accompany the examples illustrating methods of using the psychrometric chart.

Example 1.—Given: Dry bulb temperature, 70°; wet bulb temperature, 60°. Find the percentage relative humidity and the dew point.

Locate point of intersection of vertical line representing 70° dry bulb temperature with the oblique line representing 60° wet bulb temperature.

By interpolation this point indicates the percentage of relative humidity as 56% and by following the intersecting horizontal line to the left to its intersection with curve A, the dew point is indicated as 53.4°.

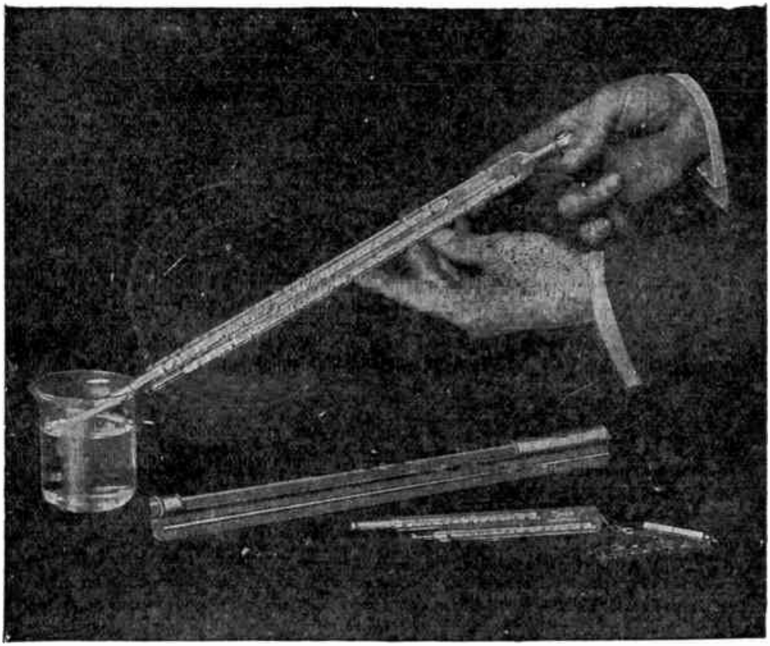


FIG. 8,772.—Two convenient forms of the sling psychrometer. The larger instrument has 12 in. thermometers graduated in one degree divisions. The smaller instrument, lying on the table, has a smaller temperature range and less open graduations, but is a convenient pocket type.

Example 2.—Given: Dry bulb temperature. 80°: relative humidity, 59%. Find the dew point and wet bulb temperature.

Locate the point of intersection of the vertical line representing 80° dry bulb temperature with the interpolated position of the curved line which would represent 59% relative humidity.

Reading horizontally to the left from this point, to curve A, the dew point is indicated as 64° and reading obliquely upward to the left, be-

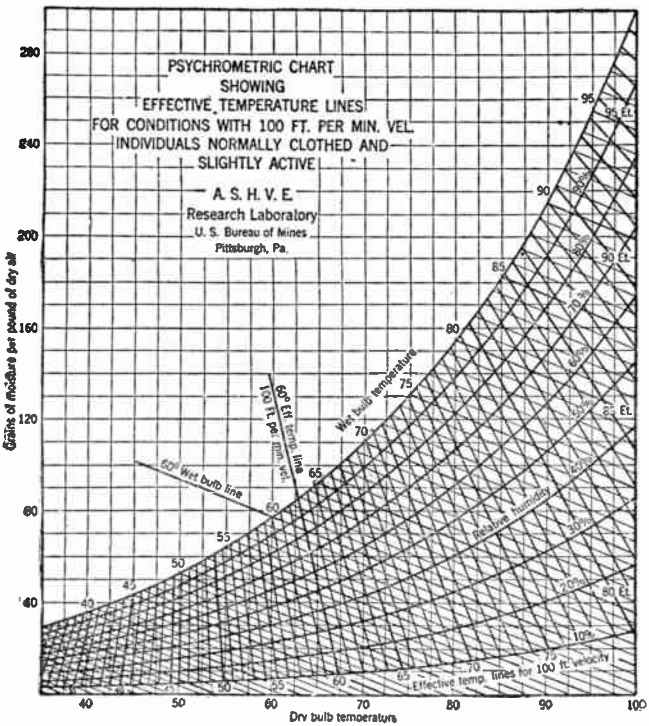


FIG. 8,773.—"Comfort Chart" for air velocity of 100 ft. per min.

tween the wet bulb lines, to curve A, the wet bulb temperature is indicated as 69.3°.

Example 3.—Given: Dry bulb temperature, 75°; dew point temperature, 55°. Find percentage relative humidity and wet bulb temperature.

Locate the point of intersection of the vertical line representing 75° dry bulb temperature with the horizontal dew point line intersecting curve A, at 55°. This point indicates the relative humidity as 50%, and by interpolation the wet bulb temperature as 62.6°.

Example 4.—Given: Relative humidity 50%; wet bulb temperature, 60°. Find dry bulb temperature and dew point.

Locate the point of intersection of the curved line representing 50% relative humidity with the oblique line representing 60° wet bulb temperature.

Reading vertically downward from this point to the dry bulb temperature scale, the dry bulb temperature is indicated as 71.8° and, reading horizontally to the left to curve A, the dew point is indicated as 52°.

Example 5.—Given: Wet bulb temperature, 55°; dew point, 50°. Find dry bulb temperature and relative humidity.

Locate the point of intersection of the oblique line representing 55° wet bulb temperature with the horizontal line representing the dew point of 50°.

Reading vertically downward from this point to the dry bulb temperature scale, the dry bulb temperature is indicated as 61.5°, and by interpolation, the relative humidity is indicated as 67%.

Example 6.—Given: Relative humidity, 40%; dew point, 40°. Find dry bulb temperature and wet bulb temperature.

Locate the point of intersection of the curved line representing 40% relative humidity with the horizontal line intersecting curve A at 40° dew point temperature.

Reading vertically downward from this point to the dry bulb temperature scale, the dry bulb temperature is indicated as 65°, and reading obliquely upward to the left, along the wet bulb lines, to curve A, the wet bulb temperature is indicated as 52°.

TEST QUESTIONS

1. *What is air conditioning?*
2. *Define humidity.*
3. *What is the difference between absolute and relative humidity?*

4. *Which kind of humidity is important?*
5. *Define the term dew point?*
6. *What happens if air be cooled below the saturation point?*
7. *Describe the wet and dry bulb hygrometer.*
8. *Describe the dew point.*
9. *What is the moistening effect of air?*
10. *How does the drying effect of air vary?*
11. *Describe the heating effect of air.*
12. *Name the four items of air conditioning.*
13. *Describe several methods of air conditioning.*
14. *What is a unit air conditioner?*
15. *What is a hygrostat?*
16. *Describe the construction of washer eliminator plates.*
17. *What is a de-humidifier?*
18. *What name is given to the addition of moisture to air?*
19. *Name an important item in air conditioning.*
20. *What is a sling psychrometer?*
21. *State precautions in using the sling psychrometer.*
22. *How is a psychrometric chart used?*
23. *Give examples showing methods of using the psychrometric chart.*

CHAPTER 59

Air Compressors

Compressed air is *air forced into a smaller space than it originally occupied*, thus increasing its pressure.

The power available from compressed air is used in many applications as a substitute for steam or other force as in operating rock drills, shop tools and engines.

A compressor is *a machine (driven by any prime mover) which compresses air into a receiver to be used at a greater or less distance.* The system is not subject to the loss by condensation in the pipes, as is the case of carrying steam in pipes long distances.

Air stored under pressure in a reservoir can be used expansively, in an ordinary steam engine returning an equivalent amount of work that was required to compress it, less the friction.

The Compression of Air.—When the space occupied by a given volume of air is changed, both its pressure and temperature are changed in accordance with the following laws:

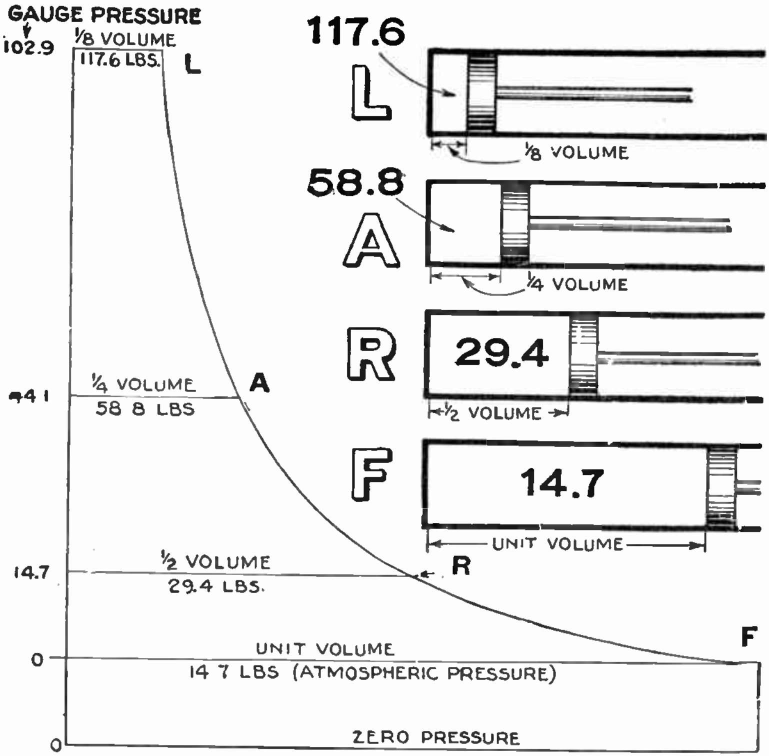
Boyle's law: *At constant temperature, the* **absolute** *pressure of a gas varies* **inversely** *as its volume.*

Charles' law: *At constant pressure, the volume of a gas is proportional to its* **absolute** *temperature.*

In the ordinary process of air compression, therefore, two elements are at work toward the production of a higher pressure:

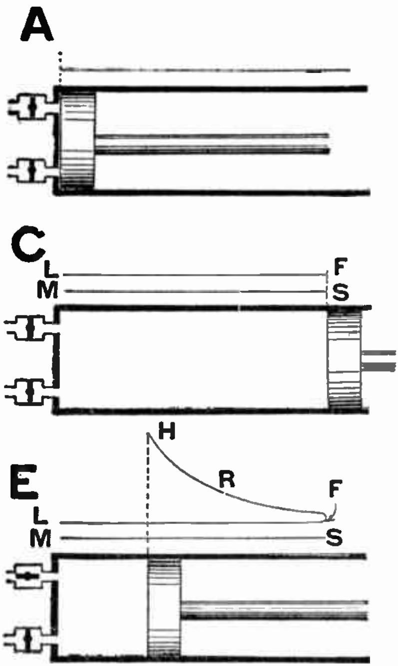
1. The reduction of volume by the advancing piston;

2. The increasing temperature due to the increasing pressure corresponding to the reduced volume.



FIGS 8,927 to 8,931.—Diagram and compression stroke progressively shown illustrating *Boyle's law*. As the piston travels from position F, to R, A, L, the pressures are 14.7, 29.4, 58.8, 117.6 lbs absolute, respectively, being *inversely proportional to the volume*. The points F, R, A, L, on the compression curve correspond to the piston positions F, R, A, L as shown.

The application of the two laws is illustrated in fig. 8,938, which shows a cylinder fitted with an air tight piston. If the cylinder be filled with air at atmospheric pressure (14.7 lbs



FIGS. 8,932 to 8,937.—Compression cycle illustrated by indicator diagrams and elementary compressor. A, beginning of intake stroke; B, intermediate position of intake stroke; C, end of intake stroke, note atmospheric intake line LF, and vacuum line MS; D, intermediate position R, of compression stroke; E, point of maximum compression, note compression curve FRH; F, end of cycle, note horizontal discharge line HD, indicating discharge into receiver at constant pressure.

per sq. in. **absolute**) represented by volume A and the piston. be moved to reduce the volume, say to ⅓ A, as represented by B, then according to Boyle's law the pressure will be trebled or $=14.7\times3=44.1$ lbs. absolute, or $44.1-14.7=29.4$ **gauge** pressure. **In reality,** *however, a pressure gauge on the cylinder would at this time show a higher pressure than* 14.7 **gauge** *pressure because of the* **increase in temperature** *produced in compressing the air.*

Now, in the actual work of compressing air, it should be carefully noted that *the extra work which must be expended to overcome the excess pressure due to rise of temperature* **is lost,** *because after the compressed air leaves the cylinder* **it cools,** *and the* **pressure drops** *to what it would have been if compressed at constant temperature.*

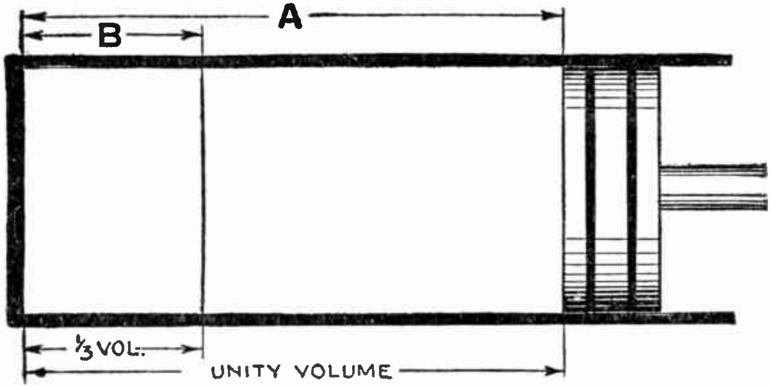


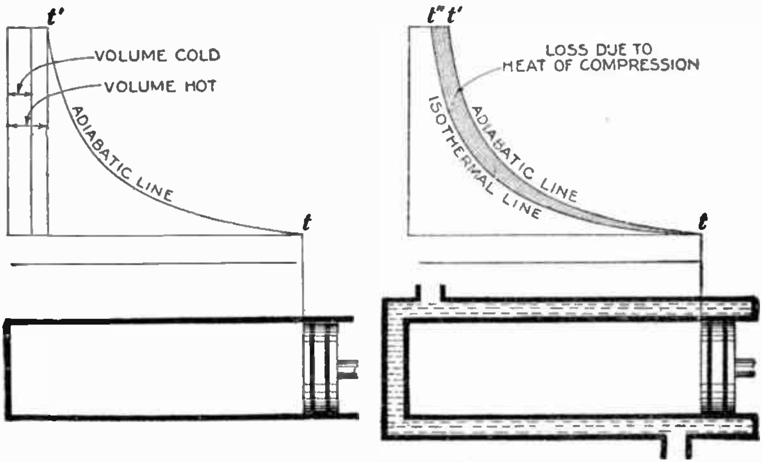
FIG. 8,938.—Elementary air compressor illustrating the phenomena of compression as stated in Boyle's and Charles' laws and explained in the accompanying text.

Accordingly, in the construction of air compressors, where working efficiency is considered, some means of cooling the cylinder is provided, such as projecting fins, or jackets for the circulation of cooling water.

NOTE.—*In air compressor problems* careful distinction should be made between *gauge pressure* and *absolute pressure,* the former being the pressure as indicated by a pressure gauge, as distinguished from absolute pressure which is the gauge pressure plus 14.73 lbs., the weight of the atmosphere at sea level, when the barometer reads 30 ins. or, for ordinary calculations, 14.7 lbs.

Free Air.—By definition free air is *air at ordinary atmospheric pressure and temperature.*

Heat of Air Compression.—This subject has probably received more consideration in air compressor design than any other. The principal losses in the earlier compressors were traceable to this source. Figs. 8,939 to 8,942 show why the heat of compression results in a loss.



FIGS. 8,939 to 8,942.—Diagrams and elementary compressors illustrating loss due to heat of compression. If no means be provided to carry off this heat, compression will be *adiabatic* as indicated by the curve *tt'* fig. 8,939. Assuming all the heat to be carried off by the water jacket (fig. 8,942) compression will be *isothermal* as indicated by the curve *tt''* fig. 8,940. Here both curves are shown, the shaded area representing loss. Hence in compressor construction provision is made to carry off as much of the heat of compression as possible.

It should be noted that the heat of compression, as already explained, represents work done upon the air for which there is usually no equivalent obtained, since the heat is all lost by radiation, before the air is used.

The selection of an air cylinder lubricant is, of course, governed to a considerable extent by a knowledge of the cylinder temperature it must withstand.

Knowing the air pressures, the corresponding temperatures are ascertained fairly accurately, as shown in the following table.

Cylinder Temperatures at End of Compression

Air Compressed to Lbs. Gauge	Final Temperature Single Stage Deg. F.	Final Temperature Two Stage Deg. F.
10	145	---
20	207	---
30	255	---
40	302	---
50	339	188
60	375	203
70	405	214
80	432	224
90	459	234
100	485	243
110	507	250
120	529	257
130	550	265
140	570	272
150	589	279
200	672	309
250	749	331

This table gives the final temperature in the cylinder at the end of the compression stroke, for single stage, also for two stage (or compound) compression, when the free air entering the cylinder is 60° Fahr.

Variations from these temperatures will occur in actual practice due to water jacketed air cylinders and radiation, tending to lower the temperature at the higher pressures. However, at say, 50 lbs. pressure and lower, the heat is likely to be somewhat greater than given by the table, particularly if the compressor be run at high speed and also if it be not water jacketed.

Methods of Abstracting the Heat of Compression.—Since the heat of compression results in a loss, various methods have been devised to carry off this heat so that the temperature of the air during compression will remain as near constant as possible.

The two important methods are known as:

1. Wet compression;
2. Dry compression.

In the earlier compressors, compression was accomplished in one stage or single cylinder machines, and the heat of compression was removed by

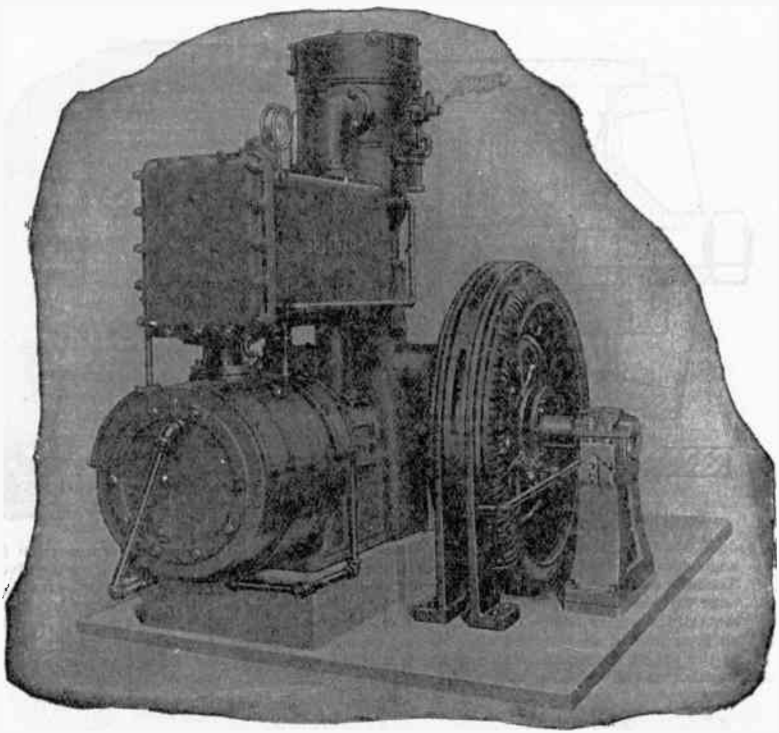
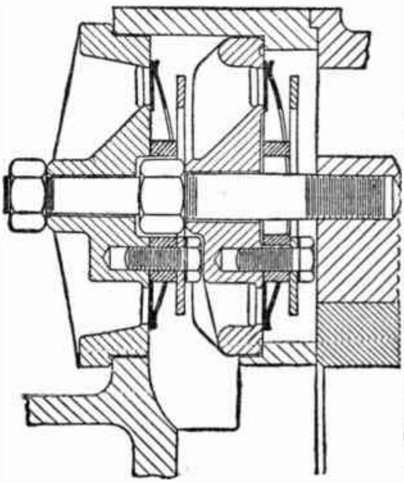


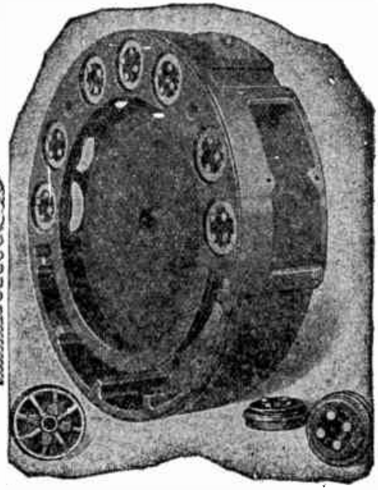
FIG. 8,943.—Sullivan angle-compound compressor direct connected to electric motor. Recent improvements in synchronous motors have made it possible to employ a simple and compact design of direct connected motor drive on angle-compound compressors. The rotor is mounted directly on the crank shaft close to the compressor frame, allowing sufficient room for getting at the bearing boxes.

injecting water into the cylinder in the form of a spray; or, in another type, the water was used as a piston for compressing.

The spray injection cylinder has now given way almost entirely in this country to the dry or jacketed cylinder.

The advantage of spray injection is higher thermal efficiency but from a commercial point of view its efficiency is not so high as with dry compression, for the water in the cylinder prevents proper lubrication, and the impurities therein attack the cylinder walls.

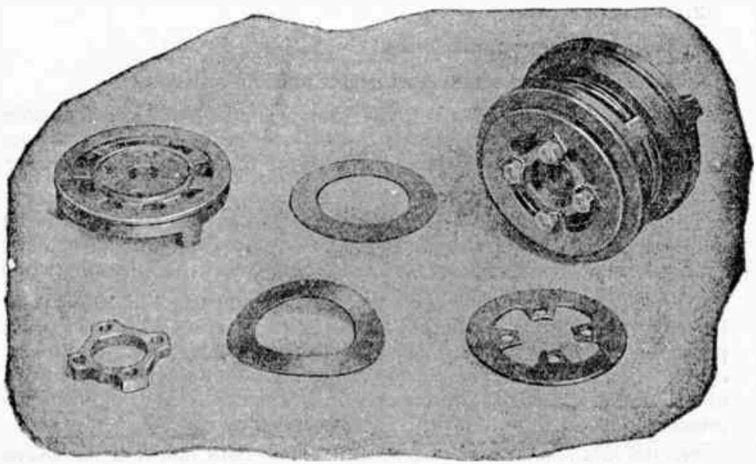




FIGS. 8,944 and 8,945.—Sullivan "wafer" valves. Fig. 8,944 valves and port arrangement for angle-compound compressors; fig. 8,945, cylinder head showing arrangement of *wafer* valves. The inlet and discharge valves are seated in pairs in tandem, one pair in each port, providing large valve area and small clearance space. *They consist of* thin flat rings resting on ground seats of the same shape. These valves are fully automatic. They are held to their seats by air pressure and are returned after opening by annular springs of the same size and material as the valves themselves. One spring is used on each inlet valve and two springs nested together on the discharge valves.

In dry compression a jacketed cylinder is provided and cold water circulated through the jacket which keeps the cylinder walls sufficiently cool so that proper lubrication is not interfered with and all other disadvantages of the wet compressor are obviated.

Single Stage and Two Stage Compressors.—In a single stage compressor the air is compressed to the desired pressure in one operation; or, in other words, the air is taken into the air cylinder at zero gauge pressure (that is, atmospheric pressure or 14.7 lbs. per sq. in.) and compressed with one stroke of the piston to the desired pressure. It is then discharged directly into the air receiver.



Figs. 8,946 to 8,951.—Sullivan *wafer* air valves and parts. When placing these valves in the heads, be sure that the inlet valves come up to the seats; to do this make sure that the cap bolt heads on the inlet valve guards clear the ribs on the discharge valve seats; by turning the valve slightly this position can easily be found.

In a two stage compressor the desired pressure is reached in two operations, and two separate cylinders are required. The air is taken into the low pressure (large) cylinder and compressed to an intermediate pressure, whence it is passed through an intercooler to the high pressure (small) cylinder, in which the compression to the desired pressure is completed.

The principal advantage of compound compression over simple compression is the reduction of the loss due to the heat of compression.

This is due to the fact that more time is taken to compress a certain volume of air, and that this air while being compressed is brought into contact with a larger percentage of jacketed surfaces.

Other important advantages due to compounding may be enumerated as follows:

1. Cooler intake air;
2. Better lubrication;
3. Reduction of clearance losses;
4. Lower maximum strains and nearer uniform resistance.

The temperature of air leaving the intake cylinder being low, the cooling influence of the jacket is better, the cylinder walls are cooler between strokes, and the air enters the cylinder cooler than in a single stage compressor.

The lubricant for cylinders and valves is not subject to the pernicious influence of high temperatures; and the clearance losses, or losses due to dead spaces, are less in a compound compressor than in a simple compressor.

Clearance loss in an air compressor is principally a loss in capacity, and therefore affects only the intake cylinder; it increases with the terminal pressure, but since the terminal pressure of the intake or low pressure cylinder of a compound compressor is much less than the terminal pressure of a simple compressor, the volumetric efficiency of the compound compressor is greater than that of the simple compressor.

The life of a compound compressor is longer than that of a simple compressor for like duty, due to better distribution of pressures.

More heat is generated in compressing to a high pressure than a low pressure. Up to a pressure of about 60 lbs. per sq. in. it is not practical to remove this heat, and single stage compressors should be used. Above 60 lbs. a two stage compressor will not only deliver more air than a single stage compressor of equal size, but will consume less power.

NOTE.—*Air cooling.*—Hot air in the cylinder of an air compressor means a reduction in the efficiency of the machine. The trouble is that there is not sufficient time during the stroke to cool thoroughly by any available means. Water jacketing is the generally accepted practice, but it does not by any means effect thorough cooling. The air in the cylinder is so large in volume that but a fraction of its surface is brought in contact with the jacketed parts. Air is a bad conductor of heat and takes time to change its temperature. The piston while pushing the air toward the head, rapidly drives it away from the jacketed surfaces so that little or no cooling takes place.

Inter-coolers.—By definition an inter-cooler is *a species of surface condenser placed between the two stages of a compound air compressor* so that the heat of compression liberated in the first cylinder may be removed from the air as it passes to the second or high pressure compression cylinder.

The cooling surface usually consists of nests of small brass or copper tubes through which water circulates.

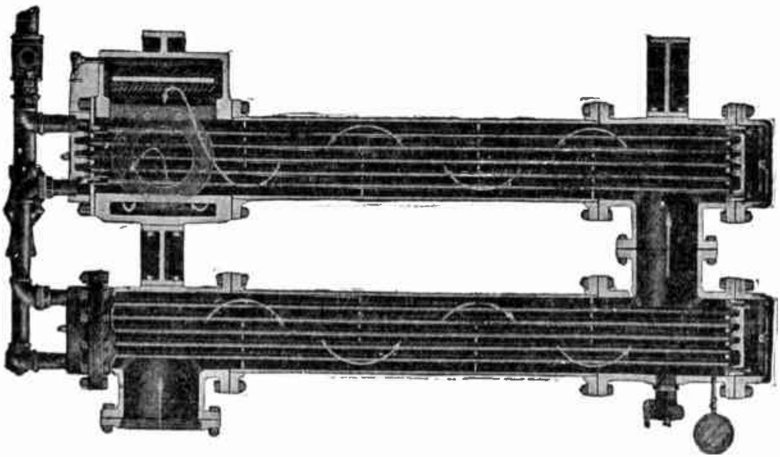


FIG. 8,952.—Ingersoll-Rand horizontal after cooler. The arrows show the course of the air or gas. The moisture separator is in the base below the right hand end of the lower tube nest.

After-coolers.—Moisture in compressed air or gas is costly and annoying. Carried into the lines in the form of vapor, it condenses when cooled and has many harmful effects. In compressed air, it washes away lubricant from the tools and machines through which it passes. It freezes in valves, ports and other openings because of the sudden expansion of the air. It hastens corrosion of all metal that it reaches and hastens the decay of rubber hose.

In the case of compressed gas for distribution, it is one of the leading causes of line and meter troubles.

Removal of moisture before the air or gas is introduced into the lines is the best method of procedure. This can be done effectually by an after-cooler which cools the air (or gas) to a point where most of the moisture and oil condense and can be removed.

This is accomplished by bringing the air (or gas) into contact with pipes through which cooling water is constantly circulated. This not only eliminates the difficulties which moisture causes at points where the air is used, but also insures more effective distribution.

The air leaves the after-cooler at a uniform and relatively low temperature, thus obviating the alternate lengthening and contraction of lines previously referred to.

With efficient after-coolers, sufficient moisture is removed to satisfy most applications of air, and no further care need be exercised.

Where the air is used for such purposes as paint spraying, enameling, food preparation, and the like, further drying of the air can be effected by passing it through special separators immediately before it is used. These remove the moisture which may condense due to further cooling of the air in pipe lines following the cooler.

Piston Displacement.—The displacement of a compressor is *the volume displaced or swept through by the piston during the compression stroke.* It is not a measure of the amount of air which the compressor will actually deliver.

Actual Air Delivered.—The amount of air actually delivered by the compressor is *always less than the piston displacement* and is the *amount of air available for useful work.* It is expressed in cu. ft. per minute of free air.

Volumetric Efficiency.—By definition, volumetric efficiency is the *ratio of the actual air delivered to the piston displacement.*

For instance, if a compressor have a displacement of 20 cu. ft. per minute and the actual air delivered be 16 cu. ft. per minute, its volumetric efficiency is $\frac{16}{20} = 80\%$.

Pressure Regulators.—Because of varying and intermittent demands for compressed air, some form of pressure regulator is necessary to maintain a constant pressure in the receiver.

Various methods are employed depending on the type of compressor, drive, and other conditions.

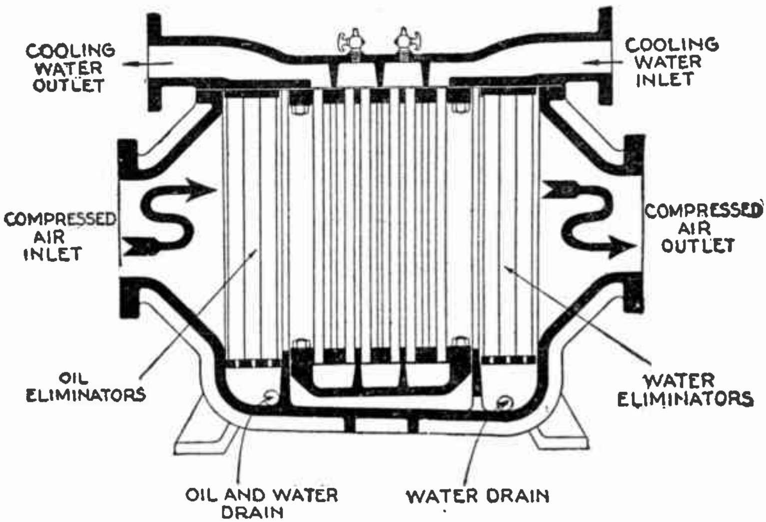
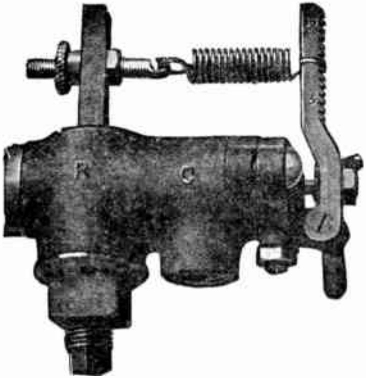
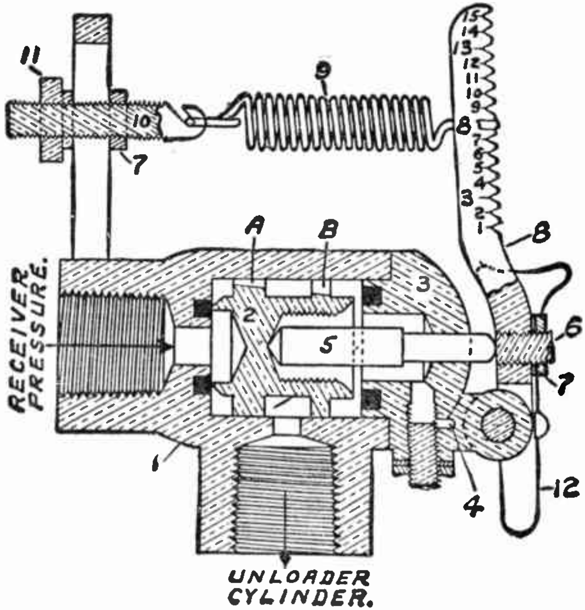


FIG. 8,953—Sullivan air or gas after cooler.

In the case of power driven machines which run at constant speed some form of "unloader" is employed which closes the inlet pipe or connects the two ends of the cylinder when the receiver pressure reaches the maximum point desired.

Duplex steam driven machines, which have a wider range of speed, may often obtain sufficient air regulation by simply varying the speed by means of a throttling or automatic governor attached to the engine.

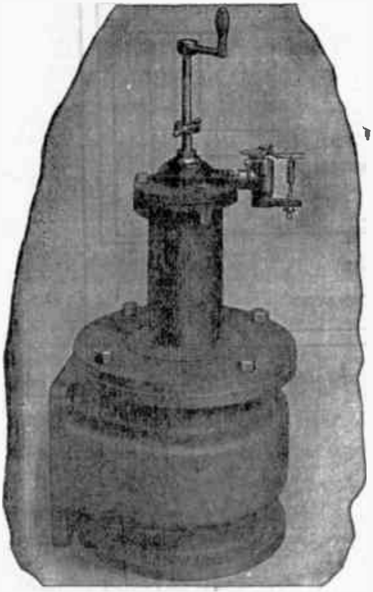




FIGS. 8,954 and 8,955.—Sullivan type R. C. pilot valve. *The parts are:* 1, body; 2, piston; 3, cap; 4, vent adjusting screw 5, stem; 6, adjusting screw; 7, lock nut; 8, lever with hand unloader; 9, spring; 10, spring hook; 11, adjusting nut. *In operation,* the pilot valve delivers receiver pressure to the unloading device at predetermined maximum receiver pressure to unload compressor and at predetermined minimum receiver pressure it shuts off receiver pressure and exhausts all pressure in unloader device to load compressor. The cycle is repeated as receiver pressure rises and falls.

When the conditions are more exacting, as in mining operations, a combined speed governor and unloader is used.

Among other methods of regulation may be mentioned the shifting of the driving belt in the case of small power machines; the starting and stopping of the motor of electrically driven compressors used in connection with air brake systems; and the varying of the clearance on the compressor as the load changes. All of these devices operate automatically through changes in the receiver pressure.



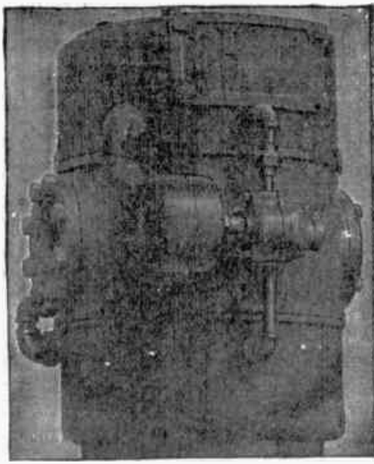


FIG. 8,956.—Sullivan unloading device with pilot valve for air intake conduit. *It consists of* a double beat valve, placed on the air inlet duct, and controlled by a pilot valve. The valve is set to shut off all the incoming air from the compressor when the receiver pressure rises above a predetermined point; that is, when the demand for air drops away. The compressor then runs under no load except that due to friction, compressing no air, and reducing the consumption of power to a very low factor. When the demand for air begins once more, that is, when the pressure in the receiver falls below the point at which the unloading device is set to act, the valve again opens fully, and the compressor automatically resumes its entire load until the demand for air again ceases, when the cycle of operation, just described, is repeated. The pilot valve may be adjusted to maintain any desired pressure in the air receiver.

FIG. 8,957.—Sullivan auxiliary control valve. This works independently of but co-ordinating with the unloader. *In operation* when the low pressure unloading valve has been on a few revolutions, and the high pressure cylinder has pumped out the inter-cooler, the auxiliary control valve on the high pressure cylinder provides that any air which may have leaked into the machine is exhausted. All chances of building up excessive heat and pressure in a closed circuit in and on crosshead pins, crank pins, guides, etc., are eliminated.

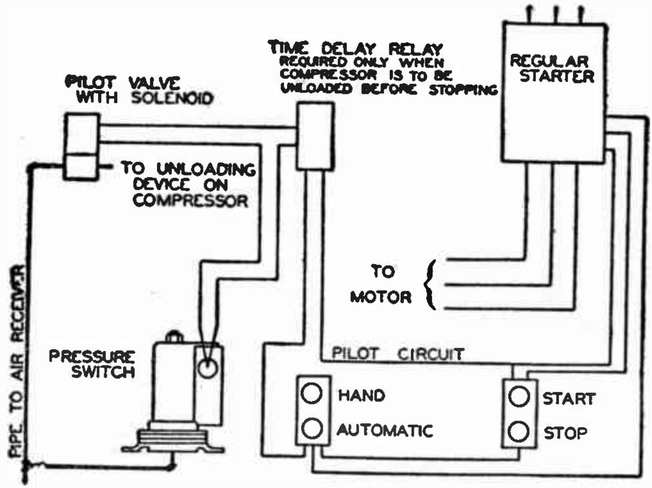


FIG. 8,958.—Sullivan diagram for automatic start and stop control of direct connected synchronous motors, when time delay relay *is used*.

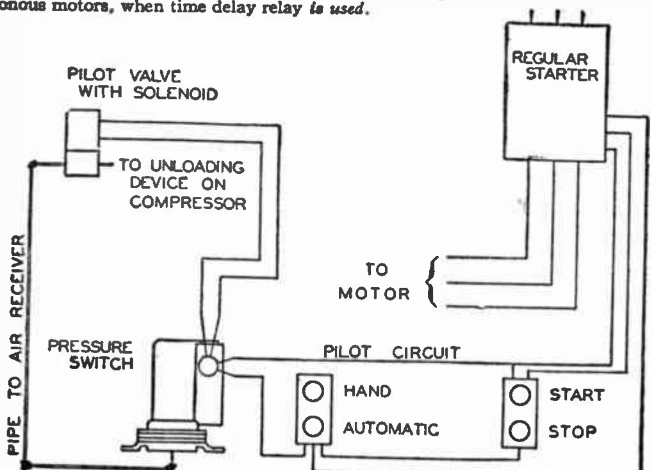


FIG. 8,959.—Sullivan diagram for automatic start and stop control of direct connected synchronous motors, when time delay relay is *not used*.

Prevailing types are shown in the accompanying illustrations.

Automatic Start and Stop Control.—As an example of this method with direct connected synchronous motor drive, two diagrams are shown, figs. 8,958 and 8,959.

In the diagram 8,959, the control consists of the regular automatic starter operated by a start and stop push button.

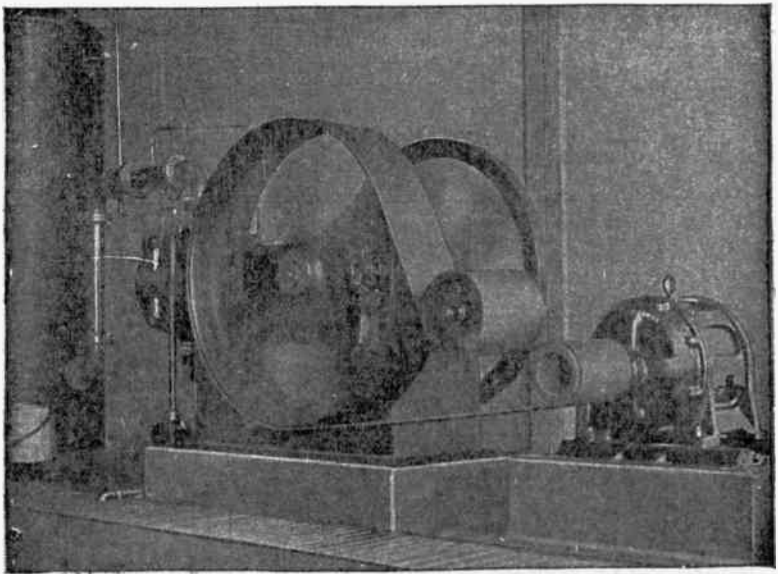


FIG. 8,960.—Sullivan close connected belt driven air compressor showing idler pulley and air filter on air inlet.

The automatic starter is an essential part of the equipment and must be substituted for the manually operated starter regularly used with slip ring induction, squirrel cage or *d.c.* motors. To this is connected, as indicated in the diagram, an electric pressure switch, a definite time delay relay and another push button, which cuts in and out at will the automatic start and stop operation. Two types of pressure switches are available.

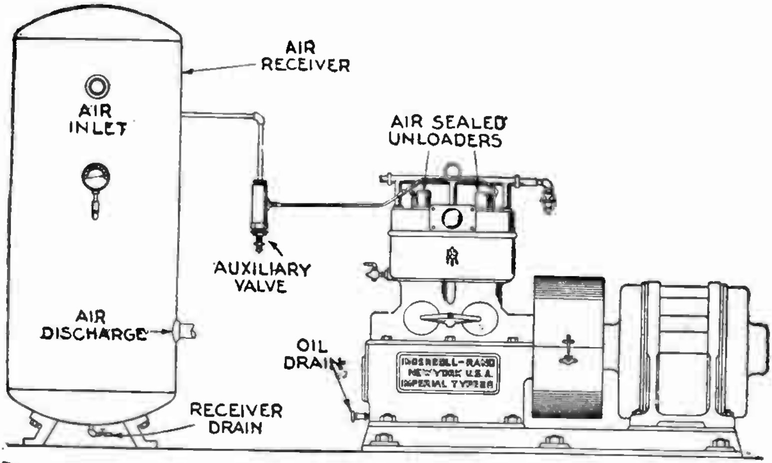


FIG. 8,961.—Piping diagram for Ingersoll-Rand stationary direct connected electric motor driven air compressor *arranged for constant speed operation.*

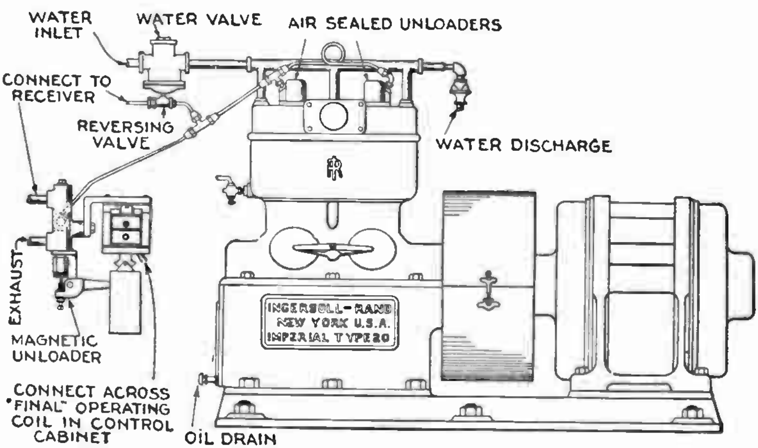


FIG. 8,962.—Piping diagram for Ingersoll-Rand stationary direct connected electric motor driven compressor arranged for *automatic start and stop control.*

The diaphragm type is operated by a diaphragm and has a differential in pressure between stopping and starting.

The gauge type is operated by a Bourdon tube and has a small differential pressure. They are interchangeable.

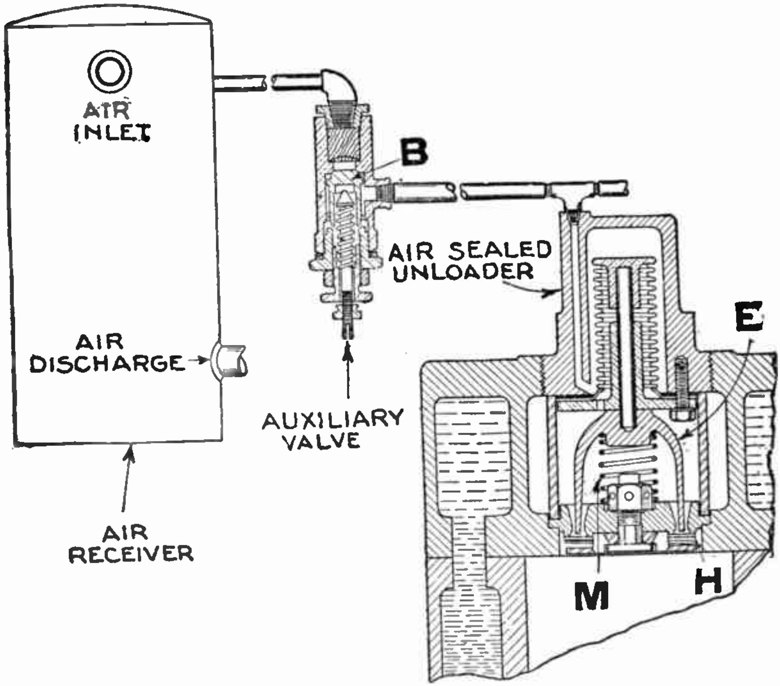


FIG. 8,963.—Ingersoll-Rand unloader for stationary direct connected electric motor driven compressor arranged for constant speed operation. See fig. 8,964 for operation.

The definite time relay provides a means for unloading the compressor before stopping or starting and is to be recommended in most cases. It is required with all short belt idler drives with multi-step control.

When the definite time relay is omitted, the wiring is as in fig. 8,959. This equipment controls the pilot valve with solenoid.

The equipment will run by hand or automatic control, depending on the position of the maintaining contact push button station used as change over switch.

When operating on hand control, that is, with the button marked *hand*, on the maintaining contact switch depressed, the motor is controlled by the regular start-stop push button. In this condition, the compressor will load and unload as governed by the setting of the unloader.

When starting, the compressor will load after the motor is up to speed and will unload simultaneously with the power being thrown off the motor when the *stop* button is depressed.

When the automatic button of the maintaining contact push button station is depressed, the regular start-stop push button station mentioned

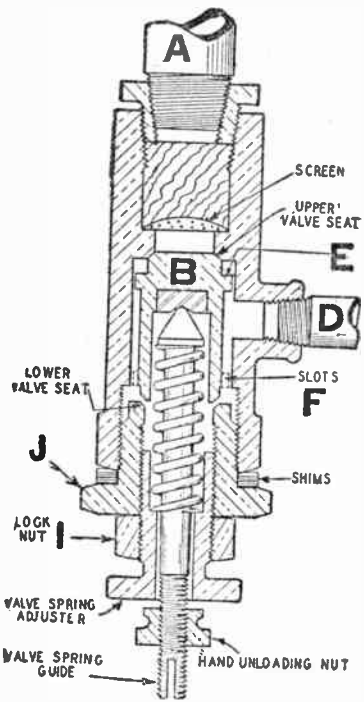


FIG. 8,964.—Enlarged view of auxiliary valve shown in fig. 8,963. ***Constant speed control:*** With the compressor operating under normal conditions, it builds up pressure in the air receiver until maximum desired pressure is reached. The auxiliary valve B, drops to the lower seat, opening up the passage and admitting receiver pressure to the air-sealed unloader. Receiver pressure applied to the unloader overcomes the resistance of spring M, and forces the plunger E, down, holding open the inlet valve H. Thus the compressor is unloaded, since no air can be compressed and discharged to the receiver. When the pressure in the air receiver has fallen approximately 10 lbs. the auxiliary valve B, is forced to its upper seat by the spring, closing the air passage between the receiver and unloader. This releases the pressure over the unloader bellows to atmosphere. The spring M, in the unloader now raises the plunger E, and the inlet valve is free to open and close. Thus the compressor is loaded and air is again compressed and discharged to the receiver. The normal operating pressure between unloading and reloading points is usually 90 to 100 lbs. giving a range of 10 lbs. This can be varied slightly by adjusting the auxiliary valve. ***Operation of auxiliary valve:*** Air enters the auxiliary valve from the receiver through piping A, passing through a strainer and screen. When the air pressure reaches say 100 lbs. this pressure acting downward on the valve B, overcomes the upward push of the spring, and the valve B, starts downward. In this position the additional surface at E, is momentarily exposed to receiver pressure, quickly forcing before, is removed from the control circuit and the pressure governor substituted. The equipment will then start and stop automatically, governed by the setting of the pressure governor.

A similar sequence of starting and stopping is obtained by the pressure governor control in that the compressor will load after the motor is up to speed and unload when power is cut off from the motor.

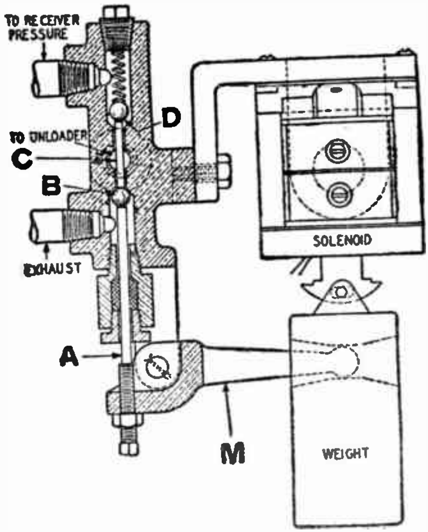


FIG. 8,965.—Magnetic unloader for Ingersoll-Rand stationary direct connected electric motor driven compressor arranged for *start and stop control*. The unloader is wired in parallel with the last step of the controller so as to load the compressor only after motor has attained full speed and full voltage conditions. When the last contact on the controller is made, electric current energizes the solenoid, which raises the weight suspended beneath it. Acting through the lever M, this drops the pin A, and unseats the ball valve B. There is a pin C, between the upper and lower ball valves of such length that when one ball is unseated the other is permitted to seat. *In shutting down*, the solenoid is de-energized and the weight

FIG. 8,964.—*Text continued.*
valve B, to the lower valve seat. Receiver pressure against the larger area now exerts a total force which more than makes up for the additional force exerted by the spring through being compressed. With the valve D, on the lower seat, pressure from the receiver passes freely out piping D, to the unloaders. When the receiver pressure has dropped about 10 lbs. then the force that the air is exerting downward on the valve is less than the spring is exerting upward and the valve returns to the upper seat. With the valve in the upper position there is an open passage from the unloaders to atmosphere. This passage is through piping D, past the slots F, and down the valve spring guide. With the escape of air from the unloaders to atmosphere, the compressor resumes its load.

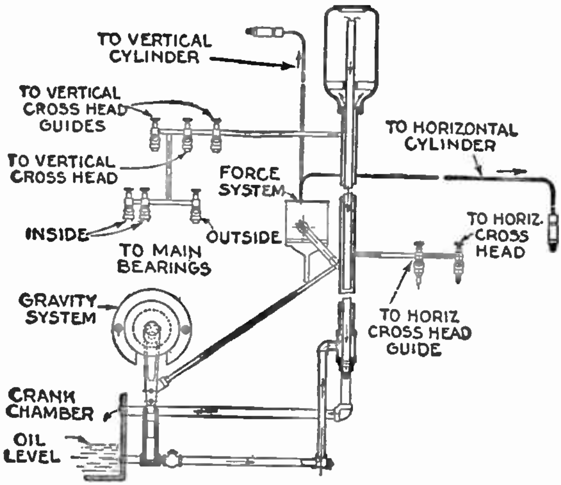


FIG. 8,966.—Sullivan oiling system for angle compound compressor. ***In operation*** the oil pump forces the oil from the crank chamber up the standpipe, into the reservoir. From the standpipe the oil is distributed through branch pipes to the various bearings to be oiled. Adjustable sight feeds are attached at each of these points in order that the flowing stream of oil may be watched and adjusted at all times. The surplus oil is returned to the crank chamber through the overflow pipe. When the compressor stops, the oil contained in the standpipe and reservoir is prevented draining back into the crank chamber by suitable check valves, thus insuring an immediate flow of oil to the bearings when the compressor is again started.

FIG. 8,965.—*Text continued.*

drops down. This moves the pin **A**, up, holding the ball valve **B**, tight against its seat. This forces the pin **C**, up, unseating the upper ball **D**, Unseating the ball **D**. opens the passage so that the receiver pressure is admitted to the unloaders. When ball **D**, is seated this passage is closed off and ball **B**, is unseated, opening a passage from the unloaders to atmosphere. When the receiver pressure rises above that for which the pressure switch is set, the switch cuts out and the motor and compressor stop. At the time the solenoid is de-energized, the weight drops and lever **M**, pushes up on pin **A**, until the ball valve **B**, is seated. Discharge pressure is now admitted past ball **D**; going to the unloaders and acting through the bellows, it holds the inlet valves open. Thus the compressor stops in an unloaded condition. When the receiver pressure drops below that for which the pressure switch is set, the switch cuts in and the motor and compressor are started up. When the last contactor in the controller is reached the solenoid is energized, lifting up the weight and moving lever **M**, so that the pin **A**, drops down and the ball valve **B**, is unseated. Until this time the compressor has been starting up *unloaded;* that is, with the inlet valves held open. With the lower ball unseated and the upper one seated, receiver pressure is cut off and the air in the unloaders exhausts to atmosphere through the unloader, permitting the inlet valves to operate and the compressor to discharge air. Pressure in the receiver now builds up until the pressure switch cuts out again, thus completing the cycle. By hooking the solenoid in with the last step in the controller, the compressor starts up unloaded, and remains unloaded until the motor has attained full speed.

Three Stage Air Compressors.—These are used *for extra high pressure air*. Taking the Ingersoll-Rand three stage compressor as an example, the low pressure air cylinder of three stage compressors is double acting, while the intermediate and

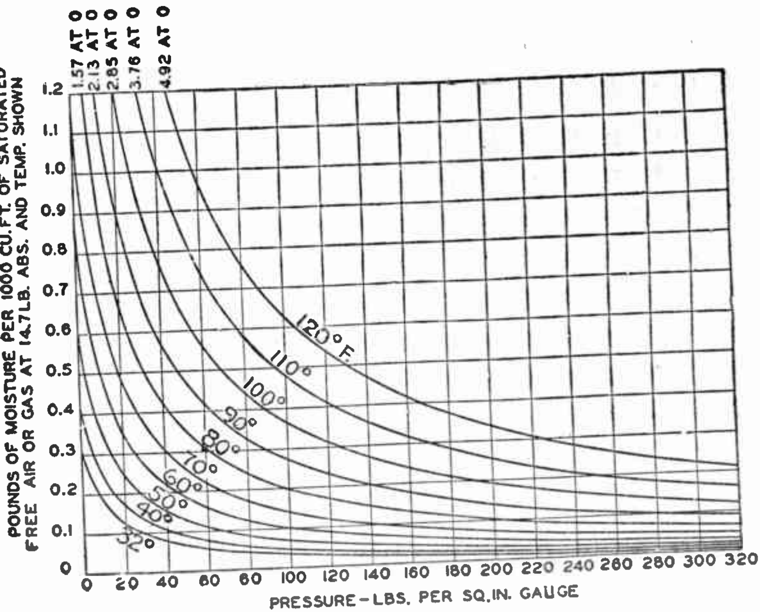


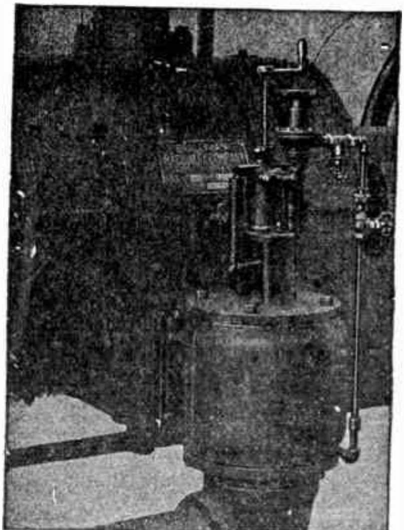
Fig. 8,967.—Curves showing moisture remaining in saturated air or gas when compressed to any pressure and cooled to temperature shown. *Example:* Saturated air at 80° at compressor intake (0 lb.) contains 1.57 lbs. of moisture per 1,000 cu. ft. Compressed to 100 lbs. and cooled to 80° with 65° water the air contains only .20 lb. per 1,000 cu. ft. or 13% of the moisture originally taken into the compressor. The rest has been condensed in the intercooler (if used) and the after cooler.

high pressure air cylinders are single acting. The low pressure cylinder is supported by a foot piece. Inlet valves are of the direct lift, poppet type, and discharge valves are of the cushioned direct lift poppet type.

All three air cylinders, as well as the steam cylinder of steam driven units, are oiled by means of a force feed lubricator having separate feeds to each cylinder.

The standard construction on three stage compressors, both belt and steam driven, also includes a cast iron box type sub-base, which extends under the entire machine.

An inter-cooler is located above and between the low pressure and intermediate air cylinders, while a second inter-cooler of coil construction is



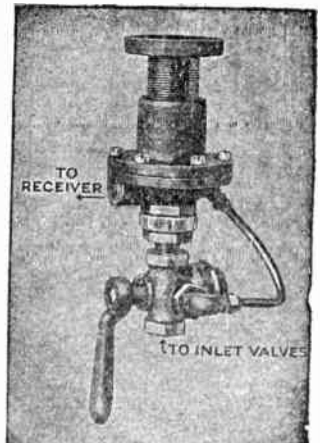


FIG. 8,968.—Sullivan unloading device with pilot valve on air intake conduit.

FIG. 8,969.—Detail of Sullivan pilot valve and piping, handle (down) in loading position (horizontal for starting).

located in the sub-base between the intermediate and high pressure air cylinders. Separators remove the condensed moisture from the air before it enters the second stage of compression.

Control Methods.—Since the power driven compressor is almost always a constant speed machine various methods of regulation are employed. Constant speed means constant piston displacement; the problem of delivering a variable volume of air with constant piston displacement, becomes one of making a portion of that displacement non-effective in the compression and delivery of air.

The following methods should be noted:

First method.—This is really one of unloading, rather than of regulating. *A pressure controlled mechanism is arranged so that when pressure exceeds normal, a communication is opened between the two sides of the compressor piston.* Usually this is accomplished by opening and holding open one or several of the discharge valves at both ends of the cylinder, the air is then simply swept back and forth from one side of the piston to the other through the open valves and the air discharge passage.

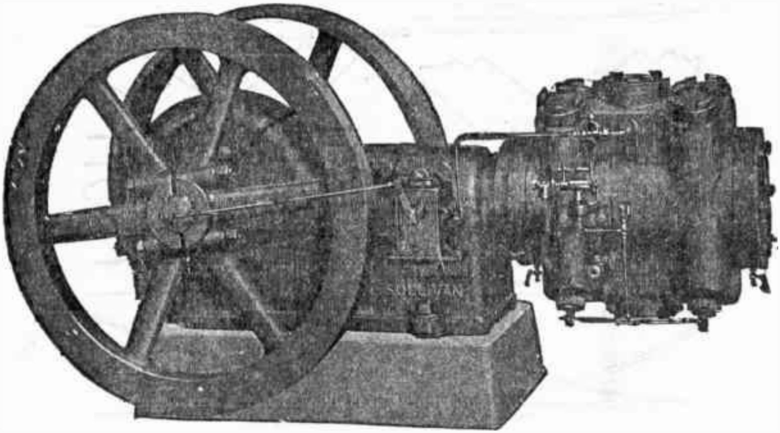
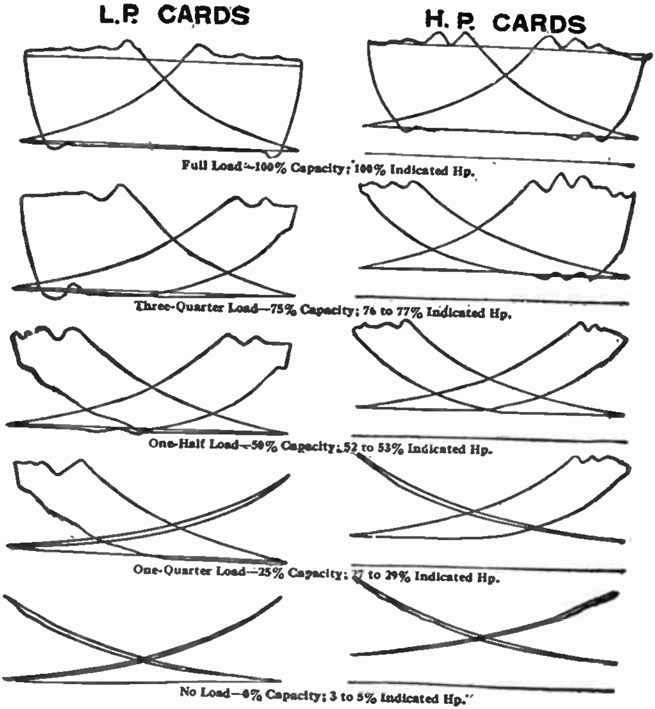


FIG. 8,970.—Sullivan straight line center crank, single stage belt driven compressor.

When normal pressure is restored, the valves are automatically closed, and compression and delivery are resumed. Evidently this is practically a total unloading of the machine for a longer or shorter period—a sudden release from load and a sudden resumption of load. Moreover, the air which is swept back and forth by the piston in its travel is air under full pressure; so that when the discharge valves suddenly close, the piston at once encounters a full cylinder of air at maximum pressure. These facts limit regulators of this class to machines of comparatively small capacity.



FIGS. 8,971 to 8,980.—Indicator cards showing operation of clearance control at five load points.

NOTE.—*Clearance control regulation for Ingersoll-Rand compressors.* This control automatically regulates the capacity of the compressor in five equal steps; namely, full, ¾, ½, ¼ and no load, keeping the power input approximately in proportion to the amount of air delivered at the compressor discharge. It further maintains a nearly uniform crank effort, not only at full load, but at all partial loads, thus eliminating the necessity for extremely heavy fly wheels required by other types of part load regulation where the crank effort is not kept uniform. Each cylinder is equipped with four clearance pockets, two at each end. With a two stage machine the volume of the clearance pockets in the high pressure cylinder bears the same relation to the volume of the low pressure clearance pockets as the cylinder ratio. On the single stage machine with two cylinders, the clearance pockets in both cylinders have the same volume. Each of these pockets is equipped with a balanced clearance valve. The regulating device which is automatically controlled from receiver pressure is built with four pilot valves, which operate in succession to control the opening and closing of the clearance pocket valves in the proper sequence. If the compressor be running at full load and rated discharge pressure and the demand for air decreases, the receiver pressure will

Second method.—*By means of a pressure operated device, the partial or total closing of the compressor intake under reduced load is accomplished.* To avoid the dangers attendant upon such an operation acting suddenly, these devices are provided with some damping mechanism so that they are compelled to operate slowly, making the release or resumption of the load gradual.

Third method.—This is very similar to the first, ***except that here the inlet valves, instead of the discharge valves, are held open when the machine is unloaded***, the piston thus simply drawing in and forcing out air at atmospheric pressure. It is open to the same criticism (though in somewhat less degree) as the first method, namely, undue shock and strain on release and resumption of load.

Fourth method.—*A pressure controlled valve is here used on the compressor discharge of single stage machine, combining also the functions of a check valve to limit the escape of air from the receiver or air line.* Excessive pressure blows the discharge to atmosphere, instead of into the line. This arrangement is also used on two stage machines by placing it on the low pressure discharge to the inter-cooler. Then, when the governor valve is opened by excess pressure, the low pressure cylinder discharges to atmosphere, and the high pressure cylinder acts simply as a low pressure cylinder with intake at atmospheric pressure.

This device is more of a relief valve than an unloader, for the piston must continue to compress to a pressure which will open the discharge valves; this volume of compressed air is wasted.

Fifth method.—*Provides auxiliary clearance spaces, or pockets, at each end of the cylinder, which are successively "cut in" as load diminishes.* The excess air is simply compressed into these clearance spaces and expanded on the back stroke. The capacity of the cylinder is reduced without any appreciable waste of power; for the energy used in compressing the clearance air is given back by its expansion.

NOTE.—*Continued.*

tend to rise until, at a predetermined point the clearance regulator functions to open the first set of clearance pockets; that is, one clearance pocket in each cylinder. In this manner approximately 25% of the air being compressed will pass into the clearance pockets, cutting the capacity of the machine to 75% of its full capacity rating. On the return stroke, the air thus trapped in the clearance pockets expands again, giving up its power to the pistons. Similarly, if the demand for air continues to decrease, the second set of pockets open, cutting the capacity of the compressor to 50%, etc., until, with all the pockets open, the machine is completely unloaded and no air is delivered to the receiver.

NOTE.—***Three things are to be avoided*** in the successful unloader or regulator for power driven machines; first, a sudden release or resumption of load, throwing heavy strains on the machine; second, undue rarefication of the intake air, resulting in a wide range of cylinder pressures and temperatures; third, the blowing off of compressed air to the atmosphere with a waste of power

TEST QUESTIONS

1. *State Boyle's and Charles' Law.*
2. *What is the difference between absolute and gauge pressure?*
3. *What is free air?*
4. *What happens when air is compressed?*
5. *Describe two methods of removing the heat of compression.*
6. *What is the object of two stage compression?*
7. *Describe the construction of compressor valves.*
8. *What are the advantages due to compounding?*
9. *What is an inter-cooler?*
10. *What is the difference between an inter-cooler and an after-cooler?*
11. *What is the piston displacement of a compressor?*
12. *Define volumetric efficiency.*
13. *Describe the various methods employed for pressure regulation.*
14. *What is a pilot valve used for?*
15. *What is the function of a start and stop by pass?*
16. *Describe automatic stop and start control.*
17. *Describe the connections of an automatic starter.*
18. *Describe the method of constant speed control.*
19. *How does a magnetic unloader work?*
20. *What are three stage air compressors used for?*
21. *Describe the five control methods in general use.*
22. *Sketch indicator cards, illustrating clearance control.*
23. *Name three things to be avoided with unloaders.*

CHAPTER 60

Radio Principles Questions and Answers

What is meant by an "A" power supply?

Ans. A power supply device providing heating current for the cathode of a vacuum tube.

What is an alternating current?

Ans. A current, the direction of which reverses at regularly recurring intervals, the algebraic average value being zero.

What is meant by amplification factor?

Ans. A measure of the effectiveness of the grid voltage relative to that of the plate voltage in affecting the plate current.

Describe an amplifier.

Ans. A device for increasing the amplitude of electric current, voltage or power, through the control by the input power of a larger amount of power supplied by a local source to the output circuit.

What is an anode?

Ans. An electrode to which an electron stream flows.

What is an antenna?

Ans. A conductor or a system of conductors for radiating or receiving radio waves.

What is meant by the term atmospherics?

Ans. Strays produced by atmospheric conditions.

Describe what is meant by attenuation.

Ans. The reduction in power of a wave or a current with increasing distance from the source of transmission.

What is the approximate length of audio frequency waves?

Ans. A frequency corresponding to a normally audible sound wave. The upper limit ordinarily lies between 10,000 and 20,000 cycles per second.

What is an audio frequency transformer?

Ans. A transformer for use with audio frequency currents.

What is meant by autodyne reception?

Ans. A system of heterodyne reception through the use of a device which is both an oscillator and a detector.

Describe an automatic volume control device.

Ans. A self-acting device which maintains the output constant within relatively narrow limits while the input voltage varies over a wide range.

What is meant by a "B" power supply?

Ans. A power supply connected in the plate circuit of a vacuum tube.

Describe and give the function of a "Baffle."

Ans. A partition which may be used with an acoustic radiator to impede circulation between front and back.

Describe a band-pass filter.

Ans. A filter designed to pass currents of frequencies within a continuous band limited by an upper and a lower critical or cut-off frequency and substantially reduce the amplitude of currents of all frequencies outside of that band.

What is meant by the term "Beat"?

Ans. A complete cycle of pulsations in the phenomenon of beating.

What is meant by beat-frequency?

Ans. The number of beats per second. This frequency is equal to the difference between the frequencies of the combining waves.

What is meant by the term beating?

Ans. A phenomenon in which two or more periodic quantities of different frequencies react to produce a resultant having pulsations of amplitude.

What is meant by broadcasting?

Ans. Radio transmission intended for general reception.

Describe a by-pass condenser.

Ans. A condenser used to provide an alternating current path of comparatively low impedance around some circuit element.

What is meant by a "C" power supply?

Ans. A power supply device connected in the circuit between the cathode and grid of a vacuum tube so as to apply a grid bias.

What is meant by a capacity coupling?

Ans. The association of one circuit with another by means of capacity common or mutual to both.

Describe a carbon microphone.

Ans. A microphone which depends for its operation upon the variation in resistance of carbon contacts.

Describe the meaning of the term carrier.

Ans. A term broadly used to designate carrier wave, carrier current or carrier voltage.

What is meant by carrier frequency?

Ans. The frequency of a carrier wave.

What is meant by carrier-suppression?

Ans. That method of operation in which the carrier wave is not transmitted.

What is a carrier wave?

Ans. A wave which is modulated by a signal and which enables the signal to be transmitted through a specific physical system.

What is a cathode?

Ans. The electrode from which the electron stream flows.

Describe and give the function of a choke coil.

Ans. An inductor inserted in a circuit to offer relatively large impedance to alternating current.

Describe a condenser loud speaker.

Ans. A loud speaker in which the mechanical forces result from electrostatic reactions.

Describe a condenser microphone.

Ans. A microphone which depends for its operation upon variations in capacitance.

What is meant by continuous waves?

Ans. Continuous waves are waves in which successive cycles are identical under steady state conditions.

Define the meaning of Conversion transconductance.

Ans. The ratio of the magnitude of a single beat-frequency component (f_1+f_2) or (f_1-f_2) of the output current to the magnitude of the input voltage of frequency f_1 under the conditions that all direct voltages and the magnitude of the second input alternating voltage f_2 must remain constant. As most precisely used, it refers to an infinitesimal magnitude of the voltage of frequency f_1.

Describe a converter generally as applied to super-heterodyne receivers.

Ans. A converter is a vacuum tube which performs simultaneously the functions of oscillation and mixing (first detection) in a radio receiver.

What is meant by coupling?

Ans. The association of two circuits in such a way that energy may be transferred from one to the other.

What is meant by cross modulation?

Ans. A type of intermodulation due to modulation of the carrier of the desired signal in a radio apparatus by an undesired signal.

What is meant by current amplification?

Ans. The ratio of the alternating current produced in the output circuit of an amplifier to the alternating current supplied to the input circuit for specific circuit conditions.

What is a cycle?

Ans. One complete set of the recurrent values of periodic phenomenon.

What are damped waves?

Ans. Waves of which the amplitude of successive cycles at the source, progressively diminishes.

What is a decibel?

Ans. The common transmission unit of the decimal system, equal to 1/10 bel.

$$1 \text{ bel} = 2 \log_{10}\frac{E_1}{E_2} = 2 \log_{10}\frac{I_1}{I_2}$$

What is meant by detection?

Ans. Any process of operation on a modulated signal wave to obtain the signal imparted to it in the modulation process.

What is a detector?

Ans. A device which is used for operation on a signal wave to obtain the signal imparted to it in the modulation process.

Describe a diode vacuum tube.

Ans. A type of thermionic tube containing two electrodes which passes current wholly or predominantly in one direction.

What is meant by direct capacitance (C) between two conductors?

Ans. The ratio of the charge produced on one conductor by the voltage between it and the other conductor divided by this voltage, all other conductors in the neighborhood being at the potential of the first conductor.

What is meant by direct coupling?

Ans. The association of two circuits by having an inductor, a condenser, or a resistor common to both circuits.

What is a direct current?

Ans. An unidirectional current. As ordinarily used, the term designates a practically non-pulsating current.

Describe what is meant by distortion.

Ans. A change in wave form occurring in a transducer or transmission medium when the output wave form is not a faithful reproduction of the input wave form.

What is meant by double modulation?

Ans. The process of modulation in which a carrier wave of one frequency is first modulated by the signal wave and is then made to modulate a second carrier wave of another frequency.

Describe an R.C.A. dynamic amplifier.

Ans. This is a variable gain audio amplifier, the gain of which is proportional to the average intensity of the audio signal. Such an amplifier compensates for the contraction of volume range required because of recording or transmission line limitations.

What is meant by the dynamic sensitivity of a phototube?

Ans. The alternating current response of a phototube to a pulsating light flux at specified values of mean light flux, frequency of pulsation, degree of pulsation, and steady tube voltage.

What is an electro-acoustic transducer?

Ans. A transducer which is actuated by power from an electrical system and supplies power to an acoustic system or vice versa.

Describe what is meant by electron emission.

Ans. The liberation of electrons from an electrode into the surrounding space. In a vacuum tube it is the rate at which the electrons are emitted from a cathode. This is ordinarily measured as the current carried by the electrons under the influence of a voltage sufficient to draw away all the electrons.

What is an electron tube?

Ans. A vacuum tube evacuated to such a degree that its electrical characteristics are due essentially to electron emission.

What is meant by emission characteristics?

Ans. A graph plotted between a factor controlling the emission (such as the temperature voltage or current of the cathode) as abscissas, and the emission from the cathode as ordinates.

What is meant by facsimile transmission?

Ans. The electrical transmission of a copy or reproduction of a picture, drawing or document. This is also called picture transmission.

What is fading?

Ans. The variation of the signal intensity received at a given location from a radio transmitting station as a result of changes occurring in the transmission path.

What is meant by fidelity?

Ans. The degree to which a system, or a portion of a system, accurately reproduces at its output the signal which is impressed upon it.

What is a filament?

Ans. A cathode in which the heat is supplied by current passing through the cathode.

Generally define and give the function of a filter.

Ans. A selective circuit network, designed to pass currents within a continuous band or bands of frequencies or direct current, and substantially reduce the amplitude of currents of undesired frequencies.

What is meant by the term frequency?

Ans. The number of cycles per second.

Describe a full-wave rectifier.

Ans. A double element rectifier arranged so that current is allowed to pass in the same direction to the load circuit during each half cycle of the alternating current supply, one element functioning during one-half cycle and the other during the next half cycle, and so on.

What is meant by fundamental frequency?

Ans. The lowest component frequency of a periodic wave or quantity.

What is meant by fundamental or natural frequency of an antenna?

Ans. The lowest resonant frequency of an antenna, without added inductance or capacity.

What is a gas phototube?

Ans. A type of phototube in which a quantity of gas has been introduced usually for the purpose of increasing its sensitivity.

What is a grid?

Ans. An electrode having openings through which electrons or ions may pass.

What is meant by grid bias?

Ans. The direct component of the grid voltage.

What is a grid condenser?

Ans. A series condenser in the grid or control circuit of a vacuum tube.

What is a grid leak?

Ans. A resistor in a grid circuit, through which the grid current flows, to affect or determine a grid bias.

What is meant by the grid-plate transconductance?

Ans. The name for the plate current to grid voltage transconductance. This has also been called mutual conductance.

Describe a ground system of an antenna.

Ans. That portion of the antenna system below the antenna loading devices or generating apparatus most closely associated with the ground and including the ground itself.

What is a ground wire?

Ans. A conductive connection to the earth.

Describe a half-wave rectifier.

Ans. A rectifier which changes alternating current into pulsating current, utilizing only one-half of each cycle.

What is meant by a harmonic?

Ans. A component of a periodic quantity having a frequency which is an integral multiple of the fundamental frequency. For example, a component the frequency of which is twice the fundamental frequency is called the second harmonic.

Describe a heater.

Ans. An electrical heating element for supplying heat to an indirectly heated cathode.

Describe heterodyne reception.

Ans. The process of receiving radio waves by combining in a detector a received voltage with a locally generated alternating voltage. The frequency of the locally generated voltage is commonly different from that of the received voltage. Heterodyne reception is sometimes called beat reception.

What is meant by homodyne reception?

Ans. A system of reception by the aid of a locally generated voltage of carrier frequency. Homodyne reception is sometimes called zero-beat reception.

Describe an expansion type hot-wire ammeter.

Ans. An ammeter dependent for its indications on a change in dimensions of an element which is heated by the current to be measured.

What is meant by an indirectly heated cathode?

Ans. A cathode of a thermionic tube in which heat is supplied from a source other than the cathode itself.

Describe an induction loud speaker.

Ans. It is a moving coil loud speaker in which the current which reacts with the polarizing field is induced in the moving member.

What is meant by inductive coupling?

Ans. The association of one circuit with another by means of inductance common or mutual to both.

What is meant by interelectrode capacitance?

Ans. The direct capacitance between two electrodes.

Describe what is meant by interference.

Ans. Disturbance of reception due to strays, undesired signals, or other causes; also that which produces the disturbance.

What is meant by intermediate frequency in superheterodyne reception?

Ans. A frequency between that of the carrier and the signal, which results from the combination of the carrier frequency and the locally generated frequency.

What is meant by intermodulation?

Ans. The production in a non-linear circuit element, of frequencies corresponding to the sums and differences of the fundamentals and harmonics of two or more frequencies which are transmitted to that element.

Describe what is meant by interrupted continuous waves.

Ans. These are waves obtained by interruption at audio frequency in a substantially periodic manner of otherwise continuous waves.

What constitutes an ion?

Ans. It is an atom or molecule having an electrical charge either positive or negative.

What does the term "kilocycle" stand for?

Ans. When used as a unit of frequency, it is one-thousand cycles per second.

Describe a lead-in.

Ans. That portion of an antenna system which completes the electrical connection between the elevated outdoor portion and the instruments or disconnecting switches inside the building.

What is meant by linear detection?

Ans. That form of detection in which the audio output voltage under consideration is substantially proportional to the modulation envelope throughout the useful range of the detecting device.

Describe and give the function of a loading coil.

Ans. An inductor inserted in a circuit to increase its inductance but not to provide coupling with any other circuit.

What is generally meant by a loud speaker?

Ans. A telephone receiver or apparatus designed to radiate acoustic power into a room or open air.

What is meant by a magnetic loud speaker?

Ans. One in which the mechanical forces result from magnetic reactions.

What is a magnetic microphone?

Ans. A microphone whose electrical output results from the motion of a coil or conductor in a magnetic field.

Describe a master oscillator.

Ans. An oscillator of comparatively low power so arranged as to establish the carrier frequency of the output of an amplifier.

How many cycles per second is one megacycle?

Ans. When used as a unit of frequency, it is one million cycles per second.

Describe a mercury-vapor rectifier.

Ans. A mercury-vapor rectifier is a two electrode, vacuum-tube rectifier which contains a small amount of mercury. During operation, the mercury is vaporized. A characteristic of mercury-vapor rectifiers is the low voltage drop in the tube.

Describe a microphone.

Ans. A microphone is an electro-acoustic transducer actuated by power in an acoustic system and delivering power to an electric system, the wave form in the electric system corresponding to the wave form in the acoustic system. This is also called a telephone transmitter.

What is generally understood by a "Mixer tube" in superheterodyne receivers?

Ans. A mixer tube is one in which a locally generated frequency is combined with the carrier signal frequency to obtain a desired beat frequency.

What is a modulated wave?

Ans. A wave of which either the amplitude, frequency or phase is varied in accordance with a signal.

Describe what is meant by modulation.

Ans. Modulation is the process in which the amplitude, frequency or phase of a wave is varied in accordance with a signal, or the result of that process.

Describe what is meant by monochromatic sensitivity.

Ans. The response of a phototube to light of a given color, or narrow frequency range.

What is a moving-armature speaker?

Ans. A magnetic speaker whose operation involves the vibration of a portion of the ferromagnetic circuit. This is sometimes called an electromagnetic or a magnetic speaker.

Describe a moving coil loud speaker.

Ans. A moving coil loud speaker is a magnetic loud speaker in which the mechanical forces are developed by the interaction of currents in a conductor and the polarizing field in which it is located. This is sometimes called an electro-dynamic or a dynamic loud speaker.

What is meant by Mu-factor?

Ans. A measure of the relative effect of the voltages on two electrodes upon the current in the circuit of any specified electrode. It is the ratio of the change in one electrode voltage to a change in the other electrode voltage, under the condition that a specified current remains unchanged.

What is an oscillator?

Ans. A non-rotating device for producing alternating current, the output frequency of which is determined by the characteristics of the device.

Describe an oscillatory circuit.

Ans. A circuit containing inductance and capacitance, such that a voltage impulse will produce a current which periodically reverses.

Describe a pentode tube.

Ans. A type of thermionic tube containing a plate, a cathode, and three additional electrodes. Ordinarily the three additional electrodes are of the nature of grids.

What is meant by percentage modulation?

Ans. The ratio of half the difference between the maximum and minimum amplitudes of a modulated wave to the average amplitude, expressed in per cent.

Describe a phonograph pickup.

Ans. An electro-mechanical transducer actuated by a phonograph record and delivering power to an electrical system, the wave form in the electrical system corresponding to the wave form in the phonograph record.

What is a phototube?

Ans. A vacuum tube in which electron emission is produced by the illumination of an electrode. This has also been called photoelectric tube.

What is meant by the plate in a vacuum tube?

Ans. A common name for the principal anode.

Describe what is meant by power amplification of an amplifier.

Ans. The ratio of the alternating current power produced in the output circuit to the alternating current power supplied to the input circuit.

What is meant by power detection?

Ans. That form of detection in which the power output of the detecting device is used to supply a substantial amount of power directly to a device such as a loud speaker or recorder.

Describe what is meant by pulsating current.

Ans. A periodic current, that is, current passing through successive cycles, the algebraic average value of which is not zero. A pulsating current is equivalent to the sum of an alternating and a direct current.

What is a push-pull microphone?

Ans. One which makes use of two functioning elements 180 degrees out of phase.

Define the term radio-channel.

Ans. A band of frequencies or wave-lengths of a width sufficient to permit of its use for radio communication. The width of a channel depends upon the type of transmission.

What is a radio compass?

Ans. A direction finder used for navigational purposes.

Describe what is meant by radio frequency.

Ans. A frequency higher than those corresponding to normally audible sound waves.

What is a radio-frequency transformer?

Ans. A transformer for use with radio-frequency currents.

What is a radio receiver?

Ans. A device for converting radio waves into perceptible signals.

Describe what is meant by radio transmission.

Ans. The transmission of signals by means of radiated electro-magnetic waves originating in a constructed circuit.

What is a radio transmitter?

Ans. A device for producing radio-frequency power, with means for producing a signal.

Describe a rectifier.

Ans. A device having an asymmetrical conduction characteristic which is used for the conversion of an alternating current into a pulsating current. Such devices include vacuum-tube rectifiers, gas rectifiers, oxide rectifiers, electrolytic rectifiers, etc.

What is meant by a Reflex circuit arrangement?

Ans. A circuit arrangement in which the signal is amplified, both before and after detection, in the same amplifier tube or tubes.

Describe what is meant by regeneration.

Ans. The process by which a part of the output power of an amplifying device reacts upon the input circuit in such a manner as to reinforce the initial power, thereby increasing the amplification. This is sometimes called "feedback" or "reaction".

What is a resistance coupling?

Ans. The association of one circuit with another by means of resistance common to both.

What is meant by the term "resonance frequency" of a reactive circuit?

Ans. The frequency at which the supply current and supply voltage of the circuit are in phase.

Describe a rheostat.

Ans. A resistor which is provided with means for readily adjusting its resistance.

What is the function of the screen grid in a vacuum tube?

Ans. A screen grid is a grid placed between a control grid and an anode, and maintained at a fixed positive potential, for the purpose of reducing the electrostatic influence of the anode in the space between the screen grid and the cathode.

What is secondary emission?

Ans. Electron emission under the influence of electron or ion bombardment.

What is meant by the term selectivity?

Ans. The degree to which a radio receiver is capable of differentiating between signals of different carrier frequencies.

What is meant by sensitivity?

Ans. The degree to which a radio receiver responds to signals of the frequency to which it is tuned.

Describe sensitivity as applied to the photo-electric tube.

Ans. The electrical current response of a phototube with no impedance in its external circuit, to a specified amount and kind of light. It is usually expressed in terms of the current for a given radiant flux, or for a given luminous flux. In general the sensitivity depends upon the tube voltage, flux intensity, and spectral distribution of the flux.

What is meant by the term "service band"?

Ans. A band of frequencies allocated to a given class of radio communication service.

What is meant by the term "side band"?

Ans. The bands of frequencies, one on either side of the carrier frequency, produced by the process of modulation.

What is a signal?

Ans. The intelligence, message or effect conveyed in communication.

Describe what is meant by single-side band transmission.

Ans. That method of operation in which one side band is transmitted, and the other side band is suppressed. The carrier wave may be either transmitted or suppressed.

What is static?

Ans. Strays produced by atmospheric conditions.

What is meant by the static sensitivity of a phototube?

Ans. The direct current response of a phototube to a light flux of specified value

Describe a stopping condenser.

Ans. A condenser used to introduce a comparatively high impedance in some branch of a circuit for the purpose of limiting the flow of low-frequency alternating current or direct current without materially affecting the flow of high frequency alternating current.

What is meant by the term "strays"?

Ans. Electromagnetic disturbances in radio reception other than those produced by radio transmitting systems.

Describe superheterodyne reception.

Ans. Superheterodyne reception is a method of reception in which the received voltage is combined with the voltage from a local oscillator and converted into voltage of an intermediate frequency which is usually amplified and then detected to reproduce the original signal wave. This is sometimes called double detection or supersonic reception.

What is meant by the term "swinging"?

Ans. The momentary variation in frequency of a received wave.

Describe a telephone receiver.

Ans. An electro-acoustic transducer actuated by power from an electrical system and supplying power to an acoustic system, the wave form in the acoustic system corresponding to the wave form in the electrical system.

What is television?

Ans. The electrical transmission of a succession of images and their reception in such a way as to give a substantially continuous reproduction of the object or scene before the eye of a distant observer.

Describe a tetrode vacuum tube.

Ans. A type of thermionic tube containing a plate, a cathode, and two additional electrodes. Ordinarily the two additional electrodes are of the nature of grids.

What is meant by the term thermionic?

Ans. It is a term relating to electron emission under the influence of heat.

Describe what is meant by thermionic emission.

Ans. Electron or ion emission under the influence of heat.

Describe a thermionic vacuum tube.

Ans. An electron tube in which the electron emission is produced by the heating of an electrode.

How does a thermo-couple ammeter operate?

Ans. An ammeter dependent for its indications on the change in thermo-electro-motive force set up in a thermo-electric couple, which is heated by the current to be measured.

What is meant by the term "total emission"?

Ans. The value of the current carried by electrons emitted from a cathode under the influence of a voltage such as will draw away all the electrons emitted.

What is meant by transconductance?

Ans. The ratio of the change in the current in the circuit of an electrode to the change in the voltage on another electrode, under the condition that all other voltages remain unchanged.

Describe a transducer.

Ans. A device actuated by power from one system and supplying power to another system. These systems may be electrical, mechanical or acoustic.

What is a transmission unit?

Ans. A unit expressing the logarithmic ratios of powers, voltages, or currents in a transmission system.

Describe a triode vacuum tube.

Ans. A type of thermionic tube containing an anode, a cathode, and a third electrode, in which the current flowing between the anode and the cathode may be controlled by the voltage between the third electrode and the cathode.

Describe a tuned transformer.

Ans. A transformer whose associated circuit elements are adjusted as a whole to be resonant at the frequency of the alternating current supplied to the primary, thereby causing the secondary voltage to build up to higher values than would otherwise be obtained.

What is tuning?

Ans. The adjustment of a circuit or system to secure optimum performance in relation to a frequency; commonly, the adjustment of a circuit or circuits to resonance.

What constitutes a vacuum?

Ans. Vacuum is absolutely nothing, if we can conceive of such a thing. The degree of vacuum is measured in microns, one micron represents one-millionth part of the usual atmospheric pressure which is approximately 14.7 pounds per square inch. Thus a perfect vacuum would be zero microns; such a state is however only a theoretical ideal that can never be realized even with the most perfect laboratory technique.

Describe a vacuum phototube.

Ans. A type of phototube which is evacuated to such a degree that the residual gas plays a negligible part in its operation.

What is a vacuum tube?

Ans. A device consisting of a number of electrodes contained within an evacuated enclosure.

What is a vacuum tube transmitter?

Ans. A radio transmitter in which vacuum tubes are utilized to convert the applied electric power into radio-frequency power.

Describe a vacuum tube volt-meter.

Ans. A device utilizing the characteristics of a vacuum tube for measuring alternating voltages.

Define voltage amplification.

Ans. The ratio of the alternating voltage produced at the output terminals of an amplifier to the alternating voltage impressed at the input terminals.

What is a voltage divider?

Ans. A resistor provided with fixed or movable contacts and with two fixed terminal contacts; current is passed between the terminal contacts and a desired voltage is obtained across a portion of the resistor. The term potentiometer is often erroneously used for this device.

Generally what is meant by the term "Wave"?

Ans. *a.* A propagated disturbance, usually periodic, as an electric wave or sound wave. *b.* A single cycle of such a disturbance, or *c.* A periodic variation as represented by a graph.

Describe what is meant by wavelength.

Ans. The distance traveled in one period or cycle by a periodic disturbance.

INTERNATIONAL MORSE CODE AND CONVENTIONAL SIGNALS

TO BE USED FOR ALL GENERAL PUBLIC SERVICE RADIO COMMUNICATION

1. A dash is equal to three dots.
2. The space between parts of the same letter is equal to one dot.
3. The space between two letters is equal to three dots.
4. The space between two words is equal to five dots.

A	· —
B	— · · ·
C	— · — ·
D	— · ·
E	·
F	· · — ·
G	— — ·
H	· · · ·
I	· ·
J	· — — —
K	— · —
L	· — · ·
M	— —
N	— ·
O	— — —
P	· — — ·
Q	— — · —
R	· — ·
S	· · ·
T	—
U	· · —
V	· · · —
W	· — —
X	— · · —
Y	— · — —
Z	— — · ·
Ä (German)	· — · —
Á or Å (Spanish-Scandinavian)	· — — · —
CH (German-Spanish)	— — — —
É (French)	· · — · ·
Ñ (Spanish)	— — · — —
Ö (German)	— — — ·
Ü (German)	· · — —
1	· — — — —
2	· · — — —
3	· · · — —
4	· · · · —
5	· · · · ·
6	— · · · ·
7	— — · · ·
8	— — — · ·
9	— — — — ·
0	— — — — —

Period	· · · · · ·
Semicolon	— · — · — ·
Comma	· — · — · —
Colon	— — — · · ·
Interrogation	· · — — · ·
Exclamation point	— — · · — —
Apostrophe	· — — — — ·
Hyphen	— · · · · —
Bar indicating fraction	— · · — ·
Parenthesis	— · — — · —
Inverted commas	· — · · — ·
Underline	· · — — · —
Double dash	— · · · —
Distress Call	· · · — — — · · ·
Attention call to precede every transmission	— · — · —
General inquiry call	— · — · — — · —
From (de)	— · · ·
Invitation to transmit (go ahead)	— · —
Warning—high power	— — · · — —
Question (please repeat after ......)—interrupting long messages	· · — — · ·
Wait	· — · · ·
Break (Bk.) (double dash)	— · · · —
Understand	· · · — ·
Error	· · · · · · · ·
Received (O. K.)	· — ·
Position report* (to precede all position messages)	— · — ·
End of each message (cross)	· — · — ·
Transmission finished (end of work) (conclusion of correspondence)	· · · — · —

CHAPTER 61

Radio Testing

It is of the utmost importance that the serviceman, in order to intelligently cope with the various faults liable to develop in radio sets should be provided with the necessary testing instruments, of which there are a great variety available (some of which have very desirable characteristics).

The selection of instruments described in this chapter however, are by no means essential for intelligent servicing of radio sets.

Testing instruments to be of value to a radio serviceman must have the following features:

1. They should be easily portable.

2. They should be ruggedly constructed so that instruments will not be damaged or their calibration changed in transport.

3. The instruments must be designed to stand considerable overloads without damage, as in service work it is often difficult to estimate the exact magnitude of the measurements being taken.

The following instruments are required to properly service any radio set:

1. A volt-ohm milliammeter for measuring voltage, resistance and current.

2. Analyzer with the necessary selector switches and analyzer cable with adapters.

3. Output meter.

4. All-wave oscillator.

5. Capacity meter.

6. Inductance meter.

7. Tube tester.

This equipment may be supplemented by a cathode-ray oscillograph, a vacuum tube voltmeter, etc., and hence will provide the serviceman with equipment necessary to successfully cope with almost any servicing problem.

Analyzers and How to Use Them.—The fundamental purpose of an analyzer is to locate trouble in receivers without undue waste of time and without disturbance to the wiring of the radio set.

A modern analyzer consists of various resistances, capacitances, inductances and meters, which by means of switches are connected to the circuit whose values it is desired to verify, and mounted in a compact cabinet to facilitate transportation.

Preliminary Pointers.—However, before analyzing the radio set for trouble, it is well to consider possibilities of trouble in the installation itself. The aerial may be grounded or touching foreign parts; the aerial connection may be corroded; or the lead-in wire itself possibly broken inside its insulation. The lightning arrester may be leaky or short-circuited. A poor ground connection is also a frequent cause of trouble due to interference with reception from outside causes. If, by disconnecting the aerial and ground the noise disappears, the trouble is undoubtedly located outside the set.

If it be evident that the trouble is inside the radio set itself, a careful examination of the wiring connections and interior parts of the set is next in order. The condition of soldered joints should be examined to be sure that there is a good electrical connection.

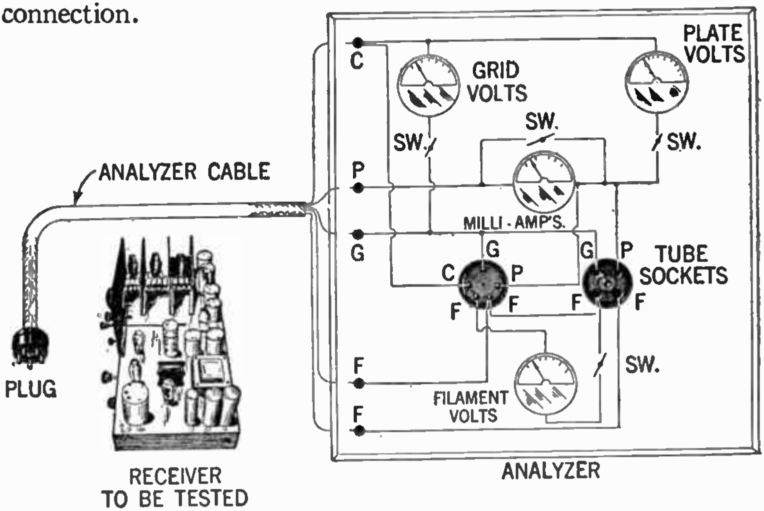


FIG. 1—Principal parts of a simple analyzer. The performance of the test is as follows: After a preliminary investigation of possible outside sources of trouble such as faulty or grounded aerials, open soldering joints, broken parts, etc., remove tube to be tested from set to proper socket in analyzer, and insert analyzer plug in place of the tube removed from set. Test the tubes one by one, starting with the antenna stage and proceed until the power amplification stage is reached. This test will indicate the location of troubles in the various circuits or in the tubes as well as in their power supply.

It should be noted that the insulation of the wiring be not cut or frayed where it passes through metal, around the edges of tube socket contacts, etc. The tube socket fingers should be clean and tight. The possibility of variable condenser plates touching should be checked. A visual inspection of this kind may quickly locate the cause of the trouble.

Electrical Tests.—The first electrical check on the set should be on the power supply to insure a normal supply of voltage to the various circuits in the radio set.

If the set be a battery operated type, check the condition of the various batteries by making use of the tip jacks on the analyzer and the test leads supplied with it. If the set be supplied with power from an alternating current house lighting circuit, measure the line voltage to be sure that it is correct for the set as indicated on the name plate of the radio set. The various batteries should give approximately their rated voltage readings with the radio set connected and turned on. If the batteries are low they should be re-charged or replaced.

Having checked the source of power to the radio set, the next step is to check the current and voltage supplied to each tube. A suggested method is to check the tubes in the order in which the signal passes through them. That is, start with the antenna stage and end with the power amplifier stage.

After making preliminary tests and a visual inspection and finding everything in good order, the electrical tests should be made. These electrical tests will show the location of troubles in the various circuits, in the tubes and in the power supply to them.

First, place the radio set as near as possible in good operating condition. If battery operated, all batteries should be properly connected. If power operated, connect to the proper power circuit. Turn on the set and make such adjustments as are normally necessary to bring in a good signal.

In general, all electrical tests should be made with the volume control in the maximum volume position, since this position generally gives the optimum distribution of currents and voltages through the various circuits in the radio set. A second set of readings with the volume control in the average working position is often helpful in locating trouble. This second set of readings is the current and voltage values in the various circuits under average conditions and should compare favorably with the first set. Radical differences should be checked up for a possible source of trouble.

In a battery operated set all batteries should be checked; any which are low in voltage should be replaced before proceeding with a more detailed analysis of the radio set.

Selection of Voltmeter Scales.—It is advisable when reading direct current voltages to set the selector switch on the range which will give the smallest deflection of the instrument which can be read satisfactorily. While this may seem to be contrary to general practice, the fact that many modern radio receivers have individual voltage divider networks for each tube, allows the current drawn by the voltmeter to throw the voltage applied to the tube somewhat in error.

It is obvious that a network supplying three milliamperes plate current to a tube will be upset to a considerable extent by connecting a voltmeter to it which requires one milliampere full scale. Consequently, deflections of less than half scale, as would be obtained on a higher range, will introduce less error than deflections of approximately full scale on a lower range, since the latter require considerably more current from the voltage divider network. When a difference in voltage indicated on the instrument scale exists as the range selection is changed, the indication read on the highest full scale voltage should be taken as the more accurate.

Selection of Current Scales.—In reading current always take the reading on the range which will give the largest possible deflection. By doing this the greatest possible accuracy will result.

Testing a Triode.—For a complete analysis of a triode for example, it is necessary to measure the following values:

1. Plate voltage
2. Plate current
3. Grid voltage
4. Grid current
5. Filament voltage.

In addition where cathode screen grid or pentode tubes are being tested, it is necessary to measure—

6. Cathode voltage
7. Screen grid voltage.
8. Screen grid current.

A complete outline of the above tests is given on pages 1,382 to 1,387.

Test Oscillators and Their Use.—The fundamental use of a test oscillator is to replace the broadcast signal for test and adjustment of radio receivers. Of special importance to the servicemen are the following uses:

Alignment of *IF*, *RF* and oscillator padding circuits. Checking the condition of tubes. To determine the gain in any part of radio receivers. For testing *a.v.c.* circuits. For checking selectivity.

Alignment Procedure.—Unless the manufacturer of the receiver instructs otherwise the following sequence should be followed in the alignment of a radio set:

1. The various tuned circuits of the *IF* amplifier are first aligned properly at the intermediate frequency for which the amplifier was designed.

2. The oscillator tracking condenser should then be adjusted at about 1,400 *k.c.* so that it tracks properly at the high frequency end of the dial. Adjust the padding condenser at about 600 *k.c.* so that it tracks at the low frequency end of the dial.

3. Align the radio frequency, the pre-selector, amplifier or tuned circuit last.

If double spot or image suppression circuit be employed in the receiver, the manufacturer's instructions should be consulted for the proper procedure. Maximum transfer of energy in output is only obtained when every section is synchronized properly.

Use of Output Meters.—To determine the condition of tubes feed the signal from the oscillator to the aerial and ground connections of the receiver. Connect an output meter to the radio set; substitute new tubes for those in the radio set, one at a time and if the output meter indicates a greater value when each new tube is placed in the set, the original tube should be replaced.

To determine the gain in any part of the receiver, connect output meter as before and feed signal to aerial connection of radio set. Adjust oscillator to a high output and move the oscillator aerial connection to each succeeding *RF* or *IF* stage, noting the drop in the output voltage as shown on the output meter. Always use the proper frequency and proper scales for the output meter.

To check *a.v.c.* to determine when it is functioning properly, wide changes in the alignment with a large signal voltage will produce no appreciable change in output.

To check selectivity feed a signal of low value to aerial and ground connections, tune oscillator to perfect resonance, move oscillator signal dial until signal disappears. Note number of kilocycles between resonance and inaudibility.

Capacity Measurements.—On account of the fact that capacitors very frequently give rise to trouble in *a.c.* receivers, it is necessary to be able to measure and compare the value received by that as given in the manufacturer's circuit diagram. Hence it is important that the serviceman should understand the theory of capacity values and how they are derived.

The dial of most *a.c.* milliammeters are calibrated to read directly in microfarads (*M.F.*). The capacitive reactance of a condenser in ohms is given by the following formula:

$$X_c = \frac{1{,}000{,}000}{2 \times \pi \times f \times C_{m.f}} \text{ohms} \ldots\ldots\ldots\ldots\ldots (1)$$

When a 60 cycle current is used ($f=60$) and C is measured in microfarads, this formula then bec...

$$C_{m.f} = \frac{2{,}650}{X_c} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

From this last equation it is possible to calibrate an *a.c.* milliammeter to read directly in capacity.

If any other frequency than 60 cycles is used, the result obtained in equation 1 or 2, must be multiplied by the fraction $\frac{F}{f}$, where (F) is 60 cycles and (f) is a cycle of the current being used. For example, if a 50 cycle current be used, then the values of equations 1 or 2 must be multiplied by $\frac{60}{50}$ or 1.2.

Before using any instruments designed for use on 60 cycles, on any other frequency, one must make sure that the equipment will function at the new frequency.

How to Make Capacity Measurements When the Capacitor Be Shunted by a Non-Inductive Resistor.—In *a.c.* receivers it is very frequently desired to obtain the values in microfarads when an ohmic resistor is shunted by a condenser as shown in fig. 2.

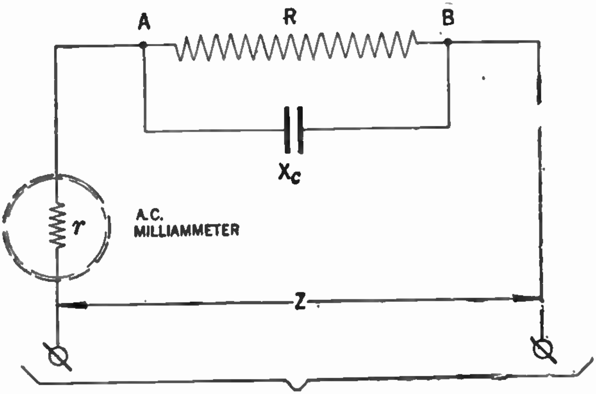


FIG. 2—Connection for measurement of capacity when capacitor is shunted by a non-inductive resistor.

The impedance Z, of the above circuit combination is obtained by the following formula:

$$Z=\sqrt{r^2+\frac{(R+2r)RX_c^2}{R^2+X_c^2}} \quad \text{.................} (3)$$

in which r = Resistance of the *a.c.* milliammeter in ohms
R = Resistance of the shunt resistor in ohms
X_c = The reactance of the capacitor to be measured in ohms
Z = The impedance of the circuit combination, in ohms.

The X_c values as used in formula (3) are the effective resistance values of capacitors given by formula (1).

From the above mathematical relationship, curves may be plotted as shown in chart, fig. 3. In this chart the resistance value from 500 to 5,000 ohms and capacitors from 0.1 to 15 microfarads are covered. The chart is used as follows:

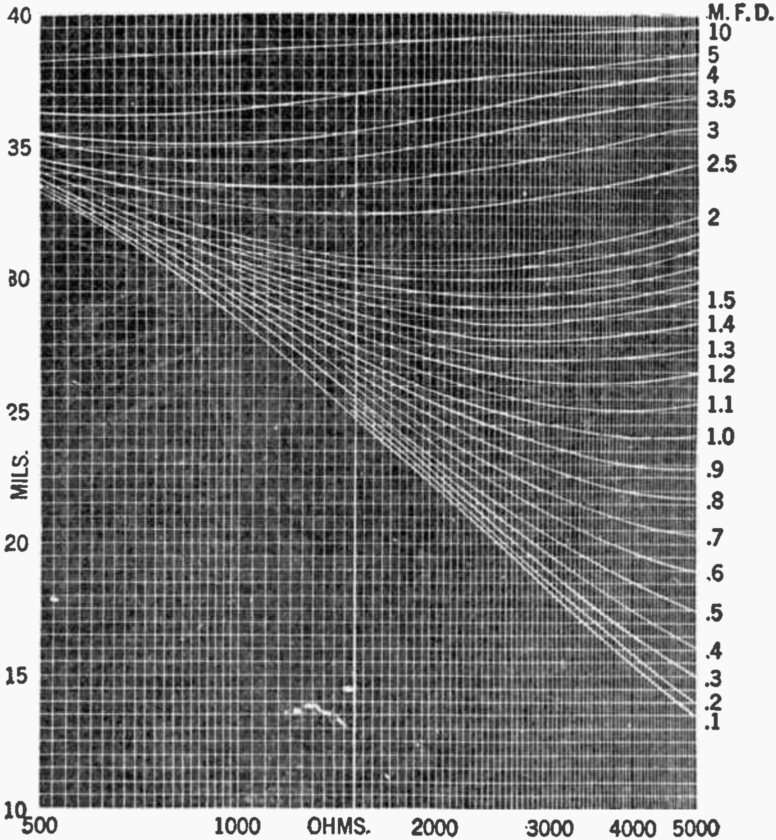


FIG. 3—Parallel resistance-capacity chart. Charts may conveniently be designed to suit individual requirements.

The value of r, is the resistance of the meter being used.

The value of R is obtained by an ohmmeter (*d.c.*). The *a.c.* milliammeter reading is obtained by placing it across the points A and B of fig. 2 as indicated.

The intersection of the line corresponding to the *a.c.* milliammeter readings and the resistance given by the ohmmeter will intersect on one of the curves and following this curve out, the value of the condenser in microfarad is obtained.

Example.—*If the* a.c. *milliammeter reads* 30 *M.A., and the resistance* (R) *is found by the ohmmeter to be* 2,500 *ohms, what is the value of the condenser?*

Solution.—Following the curve fig. 3 at the intersection of the 30 *M.A.* and the 2,500 ohms line shows the value of C to be 1.82 microfarads.

Inductive Measurements.—Inductance values may be obtained in a manner similar to that already described in capacity measurements. It should however be remembered that inductive reactance is vectorially positive whereas capacitive reactance is negative, and that the larger the value of the inductive reactance the lower will be the reading of the *a.c.* milliammeter. Also the larger the capacitive reactance the higher will be the reading of the *a.c.* milliammeter.

The formula for the inductive reactance (X_L) in ohms is:

$$X_L = 2\pi f L \text{ ohms} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

or if $f = 60$ cycles, then

$$L = \frac{X_L}{377} \text{ henries} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

When i = the *a.c.* current in amperes

e = Impressed *a.c.* voltage

R = Resistance of *a.c.* meter in ohms

X_L = Effective resistance of the inductor in ohms

then the formula for current is as follows:

$$i=\frac{e}{\sqrt{R^2+X_L^2}} \qquad (6)$$

The reading of the *a.c.* milliammeter may conveniently be referred to a chart computed from equation (4) from which the value of the inductance can be found similarly as previously shown.

If 50 cycles is used instead of 60 cycles the results should be multiplied by $\frac{60}{50}$ or 1.2.

Commercial Type Analyzers

Weston Model 665 Selective Analyzer.—The external view of this instrument is shown in fig. 4. and its internal connection diagram in fig. 5.

The instrument is principally a volt-ohm-milliammeter for both *a.c.* and *d.c.* service.

All voltage ranges are available at the pin jacks, and by means of socket selector units may be had through the plug. They are 0–1/2.5/5/10/25/100/250/500/1,000 volts, either *a.c.* or *d.c.* The individual ranges are selected by means of the large selector switch. A reading cannot be had till either the *d.c.* or *a.c.* push button at the bottom of the panel is pressed. These are locking types and should be returned to their original position after each test is completed.

All current ranges are available at the pin jacks and are also available for current measurements at the socket by means of the socket selector units. These ranges are 0–/2.5/5/10/25/50/-100/250/500 milli-amperes, *d.c.* only.

Resistance measurements may be had with test leads and the various ohmmeter pin jacks, as a point-to-point tester. Also by means of a socket selector unit, resistance measurements may be taken between any two socket prongs or a socket prong and ground.

A very useful feature in this instrument is that it may easily be converted into a complete analyzer by addition of the 666 socket selector shown in fig. 6, thus bringing the tube socket connections to the analyzer circuit.

With reference to the **Tube Base Chart** shown on page 1,385 the various measurements should be made as follows:

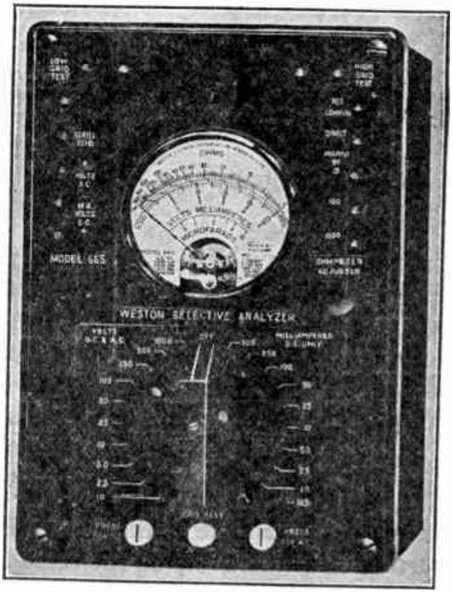


FIG. 4—Front view of Weston Model 665 selective analyzer.

Heater Voltage.—This is read between 1 and 4 on 4 prong tubes; 1 and 5 on 5 prong tubes; 1 and 6 on 6 prong tubes, and 1 and 7 on 7 prong tubes. However, it is advisable to check with the tube base chart because no fixed rule for the location of any terminal can be given.

Plate Voltage.—The plate is generally terminal No. 2 and for heater type tubes this voltage would be read between plate and cathode and for filament type between plate and negative filament. Since the plate and cathode terminal are not in the same locations for all type tubes, reference to the tube base chart is suggested.

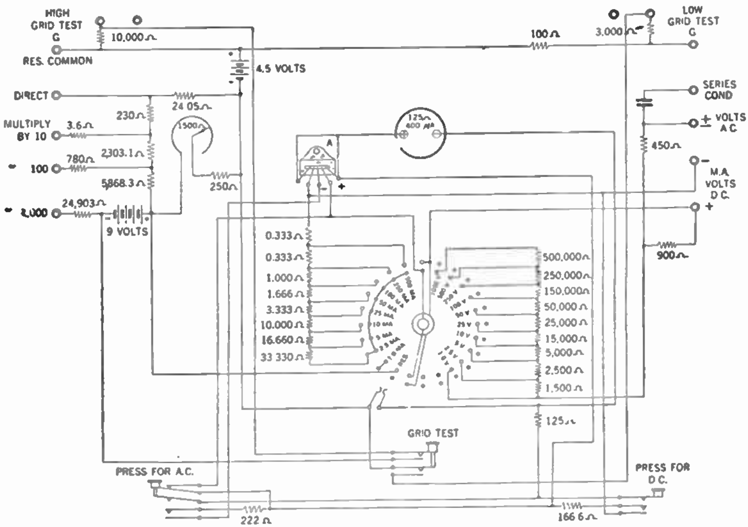


FIG. 5—Internal connection diagram of Weston Model 665 selective analyzer.

Grid Voltage.—There are a number of grids such as control, screen, suppressor, anode, etc. For heater type tubes the voltage is measured from the cathode to the desired grid and for filament type tubes from the negative filament to the desired grid. Reference to the tube base chart will give the correct location of the various grids for the tube in question.

Reference should be made to the service manual of the radio set being tested for the determination of the correct values of grid and plate voltage.

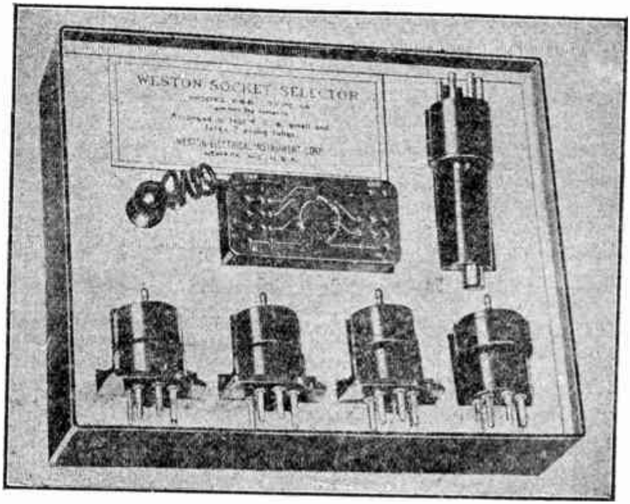


FIG. 6—Socket selector for use with Weston Model 665 analyzer.

Plate Current.—A pair of leads are plugged into the M.A. pin jacks on the panel; the other ends of these leads are placed in the two jacks opposite the plate terminal on the socket selector unit. The dial switch is turned to the desired milliampere range. This will give a plate current reading on the milliammeter. It is necessary to hold down the "Press for D.C." button.

True total current in any lead is read in this way, since the inner jack of each pair functions as a closed circuit jack switch. When a pin tip is plugged into the inner of a pair of jacks, the main circuit is opened between the jacks. The total current,

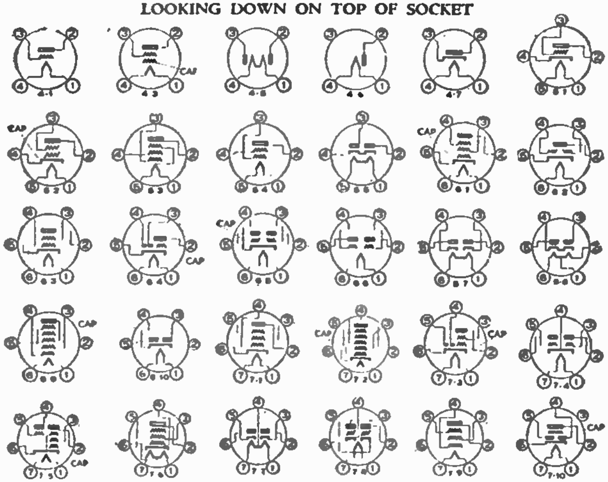
TUBE BASE CHART

FOR USE WITH

THE WESTON METHOD OF SELECTIVE ANALYSIS

Tube	Base	Tube	Base	Tube	Base	Tube	Base	Tube	Base	Tube	Base
00A	4-1	27	5-1	47	5-3	71	4-1	98	5-5	12A5	7-6
01A	4-1	27HM	5-1	48	6-3	71A	4-1	X99	4-1	14Z3	4-7
01AA	4-1	29	6-2	49	5-4	71B	4-1	1A6	6-9	25Z3	4-7
1	4-7	30	4-1	50	4-1	75	6-4	2A3	4-1	25Z5	6-7
1V	4-7	31	4-1	51	5-2	76	5-1	2A3H	4-1	182B	4-1
G2	5-5	32	4-2	52	5-3	77	6-1	2A5	6-3	183	4-1
G4	5-5	33	5-3	53	7-4	78	6-1	2A6	6-4	213	4-5
KR1	4-7	34	4-2	55	6-4	79	6-5	2A7	7-2	216B	4-6
KR2	4-7	35	5-2	56	5-1	80	4-5	2B6	7-8	482A	4-1
KR5	5-3	36	5-2	57	6-1	80M	4-5	2B7	7-3	482B	4-1
10	4-1	36A	5-2	57AS	6-1	81	4-6	5Z3	4-5	483	4-1
12A	4-1	37	5-1	58	6-1	81M	4-6	6A4	5-3	484	5-1
WX12	4-1	37A	5-1	58AS	6-1	82	4-5	6A7	7-2	485	5-1
14	5-2	38	5-2	59	7-1	82V	4-5	6B7	7-3	585	4-1
15	5-2	38A	5-2	59B	7-9	83	4-5	6C6	6-1	586	4-1
17	5-1	39	5-2	64	5-2	83V	4-5	6C7	7-10	864	4-1
18	6-3	39A	5-2	64A	5-2	84	5-5	6D6	6-1	950	5-3
19	6-6	40	4-1	65	5-2	G84	4-6	6D7	7-2	951	4-2
20	4-1	41	6-3	65A	5-2	85	6-4	6E7	7-2	AD	4-7
22	4-2	42	6-3	67	5-1	89	6-1	6F7	7-5	AF	4-5
24	5-2	43	6-3	67A	5-1	90	6-2	6Y5	6-10	AG	4-5
24A	5-2	44	5-2	68	5-2	92	6-2	6Z3	4-7	LA	5-3
KR25	6-3	45	4-1	68A	5-2	95	6-3	6Z4	5-5	PZ	5-3
26	4-1	46	5-4	69	6-2	96	4-7	6Z5	6-8	PZH	6-3

LOOKING DOWN ON TOP OF SOCKET



therefore, must flow out through the measuring instrument and back into the other jack. Note that voltage measurements cannot be made in the inner jacks, since the circuit is opened when pin tips are placed in them.

Grid Current.—Grid and screen current measurements are made in the same manner as the plate current. All current ranges are available for this purpose. The push button marked "Press for D.C." must be held down for this test. These readings are obtained by placing one end of each of a pair of leads in the "M.A." pin jacks and the other ends in the two pin jacks opposite the terminal of the grid desired.

The plate current of the second plate of rectifier tubes is tested as above. It is advisable to consult the tube base chart for location of the terminals for the various elements.

Grid Tests.—Two grid tests are available, one with a low shift of 4.5 volts, the other a high shift of 13.5 volts for power tubes only. A separate set of pin jacks is provided on the panel for each shift.

A pair of short leads is plugged into the panel at the upper corner marked "Grid test" and the other ends plugged into the pin jacks opposite the control grid terminal desired on the selector unit. Be sure lead from "G" pin jack is inserted in the pin jack nearest the tube on selector unit.

Another pair of leads is plugged into the M.A. pin jacks on the panel, the other ends of these leads are placed in the two jacks opposite the plate terminal on the socket selector unit. The dial switch is turned to the desired M.A. range. This will give a plate current reading on the milliammeter. Pressing the "Grid Test" button (located in center of lower edge of panel) will give an increase in the plate current reading.

The grid test reading is an indication of the relative goodness of the tube, and is proportional to the mutual conductance. No values can be given for this reading because of the high plate circuit resistance in many radio sets.

Cathode Voltage.—Cathode voltage is measured with reference to the heater. In some sets the cathode is connected directly to the heater, in which case the cathode voltage reading will be zero.

In other sets the cathode is grounded through the grid bias resistor with heater connected to some positive potential, in which case the cathode will read negative with reference to the heater. In most alternating current radio sets the cathode is grounded through the grid bias resistor with the heater grounded, in which case the cathode will read positive with reference to the heater.

Output Test.—This test is made exactly like the measurement of *a.c.* voltage, except when *d.c.* is present in the output circuit, then the "Series Condenser" pin jack must be used. All voltage ranges are available for this test. It is necessary to hold down or lock in position the "Press for A.C." push button.

Weston Model 571 Output Meter.—The external view of this meter is shown in fig. 7 and its internal connection in fig. 8.

This instrument has a constant resistance of 4,000 ohms on each range, is usually used as a terminating impedance on sound line or receiver output circuits. It can be used, however, on bridging measurements on low impedance lines. It is also valuable as a multi-range *a.c.* volt-meter of wide adaptability.

The 5 voltage ranges are available at pin-jacks and are selected by means of a dial switch. It also has a self-contained condenser for blocking any *d.c.* components. This condenser is connected to a separate pin-jack.

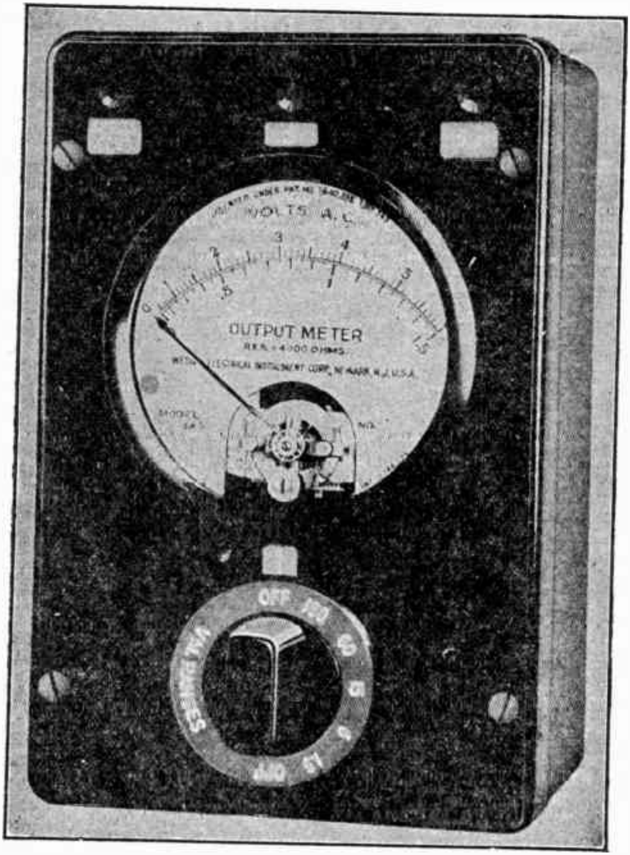


FIG. 7—Panel view of Weston Model 571 output meter.

The voltage ranges are: 0–1.5/6/15/60/150. Test leads and adapter for connection to the plate pin of any output vacuum tube are provided for the meter.

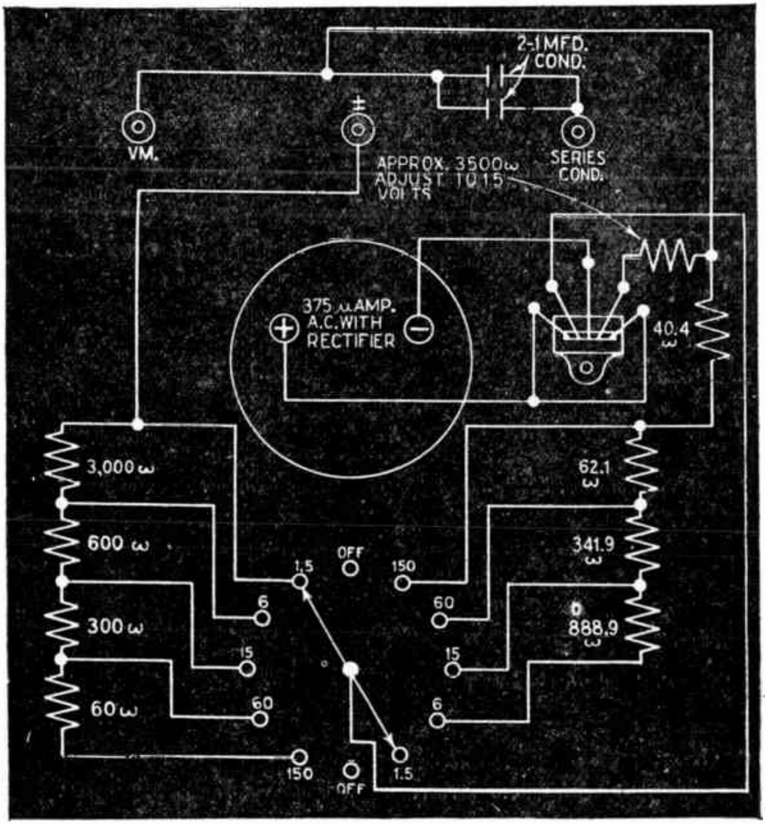


FIG. 8—Schematic wiring diagram of Weston Model 571 output meter.

Weston Model 763 Ohmmeter.—Front view and connection diagram of this instrument is shown in figs. 9 and 10 respectively.

FIG. 9—Panel view of Weston Model 763 ohmmeter.

With this instrument resistance measurements of from 0.2 ohms to 300 megohms may be made with high accuracy on 6 ranges. It can also be used with good results on the top range as a modified megger in which 125 volts (maximum current 50 microamperes) is available for insulation tests.

The power consumption is small, as the instrument requires only 50 microamperes for full scale deflection.

Leakage on all types of condensers, even those having resistances of up to approximately 300 megohms can easily be measured. A filament type vacuum tube requiring a very short heating time is used as a rectifier, and the operating power is obtained from any 105-130 volts, 50-60 cycle *a.c.* source.

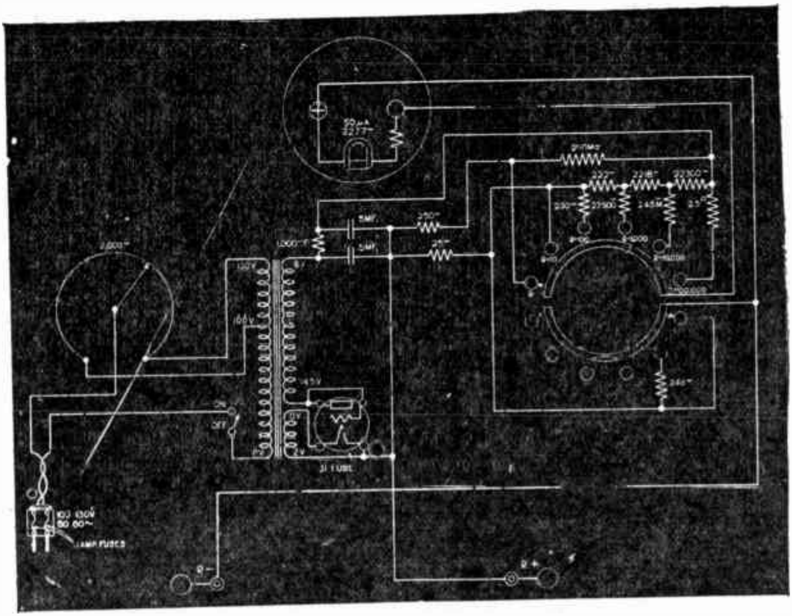


FIG. 10—Wiring diagram for internal connection of Weston Model 763 ohmmeter.

Weston Model 765 Analyzer.—A front view and internal connection diagram of this instrument is shown in figs. 11 and 12 respectively.

This instrument is claimed to be of very high sensitivity. For

FIG. 11—Front view of Weston Model 765 analyzer.

example the *d.c.* and *a.c.* sensitivity according to the manufacturer is 20,000 ohms per volt and 1,000 ohms per volt respectively. This minimum loading effect permits checking of sensitive relay circuits without interrupting operation and facilitates a great multiplicity of measurement which are practically impossible with instruments of lower sensitivity.

The over-all *a.c.* accuracy of the instrument is held within 3%, whereas for *d.c.* measurements the accuracy is within 2%.

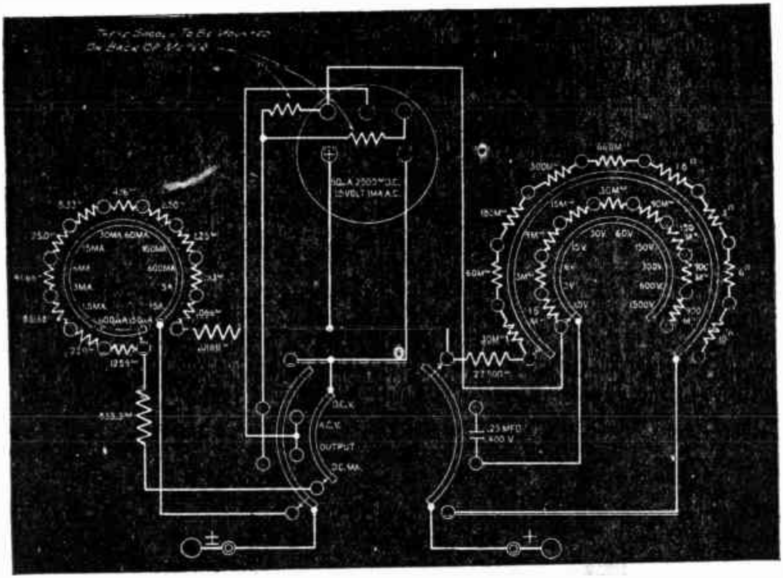


FIG. 12—Diagram showing internal connection of Weston Model 765 analyzer.

In addition a special rectifier circuit is incorporated designed for temperature compensation between 50 and 110 degrees F. limiting temperature errors to within 2%.

The ranges for *a.c.* and *d.c.* voltage measurements are as follows: 0–/1.5/3/6/15/30/60/150/300/600/1,500.

Ranges for *d.c.* current measurements are:
0–150 μ.*a.*/600 μ.*a.*/1.5/3/6/15/30/60/150/600 *m.a.*/3*a*/15*a*.

The decibel ranges provides measurements of power levels between—18 to +58 *db.*

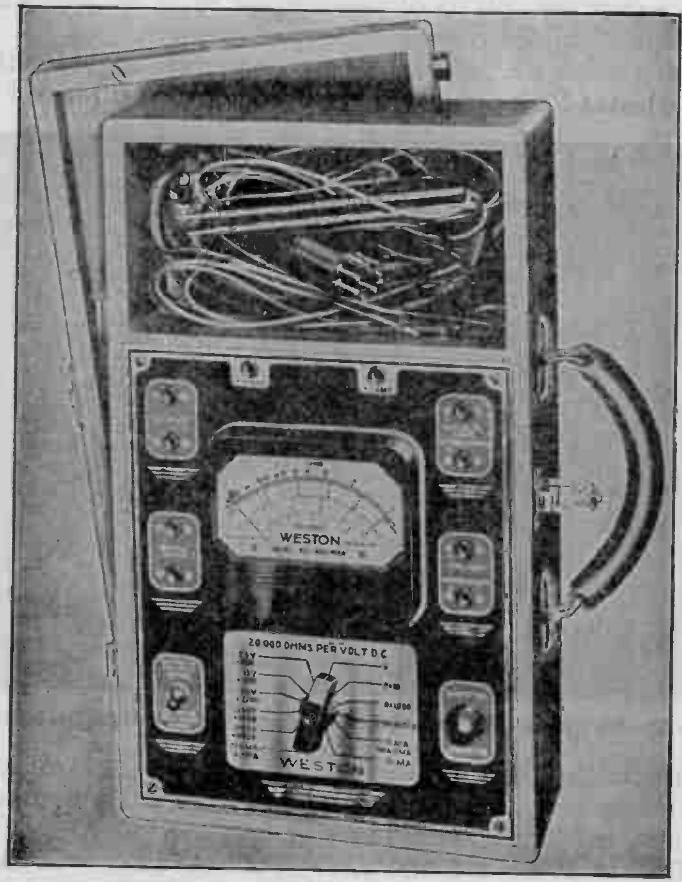


FIG. 13—Panel view of Weston Model 772 analyzer.

Weston Model 772 Analyzer.—This analyzer is designed to make the necessary tests on present day equipment such as commercial radio receivers, transmitters, television receivers,

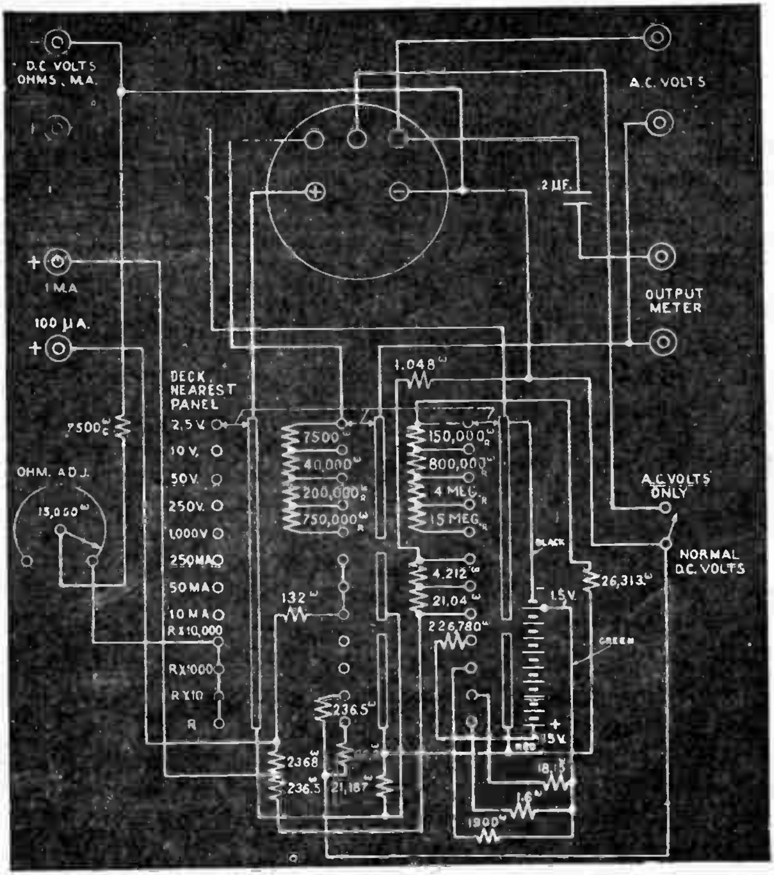


FIG. 14—Wiring diagram of Weston Model 772 analyzer.

public address systems, vacuum tube and cathode ray equipment, etc.

The instrument is illustrated in fig. 13 and its connection diagram in fig. 14.

It has a 20,000 ohms per volt sensitivity on five *d.c.* voltage ranges. *A.c.* readings are made on single arc scale.

The ranges for *d.c.* current measurements are 0–/0.1/10/50/-250 *m.a.*/1*a*/10*a*.

A.c. or *d.c.* voltage measurements have the following ranges: 0–2.5/10/50/250/1,000 *v*. Five decibel ranges provide power level measurement from—14 to +54 *db*.

Resistances are measured on the following scales 0–3,000/-30,000/3 Meg./30 Megohms.

The instrument is equipped with pin jacks for mounting model 666 socket selector unit.

Weston Model 773 Tube Checker.—This instrument is manufactured both for counter and movable service, as shown in figs. 15 and 17 with a common diagram of connections in fig. 16. It has eight sockets for the various types of tubes, a direct reading "Bad-Good" meter scale, two selector switches, voltage adjustment switch, in addition to position and test switches.

With this instrument a complete analysis of any tube may readily be obtained. Separate electrode switches for grid, plate, screen, suppressor, diode or cathode are provided for emission, short and leakage tests. This point to point testing feature will be recognized as extremely important whenever doubtful tubes are encountered.

A most frequent source of trouble in radio tubes are the defects in circuit continuity of the electrodes and although an over-all efficiency test may at times fail to disclose these defects, a point to point electrode check will nearly always disclose the trouble.

FIG. 15—Front view of counter type Weston Model 773 tube checker.

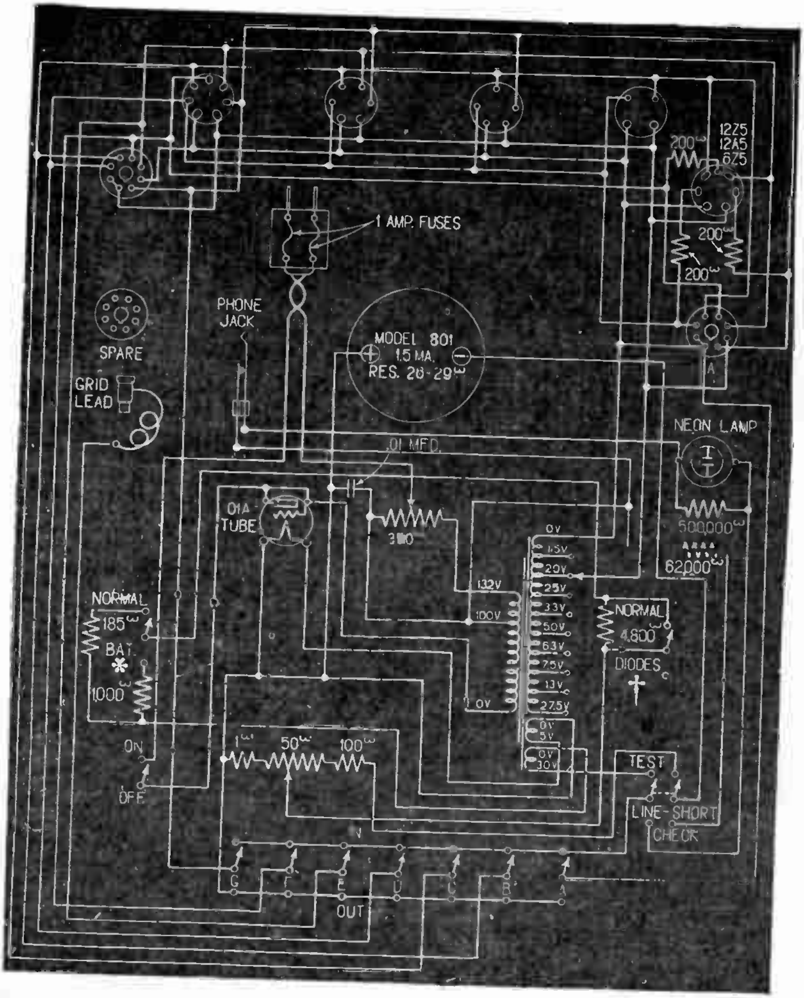


FIG. 16—Diagram of connection for Weston instruments Model 773.

FIG. 17—Panel view of Weston Model 773 movable type tube checker.

Weston Model 655-2 Selective Analyzer.—The internal connection of this instrument is shown in fig. 18.

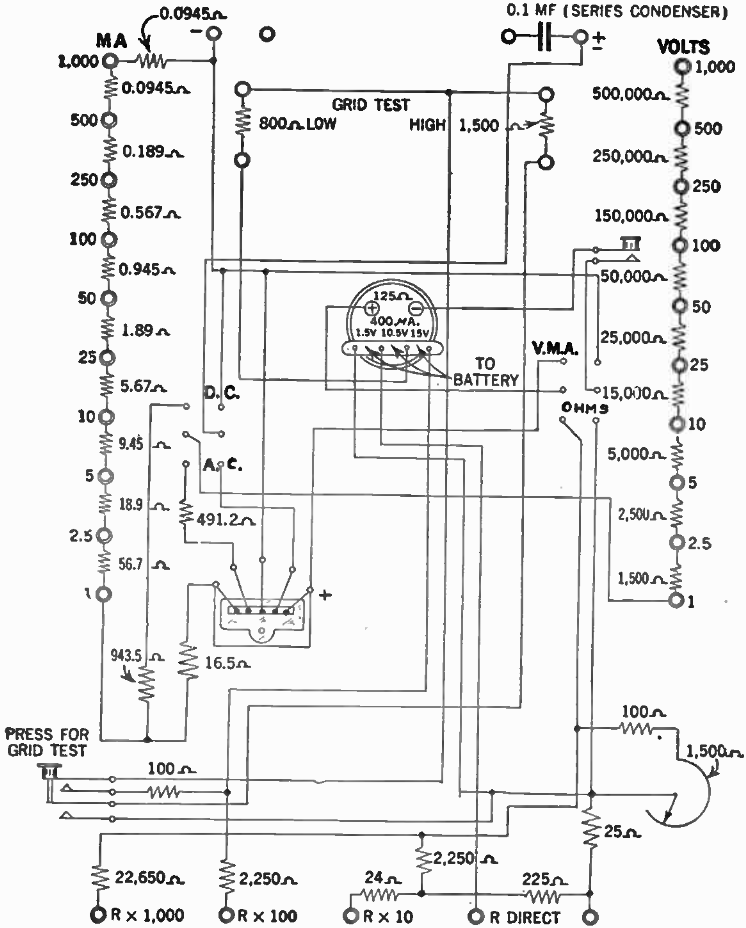


FIG. 18—Connection diagram of Weston Model 665-2 radio set analyzer.

The principal difference between this instrument and the 655 previously described is that the various scales are available by means of pin jacks instead of a rotary switch. The volt meter ranges *a.c.* or *d.c.* are: 0–1/2.5/5/10/25/50/100/250/500/1000 volts. The current ranges *d.c.* only are 0–1/2.5/5/10/25/50/100/250/500/1000 milliamperes.

Supreme Model 339 Analyzer.—The panel view and connection diagram of this instrument is shown in figs. 19 and 20 respectively.

It has five sockets for various types of tubes, a sensitive d'Arsonval fan shaped meter, and a rugged 4-gang, 5-position rotary switch for selectivity connecting the meter to any of the following measuring circuits:

(a) *d.c.* milliammeter—0/5/25/125/250/500 *m.a.*, and 0/1.25 ampere.

(b) *d.c.* voltmeter—0/2/25/125/250/500/1,250 volts.

(c) Ohmmeter—0/2,000/20,000/200,000 ohms and 0/2/20 megohms.

(d) *a.c.* voltmeter—0/5/25/125/250/500/1,250 volts.

(e) Capacity Meter—0/0.05/0.25/1.25/2.5/5.0/12.5 *mfds.* electro-static (paper) and electrolytic.

For current, potential and resistance measurement the meter is "built up" to a resistance value of 300 ohms by means of a multiplier resistor connected in series with the meter, and all shunt and multiplier resistance values are calculated on the basis of a full scale current sensitivity of 1.0 milliampere and a resistance value of 300 ohms for the meter.

The actual armature resistance of the meter is approximately 115 ohms. The operating procedure for the various measurements is as follows:

1. **Current Measurements.**—When it is desired to obtain current in terms of milliamperes the meter is shunted as shown

in fig. 20. The total shunt value of 75 ohms is determined by the lowest current-measuring range of 5 milliamperes. The meter, with its resistance built up to a value of 300 ohms, requires a potential of 0.3 volt (300 millivolts) to cause a full scale current of 1.0 milliampere to pass through the meter.

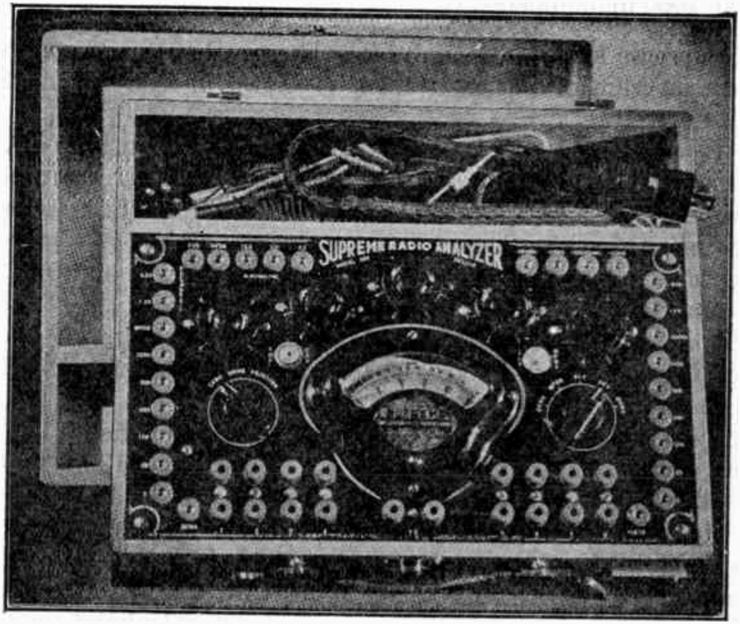


FIG. 19—Front view arrangement of Supreme Model 339 radio set analyzer.

The shunt resistor for the 5 milliampere range, being in parallel with the meter, will have the same 0.3 volt potential difference. Since 1.0 milliampere of the 5 milliampere range will pass through the meter, the shunt resistor will pass the other 4.0 milliamperes and its value is determined by dividing 4.0 milliamperes (0.004 ampere) into 300 millivolts (0.3 volts).

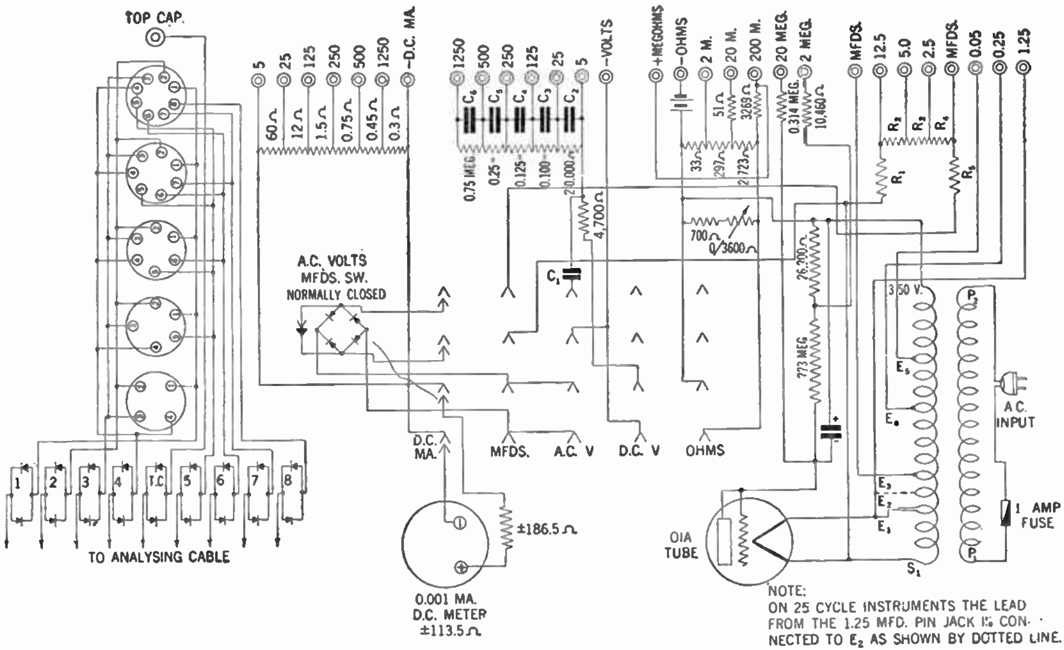


FIG. 20—Wiring arrangement and resistance values in Supreme Model 339 radio set analyzer.

For the current measuring ranges above the 5.0 milliampere range, the 75 ohm shunt resistor is divided into smaller values, thereby forming what is known as a "ring type" shunt, the total "ring" resistance value being 375 ohms.

The resistance values of the 75 ohm shunt resistors are determined by multiplying the total "ring" resistance by the full scale current of the meter, dividing the result by each range value, in turn, from the common terminal, and subtracting the sum of the preceding values from each newly-determined value.

When the "ring" value of 375 ohms is multiplied by the full scale sensitivity value of 0.001 ampere, 0.375 is the result, into which each range value is divided, in turn, for determining the required shunt values. For example, the shunt value for the 1.250 ampere range is determined by dividing 1.250 into 0.375, giving a value of 0.3 ohm for that range.

For the 500 milliampere range, 0.500 ampere is divided into 0.375, giving a value of 0.75 ohm for the 500 milliampere range; but since there already is a value 0.3 ohm for the preceding range, it is necessary to subtract 0.3 ohm from 0.75 ohm, leaving a value of 0.45 ohm for the second section of the shunt.

For the 250 milliampere range, 0.250 ampere is divided into 0.375, giving a value of 1.5 ohms for the 250 milliampere range; but since there already is a value of 0.75 ohm for the two preceding ranges, it is necessary to subtract 0.75 ohm from 1.5 ohms, leaving a value of 0.75 ohm for the third section of the shunt. The shunt sections for the other ranges are determined in a similar manner, and can be checked by Ohm's law.

For example, the shunt value of 0.3 ohm for the 1.250 ampere (1,250-milliampere) range is in parallel with the remaining 374.7 ohms of the "ring" circuit, which when multiplied by the meter current of 0.001 ampere, produces a potential drop of 0.3747 volt. With 0.001 ampere going through the meter, the remaining value of 1.249 amperes will be going through the 0.3 ohm shunt, producing potential drop of 0.3 times 1.249 or 0.3747 volt. Since the potential drop across both parallel paths is identical by Ohm's law, it is concluded that the calculations are correct. The other ranges may be similarly checked by Ohm's law.

2. **D.C. Potential Measurements.**—When the meter is being used for potential measurements, enough resistance must be connected with it to limit the current to within the full scale sensitivity value of the meter.

The value of the multiplier resistor for the 5-volt range is established by subtracting the meter resistance value of 300 ohms from the 1,000 ohms-per-volt value of 5,000 ohms leaving a multiplier resistance value of 5,000-300 or 4,700 ohms.

For the higher ranges the multiplier resistance values are calculated on this basis of 1,000 ohms per volt.

3. **Resistance Measurements.**—For resistance measurements, the meter is used primarily as a voltmeter, with the current passing through the meter calibrated on an "Ohms" scale instead of being calibrated on a "Volts" scale. In the multirange ohmmeter circuits of this tester, however, shunts are used to enable the different sensitivities required for each range, and to this extent, the ohmmeter circuits resemble current measuring circuits in which shunts are usually required.

It will be observed from diagram fig. 20, that for the lowest or 2,000 ohm range, the 33 ohm resistor is a shunt resistor, while the 297 ohm and the 2,723 ohm resistors act as multipliers to the meter with its 700/4,300-ohm shunting resistor made up of a fixed 700 ohm resistor and a variable 5,600 ohm rheostat for accommodating battery potential variations.

For the 20,000 ohm range, the 33 ohm and the 297 ohm resistors, totaling 330 ohms, act as a shunting resistor, with the 51 ohm and 2,723 ohm resistors functioning as multipliers. For the 200,000 ohm range, the 33 ohm, 297 ohm and 2,723 ohm resistors act as a shunting resistor, and a 3,269 ohm resistor acts as a multiplier resistor.

4. **A.C. Potential Measurements.**—The *a.c.* potential measuring functions differ from the *d.c.* potential in that the meter is connected to the output terminals of a full-wave instrument rectifier and a capacitor is substituted for the 4,700 ohm multiplier resistor, the capacitor being connected in series with the rectifier input circuit. Each of the multiplier resistors above the 5-volt range is by-passed with a calibration capacitor. The elements involved in the *a.c.* potential measuring functions are indicated in wiring diagram.

5. **Capacity Measurements.**—When the meter is used for capacity measurements, the resistance value of the meter and of the shunt and multiplier resistors associated with the measuring circuit constitutes one leg of an impedance triangle. See fig. 21. The reactance of a capacitor of unknown value, which may be connected into the measuring circuits for the purpose of determining its value, constitutes another leg of the same impedance triangle.

It is obvious that the resistance value of the meter and of its associated shunt and multiplier resistors is a constant value for any particular capacity-measuring range, regardless of the capacitive value of any capacitor which may be connected to that range, and that the capacitive reactance, in every case, is determined by the capacitive value of the capacitor which may be subjected to the measurement; therefore, the capacitive leg of the triangle is the variable element.

It is further obvious that the meter current is related directly to the hypotenuse of the impedance triangle and will not, therefore, have a linear relationship to capacitive values. For example, assume an impedance triangle in which a full-scale meter current corresponds to a certain hypotenuse length, and in which the reactance leg corresponds to a capacitive value of

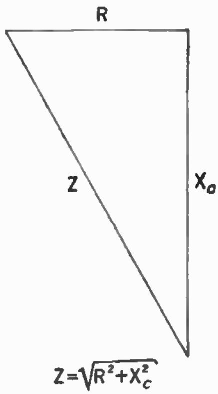


FIG. 21—Arrangement of impedance triangle in capacity measurements.

5.0 microfarads; if we remove the 5.0 mfd. capacitor and put in its place a 2.5 mfd. capacitor, the length of the reactive leg of the triangle will be doubled, but the length of the hypotenuse will not be doubled, and, therefore, the meter current will not be reduced to one-half of its former full scale value. In other words, a linear or evenly-divided scale cannot be used on the basis of fixed resistance values for the meter and its associated shunt and multiplier resistors.

From what has just been explained, it is natural to ask a question as to how capacitive measurements are enabled on an evenly divided scale in this tester. The answer lies in the fact that, although the meter, shunt and multiplier resistance values constitute a fixed resistive value for each capacity measuring range, a variable resistive value is introduced by the full wave instrument rectifier employed, and shunts and multipliers are employed of such values as will enable the variable element of the rectifier resistance to approximately counterbalance the variable reactive element introduced by the different capacitive values which may be encountered for measurement.

In other words, the divisions of a meter scale would be crowded on the upper end of the scale for capacitive measurements if the rectifier were linear in its characteristics, and the non-linear characteristics of the rectifier would cause the divisions of the meter scale to be crowded on the lower end of the scale, if no capacitive variable elements are introduced into the circuit; but when both variable elements are introduced into the circuit in approximately equal and opposite proportions, the meter scale divisions can be equally separated across the whole scale, or, what amounts to the same thing, the regular evenly-divided scales can be utilized for capacitive measurements.

For the measurement of electrostatic (paper) capacitive values, comparatively high *a.c.* potentials are used, but it is necessary to use comparatively low *a.c.* potential values for the measurement of electrolytic capacitive values, so as not to puncture the electrolytic film around the electrodes. Actually the *a.c.* potential applied to electrolytic capacitors in the 0/1.25/2.5/12.5 mfd. ranges is about 9 volts. The capacity-measuring circuits are shown in the wiring diagram.

Supreme Model 585 Diagnometer.—This instrument shown in fig. 22 with the connection diagrams of the tube testing circuit in fig. 23 has the following service facilities. It actually consists of 14 instruments in one compact assembly, for complete circuit and tube checking on all radios, P.A. amplifiers and television sets.

The instrument is a complete point to point set tester, or the "Free Reference" system of analysis direct from tube sockets may be chosen.

The meters provide for the following ranges:

1. Six *d.c.* potential ranges of 0–7/35/140/350/700/1,400 volts.

2. Six *a.c.* potential measuring ranges of 0–7/35/140/350/700/1,400 volts.

3. Seven *d.c.* current measuring ranges of 0–1/7/35/140/350/700/1,400 *m.a.*

A *d.c.* scale 0–14 amp. is provided for checking drain of auto radios and 6 volt mobile sound systems. There are six output meter ranges, ohms 0–200/2,000/20,000/200,000. The first division on the 200 ohm scale is 0.25 ohm. Can be read to 0.05 ohm. Megohmeter 0–2/20.

The 20 megohm range operating at 450 volts is an excellent electrostatic and main filter electrolytic condenser breakdown tester.

Decibels—10 to +6/0 to +16/+10 to +26/+20 to +36/+30 to +46 direct reading on the 500 ohm line; zero level 0.006 watts Electrostatic capacity meter 0–.07/0.35/1.4/3.5/7.0/14.0 Mfd.

Electrolytic capacity meter 0–3.5/7.0/14.0 Mfd. Direct meter leakage test for main filter electrolytics on colored "Good-Bad" scale.

Also a sensitive full size neon test for electrolytic condensers.

All meter services and ranges are selected by indicating rotary switches. New "Free Reference" tube for all old and new radio, P.A. and television tubes, except thyratrons and kinescopes.

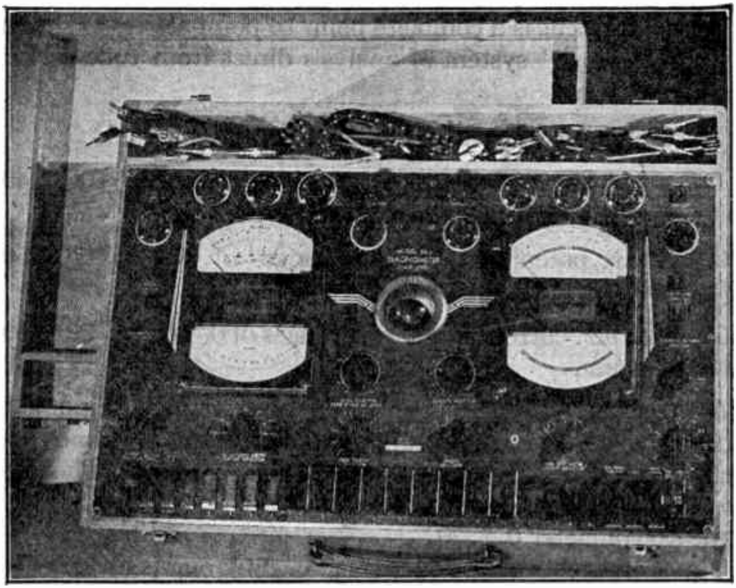


FIG. 22—Front view showing arrangement of instruments and switching devices in Supreme Model 585 diagnometer.

With this diagnometer it is possible to test all multi-purpose tubes section by section, as well as for overall performance, there are 48 possible basic combinations of load and voltage to insure proper and accurate tests of every conceivable type of tube.

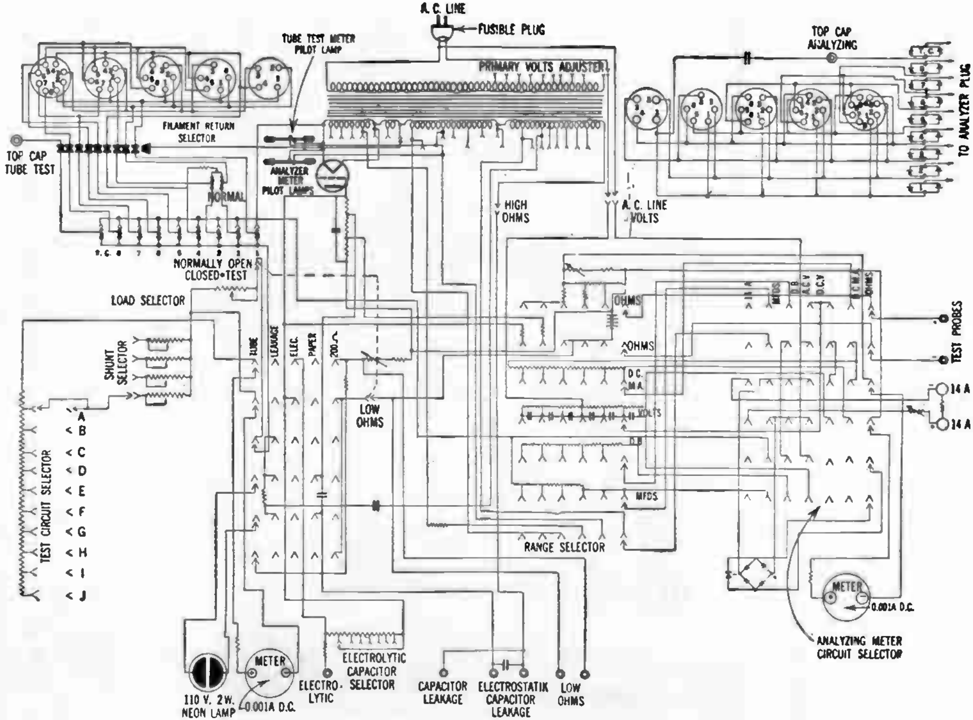


FIG. 23—Internal connection of Supreme Model 585 diagnometer.

Supreme Model 501 Tube Tester.—The panel view of this tester is shown in fig. 24 and illustrates the various controls. The connection diagram is shown in fig. 25. This new improved circuit tests all old and new tubes for radio, public address systems, and television, except thyratrons and kinescopes. It tests all multi-purpose tubes section by section, as well as for overall performance.

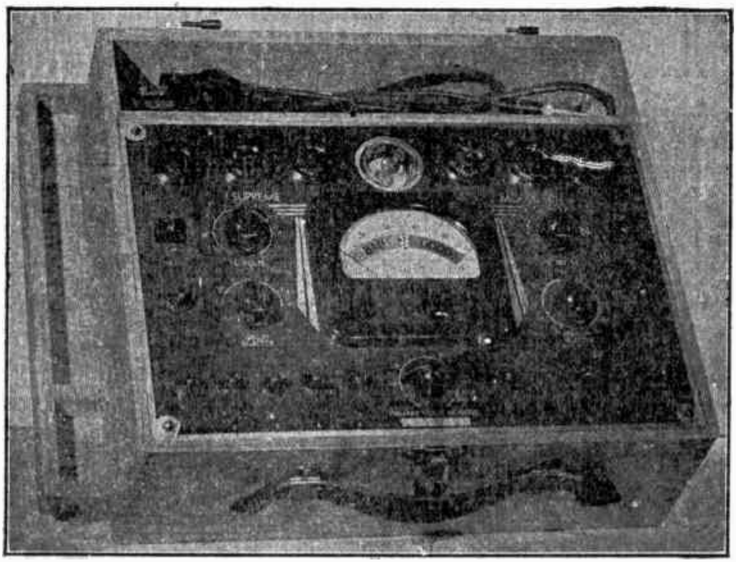


FIG. 24—Front view of Supreme Model 501 tube tester.

All quality tests are made at full rated load for highest accuracy. Six sockets test all types and combinations of tubes, as both ends of the filament or heater are free, through switches, for instant connection to any pair of tube terminals including the top cap.

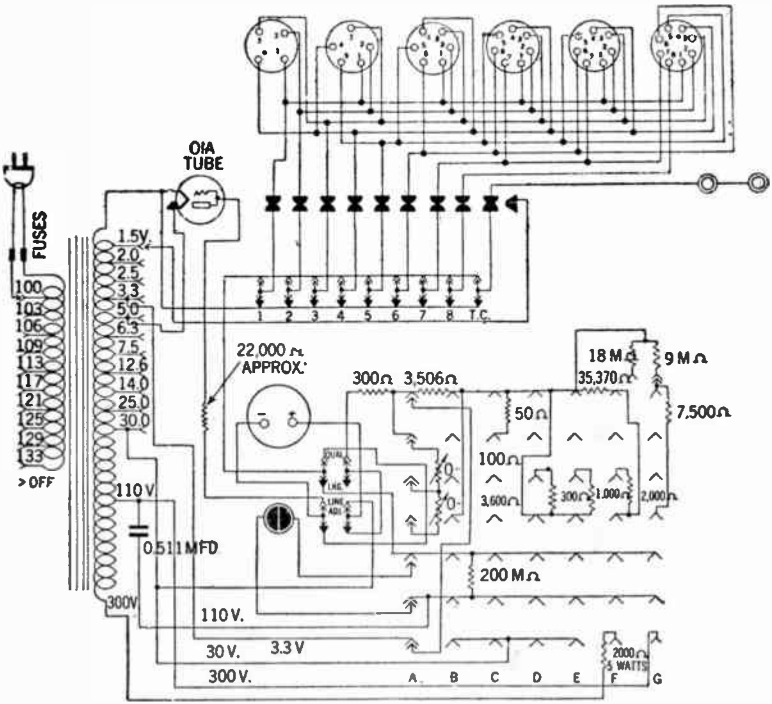


FIG. 25—Schematic wiring diagram of internal connection in Supreme Model 501 tube tester.

Supreme Model 551 Analyzer.—The panel view and connection diagram of this instrument are shown in figs. 23 and 24 respectively.

This set analyzer will handle all service and circuit problems of all types of radios, P.A. amplifiers and television sets. It is also as useful in servicing industrial vacuum tubes and photocell devices.

It has five sockets for the various types of tubes, and a sensitive 4 in. square meter, with easily readable scale. The various ranges and services are quickly available by means of an indexed rotary switch connecting the meter to any of the following measuring circuits:

a. D.c. volts....................0–7/140/350/1,400

b. A.c. volts....................0–7/140/350/1,400

c. D.c. milliamperes.............0–1/7/35/140

d. Ohms.........................0–200/2,000/20,000

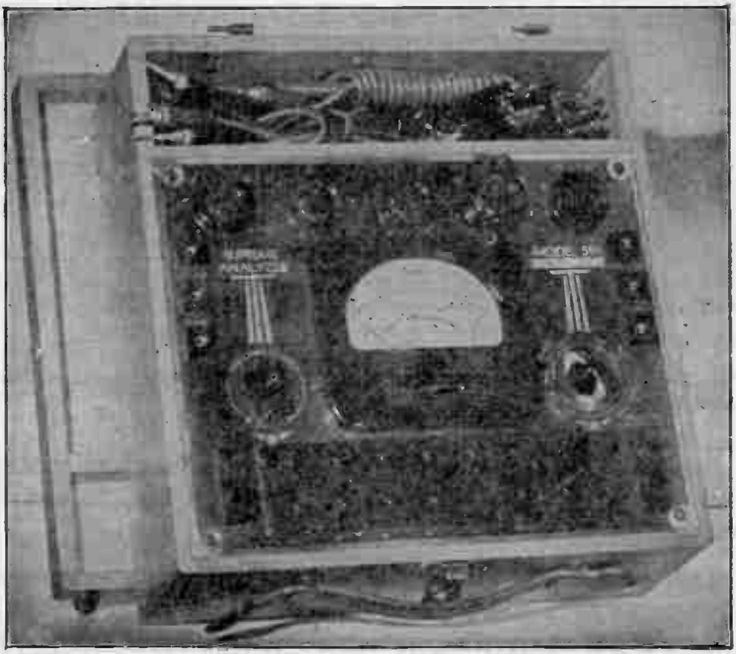
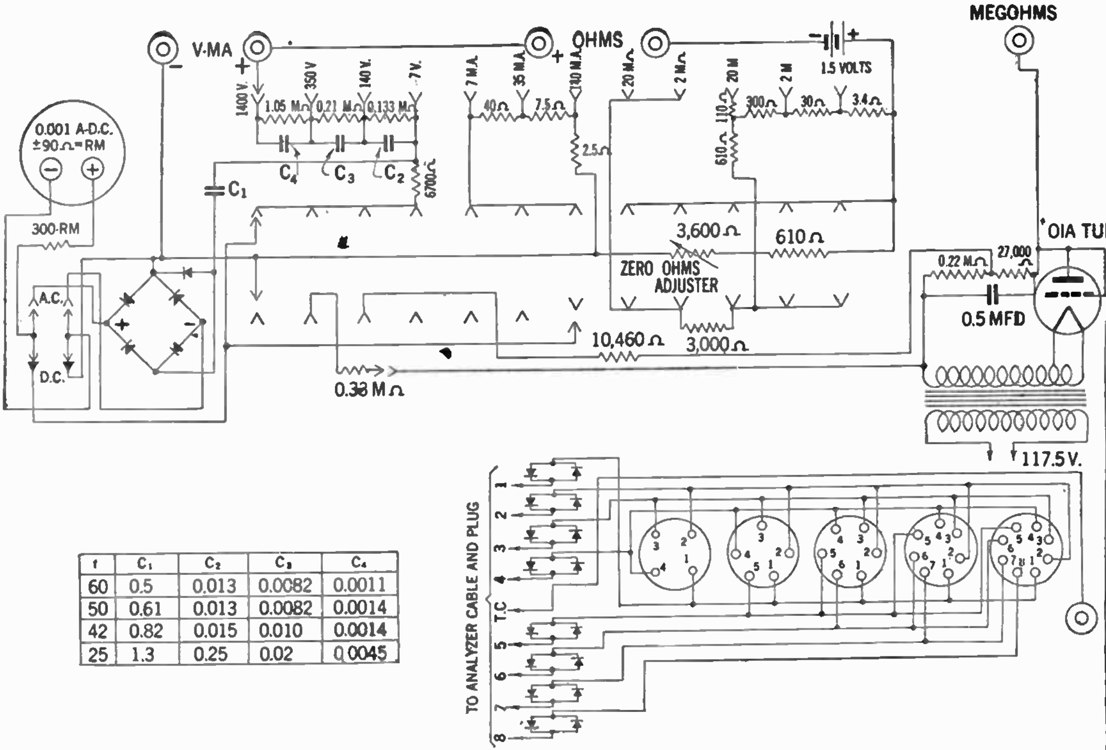


FIG. 26—Exterior view of Supreme Model 551 analyzer.



f	C_1	C_2	C_3	C_4
60	0.5	0.013	0.0082	0.0011
50	0.61	0.013	0.0082	0.0014
42	0.82	0.015	0.010	0.0014
25	1.3	0.25	0.02	0.0045

FIG. 27—Wiring diagram of Supreme Model 551 analyzer.

The first scale division of the 0–200 ohm range is 0.1 ohm, and at center scale the resistance reading is 3.5 ohms. This extreme open scale which can easily be read as close as 0.02 ohms is especially valuable when checking the resistance of shorted voice coils, filament windings on transformers, rosin joints, shorted turns in converter armatures, etc.

The megohmeter has two ranges 0–2/20 megs, which is operated from a self-contained power supply for high resistance and cable leakage testing.

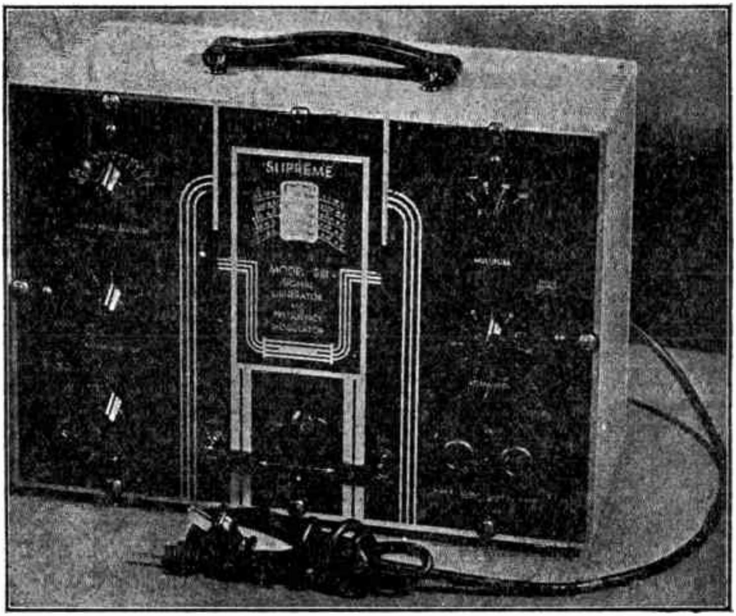


FIG. 28—Panel view of Supreme Model 581 signal generator.

Supreme Model 581 Signal Generator.—This all wave *r.f.* oscillator has a range of 130 *k.c.* to 60 *m.c.* on 5 fundamental bands and 3 harmonically related bands.

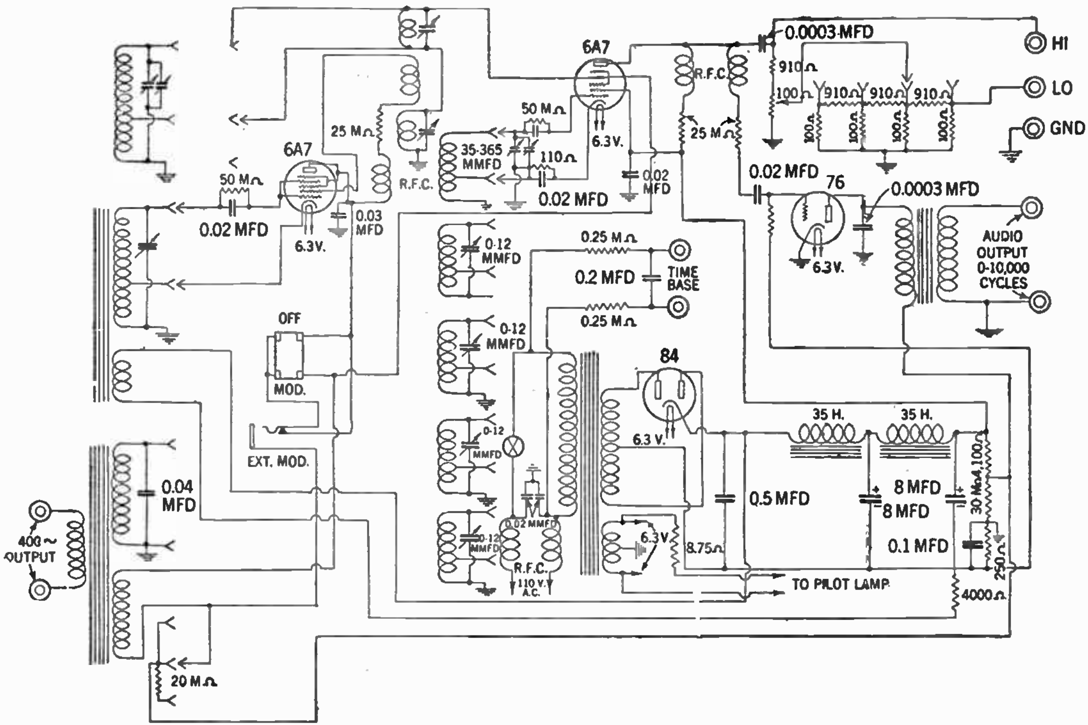


FIG. 29—Circuit diagram of Supreme Model 581 Signal generator.

Other noteworthy features includes a 400 cycle modulating oscillator which modulates the *r.f.* carrier the standard 30%; a beat frequency audio frequency oscillator having a 60/10,000 cycle range with less than 5% harmonic distortion; and an electronic frequency modulator or "Wobbulator."

This model is useful for alignment testing by the output meter (amplitude modulated *r.f.* signal) method or the visual cathode ray tube (frequency modulated *r.f.* signal) method; demodulation and detector testing; checking fidelity and overall response, and gain of audio and P.A. amplifier systems, band pass width; selectivity curves of *i.f.* amplifiers, etc.

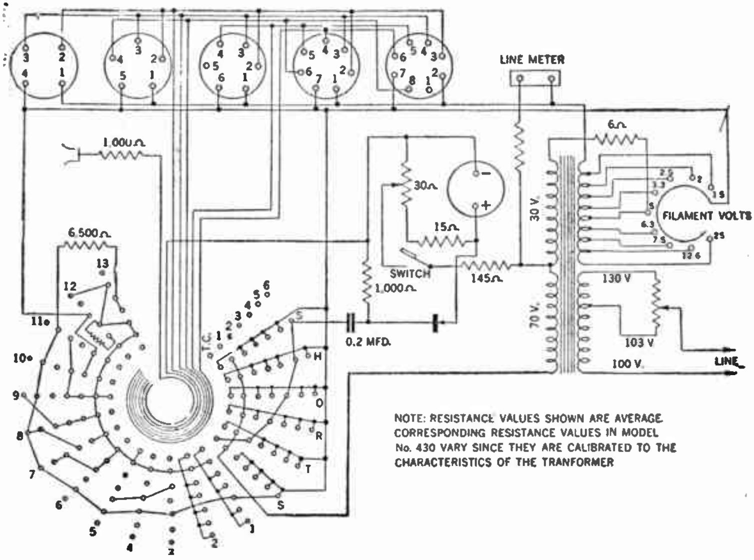


FIG. 30—Internal connection diagram of Readrite Model 430 tube tester.

The whole circuit is very stable, using a modified electron coupled system, which will not drift due to changes in line voltages, ambient temperature or attenuator control operation.

The circuit shown in fig. 29 has incorporated in it two 6A7, one 84 and one 76 tube.

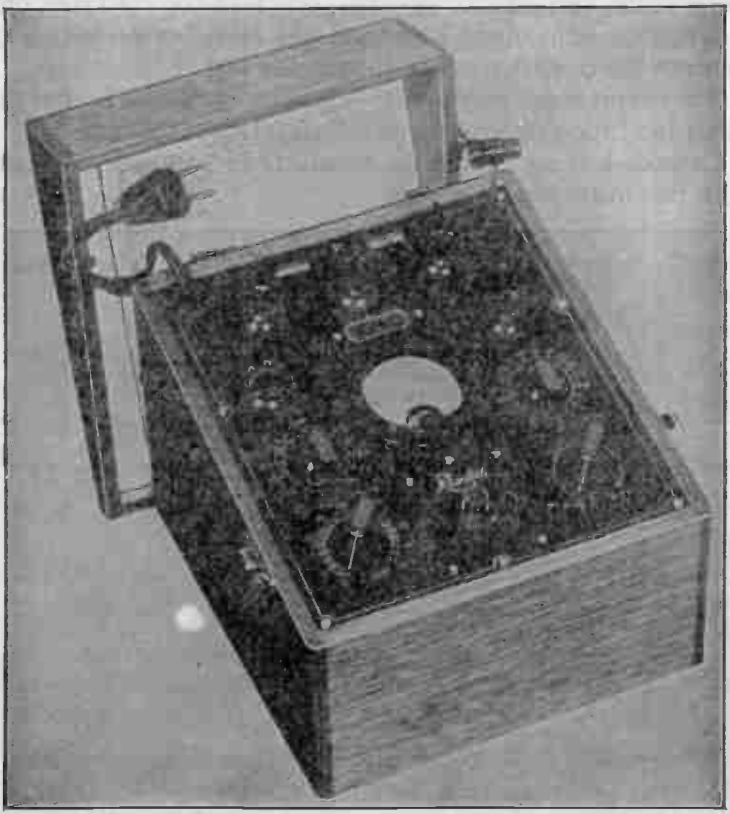


FIG. 31—Front view arrangement of devices in Readrite Model 430 tube tester.

Readrite Model 430 Tube Tester.—The wiring diagram and panel view of this type of instrument is shown in figs. 30 and 31 respectively.

This instrument is designed to test both metal and glass types of tubes.

The panel has five sockets and a direct reading "GOOD-BAD" meter scale, two selector switches, one load control knob, one *a.c.* voltage adjustment knob and one push button switch to indicate the condition of the tube under test.

The circuit is designed on the "emission" principle in that the meter indication depends on an emission test of the tube.

Cathode-leakage and short-circuit tests can also be made with this instrument.

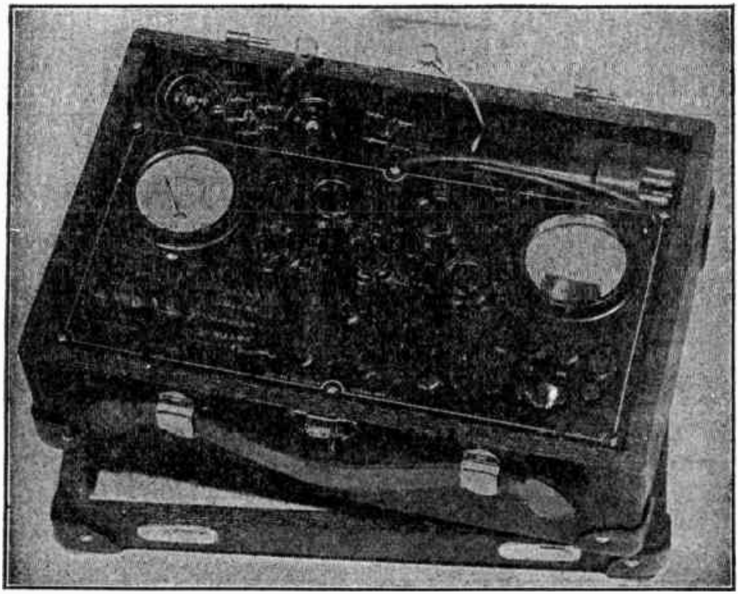
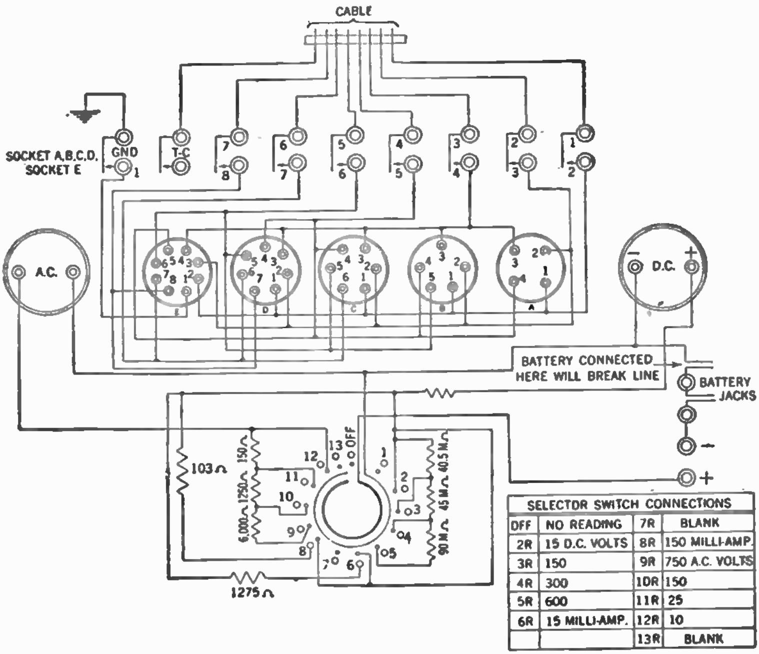


FIG. 32—Panel view of Readrite Model 720-A point to point panel.

Readrite Model 720-A Point-to-Point Tester.—This tester is equipped to handle both the glass and the glass-metal tubes. It may be used to measure resistance capacity and continuity, as well for voltage checking of any tube circuit.

The point-to-point tests are made through an eight conductor cable, which is plugged into the receiving set socket. Tester socket terminals are arranged according to R.M.A. standards, thereby making it unnecessary to remove chassis from cabinet when localizing faults. Arrangement of the different tube elements does not affect tests.



SELECTOR SWITCH CONNECTIONS			
OFF	NO READING	7R	BLANK
2R	15 D.C. VOLTS	8R	150 MILLI-AMP.
3R	150	9R	750 A.C. VOLTS
4R	300	10R	150
5R	600	11R	25
6R	15 MILLI-AMP.	12R	10
		13R	BLANK

FIG. 33—Connection diagram of Readrite Model 720-A point to point tester.

The tester is equipped with two meters; a *d.c.* meter having scale for reading 15-150-300-600 volts, 15-150 milliamperes and an *a.c.* meter for reading 10-25-150 and 750 volts.

Separate meter ranges made available by connecting a single pair of jacks and using the selector switch. For diagram of connection and panel view, see figs. 33 and 32.

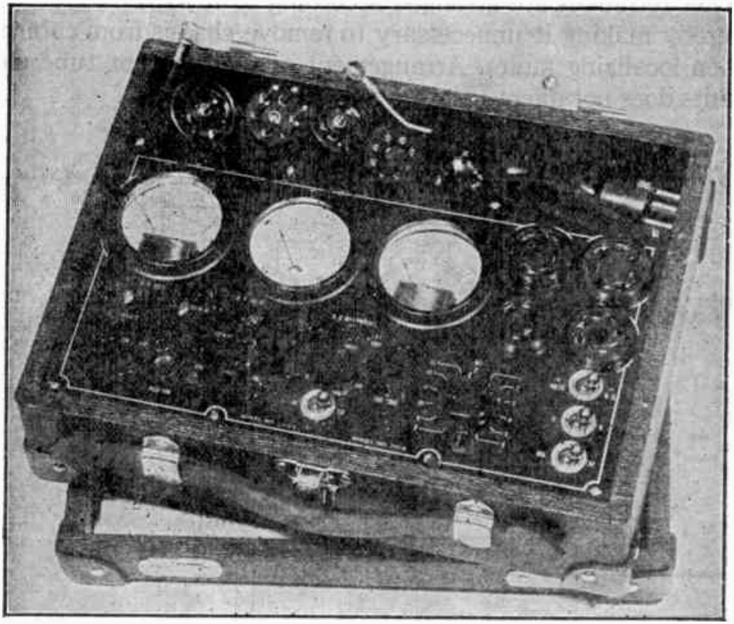
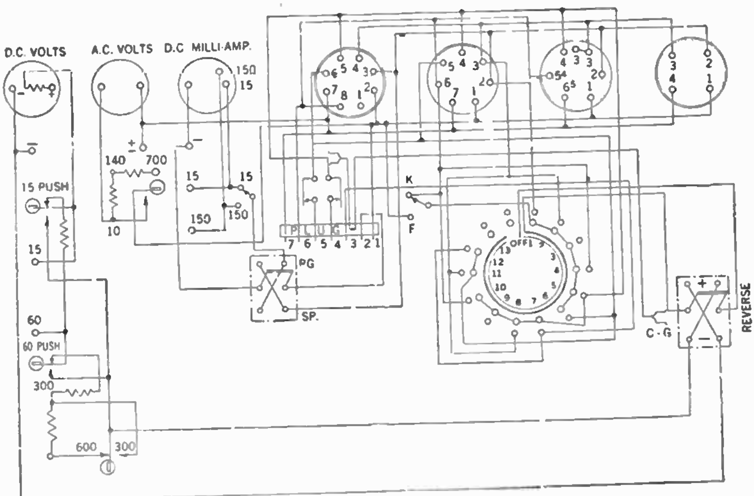


FIG. 34—Front view arrangement of Readrite Model 710-A tester.

Readrite Model 710-A Tester.—This instrument is used to test all parts of the tube circuits by plugging directly into the receiving set socket.

It will handle sets equipped with either glass or glass-metal tubes.

There are three meters, a *d.c.* volt-meter which reads 0–20/60/300/600 volts, and has 1,000 ohms resistance per volt, a *d.c.* milli-ammeter scale 0–15/150 and an *a.c.* voltmeter, scale 0–10/140/700.



SELECTOR SWITCH	CONTACTS 7-PRONG SOCKET	SELECTOR SWITCH	CONTACTS 7-PRONG SOCKET
1	2 – 6	7	4 – 2
2	3 – 6	8	4 – 3
3	C-G – 6	9	4 – 5
4	1 – 6	10	4 – 6
5	6 – 4	11	5 – 3
6	6 – 5	12	5 – 4

FIG. 35—Schematic diagram of connections in Readrite Model 710-A tester.

A special positive contact selector switch connects all *d.c.* circuits to the *d.c.* volt meter. Panel jacks are provided to make individual range connections for the three meters.

The panel view and connection diagram are shown in figs. 34 and 35.

Philco Model 025 Signal Generator and Radio Tester.—This instrument consists principally of a volt-ohm-milliammeter for both *a.c.* and *d.c.* service.

The *a.c.* and *d.c.* voltage scales are 0–10/30/100/300/1,000. Current up to 10 amperes may be read directly on the milliammeter by using a special shunt.

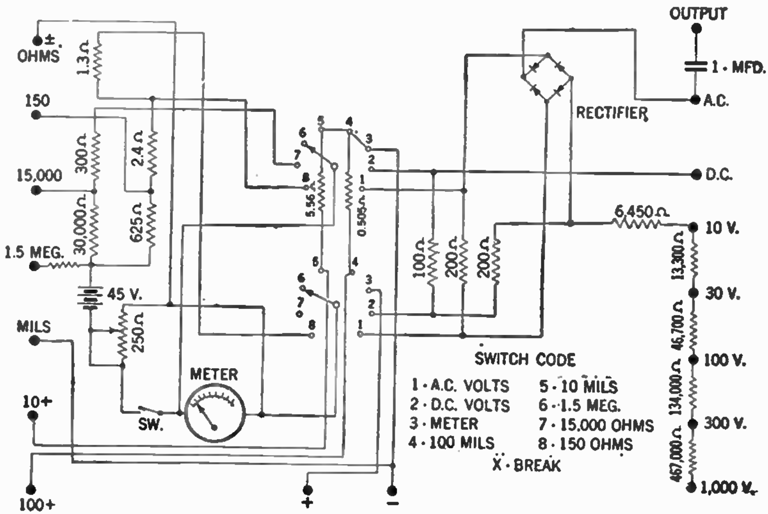


FIG. 36—Wiring diagram of Philco Model 025 radio tester.

The circuit is designed for capacity and resistance measurements which values are recorded on special scales, although in reading capacity (Mfd.) a special calibration chart should be consulted.

For internal connection and exterior views of instrument, see figs. 36 and 37.

Readrite Model 557 Signal Generator.—This signal generator is equipped with coil combinations to obtain frequency band as follows:

Coil "A" covers the band from	110 to	295	K.C.
Coil "B" covers the band from	275 to	840	"
Coil "C" covers the band from	820 to	2,800	"
Coil "D" covers the band from	2,500 to	8,500	"
Coil "E" covers the band from	8,000 to	20,500	"

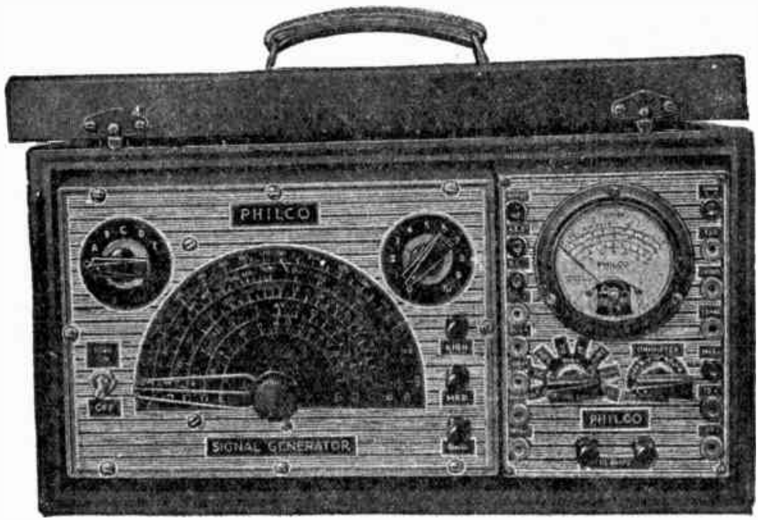


FIG. 37—Panel view of Philco Model 025 Signal generator and radio tester.

The operation of the oscillator is as follows: After determination of the frequency to be covered, select proper plug in the coil as shown under heading "Plug-in Coils"; place coil in 6-hole socket in shield can which is accessible by removing the nickle cap near the toggle switch marked "On-Off". Connect oscillator and set the attenuator to approximately 75 on the dial, after which the toggle switch marked "MOD-UNMOD" is set to position desired.

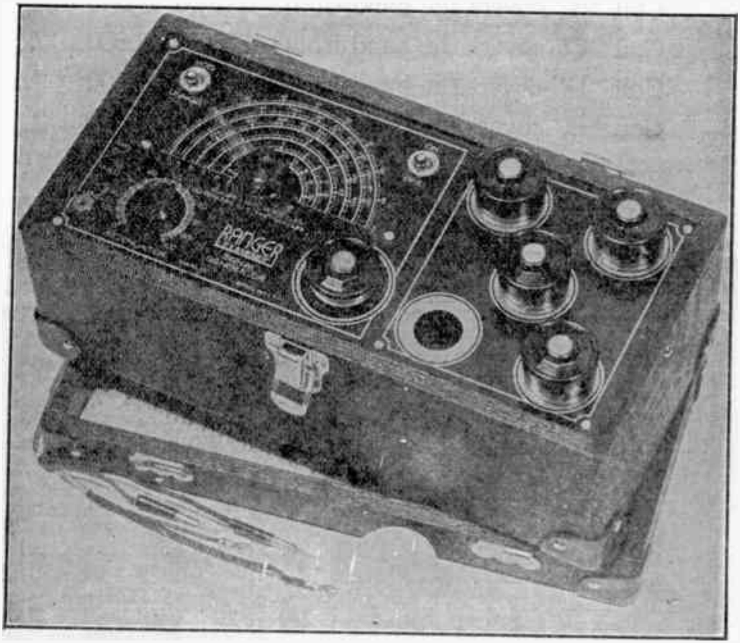


FIG. 38—Panel arrangement of Readrite Model 557 signal generator.

Generally speaking, all oscillator alignments are made with a modulated signal. Consult graph chart for the coil selected. Note dial setting for the frequency desired. Set dial pointer of frequency selector dial to the position as shown on graph. Turn oscillator power on by throwing the OFF-ON switch to the ON position and attenuate the signal to desired level by rotating the attenuator control so that a minimum signal is reached. If further reduction in signal strength is wanted, use jacks marked Minimum and Ground.

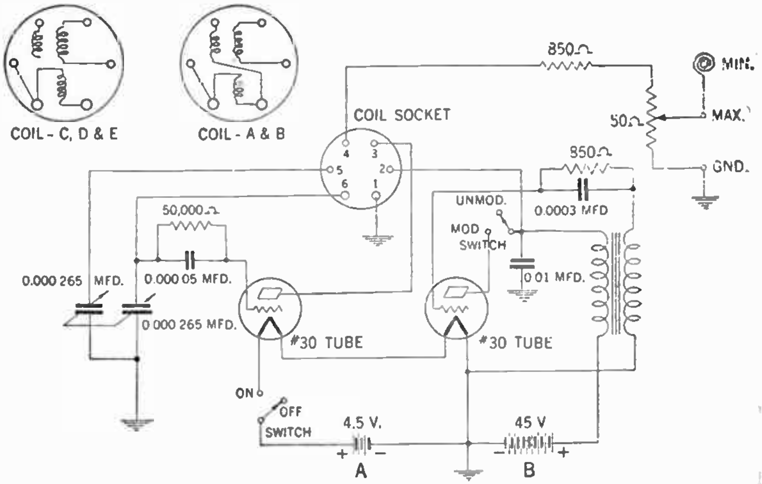


FIG. 39—Wiring diagram and coil arrangement in Readrite Model 537 signal generator.

Output Meter.—An output meter should always be connected to the radio output when using a signal generator. In order to avoid serious energy loss the output meter should be connected between the plate of output tube and chassis. If the output meter does not have a condenser there should be a condenser inserted in the output plate lead. This will prevent a burnout of meter. A .5 mfd. 400 volt condenser is suitable.

Vacuum Tube Voltmeters (General).—The vacuum tube voltmeter is an instrument used in service work for direct measurement across high impedance circuits, such as in the measurements of radio-frequency and audio-frequency voltages where the use of power consuming instruments would be unsatisfactory on account of the small current in the circuit.

For example, the impedance of an *r.f.* circuit such as is used in the first and second stage of a receiver may be as high as 2 or 3 megohms when adjusted to resonance with an incoming signal.

To make any measurement of potential across such a circuit it is obvious that a meter having a resistance of 3 to 4 megohms would be required, as a meter having a lower resistance might change the potential condition in the circuit it is desired to measure, too much, and hence make the measurement unsatisfactory.

It has been found that the only connection that could profitably be made across such a circuit without upsetting the circuit potentials would be that of another vacuum tube, the connection being made across the grid and cathode of said tube.

Essentially, the vacuum tube volt meter as the name implies, is nothing more than a vacuum tube connected through a meter in its plate circuit to a suitable power supply.

The grid and the cathode of the tube are connected across the circuit to be measured, the potential of said circuit causing a change in grid voltage on the tube and thus, a resultant change in plate current is indicated on the instrument.

As the vacuum tube is also a rectifier, potentials of any frequency placed across the grid and cathode of the vacuum tube voltmeter will result in a direct current deflection on the instrument in the plate circuit.

It is for this reason that the vacuum tube voltmeter can be used for measuring audio as well as radio frequency potentials provided the circuit is worked out correctly to cover this broad range of frequency.

Weston Model 669 Vacuum Tube Voltmeter.—Front view and internal connection of the instrument is shown in figs. 40 and 41 respectively. The principal characteristics of this type of instrument is as follows:

1. It has 6 self-contained ranges controlled by a rotary switch in the lower left hand corner, the full scale readings being 0–/1.2/3/6/8/12/16 volts. This meter is different from other multiple range vacuum tube voltmeters in that on all of these ranges only the grid to cathode impedance of the vacuum tube appears across the circuit to be measured.

2. The device operates directly from a 120 volt 60 cycle *a.c.* line, a self-contained transformer and power supply providing the necessary direct current potentials. A neon regulator bulb is used to hold the *d.c.* grid and plate voltages fixed irrespective of variations in line voltage. Up to the present time the problem of eliminating variations in vacuum tube meter readings with line voltage fluctuations has been a serious problem. The use of this regulator bulb has therefore put measurements of this type on a different plane as readings in the vicinity of .2 to 1 volt were practically impossible without having some sort of regulation of supply voltages.

3. Tubes used in the instrument are a type 78 and a type 1V, the former being the measuring tube and the latter the rectifier for the power supply. The 78 tube is mounted with the top projecting through the panel so that direct connection can be made to the grid cap using short leads. In the same way the grid is kept approximately 1 in. from any other metal surface and in this way input capacity is kept at a minimum.

4. A six range scale is provided, all *a.c.* readings being made directly without reference to curves or charts of any kind. The circuit has been worked out so that readings can be taken on 60 cycle lines without visible error, the frequency coverage of the device being from approximately 40 cycles up through receiver

short wave ranges. On very high frequencies such as from 10 to 20 megacycles slight errors will occur due to tube capacity even though this has been kept at a very low value. Such errors, however, are not very great being of approximately the same order as attained on other instruments used in this frequency range.

Among the measurements which can be made on this instrument is analysis of oscillator performance on super-heterodyne receivers, measurements of gain per stage in all types of receivers, checking of resonance, automatic volume control measurements, etc.

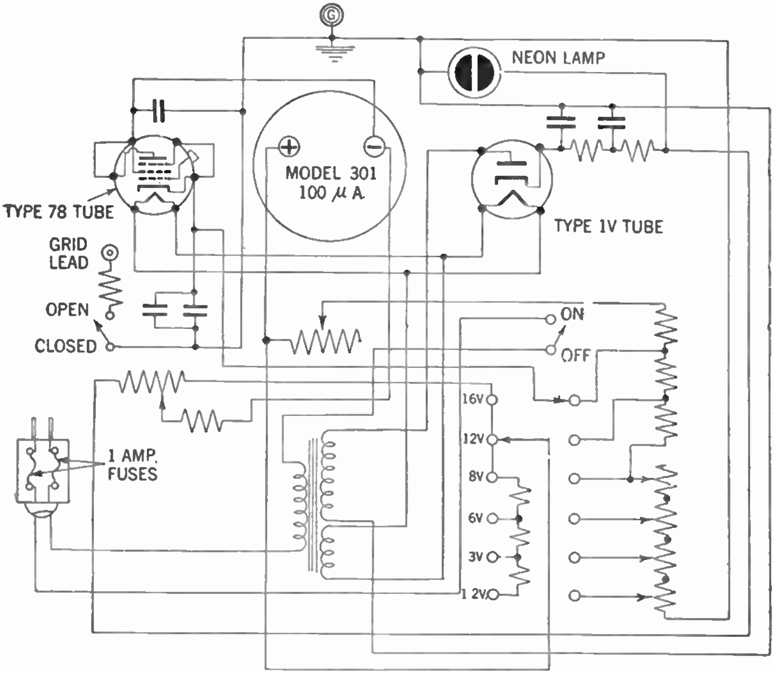


FIG. 41—Schematic wiring diagram of Weston Model 669 vacuum tube voltmeter.

CHAPTER 62

Resuscitation

General Points to be Observed.—The following suggestions should be carefully noted:

1. **Take Care of the Patient.**—An unconscious person becomes cold very rapidly, and chilling means a further strain on a vitality already weakened.

Experience has shown that the cold to which the victims of gassing, electric shock, or drowning are often carelessly exposed, is probably the most important cause of pneumonia, and this disease is the most dangerous after effect of all these accidents.

As far as possible keep the patient covered and warm both during and after resuscitation. Use hot pads, hot water bottles, hot bricks, radiant heaters or other similar means, but remember that an unconscious man has no way of telling when he is being burned. Do not permit the patient to exert himself. If it should be necessary to move him, keep him lying down.

2. **Medicines and Medical Help.**—Never give an unconscious man anything to drink. It may choke him. Medical science knows no drug which of itself will start the breathing in a patient whose breathing has ceased.

There is great danger of prematurely ceasing resuscitation. Breathing has been re-established after eight hours of resuscitation in cases of electric shock and of gas asphyxiation. Therefore, the ordinary and general tests for death should not be accepted, and any doctor should make several very careful examinations and be sure that specific evidence, such as the onset of rigor mortis, is present before the patient is pronounced dead and resuscitation is stopped.

Considering the widespread use of electricity for light, power, heat and many other purposes, it is almost surprising how few cases occur of serious electric shock from coming in contact with live wires.

However, when a case does occur, it often finds the witnesses as helpless as the victim because they don't know how to help him. Prompt help he needs and it can be easily given. Power plant engineers should be familiar with the subject because electricity is being used more and more in their plants.

In this chapter is given instructions for resuscitation from:

1. Electric shock;
2. Gas poisoning;
3. Drowning.

1. Prone Pressure Method for Resuscitation

Recommended by

National Electric Light Association

Follow These Instructions Even if Victim Appear Dead

I. Free the Victim from the Circuit Immediately

1. Quickly release the victim from the current, being very careful to avoid receiving a shock.

Use any dry insulator (rubber gloves, clothing, wood, rope, etc.) to move either the victim or the conductor. Beware of using metal or any moist material. If both of the victim's hands be grasping live conductors endeavor to free them one at a time. If necessary shut off current.

Begin at once to get the subject to breathe (resuscitation), for a moment of delay is serious. Use "Prone Pressure Method" for four (4) hours if necessary, or until a doctor has advised that rigor mortis has set in.

2. Open the nearest switch, if that be the quickest way to break the circuit.

3. If necessary to cut a live wire, use an ax or a hatchet with a dry wooden handle, turning your face away to protect it from electrical flash.

II. Attend Instantly to Victim's Breathing

1. As soon as the victim is clear of the live conductor, quickly feel with your finger in his mouth and throat and remove any foreign body (tobacco, false teeth, etc.).

If the mouth be tight shut, pay no attention to the above-mentioned instructions until later, but immediately begin resuscitation. The patient will breathe through his nose and after resuscitation has been carried on a short time, the jaws will probably relax, and any foreign substance in the mouth can then be removed. Do not stop to loosen the patient's clothing; ***every moment of delay is serious.***

2. Lay the patient on his belly, one arm extended directly overhead, the other arm bent at elbow and with the face resting

---

NOTE.—***Observe the Following Precautions:*** *a*. The victim's loose clothing, if dry, may be used to pull him away; do not touch the soles or heels of his shoes while he remains in contact—the nails are dangerous. If this be impossible, use rubber gloves, a dry coat, a dry rope, a dry stick or board, or any other ***dry insulator*** to move either the victim or the conductor, so as to break the electrical contact. *b*. If the bare skin of the victim must be touched by your hands, be sure to cover them with rubber gloves, mackintosh, rubber sheeting or dry cloth; or stand on a dry board or on some other dry insulating surface. If possible, use only *one* hand. If the man receive a shock while on a pole, first see that his belt is secure around the pole, if possible above cross arm so victim will not fall, then break the current. Pass a hand line under his arms, preferably through his body belt, securely knot it, and pass the end of the line over the first cross arm above the victim. If you be alone, pass the line once around this cross arm. If you be not alone, drop the line to those at the base of the pole. As soon as the rope is taut, free the victim's safety belt and spurs and descend the pole, guiding the victim. When the victim is about three feet from the ground, lower rapidly so that the victim's feet hit the ground hard.

on hand or forearm so that the nose and mouth are free for breathing, as in fig. 9,053.

3. Kneel, straddling the patient's hips, with the knees just below the patient's hip bones or opening of pants pockets.

Place the palms of the hands on the small of the back with fingers resting on the ribs, the little finger just touching the lowest rib, the thumb alongside of the fingers, the tips of the fingers just out of sight as in fig. 9,053.

4. With arms held straight, swing forward slowly so that the weight of your body is gradually brought to bear upon the subject, as in fig. 9.054.

FIG. 9,053.—Resuscitation from electrical shock by Prone pressure method. ***First Position.***

This operation, which should take from two to three seconds, *must not be violent*—internal organs may be injured. The lower part of the chest and also the abdomen are thus compressed, and air is forced out of the lungs, the diaphragm is kept in natural motion, other organs are massaged and the circulation of the blood accelerated.

5. Now *immediately* swing backward so as to completely remove the pressure, thus returning to the position shown in fig. 9,055.

Through their elasticity, the chest walls expand, and the pressure being removed the diaphragm descends, and the lungs are thus supplied with fresh air.

6. After two seconds swing forward again.

Thus repeat deliberately twelve to fifteen times a minute the double movement of compression and release—a complete respiration in four or five seconds. If a watch or a clock be not visible, follow the natural rate of your own deep breathing, the proper rate may be determined by counting—swinging forward with each expiration and backward with each inspiration.

7. As soon as this artificial respiration has been started and while it is being continued, an assistant should loosen any tight

FIG. 9,054.—Resuscitation from electrical shock by Prone pressure method. *Second position.*

clothing about the patient's neck, chest or waist. (*Keep the patient warm.*)

Place ammonia near the nose, determining safe distance by first trying how near it may be held to your own. Then the assistant should hit the patient's shoe heels about twenty times with a stick, and repeat this operation about every five minutes, until breathing commences. Do not give any liquids whatever by mouth until the patient is fully conscious.

8. Continue artificial respiration without interruption (if necessary for four hours) until natural breathing is restored.

Cases are on record of success after three and one-half hours of effort. The ordinary tests for death are not conclusive in cases of electric shock and doctors must be so advised by *you*, if necessary.

9. When the patient revives, he should be kept prone (lying down)—and not allowed to get up or be raised under any consideration unless on the advice of a doctor.

If the doctor has not arrived by the time the patient has revived, he should be given some stimulant, such as one teaspoonful of aromatic spirits of ammonia in a small glass of water, or a drink of hot ginger tea or coffee. The patient should then have any other injuries attended to and be kept warm, being placed in the most comfortable position.

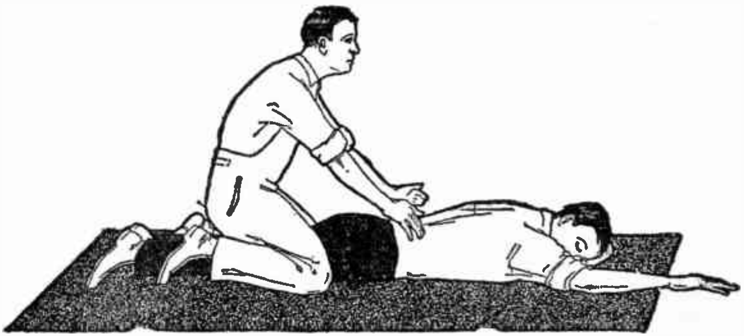


FIG. 9,055.—Resuscitation from electrical shock by Prone pressure method. *Third position.*

10. Resuscitation should be carried on at the nearest possible point to where the patient received his injuries.

He should not be moved from this point until he is breathing normally of his own volition, and then moved only in a lying position. Should it be necessary, due to extreme weather conditions, etc., to move the patient before he is breathing normally, he should be kept in a prone position and placed upon a hard surface (door or shutter) or on the floor of a conveyance, resuscitation being carried on during the time that he is being moved.

11. A brief return of spontaneous respiration is not a certain indication for terminating the treatment.

Not infrequently, the patient, after a temporary recovery of respiration, stops breathing again. The patient must be watched, and if normal breathing stops, artificial respiration should be resumed at once.

III.—Send for a Doctor

If other persons be present when an accident occurs, send one of them for a doctor without a moment's delay.

If alone with the patient, do not neglect the immediate and continued resuscitation of the patient for at least one hour before calling a doctor to assist in further resuscitation efforts. A published up-to-date list of doctors posted by the company is recommended.

IV.—First Care of Burns

When natural respiration has been restored, burns, if serious, should be immediately attended to while waiting for the doctor to arrive.

A raw or blistered surface should be protected from the air. If clothing stick, do not peel it off—cut around it. The adherent cloth, or a dressing of cotton or other soft material applied to the burned surface, should be saturated with picric acid (.5 per cent). If this be not at hand, use a solution of baking soda (one teaspoonful to a pint of water), or the wound may be coated with a paste of flour and water, or it may be protected with vaseline, carron oil, olive oil, castor oil or machine oil, if clean. Cover the dressing with cotton gauze, lint, clean waste, clean handkerchief, or other soft cloth, held tightly in place by a bandage. The same coverings should be lightly bandaged over a dry, charred burn, but without wetting the burned region or applying oil to it. Do not open blisters.

2. Gas Poisoning and the Inhalation Treatment

1. What Carbon Monoxide Does

The reason that automobile exhaust gas, the gases from coal heating furnaces, the smoke from fires, producer gas, coke oven gas, blast furnace gas, carburetted water gas, coal gas and other manufactured gases are poisonous if actually breathed is that they all contain carbon monoxide.

When carbon monoxide is breathed it combines with the blood. The more carbon monoxide there is in the blood, the less oxygen the blood will hold.

The gas victim becomes asphyxiated just as if he were being gradually choked to death. As low as one-tenth of 1% of carbon monoxide, or even less, in the air will kill a man in time; 1% will kill in a few minutes.

If the patient do not die in the gas, but is removed to fresh air, the carbon monoxide leaves the blood in a few hours. The quicker it is breathed out of the blood, the better are the chances of recovery.

If the asphyxiation has not been too long or severe, and the first aid treatment has been prompt and correct, the patient will recover completely.

2. Protect Yourself

Do not breathe gas yourself even for a short time. If it do not overcome you, it will cut down your strength. If you have to go into gas to get a man out, remember that nobody is immune. Protect yourself.

A handkerchief tied about the nose and mouth is not a gas mask; many have died in the belief that it is. It does not stop carbon monoxide; it simply filters off the irritating fumes in smoke, but carbon monoxide itself does not irritate the throat and has no smell. It gives no warning. It often paralyzes the legs first, and so suddenly that the man even though conscious may fall down, and cannot walk or crawl.

If you must go into gas or smoke wear a mask equipped with an air hose, or an oxygen breathing apparatus.

3. Get the Man out of Gas

When a man is overcome by gas, the first thing to do is to get him into fresh air quickly.

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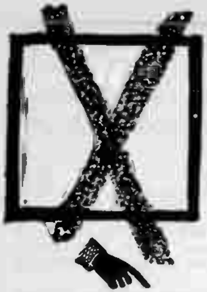

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