Cyclopedia
of
Applied Electricity

A General Reference Work on

DIRECT-CURRENT GENERATORS AND MOTORS, STORAGE BATTERIES, ELECTRIC WIRING, ELECTRICAL MEASUREMENTS, ELECTRIC LIGHTING, ELECTRIC RAILWAYS, POWER STATIONS, POWER TRANSMISSION, ALTERNATING-CURRENT MACHINERY, TELEPHONY, TELEGRAPHY, ETC.

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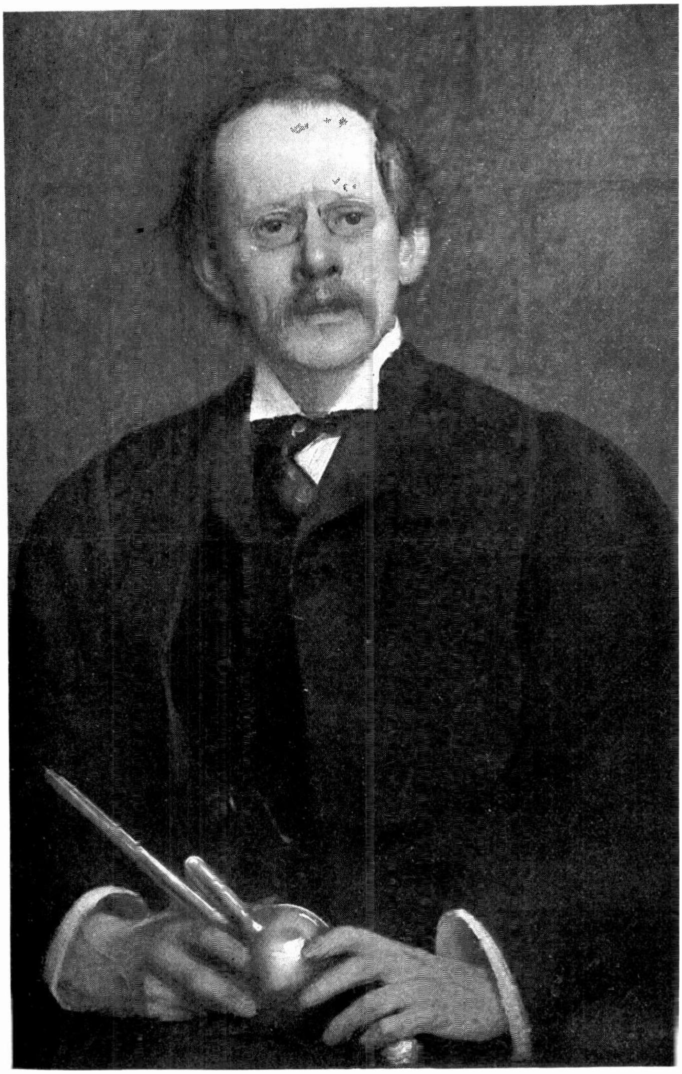

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THE editors have freely consulted the standard technical literature of America and Europe in the preparation of these volumes. They desire to express their indebtedness, particularly to the following eminent authorities, whose well-known works should be in the library of every electrician and engineer.

Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms and manufacturers in making these volumes thoroughly representative of the very best and latest practice in the design, construction, and operation of electrical machinery and instruments; also for the valuable drawings, data, suggestions, criticisms, and other courtesies.

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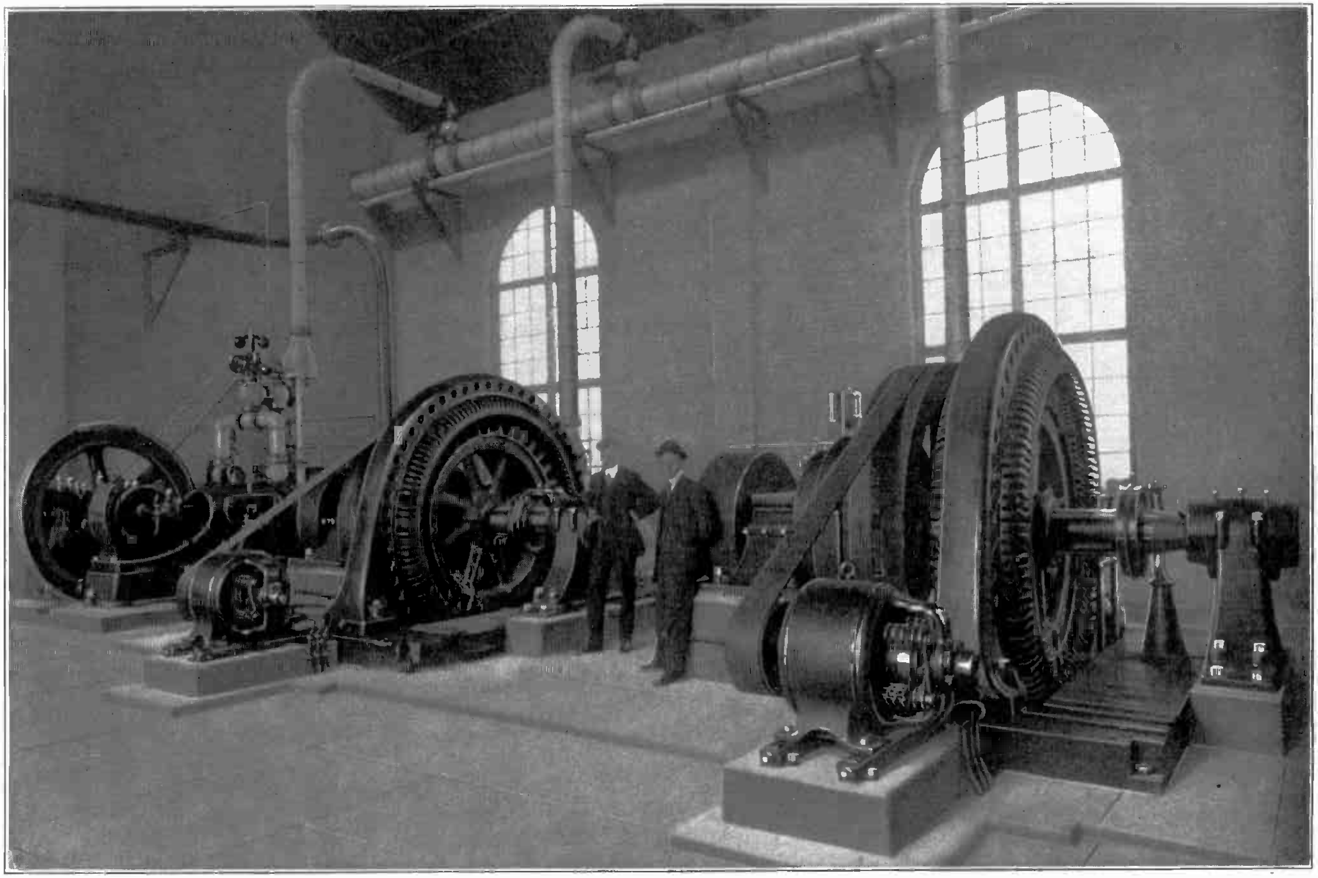

POWER HOUSE INSTALLATION OF THE HOCKING VALLEY RAILWAY COMPANY'S SHOPS AT LOGAN, OHIO
Allis-Chalmers Co., Milwaukee, Wis.

Foreword

ONE of the simplest acts in modern life is switching on the electric current that gives light or power, or that makes possible communication between distant points. A child can perform that act as effectively as a man, so thoroughly has electricity been broken to the harness of the world's work; but behind that simple act stand a hundred years of struggle and achievement, and the untiring labors of thousands of the century's greatest scientists. To compact the results of these labors into the compass of a practical reference work is the achievement that has been attempted—and it is believed accomplished—in this latest edition of the Cyclopedia of Applied Electricity.

¶ Books on electrical topics are almost as many as the subjects of which they treat and many of them are worthy of a place in the first rank. But many, also, worthy in themselves, are too scientific in their treatment to be available for the mass of electrical workers; and all of them, if gathered into a great common library, would contain so many duplicate pages that their use would entail an appalling waste of time upon the man who is trying to keep up with electrical progress. To overcome these difficulties the publishers of this Cyclopedia went direct to the original sources, and secured as writers of the various sections, men of wide practical experience and thorough technical training, each an acknowledged authority in his work; and these contributions have been correlated by our Board of Editors so as to make the work a unified whole, logical in arrangement and at the same time devoid of duplication.

¶ The Cyclopedia is, therefore, a complete and practical working treatise on the generation and application of electric power. It covers the known principles and laws of Electricity, its generation by dynamos operated by steam, gas, and water power; its transmission and storage; and its commercial application for purposes of power, light, transportation, and communication. It includes the construction as well as the operation of all plants and instruments involved in its use; and it is exhaustive in its treatment of operating "troubles" and their remedies.

¶ It accomplishes these things both by the simplicity of its text and the graphicness of its supplementary diagrams and illustrations. The Cyclopedia is as thoroughly scientific as any work could be; but its treatment is as free as possible from abstruse mathematics and unnecessary technical phrasing, while it gives particular attention to the careful explanation of involved but necessary formulas. Diagrams, curves, and practical examples are used without stint, where they can help to explain the subject under discussion; and they are kept simple, practical, and easy to understand.

¶ The Cyclopedia is a compilation of many of the most valuable Instruction Books of the American School of Correspondence, and the method adopted in its preparation is that which this School has developed and employed so successfully for many years. This method is not an experiment, but has stood the severest of all tests—that of practical use—which has demonstrated it to be the best devised for the education of the busy, practical man.

¶ In conclusion, grateful acknowledgment is due to the staff of authors and collaborators, without whose hearty co-operation this work would have been impossible.

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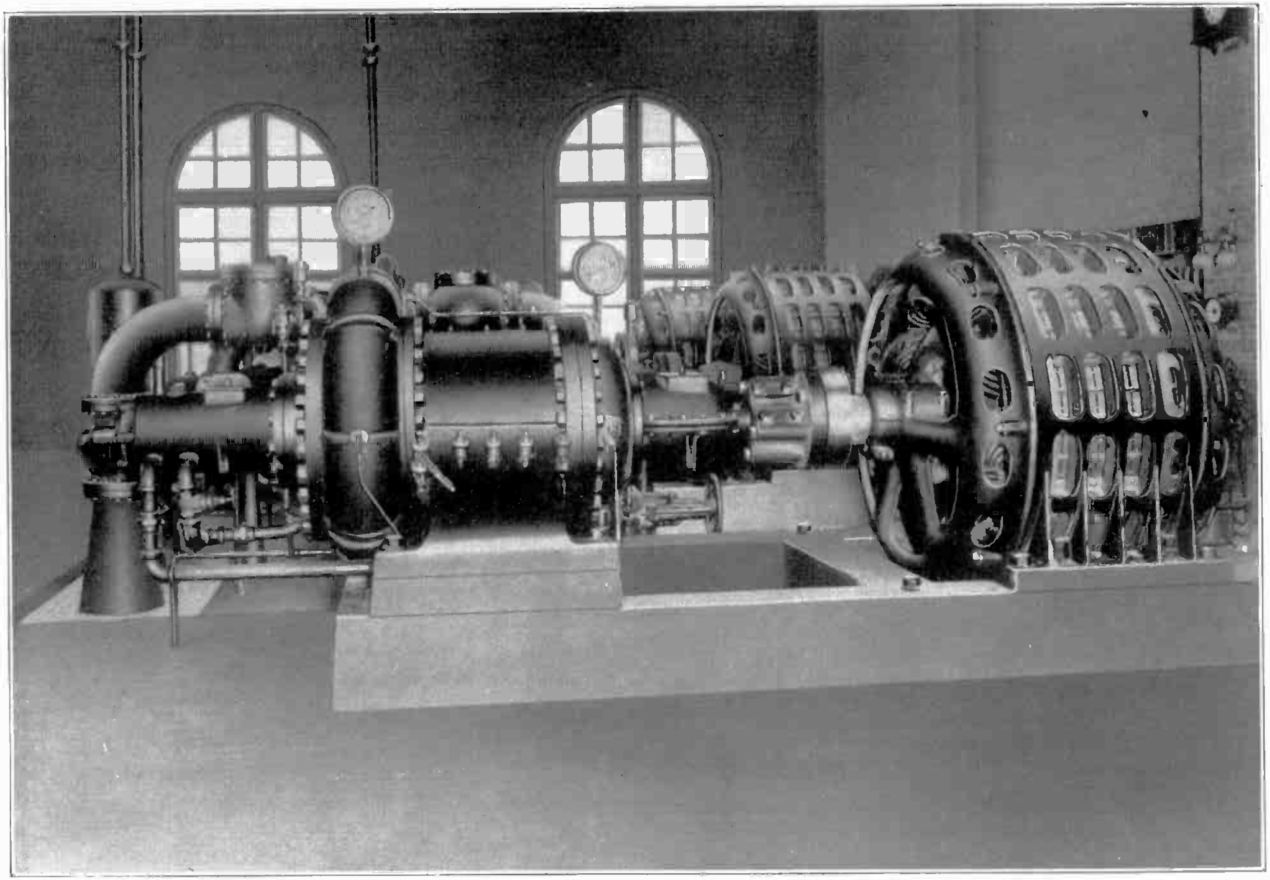
† For professional standing of authors, see list of Authors and Collaborators at front of volume.



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DIRECT-CURRENT MOTORS

Comparison between Dynamos and Motors. The dynamo is a machine for the conversion of mechanical into electrical energy; conversely, the electric motor converts electrical energy into mechanical work. The electrical energy delivered by the dynamo must be obtained from a steam engine, water-wheel, or other power; and the mechanical power obtained from the electric motor comes from the energy of the current flowing through its armature. The two machines are exactly complementary; and, in the case of direct-current apparatus, we shall see that the same structure can be used for either service. The differences that are found in practice are largely mechanical, and arise chiefly from the conditions under which the motor must work.

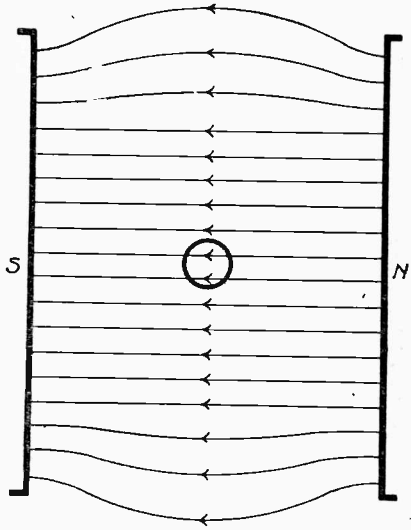


Fig. 1. Conductor Carrying No Current, in a Magnetic Field.

The study of the electric motor, therefore, begins with a knowledge of the dynamo; and before reading the following pages, the student should be sure that he understands fully the fundamental principles and mechanical details of Dynamo-Electric Machinery.

Force on a Conductor Carrying a Current. Fig. 1 represents a wire lying in a magnetic field, and carrying no current. If the polar surfaces of the field are large and close together, the magnetic lines pass straight from one to the other; they are not distorted, whether the wire is at rest or in motion. This is the condition in the air-gap of a dynamo or motor when no current is flowing in the armature conductors. The rotation of the armature in the magnetic field generates an electromotive force, but there is no mechanical force upon the conductors due to this action in itself. When, however, a current flows, it sets up a magnetic field of its own about the conductor, as shown in Fig. 2; and this field distorts the original field in which the conductor lies, making the magnetic lines denser on one side and less dense on the other. This is shown in Fig. 3.

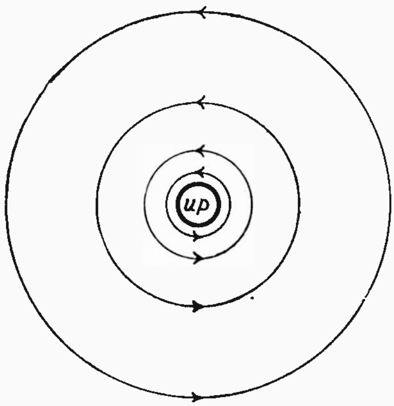


Fig. 2. Magnetic Field about a Conductor Carrying a Current.

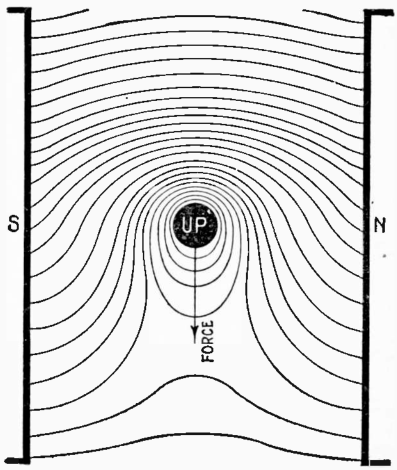


Fig. 3. Magnetic Field around Conductor in Dynamo or Motor Air-Gap.

Since the magnetic lines of a field endeavor to straighten and shorten themselves, the result of this distribution is a force upon the wire, pushing it in the direction of the arrow; and this is the principle of the electric motor. As in the dynamo, there are required: (1) a magnetic field; (2) a conductor lying perpendicular to it; and (3) provision for motion of the conductor across the field, in a direction perpendicular both to itself and to the field.

Fleming's Rule. The relation between the directions of the force, current, and magnetic lines can be most easily remembered by what is known as *Fleming's Rule.* Extend the forefinger, middle finger, and thumb, at right angles to one another; for example, the forefinger directly forward, the middle finger sideways, and the thumb upwards. Then if the forefinger represents the direction of the magnetic lines (that is, from the N pole through the air to the S pole), the middle finger will represent the direction of the current, and the thumb the direction of the motion. The right hand is to be used for the case of the dynamo, the left hand for the case of the motor.

Barlow's Wheel. An illustration of this principle is found in the simple electric motor invented by Peter Barlow in 1823, and illustrated in Fig. 4. A star-shaped metal wheel, usually of copper, rotates with its lowest points dipping into a little insulated pool of mercury. The wheel is connected through its bearings with one pole of a battery, the mercury to the other pole, the current flowing radially upward or downward through the wheel. When a horseshoe magnet is brought over the wheel, so that the portion carrying the current lies between the magnet-poles, the wheel revolves briskly, the direction of rotation changing whenever the direction of the current or the magnetic field is reversed.

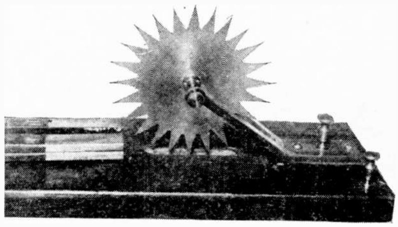


Fig. 4. Barlow's Wheel.

Magnitude of the Force on a Wire Carrying a Current. If the magnetic field has one line of force per square centimeter, and one absolute electromagnetic unit of current (10 amperes) is flowing in the conductor, the force upon each linear centimeter of the conductor will be one dyne. Hence, since the effects are directly proportional to the quantities involved, a wire L centimeters long, lying across a field of B lines per square centimeter, and carrying a current of I amperes, will be subjected to a force of:

$$L\ B\ \frac{I}{10}\ \text{dynes}.$$

This is practically a corollary of the definition of the ampere in electromagnetic measure.*

This expression may be reduced to the inch and pound units which are more common in American shop practice, by noting that one inch equals 2.54 centimeters; that one dyne is $\frac{1}{981}$ of the weight of a gram, nearly; and that 453.59 grams, or nearly 445,000 dynes, equal the weight of one pound. Hence the force F' upon

*Consult S. P. Thompson's *Elementary Lessons in Electricity and Magnetism*, or any similar textbook on Electricity.

a wire L'' inches long, lying perpendicularly across a field of B'' lines per square inch, and carrying a current of I amperes, will be:

$$2.54\ L'' + \frac{B''}{(2.54)^2} \times \frac{I}{10} \text{ dynes;}$$

or,

$$F' = \frac{L''\ B''\ I}{2.54 \times 445{,}000 \times 10} = \frac{L''\ B''\ I}{11{,}303{,}000} \text{ pounds, approximately.}$$

Upon N similar wires, the force will be N times as great.

Example. Fourteen hundred conductors of a certain large armature, each 11 inches long, lie in magnetic fields of 42,000 lines per square inch. What is the total drag upon them when each carries a current of 60 amperes?

Solution. The force is:

$$\frac{1{,}400 \times 11 \times 42{,}000 \times 60}{11{,}303{,}000} = 4{,}318 \text{ pounds, nearly.}$$

EXAMPLE FOR PRACTICE

Under the poles of a certain 25-kilowatt machine, there are 225 conductors, each $6\frac{1}{2}$ inches long, in magnetic fields of 40,000 lines per square inch. What current must flow in each conductor in order to give a total rotative force of 200 pounds?

ANS. 38.64 amperes, nearly.

In considering questions like the above, it is important to observe that only the conductors lying beneath the poles are subjected to these forces; and that the current in the individual conductors is not the full current of the machine, but only a fraction of it—one-half in the case of bipolar and wave-wound armatures; and one-fourth, one-sixth, or less, in the case of lap-wound armatures, according as the machine has four, six, or more poles.

It will now be clear that the driving force upon a dynamo armature must be increased in direct proportion to the load put upon the machine, and that the force causing a motor armature to rotate also depends on the current in it. The dynamo current is determined by Ohm's law, and the engine or water-wheel governor takes care of the power supply; but the way in which the electric motor adapts itself to the variations in its work, taking always just the necessary current for the work in hand, is not so clear at first sight. The explanation involves a most important property of the machine, known as the *counter-electromotive force.*

Counter-E.M.F. of a Motor. Since the armature wires rotate in magnetic fields, exactly as in the case of the dynamo, all the conditions for the generation of E.M.F. are fulfilled; and we should expect the motor armature to generate an E.M.F. accordingly, while in motion. The existence of such an E.M.F., and its direction, may be shown by the following experiment:

Take a small shunt-wound motor, and connect it as for ordinary running, but with the addition of a suitable incandescent lamp *L* and an ammeter *A* across the armature terminals, as shown in Fig. 5. When the motor is running, the lamp will glow, obviously supplied from the line; and the ammeter will show the direction of the current through it, as indicated by the arrow at *L*. The dotted arrows show the direction of the current in the other parts of the circuit. Now let the double-pole switch be opened; so far as the electrical conditions are concerned, the circuits may then be represented by Fig. 6; and the machine will run for a little while as a dynamo, driven by the energy stored in the rotating armature. The lamp still glows, and the ammeter shows that the current through it is in the original direction, dying out as the armature slows down to rest. Since the source of E.M.F. in the system is the revolving armature, and the direction of the current through the ammeter is known, it follows that in the other parts of the circuit the current must flow as indicated by the dotted arrows in Fig. 6. The reversal of the current in the armature can be shown directly by putting a second ammeter into the armature circuit, as indicated at *B*, Fig. 6, but the experiment can be performed equally well without it.

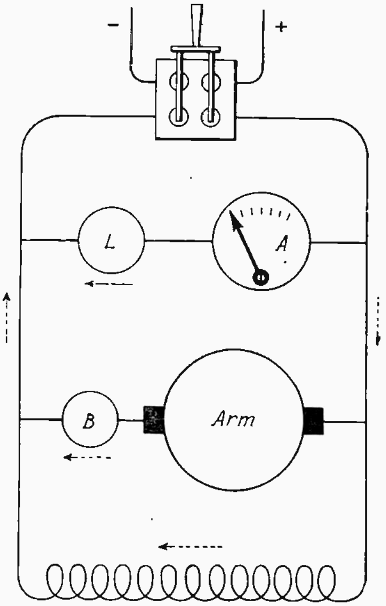


Fig. 5. Motor Connections to Show Counter-E.M.F.

This experiment is very instructive if performed with a motor of several horse-power. The experimenter should prevent the arm of the starting rheostat from flying back until the armature has entirely ceased to revolve.

A comparison of Figs. 5 and 6 now brings the conclusion that the direction of the current in the various parts of the circuit must be due to the existence of an E.M.F. in the revolving motor armature which is opposite in direction to the line E.M.F., and hence opposes the flow of current through the armature. For this reason it is called the *counter-E.M.F.* The electrical difference, therefore, between a dynamo and a motor is that in the dynamo the current flows *with* the E.M.F. of the armature, while in the motor it flows *against* it.

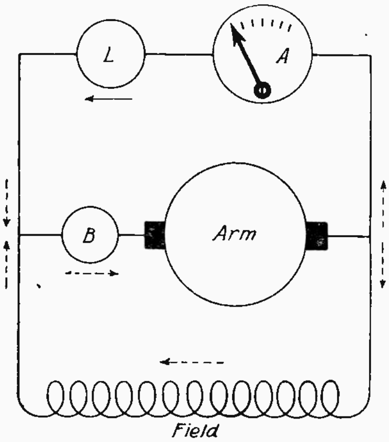


Fig. 6. Currents in Motor Circuits after Opening Main Switch.

Fundamental Motor Equation. From the above it follows that the current through the revolving motor armature is always less than the value obtained by simple calculation from Ohm's law, because E, the line E.M.F., is partially neutralized by e, the opposing counter-E.M.F. Hence the fundamental motor equation may be written:

$$I = \frac{E - e}{R}, \qquad (1)$$

in which I represents the current through the armature, and R the resistance of the armature circuit—armature, brush gear, and any other resistance that may be present.

The counter-E.M.F. is not readily measured; it is best calculated from Equation 1 with a knowledge of the other three quantities, which are easily measurable.

Example. A certain motor armature with its brush gear has a resistance of 0.188 ohm; and when running at a certain speed, takes a current of 55 amperes from a 220-volt line. What counter-E. M. F. is developed under these conditions?

Solution. Substituting the given values in Equation 1, we have:

$$55 = \frac{220 - e}{0.188};$$

whence,

$$e = 209.66 \text{ volts.}$$

EXAMPLE FOR PRACTICE

What current will flow through the above armature when its counter-E.M.F. is nine-tenths of the line voltage?

ANS. 117 amperes, nearly.

From these considerations it is plain that in the absence of other resistance in the armature circuit than that of the armature itself, a slight change in the counter-E.M.F. may make a great difference in the strength of the current flowing. Further, since the figures are taken from actual machines, it is to be noted that under ordinary running conditions the counter-E.M.F. rises well up toward the value of the line E.M.F. It can of course never quite equal the line E.M.F., for in that case no current would flow; and even when running without load, the friction and electrical losses of the motor absorb some power, so that a small fraction of the full-load current will flow, though the armature delivers no power at the pulley.

Efficiency and Losses. The energy-losses of the motor are the same as those of the dynamo, and may be classified under two heads:

Electrical Losses:

(*a*) I^2R losses in armature conductors and brush gear.
(*b*) I^2R losses in field windings.

Stray-Power Losses:

(*c*) Friction: of bearings, brushes, and air-currents.
(*d*) Iron losses: eddy currents in armature core, teeth, and magnet-poles; hysteresis in armature core and teeth.
(*e*) Commutator losses: wasteful currents in coils during commutation.
(*f*) Eddy currents in armature conductors.

The electrical losses (*a*) and (*b*) are measurable without much trouble; the others are very difficult to obtain separately, and are usually taken together under the general name *stray power*. For shunt motors, the field I^2R loss is independent of the load; the armature I^2R, of course, varies with the load. In the series motor, both field and armature I^2R vary with the load, since the same current passes through both. The stray-power loss is nearly constant for ordinary operating conditions, though it increases slightly with the speed of the armature.

The commercial efficiency η of a motor is simply the fraction of the power supplied that is available at the shaft; that is, it is the ratio of the power delivered to the power supplied; or, in the form of an equation:

$$\eta = \text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Input} - \text{Losses}}{\text{Input}}. \quad . . . (2)$$

The following table shows average values for the commercial efficiency of ordinary motors of various sizes, at full load:

TABLE I

Commercial Efficiency of Ordinary Motors

FULL LOAD H.P.	EFFICIENCY (Per Cent)
0.02 (Fans)	30
0.05 "	42
0.1	50
0.5	63
1.	70
5.	82
10.	85
25.	88
50.	89.5
100.	91
200.	92.5

The low figures for small motors are caused by disproportionately large field I^2R and friction losses.

Variation of Efficiency with Load. The efficiency varies with the load, because some of the losses are constant and some variable, the chief variable being the armature I^2R. When the motor is running idle, the current is small, and all its energy goes to supply the losses, the commercial efficiency being therefore zero. As the motor is loaded, the output at first increases faster than the losses, and the efficiency rises rapidly, reaching a maximum at a certain load which depends on the design of the machine. When the load is very heavy, the great increase in the armature I^2R causes the efficiency to fall again.

The efficiency is a maximum when the constant and variable losses are equal—for example, in the case of a shunt motor, when the armature I^2R loss equals the sum of the stray-power and field I^2R losses.* Since the distribution of the losses may be controlled by

*This proposition may be proved by algebraic methods, as follows:

Denoting by S the sum of the field I^2R loss and the stray power, the efficiency may be written:

$$\eta = \text{Efficiency} = \frac{EI - I^2R - S}{EI} = 1 - \left(\frac{IR}{E} + \frac{S}{EI}\right).$$

the designer within fairly wide limits, it follows that a motor (or a dynamo) may be designed to show its maximum efficiency at any specified fraction of its full load, or even at overload, though the latter is unusual. Motors should be designed to have their maximum efficiency with the load at which they are most used. An ordinary shop motor should show a maximum at about 75 per cent of its full rated load; a street-railway motor, at about two-thirds of the maximum power it is expected to develop (see Fig. 33); a fan motor, at its full load; and so on. A motor with large constant losses and small variable losses will have a low efficiency at light loads, and a high one at full load; while a machine with small constant and large variable losses will have a much higher efficiency at light loads than at full load. The most important point is not the full-load efficiency, but rather the maximum efficiency, coupled with another figure which we may call the *all-day efficiency*.

All-Day Efficiency. This is a matter of some importance in practice. It is simply the ratio between the work obtained from the motor during the day, and the energy taken from the line in the same time.

The difference between the performances of different machines in this respect, is best shown by an example. Suppose we have two 100-horse-power motors, motor *A* having constant losses of 2,700 watts, and armature I^2R losses of 6,400 watts; and motor *B* having constant losses of 4,800 watts, and armature I^2R losses of 3,200 watts. Suppose them to run through a 9-hour day, and that

---

For maximum efficiency, it is plain that $\frac{IR}{E} + \frac{S}{EI}$ must be a minimum; or, since E is a constant, that $IR + \frac{S}{I}$ must be a minimum. The sum of these two terms will be large when I is either very large or very small, and the problem is to determine the particular value of I for which it will be smallest. Denoting the sum by k, we may write:

$$IR + \frac{S}{I} = k, \quad \ldots\ldots\ldots\ldots \quad \text{(a)}$$

which is a quadratic equation in I. Solving this by ordinary algebra gives:

$$I = \frac{k}{2R} + \frac{1}{2R}\sqrt{k^2 - 4RS} \quad \ldots\ldots\ldots \quad \text{(b)}$$

Now, since a negative quantity cannot have a square root, the quantity under the radical sign cannot be less than zero, and therefore the smallest value k can have will be determined from the equation;

$$k^2 - 4RS = 0. \quad \ldots\ldots\ldots\ldots\ldots \quad \text{(c)}$$

Inserting in (a) the value of k obtained from (c), and reducing, gives as the final result $I^2R = S$; or, in other words, when a motor is working at its highest efficiency, the armature current is such as to make the variable losses just equal to the constant losses.

they run for 2 hours at quarter-load, 4 hours at half-load, and 3 hours fully loaded; let us calculate the energy actually delivered, and the energy taken from the line. Remembering that 1 H.P. = 746 watts, and that the I^2R loss varies as the square of the current, we have, for motor A, the following:

Constant Losses:	2,700 watts for 9 hours,	24,300 watt-hours.
I R Losses:	$\frac{1}{16}$ of 6,400 watts for 2 hours,	800 "
	$\frac{1}{4}$ of 6,400 watts for 4 hours,	6,400 "
	6,400 watts for 3 hours,	19,200 "
Output:	$\frac{1}{4}$ of 74,600 watts for 2 hours,	37,300 "
	$\frac{1}{2}$ of 74,600 watts for 4 hours,	149,200 "
	74,600 watts for 3 hours	223,800 "
	Input for the day:	461,000 watt-hours.

The all-day efficiency is therefore:

$$\frac{\text{Output}}{\text{Input}} = \frac{410,300}{461,000} = 89 \text{ per cent}$$

For motor B, we have:

Constant Losses:	4,800 watts for 9 hours,	43,200 watt-hours.
I^2R Losses:	$\frac{1}{16}$ of 3,200 watts for 2 hours,	400 "
	$\frac{1}{4}$ of 3,200 watts for 4 hours,	3,200 "
	3,200 watts for 3 hours,	9,600 "
Output:	as for motor A,	410,300 "
	Input for the day:	466,700 watt-hours.

Hence the all-day efficiency is:

$$\frac{410,300}{466,700} = 87.9 \text{ per cent.}$$

Thus, although motor B has a higher full-load efficiency than motor A (90.3 per cent as compared with 89.1 per cent), the latter returns the larger percentage of the energy put into it during the day, the difference being 5,700 watt-hours, or 5.7 kilowatt-hours in favor of A. It is thus seen to be a matter of some importance to keep the constant losses down to the lowest point consistent with satisfactory operation in other respects; and machines should be selected by the purchaser with reference to this point, as well as for full-load efficiency. For this reason the efficiency values at different loads may vary several per cent in motors of different but equally good design; and the figures in the preceding efficiency table must be regarded as only approximate. Most shop and factory motors are subjected to very variable loads; and the average load of a large number of motors in a given plant will often be found to be considerably less than 25 per cent of the total rated capacity of the motors in circuit. With motors designed upon the lines mentioned above, it may be said that the saving at average day loads would range from 4 per cent to 10 per cent in the larger motors (from 60 to 120 horse-power), up to a saving of 8 per cent to 15 per cent in the smaller motors.*

EXAMPLE FOR PRACTICE

Suppose a 100-horse-power motor were designed so as to have constant losses of 6,400 watts and armature I^2R losses of 2,700 watts, and that it works under the same conditions as those given for motor A in the preceding example. What would its all-day efficiency be, and how much more energy would it take from the lines in one day than motor A? ANS. 85.7 per cent; 18 + kilowatt-hours.

Current Required by Motors. The value of the full-load current is usually stamped upon the name-plate of the machine. If not, it can be approximately found from the rated output by assuming a value for the efficiency.

Example. What current will be required by a 220-volt, 15-horse-power motor?

Solution. From Table I (p. 8), the efficiency may be taken as 86 per cent. The output is:

$$15 \times 746 = 11{,}190 \text{ watts.}$$

The input is:

$$\frac{11{,}190}{0.86} = 13{,}012 \text{ watts.}$$

The current is therefore:

$$\frac{13{,}012 \text{ watts}}{220 \text{ volts}} = 59.1 \text{ amperes.}$$

EXAMPLES FOR PRACTICE

1. A 50-horse-power motor is connected to a 500-volt line which will carry 60 amperes. Can the motor be operated at full load? ANS. No.

2. Assuming an efficiency of 88 per cent, what is the maximum power that can be obtained from the above motor without overloading the line? ANS. 35.4 horse-power, nearly.

*Hobart, *Electric Motors*, 1904.

Effect of Counter-E.M.F. on Efficiency. At first sight it might appear that the counter-E.M.F. is merely an incident of operation, or at least a hindrance to the best performance of the machine; but a more careful study of the question shows that it is an essential factor in the economy of the motor. This can be most clearly shown by taking the artificially simple case of a motor whose only losses are the armature I^2R. This would be very nearly realized by a frictionless magneto-motor. Its efficiency η would be:

$$\eta = \frac{\text{Input} - \text{Losses}}{\text{Input}} = \frac{EI - I^2R}{EI} = \frac{E - IR}{E}. \quad \ldots (3)$$

But,

$$I = \frac{E - e}{R};$$

whence,

$$IR = E - e.$$

Substituting this value of IR in Equation 3, we have:

$$\eta = \frac{E - (E - e)}{E} = \frac{e}{E}. \quad \ldots\ldots\ldots\ldots (4)$$

That is, the efficiency is directly proportional to the counter-E.M.F.

This proposition is known as *Siemens' Law of Efficiency.* It should not be understood as implying anything concerning the output. The current taken by the motor diminishes as the counter-E.M.F. rises; and the power delivered also diminishes as the armature approaches full speed. But the equation does mean that the power delivered per ampere taken from the line is greater as the value of e approaches E; and therefore, though the actual power delivered is less, the available *percentage* of the line energy is greater than if the actual output were larger. For this reason it is entirely possible to operate a motor beyond its rated capacity, though at a reduced efficiency, the permissible amount and duration of the overload depending chiefly on the time required for the increased losses to heat up the machine dangerously.

In the actual motor, where other losses enter, the case is not quite so simple and direct as the above; but the difference is small, the complete equation being:

$$\eta = \frac{e - \frac{S}{I}}{E},$$

in which S is the sum of the field I^2R and the stray power, as on page 8. The fraction $\frac{S}{I}$ is only a few per cent of E, in ordinary running under load, so that the Siemens law holds, except for small values of I—that is, for light loads.

So it follows that the counter-E.M.F. is a valuable property of the motor, to be cultivated rather than ignored or eliminated; and the lack of success of early types of motors was in part due to a failure to realize this. In other words, the motor should be designed and operated to generate an E.M.F. exactly like a dynamo; and the formula for efficiency shows that the electrical and mechanical losses should be kept as small as practicable. The requirements for dynamos and motors are therefore the same, and it should now be clear that they must be designed along the same electrical lines. Consequently they are interchangeable.

The fact that a dynamo will transmit power to a similar machine as a motor is said to have been brought to light by a Paris workman in 1873, who accidentally connected the wires of an idle dynamo to the terminals of one in operation, whereupon the motionless armature immediately started up at full speed. The discovery of the general principle of interchangeability, however, dates back to 1852, and perhaps earlier.*

Torque. The torque of a motor is the turning moment or twist exerted upon the shaft. Grasp the pulley of a small motor firmly in the hand, and close the switch; a strong twisting action will be felt, which will set the armature in rapid rotation when freed. With the armature stationary, the torque is sometimes called *static torque*, to distinguish it from the *running torque* of the rotating armature, available at the pulley; the latter is less than the former by the amount necessary to overcome armature friction and core losses.

Since torque is caused by a force acting at the end of a lever arm, it is measured by the product of the force and the length of the arm—for example, by the product of the working pull of the belt and the radius of the pulley; or by the force upon the armature wires, multiplied by their average distance from the axis of the shaft. This product is generally expressed in *pound-feet*, which term denotes the

*S. P. Thompson, *Dynamo-Electric Machinery*, Edition of 1888, p. 13.

pull in pounds multiplied by the length of the lever arm in feet.* Thus a torque of 60 pound-feet may represent a working belt-pull of 60 pounds on a pulley 1 foot in radius, or a pull of 72 pounds on a pulley whose diameter is 20 inches, or any other combination of force and arm whose product is 60 pound-feet. For simplicity, torque is sometimes expressed in pounds only, a radius of one foot being understood or implied; but this is liable to cause confusion, because torque is not a force, but the moment of a force, and the radius of its action should always be given.

EXAMPLE FOR PRACTICE

If a motor has a torque of 40 pound-feet, what pull will be exerted at the rim of a pulley 16 inches in diameter?

ANS.. 60 pounds.

The torque of a motor may be measured by means of a Prony or friction brake. The arrangement of the apparatus is shown in

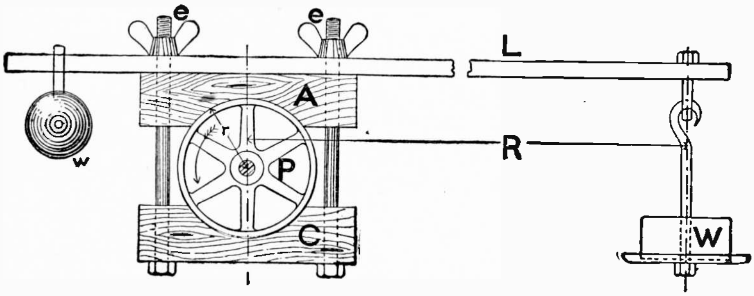


Fig. 7. Friction Brake.

Fig. 7. *P* is the motor pulley, *A* and *C* blocks of hardwood clamped against it, the pressure being regulated by the wing-nuts *e e*. The lever *L*, which may be of any convenient length, is counterbalanced by the weight *w*. When the pulley rotates in the direction of the arrow, the friction on the blocks tends to raise the weight *W*; and by adjusting the pressure on the blocks and varying *W*, a balance may be obtained, so that *W* when hanging free just neutralizes the tendency of the lever *L* to revolve. The torque of the motor is then $W \times R$, where *R* is the perpendicular distance from the axis of the shaft to the line of support of *W*.

*The term *foot-pounds* should not be used in this connection, for the foot-pound is a commonly used unit of work, and torque by itself is not work.

To find the torque when the motor is running at a certain speed or is taking a certain current, the nuts *e e*, must be adjusted until the speed or current is as desired, preventing the lever *L* from revolving by stops, and then varying *W* until a balance is obtained, when the stops are taken away. In making the measurement, it may be necessary to allow a little water to run upon the inside of the pulley, to absorb the heat generated by the friction. The wood blocks run best when dry, and a little smoke does no harm to the measurement. Instead of an adjustable weight *W*, a spring balance is more convenient. This is a very satisfactory method of testing small motors; for large ones, the heat is too great to be readily dissipated unless a special pulley is used which will hold water inside the rim.

The *power* of a motor is the product of the torque and the speed. For, if a force *W* acts at the end of an arm *R* fastened to a shaft, in one revolution the distance traversed by the point of application of the force is $2\pi R$, and the work done $2\pi R \times W$. In the case represented by Fig. 7, the work done by the revolving shaft is the same as if a weight *W* were being continually wound up on a pulley of radius *R*. If the shaft revolves *N* times per minute, the work done per minute is $2\pi R W \times N$; or, since RW is the torque, we may write:

$$\text{Power} = 2\pi \times \text{Torque} \times \text{Speed.} \qquad (5)$$

Denoting the torque by *T*, we have the further result:

$$\text{Horse-Power} = \frac{2\pi T N}{33{,}000} \qquad (6)$$

From Equations 5 and 6, it follows that different motors of the same power may have very different properties. They may give a strong torque at low speed, or a light torque at high speed, or may have intermediate values of both, different kinds of work requiring one property or the other. From the discussion on page 3, it follows that the actual force upon the armature wires depends upon their number and on the strength of the field, and the torque will also vary with the diameter of the armature. A strong torque will therefore be obtained by using an armature of large diameter, with many wires revolving in a strong field; but since these are just the conditions for a high E.M.F., such an armature will generate its full counter-E.M.F. at a lower speed than a smaller armature with fewer wires; that is, for a given voltage, the high-torque armature will run at relatively slow speed.

With the aid of Equation 6, it is a simple matter to measure the output of a motor by the brake.

Example. For a certain motor the distance R was 30 inches, the weight W 12.4 pounds, and the speed 1,400 revolutions per minute. What horse-power was developed?

Solution. Since R must be expressed in feet,

$$T = 2.5 \times 12.4 = 31 \text{ pound-feet.}$$

Substituting this value of T in Equation 6, gives:

$$\text{Horse-Power} = \frac{2 \times 3.1416 \times 31 \times 1{,}400}{33{,}000} = 8.25. \qquad \text{Ans.}$$

EXAMPLE FOR PRACTICE

A 500-volt motor rated at 15 horse-power takes a current of 25 amperes when driving a certain machine. It is then disconnected and fitted with a brake; and a test shows that with $R = 32$ inches,

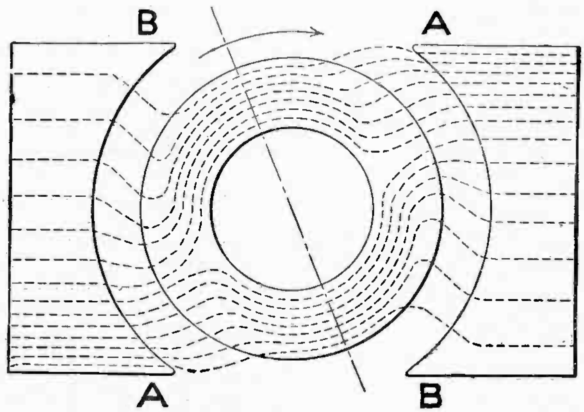
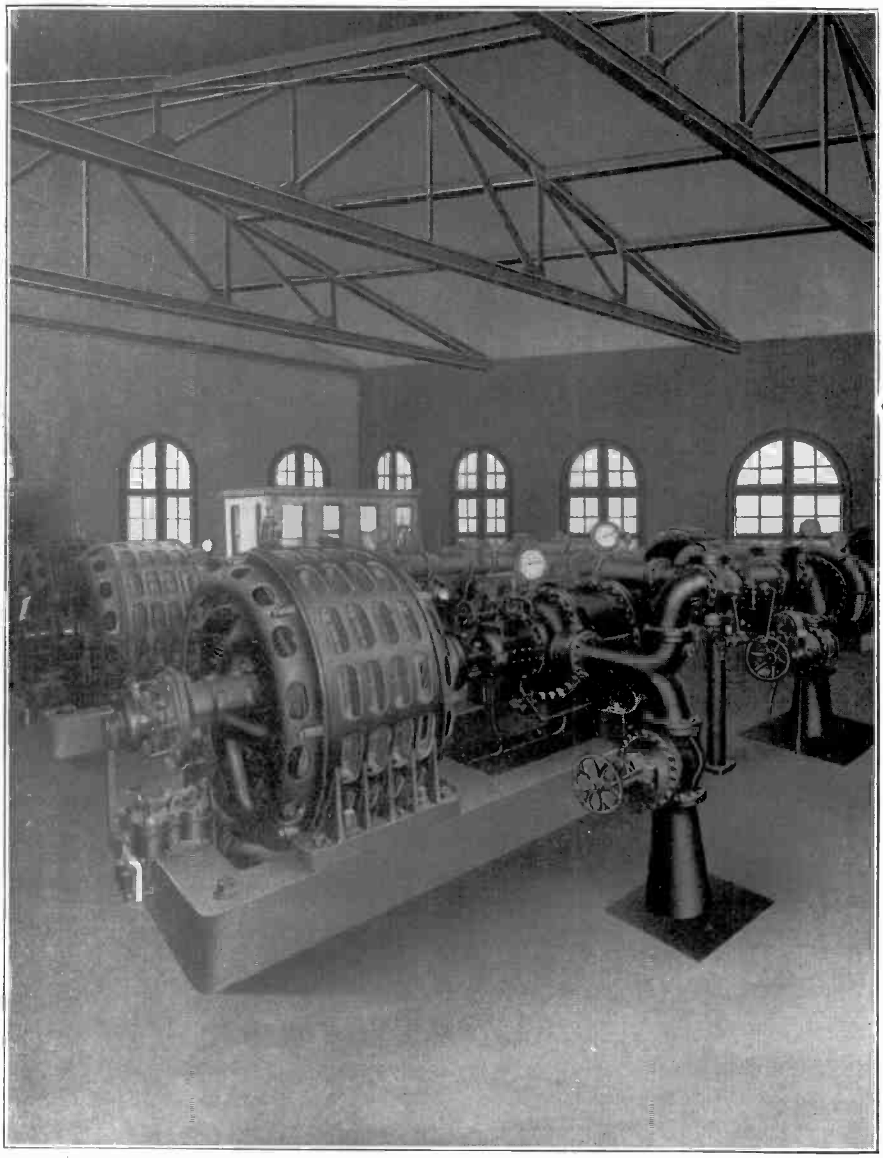


Fig. 8. Armature Reaction in Motor.

and the wing-nuts adjusted until the current is 25 amperes, the speed is 755 revolutions per minute; and $W = 36$ pounds. What is (*a*) the actual horse-power needed to drive the machine; and (*b*) the efficiency of the motor? Ans. 13.8 horse-power, nearly. 82.3 per cent.

Armature Reaction in Motors. In a motor the direction of the armature current, and hence the direction of its magnetic field, are opposite to those in a generator. The resultant field in the motor armature and air-gap will therefore be as shown in Fig. 8. It is evident that the neutral points are shifted backwards, while in a



INTERIOR VIEW OF MANHATTAN HIGH-PRESSURE FIRE SERVICE PUMPING STATION
Showing Five Allis-Chalmers Motor-Driven Centrifugal Pumps.

generator they are shifted forwards; hence for good commutation the brushes must be shifted *against* the rotation, while in the dynamo they are shifted *with* it. Most motors are required to operate without change of brush lead throughout the entire range of load; and this necessitates careful design, to the end that the field-magnets shall entirely overpower the armature reaction and keep the distortion of the field small, so that commutation may be good with the brushes fixed in position, no matter what the load may be. Many motors, particularly railway motors, must in addition run in either direction; and this requires fixing the brushes at the no-load neutral point. Such motors, however, cannot give as good commutation as those in which the brushes may be set backwards—a fact which is shown by the more rapid roughening and wear of the commutator and brushes. Nearly all motors are operated on constant-potential circuits, and carbon brushes are used almost without exception.

General Speed Formula. The factors upon which the speed of a motor depends can be obtained as follows:

The counter-E.M.F. depends upon the strength of the field f, the number of armature conductors z, and the speed of rotation s. Hence we may write $e \propto s f z$, or, in the form of an equation,

$$e = k s f z,$$

in which k is a constant depending on the design of the motor. Substituting this value of e in Equation 1, we have:

$$I = \frac{E - e}{R} = \frac{E - k s f z}{R};$$

and, solving for s,

$$s = \frac{E - IR}{k f z}. \qquad (7)$$

As already stated, IR is only from 3 per cent to 5 per cent of E in motors of ordinary size; and if we disregard it, we may write the simple relation:

$$s = \frac{E}{k f z}. \qquad (8)$$

That is, the speed of a motor is directly proportional to the E.M.F. at the brushes, and inversely proportional to the number of conductors on the armature and the strength of the field.

Other conditions remaining the same, it is plain that an increase in E will increase the speed, for increased E increases the current and therefore the torque, and the speed must evidently rise as an immediate consequence. But at first sight it is not so clear that the same result will be produced by weakening the field. The reason may be seen, however, by anticipating the result of the calculation on page 20, where it is shown that any reduction of the counter-

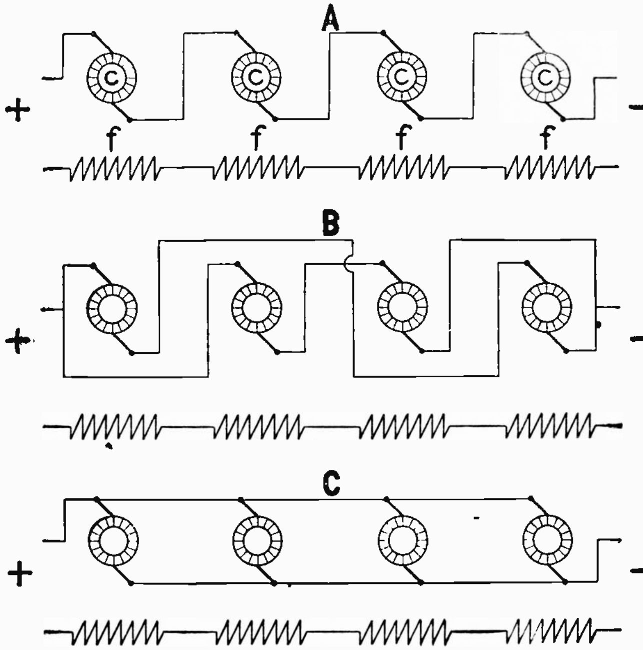


Fig. 9. Series-Parallel Connections of Four Motors.

E.M.F. increases the current in a much greater ratio. In the example there given, reducing the field strength 1 per cent increases the armature current 24 per cent, so that the actual increase in the torque is $\frac{99}{100}$ of 24 per cent (or 23.76 per cent), or practically in proportion to the current. Hence the speed increases, the increased current much more than compensating for the slight diminution in the field strength.

It is often desirable to vary the speed of a motor, and Equation 8 thus gives the three general methods for accomplishing the desired result—namely:

(1) By varying the E.M.F. at the brushes.
(2) By varying the strength of the field.
(3) By changing the number of wires on the armature.

Of these, methods 1 and 2 differ in details with different types of motor, and are discussed under each type. Method 3 is not practicable, since for satisfactory operation it would involve several independent windings, each with its own commutator. But where several motors drive one machine, the same result can be obtained by connecting the motor armatures in series or parallel combinations. Thus two motors may have their armatures connected in series or parallel by a suitable switch or controller; in the first case, half the line E is supplied to each armature; in the second case, the full E. With four motors the connections might be made as shown in Fig. 9, giving speeds in the ratio 1 : 2 : 4 with the arrangements A, B, and C, respectively, the motor fields f being kept constant. In the actual case, however, two-motor or four-motor combinations are used only in railway work; and four-motor sets are operated with the motors connected in pairs, like a two-motor equipment; in the latter case the additional flexibility of operation does not justify the extra complication introduced by taking the four as separate units. In general, this method of speed regulation is favorable to economical working, for the use of wasteful resistances is much reduced; but it does not warrant the installation of two motors when one will do the work.

CLASSES OF MOTORS

The preceding propositions are true for all classes of direct-current motors; but there are also many special properties depending on the relations that exist between the armature and field, so that it is next necessary to classify motors, like dynamos, with respect to the different methods of exciting the field. We have, accordingly:

1. Magneto motors.
2. Shunt motors.
3. Series motors.
4. Compound motors.

Magneto Motors. Because of the difficulty of making them self-exciting, very small dynamos are built with permanently magnetized fields. With motors, however, there is no such difficulty in obtaining the field, so that the magneto motor is not used, except where rotation in one direction or the other is desired by simply reversing the current without further complication. This is sometimes required in light mechanisms or controlling apparatus.

SHUNT MOTORS

To this class belong most of the motors used for all direct-current power service except railway work. The construction and electrical connections are exactly the same as for shunt dynamos, and any good shunt dynamo will make a correspondingly good motor. Shunt motors are practically always operated on constant-potential circuits, and, except at starting, the electrical connections are as shown in Fig. 10, both armature and field being connected across the line. Hence the field current and the field strength will be constant, and the torque will vary directly as the current through the armature, the current itself being determined by Equation 1.

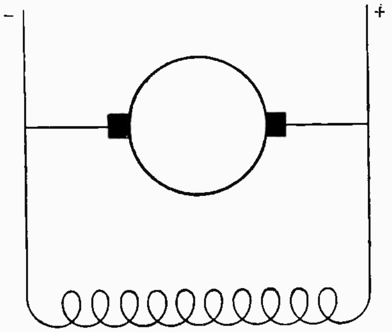


Fig. 10. Connections of Shunt Motor when Running.

The action of the shunt motor may be explained as follows:

Since the counter-E.M.F. varies as the product of the speed, strength of field, and number of armature wires, and the two latter factors are constant in this case, it follows that any change in the speed will cause a proportionate change in the counter-E.M.F. e; but, since e is nearly equal to E (the line E.M.F.), the current through the armature will change in a much greater ratio, a small decrease in the counter-E.M.F. causing a much greater increase in the current, and hence in the power delivered by the motor. For example, if the counter-E.M.F. of a 125-volt motor is 120 volts at a speed of 1,000 revolutions per minute, and the armature resistance is 0.2 ohm, the current at this speed is:

$$\frac{E - e}{R} = \frac{125 - 120}{0.2} = 25 \text{ amperes.}$$

If an additional load is put upon the armature, it naturally slows down. Suppose it to slow down to 990 revolutions per minute. The counter-E.M.F. will then decrease to $\frac{990}{1{,}000}$ of 120, or 118.8 volts; and the current will rise to:

$$\frac{125 - 118.8}{0.2} = 31 \text{ amperes.}$$

That is, a decrease of 1 per cent in the speed causes an increase of 24 per cent in the current; and the speed will continue to diminish until the current increases enough to supply sufficient power to prevent further speed reduction—that is, until the increased input equals the increased demand. Similarly, a diminished load which will allow the armature to speed up to 1,100 revolutions per minute will be accompanied by a decrease of 24 per cent in the current. Small variations of speed like this are not readily noticed; and to the casual observer the motor seems to adapt itself with uncanny knowledge to its work, in taking without apparent effort the precise current for every demand. The explanation lies, as we see, in the fact that only a slight change is needed in the delicate balance between E and e to

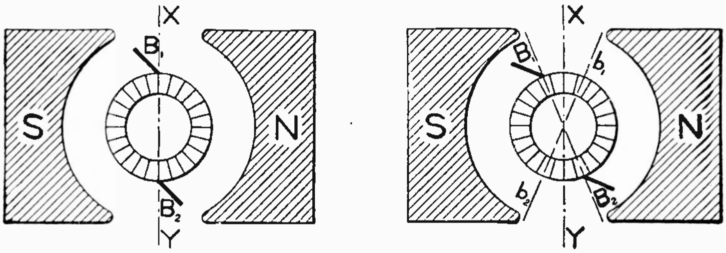


Fig. 11. Demagnetizing Effect of Motor Armature.

accomplish the observed result, by speed variations which are usually too small to notice, unless very sudden. If the load should be removed entirely, there is no tendency for the motor armature to race, for every slight increase in the speed increases e and diminishes the flow of current from the line, thus cutting off the power supply when it is not wanted.

The smaller the value of R, the greater will be the change in I for a given change in e; in other words, the smaller will be the variations in speed with changes of load. Since e differs from E by IR, the E.M.F. required to send the current through the ohmic resistance of the armature, and in well-designed machines IR is only from 3 per cent to 5 per cent of E, the speed falls off from no load to full load only by this small percentage; and we have in consequence the very valuable ability of the shunt motor to run at practically constant speed, irrespective of the load upon it. The small variations that actually do occur are not, as a rule, of sufficient importance to warrant special devices for their correction.

EXAMPLE FOR PRACTICE

Calculate the current through the above-mentioned motor when the speed is 1,100 revolutions per minute.

Ans. 18.95 amperes.

Effect of Armature Reaction on Speed. To eliminate sparking, we have seen that it is necessary to shift the brushes of a motor backward, and those of a generator forward. In both cases, there is introduced a demagnetizing belt of conductors, which weakens the field. This is illustrated in Fig. 11, which shows the motor brushes drawn backward from the no-load position. This action creates a demagnetizing belt of conductors lying between B_1 and b_1, and between B_2 and b_2. As the motor is loaded, the field is therefore progressively weakened by the increased current through this belt of conductors, and the counter-E.M.F. reduced correspondingly, which tends to increase the speed. Thus, by giving considerable backward lead to the brushes, it is possible to obtain nearly constant speed at all loads. Not all motors are designed to operate with so great a lead as this would often require; but the effect is always present in some degree, to the further advantage of the constant-speed tendency of the shunt motor.

Speed of Shunt Dynamo Used as Motor. If a shunt dynamo is used as a motor on a line of the same voltage, its speed as a motor will be less than when generating the line voltage as a dynamo. To find what the motor speed will be, we may proceed as follows:

To supply I amperes to the line at E volts, E_d, the E.M.F. generated in the armature, must be $E_d = E + IR$, where R is the armature resistance, because some of the E.M.F. generated is expended in sending the current through the armature itself. The E.M.F. generated in the armature of the same machine used as a motor is, from Equation 1:

$$e = E - IR.$$

Since the field strength is the same in the two cases, both being supplied at E volts, the armature E.M.F.'s will be directly proportional to the speed; or,

$$\frac{\text{Motor Speed}}{\text{Dynamo Speed}} = \frac{e}{E_d} = \frac{E - IR}{E + IR} = 1 - \frac{2\,IR}{E}, \text{ approximately.} \quad (9)$$

Since $\frac{IR}{E}$ lies ordinarily between 0.03 and 0.05, as we have seen, it follows that the speed of a given machine as a motor will be generally from 6 per cent to 10 per cent less than its speed as a dynamo. If, however, the field strength is not constant, either because of armature reaction or changes in the field current, the relation, of course, ceases to hold.

EXAMPLE FOR PRACTICE

A certain dynamo is rated at 25 kilowatts at 220 volts and 600 revolutions per minute. Its armature resistance is 0.08 ohm. What is its full-load speed as a motor? Ans. 550 r.p.m.

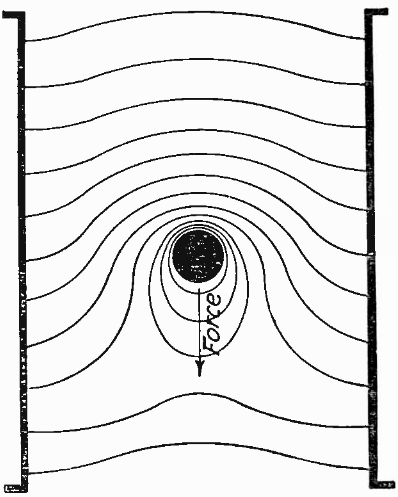


Fig. 12. Force on Dynamo Armature Conductor Moving Upward.

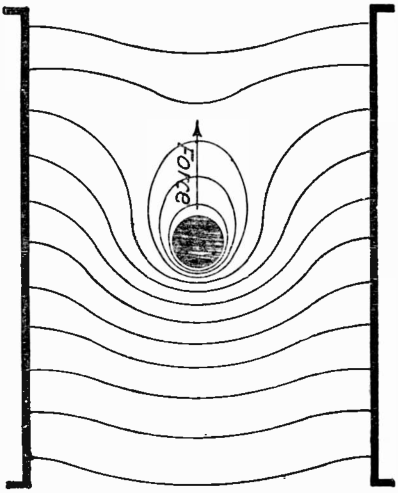


Fig. 13. Force on Motor Armature Conductor Moving Upward.

Direction of Rotation of Shunt Motor. To examine the behavior of a shunt dynamo used as a motor, a modification of Fig. 3 may be used. Fig. 3 gives the general directional relations between the field, current, and force upon an armature conductor; and Fig. 12 represents the case of a wire on a dynamo armature, moving toward the top of the page, the current creating a force on the wire which is against the direction of the motion, so that power is required to keep up the rotation. Now, if the machine is used as a motor driven by current from the same line, the direction of the field remains the same; but the current through the armature is reversed, and the field of Fig. 12 will be changed to that of Fig. 13. The force on the armature wires is reversed, and is now in the direction of the rotation, instead of against it as in the dynamo; consequently the armature will rotate in the direction of its rotation as a dynamo. The reversal of the current through the armature, and not through the field, is shown in Fig. 14.

This property is of considerable importance when shunt dynamos are operated in parallel. If reduced speed should cause the E.M.F. of any machine to fall slightly below the line E.M.F., the armature merely continues to revolve in the same direction as a motor, and no harm is done.

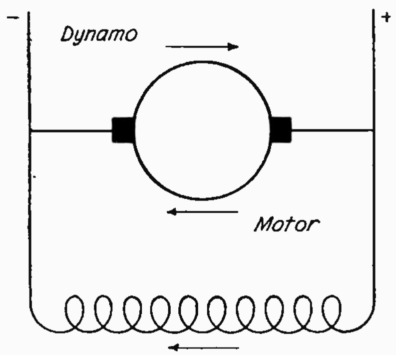


Fig. 14. Direction of Current in Shunt Dynamo and Motor.

To convert a shunt dynamo into a motor, therefore, if the direction of rotation is to remain the same, no change whatever is necessary. A starting rheostat must be added, but the machine itself needs no alteration.

The Starting Resistance. Very small motors are started by simply closing the switch that connects them to the line. No further apparatus is necessary, especially if they are series-wound, as is frequently the case to save the expense of a fine-wire shunt winding. For motors larger than about one-quarter of one horse-power, at full speed, the counter-E.M.F. prevents the current from exceeding safe values; but at starting, e is of course zero; and since R is always very small, the rush of current that would take place on throwing the full line voltage upon the motionless armature would blow out all the fuses, or might damage the armature or even the line itself. Hence it becomes necessary to insert a resistance temporarily in the armature circuit, cutting it out gradually as the speed rises. Such a resistance is called a *starting rheostat* or *starting box*.

The diminution of current through the armature as the speed increases may be easily shown by putting an incandescent lamp of about 50 candle-power in series with the armature of a small motor. Fan motors are usually series-wound; and with such it is enough to put the lamp anywhere in the circuit between the motor and the line. When the switch is closed, the lamp burns brightly for a moment and then grows dim as the armature speeds up, showing that under these conditions the starting current is much greater than the running current. The resistance of such small motors is high enough to prevent damage to the motor during the two or three seconds required to come to full speed, even though no starting resistance is used.

The starting box itself consists mainly of a resistance divided into small sections and arranged with suitable contacts so that by moving the arm of a switch the sections can be cut out one after another. At full speed, the entire resistance is cut out, and the full line E.M.F. is applied to the armature terminals. The resistance

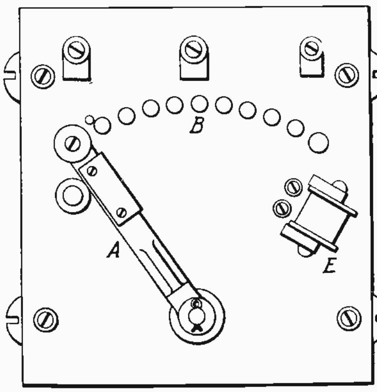


Fig. 15. Face of Starting Box.

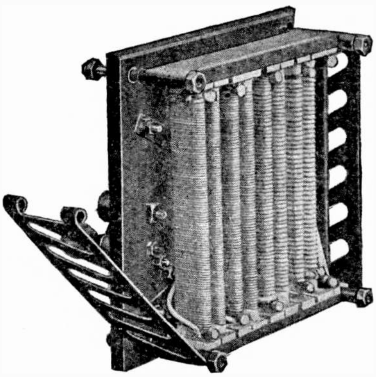


Fig. 16. Interior of Starting Box. Westinghouse Electric & Manufacturing Company, Pittsburg, Pa.

itself is made of iron wire or ribbon, wound upon asbestos-insulated tubes or strips, or embedded in insulating enamel.

The face of such a rheostat has the general appearance shown in Fig. 15, which shows the movable switch arm *A*, the row of contact studs *B*, and a small magnet *E* whose function will be explained later. The interior of a rheostat is illustrated in Fig. 16. One side and the bottom of the box are shown removed for inspection of the resistance coils or for repairs.

When the motor is of 50 horse-power or over, the sparking that always occurs at the contact-studs soon burns them and causes trouble, and the form of rheostat shown in Fig. 15 is being superseded by a type in which the sections of the resistance are cut out by separate switches. One such form is shown in Fig. 17. The cut represents a multiple-switch starter for a 500-horse-power, 220-volt motor.

The first switch on the left is held closed by an electromagnet through which the field current passes; and the other switches are held by latches. Each switch has upon it a metal plate which prevents closing it until the switch at its left has been closed; and the interlocking mechanism thus obtained prevents a careless operator from closing the switches in the wrong order. When the current is cut off, the switch on the left is opened automatically by a spring, and this

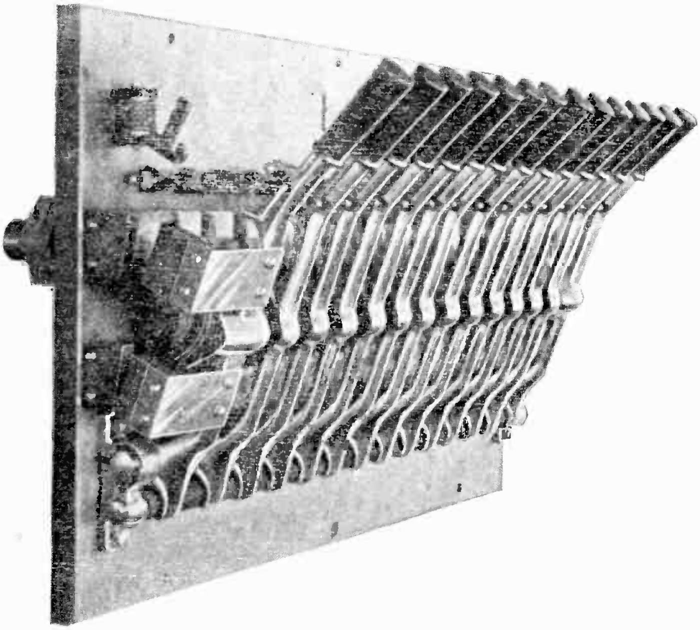


Fig. 17. Front of Multiple Switch Motor Starter, with Automatic Release.
Cutler-Hammer Manufacturing Company, Milwaukee, Wis.

frees the switch next to it; this opens in turn; and so on until all have opened, when the apparatus is ready for starting the motor again.

In starting motor-generator sets, rotary converters, and other apparatus where the starting current is only a small fraction of the running current, it is desirable to cut out the entire starting mechanism after full speed is attained. In such cases a simpler starting device is often used, of relatively small capacity and without automatic attachments. One form of such starting device is shown in Fig. 18. The picture shows clearly the way in which the steps of the resistance are cut out as the switch-blade is slowly pushed home. This switch is placed on the general switchboard of the apparatus, and the resistance mounted separately.

The maximum resistance R of the starting rheostat is determined by the equation $R = \frac{E}{I}$, where I is the current required to start the motor. Frequently motors must start under load, and the necessary starting current is considerabl greater than the normal full-load running current —sometimes two or three times as much. An good motor will safely endure this overload for the 15 or 30 seconds required to come up to speed; and many starting rheostats are designed to carry for this ti a 50 per cent excess over the full-load motor current. But when a greater starting current than this is needed, or when it is desirable to allow the motor a minute or more in which to come up to speed, the ordinary starting rheostat is liable to overheat, and one of larger size must be installed. With a designed to start the motor under load, the speed will rise rather quickly if the motor is not loaded; but this does no harm if the current is not excessive.

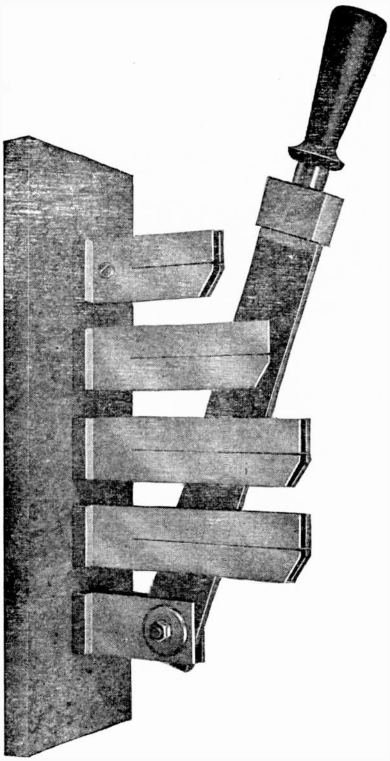


Fig. 18. Multi-Point Switch.
Westinghouse Electric & Manufacturing Company, Pittsburg, Pa.

Electrical Connections of Shunt Motor. Fig. 19 represents perhaps the simplest method of wiring a shunt motor and starting rheostat on constant-potential mains. From the line, the wires lead through a fuse-block F and a double-pole switch S. If the motor is a large one, a circuit-breaker is better than fuses. On tracing out the connections, it will be seen that when the switch S is closed the current flows through the motor fields. With the rheostat arm a in the position shown, no current flows through the armature; but on moving the arm to the first contact, the armature circuit is closed through the resistance *R*, which is gradually cut out as the handle is moved to the left. Opening the main switch cuts off the line current, but leaves the field connected across the armature terminals, as in a dynamo; so that, as the motor comes to rest, the fields die down

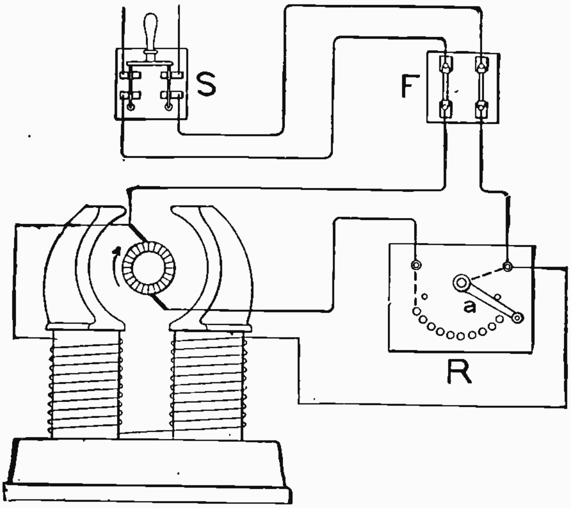


Fig. 19. Wiring Connections of Shunt Motor.

gradually without the destructive flash that would occur if the field circuit were opened suddenly while the magnets are excited. For this reason the field circuit should not be opened first.

When the armature has come nearly to rest, the rheostat arm is restored to the original position, and the motor is ready for starting again.

Automatic Release. The preceding diagram has been drawn to reduce the principle to its lowest terms and to keep the drawing clear; but in practice the simple rheostat shown is seldom used. After the motor is shut down by opening the main switch, the rheostat lever must be moved back by hand, to the starting position; and this is an operating detail that is very easily forgotten. Consequently, when the motor is to be started again, the position of the arm may not be noticed, and damage may be done by closing the switch with no resistance in the armature circuit. Furthermore, the power supply may be cut off and the line may become "dead" while the motor is running, whereupon the motor stops of itself with the rheostat arm in the running position as before. It is therefore the almost universal custom to install rheostats which are arranged to allow the arm to fly back automatically to the off position whenever the power is shut off from the motor. One method of accomplishing this is to connect the auxiliary or retaining magnet shown in Fig. 15 in series with the

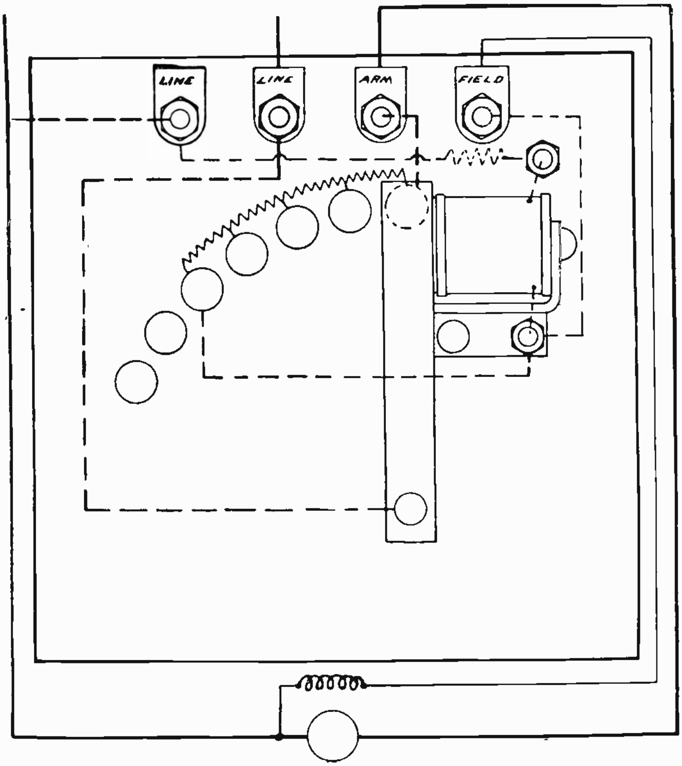


Fig. 20. Connections of Motor-Starting Rheostat with No-Voltage Release.

motor fields, the rheostat arm being provided with a spring tending to throw it back into the off position. When in the running position, as shown, the iron arm is held by the attraction of the magnet against the force of the spring; but when the motor loses its field, the magnet loses its power, and the spring carries the arm back into the off position. The retaining magnet is placed in series with the field rather than the armature, because it is thus independent of the load on the machine, and in addition affords protection in case the field circuit should be broken while running, thus leaving the armature without any counter-E.M.F.

There are other ways of accomplishing the same result. The one shown in Fig. 20 represents a method of connection employed by the General Electric Company. Here, as may be seen by tracing out the connections, the retaining magnet is connected across the armature terminals. When the line circuit is opened, the rheostat arm is held by the current generated in the magnet-coils by the armature E. M. F., until, as the armature slows down, the magnet weakens, and the spring pulls the arm over into the starting position.

Wiring Connections. Figs. 15 and 19 are typical. The ordinary starting rheostat has three terminals, which are usually marked *Line*, *Armature*, and *Field* or *Shunt Field*. There are four terminals on the motor (*a*, *b*, *c*, *d*, Fig. 21)—two for the armature and two for the field; but one armature and one field terminal are always at the same potential and may therefore be connected, leaving three separate terminals *c′*, *a*, and *b* on the motor, which may be called *Line*, *Armature*, and *Field*, respectively.

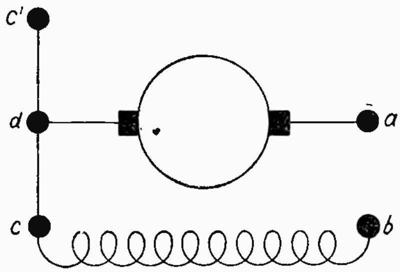


Fig. 21. Motor Field and Armature Terminals.

If the rheostat terminals are marked as above, the wiring of a shunt motor then becomes a simple matter. After putting in the fuses and double-pole switch, first run a wire from one pole of the switch to the rheostat terminal marked *Line*. Run a second wire from the *Armature* terminal of the rheostat to the free terminal *a* of the motor armature, and a third wire from the *Field* terminal of the rheostat to the free terminal *b* of the motor field. This wire, which carries only the field current, may often be made smaller than the others. Finally, run a wire from *c′*, the common terminal of the motor field and armature, back to the other pole of the switch.

A common mistake in wiring consists in interchanging the *Line* and *Armature* wires at the starting box. On the first contact-stud, this puts the field across the brushes and therefore in parallel with the armature, both being in series with the starting resistance. Hence, since most of the line E.M.F. is expended in the resistance, there is very little across the terminals of the field winding and the armature; and the field is consequently so weak that the motor may not develop sufficient starting torque unless the current is large enough to injure the starting box. This is one of the first places to look for the trouble, if a motor does not start properly when first installed.

There are several methods of arranging the connections inside the starting box itself, as shown in Fig. 22, in which the retaining magnet E is drawn outside the box for clearness. It will be noticed that the only difference is in the connection of the field circuit. In the upper diagram, closing the switch establishes the field circuit; while in the lower diagram, no current flows until the rheostat arm is moved to the first stud. In the lower diagram the starting resistance is always in the field circuit; but its resistance is so small compared with that of the field coils that its effect is not noticed. By an auxiliary contact m, the resistance is sometimes cut out entirely. The little magnet E takes only a few watts, and is without effect on the operation of the motor.

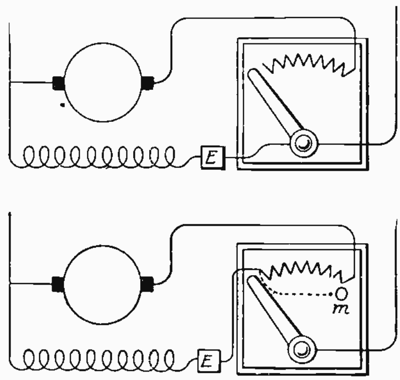


Fig. 22. Starting-Box Connections.

Overload Release. This is a useful addition to the starting box, for the purpose of cutting the motor out of circuit when the armature current becomes excessive, without relying on the fuses or circuit-breaker. It consists of a second electromagnet through which the armature current passes, mounted on the face of the starting box, and provided with a movable armature which hangs down like a hinge below the magnet-poles. When the current exceeds the proper strength, the armature is lifted by the attraction of the magnet and presses against little contact-pins, short-circuiting the release magnet holding the rheostat arm, whereupon the arm at once flies back to the off position.

This device is not intended to be used as a substitute for the fuses, but is adjustable and useful for taking care of overloads not exceeding about 50 per cent. Heavier fuses may then be used, giving the necessary protection but saving the annoyance of frequently blown fuses. Fig. 23 shows the connections of a rheostat equipped with an overload release of this type.

OPERATION OF MOTOR

To Start the Motor. In starting the motor, the following directions are to be observed:

1. Close the main switch. According to the method of con-

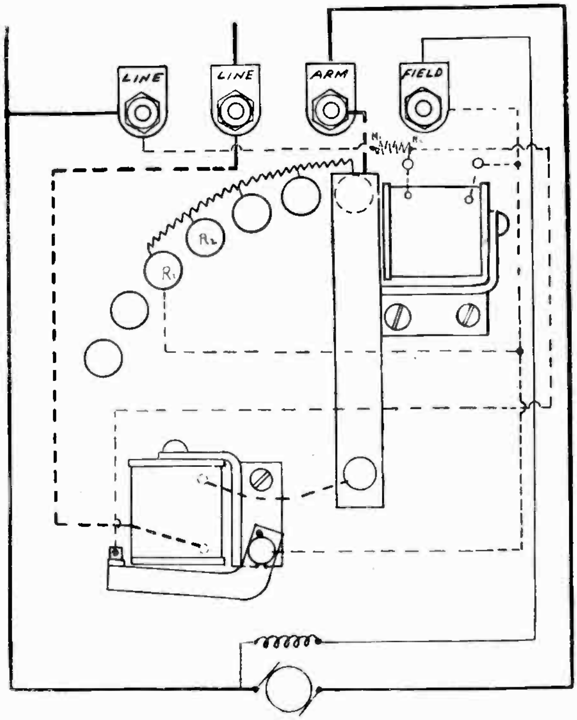
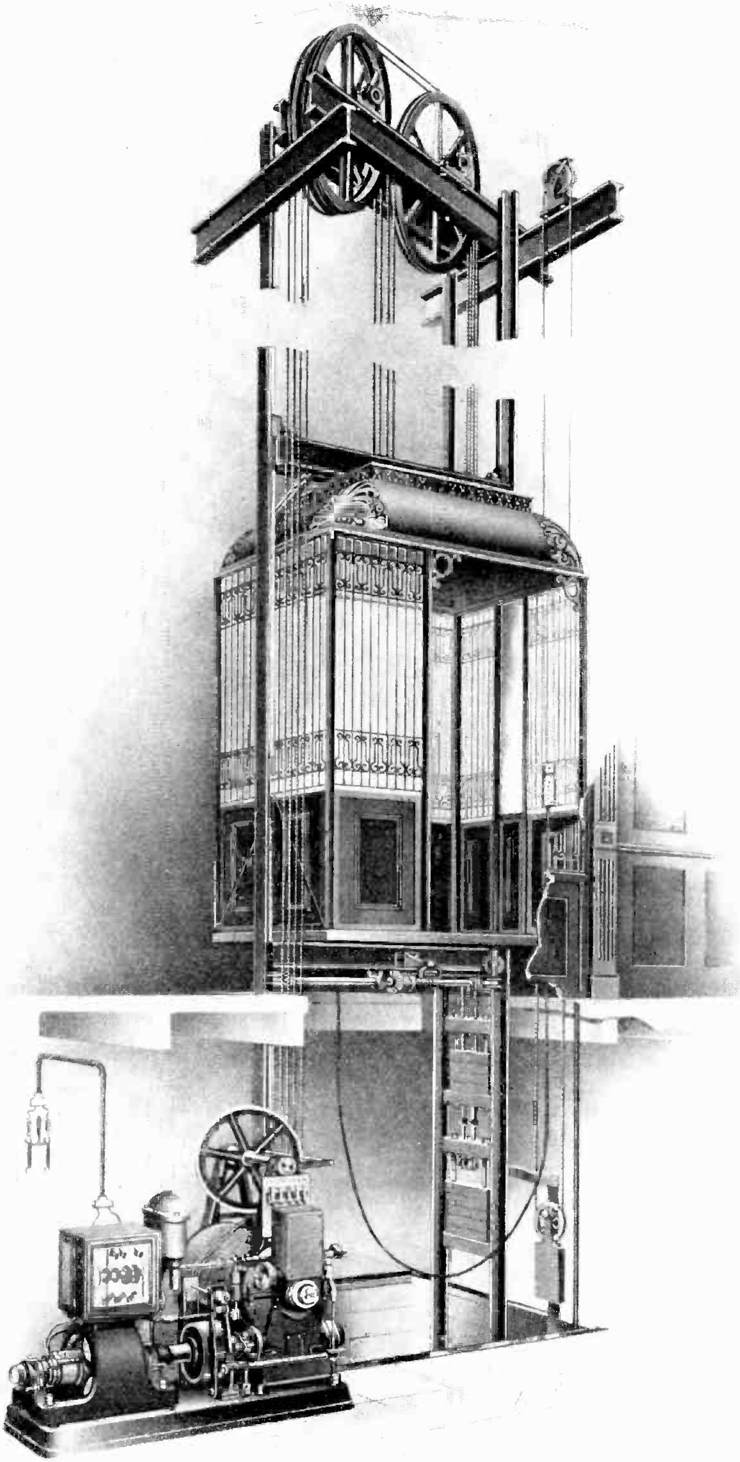


Fig. 23. Connections of Motor-Starting Rheostat with No-Voltage and Overload Release.
General Electric Company, Schenectady, N. Y.

nection, as shown in Fig. 22, this will either establish the current through the field, or will merely bring the line voltage up to the starting box.

2. Move the rheostat lever to the first contact, and hold it there for one or two seconds.

3. Move the lever to the second stud, and hold it there for about one second; and so on, until all the studs have been passed



WARNER AUTOMATIC PUSH-BUTTON ELEVATOR
No "Elevator Boy" Needed.

over and the resistance is short-circuited. The lever should then be firmly held by the retaining magnet. The entire operation should not consume more than 15 to 30 seconds.

If the motor does not start when the lever is on the third stud, open the main switch, and look for the trouble. It may be due to one or another of the following causes:

1. Overload.
2. An open circuit somewhere.
3. A short circuit somewhere.
4. Wrong connections.

No cause of motor trouble is more common than simple overloading. Always at the time of installation, and occasionally thereafter, an ammeter should be connected into the motor circuit, and its reading compared with the rated current of the motor. Motors are designed to do their work with but little attention. They frequently get none at all; belt, commutator, and bearings are neglected; additional machinery is put into the shop and operated from the original motor; and so on—with the inevitable result of overload.

The methods of locating troubles and remedying them, and of caring for dynamo-electric machinery in general, are matters of such importance that their full discussion requires treatment in a separate paper.

To Stop the Motor. Open the main switch. The motor will run for a little time by its own momentum, and the retaining magnet will not allow the rheostat arm to fly back until the armature has slowed down considerably. If the contact-studs are dirty, the lever may not move readily over them; and if it does not fly back sharply, they should be cleaned, and the spring on the lever adjusted if necessary.

Reversing Direction of Rotation. Most motors are now built with radial brushes, and may rotate equally well in either direction. To reverse the rotation, it is necessary to change the direction either of the field or of the armature current, but not of both, since the double reversal would be equivalent to turning Fig. 3 over twice, leaving the force upon the armature, and consequently the rotation, in the same direction as before.

To allow easy connection for rotation in either direction, some motors are provided with separate field and armature terminals, as shown in Fig. 24. The direction of the armature current can then be reversed by changing the connections as shown.

In motors which are to be reversed while in operation, the armature connections are the ones changed, because this causes less severe

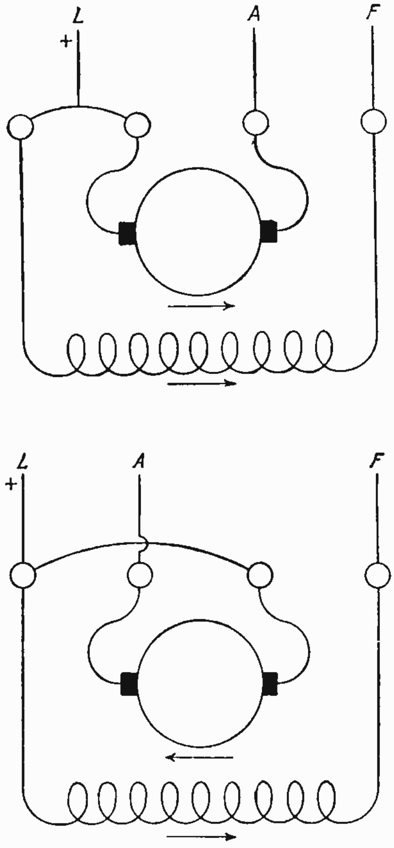


Fig. 24. Connections for Reversing a Motor.

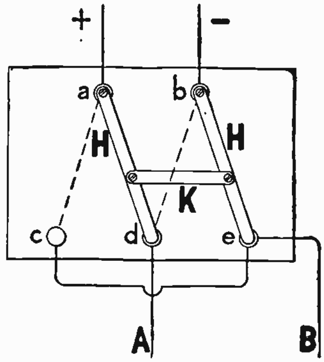


Fig. 25. Reversing Switch.

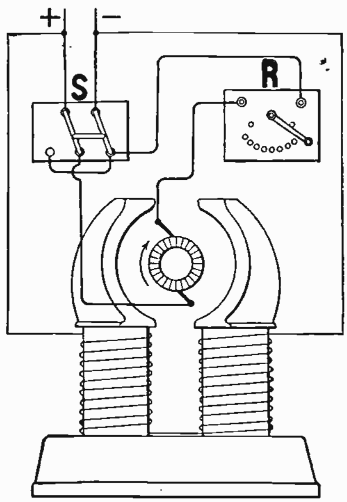


Fig. 26. Connections of Reversing Switch.

strains on the insulation than reversing the highly inductive field circuit. If the motor is merely to be reversed once for all, the brushes should be shifted to the proper lead on the other side of the no-load position; but if it must run in either direction while at work, of course no lead can be given to the brushes, and they must be fixed permanently in the no-load position.

A motor should never be reversed while running, except for the most necessary reasons, and then not until the full resistance is inserted in the armature circuit. For with the line E.M.F. reversed, the counter-E.M.F. of the armature is for a moment added to that of the line, and the excessive current that flows brings the armature to a stop with a severe jolt that is very likely to cause damage.

Fig. 25 shows one form of reversing switch; and Fig. 26, the manner of its connection into the armature circuit. In Fig. 25, *H* and *H* are brass bars pivoted at *a* and *b*, and connected by a fiber cross-piece *K*. As shown, they are in contact with the studs *d* and *e*. When *K* is moved so as to bring the bars on the studs *c* and *d*, as shown by the dotted lines, it is easy to see that the current will be reversed in the circuit *AB*.

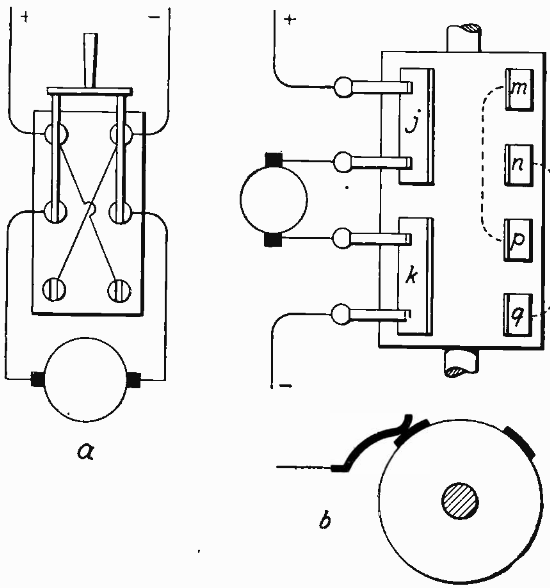


Fig. 27. Reversing Switches.
a—Knife Switch; *b*—Cylinder Switch.

Fig. 27 shows, at *a*, a simple and satisfactory reversing switch made by cross-connecting the clips of an ordinary double-pole, double-throw knife switch. The line circuit is connected to the clips; the circuit to be reversed is connected to the switch-blades; and simply throwing the switch up or down accomplishes the result.

At *b* in Fig. 27 is shown the principle of cylinder construction which, in a more elaborate form, is much used for speed controllers. In the diagram, an insulating cylinder carries two rows of contact-blocks against which spring contact-fingers press, connected to the various terminals of the motor circuit. When the cylinder is turned to bring the blocks *j* and *k* into contact with the fingers, the current will flow downwards through the motor armature; and with the blocks *m*, *n*, *p*, and *q* in contact, the current will flow upwards. It is obvious that this arrangement may be extended to execute much more complicated combinations of circuits, by the use of more fingers and more rows of contact-blocks; and in a highly developed form it is widely used for controlling the motors of street-railways.

Automatic Starters. The control of a motor from a distance usually involves the necessity of a *self-starting apparatus*, by which all the motions of the starting rheostat are automatically performed on closing the distant control switch. The movement of the rheostat arm is effected by a solenoid, and the rate of its motion is governed by a dashpot filled with oil. A valve in the dashpot allows the total time of the motion to be varied as required; or thick or thin oil may be used for the same purpose. Perhaps the most common instance of this kind of service is the supply of open tanks with water, and closed reservoirs with compressed air. In the first case, a float switch starts the pump when the water falls below a certain level, and stops it when the tank is full; in the second case, the pressure must be kept within certain limits, and a diaphragm valve makes and breaks the control circuit.

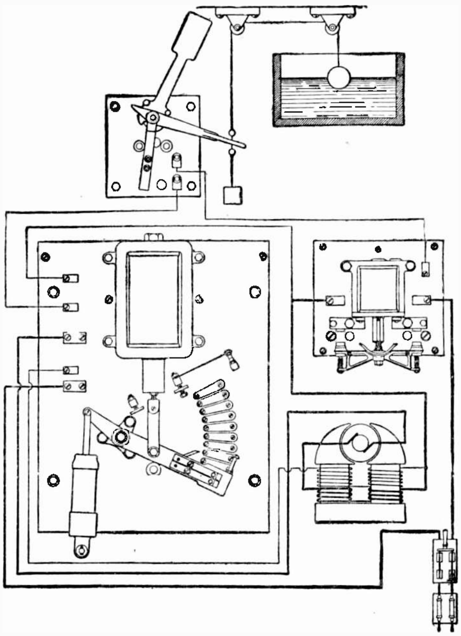


Fig. 28. Self-Starter Used with Motor-Driven Pump.
Cutler-Hammer Mfg. Co., Milwaukee, Wis.

Fig. 28 shows a self-starter operated by a float switch. This switch, when closed, energizes the solenoid of the main switch shown above the motor in the diagram. Closing the main switch also energizes the solenoid on the rheostat arm, and the arm rises, thus starting the motor. At the end of its travel, the arm breaks a contact, and by so doing inserts an incandescent lamp in the circuit of the solenoid, preventing overheating, a small current being enough to hold the arm in place. The motion of the arm also inserts a lamp resistance in the circuit of the main switch solenoid, as a safety device. For if the main switch is opened, and then closed before the rheostat arm has inserted all the resistance into the motor circuit, the rush of current might blow the fuses; but the lamp is short-circuited only in the off position of the arm; and only under these conditions is the current strong enough to lift the plunger and close the switch.

Reversing Starters. Lathes and other machine tools must often run backwards as well as forwards. Fig. 29 shows a starting apparatus designed to meet this condition. It is in effect a pair of starting rheostats, designed to bring the motor to full speed in either direction. When the handle is in the middle position, the motor is cut out of circuit; and moving the handle to one side or the other starts the motor forward or backward correspondingly.

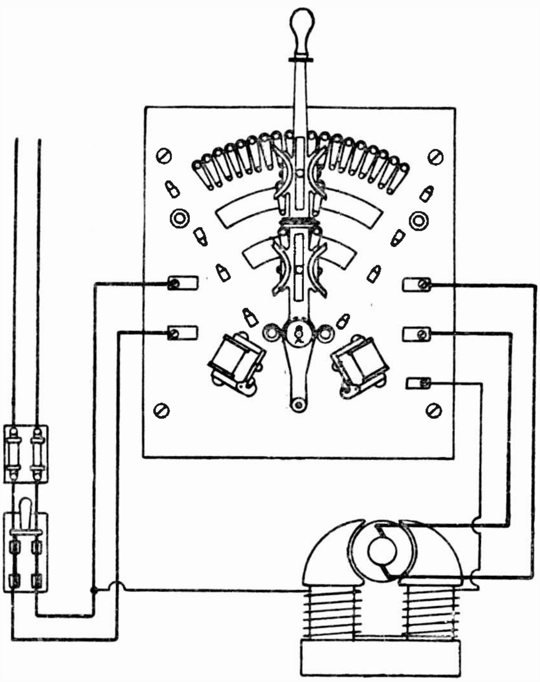


Fig. 29. Full Reverse Motor Starter.
Cutler-Hammer Mfg. Co., Milwaukee, Wis.

SPEED CONTROL OF SHUNT MOTORS

Varying E. M.F. at Brushes. A wide range of speed is easily obtained by simply inserting a suitable resistance in the armature circuit, as indicated by R, Fig. 30, leaving the field circuit FF unchanged. The amount of resistance inserted in order to obtain the desired speed and torque can be calculated in several ways.

Example. A certain 110-volt shunt motor takes 75 amperes at full load, at a speed of 700 revolutions per minute. What resistance must be put in series with the armature to obtain half-speed at two-thirds of the full-load torque?

Solution. In Equation 7 (page 17),

$$s = \frac{E - IR}{k\,f\,z},$$

R includes not only the armature resistance, but any other resistance that may be in series with it. At full speed there is no resistance in the armature circuit, except that of the armature itself; and this is negligible in problems like these, so that in this case we may write:

$$s = \frac{E - 0}{k\,f\,z} = 700 = \frac{110}{k\,f\,z}\text{; whence } k\,f\,z = 0.157.$$

The torque at the new speed will obviously require two-thirds of 75 amperes, or 50 amperes. Therefore, using Equation 7 again,

$$s = \frac{E - IR}{k\,f\,z} = 350 = \frac{110 - 50\,R}{0.157}\text{; whence } R = 1.1 \text{ ohms, nearly.}$$

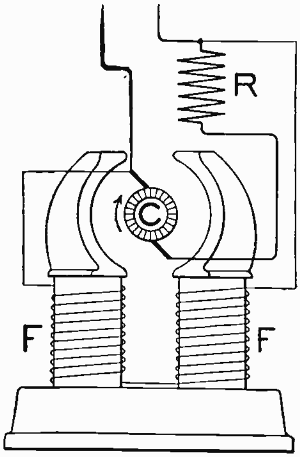


Fig. 30. Speed Control by Resistance in Armature Circuit.

For a more exact solution, the armature resistance should be known; but the above method is quite accurate enough for all ordinary cases.

The above method of speed control has the advantage of simplicity, cheapness, and wide range. It is objectionable, however, when the load is fluctuating, for the E.M.F. at the armature terminals, and hence the speed, depend upon the IR loss in the resistance; and IR of course varies with every change in I. Thus, whenever the load increases, the speed will decrease, and conversely; and this is objectionable in many classes of work. A second objection is that the voltage taken up in the resistance represents just so much power wasted, the loss in watts being simply I^2R. With a large motor, this loss may be a somewhat expensive matter; with a small one, the simplicity and convenience largely offset the cost of operation.

EXAMPLES FOR PRACTICE

1. The full-load current of a 250-volt motor is 20 amperes, and the speed 800 revolutions per minute. What resistance is required in series with the armature, to give $\frac{3}{4}$-speed with $\frac{1}{2}$-full-load torque?

Ans. 6.25 ohms.

2. What is the power loss in the resistance added to the 110-volt motor discussed above? ANS. 2,750 watts.

3. What fraction of the power supplied to the 220-volt motor above discussed is wasted in the added resistance?

ANS. 25 per cent.

It is important to note that for the above purposes the starting rheostat must never be used. The specific heat of the materials of the rheostat is utilized to keep its temperature within safe limits during the brief time required for starting. The box is not large enough to

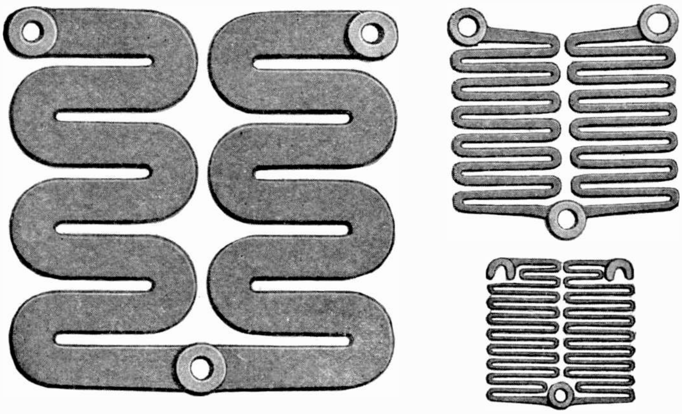


Fig. 31. Standard Grids.
Westinghouse Electric & Manufacturing Company, Pittsburg, Pa.

dissipate much heat, and, if used as a speed controller, would burn out in a very short time. Resistances used to dissipate much energy continuously, must have liberally proportioned surfaces and free ventilation. Small ones are usually made of iron wire, larger ones of iron ribbon, wound on asbestos supports to expose as much surface as possible to the air; very large ones are made of zigzag strips of cast iron, called *grids*. Fig. 31 shows single grids of various sizes. As many elements as needed are assembled in iron frames.

Speed Control by Varying Field. This method is very simple in principle, and wastes but little energy in the controlling resistance. By varying a resistance in series with the field windings of a shunt motor, the field, and hence the speed, are controllable to a certain extent. The advantage of this method of control is in its simplicity, and in the fact that since the field current is small, there is but little energy wasted and little heat to dissipate from the rheostat. Further, the speed is adjustable by small steps. The disadvantage of the method arises from the fact that the field must not be weakened below the point of satisfactory commutation. This, with an ordinary motor, limits the speed variation to about 25 per cent, or perhaps 30 per cent. If a greater range than this is required, a larger and

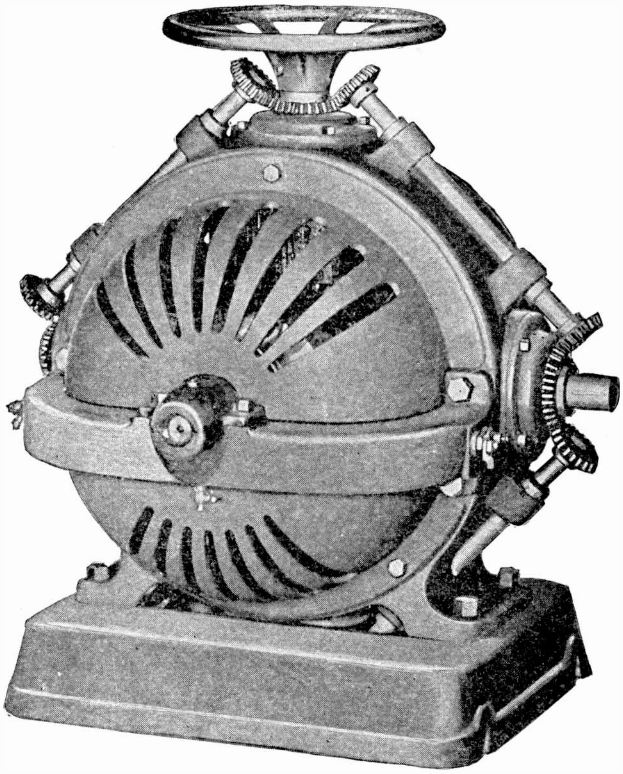


Fig. 32. Variable-Speed Motor.
Stow Manufacturing Co. Binghamton, N. Y.

heavier field-magnet must be provided; for example, for a 2 to 1 variation, a 15-horse-power frame should be used for a 10-horse-power motor, while a 3 to 1 variation requires a 20-horse-power frame for a 10-horse-power motor, with other sizes in proportion. This, of course, means a motor of large size in proportion to its output. The torque diminishes with the weakened field, and this is just compensated by the increased speed, so that the motor runs with practically constant horse-power output. For still greater speed variations, special constructions are used, which will be described later. Fig. 43 (page 52) shows an adjustable-speed motor giving a 3 to 1 variation in speed by variation of field resistance.

Apart from the extra size of the motor, speed control by this system is very satisfactory where conditions do not warrant the installation of a multiple-voltage system.

Control by Varying Magnetic Reluctance. If the reluctance of the magnetic circuit is varied, the field strength will vary though

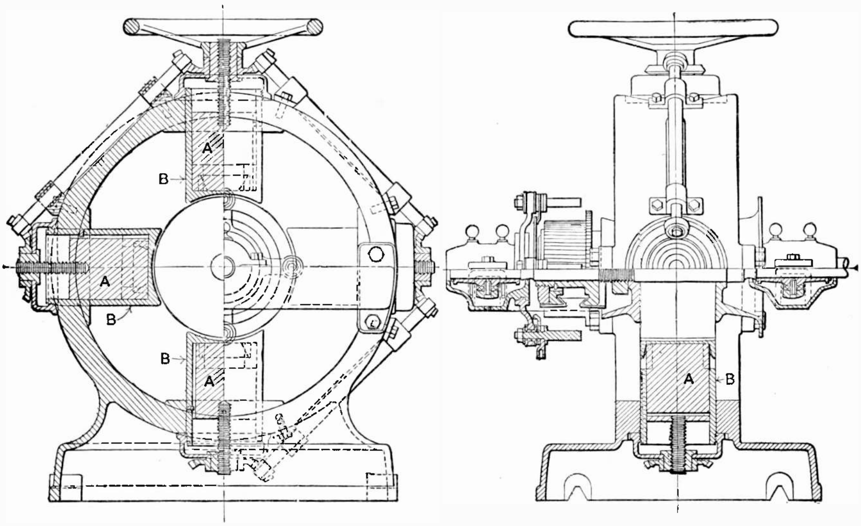


Fig. 32A. Sectional Views of Variable-Speed Motor Shown in Fig. 32.

the field current is kept constant. Advantage of this is taken in the motor illustrated in Fig. 32. In this machine the field cores and poles are hollow and provided with iron plungers, which can be moved toward the armature or away from it by a hand-wheel operating suitable gearing. The advantage of this construction is that, when the plungers are withdrawn, the magnetic flux is obliged to enter the armature through the edges of the pole-pieces; and hence, even with the weakest total field, the actual distribution is always such as to give proper commutation. Moreover, the armature reaction is reduced with weak fields, because iron is removed from the path of the cross-flux, and this also assists commutation. A 3 to 1 speed variation is obtained.

Control by Varying Line E.M.F. This will be discussed later, under the heading *Multi-Voltage Systems.*

Combination Methods. It is evident that the preceding methods of speed control are largely independent of one another, and may therefore be used in combination, giving a wide range of speed; and several combinations are discussed in the following pages. They are applicable to shunt and series motors alike. When a number of running speeds forward and backward are required, as in hoisting machinery and machine tools, and the stops and starts are frequent, as in elevator service, the controlling apparatus must be of the most substantial construction, and is often very elaborate.

SERIES MOTORS

As with series dynamos, the armature and field windings of these machines are in series, and the same current therefore passes through both. They are always used upon electric railways, and in general for operating hoisting and mill machinery, where a strong starting torque is required without the necessity of constant speed. Like shunt motors, they are practically always operated on constant-potential circuits.

Direction of Rotation. In considering the direction of rotation of a shunt dynamo used as a motor (page 23), it was noted that the field and the direction of rotation remain unchanged when the armature current reverses its direction, and the dynamo becomes a motor; but in the case of a series dynamo used under like conditions, the reversal of the current reverses the field as well, and hence the armature tends to rotate in the opposite direction. If, therefore, a series dynamo were feeding a constant-potential circuit, and its E.M.F. fell below that of the line for any reason, its rotation would be reversed and the machine would be injured.

A series motor will run in the same direction, no matter which direction the current takes through it; for reversing the armature current reverses the field as well, and hence leaves the rotation unchanged. To reverse the rotation, it is necessary to reverse the relation of the armature and field currents, and this is usually done by interchanging the armature terminals.

Speed and Torque Curves. When a series motor running at a given speed on constant-potential mains has an additional load put upon it, the armature slows down, the counter-E.M.F. decreases, and more current flows from the line. But since this current passes through the field-coils, the field strength will increase, and this will further reduce the speed, while the torque will increase enough to take care of the increased load. Throwing off the load will allow the armature to speed up, and this will increase the counter-E.M.F., reducing the current, which in turn reduces the field strength and still further increases the speed, until the power delivered and the losses together equal the power taken from the line. Hence the series motor has a different speed for every load. If the strength of the field were proportional to the current, the speed curve would be a straight line; but as the current increases, the magnets are more nearly saturated, and the speed decreases less rapidly toward full load. The speed curve takes, in general, the form shown in Fig. 33, which is from a 50-horse-power railway motor. By having so many turns of wire on the field-magnets that they are well saturated with only a part of the full-load current, the speed variations in the neighborhood of full load are much reduced.

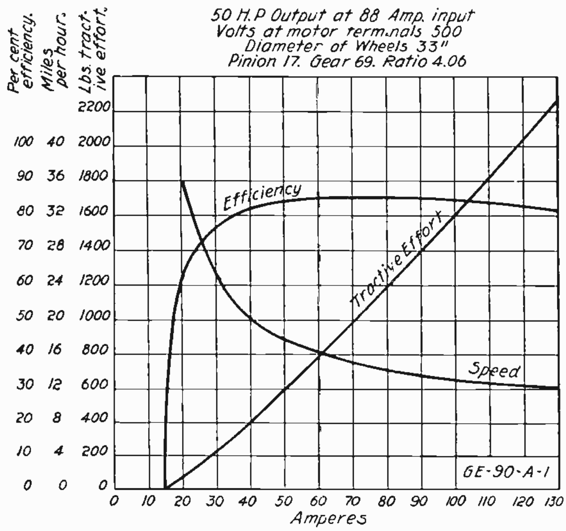


Fig. 33. Speed, Torque, and Efficiency Curves of a Railway Motor.

A valuable property of the series motor is the increase of torque in a greater ratio than the increase of current, due to the strengthening of the field at the same time. This is shown by the curve marked "Tractive Effort" in Fig. 33; for a shunt motor, this curve would be a straight line. Hence the torque of the series motor is large when starting under load, and this makes it especially valuable for railway and other service where the starting duty is severe.

When the load is removed entirely from a series motor, the diminution of the current, and consequent weakening of the field, are likely to cause excessive and often dangerous speeds, so that it is necessary to provide some safety device for cutting off the current at high speeds, unless the conditions are such that the motor cannot be wholly freed from its load, as in the case of street-cars. Very small motors, such as fan motors, are series-wound; but their normal running current is so small that they cannot take enough power from the line to injure themselves, even when running free.

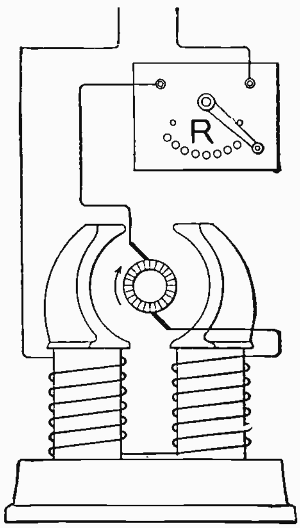


Fig. 34. Wiring Connections of a Series Motor.

Starting Rheostat. The same general principles apply to starting both shunt and series motors; but since there is only one circuit in the series motor, the wiring is simpler. The connections are as in Fig. 34, in which, however, the switch and fuses are not shown. The resistance of the field windings is always in circuit; and this, together with its highly inductive character, helps to cut down the rush of current at starting. The little magnet *E* of the automatic release (Fig. 22) is connected through a resistance across the motor terminals.

SPEED CONTROL OF SERIES MOTORS

Varying the E. M.F. at Armature Terminals. As in the case of shunt motors, all three methods of speed control are practicable, and may be used separately or in combination. With a single motor, varying the E.M.F. at the armature is most easily accomplished by a resistance in series with the motor. The connections are as in Fig. 34, where *R* may represent either a starting rheostat or a speed-controlling resistance, though of course neither piece of apparatus can be used for the purposes of the other unless specially constructed. Controlling the speed by varying the strength of the field is accomplished either by shunting the field windings so that part of the current is diverted through the shunt, or, in some cases, by short-circuiting a part of the field winding, thus reducing the effective number of turns in the coils. Motors have also been used in which the field-coils were connected in various series-parallel combinations.

Railway Motors. The most important application of the series motor is on the electric railway, the equipment being generally two motors per car. The starting rheostat is specially designed to serve as a speed-regulating resistance as well, and the various armature and field combinations are made by a controller, built like an elabor-

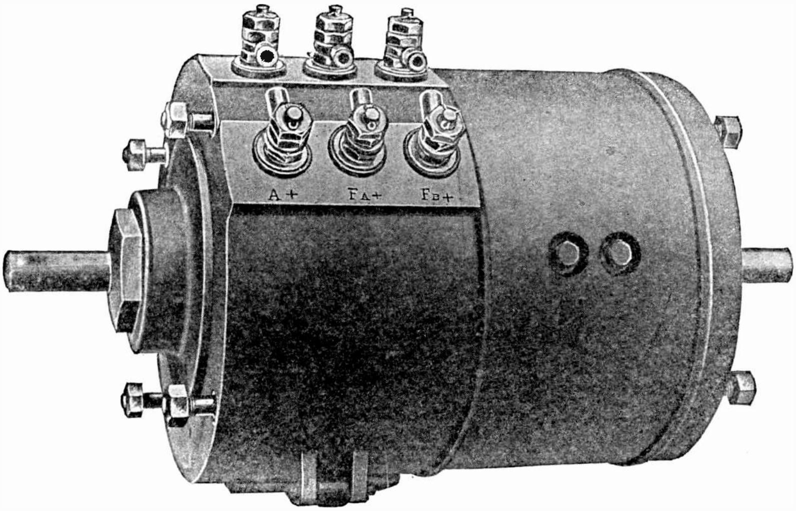


Fig. 35. Vehicle Motor.
Westinghouse Electric & Manufacturing Company, Pittsburg, Pa.

ated form of that shown at *b* in Fig. 27. At starting, the controller connects both motors and a resistance in series, and the resistance is gradually cut out, leaving the motors in series across the line, each receiving one-half of the line voltage and hence running at half-speed. The next position of the controller handle shunts the field or short-circuits a part of the field winding, giving an increase in speed. Further movement of the handle removes the shunt, and connects the motors in parallel, but with a resistance in series with the pair. This is again gradually cut out until each motor receives the full line voltage across its terminals. Finally, the fields are again shunted, and the car runs at its highest speed.

There are slight variations from this program, depending somewhat on the service the motors are called upon to perform. But these details of the subject of railway working are given special discussion in a separate paper.

Automobile Motors. These are series-wound, usually for operation at 40 to 80 volts, requiring 20 to 40 cells of battery respectively. A ball-bearing vehicle motor is shown in Fig. 35. The requirements for such motors are slow speed, light weight, high torque, complete mechanical protection, liberal overload capacity, and as good an efficiency as can be secured consistently with the above requirements. When two motors are used on the same vehicle, the controller may first connect the motors in series, and the halves of the battery in parallel, other changes following until the motors are in parallel across the full battery voltage, with weakened fields. No rheostat is necessary, as the voltages are low, and the total power delivered usually small.

COMPOUND MOTORS

A reversed compound dynamo becomes a differential motor. Fig. 36 represents a compound dynamo D supplying current to a similar machine M used as a motor. It is clear that the current through the series coil of the motor is reversed; and therefore opposes the magnetizing effect of the shunt current, so that the field is weaker than if the shunt were used alone. Furthermore, the motor field is progressively weakened as the armature current increases, and this tends to increase the speed; while the speed of a plain shunt motor under like conditions would decrease. Hence, by suitably designing the series winding, it is possible to obtain a motor whose speed throughout its whole range of load varies very little. This advantage was early recognized; but at the time the speed of ordinary shunt motors was sufficiently constant for most purposes, and the *differential compound motor* made little headway. For some purposes, however, particularly in the operation of textile machinery, it is very necessary to have the speed as uniform as it can be made; and the differential

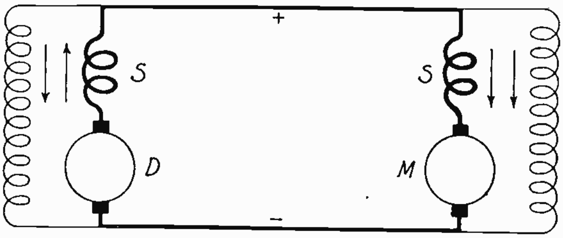


Fig. 36. Compound Dynamo Driving Compound Motor.

motor, after a period of comparative retirement, has now a wide field of usefulness.

If the current through the field is reversed, so that it assists the shunt winding instead of opposing it, the machine is called a *cumulative compound motor,* and partakes to a certain extent of the properties of both the shunt and series types, the shunt predominating. These machines are used for elevator and other service where a powerful starting torque is required, together with the general characteristics of the shunt motor. Sometimes the series field is cut out after the armature attains full speed, in which case the strong starting torque of the series motor is combined with the constant-speed property of the shunt motor.

A compound dynamo with a very strong series field will not usually run safely as a differential motor, for an overload might reduce the field so much that with the weakened torque the armature might stop entirely.

Variable-Speed Compound Motors. The success attending the the use of the *commutating pole* in generators, has led to the adoption of the same principle for motors designed for wide ranges of speed. The commutating pole is a small additional pole, placed midway between adjacent field-poles, and wound with a few turns of the series winding. Its function is to provide the necessary commutating field for the coil under the brushes, independently of the field of the main poles.

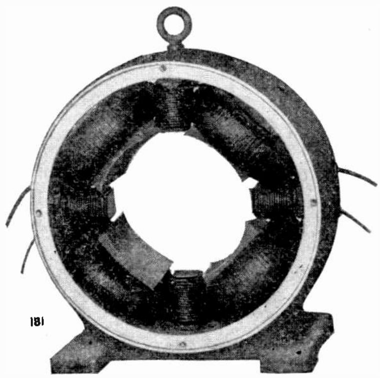


Fig. 37. Interpole Motor.
Electro-Dynamic Company, Bayonne, N. J.

Thus satisfactory commutation not only can be obtained with the brushes in a fixed position, but practically is equally good at all loads, since the strength of the pole, and hence of the commutating field, is proportional to the armature current, and this is exactly what is wanted for good commutation. Applied to motors—since commutation is practically independent of the main field—the use of the commutating pole allows the main field to be weakened much more than with the ordinary construction, and hence a much wider range of speeds is obtainable without sparking. Fig. 37 shows a motor of this type giving a speed range of 4 to 1, entirely by field control.

MULTI-VOLTAGE SYSTEMS

When a generator is to supply only one motor, the line E.M.F. can be varied at pleasure by varying the generator E.M.F., having the generator field rheostat at the motor. This method gives any desired motor speed within a very wide range, but is obviously limited to a few special cases. The so-called *teaser* systems are in effect modifications of this principle; the E.M.F. of small motor-driven generators is added to that of the main line or subtracted from it. This particular modification of the variable line-voltage principle is useful for operating large printing presses or other machinery which must run very slowly at times under absolute control, as well as at various operating speeds.

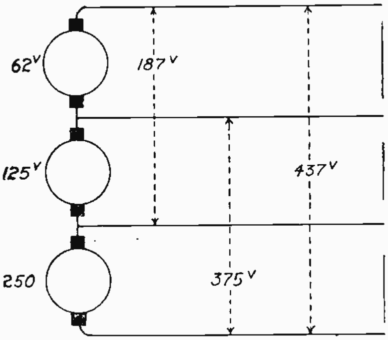


Fig. 38. H. Ward Leonard Multi-Voltage System, 1892.

The electric automobile affords an example of speed-control by varying line voltage. The batteries of the vehicle are in two sets, which are connected in parallel at starting, and then shifted to series connection at the higher speeds.

The familiar Edison three-wire system affords another illustration. In this case the fields of a 220-volt motor would be supplied from the outside wires, and the armature at either 110 or 220 volts, giving two speeds without the use of resistances.

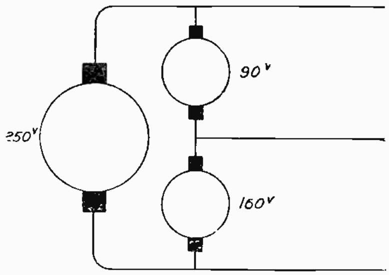
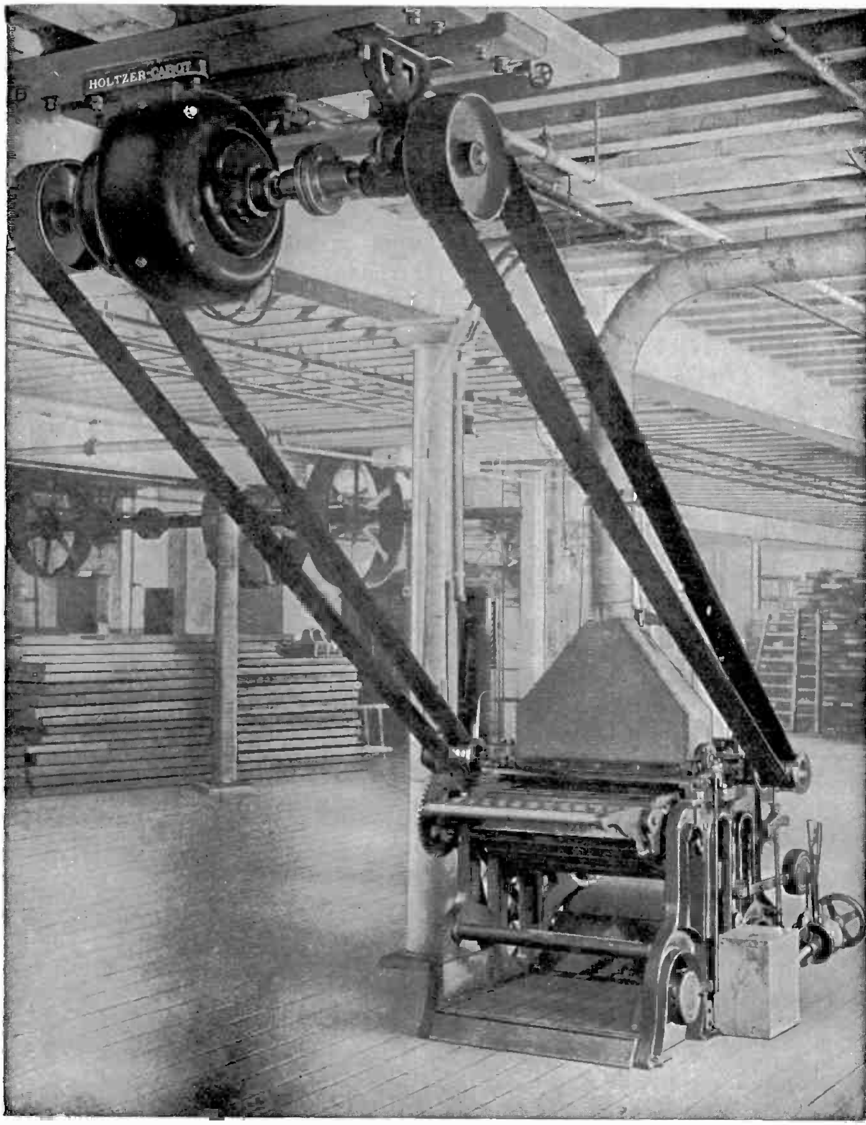


Fig. 39. Connections of Balancer Set.

By making the two sides of the system unequal in voltage, three voltages are obtained. In such a case, the lighting system of the shop, the cranes, and constant-speed motors are operated on the outside wires. A system of this kind was first brought out by Mr. H. Ward Leonard in 1892, using three generators in series and a four-wire system, obtaining the six voltages shown in Fig. 38.

The Bullock Electric Company employs a three-wire system



DUST-PROOF MOTOR BELTED TO LAG BED PLANER.

Holtzer-Cabot Electric Company.

with 90 and 160 volts, and a four-wire system with 60, 80, and 110 volts, with outside voltages of 250 in both cases. The Crocker-Wheeler Company use a four-wire system with 40, 120, and 80 volts, giving 240 volts on the outside wires. Whatever voltages may be used, it is well to have at least one of the voltages *standard*—that is, 110 to 125 volts, or 220 to 250 volts, because these are standard voltages for lamps and motors.

In practice it is found that the intermediate wires carry only a small proportion of the total load, usually not over 10 per cent. This has led to the use of a single large generator and *balancers*, which are

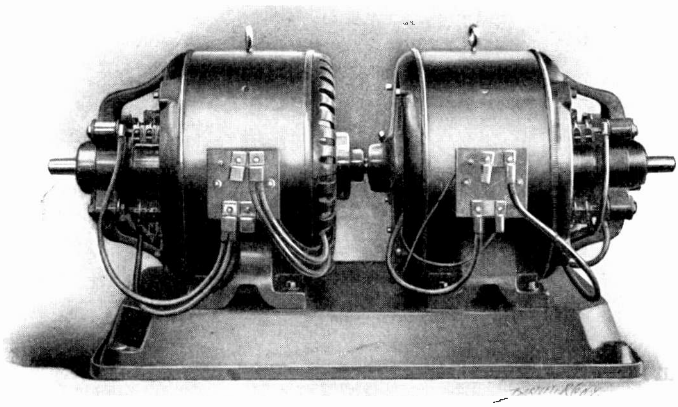


Fig. 40. Three-Wire Balancers for Bullock Multiple-Voltage System. Allis-Chalmers Company, Milwaukee, Wis.

simply smaller shunt or compound dynamos with their armatures coupled together and electrically connected in series across the outside wires. The general arrangement is shown in Fig. 39, and Fig. 40 illustrates a Bullock three-wire balancer set.

The action of the balancer is complex, and a full explanation is not desirable here. In general terms, however, it may be stated that when there is no current in the middle wire of a three-wire system the current through the balancer armatures is only enough to supply the running losses; but when current is drawn from either side of the system, the balancer on the other side will act as a motor, driving its companion as a generator to help furnish the required power. This is illustrated in Fig. 41, where one outer wire carries 100 amperes, the middle wire 20 amperes, and the other outer wire 80 amperes. If the balancers are equal, and there are no losses, the 20 amperes divide equally between the armatures, 10 amperes flowing downward through one as a motor to the negative main, the armature then acting as a motor driving the other machine as a generator and helping it to force the remaining 10 amperes up into the positive main again. Supposing the voltage of the main generator to be 200 volts, its output would be 90 amperes at 200 volts, or 18,000 watts. The load on the line is 80 amperes at 200 volts, and 20 amperes at 100 volts = 18,000 watts, as before.

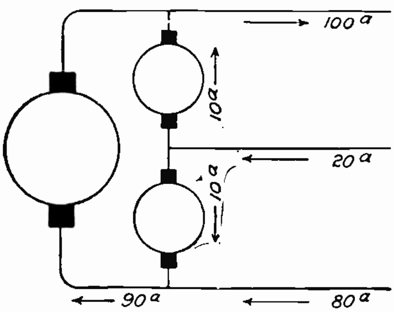


Fig. 41. Current through Balancer Set.

Of course there are always losses in the balancer armatures, so that in the arrangement shown the current through the armature acting as a motor is always greater than the current through the armature acting as a dynamo.

EXAMPLE FOR PRACTICE

If 13 amperes, instead of 10, flow through the balancer motor armature in the above example, what is the output of the main generator, and what power is delivered to the line?

ANS. 18,600 watts from the generator.
18,000 watts on the line.

This would represent 600 watts loss in the balancers, which is, however, much less than would be required to operate the second generator of an ordinary three-wire system.

The size of the balancers is determined by the maximum unbalanced load. On a three-wire system it should be large enough to operate the largest individual motor running alone on either voltage. For example, suppose we have a three-wire, 125- to 250-volt system. If a motor connected to it can develop 50 horse-power at the full voltage 250, it can develop 25 horse-power when operated on one side at 125 volts. This will require two balancers of $12\frac{1}{2}$ horse-power each, since there are two machines to take care of the unbalanced current. In other words, the balancers should have 25 per cent of the capacity of the largest motor, rated at its highest voltage; and this, of course, means that the balancers may be relatively small machines.

Motors operated on this system have their fields excited from some one of the circuits, usually the one of highest voltage. The armatures are connected to either line voltage as desired, and resistances are introduced to prevent too sudden changes of current at the transition points; additional speed variations are provided by weakening the motor fields. All these connections are made upon controllers of the cylindrical type, of which Fig. 42 is a good example. It represents 20-horse-power and 40-horse-power Bullock controllers without their covers; the larger size gives 12 running speeds forward, and 9 reverse.

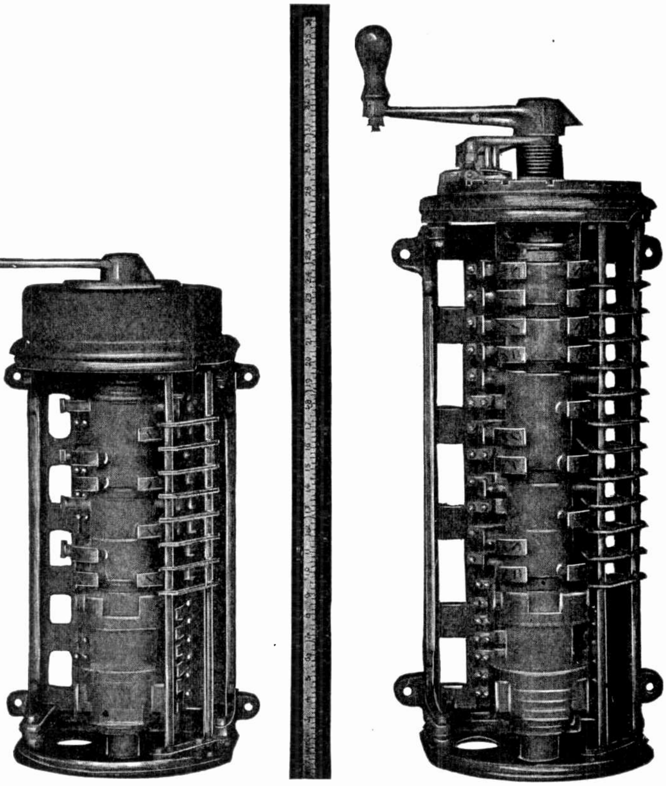


Fig. 42. Controllers Used with Bullock Multiple-Voltage System. Allis-Chalmers Company, Milwaukee, Wis.

MECHANICAL POINTS OF MOTOR DESIGN

Motors need ample protection for the commutator and brush gear. This protection is well shown in the adjustable-speed motor illustrated in Fig. 43. This type of motor is also designed to run with the shaft vertical, in which case the lower bearing runs submerged in oil, and the upper bearing is made of anti-friction metal, running without attention. Motor end-frames or *bells* should be made so that they can be turned through 90° or 180°, to enable the machine to work with the oil wells in the proper position when mounted on a wall or ceiling. If the motor must work in a very dusty or dirty place, the ends may be protected with wire gauze covers, or even tightly enclosed with solid plates. In such cases, however, the machine has much more difficulty in dissipating heat; and for the same rise of temperature, the rating of an *enclosed* (and therefore unventilated) motor is not usually more than about half as much as if it were well ventilated. Fig. 44 shows one form of an enclosed motor. Sometimes the frames of enclosed motors are cast with projecting external ribs, to increase the cooling surface.

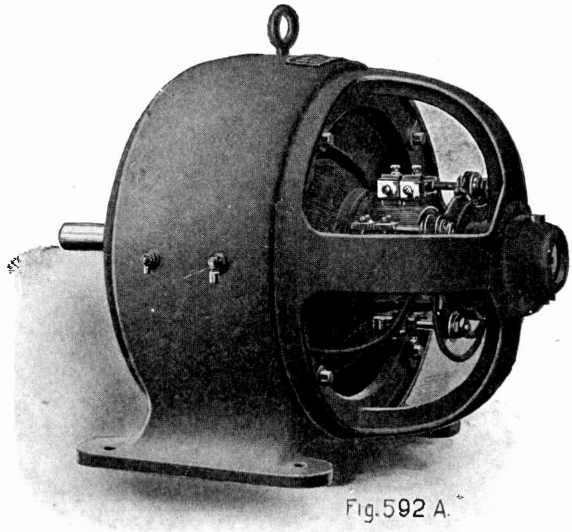


Fig. 43. Adjustable-Speed Motor.
Crocker-Wheeler Company, Ampere, N. J.

To obtain very low speeds without using a motor of disproportionately large size for its output, *back-gearing* is often used. Figs 45 and 46 give two views of a back-geared motor. To diminish wear and noise, such gears are often enclosed in cases and run in grease, like the gears of a railway motor.

Motors of large output—which, as a rule, are installed in more favorable surroundings and receive more careful handling than small motors driving individual machines—do not need special mechanical design. They are therefore built along the line of generators; and to a great extent the same parts are used for both.

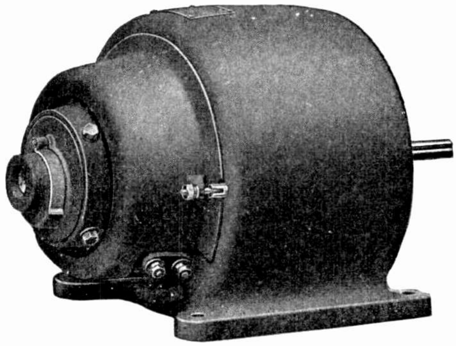


Fig. 44. Enclosed Type R Motor.
Westinghouse Electric & Manufacturing Company, Pittsburg, Pa.

ELECTRICAL POINTS OF MOTOR DESIGN

Since the motor is electrically identical with the dynamo, it is necessary merely to design a dynamo which will deliver the rated current at the given speed and the *counter-E.M.F.* of the motor. A single illus-

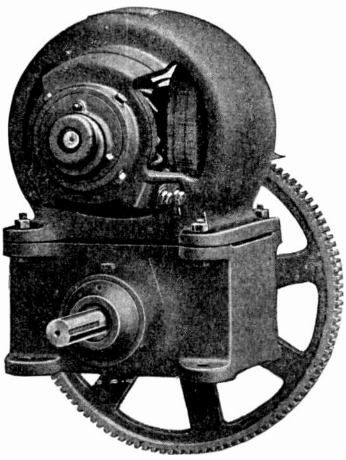


Fig. 45.

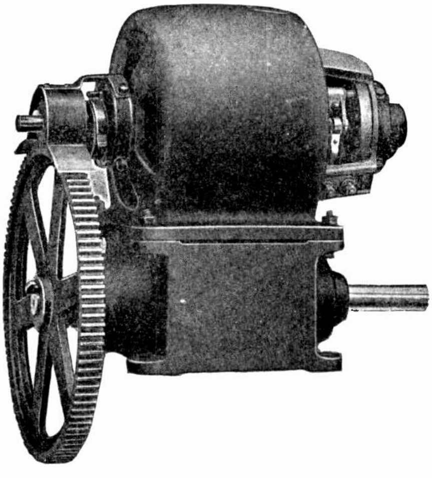


Fig. 46.

Two Views of Type R Motor with Back-Gears.
Westinghouse Electric & Manufacturing Company, Pittsburg, Pa.

tration will suffice. Suppose it is desired to design a 230-volt motor to deliver 10 horse-power at a speed of 825 revolutions per minute. The efficiency of such a machine should be about 85 per cent; so that the current required would be:

$$\frac{7{,}460}{0.85} \text{ watts} \div 230 \text{ volts} = 38.1 \text{ amperes.}$$

To allow for any error in estimating the assumed efficiency, let us say, in round numbers, that a current of 40 amperes would be required. The resistance of the armature of a machine of this size and voltage will be about 0.3 ohm. Then, from the fundamental motor equation, the counter-E.M.F. can be calculated:

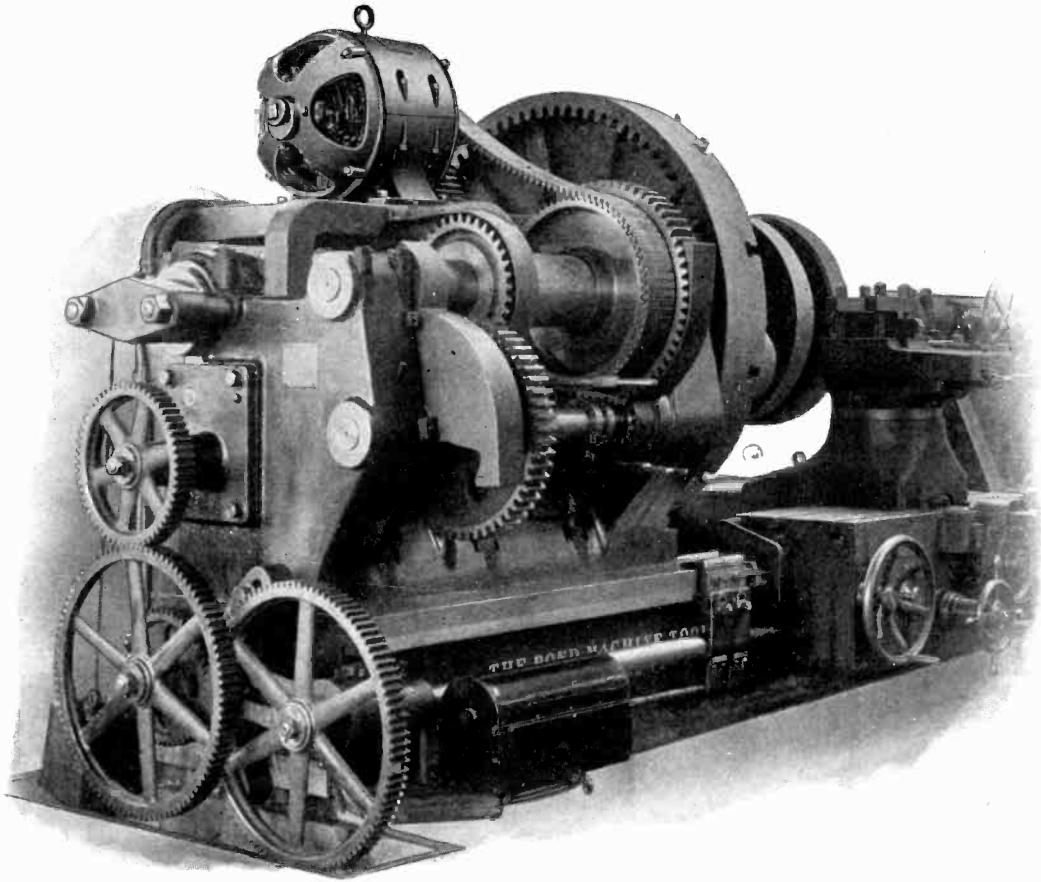
$$I = \frac{E - e}{R} = 40 = \frac{230 - e}{0.3};$$

whence,

$$e = 218 \text{ volts.}$$

That is, a dynamo should be designed whose output at 825 revolutions per minute will be 40 amperes at 218 volts, and whose armature resistance is 0.3 ohm. Its field windings should be calculated for excitation at 230 volts.

For supplementary reading on the subject of the Electric Motor, the reader is referred to the following works: *Dynamo-Electric Machinery*, by F. B. Crocker, and *Electric Railways*, by J. R. Cravath (published by the American School of Correspondence, Chicago, Ill.); *Electric Motors*, by Henry M. Hobart (published by Whittaker & Co., London and New York, 1904); and a series of articles entitled "Direct-Current Motors: Their Action and Control," by F. B. Crocker and M. Arendt, published in the *Electrical World* in 1907 and 1908.



72-INCH LATHE DRIVEN BY 15 H.P. THOMPSON-RYAN MOTOR.

850-1750 Rev. per Minute.

Ridgway Dynamo and Engine Co

ELECTRIC MOTORS IN MACHINE-SHOP SERVICE.*

I intend to consider the subject "electric motors in machine-shop service" from the standpoint of the shop engineer, whose one thought is economy in the broadest sense of the word. To such a man, the motor is but a single detail of the equipment—possibly one of the most important details, but only so when its relation to the problem as a whole, is understood. The development of alloy steels, permitting of cutting speeds from two to four times as great as was heretofore possible, requiring, in many instances, machines of new design; the introduction of the grinding machine, which is rapidly replacing the lathe for much finishing work; the milling machine; the electric motor as a means of driving; and types of management to assure efficient use of equipment, are among the most important factors requiring his attention.

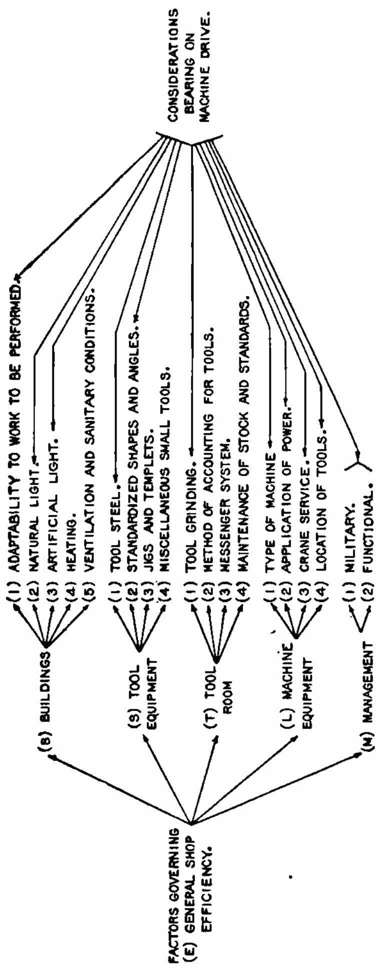
The manufacturers of electrical apparatus too often defeat their own ends by overenthusiasm, or rather, by extravagant claims that they cannot possibly substantiate. There is no use trying to convince the shop engineer that the words "motive drive" are synonymous with "low cost," for he knows that efficiency attained depends upon the co-operation of a multitude of things, and primarily the intelligence with which the equipment is handled. If, however, the possibilities of the motor drive are properly presented, he can appreciate them better than any one else, for they fill a definite need, the importance of which he will understand.

It is not necessary to dwell upon substantial progress recently made in shop practice, which has resulted, in many instances, in greatly increased output with consequent reduction in cost. I shall consider rather what is needed to increase efficiency in the average shop, where it is still extremely low, for even when adequate funds are provided for the purchase of new equipment, the end in view is often defeated through lack of proper insight in connection with its purchases, installation, and use.

At the same time electrical manufacturers have not made the progress that would have been the case had they possessed a

* This paper was presented before the International Electrical Congress of St. Louis, 1904, by Charles Day of the firm of Dodge & Day, Engineers, Philadelphia, Pa.; and is reprinted by special permission.

thorough understanding of shop requirements. Our experience has been confined largely to the installation and operation of electrical equipment under working conditions, therefore I shall treat the subject from this side, with the hope that I may bring more



Shop Considerations Bearing on Machine Drive.

Fig. 1.

clearly before the manufacturers the conditions they must meet, and at the same time aid the customer in specifying his requirements and securing results.

Generally speaking, the electric motor (either for group driving or individual operation of machines) is conceded as the proper means of power distribution. My paper will deal with the subject under the following headings:

(1) Shop Requirements.
(2) Notes Concerning Motor-Drive Systems.
(3) Notes Concerning Different Makes of Apparatus.
(4) General Conclusions.

(1) SHOP REQUIREMENTS.[1]

My paper will only permit of a general outline of shop considerations bearing on the subject; these are illustrated in Fig. 1. Each factor must be carefully considered and, when treating the subject generally, certain assumptions made. For example, we are justified in assuming that the best tool steel should be used and design accordingly, while crane service and type of workmen are, on the other hand, matters depending on class of work handled and local conditions.

An intimate knowledge of shop practice is quite as necessary to the designer of electrical apparatus for machine *driving* as to the builder of the machine, and, while frequently difficult to show the direct bearing of the various features of management and methods upon a single factor, such as the one under consideration, the most useful conclusions can be drawn only by those familiar with the subject in detail. Improved systems of management are doing much to assure proper use of equipment, but in any event the need of explanation in connection with its operation should be eliminated to as great a degree as is possible. In other words, apparatus should primarily be designed to give satisfactory results in the hands of average workers. Where its adjustment and manipulation is dependent upon the operator, he must be fully considered

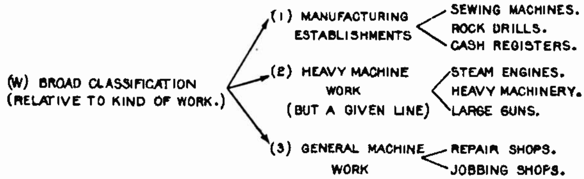
1. The words "machine" and "tool," as used in connection with machine-shop work, are very frequently ambiguous. I will use them in the following sense: *Machine.*—Definition (Standard Dictionary). Any combination of inanimate mechanism for *utilizing* or *applying power.* A construction for mechanical production or modification. Example—Lathes, pneumatic drills, power shears, etc. *Machine Tool.*—This term is often confusing and need not be used in present paper. *Tool.*—Definition (Standard Dictionary). A *hand instrument.* Not a mechanism. Used directly for production. Examples.—Chisel, hammer, saw, etc.

Tools for removing metals will be further subdivided as follows: Cutters, millers, drills, etc.

in the design, but when attention is required for inspection at intervals only, the personal equation does not enter into the problem to as great an extent. Lathe and elevator drives illustrate the two cases.

If cuts are of long duration, the cutting speed can readily be determined by experiment, but this is not practical in the run of machine-shop work. The determination of cutting speed for miscellaneous work is a difficult matter, and must be given special study in each case, every means toward uniformity of product being resorted to.

The drive is but a detail of the machine. We should aim at a harmonious whole, not combining an efficient drive with an out-of-date tool. The motor-driven tool of the future should not be considered a combination, but a *unit* suited to certain specific ends. The motor-drive problem is essentially a matter for the machine



General Machine Shop Classification.

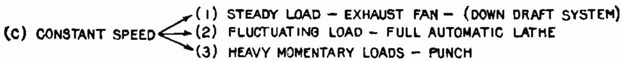
Fig. 2.

builder to settle, and when a machine is purchased, the customer should have the assurance *that the drive has been given the same care in design and construction as any other part of the machine, and need not be considered as a distinct issue.*

Machine shops may be broadly classified according to character of output as follows:

Shops of the first class can be laid out in every detail with regard to a definite need. Machines are purchased to do just one job, and frequently it pays to design special machinery for such duty. After it is properly adjusted for the character of material to be worked and for the cutters, no changes are required until better methods or facilities are developed. Here, as far as the drive is concerned, we find the simplest conditions. Usually constant speed with adequate power suits the case.

In shops classified under the second heading, little opportunity for duplication, in the sense just considered, exists. Machines must handle a variety of work, and even those purchased for specific operations are usually suited for other purposes so they may be kept busy the greater part of the time. Variation in size of work, material and cutters, demands an adjustable speed drive

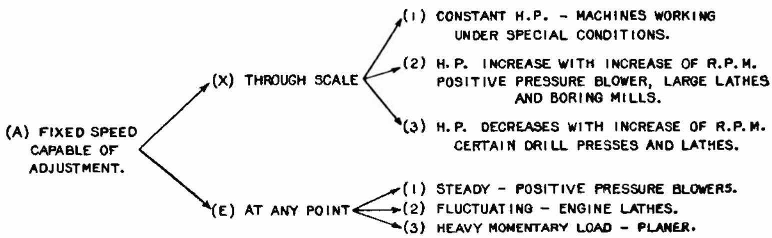


Character of Load for Constant Speed Drive.

Fig. 3.

together with change feeds, if most economical results are desired. This is true to a still greater degree for machines in the third class.

The drive requirements from a consideration of work to be performed can be further analyzed as shown below:



Character of Load for Adjustable Speed Drive.

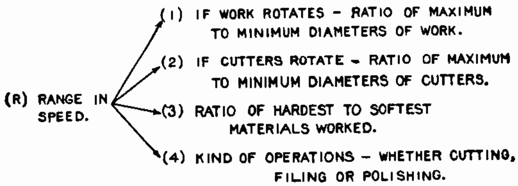
Fig. 4.

Figs. 3 and 4 relate to *character* of load. Figs. 5 and 6 are a further analysis of adjustable speed drive, for machines using cutters, giving details that should determine *range* and *number* of speeds.

Adjustable speed[2] may be desirable on grinding machines also, and in this case will depend on ratio of maximum to minimum wheel diameters and other matters that must be considered separately in individual cases.

2. The words "variable speed" are now generally used for describing motors adapted for individual operation of machines, but to distinguish from the crane motor, for example, which is truly the variable-speed type, I shall use the words "adjustable speed" as describing a fixed speed capable of adjustment over a given range. Variable-speed motors are used principally for railway and crane service where the load is intermittent and torque variable. Direct-current apparatus has been developed to give such thoroughly satisfactory results for this duty that I shall not consider it other than in its relation to the general machine-shop problem.

Machines for punching and shearing, while usually arranged for constant speed, frequently require an adjustable-speed drive. For example, assume a punch operating at 28 strokes per minute. The operator may have work of such a character that he can easily punch a hole each stroke, while in another case, due to heavier sheets or greater accuracy required, he is compelled to skip every other stroke, punching but 14 holes a minute, while if the machine



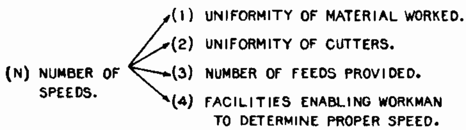
Factors That Influence Range of Speed.

Fig. 5.

would permit he could readily do 28. Such a saving on this class of machinery usually yields a large actual return as the time required for setting up or making ready is, as a rule, small.

The *amount* of horse-power required for machines of different types depends on the factors given in Fig. 7.

I have given the principal items to consider when designing or selecting machine drives, but to more fully explain the line of



Factors That Influence Number of Speeds.

Fig. 6.

reasoning that should be followed, I shall assume definite conditions, and consider the equipment needed to fulfill them.

EXAMPLE.

LATHE........ for general work in shop of A. ———. B. ———. Company, manufacturer of air compressors.

General features of this plant and its organization that influence type of drive (see Fig. 1).

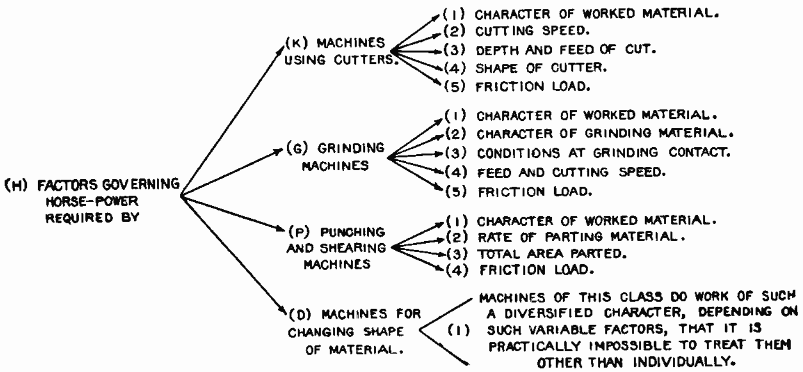
E.B.—1. The machine under consideration is to run in an old plant, hence no saving in cost of buildings could be effected by type of drive.

E. B.—2. The natural light at point where lathe is to be located is very poor, and it is important not to obstruct it any more than absolutely necessary.

E. B.—3. Artificial light has in the past been supplied by independent company, but they desire to install a power plant that will take care of this feature as well as power. It is desirable to depend largely upon general illumination by arc lamps with incandescent lights for detail work.

E. S.—1-2, and E. T.—1. For roughing work the best alloy steels, forged, treated, and maintained by special department, assuring uniformity and high efficiency, will be used.

E. L.—1, 2, 3, 4. Character of work necessitates constant use of power crane, making overhead belting and fixtures objectionable and difficult to provide for on account of location in main bay of shop. As cost of power in this plant amounts to less than 3 per cent of total cost of product, it is not a determining factor in character of drive.



Factors Governing Horse-Power Required for Different Types of Machines.

Fig. 7.

E. M.—2. The type of management being introduced at this plant should ultimately assure intelligent direction of work and proper use of equipment.

Referring to Fig. 2:

We find that this shop will come under the class indicated by the symbol *W-2.*

Referring to Fig. 4:

(A)—X—1—F—2. Majority of work (probably 80 per cent) will be steel and gray-iron castings between 18 ins. and 48 ins. diameter. Maximum conditions call for removal of same amount of metal between these limits, and approximately constant cutting speed. Maximum horsepower requirements are consequently constant through the range, but subject to fluctuations at any one point below the said maximum.

Referring to Fig. 5:

R—1. At times it will be necessary to machine work as small as 10 ins. diameter, or as large as 60 ins. diameter; consequently a range in speed of 5 : 1 would be required for this purpose.

R—2. Cutters will always be stationary.

R—3. The ratio of hardest to softest material required by specification will be approximately 2 : 1. This will increase the necessary speed range to 10 : 1.

R—4. The majority of work will be roughing and finishing with cutters. Some filing and finishing with emery cloth will, however, be necessary, and for this purpose experience would dictate a cutting speed of 150 ft. per minute on 10 ins. diameter It will be necessary to provide a cutting speed of 15 ft. per minute on the largest diameter on account of the frail character and difficulty of driving some of the castings to be machined. Total range of speed is determined by limiting conditions of a cutting speed of 15 ft. per minute on 60-in. work and 150 ft. per minute on 10-in. work. I have purposely chosen these extreme conditions to better illustrate my point. In practice a 60-in. lathe is seldom required to run at 57 r.p.m.

$$\frac{150}{\frac{10 \times 3.14}{12}} = 57.3 \quad \text{r.p.m.}$$

$$\frac{15}{\frac{60 \times 3.14}{12}} = \quad .95 \text{ r.p.m.}$$

Consequently, for all practical purposes, the face plate of the lathe should run from one revolution per minute to 57 revolutions per minute.

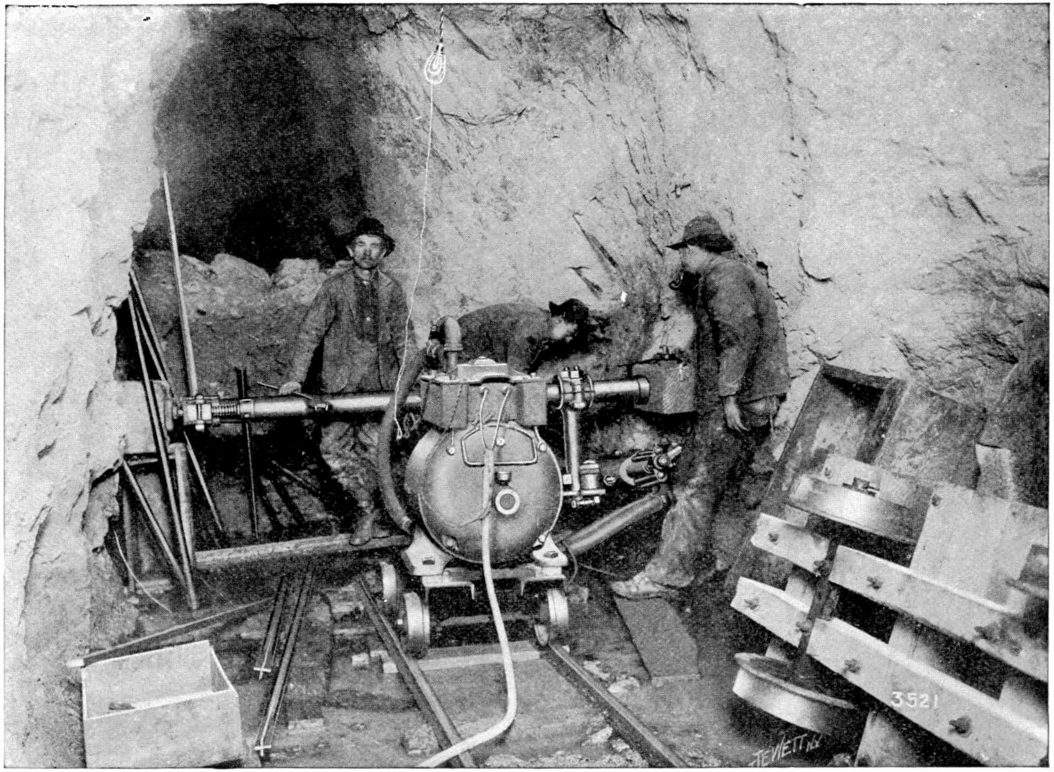
Referring to Fig. 6:

N—1. It was stated above that the character of material would vary in the proportion of 2 : 1, this being a requirement of the products manufactured. Uniformity of material, or how nearly the requirements can be attained under shop conditions, is one of the factors influencing the number of face-plate speeds.

A fully-equipped laboratory, under the direction of an able chemist, who has entire charge of the cupolas and Bessemer steel converters, assures a much more uniform product in the plant in question than is usually the case. A great deal of experiment and investigation will be necessary however, before we can make definite assertions in this direction, but castings from the same pattern should not vary more than 20 per cent.

N—2. Cutter of the character indicated above (E.S.—1) should not vary in efficiency more than 10 per cent.

N—3. The full consideration of this point involves an understanding of the laws governing speed, feed, and cut for various materials. It will not be practical to include here full data on this detail. Hundreds of



AN ELECTRIC-COMPRESSED-AIR DRILL IN THE "SEVEN MILE TUNNEL," DUMONT, COLORADO
Ingersoll Sargant Drill Co.

tons of steel and cast iron have been cut up to determine these relations, and constant experiment is necessary to keep abreast of rapid improvements. I will only say that it is quite as necessary to provide an adequate number of feeds as it is spindle-speeds, and in fact a limited number of either one of these factors will give efficient results provided a very close regulation can be had on the other.

In the present instance it was not considered advisable to specify changes to the standard feeding mechanism, as this feature had been well taken care of by the builder.

N—4. As the operation of the machine is ultimately governed by the facilities at the disposal of the machinist who runs it, it is absolutely essential that this point be given most careful study. It involves practically every feature of shop system and management, and it is only under such systems as that developed by Mr. Fred W. Taylor, of which functional foremanship is but a single detail, that the conditions, as outlined above, can be fulfilled. It necessitates that the operator of the machine be informed as to the character of the material, efficiency of the cutter, proper cutting speed in consideration of duration of cut, and many other equally important factors.

So it will be seen that we cannot arrive at any data which would enable us to specify definitely the number of spindle-speeds required. Our conclusions must necessarily be based principally on experience in shop practice, and for this reason engineers differ widely in their views. For the example under consideration, speeds increasing in increments of 15 per cent are, in our estimation, quite as close as can be used to advantage. It is well, however, to err on the safe side, providing too many speeds rather than too few.

Referring to Fig. 7:

H. K.—1, 2, 3, 4. Maximum permissible cutting speed on steel castings will be 60 ft. per minute; on gray-iron castings 60 ft. per minute (determined by actual requirements on a large variety of work). Maximum cut, cast-steel, $\frac{3}{8}$ in. deep, $\frac{1}{16}$ in. feed; gray-iron, $\frac{3}{8}$ in. deep, $\frac{1}{16}$ in. feed. (These conditions are established by character of work.)

The experiments conducted to determine the laws governing speed, feed, and depth of cut, for various materials referred to above (*N—3*) have been made available for purposes of design by means of slide rules, based on the derived empirical formulæ.

For the depth of cut and feed under consideration (cast-steel), the calculated pressure on the tool would be: 5,550, or horse-power required=
$\frac{5550 \times 60}{33{,}000} = 10.1$ hp.

H. K.—5. The friction load can only be arrived at through experience and depends not only on the machine, but character and method of driving work. Experimental data on machines quite similar to the one under consideration would indicate 3 horse-power through the entire range as sufficient to allow for this purpose.

These conditions are plotted in Fig. 8. It will be noticed that the horse-power falls off on either side of the working part of the scale.

While it is easy to theorize as to the horse-power required for work of various diameters, in actual practice the conditions are about as I have shown. It must be borne in mind that the machine under consideration should be primarily adapted for the majority of work that it will handle. We have assumed that 80 per cent of this will be between 18 ins. and 48 ins. in diameter, so that work outside of these limits is the exception. On small work, such as would be handled, there is not likely to be opportunity for as heavy roughing cuts, and castings over 48 ins. in diameter cannot be swung over the carriage, nor would it be good policy to aim at high efficiency at this point for the additional cost would not be justified by the saving effected on such a small fraction of the total output.

As the horse-power between the working limits shown above was figured for the maximum cutting speed of 60 ft. per minute, we can plot a relation between revolutions per minute and horse-power. (See Fig. 9.) The selection of electrical equipment for this lathe will be taken up further on.

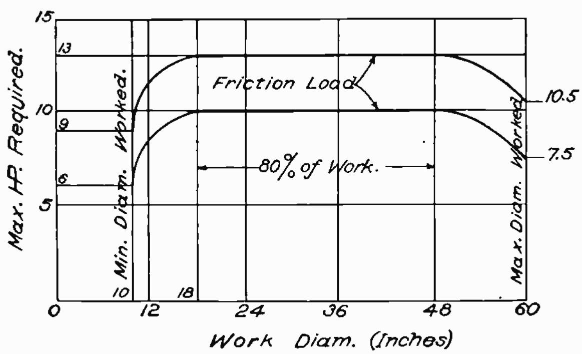


Fig. 8.

The analysis of conditions presented above is, as was stated, essentially a problem for the machine builder to work out—in other words, the electrical companies should look to him for general specifications covering motors and controllers.

When equipping machines of old design with motor drive, or remodeling them to better their efficiency, each one should be considered separately with regard to the special line of work it handles. As manufacturing becomes more specialized it will be possible for the builder of machines to design with more intelligence, for he can then treat a type as we have treated an individual.

To avoid repetition, I will assume the following conclusions have been established.

(1) Machines of present design of comparatively small work, requiring constant-speed drive should, in most instances, be grouped

and operated from motor-driven line shafts. Specifications for new machines for such duty should be made with a view to special requirements. Indirect savings in one plant may much more than offset additional cost of constant-speed motor on each machine, while this would not be true in another.

(2) For group driving, both direct- and alternating-current motors give thoroughly satisfactory results. In either instance, if properly installed, repairs should not be an important feature. In

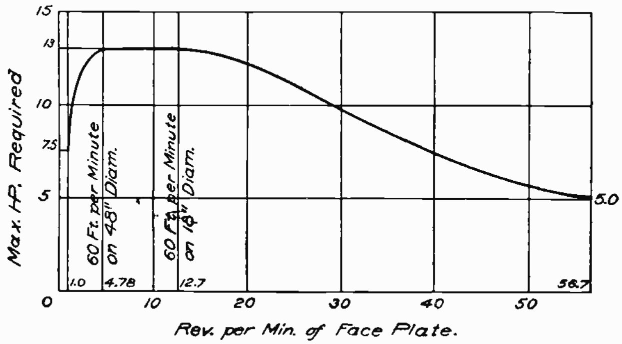


Fig. 9.

certain industries—the textile mills for example—the induction motor has decided advantages on account of close-speed regulation with varying loads and lessened fire risk, but for machine shops these features are unimportant.

(3) Mechanical means of speed control, including step cone pulley and variable-speed countershafts, while suited for certain specific cases, do not meet the general requirements of machine drive. An attempt to obtain the necessary speeds by gearing, for example, is not only costly (if a sufficient number of changes are provided), but inefficient, in that as a rule, the machinery must be stopped to change from one speed to another, and cannot be controlled from an independent point.

(4) For adjustable speed work, direct-current motors only give satisfactory results at the present time. It is not practical by this means to use a range greater than 6 to 1, while in the majority of cases 3 to 1 gives the most economical results. In other words, in most instances, it is necessary to resort to a combination of mechanical and electrical control, the disadvantages of

each being largely eliminated by this means. For example, even where machines are handling a very general line of work, the greater part of it will be covered by a range of 3 to 1, so that if this amount is obtained electrically, gear changes will be seldom necessary, and at the same time a comparatively inexpensive motor required. Consequently the lathe requirements specified above are of quite as much value to the man who designs the mechanical features of the machine as the one who furnishes the electrical apparatus.

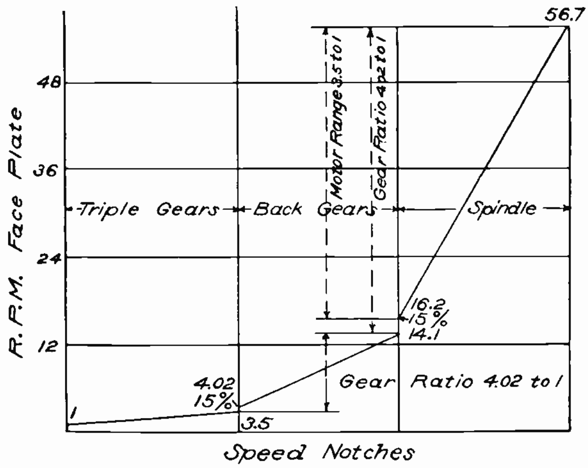
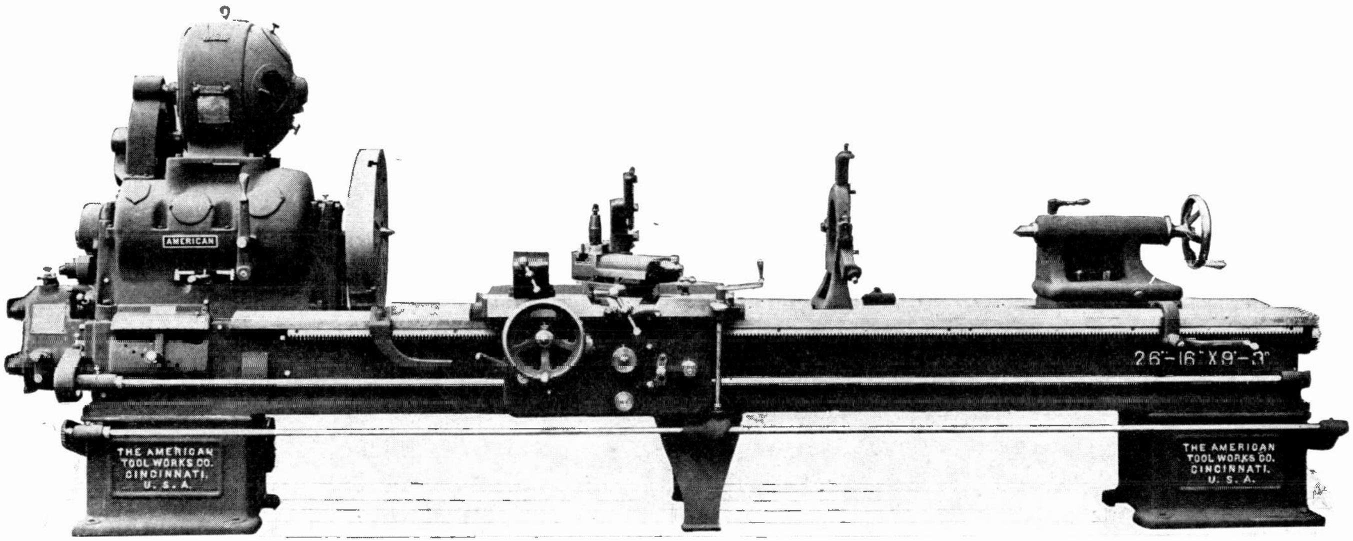


Fig. 10.

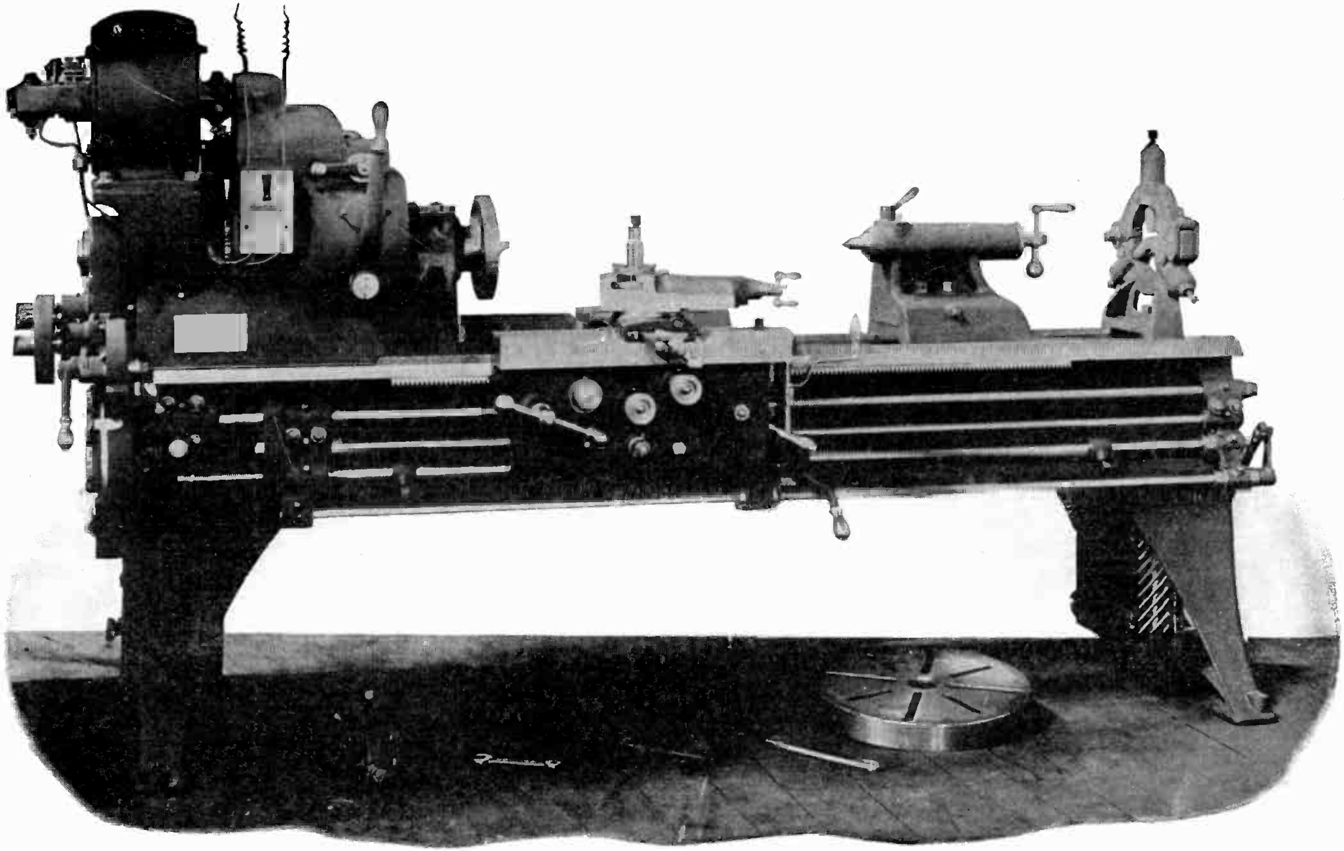
(5) Long transmission lines may make alternating-current desirable, and, for certain extended plants, the best results can be obtained by its use, together with motor-generator for direct-current variable-speed motors. If, however, but one kind of current will be available, decision should be largely governed by number of individual drives required. In many instances, while group drives may be desirable at the start, new equipment should be purchased with individual motors for the sake of adjustable speed and ease of control.

Returning to the 60-in. lathe considered above, the total speed range of 57 to 1 can be covered by the usual triple gear arrangement, with the resulting ratios shown on the chart. The range in motor speed, of 3.5 to 1, is quite practical and can be taken care of by any one of the systems referred to above.



LATHE EQUIPPED WITH CROCKER-WHEELER MULTIPLE-VOLTAGE APPARATUS.

Controller Arranged so that the Operator Can Start, Stop, and Obtain Any Spindle Speed Within Range of Motor, without Leaving His Work.



LATHE WITH SINGLE-VOLTAGE FIELD-WEAKENING MOTOR.

Controller Operated by a Handle on the Carriage.

I shall not dwell upon the strictly mechanical details of the drive, rather assuming that this part of the work is properly taken care of, but pass on to a consideration of the motor-drive systems.

(2) NOTES ON MOTOR-DRIVE SYSTEMS.

Systems now on the market for obtaining adjustable speed by means of motor drive, and advocated by prominent manufacturers, are given below:

(1) Field weakening only

(2) Double commutator motor combined with field weakening.

(3) Edison three-wire system combined with field weakening.

(4) Unbalanced three-wire system combined with field weakening.

(5) Four-wire multiple-voltage system combined with field weakening.

There are two classes of purchasers, with widely differing requirements, and to whom different systems appeal:

(1) The customer who buys motors for his own use to equip machines already in operation, or special machinery which must be given individual consideration.

(2) The customer who buys for an unknown third party. The builder of machines, for example, who manufactures his product without any knowledge as to whom the purchaser may be, and consequently must design equipments that will meet conditions existing in plants where his product is solicited.

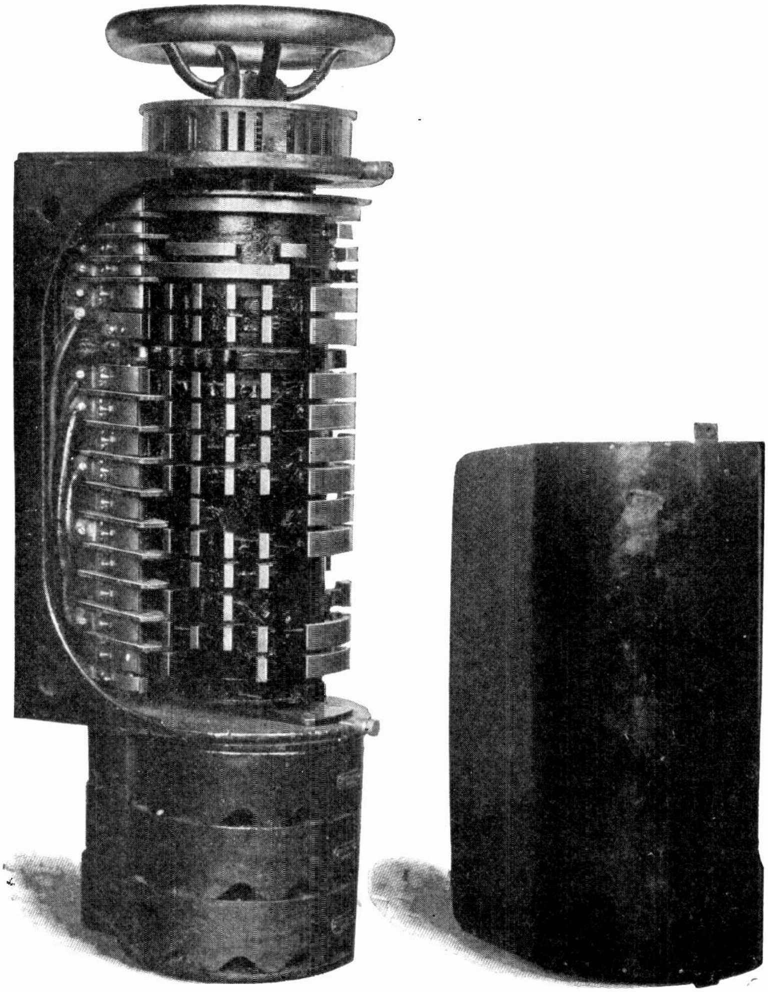
The electrical manufacturers have been slow in realizing this almost self-evident classification. The very essence of modern manufacturing consists in specialization, as it is only in this way that cost can be reduced to a minimum. Such establishments must be classified under the second division referred to above, and the product considered as a *type*, while in the first class given machines or given establishments can be treated separately.

Conditions in the past have in either case demanded a separate consideration of drive for practically every customer, on account of special character and numerous types of motor-drive equipment, but substantial progress, as far as the machine builders are concerned, will not be made until their product is manufactured complete in every essential. This means the adoption of a motor that can be operated on 110 or 220 volts, direct current, as one of these is not only found in nearly every large establishment, where it is used for cranes and lighting, but in many of the small shops.

The three- and four-wire systems, on the other hand, have been installed by a very small percentage of the shops who are, from time to time, purchasing new equipments, hence for commercial reasons such apparatus does not appeal to machine builders. It may, however, possess distinct advantages to purchasers of the first class who contemplate the motor equipment of an entire shop, either at once or as conditions demand. As they can exercise the greatest freedom in selection of equipment for motor drive, I shall consider the systems enumerated above from their standpoint. It will then be a comparatively simple matter to apply these conclusions to the more special conditions which must be met by the machine builders.

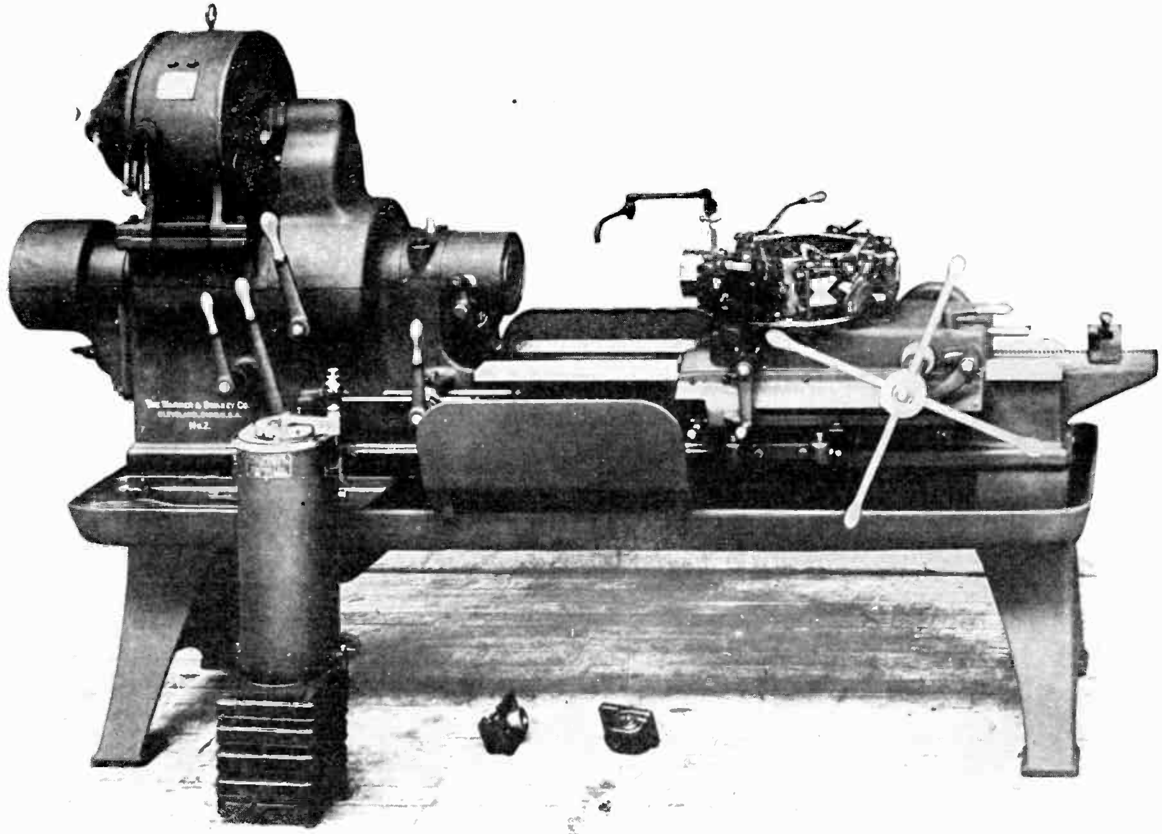
All customers, unless they employ consulting engineers, are called upon to decide themselves upon the system to adopt, and, as their experience does not, as a rule, cover the details of electrical engineering, they must depend largely on the statements put forward by electrical companies.

There is no doubt that the manufacturers in many instances have taken advantage of the special character of machine work to rate their motors in a way that is very deceptive. The words "full load" are almost universally abused, and as there is no standard specification adhered to, the only safe basis for comparison is through a knowledge of the weight and maximum speed for a given horse-power through a given range, with the understanding that a specified overload must be carried at any point for a certain time. Such an analysis would, according to the views of the various builders, give at least an intelligent idea of the equipment required to fill a definite need, but in a number of instances our experience has indicated that claims made by leading manufacturers have not been fulfilled in actual test. Machine-tool duty unquestionably permits of a different basis of rating from constant horse-power work in much the same way that street railway motors are rated on a basis of their own, but when one manufacturer adheres strictly to a rating of present standard, and another departs from it without the knowledge of the customer, the latter is likely



MULTIPLE-VOLTAGE CONTROLLER.

Crocker-Wheeler Company.



WARNER AND SWASEY TURRET LATHE WITH BALANCED THREE-WIRE EQUIPMENT.

Controller within Easy Reach of Operator.

to be comparing bids on two radically different equipments. This we have repeatedly found to be the case. We feel that this matter should be given careful consideration by such a body as the American Institute of Electrical Engineers and a definite understanding arrived at.

I shall assume general familiarity with the systems under consideration. In general, a motor for a given maximum speed and a given range, to deliver a given horse-power through this range, will be at least as large when operated by field weakening only, as when a combination of either two or more voltages with field weakening is adopted. Unless the motor is specially designed for field weakening, it will be larger than in the latter case. We have been unable to obtain any satisfactory data from the engineering departments of electrical manufacturers concerning variation of horse-power with field strength, so prefer to base our conclusions upon tests which we have conducted in connection with work for various clients.

As the cost of variable-speed motors and auxiliary power transmission equipment, such as chain or gears, is in proportion to the speed at which it operates, we should see that the latter is as high as is consistent with the various engineering considerations. A number of the manufacturers of motors do not give sufficient thought to the adaptation of motor speeds to available means of transmitting power to the machine. There are three methods in common use, namely: leather belts, gears (including worm and spiral gearing) and chain. While the great flexibility of the belt, in relieving the machine of sudden jar, has distinct advantages in certain instances, gears and chain are used in the majority of cases for individual drive.

(1) FIELD WEAKENING (WITH A SINGLE VOLTAGE).

A number of manufacturers have recently placed on the market motors designed to run on a single voltage, but that may be varied in speed by means of field weakening over a range, in some cases, as high as 6 to 1. Until recently, ranges as great as the above have not been considered practicable and our tests of motors of various makes have indicated that in this respect much can be accomplished through careful motor design. Manufacturers that adhere to the simple shunt type do not advocate, except for special work, a range exceeding 4 to 1, while others who have adopted either additional poles or special windings claim to have eliminated the difficulties usually encountered, and are prepared to furnish motors giving any variation desired. These types, however, have not been in operation a sufficient length of time to enable us to confirm their statements.

We have found that customers are frequently misled concerning the size of frame required for a given duty for motors operating on this system. As the horse-power that can be developed with a given frame is in proportion to the speed of the armature, it is necessary to use, for a range of 4 to 1, a motor frame rated at least four times as large as the power required if practical speeds are not to be exceeded. Even such a frame will not, in most cases, make it possible to rate the motor as liberally as is the case with standard constant-speed apparatus, as the exceptionally strong field required is likely to cause heating at the slow speed, and at the high speed the weakened field will cause poor commutation.

We have not yet experimented with a motor of this type that would operate continuously under the full-load current at its highest speed without giving some trouble at the commutator. It is true, as was stated above, that such conditions would rarely be met in the machine shop, but to purchase with intelligence it is necessary to know how much manufacturers depend on this fact. Motors with a range of 3 to 1 have already been successfully applied to machines requiring a comparatively small amount of power, although, as will be pointed out later, the apparatus has not been perfected as fully as is the case with other systems.

If the lathe considered above be equipped with apparatus operating on this system, the relation between motor horse-power and that required by the machine, shown in Fig. 11, should fulfill the conditions satisfactorily, as the upper curve is drawn through maximum values, and when they are reached the overload on the motor would only be 30 per cent.

Referring to the dimensions and ratings furnished by one of the manufacturers, whose apparatus has shown up very favorably under test, we find that a motor weighing 1,615 lbs. will deliver 10 horse-power between a range of 350 r.p.m. and 1,050 r.p.m., or one weighing 2,300 lbs. will deliver 10 horse-power between 225 r.p.m. and 900 r.p.m. We recommend the use of the last frame, as satisfactory commutation should be assured by the smaller speed range, namely, 225 r.p.m. to 787 r.p.m.

(2) DOUBLE COMMUTATOR MOTOR (COMBINED WITH FIELD WEAKENING).

The additional cost of the double commutator motor, together with the maintenance of two commutators instead of one, are objections to this system that, in our estimation, offset its advantages for other than special cases.

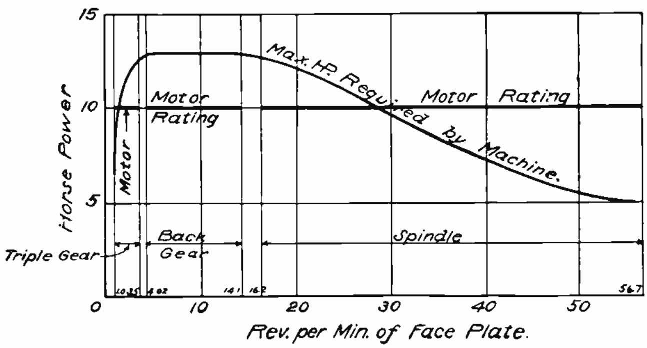


Fig. 11.

(3) EDISON THREE-WIRE SYSTEM.

The combination of the Edison three-wire system with field weakening permits of a range of 4 to 1, with but 100 per cent increase in speed by the latter means, and, consequently, eliminates commutator troubles to a marked extent.

The balanced three-wire system has been adopted quite generally in the past for lighting purposes, and may be obtained either by means of standard generator, together with a separate balancer, or by providing the former with slip rings connected to an autotransformer from the middle point of which the neutral is taken. The latter arrangement is advocated by manufacturers of this apparatus.

The selection of motor to operate on three-wire system for the 60-in. lathe should be based on curves shown in Fig. 12. The same assumptions are made regarding overload as in the former case.

The motor required for these conditions, according to one of the principal advocates of the Edison three-wire system, would weigh 2,600 lbs. and operate from 220 r.p.m. to 880 r.p.m.

(4) THE UNBALANCED THREE-WIRE SYSTEM.

The unbalanced three-wire system was developed to give, with a minimum size motor, a range somewhat greater than 6 to 1.

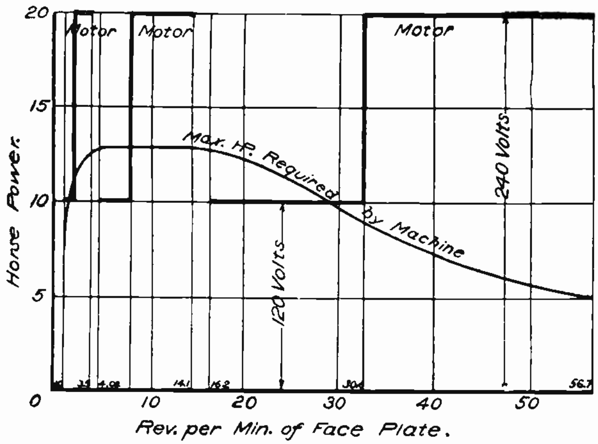


Fig. 12.

For a range of 4 to 1, or under, it has no advantage over the balanced three-wire system, nor does it possess the several good features of the one last named.

(5) FOUR-WIRE MULTIPLE VOLTAGE SYSTEMS.

The principal advantage of the multiple-voltage system is that absolutely standard motors (the same as are used for constant-speed duty) are used with perfectly satisfactory results. This is not true of any of the other systems. Motors designed to operate on a three-wire system must run with full field, full voltage at about half the speed of a constant-speed motor for the same duty, therefore cannot be economically used for the latter purpose. This is true to a still greater degree for motors designed to give a wide range of speed by means of field weakening only.

The maximum range in speed obtainable by the system under consideration depends upon the voltages adopted and the amount the field is weakened, but for purposes of economy, except where constant torque is required, the working scale is usually confined to the higher voltages. The lower voltages, while used chiefly for starting, prove of great assistance at times for setting up work.

The two systems which have been advocated differ in that one requires an arithmetical series of voltages, and the other a geometrical series. In either case a balancer, or specially designed generator, is required to give the voltage referred to and four wires employed for distribution. These two features are frequently cited as disadvantages that more than offset the good points of this

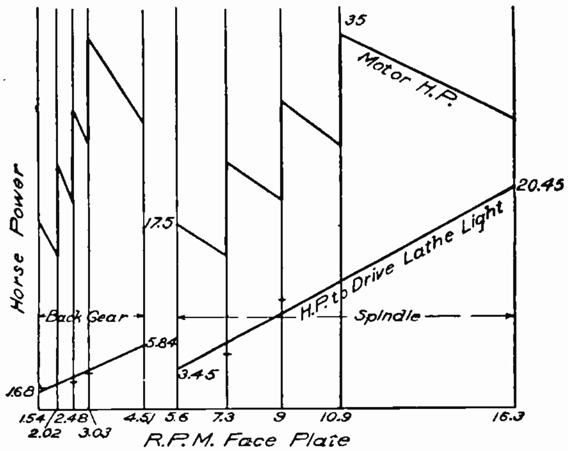


Fig. 13.

system, but, in reality, they do not complicate matters to any great extent nor add materially to the cost of a large installation.

While, as stated above, the average machine tool may be considered as requiring constant horse-power through its working range, in numerous instances, particularly when dealing with large machinery, we find that requirements call for an increased horse-power with an increased speed. For such cases the multiple-voltage system is most desirable as is clearly shown by the curves in Fig. 13.

This data relates to a large gun lathe, driven by multiple-voltage apparatus. The lower curves are drawn through points determined by actual test and show the power required to drive the lathe with face plate in place, but otherwise running light. The power available for useful work is represented by the vertical height between the curves just referred to and the upper ones, which show the relation between horse-power and speed of a standard 35-horse power Crocker-Wheeler motor. Such examples are, of course, exceptional.

Thus far, I have assumed the use of the same range in motor speeds, when operating on the spindle, backgear, and triple gear, and in the case of field weakening motors, or those operating on a

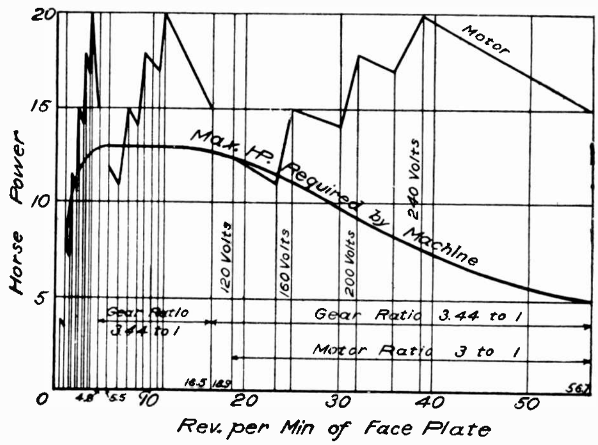
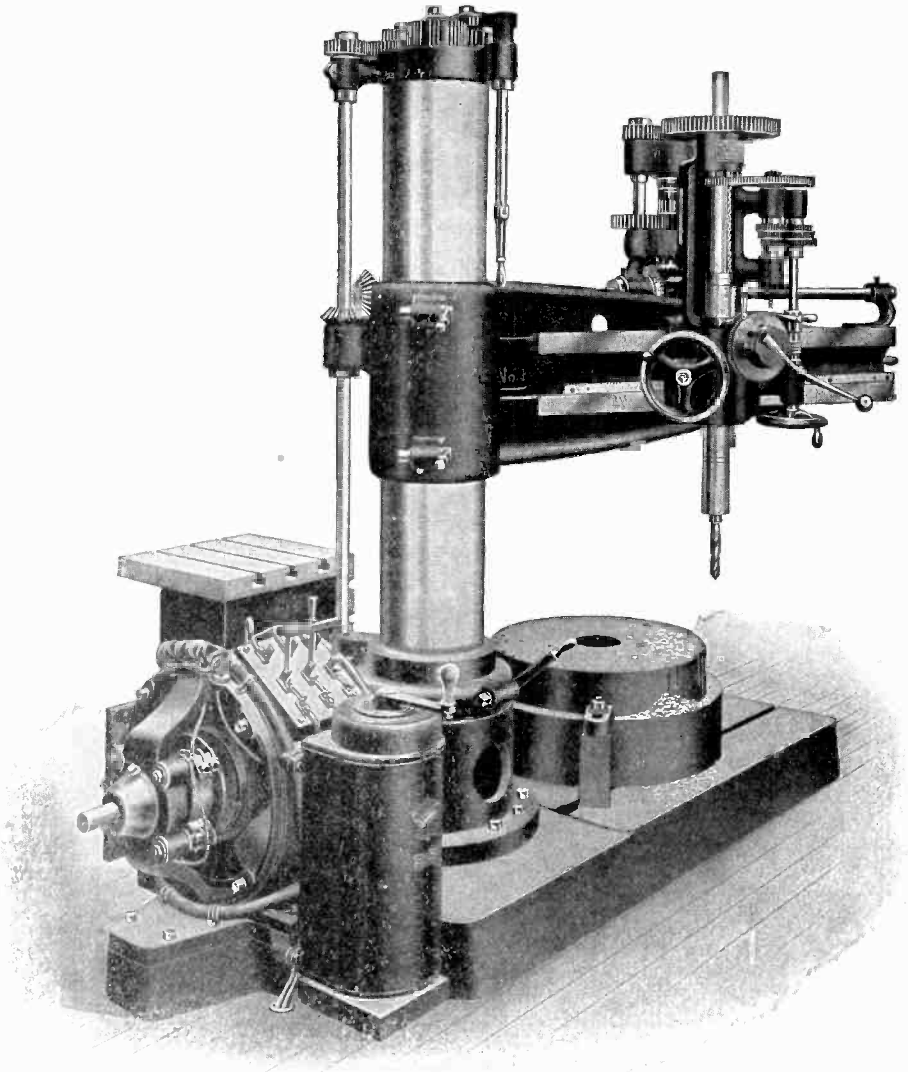


Fig. 14.

balanced three-wire system and rated as above there would not be any advantage in doing otherwise. The characteristics of the multiple-voltage system, however, are such that a smaller motor can frequently be used. The gear ratios are determined by the nature of the load curve. This fact was borne in mind when plotting the curves shown in Fig. 14 relative to multiple-voltage equipment for lathe A.–B. Company.

A motor weighing 2,350 lbs. and operating from 236 r.p.m. to 820 r.p.m. is recommended by one of the leading manufacturers of this apparatus. They prefer to rate their motors very conservatively, which accounts for the decrease in horse-power with field weakening. By actual test their motors stand up under these conditions as well as many other makes that are said to deliver constant horse-power through a range of 2 to 1.



ALLIS-CHALMERS A. C. MOTOR DRIVING RADIAL DRILL

(3) NOTES CONCERNING DIFFERENT MAKES OF APPARATUS.

In every instance final decision must rest with the perfection of apparatus. One of the most important details so far as efficient shop use of the motor drive is concerned is the controlling mechanism. For machine-shop duty thoroughly rugged and compact controllers are required. No contacts should be exposed as is now the case with the apparatus furnished by a number of manufacturers of field weakening motors. With thoroughly efficient apparatus it is practically impossible to damage either the motor or controller by the rapid operation of the latter. I do not mean by this that it is well to swing the controller handle suddenly from the off position to the full-speed point, but such action should not result in destructive sparking at the commutator or arcing at the controller points.

The satisfactory operation of a controller for the conditions under consideration depends largely upon the success with which the manufacturer has fulfilled the following conditions:

(1) Controllers should be completely inclosed in iron casing.

(2) It should be impossible through the manipulation of the controller to stop the motor at any place on the scale other than the off position.

(3) Rapid operation of the controller should not cause serious damage to either motor or controller.

(4) They should be so designed that they can be easily operated from a convenient point on machine.

(5) A sufficient number of speeds should be provided, depending on machine requirements.

(6) Controllers that require frequent operation must be designed with liberal contact surface and more rugged in every respect than those used principally as "speed setters," and as a result only operated at intervals.

(7) The design should permit of repairs with the greatest ease. In this connection the location and type of resistance grids should be given careful consideration.

(8) Each speed should be clearly defined either by a star-wheel and pawl or other means.

A number of manufacturers have placed on the market controllers that are giving good results, and in most respects comply with the above requirements.

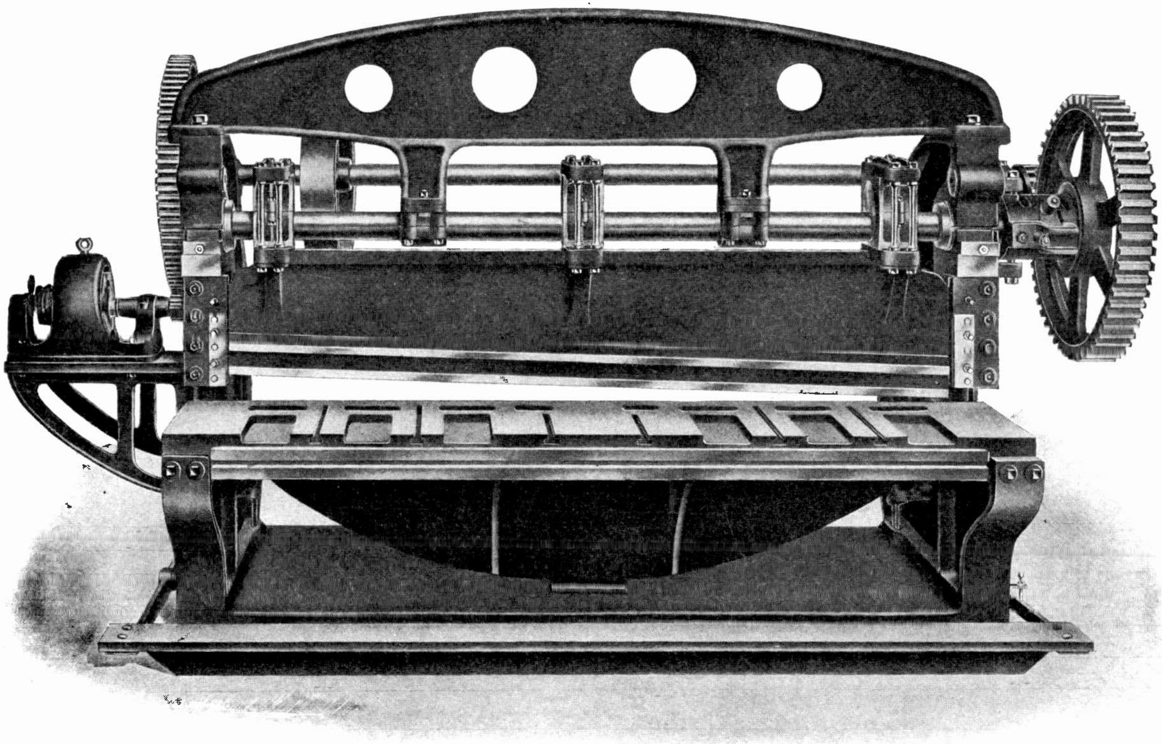
Motors have been designed to accompany these controllers that are well suited for application to machines, in so far as their external dimensions are concerned, but at the same time we feel sure that the electrical manufacturers who are willing in certain cases to depart from present designs will gain a strong position with the machine builders.

(4) CONCLUSIONS.

In all probability a paper such as I have prepared for this meeting of electrical engineers, would have seemed decidedly out of place some years ago. I have dealt with matters which would then have been considered the business of the machine builder or mechanical engineer, and not requiring the thought and study of the electrical profession. It is now realized, however, that the motor-drive problem presents many new features, and is a distinctly different one from the manufacture and sale of standard generators, for example. The earning power of the latter is largely dependent upon the design and workmanship, features that can be passed upon before the machinery leaves the works. If a power plant is found to be too small, more units can be readily added without in any way interfering with those in use. On the other hand the earning power of a motor equipment for individual operation of machines depends largely on conditions over which the manufacturer has no control. The continued growth of this department of his plant, however, is governed by results actually obtained with his product under working conditions, so to protect himself he is called upon to see that the proper equipment is selected, and if possible, advise as to its use. As far as the customer is concerned, it would usually be better for him to close his eyes and grasp any one of possibly four makes of apparatus, devoting his time to its proper installation and operation, rather than reversing the process as is so often done.

The conclusions reached above concerning the motors required for the 60-in. lathe are summarized in the table below:

	Weight.	Min. R.P.M.	Max. R.P.M.
Field weakening	2,300	225	787
Three-wire system	2,600	220	770
Four-wire system	2,350	235	820



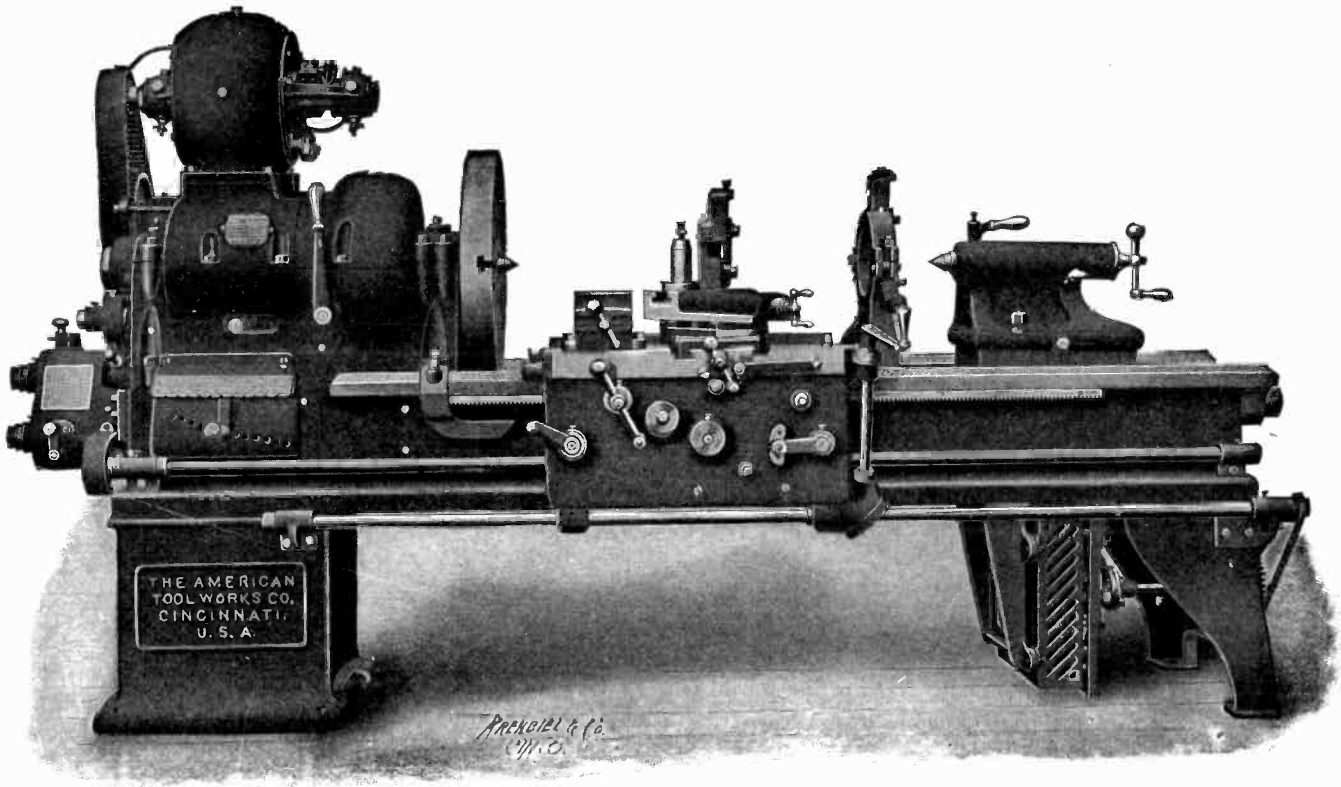
GUILLOTINE SHEARS. MOTOR DRIVEN.

Erie Foundry Company.

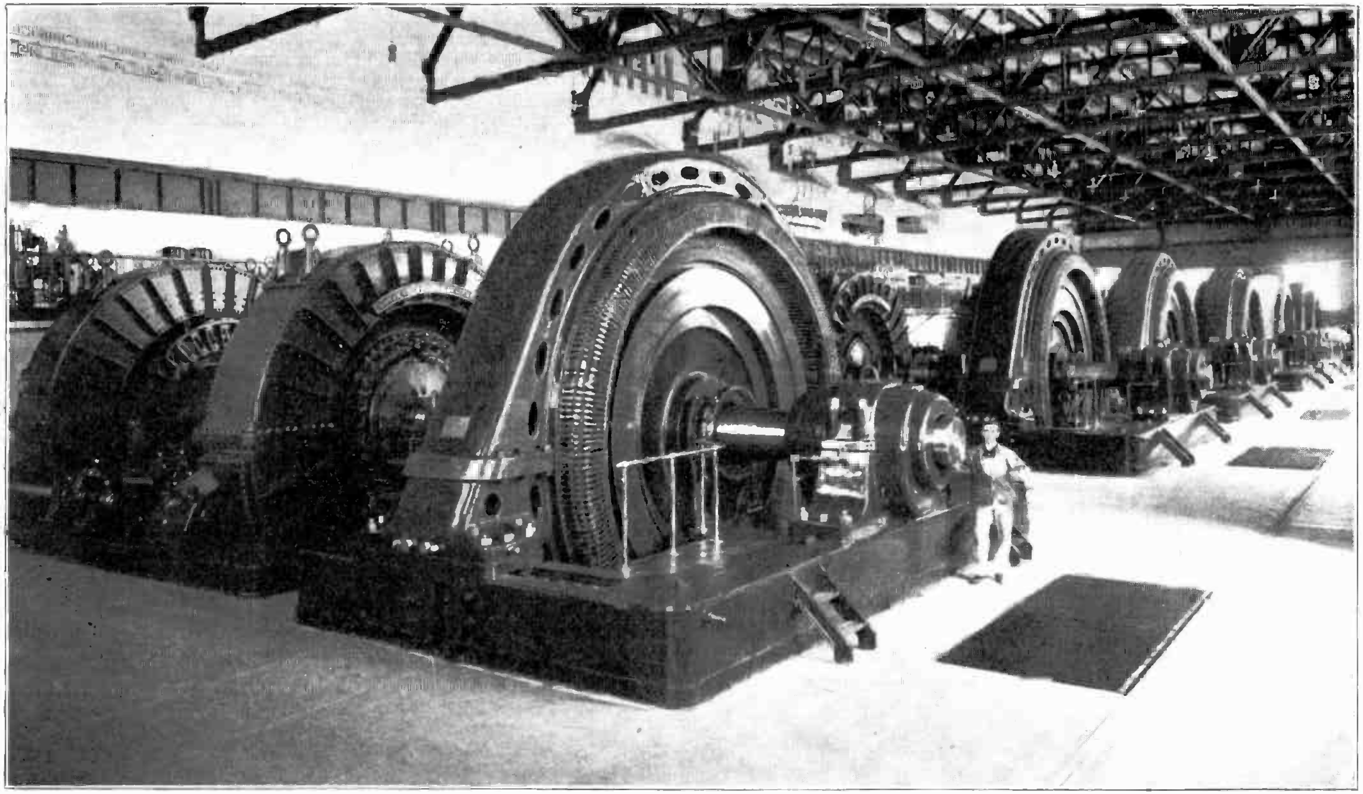
It must be remembered that the ability of these motors to fill the imposed conditions was not determined by actual test, the data being the recommendations of well-known electrical companies who manufacture the respective types of apparatus. These figures should at least make it clear that many statements constantly made concerning the size of motor required for a given horse-power and speed range cannot be other than erroneous.

I pointed out above the conditions which must be met by the machine builder necessitating the selection of a type that does not require for its operation special auxiliary apparatus. While motors operating on two wires and giving a range as high as 4 to 1 by means of field weakening do not at present give as good all-round results as those operating on the multiple-voltage and three-wire systems, we feel that their adoption by the manufacturers referred to is certainly justified. When this is more fully appreciated the electrical companies should rapidly achieve better results in this direction.

The customer purchasing for his own use should, on the other hand, *differentiate clearly between the machine builders' requirements and his own*, for in many cases he can secure more satisfactory results, all things considered, through the adoption of a system combining with field weakening a number of voltages.



MOTOR-DRIVEN AMERICAN ENGINE LATHE.



INTERIOR OF GENERATING STATION OF THE ONTARIO POWER COMPANY, NIAGARA FALLS, ONT.
The generators are direct-connected to horizontal double turbines.

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

The object of this instruction paper is to set forth the most important features which must be considered in the actual handling and operation of electric generators and motors. The principles and general construction of direct-current (D. C.) and alternating-current (A. C.) generators and motors, are treated elsewhere.

The subject may be divided into three parts as follows:

A. The Selection, Erection, Connection, and Operation.

B. The Inspection and Testing.

C. The Troubles or "Diseases" and Remedies.

SELECTION OF A MACHINE.

The voltage, capacity, and type of machine are dependent upon the system to which it is to be connected, and the purpose for which it is to be utilized, but there are certain general features which should be considered in every case.

Construction. This should be of the most solid character and guaranteed first-class in every respect, including materials and workmanship.

Finish. A good finish is desirable, since it is likely to cause the attendant to take greater care of the equipment.

Simplicity. The machine should be as simple as possible in all its parts; peculiar or complicated features should be avoided, unless absolutely essential for the operation of the system.

Attention. The amount of attention required by the machine should be small. The number of screws or nuts should be reduced to a minimum, and they ought always to be provided with some locking device to prevent them from becoming loose. The brushes should be capable of being easily adjusted and self-feeding, so that they may "follow" or make up for any trifling eccentricity of the commutator. The bearings should be self-oiling, and in the smaller sizes self-aligning.

Handling. An eye-bolt or other means by which the machine can be easily lifted and moved is desirable. It ought to be possible to take out the armature conveniently by removing one of the bearings, or the tops of the field magnet, frame and bearings, or by moving the halves sideways if the frame is split vertically. The armature and field windings should be so designed and mounted that their removal for repairs is an easy matter.

Interchangeability. The machine selected should preferably be one of a regular and standard type, so that extra parts can be obtained without needless delay.

Regulation. Some form of regulating device should be provided by means of which the E. M. F. or current of a generator, or the speed, and in some cases the direction of rotation of a motor, can be readily and accurately controlled.

Form. The machine should be symmetrical, well-proportioned, compact and solid in form. The large and heavy portions should be placed as low as possible, to give greater stability.

Weight. It is a mistake to select a very light machine when it is for stationary use, since weight increases its strength, stability, and durability.

Capacity. This should be ample for the work to be done; in fact it is advisable to allow a margin for increase. The machine should be provided with the maker's name-plate, specifying the rated current, voltage, speed and capacity. The manufacturer should also guarantee the following: That the machine does not heat up in any part of its windings, to more than 50° C, after a run of six hours' duration, under rated load conditions;* also that it is able to carry a 25 per cent overload for two hours, and momentary overloads of 50 per cent, without excessive heating or sparking.

Cost. It is usually an error to select a generator or motor simply because it is cheap, since both the materials and workmanship required for the construction of a high-grade electrical machine are costly.

MECHANICAL CONDITIONS.

Location. The place chosen for the machine should be *dry, free from dust or grit, light, and well ventilated.* It must also be arranged so that there is room enough for the removal of the armature without shifting or turning the machine.

Foundations. It is of great importance to have the machine

*NOTE. By resistance measurements.

firmly placed upon a good and solid foundation; otherwise, no matter how well constructed and managed, the vibrations occurring on a poor foundation will produce sparking at the brushes, and its accompanying troubles.

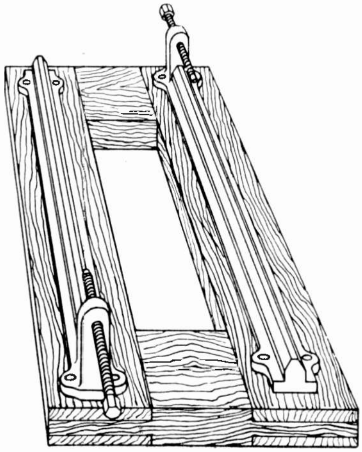


Fig. 1.

It is also necessary, if the machine is belt-driven, to mount it upon rails or a sliding bed-plate provided with holding-down bolts and tightening screws for aligning and adjusting the belt while the machine is in operation. (See Fig. 1). The machinery foundations consist of a mass of stone, masonry, brickwork, or concrete, upon which the machinery is placed and usually held firmly in place by bolts passing entirely through the mass. These bolts are built into the foundations, the proper position for them being determined by a wooden template suspended above the foundation, as shown in Fig, 2. The bolts are preferably surrounded by iron

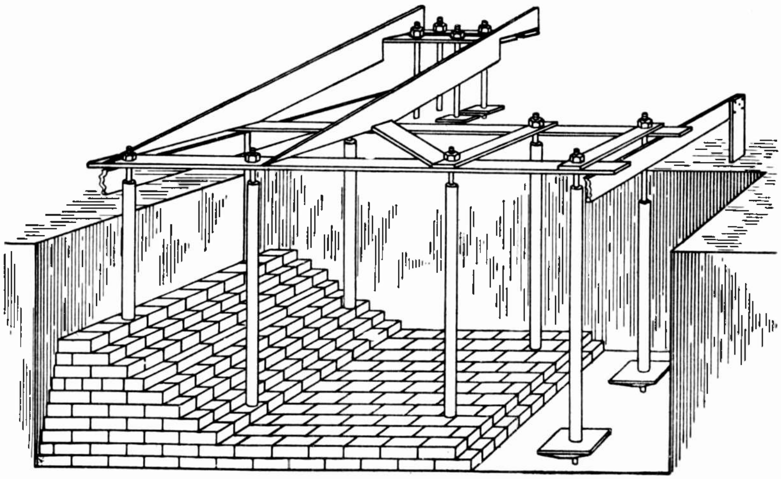


Fig. 2.

pipe that fixes them longitudinally but allows a little side play which may be necessary to enable them to enter the bed-plate holes readily. The brickwork for machinery foundations should consist of hard burned bricks of first quality, *laid in good cement mortar.* Ordinary *lime mortar is entirely unfit* for the purpose, being likely to crumble away under the effect of the vibrations caused by the machinery. Brick or concrete foundations should be finished with a cap of bluestone or cement. This tends to hold the foundation together, and forms a level surface upon which to set the machinery. If the engine and generator are provided with a cast-iron sub-base, the capping may be dispensed with

Fixing the Machine. In fixing either direct-connected or belt-driven machines, first determine, with a long straight edge and spirit level, if the top of the foundation is level and true. If this is found to be the case, the holding-down bolts may be dropped into the holes in the foundation, if they are not already built in, and the machine carefully placed thereon, the ends of the bolts being passed through the holes in the bed-plate and secured by a few turns of the nuts. The machine should then, if belt-connected, be carefully aligned with the transmitting pulley or fly wheel. Particular attention should be paid to the alignment of the pulleys in order that the belt may run properly. If direct-connected, the dynamo bed-plate and armature shaft must be carefully aligned and adjusted with respect to the engine shaft, raising or lowering the bed-plates of the corresponding machines by means of thin cast-iron or other wedges; and the generator frame should also be adjusted to its proper height by means of thin strips of metal or fiber set between its supporting feet and the bed-plate. Having thus aligned and leveled the machine, it should next be grouted with thin cement. This is done by arranging a wall of mud or wooden battens around the bed-plates of the machines, and running in thin cement until the holding-down bolt holes are filled, and the cement has risen to the level of the under side of the bed-plate. When the cement has set, the wall may be removed and the nuts on the holding-down bolts drawn up. This firmly fixes the machine upon its foundation.

Mechanical Connections. Various means are employed to connect the engine or other prime mover with the generator, or the motor with the apparatus to be driven. The most important are as follows:

Direct Connection.
Belting.
Rope Driving.
Toothed Gearing.

Other apparatus, such as shafting, clutches, hangers and pulleys, are used in connection with the above means.

Direct Connection. This is the simplest, and for that reason the most desirable, means of connection, provided it can be carried out without involving sacrifices that offset its advantages. This

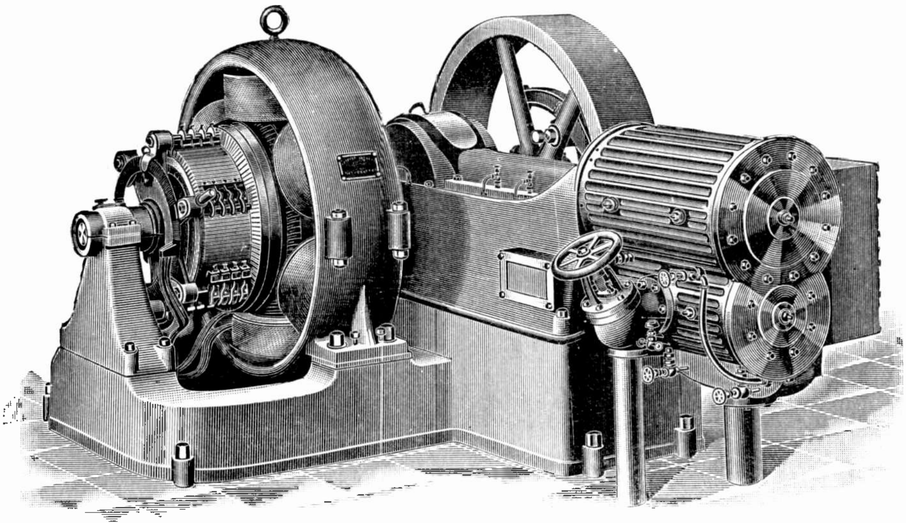


Fig. 3.

method, also called direct coupling or direct driving, compels the engine and generator to run at the same speed, which gives rise to some difficulty, as the most desirable speeds of the two machines do not usually agree. The natural speed of a generator is high, while that of an engine is low; hence to obtain the same voltage from a direct-connected generator, more inductors are necessary, or the flux cut must be increased. Accordingly, the armature and frame of the direct-connected generator must be larger, thus making it a more expensive machine than the belt-driven.

The direct connection of an engine and generator is accomplished in several ways; the simplest of which consists in mounting the armature of the generator directly on one end of the shaft of the engine. This may be accomplished in any one of several ways. Fig. 3 represents the three-bearing method. Two-and-four-bearing methods are also used. These secures the great advantages: that accurate alignment is readily obtained, and space occupied reduced to a minimum, and the mounting of the bearings on a common sub-base avoids trouble due to unequal settling.

Another form of direct coupling is that in which an engine and a generator, each complete in itself, and each having two bearings, are coupled together by some mechanical device, which may be either rigid or slightly elastic or adjustable. In the former case the two shafts are practically equivalent to a single one, which, while making it easy to remove either machine for repairs, is somewhat objectionable owing to the fact that it requires larger foundations, and introduces the difficulty of accurately aligning four bearings. The use of a flexible coupling avoids the necessity of perfect alignment, and also the serious trouble that might arise if the settling or the wear of the bearings should be uneven. There are various forms of flexible coupling. One of the forms manufactured by the Westinghouse Machine Company is shown in Fig. 4, the flexibility being provided by the springs which hold the two parts of the coupling together.

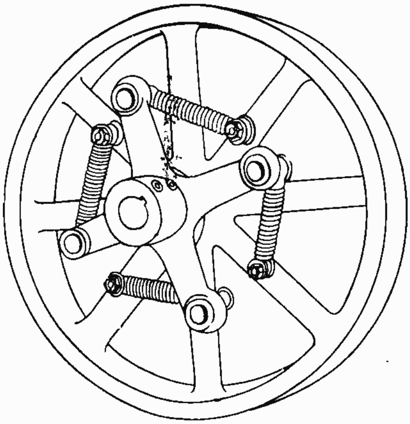


Fig. 4.

The direct coupling of generators with turbines can be carried out without departing from the natural speed of either machine, since the ordinary speed of a turbine agrees closely with the normal speed of a generator of the corresponding capacity.

The relative efficiency of direct coupling and belting depends greatly upon the conditions; but in general the former is more efficient at or near rated load, and the latter at light loads. *The simplicity, compactness, and positive and noiseless action of direct connection* have caused it to become the most approved method.

Belting. If the generator or motor is not directly connected, one to the prime mover and the other to the apparatus to be driven, they are usually connected by some form of belting. The kind of belting selected depends greatly upon conditions of drive, distances, etc.; and it may be leather, rawhide, rubber, or rope. For ordinary short drives, leather is the most desirable, though, when the power to be transmitted is small, rawhide belts are also satisfactory, especially as the cost is less than for leather belts. For considerable distances, rope driving answers very well because it is so much lighter and cheaper than an equivalent leather belt, though grooved pulleys are required, making the total cost about the same. Rubber belts are used to advantage in driving generators from water turbines, where the belt might be exposed to moisture. Leather belting is usually the most reliable and satisfactory for general application, except for very short drives, where a form of chain belt works best. There are three thicknesses of leather belting—single, light-double, and double. For use in connection with generators, motors, or other high-speed machinery, the "light-double" belting is usually the best.

The exact amount of power that a given belt is capable of transmitting is not very definite. The ordinary rule is that "single" belt will transmit 1 horse-power for each inch of its width when traveling at a speed of 1,000 feet per minute. If the speed is greater or less, the power is proportionately increased or decreased. The statement of H. P. transmitted is based upon the condition that the belt is in contact with the transmitting pulley around one-half of its circumference, or 180°, which is usually the case. If the arc of contact is less than 180°, the power transmitted is less in the following proportion: An arc of 135° gives 84 per cent, while 90° contact gives only 64 per cent of the power derived from a belt contact of 180°. If on the other hand, the upper side sags downward, which is always desirable, the belt is in contact with more than half the circumference of the pulley; and thus the grip is considerably increased and more power can be transmitted. These facts make it very desirable to have the *loose side of the belt on top*. If the loose side is below, it sags away from the pulley and is also likely to strike the floor.

The complete expression for determining the width of a single belt required to transmit a given horse-power is as follows:

$$W = \frac{\text{H. P.} \times 1{,}000}{S \times C},$$

where W is the width of the belt in inches; H. P. the horse-power to be transmitted; S the speed of the belt in feet per minute, which is equal to the circumference of the driving pulley in feet multiplied by the number of revolutions per minute;* and C a factor dependent upon the arc of contact.

"Double" belting is expected to transmit one and one-half ($1\frac{1}{2}$), and "light-double" one and one-quarter ($1\frac{1}{4}$) times as much power as "single" belting of the same width. Belting formulas are only approximate, and should not be applied too rigidly, since the grip of the belt upon the pulley varies considerably under different conditions of tension, temperature and moisture. The smooth side of a belt should always be run against the pulley, as it transmits more power and is more durable. Belting used for electric machinery, being usually high-speed, should be made "endless" for permanent work, as this makes less noise; but it may be used with laced joints, temporarily. A spliced or "endless" joint is made as follows:—Both ends of the belt are pared down on one side (opposite) with a sharp knife, into the form of a long thin wedge, so that when laid together a long uniform joint is obtained of the *same thickness as the belt itself*. The parts are then firmly joined with cement and sometimes with rivets also. It may be necessary to splice or lace a belt while in position on the pulleys; and for this purpose some form of belt clamp (Fig. 5) should be employed.

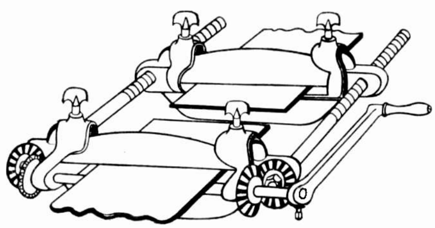


Fig. 5.

If a belt is ordered endless, or is spliced away from the pulleys, great care should be exercised in determining the exact length required. A string that will not stretch, or preferably a wire put around the pulleys in the position to be occupied by the belt, is the

* NOTE. Belts slip or "creep" on the pulley about 2 per cent; hence, in determining the size of pulleys whose speed must be accurate, the calculated belt speed should be about 2 per cent too high.

best way to avoid a mistake. In measuring for a belt, the generator or motor should be moved on its sliding base so as to make the distance between shaft centers a minimum, in order to allow for the stretch of the belt, which may be as much as $\frac{1}{2}$ inch per foot of length.

The lacing of a belt is a very simple and common method of making a joint; but should not be permanently employed at high speeds for electric machinery belting, as it is liable to pound on the pulleys, producing noise, vibration and sparking; and in the case of generators it is also likely to cause flickering in the lamps. In lacing belts, the ends should be cut *perfectly square, and there should be as many stitches of the lace slanting to the left as there are to the right;* otherwise the ends of the belt will shift

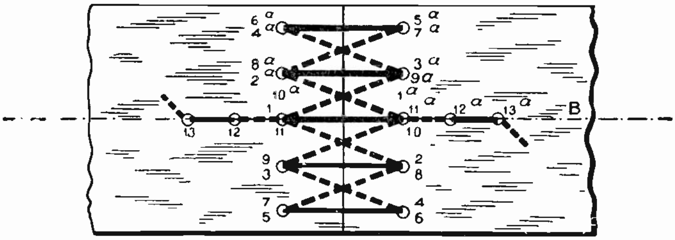


Fig. 6.

sidewise owing to the unequal strain, and the projecting corners may strike or catch in the clothing of persons. A good way to accomplish this is shown in Fig. 6. The various holes should be made with a circular punch, the nearest one being about $\frac{3}{4}$ inch from the side, and the line through the center of the row of holes about 1 inch from the end of the belt. In large belts these distances should be a little greater. A regular belt lacing of strong pliable leather or a special wire is used. The lacing is doubled to find its middle; and the two ends are passed through the two holes marked "*1*" and "*1a*," precisely as in lacing a shoe. The two ends are then passed successively through the two series of holes, in the order in which they are numbered, *2*, *3*, *4*, etc., and *2a*, *3a*, *4a*, etc., finishing at *13* and *13a*, which are additional holes for securing the ends of the lace. The great advantage of this method of lacing is that the lace lies on the pulley side perfectly parallel to the direction of motion.

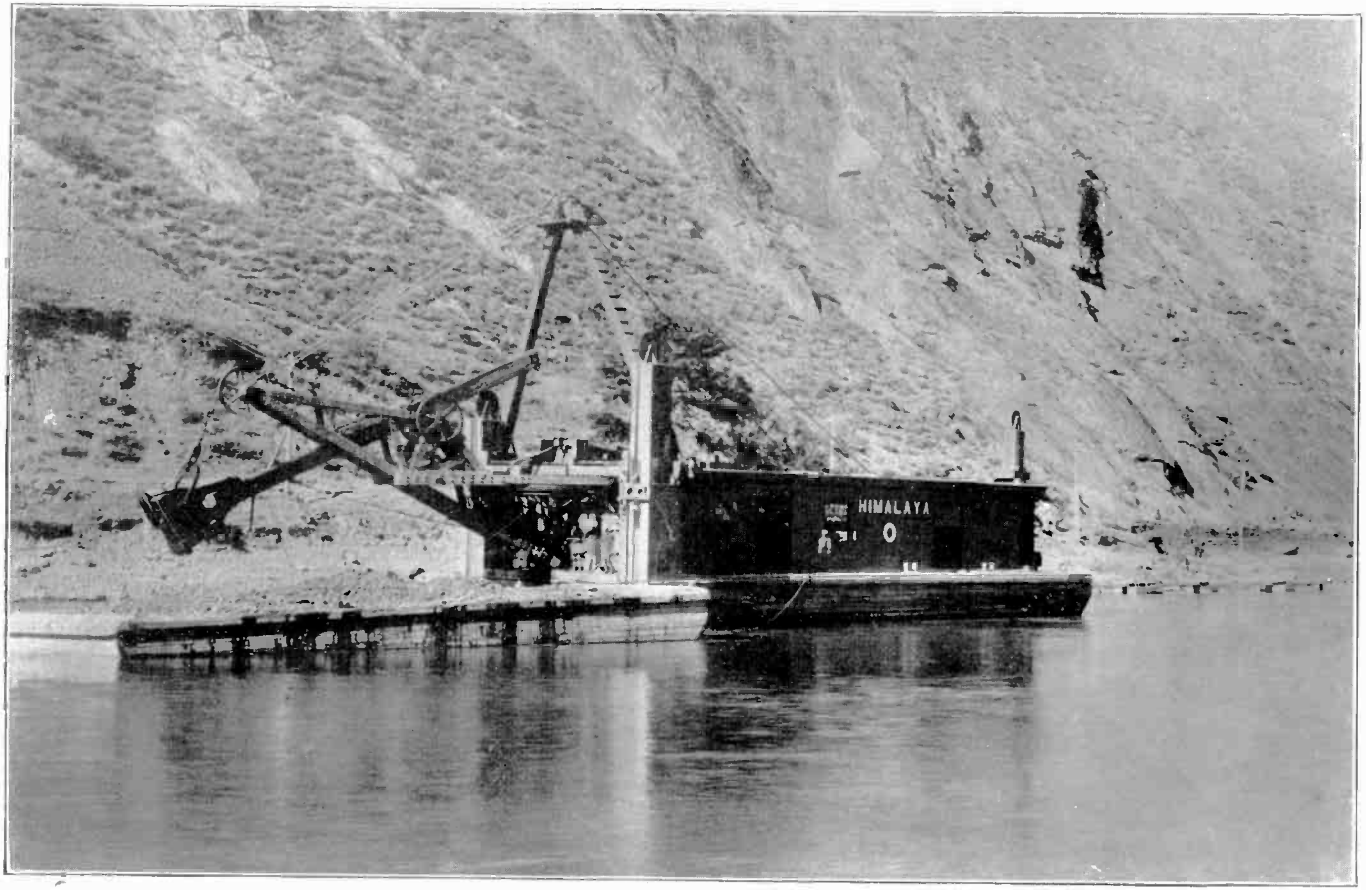
Perforated belts are often employed for the reason that a film of air is likely to be imprisoned between the belt and the pulley, thus preventing a good grip. Hence small perforations are sometimes made in the belt, especially for high-speed operation (3,000-5,000 feet per minute), to allow the air to escape; and since these are in the form of narrow slits, with their greatest dimension in the direction of motion, they do not materially reduce the strength of the belt.

Arrangement and Care of Belting. It is very desirable, for satisfactory running, that belts should be reasonably long and nearly horizontal. The distance between the centers of two belt-connected pulleys should be not less than 3 times the diameter of the larger pulley. The belt should be just tight enough to avoid slipping, without straining the shaft or bearings. The two shafts which are to be belt-connected must be perfectly parallel, and the centers of the face of the driving and driven pulleys must be exactly opposite to each other, in a straight line perpendicular to the axis of the shafts. The machines should then be turned over slowly with the belt on, to see if the latter tends to run to one side of the pulley, which would show that it is not yet properly "lined up," in which case one or both machines should be slightly shifted, until the belt runs properly. If possible, the machine and belt should be set and adjusted so as to cause the armature to move back and forth in the bearings while running, on account of the side motion of the belt, and thus make the commutator wear more smoothly, and distribute the oil in the bearings.

It is always desirable to have belts as pliable as possible; hence the occasional use of a good belt dressing—as neatsfoot oil, etc.—is recommended. Rosin and other sticky substances are sometimes applied to increase the adhesion; but this is a practice allowable only in an emergency, as it may destroy the belt surface.

In places where the belting is very much exposed, and liable to catch in the clothing of any person, it is advisable to surround it by a railing or box.

Rope Driving possesses advantages over ordinary belting in some cases. The rope runs in V-shaped grooves in the peripheries of the pulleys, and thereby obtains a great grip by a sort of wedging action. The kinds of rope ordinarily employed for this pur-



AMERICAN ENGINEERS IN THE ORIENT
A Bucyrus Electric Dipper Dredge at Work in the Vale of Kashmir.

pose are cotton, hemp, rawhide and wire. The general advantages are:

1. Economy in cost.

2. Large amount of power that can be transmitted with a given diameter and width of pulley, on account of the grip obtained.

3. It is almost noiseless.

4. Ropes, on account of their lightness, can be used to transmit power over greater distances than are possible with any other form of belting; and also for very short distances on account of the wedging action. Manila rope is generally used in the United States, being of three strands, hawser laid, and may be from $\frac{1}{2}$ inch to 2 inches in diameter. The breaking strength varies from 7,000 to 12,000 pounds per square inch of cross-section. It has been found that the best results are obtained when the tension in the driving side of the rope is only 3 to 4 per cent of the breaking strength.

The diameter of a single rope necessary to transmit a required H. P. is given by the formula:

$$D^2 = \frac{825 \text{ H.P.}}{V\left(200 - \frac{V^2}{1,072}\right)},$$

in which H. P. = horse-power transmitted;
V = velocity of rope in feet per second;
D = diameter of rope in inches.

The maximum power is obtained at a speed of about 84 feet per second. With higher speeds the centrifugal force becomes so great that the power transmitted decreases rapidly, and at about 142 feet per second it counteracts the whole allowable tension (200 D^2 pounds) and no power is transmitted.

Arrangement of Rope Belting. There are two methods of arranging rope transmission: one consists in using several separate belts; and the other employs a single endless rope which passes spirally around the pulley several times and is brought back to the first groove by a slanting idle pulley, and therefore is called the "wound" system. The separate ropes do not require the carrying-over pulley, and if one rope breaks, those remaining are sufficient to transmit the power temporarily; whereas an accident with the single-rope system entirely interrupts the service. In the "multi-rope" system it is practically impossible to make and maintain the belts of exactly equal length, hence the tensions on the various ropes differ, and they hang at different heights on the slack side, producing an awkward appearance.

Toothed Gearing possesses the decided advantages of positive action and the ability to give large ratios of speed and small side pressure on the bearings. Nevertheless it is seldom employed for driving generators. As the most extensive applications of gearing for electrical purposes are in connection with railway motors, it will be taken up under that heading.

SHAFTING.

An intermediate or counter shaft is not desirable since it increases the complication and frictional losses of the system; but it is often necessary in the generation or application of electric power, either to obtain a greater multiplication of speed than is possible by belting directly, or to enable a single engine or motor to drive a greater number of machines.

The two important kinds of shaftings are "cold-rolled" and "turned." The former is rolled to the exact size and requires no further treatment. It has the advantage of a smooth, hard surface, but it is difficult to make perfectly true and straight. Turned-steel shafting is most commonly employed, and has the advantage that shoulders, journals, or other variations in size can be easily made on it. The following table gives the ordinary data for shafting:

TABLE I.

Shafting.

Diameter in inches.	Weight lbs. per ft.	Allowable H. P. transmitted at 100 r. p. m.	Width of key seat in inches.
$1\frac{7}{16}$	5.5	4.3	$\frac{8}{8}$
$1\frac{15}{16}$	10.	10.	$\frac{1}{2}$
$2\frac{7}{16}$	15.8	20.	$\frac{3}{4}$
$2\frac{15}{16}$	23.	34.	$\frac{8}{4}$
$3\frac{7}{16}$	31.5	54.	$\frac{7}{8}$
$3\frac{15}{16}$	41.	80.	1
$4\frac{7}{8}$	62.8	156.	1
$5\frac{7}{8}$	91.1	270.	1

With speeds greater than 100 r. p. m., the allowable H. P. varies directly in proportion to the speed employed.

ASSEMBLING OF THE MACHINE.

In unpacking and putting the machine together, great care should be used to avoid the least injury to any part, to clean scrupulously each part, and to put the parts together in exactly the right way. This care is particularly important with regard to the shaft, bearings, magnetic joints, and electrical connections, from

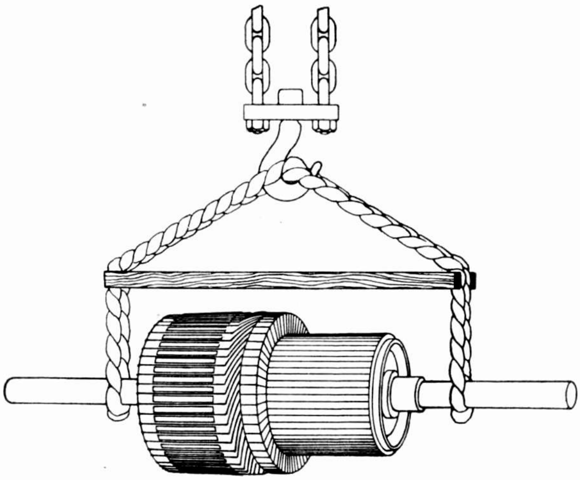


Fig. 7.

which every particle of grit, dust, metal chips, waste, etc., should be removed. It is advisable to study carefully the blue prints or instruction matter usually sent with each machine, before attempting to put it together. The armature must be handled with great care in order not to injure the wires and their insulation as well as the commutator and shaft. The armature should be handled as far as possible by the shaft, and when it must be placed on the ground a pad of cloth or layer of boards should be interposed. A convenient form of sling for handling armatures with their shafts in position is shown in Fig. 7. The bearings should be carefully cleaned, set in exactly the right positions, and firmly secured. The tops should be left loose for a short time, so that the tendency to heat up at the first run may be decreased; and after that they should be drawn up tight. The field frame should be set so that the air gap is the same for all pole pieces, as otherwise the machine will be magnetically unbalanced and tend to spark badly.

The adjustment of the brushes, etc., should preferably be left until the machine is electrically connected and ready to receive its trial run.

METHODS OF WIRING.

Before laying the wires, the circuits should be carefully mapped out and the work so planned as to secure the simplest arrangement. The wiring should then be installed neatly and in accordance with the rules of the National Board of Fire Underwriters and of the local department having supervision. Otherwise unnecessary trouble, delay and expense may be incurred.

The wire may be installed in one of two general methods, *viz.*:

Exposed on { Cleats. / Knobs. / Bushings.

Concealed in { Wooden moulding. / Iron conduit. / Terra cotta conduit.

The wire should preferably be either rubber-covered or made up in the form of lead cables. Exposed wires possess the advantages of cheapness, as well as accessibility for inspection and repair; and any short circuit or ground is readily seen and removed, whereas it might cause great uncertainty and delay when the wires are concealed.

Concealed conductors, especially where they are placed under the floor, have the great advantage over exposed wiring, in that they are entirely out of the way. This is especially important in large installations, where overhead traveling cranes are almost a necessity.

When alternating-current conductors are enclosed in iron conduits, both wires of each phase, or all the wires, must be run in the same duct, otherwise the inductance would be excessive.

All conductors, including those connecting the machine with the switchboard, as well as the bus bars on the latter, should be of ample size to be free from overheating and excessive loss of voltage. The drop between the generator and switchboard should not exceed ½ per cent at full load, because it interferes with proper regulation and adds to the less easily avoided drop on the distribution system.

The safe carrying capacities of copper conductors as recommended by the Board of Fire Underwriters, are given in the following table:

TABLE II.

Safe Carrying Capacities of Copper Wires.

B. & S. G.	Rubber Insulation. Amperes.	Other Insulations. Amperes.	Circular Mils.
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,690
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	210	312	211,600
Circular Mils.			
200,000	200	300	
300,000	270	400	
400,000	330	500	
500,000	390	590	
600,000	450	680	
700,000	500	760	
800,000	550	840	
900,000	600	920	
1,000,000	650	1,000	
1,100,000	690	1,080	
1,200,000	730	1,150	
1,300,000	770	1,220	
1,400,000	810	1,290	
1,500,000	850	1,360	
1,600,000	890	1,430	
1,700,000	930	1,490	
1,800,000	970	1,550	
1,900,000	1,010	1,610	
2,000,000	1,050	1,670	

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

The carrying capacity of Nos 16 and 18, B & S. gage wire is given, but no smaller than No. 14 is to be used.

The safe carrying capacity of insulated aluminum wire is 84 per cent of that given for copper wires of corresponding size and insulation.

Switches are devices for closing and opening the various circuits or branches of an electrical distribution system. A knife switch should always be employed when the capacity of the circuit to be controlled exceeds 10 amperes. It may be single-, double-, or triple-pole; single- or double-throw; and with or without fuses as desired. If the rated capacity of a switch exceeds 25 amperes, its terminals must be provided with lugs into which the ends of the conducting wires should be soldered. The principal parts of a knife switch (Fig. 8) are the *base* (*a*), which must consist of a non-combustible, non-absorptive insulating material; the *hinges* (*b*), which carry the *blades* (*c*); the contact *jaws* or *clips* (*d*); the insulating *cross-bar* (*e*); and the *handle* (*f*). The hinges, blades and jaws should be made of pure copper, of sufficient cross-section to insure mechanical stiffness and proper carrying capacity, and their contact surfaces must not be less than 1 square inch per 75 amperes of the rating. The hinges and contact jaws must be springy enough to insure good contact with the blades. The blades and jaws must be so shaped that they open along their entire length simultaneously; otherwise the arc which is formed upon opening a loaded circuit. will burn off the last points of contact. In fact this arc, when produced by a heavy current, is very difficult to control; and switches should never be opened on heavily-loaded circuits except in an emergency. In practice, however, some form of electro-magnetic circuit-breaker is employed for the purpose, and may be operated automatically with overload, or by hand at any time.

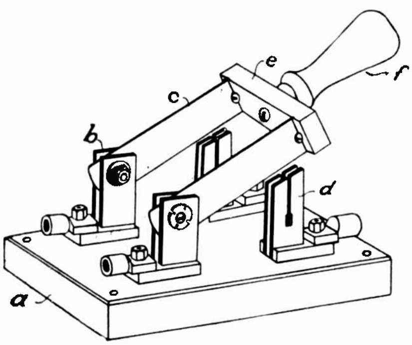


Fig. 8.

Knife switches should be so placed that *gravity tends to open* rather than to close them. They should always be located in dry, accessible places and grouped as far as possible If located in exposed positions they should be enclosed in slate or equivalently lined cabinets. The distances between the parts of opposite polarity, in an approved knife switch, must never be less than the values given in the following table:

TABLE III.

Switch Data.

125 VOLTS OR LESS:	Minimum Separation of Nearest Metal Parts of Opposite Polarity.	Minimum Break-Distance.
For Switchboards and Panel Boards—		
10 amperes or less	¾ inch	½ inch.
11-25 "	1 "	¾ "
26-50 "	1¼ "	1 "
For Individual Switches—		
10 amperes or less	1 inch	¾ inch.
11- 35 "	1¼ "	1 "
36- 100 "	1½ "	1¼ "
101- 300 "	2¼ "	2 "
301- 600 "	2¾ "	2½ "
601-1,000 "	3 "	2¾ "
126 TO 250 VOLTS:		
For all Switches—		
10 amperes or less	1½ inch	1¼ inch.
11- 35 "	1¾ "	1½ "
36- 100 "	2¼ "	2 "
101- 300 "	2½ "	2¼ "
301- 600 "	2¾ "	2½ "
601-1,000 "	3 "	2¾ "

On switchboards, the above spacings for 250 volts direct current are also approved for 440 volts alternating current. Switches on switchboards with these spacings intended for use on alternating-current systems with voltages above 250, must be stamped with the voltage for which they are designed, followed by the letters "A. C."

251 TO 600 VOLTS:		
For all Switches—		
10 amperes or less	3½ inch	3 inch.
11- 35 "	4 "	3½ "
36-100 "	4½ "	4 "

Auxiliary breaks or the equivalent are recommended for switches designed for over 300 volts and less than 100 amperes, and will be required on switches designed *for use in breaking currents* greater than 100 amperes at a pressure of more than 300 volts.

For three-wire systems switches, must have the break-distance required for circuits of the potential of the outside wires.

Safety Fuses and Cut-outs. Almost all electrical circuits, except those for constant-current arc lighting, are protected from abnormal increase of current by safety fuses. These consist of wires or strips of metal introduced into the circuit, and so designed in cross-section and resistance that they will melt and open the circuit in case of excessive current, before the rest of the system becomes unduly heated.

The requirements for effective safety fuses may be stated as follows:

1. They should melt at a definite current.
2. They should not change in this respect by the effect of time, nor by heating or other action of the current, nor, in fact, under any reasonable conditions.
3. They should act promptly.
4. They should give firm and lasting contacts with the terminals to which they are attached.

These fuses are of two general types:

(*a*) Open or link fuses.
(*b*) Enclosed or cartridge fuses.

The open or link fuses (Fig. 9) consist of strips of fusible

Fig. 9.

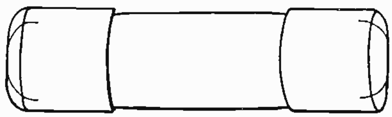


Fig. 10.

alloy provided with copper terminals. Each size is designed to carry a certain normal current, but will melt and open the circuit when the current exceeds that rating by 25 per cent. When a link 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.

Enclosed fuses (Fig. 10) have a casing around the fusible material, which prevents the dangerous spattering and which also smothers the arc that tends to form whenever a fuse blows.

Fuses should always be employed when the size of the wire changes, or where connections between any electrical apparatus and the conductors are made. They must be mounted on slate, marble, or porcelain bases; and all metallic fittings employed in making electrical contacts must have sufficient cross-section to insure mechanical stiffness and carrying capacity.

Electro-magnetic Circuit-Breakers or **Limit Switches** are frequently used in place of fuses to protect electrical circuits. Their

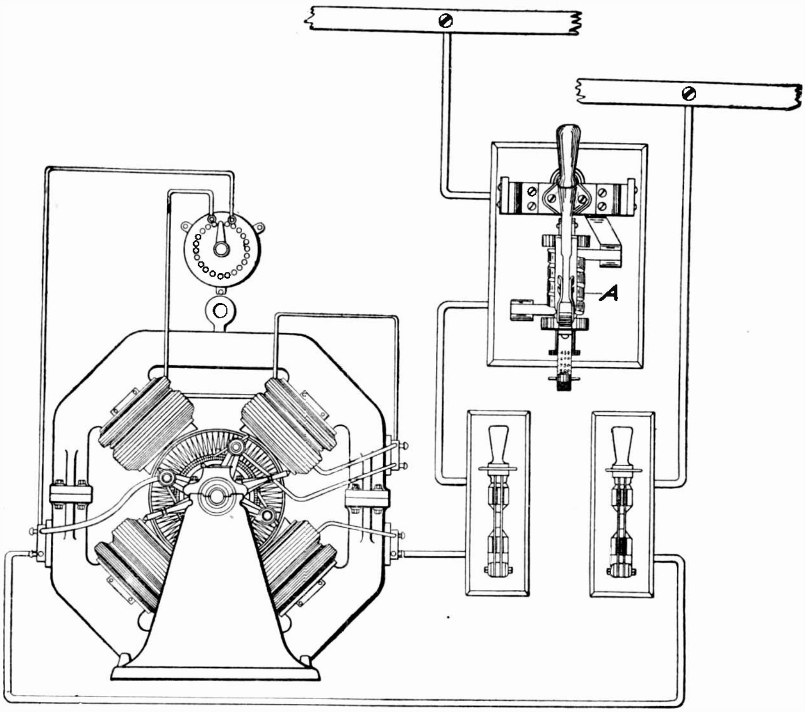


Fig. 11.

general construction and application are indicated in Fig. 11. The current is led through a helix A the electro-magnetic action of which, when the current reaches a predetermined limit, automatically releases the blades from contact with the jaws and thus opens the circuit. The final break occurs at carbon tips, thus preventing destructive arcing at the copper contacts. Circuit-breakers possess the following advantages over fuses:

1. They can be employed as switches if desired.

2. They can easily be reset and thus put into condition for acting again.

3. Their range can be easily varied within considerable limits.

4. They can also be made to operate "tell tales" whenever the circuit they control is opened.

On account of these general advantages, their use is advisable on switchboards of systems that are liable to frequent overloads. The circuits, however, should, as a rule, be provided also with fuses, since it is possible that the circuit-breaker may fail to open, owing to corrosion or other cause.

Starting-Boxes should always be furnished with D. C. motors, for the following reason: If the line voltage should be applied directly to the terminals of the armature while it is standing still, a very excessive current would flow, since the resistance is low and no C. E. M. F. exists. Hence, to prevent injury to the winding, a resistance is inserted between one supply terminal and the armature in order to reduce the electromotive force at the motor terminals while it is speeding up, the resistance being gradually reduced until completely removed when rated speed is reached. All motor starting-boxes must also be provided with a **no-voltage release.** This consists of an electro-magnet in series with the shunt-field circuit, which holds the rheostat arm in the operating position as long as current flows through the shunt field from the line. If the line switch be opened or the shunt-field circuit accidentally broken, the device becomes demagnetized and releases the arm, which returns to its starting position (all resistance in circuit) by the action of a spring or of gravity. The starting-boxes of larger motors are also frequently equipped with **overload releases.** These, practically, are electro-magnetic circuit-breakers which open the supply lines if the motor becomes greatly overloaded. The general arrangement of switches, cut-outs and starting-boxes should be in accordance with the following extract from the Rules of the National Board of Fire Underwriters:

"Each motor and starting-box must be protected by a cut-out and controlled by a switch, said switch plainly indicating whether 'on' or 'off.' The switch and rheostat must be located within sight of the motor, except in cases where special permission to locate them elsewhere is given, in writing, by the Inspection Department having jurisdiction.

"Where the circuit-breaking device on the motor-starting rheostat disconnects all wires of the circuit, this switch may be omitted.

"Overload-release devices on motor-starting rheostats will not be considered to take the place of the cut-out required if they are inoperative during the starting of the motor.

"The switch is necessary for entirely disconnecting the motor when not in use; and the cut-out, to protect the motor from excessive currents due to accidents or careless handling when starting. An automatic circuit-breaker disconnecting all wires of the circuit, may, however, serve as both switch and cut-out."

The **Various Kinds of Circuit** on which motors and generators are commonly used, and the best type of machine in each case, are as follows :

TABLE IV.

Types of Machine for Various Kinds of Circuits.

DIRECT-CURRENT, CONSTANT-POTENTIAL.

Circuits on which potential or voltage is kept constant; machines, lamps, etc., being run in parallel.

Currents intended for—	Potential.	Generator should be—	Motor should be—
Electro-metallurgy.	1 to 150 volts	Shunt-wound.	Not used.
Incandescent lighting.	110 to 125 volts (2-wire sys.) 220 to 250 volts (2- or 3-wire sys.)	Shunt- or compound-wound.	Shunt-wound for constant speed. Sometimes series- or compound-wound for variable speed.
Electric railway Electric power.	500 to 660 volts	Compound-wound.	Series-wound for railway. Shunt-wound for stationary.

DIRECT, CONSTANT-CURRENT.

Circuits on which current or amperes are kept constant; machines, lamps, etc., being run in series.

Circuits intended for—	Current in Amperes.	Generator should be—	Motor.
Arc lighting.	6.8 or 9.6	Series-wound with current regulator.	No longer used.

ALTERNATING-CURRENT, POLYPHASE.

Constant-potential, two- or three-phase currents.

Circuits intended for—	Potential in Volts.		Generator should be—	Motor is—
Power transmission.	On the line, 5,000 to 60,000.	In the machines, varying 500 to 12,000	Separately excited.	Synchronous or Induction.

ALTERNATING-CURRENT, SINGLE-PHASE.

Almost always constant-potential.

Circuits intended for—	Potential in Volts.		Generator should be—	Motor should be—
Incandescent lighting. Arc lighting. Sometimes constant-current. Electric power.	Primary, 1,000 or more,	Secondary, 104 or 208.	Separately excited. Also sometimes composite-wound.	Synchronous. Induction. Series. Repulsion.

Diagrams of Connections are given for each important case to show what is actually required. These merely represent the path of the currents in the simplest way, the important thing being to have these paths right, and to know which parts or wires are to be connected. The case of plants operating with only a single generator will be first considered, and then the parallel or series operation of several machines described.

Shunt Dynamo, Supplying Constant - Potential Circuit. A machine of the above type is represented in Fig. 12, with the necessary connections. The brushes are connected to the two conductors forming the main circuit; also to the field-magnet coils *Sh* through a resistance-box R, to regulate the strength of current and therefore the magnetism in the field. A voltmeter is also connected to the two brushes or main conductors, to measure the voltage or electrical pressure between them. One of the main conductors is connected through an ammeter A, which measures the total current on the main circuit. The lamps L, or motors M, are connected in parallel between the main conductors or between branches from them. This represents the ordinary low-tension system for electric light and power distribution from isolated plants or central stations.

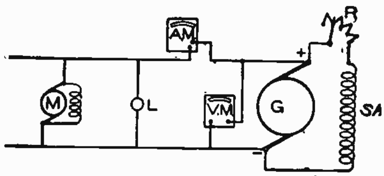


Fig. 12.

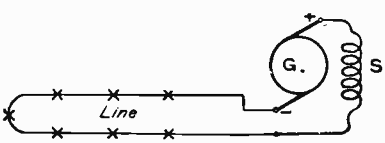


Fig. 13.

Series Dynamo Supplying Constant-Current Circuits. The connections in this case are extremely simple, the armature, field coils, ammeter, main circuit, and lamps all being connected in one series (Fig. 13), the current being kept constant. This system is used for series D. C. arc lighting.

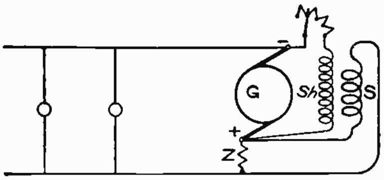


Fig. 14.

Compound Direct-Current Dynamo. This machine is a combination of the two foregoing types as regards field winding; but its load of lamps and motors are connected in parallel, as shown in Fig. 14. The resistance Z is known as the "series" shunt, and is for adjusting the percentage of compounding. The greater the resistance of Z, the greater the current passing through the series field, and the greater the compounding. This type of machine is most extensively employed in electric railway and in isolated plant work.

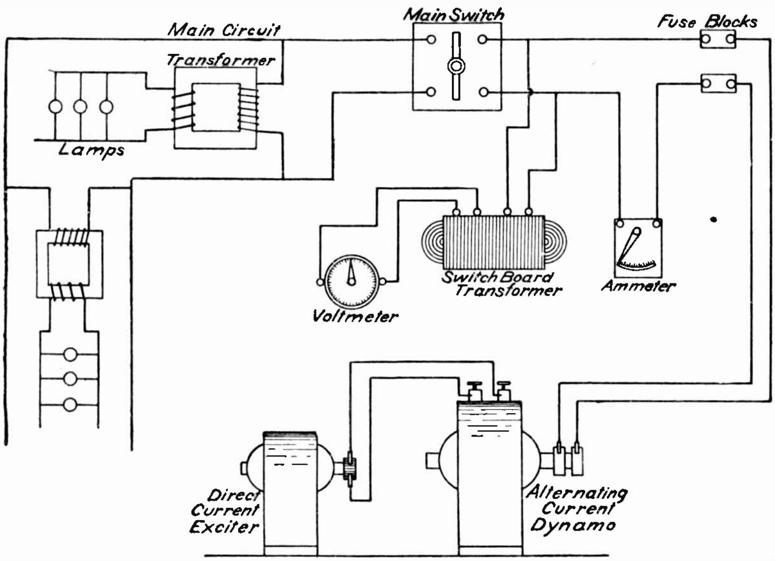


Fig. 15.

Alternating-Current Plants. The connections for a single-phase installation are shown in Fig. 15, in which the names of the different parts are given. This system is extensively used for lighting over considerable distances, and is very well adapted to street railway work. The wiring of a two-phase system is essentially double that given above, and can be treated as a system consisting of two single-phase circuits.

The wiring of a three-phase system is as shown in Figs. 16*a* and 16*b*, the former being known as the "Y" system or "Star"

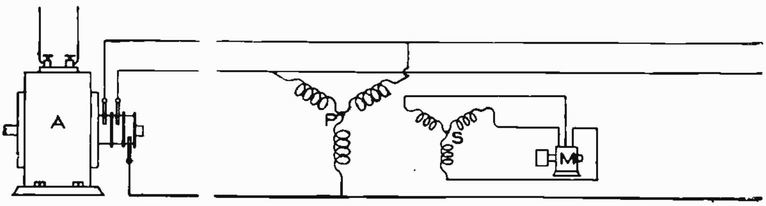


Fig. 16*a*.

system, and the latter as the "Delta" (Δ) system or "Mesh" system. When the Y system is required for both lighting and power, it is arranged as shown in Fig. 16*c*.

The **Direction of Rotation** of the various machines is sometimes a matter of doubt or trouble. Almost any generator or motor is intended to be run in a certain direction; that is, it is called "right-handed" or "left-handed" according to whether the armature does or does not revolve like the hands of a clock, when looked at from the pulley end. Generators and motors are usually

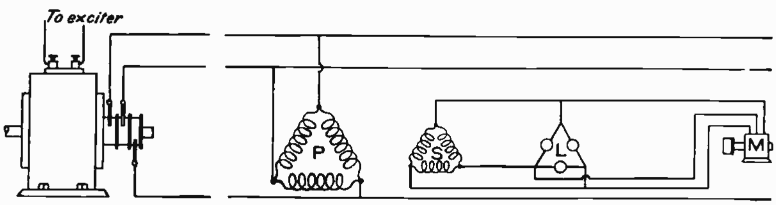


Fig. 16*b*.

designed to be right-handed, but the manufacturer will make them left handed if specially ordered. This may be required because the other pulley to which the machine is to be connected happens to revolve left-handed; or it may be necessary in order to bring the loose side of the belt on top, or to permit the machine to occupy a certain position where space is limited.

To reverse the direction of rotation of an ordinary shunt (or series) direct-current bipolar motor, the brushes may simply be reversed as indicated in Fig. 17, without changing any connection. This changes the point of contact of each brush tip 180°.

If the machine is multipolar, a similar change must be made, amounting to 90° in a four-pole, 45° in an eight-pole machine, etc.

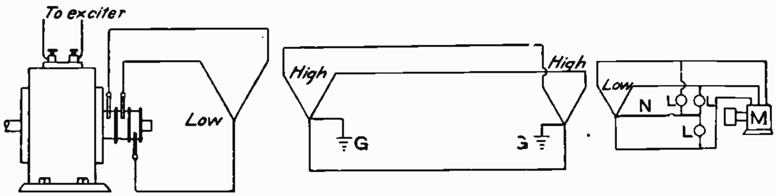


Fig. 16c

The direction of the current and the polarity of the field magnets remain the same as before; all that is changed is the direction of rotation and the position of the brushes. This applies to any machine (either motor or generator) except arc dynamos and one or two other peculiar machines, which require to be run in a certain direction to suit the regulating apparatus.

A separately excited alternating-current generator can be reversed in direction of rotation without changing any connection. A self-exciting or compound-wound alternator requires the brushes that supply the direct current to the field to be reversed upon the

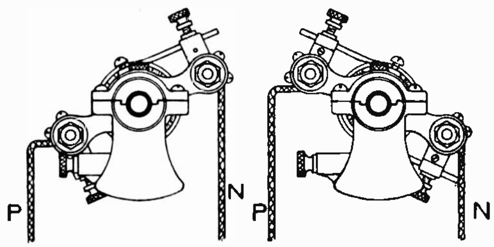


Fig. 17.

commutator, and their tips moved through an angle as above stated, if the rotation is to be reversed.

In any case, copper brushes (unless they be gauze brushes pressing radially upon the commutator) should point in the direction of rotation; but carbon brushes, particularly if they are perpendicular to the surface of the commutator, allow the armature to be revolved in either direction.

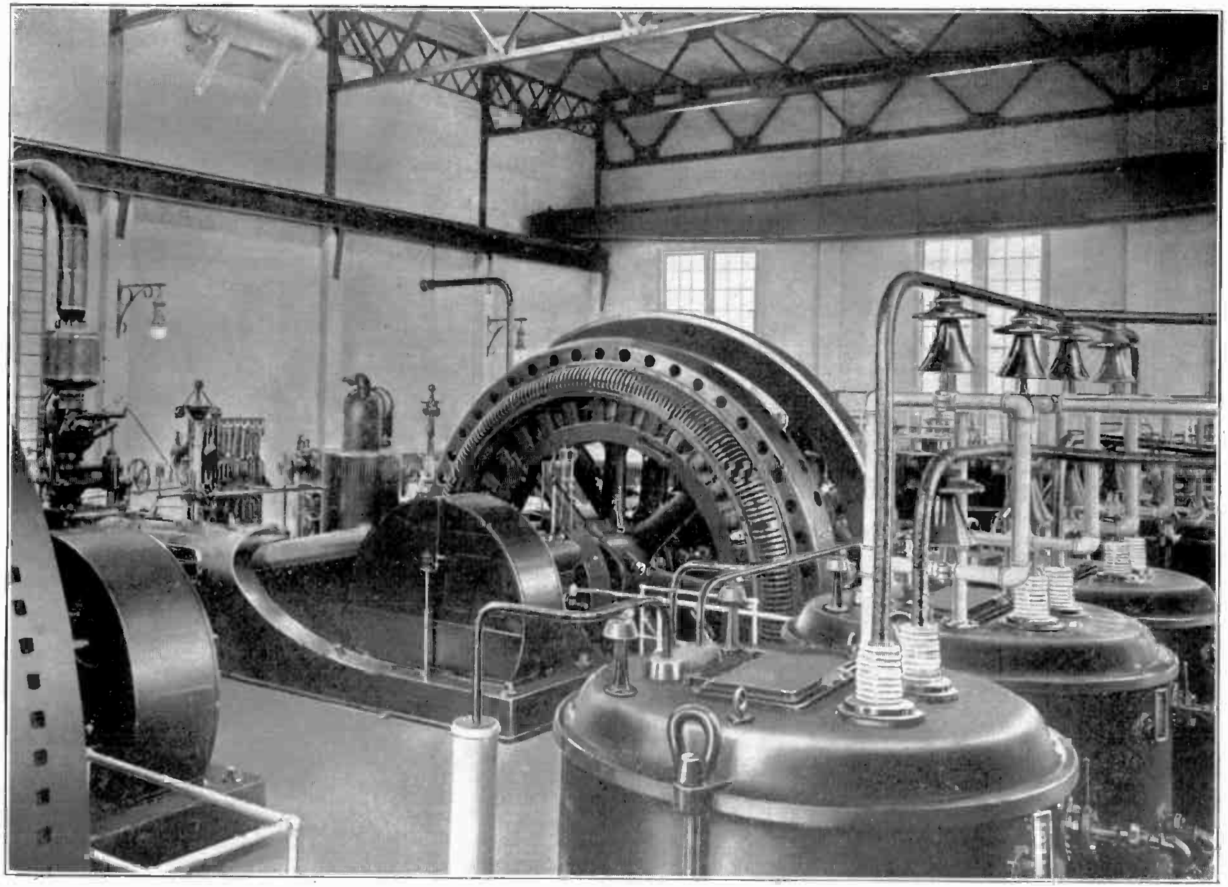
If the direction of the current from a generator is opposite to that desired, the two wires leading from it should exchange places in the terminals. If this is not desirable, the residual magnetism may be reversed by passing through the field winding a current opposite in direction to the original current.

Changing the direction of the current by reversing the main wires or otherwise, does not reverse the direction of rotation of any motor, since it reverses *both* the armature and the field. The way to reverse the direction of rotation is to reverse *either* the armature or the field connection *alone*, leaving the other the same as before.

Examination before Starting. The machine should be cleaned throughout, especially the commutator, brushes, electrical connections, etc. Any metal dust on the commutator or near electrical connections should be removed, as it is very likely to cause short circuits or grounds. Examine the machine carefully, and make sure that there are no screws or other parts that are loose or out of place. See that the oil-cups have a sufficient supply of oil, that the passages for the oil are clean, and that the feed is at the proper rate. In the case of self-oiling bearings, the rings or other means for carrying oil should work freely. See that the belt, if used, is in place, and that it has the proper tension. If the machine is being started for the first time, it should be turned a few times by hand, or run very slowly, in order to determine whether the shaft revolves easily and the belt runs on centers of pulleys.

The brushes should be carefully examined, and adjusted to make good contact with the commutator at the proper point, the switches connecting the machine to the circuit being left open. The machine should then be started with care, and brought up to full speed gradually, if possible. The person who starts either a dynamo or a motor should closely watch the machine and everything connected with it, and should be ready to throw it out of circuit and stop it instantly if the least thing seems to be wrong. He should then be sure to find out and correct the trouble before starting again.

Starting a Generator. A generator is usually brought up to



WINONA INTERURBAN RAILWAY GENERATING STATION AT WINONA LAKE, IND.
High-Tension Transformers at Left. Allis-Chalmers Co., Milwaukee, Wis.

speed either by starting its engine or other prime mover, or by connecting it to a source of power already in motion, The former should be attempted only by a person competent to manage steam engines or the prime mover in question. The mere mechanical connecting of a generator to a source of power is usually not difficult; but it should be done carefully and intelligently, even if it only requires throwing in a friction-clutch or shifting a belt from an idle pulley. To put a belt on a pulley in motion is difficult and dangerous, particularly if the belt is large or the speed is high; and should not be tried except by one who knows just how to do it. Even if a *stick* is used for this purpose, it is apt to be caught and thrown around by the machinery unless used in exactly the right way.

In many cases generators are brought to full speed before the brushes are put in contact with the commutator; but this is not necessary. If the brushes are in contact before starting, they can be more easily and perfectly adjusted, and the E. M. F. will come up slowly, so that any fault or difficulty will develop gradually and can be corrected, or the machine stopped, before any injury is done. In fact, if the machine is working alone on a system, and is absolutely free from any danger of short-circuiting any other machine or storage battery on the same circuit, it may be started while connected to the circuit, but not otherwise (see next article). With a large number of lamps connected to the circuit, the field magnetism and voltage might not be able to "build up" until the line is disconnected.

If one generator is to be connected to another or to a circuit having other generators or a storage battery working upon it, the greatest care should be taken. This coupling together of generators can be done perfectly, however, if the correct method is followed, but is likely to cause serious trouble if any mistake is made.

Two or more machines are often connected to a common circuit. This is especially the case in central stations where the load varies so much that, while one generator may be sufficient for certain hours, two, three, or more machines may be required at other times. The various ways in which this is done depend upon the character of the machines and of the circuit.

Generators may be connected together either in parallel or in series.

Generators in Parallel. In this case the + (positive or plus) terminals are connected together or to the same line, and the − (negative or minus) terminals are connected together or to the other line. The currents (*i. e.*, amperes) of the machines are thereby added, but the E. M. F. (volts) is not increased. The chief condition for the running of generators in parallel is that their voltages shall be equal, but their current capacities may be different.

For example: A generator producing 10 amperes may be connected to another generating 100 amperes, provided the voltages agree. Parallel working is therefore suited to constant-potential circuits. A generator to be connected in parallel with others or with a storage battery, must first be brought up to its proper speed, E. M. F., and other working conditions; otherwise it will short-circuit the system, and might burn out its armature. Hence it should not be connected to a circuit in parallel with others until its voltage has been tested and found to be equal to, or slightly (not over 1 or 2 per cent) greater than, that of the circuit. If the voltage of the dynamo is less than that of the circuit, the current will flow back through it and cause it to run as a motor. The direction of rotation is the same, however, if it is shunt-wound; and no great harm results from a slight difference of potential; but compound-wound machines require more careful handling.

Direct-Current Dynamos in Parallel are always Shunt-Wound (or Compound-Wound). The test for equal voltages may be made by first measuring the E. M. F. of the circuit and then of the machine by one voltmeter; or two voltmeters, one connected to each, may be compared (Fig. 18); or a differential voltmeter may be used. Another method is to connect the dynamo to the circuit through a high resistance and a galvanometer; and when the latter indicates no current, it shows that the voltage of the dynamo is equal to that of the circuit. A rougher and simpler way to do this is to raise the voltage of the dynamo until its "pilot-lamp," or other lamp fed by it, is fully as bright as the lamps on the circuit, and then to connect the dynamo to the circuit. Of course the lamps compared should be intended for the same voltage and in normal condition. Be sure to connect the positive terminal of the dynamo to the positive conductor, and the negative terminal to the negative conductor (Fig. 18); otherwise there will be a very bad short circuit.

When the dynamo is first connected in this way, it should supply only a small amount of current to the circuit (as indicated by its ammeter), and its voltage should then be gradually raised until it generates its proper share of the total current; otherwise it will cause a sudden jump in the brightness of the lamps on the circuit.

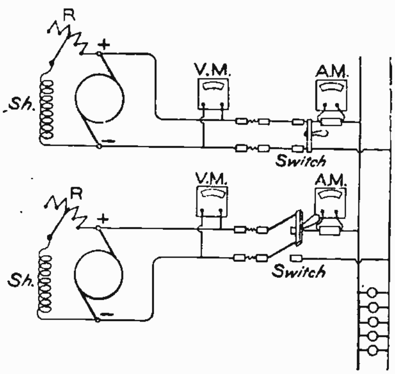


Fig. 18.

Series-Wound Dynamos in Parallel Not Used. If the machine is series-wound, the back current just described would cause a reversal of field magnetism and a very bad short circuit of double voltage. In fact, series dynamos in parallel are in unstable equilibrium, because if either tends to generate too little current, its own field, which is in series, is weakened, and thus still further reduces its current and probably will reverse the machine. This arrangement is therefore not used. One way in which this difficulty might be overcome is by causing each to excite the other's field magnet, so that if one generates too much current, it strengthens the field of the other and thus counteracts its own excess of power.

Another plan is to excite both fields by one machine, or, better, by both machines jointly, which is accomplished by connecting together the two + brushes and the two – brushes respectively, by the line and by what is called an **equalizer** (Fig. 19). In this way the electrical pressure at the terminals of the two armatures is made the same, and the currents in the two fields are also made equal. Series machines are not often run in parallel, but the principles just explained help the understanding of the next case, which is very important.

Compound Dynamos in Parallel. Since the field magnets of these machines are wound with series coils as well as with shunt coils, the coupling of them is a combination of the shunt and series cases just described.

The manner of connecting two or more compound dynamos to operate in parallel, is represented in Fig. 20, A being the armature, B the series, and C the shunt-field coils. R is the shunt-field rheostat; D and F are switches connecting the main terminals of the machine with the bus bars G and I, respectively; and E is a switch to connect the equalizer H with the brush end of the series coil B.

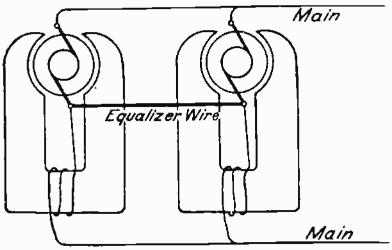


Fig. 19.

Assume that machine No. 1 is already in operation with its switches D, F, and E closed, and that it is desired to have machine No. 2 thrown in circuit. The procedure is as follows:

Bring machine No. 2 up to its rated speed, and adjust its pressure by means of the shunt-field rheostat until it is a little greater (about 1 per cent) than the difference of potential between the bars G and I. This fact may be ascertained by comparing two voltmeters connected to the dynamo and to the bus bars respectively; or by means of a single voltmeter connected through a double-throw switch, first to one and then to the other, which avoids the error due to a difference between two instruments. Another plan is to employ a differential voltmeter, that is, one having two windings on the movable coil, so that it indicates directly the difference in voltage between the two parts of the system.

After the pressure of the *incoming* dynamo has been properly regulated, the three switches E, F, and D are closed in the order named. If these points should be closed simultaneously by means of a triple-pole switch, a considerable current might flow through the series field winding, tending to increase still further the voltage of this dynamo, at the same time taking current away from the series coils of the other machines, and thereby reducing their potential. The shifting of the load thus produced might be so sudden and so great as to be objectionable. This action, however, is not of sufficient importance to overbalance the many advantages afforded by the use of a switch in which the three are combined as a triple-pole switch, thus guarding against the possibility of any accident due to closing the wrong circuit first.

After the machines have been thrown in parallel, their volt-

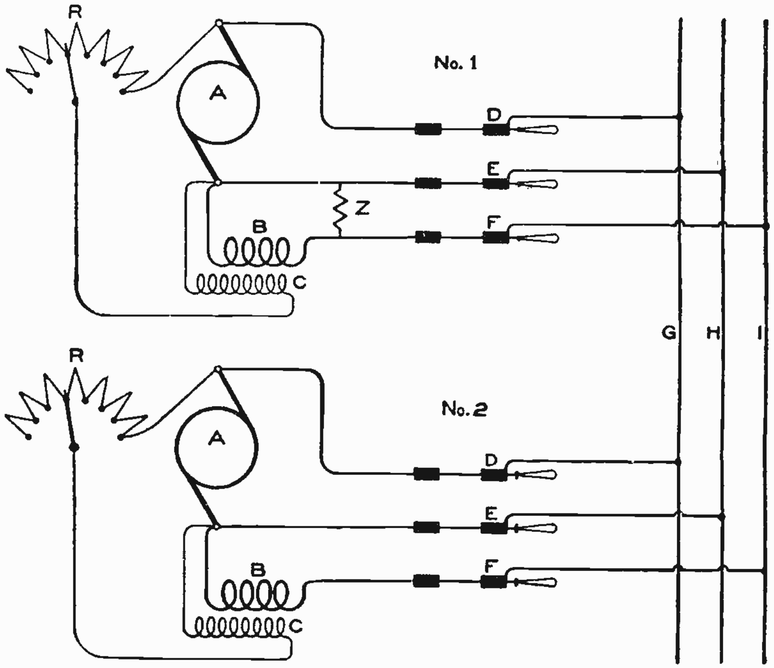


Fig. 20.

ages should be adjusted by the shunt-field rheostats so that the load is properly divided between them.

Compound dynamos of different size or current capacity may also be coupled as described, provided, of course, their voltages are equal; and provided also that the resistances of the series field coils, together with their leads to the bus bar, are inversely proportional to the current capacities of the several machines; that is, if a dynamo produces twice as much current, its series coil and lead should have half the resistance. It is further necessary that the two machines should agree in their action, so that a given increase in load will produce the same effect upon their voltages.

If they are not in agreement, they may be adjusted by slightly increasing the resistance of the series coil of that machine which tends to take too large a share of the load. This may be done by simply interposing a few extra feet of conductor of the same current capacity as the series coil, between the latter and the main conductor or bus bar. The shunts which are almost always used to adjust the effect of the series coils in compound dynamos (shown at Z in machine No. 1, Fig. 20), operate properly in the case of machines working *singly*, but are worthless for machines in parallel. The *resistances of the series coils themselves* must be adjusted as explained above, when two or more compound machines are run in parallel. The use of iron for this shunt makes the compounding effect in the dynamo more uniform, because its resistance, rising as the current through it increases, throws a greater fraction of the current through the series coils at full load, and compensates for the fact that the field magnetism, and consequently the voltage, does not increase proportionately with the increasing load current.

Shunt-wound dynamos run in parallel tend to steady each other, for, if one happens to run too fast, it has to do more work, which opposes the increase of speed ; and it also takes part of the load off the other machines, which makes them run faster, thus producing equality. This mutual regulation will take care of any slight difference between machines, such as that caused by the slip of the belt, or even small differences in the governing action of the different engines that may be driving them. Compound-wound dynamos have very much less mutual regulation, owing to the effect of the series coil ; and it is necessary that their speeds, voltages, etc., should regulate much more exactly than with simple shunt machines. They often work badly together owing to carelessness or to imperfect agreement between them, but with proper care and good apparatus they run well in parallel.

If generators are located at considerable distances from the switchboard, the equalizing connection may be run directly from one machine to the other with the equalizing switch (E, Fig. 20) on the frame of each, instead of running to the switchboard. This saves copper, especially in the case of large generators.

Alternators in Parallel. To run two alternators in parallel, several conditions have to be fulfilled: The incoming machine—as in the case of direct-current machines—must be brought up to nearly the same voltage as the first one; it must operate at exactly the same frequency; and, at the moment of switching in parallel, it must be in phase with the first machine. This correspondence of frequency and phase is called **synchronism.**

It is impossible with mechanical speed-measuring instruments to determine the speed as accurately as is necessary for this purpose. There is, however, a very simple method of electrically determining small differences in speed or frequency. In Fig. 21, let M and N represent two single-phase alternators, which can be connected by means of the single-pole switch AB Across the terminals of the switch is connected an incandescent lamp L, capable of standing twice the voltage of either machine. When AB is open, the circuit between the machines is completed through L. The two machines may be connected in parallel as follows: Assuming machine M already in operation, bring up machine N to approximately the proper speed, and voltage; then watch lamp L. If machine N is running a very little slower or faster than machine M, the lamp L will glow for one moment and be dark the next. At the instant when the voltages are equal in pressure and phase, L will remain dark; but when the phases are displaced by half a period, the lamp will glow at its maximum brilliancy. Since the flickering of the lamp is dependent upon the difference in frequency, the machines should not be thrown in parallel while this flickering exists. The prime mover of the incoming machine must be brought to the proper speed; and the nearer machine N approaches synchronism, the slower the flickering. When it is very slow, we can use the moment the lamp is dark to throw the machines in parallel by closing the switch across AB. The machines are then in phase, and tend to remain so, since if one slows down the other will drive it as a motor. It is better to close the switch when the machines are approaching synchronism than when they are receding from it, that is, at the instant the lamp becomes dark.

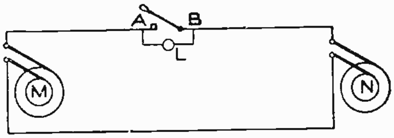


Fig. 21

This method of synchronizing is open to the following objections:

(*a*) The lamps may be dark with considerable difference in voltage. For instance, a 110-volt lamp is dark with a pressure of 20 to 25 volts.

(*b*) The lamp may be dark owing to a broken filament.

It may thus happen, with this arrangement, that the machines are placed in parallel while there is a considerable difference of voltage or phase existing, and an excessive rush of current will result.

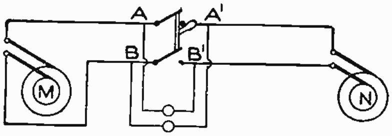


Fig. 22

A method not open to the above objections is shown in Fig. 22. The machines to be switched in parallel are each connected to the bus bars by means of double-pole switches. Two incandescent lamps, of the machine voltage, are cross-connected as shown. If the machines are in phase and the voltages generated are equal in value, the difference of potential between A and a given point is the same as that between A′ and the same point; likewise B and B′ have the same relative potential values. Hence a lamp connected between A and B′ would burn with the same brilliancy as if it were connected directly across AB; likewise with the other lamp. If, however, the machines happen to be directly opposite in phase but to be generating voltage of the same value, A and B′ are of the same relative potential value, and B and A′ are likewise of the same value; hence lamps cross-connected as in Fig. 22 would be dark. At any other phase difference the lamps will glow, but not so brightly as when in phase. Hence with this arrangement, the machines should be thrown in parallel when the lamps are on the verge of maximum brightness, a condition readily determined, but not possible with the first method.

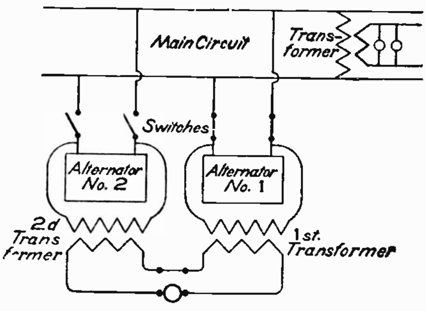


Fig. 23.

The connections as shown in Figs. 21 and 22 are not directly applicable to high-tension working, but require the introduction of transformers as shown in Fig. 23, which is a modification of Fig. 22. The secondaries (of, say, 50 volts each) should be connected in series with each other and to one 100-volt lamp. When the two machines are opposed in phase, the lamp is dim. If the lamp flickers badly, the phase is not right; but if the lamp is steady at full brightness, the machines are in phase, and they may be connected without disturbing the circuit, by closing the main switch.

If alternators are rigidly connected to each other or to the engine, so that they necessarily run exactly together, there is no need of bringing them into step each time, but they should be adjusted to the same phase in the first place.

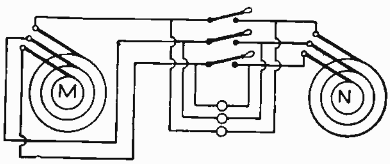


Fig. 24.

The connections of the synchronizing lamps of a three-phase system are similar to those for a single-phase system. For instance, the method employed in Fig. 21 may be extended, and lamps connected as in Fig. 24. If the three lamps simultaneously become dark or bright, the connections are correct, and the three switches may be closed at an instant of darkness. It may happen, however, that the lamps do not become bright or dark simultaneously but successively This indicates that the order of connection of the leads of one machine does not correspond with that of the other. In this case, transpose the leads of one machine until the proper or simultaneous action of the lamps is obtained. After the machines have been properly connected, it is sufficient to synchronize with one of the lamps. Similarly, with high-tension systems, only a single-phase transformer is required, connected as shown in Fig. 25.

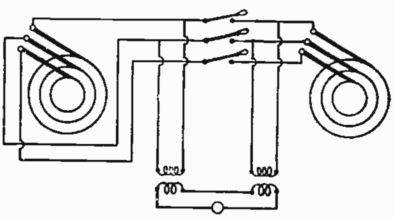


Fig. 25.

Generators in Series. This arrangement is less common than parallel working, and does not usually operate so well, except with series-wound machines on arc circuits, which is very successful. The conditions are exactly opposite to those in the preceding group—generators in parallel.

To connect machines in series, the positive terminal of one must of course be connected to the negative terminal of the next, and so on. Each must have a current capacity equal to the maximum current on the circuit, but they may differ to any extent in E. M. F. The voltages of machines in series are added together; and therefore danger to persons, insulation, etc., is increased in proportion.

Series-Wound Direct-Current Dynamos in Series are connected in the simple way represented in Fig. 26; but, usually machines connected in series are for arc lighting—for example, when two dynamos, each of 40 lights capacity, are run on one circuit of 80 lamps, in which case the dynamos usually have some

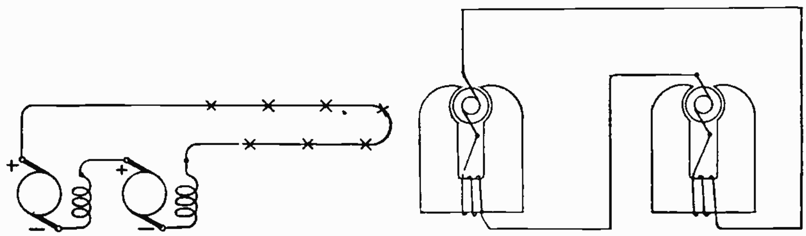


Fig. 26.

form of regulator. These regulators do not usually work well together, because they are apt to "seesaw" with each other. This difficulty may be overcome either by connecting the regulators so that they work together, or by setting one regulator to give full E. M. F. and letting the other alone control the current. This latter plan can be followed only when the variation in load does not exceed the power of one machine. Constant-current dynamos having regulators with little inertia in the moving parts, and thus little tendency to "overshoot," such as the Brush machine, can be run in series without much trouble.

Shunt or Compound Dynamos in Series run well, provided the shunt-field coils are connected together to form one shunt across both machines. If the machines are compound, all of the series coils must be connected in series with the main circuit. Another plan is to connect each shunt field so that it is fed only by the armature of the other machine ; or both the shunt coils may be connected so as to be fed by one armature, the series coils being in the main circuit as before.

Alternators in Series. The synchronizing tendency which makes it possible to run alternators in parallel, causes them to get out of step and become opposed to each other when it is attempted to run them in series. It is therefore impracticable to run them in series unless their shafts are rigidly connected so that they must run exactly in phase and thus add their waves of current instead of counteracting each other. This case rarely occurs.

Dynamos on the Three-Wire System (Direct-Current). In the ordinary three-wire system for incandescent lighting and power service, no particular precautions are required in starting or connecting the machines; and either of the two arrangements shown in Figs. 27*a* and 27*b* may be adopted. The two sides of the system are almost independent of each other, and form practically separate circuits, for which the middle or neutral wire acts as a common conductor. There is, however, a tendency for the dynamos (Fig. 27*a*) to be reversed in starting up, in shutting down, or in the case of a severe short circuit. This can be avoided by exciting the field coils of all the dynamos from one side of the system, or from a separate source. To obtain good regulation, it is necessary to balance the load equally on both sides of the system. It is advisable to employ 220-volt motors on 110-volt 3-wire systems, and to connect them across the outside conductors so that the motor load shall not unbalance the system.

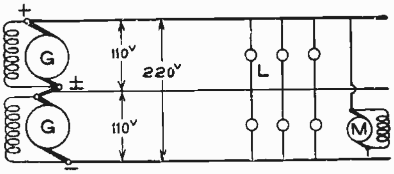


Fig. 27*a*.

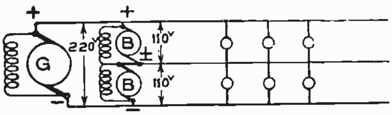


Fig. 27*b*.

KINDS OF MOTORS, CONNECTIONS, AND STARTING.

The general instructions relating to the adjustment of brushes, screws, belt, oil-cups, etc., given in relation to the generator, should be carefully followed preparatory to starting a motor. The actual starting of a motor is usually a simple matter, since it consists merely in operating a switch; but in each case there are one or more important points to be considered

CONSTANT-POTENTIAL D. C. CIRCUITS.

Shunt-Wound Motor. A motor to operate at nearly constant speed, with varying loads, on a D. C. constant-potential system (110- or 220-volt lighting circuits) is usually plain shunt-wound. This is the commonest form of stationary motor. The field coils are wound with wire of such a size as to have the proper resistance and resulting magnetizing current; and since the potential applied is practically constant, the field strength is constant.

In starting shunt motors, no trouble is likely to occur in connecting the field to the circuit. The difficulty is with the armature current, because the resistance of the armature is very low in order to get higher efficiency and constancy of speed, and the rush of current through it in starting might be twenty or more times the normal number of amperes. To avoid this excessive current, motors are started on constant-potential circuits through a rheostat or "starting-box" containing resistance coils.

The main wires are connected through a branch cut-out (with safety fuses), and preferably also a double-pole knife switch Q, to the motor and box, as indicated in Fig. 28. When the switch Q is closed, the arm S being in its left-hand position, the field circuit is closed through the contact stud *f*, and the armature circuit is closed through the resistance coils *a*, *a*, *a*, which prevent the rush of current referred to. The motor then starts, and as the speed rises it generates a counter E. M. F., so that the arm S can be turned as shown until all the resistance-coils *a*, *a*, *a*, are cut out, and the motor is directly connected to the circuit and running at full speed. The arm S should be turned slowly enough to allow the speed and counter E. M. F. to come up as the resistances *a*, *a*, *a* are cut out. The arm S should positively close the field circuit first, so that the magnetism reaches its full strength (which may take several seconds) before the armature is connected.

In the arrangement shown in Fig. 28 the release magnet has its coils in series with the field. As long as the motor is in operation, the core is energized and the arm S is held in the position shown. If, however, the current supplied to the motor is cut off and the motor comes to rest, the core of the magnet loses its attractive force, and the arm S is released, being automatically moved back to the starting position by a spring.

The coils *a*, *a*, *a* are made of comparatively fine wire, which can carry the current only for a few seconds in a "starting-box;"

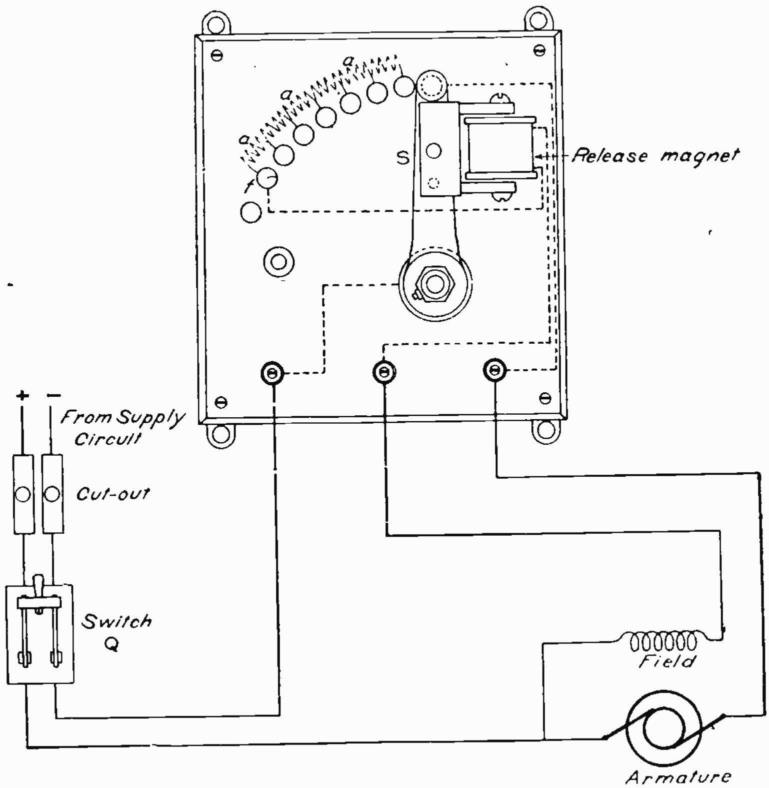


Fig. 28.

but if the wire is large enough to carry the full current continuously, it is called a "regulator," because the arm S may be left so that some of the resistances *a*, *a*, *a* remain in circuit, and they will have the effect of reducing the speed of the motor, which is often very desirable.

In some cases where a circuit is used exclusively for a single motor, the speed is regulated without heavy resistances by varying the E. M. F. of the dynamo which supplies the circuit. The dynamo regulator is then placed near the motor. The advantage is that the regulator is not compelled to control a heavy current, but a special circuit of unvaried pressure must be provided to keep the field of the motor constant.

The speed control of a shunt motor may be simply obtained as follows:

a. For lower speeds, insert resistance in series with the armature circuit. The resulting I. R. drop reduces the value of the voltage applied to the armature terminals, and thus reduces the speed.

b. For higher speeds, insert resistance in the shunt-field circuit. This reduces the magnetic flux, and to generate the same C. E. M. F. the motor must speed up.

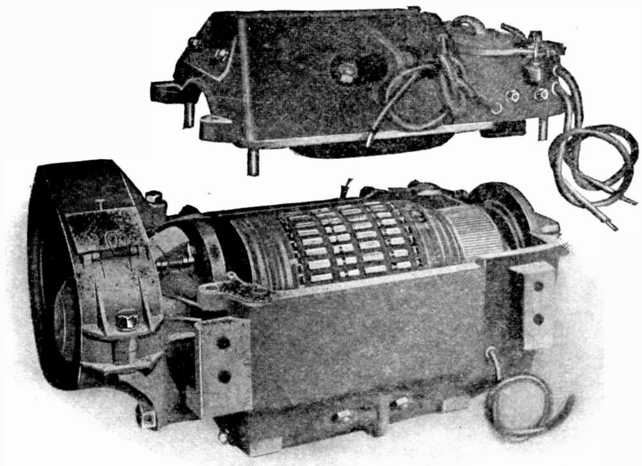


Fig. 29.

The field circuit of a shunt motor should never be opened while pressure is still applied to the armature terminals, as under these conditions the armature current becomes very excessive and the armature is likely to race and probably be damaged. A moderate decrease in field strength only is allowable ; otherwise sparking becomes excessive.

Series-Wound Motor. The ordinary electric railway motor on the 550-volt trolley system is the chief example of the class (Fig. 29.) Motors for fans, pumps, or electric elevators and hoists are either of this kind or of the compound type. A rush of current tends to occur when the series type of motor is started, similar to that in the case just described; but it is less, because the field-coils are in series, so that their resistance and self induction reduce the excess. Furthermore, the counter E. M. F. is greater even at low speed because the heavy current produces a strong field.

The connections as indicated in Fig. 30 are very simple, the armature, field-coils, and rheostat all being in series and carrying the same current.

The series-wound motor on a constant-potential circuit does not have a constant field strength, and does not tend to run at con-

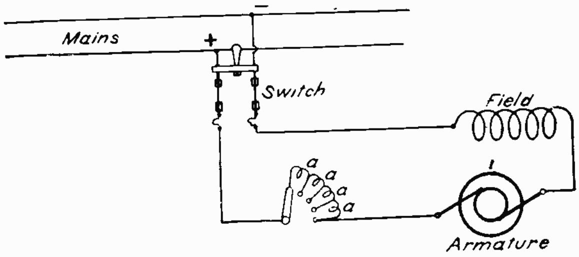


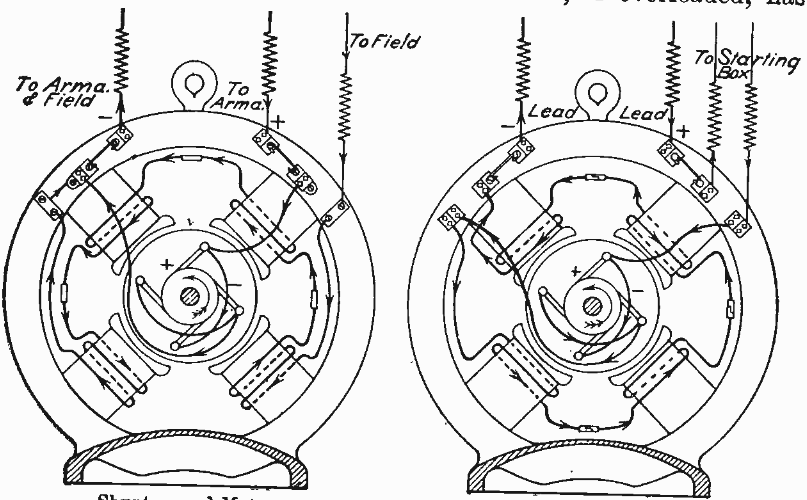
Fig. 30.

stant speed, like a shunt motor. In fact it may "race" and tear itself apart if the load is taken off entirely; it is therefore suited only to railway, pump, fan, or other work where variable speed is desired, or where there is no danger of the load being removed or a belt slipping off. It is also used where the potential is subject to sudden and large drops, as on the ends of long trolley circuits, because in such a case a shunt motor becomes momentarily a generator and sparks very badly. The fields of series motors are sometimes "overwound," that is, so wound that they will have their full strength with even one-half or one-third of the normal current. The objects are to secure a nearly constant speed with varying loads, to enable the motor to run at high efficiency when drawing small currents, and to prevent sparking at heavy loads.

In multipolar motors having more than two field-coils, the coils are all connected together, and are equivalent to the single pairs of coils shown in the several diagrams. Being separated, however, it is sometimes necessary to trace out the connections. Fig. 31 represents the necessary connections for a four-pole motor, shunt-wound and series-wound.

Differentially-Wound Motor. This is a shunt-wound motor with the addition of a coil of large wire, on the field, connected in series with the armature in such a way as to oppose the magnetizing effect of the shunt winding and weaken the field, thus causing the motor to speed up when the load is increased, as an offset to the slowing-down effect of load.

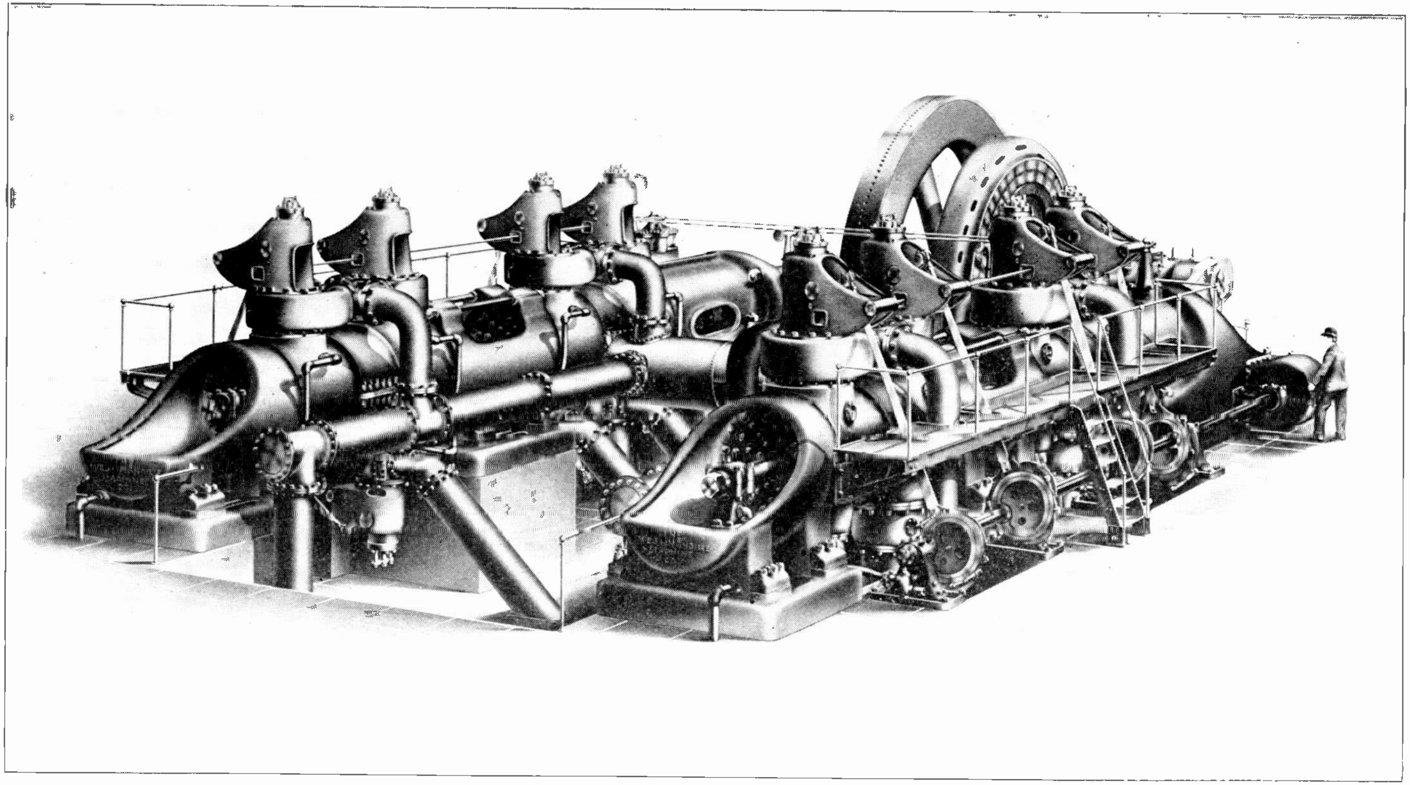
It was formerly used, for obtaining very constant speed, but it has been found that a plain shunt motor is sufficiently constant for almost all cases. The differential motor, if overloaded, has



Shunt-wound Motor. Fig. 31. Series-wound Motor.

the great disadvantage that the current in the opposing (series) field-coil becomes so great as to kill the field magnetism; and instead of increasing or keeping up its speed, the armature slows down or stops, and is likely to burn out; whereas a plain shunt motor can increase its power greatly for a minute or so when overloaded, and will probably throw off the belt or carry the load until the latter decreases to the normal amount.

Compound-Wound Motor. This type of motor is also provided with a shunt and a series-field winding, Fig. 32, but in this instance they magnetize the field in the same direction, or, in other



WESTINGHOUSE HORIZONTAL DOUBLE-ACTING GAS-DRIVEN GENERATING UNIT. TWIN TANDEM TYPE GAS ENGINE AND DIRECT-CONNECTED GENERATOR

300 H. P. Unit, Power Plant of Carnegie Steel Co., Bessemer, Pa.

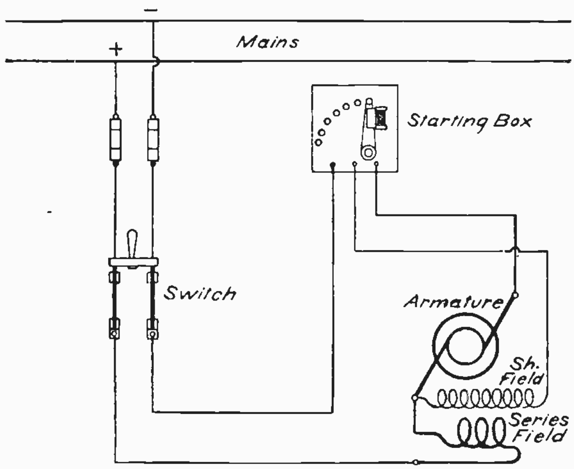


Fig. 32.

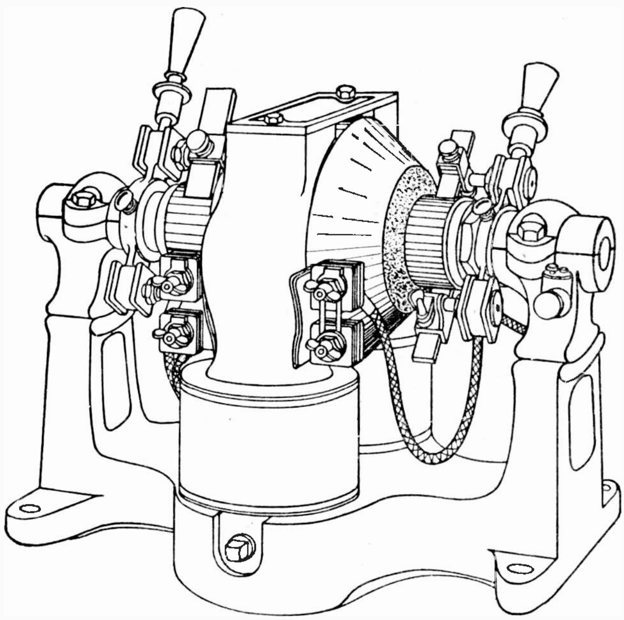


Fig. 33.

words, their effect is cumulative. This type of motor possesses the powerful starting torque feature of the series motor, but a less variable speed with varying loads. It is employed where a great starting torque and a fairly uniform running speed are required, as, for example, with electric hoists or elevators.

Dynamotors, Fig. 33, and also motor-generator sets, are started in the same way as motors; that is, the motor portion of the machine is connected to the circuit and operated precisely like the corresponding kind of motor. Usually the motor part is plain shunt-wound, and is supplied with current from a constant-potential circuit. It is therefore connected and started in the manner shown and described on page 40.

The current generated by the dynamo portion of the dynamotor may be taken from the terminals, and used for any purpose to which it is suited. The E. M. F. or current produced may be regulated by varying the resistance in the armature circuit of either the motor or dynamo. In case the dynamo armature has a separate field magnet, the E. M. F. and current may be controlled by regulating the magnetic strength of this field, or the machine may be compounded or even "over-compounded." But if the armatures of both motor and dynamo are acted upon by the same field, the E. M. F. of the dynamo cannot be varied except by inserting resistances in the circuit of either armature or by shifting the brushes. But the latter method will be likely to cause sparking.

ALTERNATING-CURRENT MOTORS.

Alternating-current motors operate on constant-potential circuits, since almost all A. C. systems are of this kind. There are several types of these motors, the simplest of which is the *series machine* for single-phase current. This is similar to the corresponding D. C. motor, except that its field must be laminated.

It possesses the characteristic of large starting torque and lends itself to variable speed control like its direct current counterpart and is coming into use very rapidly for electric railway work. Both the General Electric and the Westinghouse Electric and Manufacturing Companies have placed such machines upon the market and they are already in operation on a number of electric roads where they are giving satisfaction.

This type of motor while retaining practically all the advantages of the direct-current series motor for electric railway work permits the use of alternating current on the trolley with all its attendant advantages. A frequency of 25 seems likely to become the standard for such work. The cars can be operated on existing

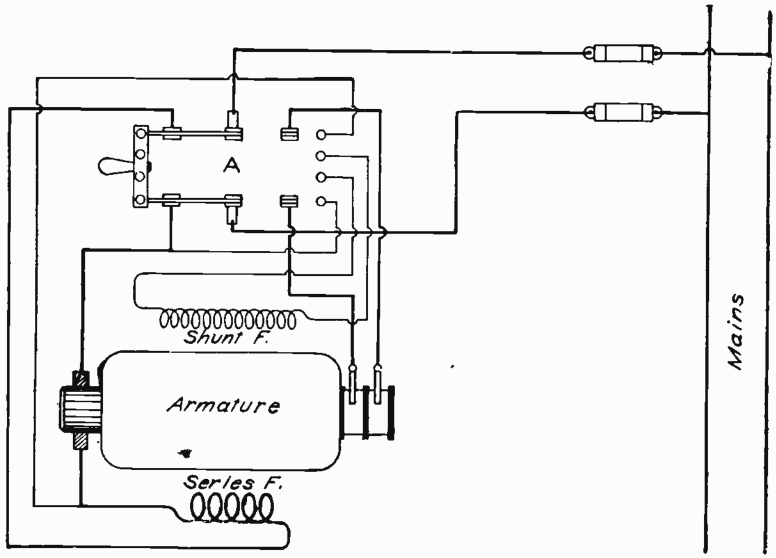


Fig. 34.

direct-current lines and the multiple unit control system can be applied to cars equipped with single-phase motors.

An ordinary single-phase alternator can be used as a motor; but it must first be brought up to synchronism with the supply generator by means of some auxiliary starting device (steam engine, polyphase induction motor, etc.) before the load can be applied. In this form the machine is known as the *single-phase synchronous motor*. The condition of synchronism is determined by one of the methods described in the paragraph on "Alternators in Parallel." After the motor is in synchronism it may be connected to the circuit by closing its supply switch; and it will then continue to run at an absolutely constant speed, unless heavily overloaded, when it falls out of step and stops.

On account of these features, the synchronous motor is not to be recommended for general application. Various manufacturers, notably the Wagner Electric Company, and the Fort Wayne Electric Company, manufacture self-starting, single-phase synchronous motors, usually limited, however, to the smaller sizes. The construction and action of the Fort Wayne motor (Fig. 34), which is a combination of the two preceding types, are as follows: The armature core is provided with a double winding, one equipped with collecting rings, and the other with an ordinary commutator. The field magnet, which is laminated, is wound with two separate circuits, one being of low resistance and a small number of turns, the other of high resistance and many turns, like an ordinary shunt-field winding. In starting, the motor runs as a series machine, the low-resistance field being in series with the commutated armature winding and the line. When it has reached synchronism, the switch A, on the top, is thrown over to the right, and the supply line connected with the collector rings and the corresponding armature winding; while the commutated end is connected to the other field winding, and thus provides the direct current necessary for field excitation.

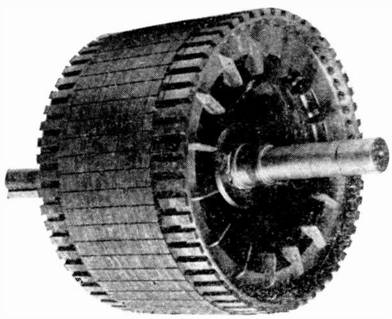


Fig. 35.

In addition to the single-phase there is also the *polyphase synchronous motor*. This latter form, however, is self-starting without field current, but will not carry a load until it is running in synchronism. When this condition is reached, the field circuit should be closed before applying the load.

A great advantage of the synchronous motor is that when its field is over-excited, it draws a leading current from the line, thus acting like a condenser and tending to neutralize the inductive effect of other machinery, so that the power factor of the whole system is raised. The most extensive use of the synchronous motor is as a part of the rotary converter, which is employed to convert alternating into direct currents, for traction and electro-chemical purposes.

The satisfactory use of alternating currents for power purposes depends mainly on the *polyphase induction motor*, as in this form the A. C. motor is self-starting with considerable torque and operates at a practically constant speed from no load to a heavy overload. Induction motors are designed for the standard voltages and frequencies.

In most induction motors now built, the primary, or part into which the currents from the line are led, is the stationary member, or *stator*. The secondary, in which the induced currents are set up, is the rotating member, or *rotor*. There are two kinds of rotor

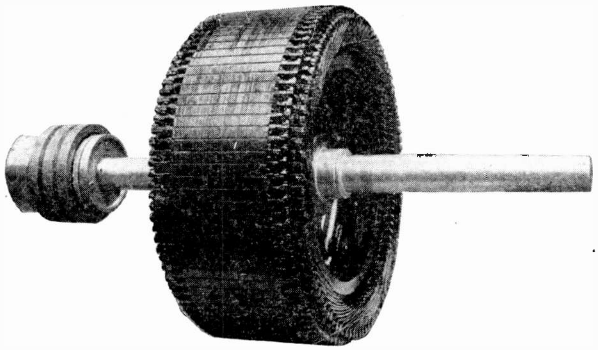


Fig. 36.

windings, the simpler being that known as the "squirrel-cage." This winding is made up of a number of copper bars, equally spaced around the rotor core, and imbedded therein. The terminals of these inductors are interconnected, or short-circuited, by means of heavy copper rings placed at both ends of the core, as shown in Fig. 35.

The other form of winding is of the drum species, usually three-phase, Y-connected; and the coils are located at 120° intervals (the arc between centers of adjacent poles being called 180°) with respect to each other. The free ends of the windings are respectively brought out to three slip or collecting rings; and on this account this type of rotor is frequently called the "slip-ring" rotor (Fig. 36).

Starting Induction Motors. In small sizes, up to 3 or 5 H. P., the induction motor can be started by connecting its stator terminals directly to the line. But with larger sizes the inrush of current is excessive and likely to disturb the system ; accordingly some form of starting device is usually necessary.*

Starting Compensators. This inrush of current can be avoided by inserting a starting resistance, or inductance, in series with the primary winding and the line, or by using some other means of cutting down the applied E. M. F. The torque of an induction motor decreases as the square of the applied voltage, so that this method of starting results in a greatly reduced starting effort. However, in many instances, motors are not started up under full load, so that this may not be a serious objection.

While a resistance could be employed as described, it is more economical to employ an auto-transformer (that is, a transformer

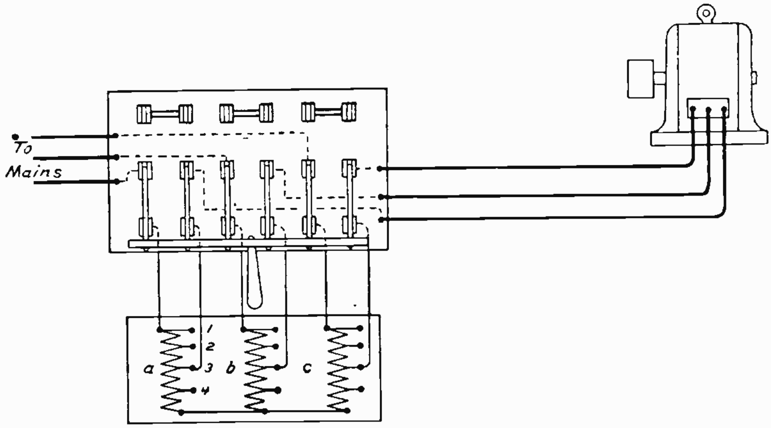


Fig. 37.

having but one coil, which serves as both a primary and a secondary), or *compensator*, as it is called when used for this purpose Compensator connections for a three-phase motor are represented in Fig. 37. The compensator consists of coils *a*, *b*, and *c*, wound on a laminated-iron core, each coil being provided with a number of taps, 1, 2, 3, etc. The pressure applied to the motor at starting is proportioned to the amount of each coil included in the circuit. While the compensator winding is provided with taps, only that one which is most suitable for the work is used after the equipment is permanently installed. When the switch is in the

* This inrush of current is frequently three times the rated load current.

lower position as indicated, a part of each coil is in series with each leg of the system leading to the motor; and the applied voltage is correspondingly cut down. After the motor reaches its rated speed, the switch is thrown to the upper or running position, and the stator or primary terminals are connected directly to the line. The compensator thus prevents an excessive inrush of current, and gives the motor a smooth start, although it decreases the starting torque, compared with that due to full line pressure.

Speed Regulation of Induction Motors. For some classes of work, it is desirable to have induction motors arranged so that their speed can be controlled, the usual methods being:

a. The insertion of a variable resistance in the rotor circuit.

b. Cutting down the voltage applied to the stator, as just described.

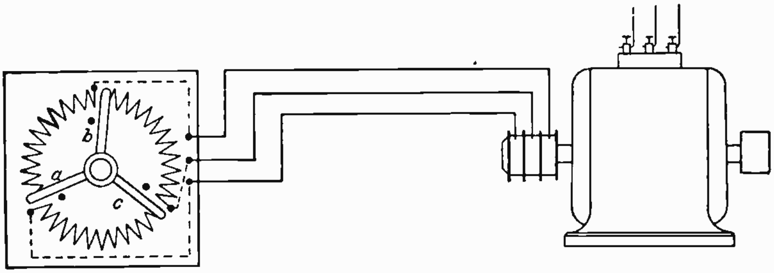


Fig. 38.

The more satisfactory method of speed control, is that with variable resistance inserted in the rotor circuit, the power-factor and hence the efficiency of the system being greater at reduced speeds than with the compensator or equivalent device. It requires, however, the use of collector rings, connecting brushes, and leads, since a resistance for continuous service is too bulky to be placed within the machine. Still further, the heat developed in the resistance would heat the machine too much. The controller itself looks like an ordinary trolley car controller, but for simplicity it is represented as a three-armed controller (Fig. 38) in which the arms *a*, *b*, and *c* are in electrical contact under the handle. The resistance is provided in three sets, one for each free end of the rotor winding; and each set is subdivided so that it can be gradually cut out of circuit as the motor speed increases. Frequently the controller is so arranged that the first motion of the handle closes the supply lines, and subsequent motions vary the resistances in the rotor circuit, thus performing the function of a supply switch and speed controller.

Another method of speed control, is to have the winding on the stator arranged so that by means of a suitable controlling switch, the number of poles can be changed. This is a very economical method from the electrical standpoint, and gives a very wide range of control, but, on account of its complexity and cost, is used only to a limited extent.

In general, the induction motor does not allow of the same range of speed control as does the direct-current motor, and the methods employed for this purpose are not efficient.

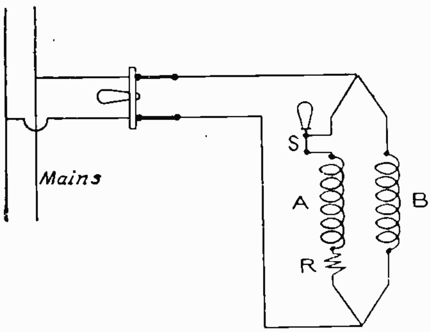


Fig. 39.

Single-Phase Induction Motor. A two or three-phase induction motor will operate fairly well, if, after reaching full speed, all but one of the phases be cut out. It will not however start from rest under the influence of single-phase excitation. Hence, to start an induction motor from the lines of a single-phase system, currents differing in phase must be obtained. This is accomplished by connecting the two primary windings A and B (in the case of a two-phase motor) in parallel to the single-phase mains, at the same time connecting in series with one winding a resistance R (Fig. 39). The currents flowing through these two windings will then differ in phase, one leading the other on account of a difference in their constants, and will thus produce a rotating field, and the motor will then start up.* When the motor has reached full speed, one phase may be cut out by opening the switch at S, and the machine will carry its load. The resistance R may be replaced to advantage by a condenser, especially on small machines. Such a machine is commonly called a "split-phase" motor.

* This field is not a rotary field in the full sense, being elliptical in character.

DIRECTIONS FOR RUNNING GENERATORS AND MOTORS.

After any one of these machines has been properly started, it usually requires little attention while running; in fact, generators or motors frequently operate all day without any care whatever.

In the case of a machine that has not been run before or has been changed in any way, it is wise to watch it closely at first. It is also well to give the bearings of a new machine plenty of oil at first, but not enough to run on the armature, commutator, or any part that would be injured by it; and to run the belt (if used) rather slack until the bearings and belt are in easy working condition.

If possible, a new machine should be run without load or with a light one for an hour or two, or for several hours in case of a large machine; and it is bad practice to start a new machine with its full load or even a large fraction of it. This is true even if the machine has been fully tested by its manufacturer and is in perfect condition, because there may be some fault in setting it up or some other circumstance that would cause trouble. All machinery requires some adjustment and care for a certain time to get it into smooth working order.

When this condition is reached the only attention required is to supply oil when needed, keep the machine clean, and see that it is not overloaded. A generator requires that its voltage or current should be observed and regulated if it varies. The attendant should always be ready and sure to detect the beginning of any trouble, such as sparking, heating, noise, abnormally high or low speed, etc., before any injury is caused, and to overcome it. Such directions should be pretty thoroughly committed to memory in order promptly to detect and remedy any trouble when it occurs suddenly, as is usually the case. If possible, the machine should be shut down instantly when any indication of trouble appears, in order to avoid injury and give time for examination.

Keep all tools or pieces of iron or steel away from the machine while running, as they might be drawn in by the magnetism, perhaps getting between the armature and pole pieces and ruining the machine. For this reason use a zinc, brass, or copper oil-can instead of one of iron or "tin" (tinned iron)

Particular attention and care should be given to the commutator and brushes, to see that the former keeps perfectly smooth and that the latter are in proper adjustment. (See "Sparking.")

Never lift a brush while the machine is delivering current unless there are one or more other brushes on the same side to carry the current, as the spark might make a bad burnt spot on the commutator, or might burn the hand.

Touch the bearings and field coils occasionally to see whether or not they are hot. To determine whether the armature is running hot, place the hand in the current of air thrown out from it by centrifugal force.

Special care should be observed by any one who runs a generator or motor, to *avoid overloading* it, because this is the cause of most of the troubles which occur.

Personal Safety. Never allow the body to form part of a circuit. While handling a conductor, a second contact may be made accidentally through the feet, hands, knees, or other part of the body, in some peculiar and unexpected manner. For example, men have been killed because they touched a "live" wire while standing or sitting upon a conducting body.

Rubber gloves or rubber shoes, or both, should be used in handling circuits of over 500 volts.* The safest plan is not to touch any conductor while the current is on; and it should be remembered that the current may be present when not expected, owing to an accidental contact with some other wire or to a change of connections. Tools with insulated handles, or a dry stick of wood, should be used instead of the bare hand.

The rule to use *only one hand* when handling dangerous electrical conductors or apparatus is a very good one, because it avoids the chance, which is very great, of making contacts with both hands and getting the current through the body. This rule is often made still more definite by saying, "Keep one hand in your pocket," in order to make sure not to use it. The above precautions are often totally disregarded, particularly by those who have become careless through familiarity with dangerous currents. The result has been that *almost all persons accidentally killed*

* These articles should be subjected to tests at frequent intervals, so as to determine their condition.

by artificial electricity have been experienced linemen or station men.

Stopping Generators or Motors. This is accomplished by following substantially the same directions as for starting them, but in the reverse order.

A generator operating alone on a circuit can be slowed down and stopped without touching the switches, brushes, etc., in which case the current gradually decreases to zero; and then the connections can be opened without sparking or any other difficulty.

However, when a generator is operating in parallel with others, or with a storage battery, it must not be stopped or reduced in speed, until it is entirely disconnected from the system, otherwise it will act as a short circuit. Furthermore, the current generated by it should be reduced nearly to zero before its switch is opened. This is accomplished by adjusting the field rheostat of the machine to be cut out, great care being taken that the change is gradual. If the reduction be rapid, the voltage of the machine may drop so low as to cause a back current to flow.

A **constant-current generator** may be cut into or out of circuit in series with others, and can be slowed down or stopped; or its armature or field coils may be short-circuited to prevent the action of the machine, without disconnecting it from the circuit. *It is absolutely necessary, however, to preserve the continuity of the circuit*, and not to attempt to open it at any point, as this would produce a dangerous arc. Hence a by-path must be provided by closing the main circuit around the generator, before disconnecting it. This same rule applies to any lamp, motor, or other device on a constant-current system.

Never, except in an emergency, should any circuit be opened when heavily loaded, for the reason that the flash at the contact points, discharge of magnetism, and mechanical shock which result, are decidedly objectionable.

A Constant-Potential Motor is stopped by turning the starting-box handle back to the position it had before starting (Fig. 28); or, *if there is a switch Q, connecting the motor to the circuit*, as there always should be, it should be opened, after which the starting-box handle is moved back to be ready for starting again.

Immediately after a machine is stopped, it should be thoroughly cleaned, and put in condition for the next run. When not in use, machines should, when feasible, be protected from dirt and moisture by covers of some waterproof material.

INSPECTING AND TESTING.

Adjustment and the other points which depend merely upon mechanical construction, are hardly capable of being investigated by a regular quantitative test, but they can and should be determined by thorough inspection. In fact a very careful examination of all parts of a machine should always precede any test of it. This should be done for two reasons: first, to get the machine into proper condition for a fair test; and, second, to determine whether the materials and workmanship are of the best quality and satisfactory in every respect. A loose screw or connection might interfere with a good test; and a poorly fitting bearing, brush-holder, or other part might show that the machine was badly made.

If it is necessary to take the machine apart for cleaning or inspection, the greatest care should be exercised in marking, numbering, and placing the parts, in order to be sure to get them together exactly the same as before. In taking a machine apart or putting it together, only the minimum force should be used. Much force usually means that something wrong is being done. A wooden or rawhide mallet is preferable to an iron hammer, since it does not bruise or mar the parts. Usually screws, nuts, and other parts should be set up fairly tight, but not tight enough to run any risk of breaking or straining anything. Shaking or trying each screw or other part with a wrench or screw-driver, will show whether any of them are too loose or otherwise out of adjustment.

Friction. The friction of the bearings and brushes can be tested roughly by merely revolving the armature by hand, or slowly by power, and noting if it requires more than the normal amount of force. Excessive friction is quite easily distinguished, even by inexperienced persons. Another method is to revolve the armature by hand or otherwise, and see if it continues to revolve by itself freely for some time. A well-made machine in good condition and running at or near full speed, will continue to run for several minutes after the turning force is removed.

A method for actually measuring the friction consists in attaching a lever (a bar of wood, for example) to the shaft or pulley at right angles to it. The force required to overcome the friction and to turn the armature without current, is then determined by known weights or, more conveniently, by an ordinary spring balance. For convenience in dividing by the length of the lever, etc., to determine the value of the friction compared with the power of the machine, it should be exactly 1, 2, or 4 feet long. The friction of the bearings alone—that is, the pull which is required to turn the armature when the brushes are lifted off the commutator—should not exceed about 2 per cent of the total torque or turning force of the machine at full load. When the brushes are in contact with the commutator with the usual pressure, the friction should not then exceed about 3 per cent; that is, the brushes themselves should not consume more than 1 per cent of the total turning force.

Another method of measuring the friction of a machine is to run it by another machine used as a motor, and determine the volts and amperes required, first, with brushes lifted off, and second, with brushes on the commutator with the usual pressure. The torque or force exerted by the driving machine is afterwards measured by a Prony brake in the manner described hereafter for testing torque, care being taken to make the Prony brake measurements at exactly the same volts and amperes as were required in the friction tests. In this way the torques exerted by the driving machine to overcome friction in each of the first two tests are determined; and these torques, compared with the total torque of the machine being tested, should give percentages not exceeding those stated above for maximum values of friction. The magnetic pull of the field on the armature may be very great if the latter is not exactly in the center of the space between the pole pieces. This would have the effect of increasing the friction of the shaft in the bearings when the field is magnetized. It occurs to a certain extent in all cases, but it should be corrected if it becomes excessive. This may be tested by turning the current into the fields, being sure to leave the armature disconnected, and then turning the shaft with the lever as before. The friction in this case should not be more than 2 to 4 per cent.

Tests for friction alone should be made at a low speed, because at high speeds the effects of Foucault currents and hysteresis enter and materially increase the apparent friction.

Balance. The perfection of balance of the armature or pulley can be roughly tested by simply running the machine at normal speed and noting if these parts cause any objectionable vibration. Of course, practically every machine produces perceptible vibration when running, but this should not amount to more than a very slight trembling. The balance of a machine can be definitely tested, and the extent of the vibration measured, by suspending the machine or by mounting it on wheels, and running it at full speed. In this case it is better to run the machine as a motor, even though it be actually a generator, in order to avoid the necessity of running it by a belt, which would cause vibration and interfere with the test. If, however, the use of a belt is unavoidable, it should be arranged to run vertically upward or downward so as not to produce any horizontal motion in addition to the vibration of the machine itself. Fig. 40 shows a machine hung up to be tested for balance, and run either as a motor or by the vertical belt indicated by the dotted lines. Any lack of balance will cause the machine to vibrate or swing horizontally, and this motion can be measured on a fixed scale.

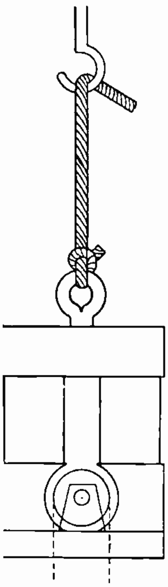


Fig. 40.

Noise. This cannot well be tested quantitatively, although it is very desirable that a machine should make as little noise as possible. Noise is produced by various causes. The machine should be run at full speed, and any noise and its cause carefully noted. A machine—especially the commutator—will nearly always run more quietly after it has been in use a week or more and has worn smooth.

Heating. The proper way to determine the temperature rise in electrical apparatus is by measurements of resistance, before and after operating for a specified time (usually 3 to 4 hours) under rated load.

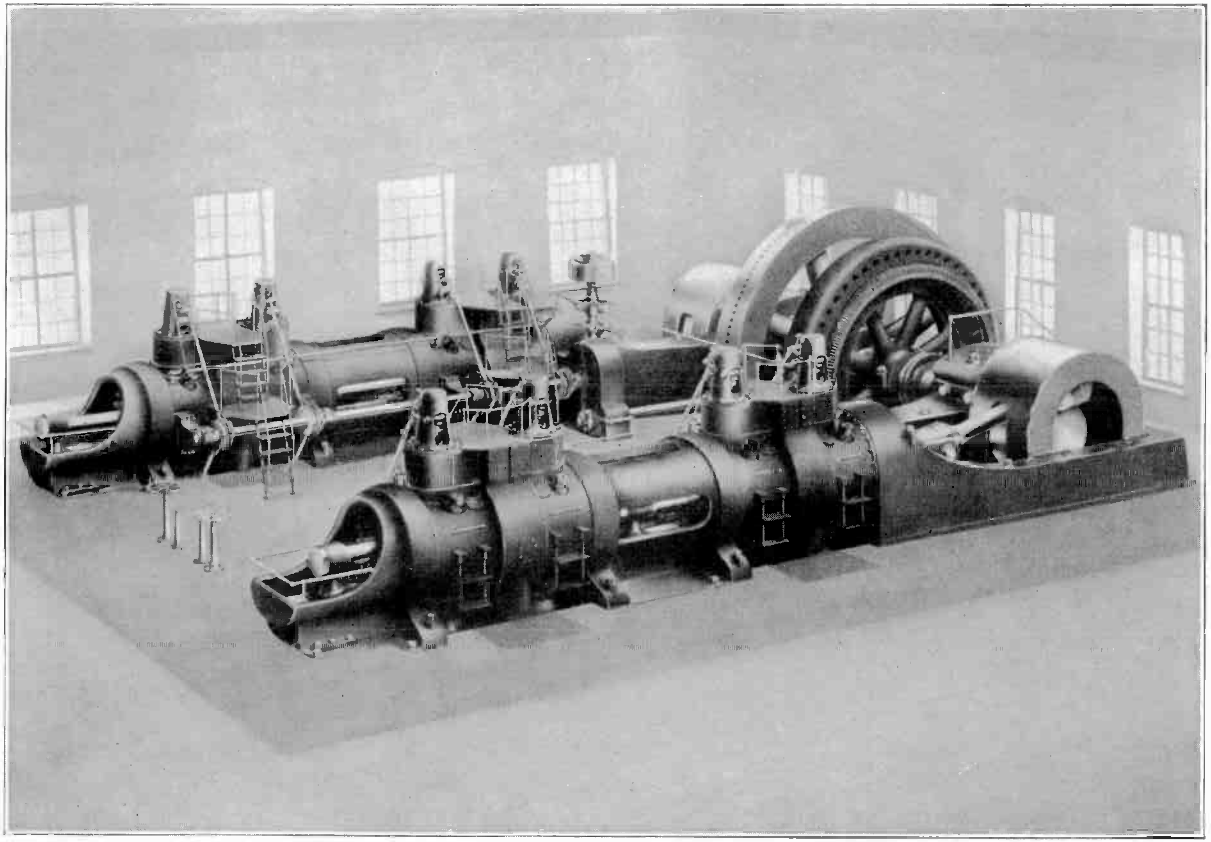
The rise of temperature is:

$$\theta = (238.1 + t)\left(\frac{(R_{t+\theta}}{R_t} - 1\right),$$

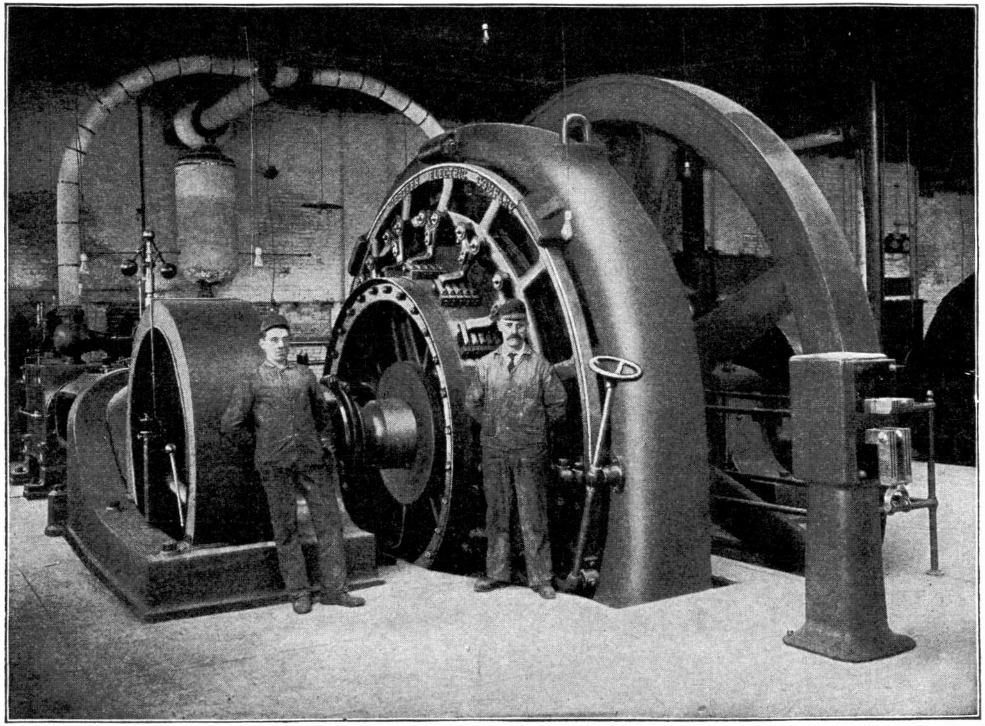
in which t is the room temperature in degrees Centigrade, R_t the resistance in ohms at room temperature, and $(R_{t+\theta})$ the final resistance at a temperature elevation of θ° C. The standard room temperature is 25° C; and if it differs from this, the determined rise should be corrected by $\mp\frac{1}{2}$ per cent for each degree C. For ordinary tests it may be assumed that the resistance of copper increases .4 per cent for each degree C rise in temperature. The allowable rise in temperature for field or armature windings is 50° C, hence their resistance for continuous operation at rated load should not be more than 20 per cent in excess of the room temperature. The heating of commutators, collector rings, and brushes that cannot be measured electrically, is tested by thermometers when the machine is stopped, the permissible rise being 50° C; and for bearings and other parts of machines the limit is 40° C When a thermometer is applied to a surface it should be covered by a pad of cotton or waste cloth, in a shallow, circular box about $1\frac{1}{2}$ inches in diameter. A large pad tends to accumulate heat. When machines are in operation, or in other cases when it is not convenient to measure resistances, especially for excessive temperatures due to abnormal conditions, thermometers may be used to test all stationary parts; but it should be noted that their indications are usually about 5° C lower than those determined by resistances, because the surface is cooler than the interior. A very simple test of heating is to apply the hand to the armature, etc., and if it can be held there without great discomfort, the temperature is not dangerous. Allowance should always be made, however, for the fact that, on account of its heat conductivity, bare metal feels very much hotter than cotton-covered wires, cloth, etc., at the same actual temperatures; but this apparent difference is much less if the hand is kept on for 10 to 20 seconds.

Sparking at the commutator cannot be accurately measured; but it is very objectionable, and in a machine in good order should be hardly perceptible. In any test one should observe carefully whether the sparking is excessive or not; and if so, to what it is due.

An approach to measurement may be made by starting with a lightly loaded machine and gradually increasing the load, meanwhile shifting the rocker-arm and brushes back and forth, and noting at what load it is impossible to find a non-sparking point. In machines the brushes must be shifted to follow the armature reaction as the load increases; but one should always be able to find a place where sparking ceases, within the rated load. In fact, a machine should be able to run with 25 per cent overload before sparking is serious. If a machine begins to spark at 50 per cent of its load, it is clearly only half as useful as it might be, and this may be taken in a sense as a measure of sparking.



FOUR-CYCLE, DOUBLE-ACTING, TWIN-TANDEM GAS ENGINE DIRECT-COUPLED TO ALTERNATING-CURRENT GENERATOR
Allis-Chalmers Co., Milwaukee, Wis.



800 K.W. GENERATOR, 250 VOLTS, 80 R.P.M.

Western Electric Company.

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

PART II

ELECTRICAL RESISTANCE.

Among the most important tests which it is necessary to make in connection with Dynamo-Electric Machinery are those for resistance.

There are two principal classes of resistance tests that must be made in connection with generators and motors. First, the resistance of the wires or conductors themselves, called the *metallic* resistance; and, second, the resistance of the insulation of the wires, known as the *insulation* resistance. The latter should always be as high as possible, because a low insulation resistance not only allows current to leak, but also causes "burn-outs" and other accidents. Metallic resistance, such, for example, as the resistance of the armature or field coils, is commonly tested either by the Wheatstone bridge or by the "drop" (fall-of-potential) method.

The Wheatstone Bridge is simply a number of branch circuits connected as indicated in Fig. 41. A, B, and C are resistances the values of which are known. X is the resistance which is being measured. G is a galvanometer, S its key, and E is a battery of one or two cells controlled by a key K, all being connected as shown. The resistance C is varied until the galvanometer shows no deflection, when the keys K and S are closed in the order named. If the key S should be closed before K, or at the same moment the

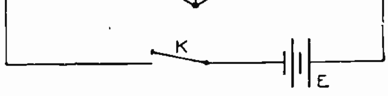


Fig. 41.

inductive effect would produce a pronounced deflection of the galvanometer needle, and thus probably cause confusion. The value of the resistance X is then found by multiplying together resistances C and B, and dividing by A; that is,

$$X = \frac{C \times B}{A}.$$

A very convenient form of this apparatus is what is known as the portable bridge (Fig. 42). This consists of a box containing the three sets of known resistances, A, B, and C, controlled by plugs; also the galvanometer G, and keys K and S, all connected

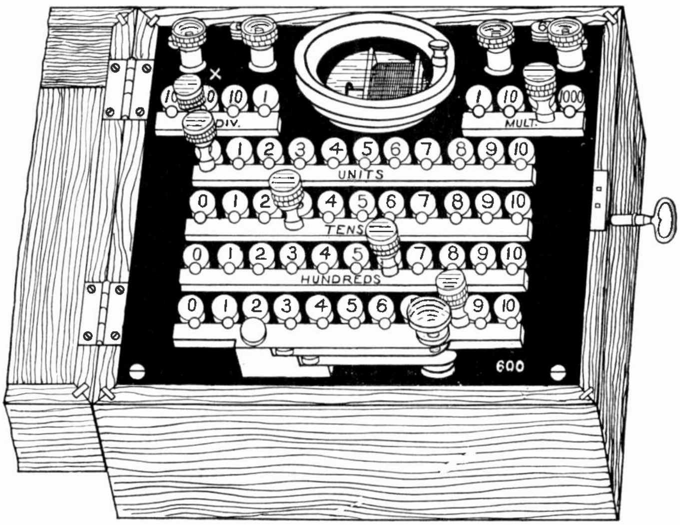


Fig. 42.

in the proper way. In some cases further convenience is secured by including the battery E in the box; but ordinarily this is not done, and it is necessary to connect one or two cells of battery to a pair of binding-posts placed on the box for that purpose. Resistances from $\frac{1}{10}$ ohm to 100,000 ohms can be conveniently and accurately measured by the Wheatstone bridge. Below $\frac{1}{10}$ ohm the resistances of the contacts in the binding-posts and plugs are apt to cause errors, and therefore special bridges provided with mercury contact cups are used. In fact, in measuring any resistance, care should be taken to make the connections clean and tight.

The ordinary bridge will not measure above 100,000 ohms, because, if the resistance in the arm B is 100 ohms, 1 ohm in A, and 1,000 ohms in C, then X is 100,000. Sometimes the arms A and B are provided with 1,000-ohm coils in addition to the usual 1-, 10- and 100-ohm coils; or sometimes the arm C contains more than 1,000 ohms in all; in either case the range will be correspondingly increased.

It should be observed, however, that the use of ratios of 1,000: 1, or even 100: 1, is not desirable, since they are likely to multiply any error due to contact resistances, etc. In fact, it is usually better to have the four resistances not very widely different in value; that is, no one of them should be more than ten times greater than any other except when very high or very low resistances are to be measured. The Wheatstone bridge may be used for testing the resistances of almost any field coils that are found in practice. Shunt fields for 110-volt machines usually vary from about 100 or 200 ohms in a 1-H. P. machine to about 5 to 20 ohms in a 100-H. P. machine. If the voltage is higher or lower than 110, these resistances vary as the square of the voltage. Series fields for arc-circuit dynamos vary from about 1 to 20 ohms. In measuring field resistances with the bridge, care must be taken to wait a considerable time after pressing the battery key, before pressing the galvanometer key, in order to allow time for the self-induction of the magnets to disappear.

The bridge may be used also for testing the armature resistance of some machines. But 110-volt shunt machines above 10 H. P. usually have resistances less than $\frac{1}{10}$ ohm, which is below the range of the ordinary bridge, as already stated. For higher or lower voltages the resistance is proportional to the square of the voltage. Arc machines have armatures of about 1 to 20 ohms resistance, and are therefore easily tested by the bridge.

The Drop (or **Fall-of-Potential**) **Method** is well adapted for locating faults quickly, and for testing the armature resistance of most generators and motors, or the resistance of contact between commutator and brushes, or other resistances which are usually only a few hundredths or even thousandths of an ohm. This consists in passing a current through the armature and connections and a known resistance (of, say, $\frac{1}{100}$ ohm), all connected in series, as represented in Fig. 43. The "drop" or fall of potential in the armature and that in the known resistance are compared by connecting a voltmeter first to the terminals of the known resistance (marked 1 and 2), and then to various other points on the circuit, as indicated by the dotted voltmeter terminals at M, N, O, Q, R, and S, so as to include successively each part to be tested. The deflections in all cases are directly proportional to the resistances included between the points touched by the terminals. The current needed depends upon the resistance of the circuit and the sensitiveness of the voltmeter. A bank of lamps or a liquid resistance is used for limiting the current. Instead of using a

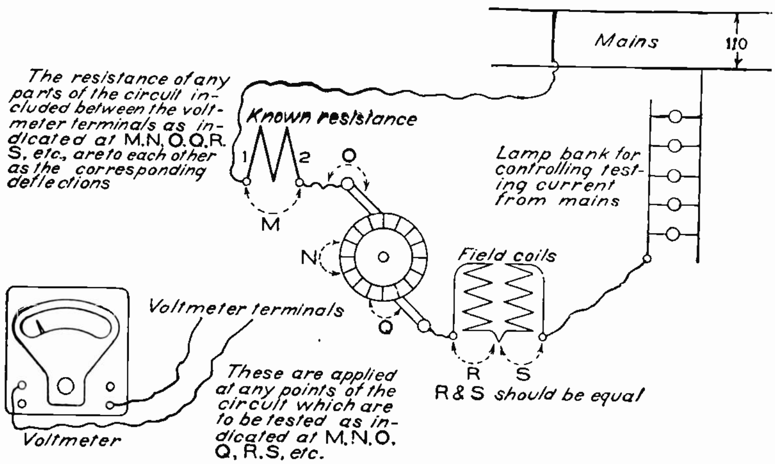


Fig. 43.

known resistance, an ammeter may be inserted in series with the resistance to be tested, the latter being then determined by Ohm's law, *viz.*, If E is the voltmeter deflection, and I represents the amperes flowing, the resistance of the part under test is $R = \frac{E}{I}$

A "station" or a portable voltmeter may be used for the readings, and its terminals may be held in the hands, or they may be conveniently arranged to project from an insulating handle like a two-pronged fork. Usually 10 to 100 amperes and a low-reading voltmeter are needed for low resistances.

It is well to start with a small testing current, and increase it until a good deflection is obtained on the voltmeter. If a current of several amperes cannot be had, a few cells of storage battery or some strong primary battery, such as a Bunsen, bichromate, or plunge battery, can be used with a galvanometer or low-reading voltmeter.

The diagram indicates the testing of a machine with series fields. Shunt fields must be connected directly to the line on account of their high resistance; while the armature can be connected as here shown, without being allowed to revolve.

This drop method of testing is also very useful in locating any fault. The two wires leading from the voltmeter are applied to any two points of the circuit, as indicated by the dotted lines —for instance, to two adjacent commutator segments, or to a brush tip and the commutator; any break or poor contact will be

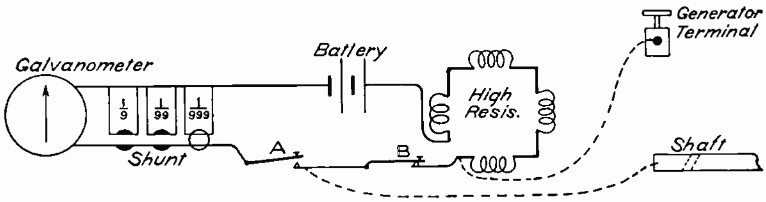


Fig. 44.

indicated immediately by the deflection being larger than at some other similar part. This shows that the fault is between the two points to which the wires are applied. Thus, by moving these along on the circuit, the exact location of any irregularity, such as a bad contact, short circuit, or extra resistance, can be found.

The *insulation resistance* of a generator or motor, that is, the resistance between its wires and its frame, should be sufficiently high so that not more than one-millionth of its rated current will pass through it at normal voltage, and it is well to have it still higher. It is therefore beyond the range of ordinary Wheatstone-bridge tests; but two good methods are applicable—the "direct-deflection" and the voltmeter method.

The Direct-Deflection Method is carried out by connecting a sensitive galvanometer, such as a Thomson high-resistance reflecting galvanometer, in series with a known high resistance, usually a 100,000-ohm rheostat, a battery, and keys, as shown in Fig. 44 The galvanometer should be shunted with the $\frac{1}{999}$ coil of the shunt, so that only $\frac{1}{1000}$ of the current passes through the galvanometer, the machine being entirely disconnected. The keys A and B are closed and the steady deflection noted. It is well to use but one cell of the battery at first, and then increase the number if necessary until a considerable deflection is obtained. The circuit is then opened at the key B, and connected by wires to the binding-post or commutator and to the frame or shaft of the machine, as indicated by dotted lines, so that the machine insulation resistance is included directly in the circuit with the galvanometer and battery. The key A is then closed and the deflection noted. Probably there will be little or no deflection, on account of the high insulation resistance; and the shunt is changed to $\frac{1}{99}$, $\frac{1}{9}$, or left out entirely if little deflection is obtained. In changing the shunt, the key should always be open, otherwise the full current is thrown on the galvanometer. The insulation is then calculated by the formula:

$$\text{Insulation resistance} = \frac{D \times R \times S}{d},$$

in which D is the first deflection without the machine being connected, and d the deflection with the machine insulation in the circuit, R the known high resistance, and S the ratio of the shunt. That is, if the shunt is $\frac{1}{999}$ in the first test, and $\frac{1}{9}$ in the second, then S is 100; and if the shunt is out entirely in the second test, S is 1,000. It is safer to leave the high resistance in circuit in the second test, to protect the galvanometer in case the insulation resistance is low. Therefore this resistance must be subtracted from the result to obtain the insulation of the machine itself.

By the above method it is possible to measure 100 megohms or even more. The wires and connections should be carefully arranged to avoid any possibility of contact or leakage, which would spoil the test. If no deflection is obtained, place one finger on the frame and one on the binding-post of the machine, which makes enough leakage to affect the galvanometer and show that the connections are right, thus proving that any poor insulation will be indicated if it exists.

The Voltmeter Test for Insulation Resistance requires a sensitive high-resistance voltmeter, such as the Weston. Take, for example, the 150-volt instrument, Fig. 45, which usually has about 15,000 ohms resistance. (A certificate of the exact resistance is pasted inside each case.) Apply it to some circuit or battery, and measure the voltage. This should be as high as possible—say, 100 volts. The insulation resistance of the machine is then connected into the circuit, as indicated in Fig. 46. The deflection of the voltmeter is less than before, in proportion to the value of the insulation resistance.

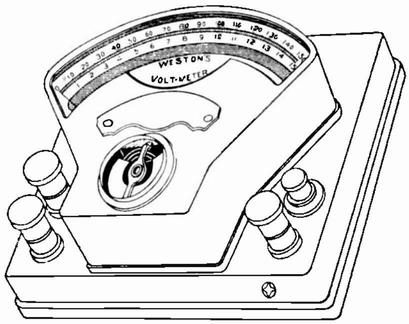


Fig. 45.

The insulation is then found by the equation:

$$\text{Insulation resistance} = \frac{D \times R}{d} - R,$$

in which D is the first and d the second deflection, and R the resistance of the voltmeter. If the circuit is 100 volts, D is 100; and if d, the deflection through the insulation resistance of the machine, is 1 division, the insulation is 1,485,000 ohms. Permanent marks indicating amounts of insulation may be put on the voltmeter scale. When making measurements, the voltage should be the same as that employed in preparing this scale (say, 115 volts). To calculate the scale use this formula:

$$d = \frac{115\ R}{X + R},$$

in which X is the insulation resistance (1 megohm, $\frac{1}{2}$ megohm, etc.), and d is the number of volts, opposite which the corresponding graduation is to be placed to form the new scale. This method does not test very high resistances; but if little or no deflection is obtained through the insulation resistance, it shows that the latter is at least several megohms — which is high enough for most practical purposes.

The ordinary magneto-electric bell may be used to test insulation by simply connecting one terminal to the binding-post of the machine, and the other to the frame or shaft.

A magneto bell is rated to ring from 10,000 to 30,000 ohms and if it does not ring, it shows that the insulation is more than that amount. This limit is altogether too low for proper insulation in any case; and therefore this test is rough, and really shows only whether or not the insulation is very poor or the machine actually grounded.

The magneto is also used for "continuity" tests, to determine whether a circuit is complete, by simply connecting the two terminals of the magneto to those of the circuit. If the bell can be rung, it shows that the circuit is complete; if not, it indicates a break. An ordinary electric bell and cell of battery can be used in place of the magneto.

The insulation of a machine should always be tested for disruptive strength, with a current of at least double the normal working pressure, to see if it will "break down" or be punctured by the current. A transformer motor-dynamo wound to give high voltage is convenient for this.

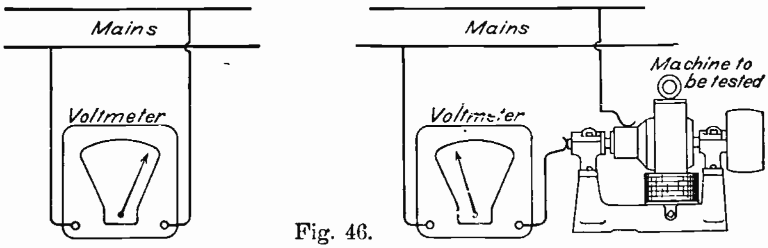


Fig. 46.

Tests of the resistances of generators or motors should properly be made when the machines are as warm as they get when running continuously at full load. This increases the resistance of conductors and decreases the insulation resistance, but it gives the actual working values.

Voltage. Instruments for measuring voltage (known as voltmeters) are in nearly all cases galvanometers of practically constant resistance. Through them flow currents which are directly proportional to the impressed voltages. A pointer connected to the moving part deflects over a graduated scale. A voltmeter should have as high a resistance as possible—at least several thousand ohms—in order not to take too much current, which might lower its reading on high-resistance circuit or consume too much power. It should not be affected by the magnetism of a generator or motor at any distance over a few feet.

The voltage of any machine or circuit is tested by merely connecting the two binding-posts or terminals of the voltmeter to the two terminals or conductors of the machine or circuit. To get the external voltage of a generator or motor, the voltmeter is usually applied to the two main binding-posts or brushes of the machine. This external voltage is what a generator supplies to the circuit. It is also called the pole difference of potential or terminal voltage, and is the actual figure upon which calculations of the efficiency, capacity, etc., of any machine are based.

A generator for constant-potential circuits should, of course, give as nearly as possible a constant voltage. A plain shunt machine usually falls from 5 to 15 per cent in voltage when its current is varied from nothing to full load. This is due to the I R drop caused by the resistance of the armature circuit, which in turn weakens the field current and magnetism; armature reaction usually occurs also, and still further lowers the external voltage. This variation is undesirable, and is usually avoided by regulating the field magnetism (varying the resistance in the field circuit) or by the use of compound-wound generators. A compound-wound dynamo should not fall appreciably from no load to full load; in fact, if it is "over-compounded" it should rise 5 per cent or more in voltage to make up for loss on the wiring.

The voltage of a constant-current generator is not important. The current should be carefully measured by an ammeter, but little attention is paid to the voltage in practical working; in fact, it changes constantly with variations in the load. But it is necessary, of course, to measure it in making efficiency or other exact tests.

A simple and fairly accurate method of measuring voltage is by means of ordinary incandescent lamps. A little practice enables one to tell whether a lamp has its proper voltage and brightness. In this way it is easy to tell if the voltage is even one or two per cent above or below the normal point. Voltages less than the ordinary can be tested by using low-voltage lamps or by estimating the brightness of high-voltage lamps. For example, a lamp begins to show a very dull red at one-third and a bright red at one-half its full voltage. Voltages higher than that of one lamp can be tested by using lamps in series. Thus 1,000 volts can be measured by using 10 lamps in series, and so on.

Current. This is measured by an ammeter (Fig. 47), which is usually cheaper than a voltmeter because it contains a comparatively small amount of wire. In testing the current of a generator or motor, it is necessary only to connect an ammeter, of the proper range, in series with the machine to be tested, so that the whole current passes through the instrument or its shunt. To test the current in the armature or the field alone, the ammeter is connected in series with the particular part. To avoid mistakes in the case of a shunt-wound generator, it is well to open the external circuit entirely in testing the current used in the field coils; for the same reason the brushes of a shunt motor should be raised before testing the current taken by the field.* In a constant-current or series-wound dynamo, the same current flows through all parts of the machine and the circuit; consequently the measurement of current is very simple.

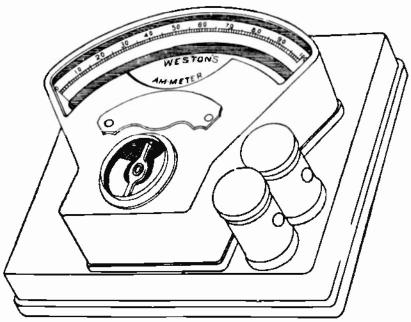


Fig. 47.

If an ammeter cannot be had, current can be measured by inserting a known resistance in the circuit and measuring the difference of potential between its ends. The volts thus indicated, divided by the resistance in ohms, gives the number of amperes flowing. If a known resistance is not at hand, the resistance of a part of the wire forming the circuit can be obtained from its diameter measured with a screw caliper or a wire gauge, by referring to any of the tables of resistances of wires; or the resistance can be measured by a Wheatstone bridge (Fig. 42), or by putting an ammeter, when one can be spared, into the circuit, while the voltmeter is connected. The volts divided by the amperes gives the resistance in ohms between the points to which the voltmeter is connected. Two connections can be attached permanently to two points on the circuit, and an ammeter tem-

* These instructions are to be followed when only one ammeter is to be had; otherwise one could be placed in the field circuit, and another in the circuit from the starting box to the independent armature terminal.

porarily inserted, and for every reading of the ammeter the corresponding reading of the voltmeter attached to these connections may be noted. Then, by keeping a list of these readings, the amperes can be found at any future time, by connecting the voltmeter to the two permanent contacts. This preliminary use of the ammeter amounts to measuring the resistance between the two contacts, and allows for the increase of resistance when the current and heating increase. In any case it is convenient to use a length of wire, or a distance between contacts, which will give an even amount of resistance, say, 1-10 or 1-100 ohm. And, as with large current the resistance will be fractional, care must be taken to avoid errors in multiplying, etc.

In testing the output of a generator, it is often quite a problem to dispose of the current produced. A bank of lamps, for

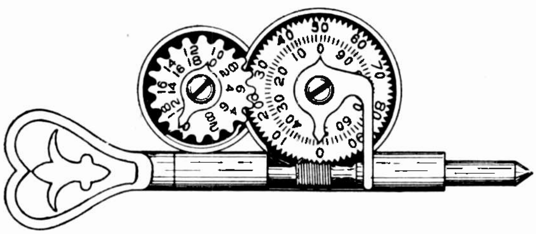


Fig. 48.

example, to use the whole current generated by a dynamo of 110 volts and 1,000 amperes, would be very expensive. A sufficient number of resistance-boxes for the purpose would also be very costly. The best way is to drive the generator by a motor, and connect it up in parallel with the line. In this way most of the power is returned instead of being wasted. If a motor cannot be had, the simplest and cheapest way to consume a large current is to place two plates of iron in a common tub or trough filled with a weak solution of carbonate of soda (common washing soda), which is better than almost any other solution because it neither gives off fumes nor eats the electrodes. The main conductors are connected to the two plates, respectively, and the current passes through the solution. The resistance and current are regulated by varying the distance between the plates, the depth they are immersed in the liquid, and the strength of the solution. The energy may be sufficient to boil the liquid, but this does no harm. Three to ten amperes per square inch of active surface of plate may be allowed.

Speed. This is usually measured by the well-known **speed counter** (Fig. 48), consisting of a small spindle which turns a wheel one tooth each time it revolves. The point of the spindle is held against the center of the shaft of the generator or motor for a certain time, say, one minute or one-half minute, and the number of revolutions is read off from the position of the wheel.

Another instrument for testing the number of revolutions per minute is the **tachometer.** The stationary form of this instrument is shown in Fig. 49. It must be belted by a string, tape, or

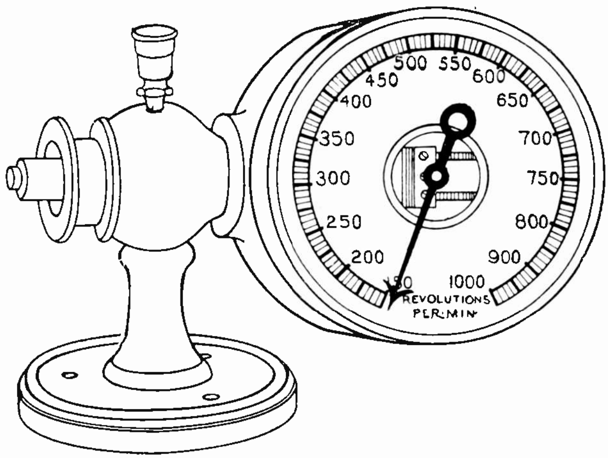


Fig. 49.

light leather belt to the machine the speed of which is to be tested. If the sizes of the pulleys are not the same, their speeds are inversely proportional to their diameters. The portable form of this instrument (Fig. 50) is applied directly to the end of the shaft of the machine, like the speed counter. The tip can be slipped upon either one of the three spindles, which are geared together, according as the speed is near 500, 1,000, or 2,000 revolutions. These instruments possess the great advantage over the speed counter that they instantly point on the dial to the proper speed, and they do not require to be timed for a certain period.

A simple way to test the speed in revolutions per minute is to make a large black or white mark on the belt of a machine, and note how many times the mark passes per minute ; the length of the belt divided by the circumference of the pulley gives the number of revolutions of the pulley for each time the mark passes. The number of revolutions of the pulley to one of the belt can also be easily determined by slowly turning the pulley or pulling the belt until the latter makes one complete trip around, at the same time counting the revolutions of the pulley. If the machine has no belt, it can be supplied with one temporarily for the purpose of the test, a piece of tape with a knot or an ink mark being sufficient. Care should be taken in all these tests of speed with belts not to allow any slip ; for example, in the case of the tape belt just referred to, this belt should pass around the pulley

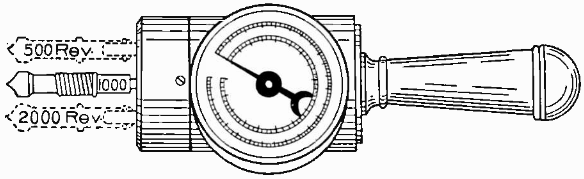


Fig. 50.

of the machine and some light wheel of wood or metal which turns so easily as not to cause any slip of the belt on the pulley of the machine.

Torque or **Pull** is measured in the case of a motor by the use of a Prony brake. This consists of a lever LL of wood, clamped on the pulley of the machine to be tested, as indicated in Fig 51. The pressure of the screws SS is then adjusted by the wing-nuts until the friction of the clamp on the pulley is sufficient to cause the motor to take a given current, and the speed is then noted. Usually, the maximum torque or pull is the most important to test; and this is obtained in the case of a constant-potential motor by tightening the screws SS until the motor draws its full current as indicated by an ammeter. What the full current should be, is usually marked on the name-plate ; if not, it may be assumed to be about 8 amperes per H. P. for 110-volt motors, 4 amperes per H. P. for 220-volt, and 1 3-4 amperes per H. P. for 500-volt motors. If the machine is rated in kilowatts, the full current in amperes can be found by multiplying by 1,000 and dividing by the voltage of the machine. The torque or pull is measured by known weights, or more conveniently by a spring balance P. I desired, the test may also be made at three-quarters, one-half, or any other fraction of the full current.

The torque or pull in pounds which should be obtained, can also be calculated from the power at which the machine is rated, by the formula;

$$\text{Torque} = \frac{\text{H. P.} \times 33{,}000}{6.28 \times \text{S}},$$

in which H. P. is the horse-power of the machine at full load, and S is the speed of the machine in revolutions per minute at full load. Torque is given at unit radius, commonly pounds at one foot. The pull at any other radius is converted into torque by multiplying by the radius; 1, 2, and 4 ft. are convenient radii or lengths of lever for measuring pull. One H. P. produced at a speed of 1,000 revolutions requires a pull of 5.25 pounds at end of 1-foot lever; at 500 revolutions, twice as much; at 2,000 revolutions half as much; and so on. If the lever is 4 feet, the pull is one-fourth as much, etc.

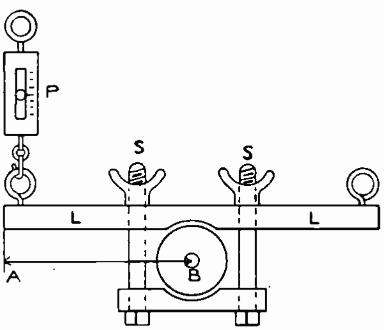


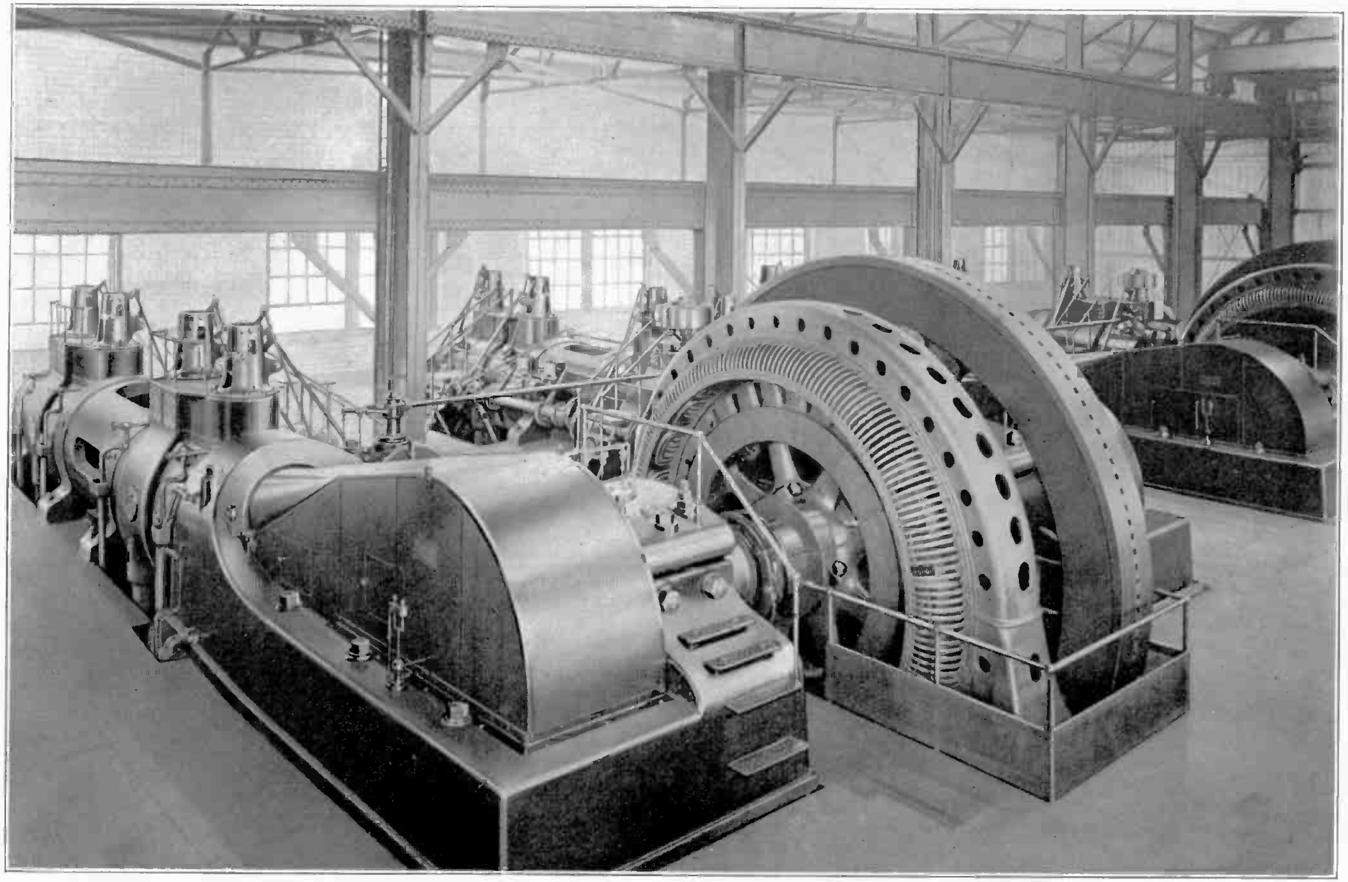
Fig. 51.

The Torque of a Generator, that is, the power required to drive it, is very conveniently determined by operating it as a motor, and testing it by the Prony brake as described above, the torque of a generator being practically equal to that of a motor under similar conditions.

Power. The electrical power of a generator or motor is found by testing the voltage and current at the terminals of the machine, as already described, and multiplying the two together, which gives the electrical power of the machine in watts.* Watts are converted into horse-power by dividing by 746, and into kilowatts by dividing by 1,000.

The mechanical power of a generator or motor, that is, the

*In testing an alternating-current machine, a wattmeter should be employed instead of a voltmeter and an ammeter, as explained later.



ONE OF FOUR 1500-H. P., FOUR-CYCLE, DOUBLE-ACTING, GAS ENGINES, EACH DRIVING A 1000-Kw. ALTERNATING-CURRENT GENERATOR

Courtesy of *Allis-Chalmers Company, Milwaukee, Wis.*

power required for or developed by it, is found by multiplying its pull by its speed and by the circumference on which the pull is measured, and dividing by 33,000. That is,

$$\text{Horse-power} = \frac{P \times S \times 6.28 \times R}{33{,}000},$$

in which P is the pull in pounds, S the speed in revolutions per minute, and R the radius in feet at which P is measured.

Efficiency. This is determined in the case of a generator by dividing the electrical power generated by it by the mechanical power required to drive it; that is,

$$\text{Efficiency of generator} = \frac{\text{Electrical power}}{\text{Mechanical power}}.$$

The efficiency of a motor is the mechanical power developed by it, divided by the electrical power supplied to it; that is,

$$\text{Efficiency of motor} = \frac{\text{Mechanical power}}{\text{Electrical power}}.$$

These are the **actual** or **commercial efficiencies** of these machines, and should be at least 90 per cent at rated load in machines of 10 H. P. and over.

The so-called "electrical efficiency" is misleading and of little practical importance, and should not be considered in commercial work. The mechanical and electrical power in the above equations are determined as already explained.

It is usually more convenient to test the efficiency of a generator by testing it as a motor with a Prony brake. But the efficiency of a generator may be determined very easily by driving it with a calibrated electric motor, that is, one in which the power developed for any given number of volts and amperes consumed is known. Then it is only necessary to measure the watts supplied by the generator when the motor is running at a certain power, and the efficiency of the generator is *the watts ÷ the known power*.

Another method is to employ two identical machines, one used as a motor driving the other as a generator. The shafts of the two machines should be directly connected by some form of coupling; a belt may be used, but its friction would cause a small loss. The watts produced by the generator, divided by the watts consumed by the motor, is the combined efficiency of the two machines; and the efficiency of each is the square root of that fraction. For example, if the combined efficiency is .81, then that of each machine is .90, since .90 × .90 = .81. This assumes that the two efficiencies are equal, which is sufficiently correct if the machines are exactly alike. The current from the generator may be used to help feed the motor, and then only the difference in current need be supplied. This latter current represents the inefficiency or losses from friction, etc., in both machines.

To test in this way, connect both machines in parallel with the source of current; couple or belt them together; and then weaken the field, or shift the brushes of the machine which is to be used as a motor, so that it will speed up and drive the other as a dynamo, or cause it to drive the other by putting a large pulley on it. In this way the motor will consume current from the circuit while the generator yields current to the circuit. Both currents are measured and the efficiencies calculated.

The efficiency of a motor-generator or ordinary converter is very easily determined by simply measuring the input and output in watts (by wattmeters or by ammeters and voltmeters for direct currents), and dividing the latter by the former.

These electrical methods of testing are preferable to mechanical, for the reason that the volts and amperes can be easily and accurately measured, and their product gives the power in watts.* Mechanical measurements of power by dynamometer or other means are difficult, and usually not very accurate.

Separation of Losses. The total losses in a generator or motor, except that caused by the electrical resistance of the armature when carrying the full current, can be closely determined at once by noting the current required to run the machine free as a motor. In a machine of 90 per cent efficiency, this should not amount to more than about 8 per cent of the current required to give rated power. Consequently the easiest way to test a machine is to run it as a motor without load.

The various losses of power that occur in a generator or motor may be determined and separated from each other as follows:

* When alternating-current machinery is being tested use wattmeters

Take a generator, for example, and drive it with another machine used as a motor in the manner described for testing friction. The motor should previously be calibrated, that is, tested to determine the exact mechanical power it develops for each amount of electrical power in watts supplied to it, as described for testing efficiency. A simple, shunt-wound motor on a constant-potential circuit is best suited to the purpose. The generator is first driven at normal speed with no field magnetism and with the brushes lifted; then the actual power developed by the motor equals the power lost in the generator by the friction of bearings and belt. The brushes are then adjusted in contact with the commutator, with the usual pressure. The increase in the power of the motor is equal to the brush friction.

Finally, excite the field magnet to full strength, and the increase in the power exerted by the motor is equal to the combined losses due to the Foucault or eddy currents and hysteresis in the iron core of the armature, provided there is no considerable side pull on the armature. The power wasted in Foucault currents varies as the square of the speed, while the hysteretic loss is only directly proportional to speed; hence the two may be separated by testing the machine at different speeds.

For example, let us call x and y the losses due to hysteresis and Foucault currents, respectively, at full speed; A the power consumed by both at full speed; and B the power consumed at half speed. Then $A = x + y$, and $B = \frac{x}{2} + \frac{y}{4}$; hence, by eliminating x, we have $y = 2A - 4B$. That is the Foucault loss is twice the power consumed by both at full speed minus four times the power consumed by both at half speed. The hysteresis loss $= A - y$. If eddy currents are developed in the copper conductors of the armature, they will increase the apparent Foucault loss as determined by the above test, since they also vary as the square of the speed. The power wasted by eddy currents might be found by testing the armature without any conductors upon it. This could be done only before the armature is wound or by unwinding it, neither of which is practicable except in the place where it is made. Ordinarily, however, eddy currents in the conductors do not amount to much unless they are very large, and even then the use of stranded conductors or conductors embedded in slots in the iron core largely overcomes the trouble.

Friction of the air might also increase the apparent Foucault loss; but it usually causes only a very small loss, and is almost impossible to separate except by running the machine in a vacuum, which is, of course, impracticable. The other losses are quite easily measured and separated, as follows:

The number of watts used in the field can be measured by a voltmeter and ammeter, or it can be calculated by the formula: $\text{Watts} = \frac{E^2}{R} = I^2R = EI$, in which E is the voltage, R the resistance, and I the current. It is sufficient if any of these two quantities are known. The loss in the armature conductors, due to ohmic resistance is found by multiplying the square of the current in the armature at full load by the armature resistance; in fact, this is usually called the "I^2R loss." This should not be more than 1 to 3 per cent in a constant-potential generator or motor, whether it be alternating- or direct-current. The sum of all the losses make up the difference between the total power consumed by the machine and the useful power that it develops.

The ordinary values of the various losses in a good generator or motor of 25 H. P. are approximately as follows:

Useful power developed	about 92	per cent.
Used in magnetizing field	about 1 to 2	"
Loss in armature resistance (I^2R)	" 1 to 2	"
Friction of bearings	about 2	"
Friction of brushes	" ½	"
Friction of air	" ½	"
Hysteresis in armature core	" 1½	"
Foucault currents in armature core	" 1½	"

Measurement of Power in A. C. Circuits. In circuits carrying alternating currents and having some inductive load either in the form of motors or arc lamps or a partly-loaded transformer, etc., the ordinary method of determining the power, by voltmeter and ammeter measurements, is not applicable, as the current is seldom in phase with the E. M. F., and therefore the product *volts* × *amperes* is not the true power.

There are several means for determining the true power of an A. C. circuit, the simplest being an indicating wattmeter. A wattmeter is an electro-dynamometer provided with two coils, a fixed one of coarse wire, the other movable and of fine wire. This movable coil is connected in series with a large non-inductive resistance, so that the time-constant of the fine-wire circuit is extremely small; and hence its impedance is practically equal to its resistance; the current in, and resulting field of, the fine-wire coil will under these conditions be practically in phase with the potential difference across its terminals. The field produced by the coarse-wire coil is directly proportional to the current flowing through it at any instant. Hence, the couple acting on the fine-wire coil is proportional at a given instant to the product of these fields; so that the reading of the instrument, which depends on the mean value of the couple, will be proportional to the mean power, and, by providing the instrument with the proper scale, it can be made to read directly in watts.

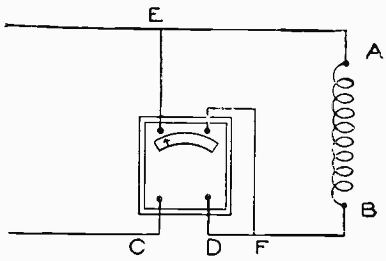


Fig. 52.

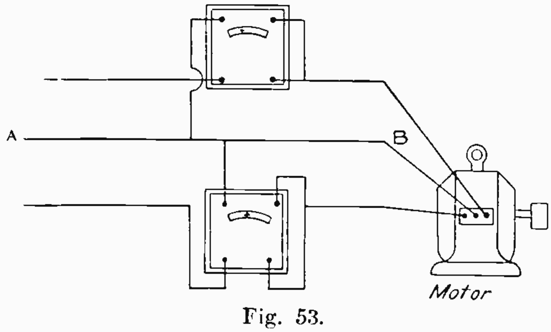


Fig. 53.

In Fig. 52, A B represents an inductive load—say, a single-phase motor—of which the power input is to be determined; C D the terminals of the thick-wire coil (current-coil) of the wattmeter; and E F the pressure-coil terminals. When connected as above indicated, the wattmeter indicates directly the power in watts supplied. In the case of a two-phase system, where the two circuits are independent, the power may be measured by placing a wattmeter in each phase, as shown in Fig. 52, and adding the two readings. If the motor be connected up as shown in Fig. 53,* where A B forms a common return, the wattmeters are placed as indicated, *care being taken to place the current-coils in the out-*

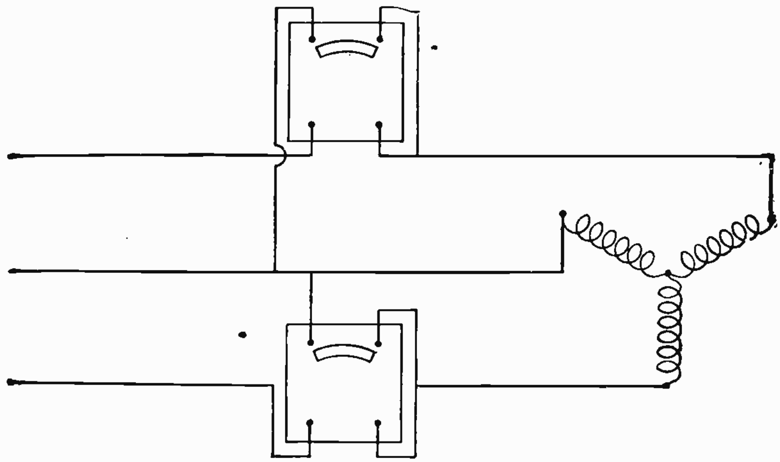


Fig. 54*a*.

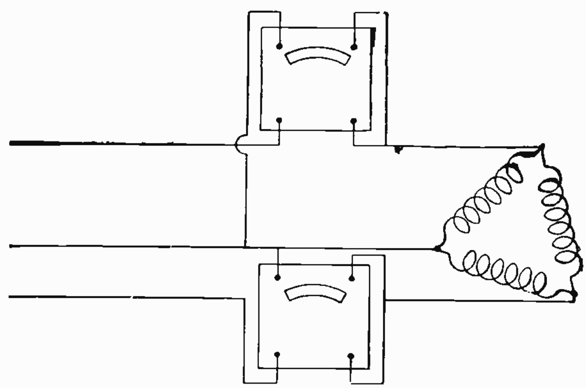


Fig. 54*b*.

side mains; and the power supplied is equal to the sum of the two wattmeter readings.

The power of a balanced or unbalanced three-phase system can be determined by the use of two wattmeters connected as

* This form of connection is possible only when the generator has two independent windings, one for each phase.

shown in Fig. 54, *a* and *b*. The current-carrying coils are placed in series with two of the wires, and the pressure-coil respectively connected between these two mains and the third wire. The *algebraic* sum of these two wattmeter readings gives the true power supplied. When the power factor of the system is less than .5, one of the wattmeters will read negatively. It is sometimes difficult to determine whether the smaller readings are negative or not. If in doubt, give the wattmeter a separate load of incandescent lamps, and make the connections such that both instruments deflect properly; then reconnect them to the load to be measured. If the terminals of one instrument have to be reversed, the readings of that wattmeter are negative.

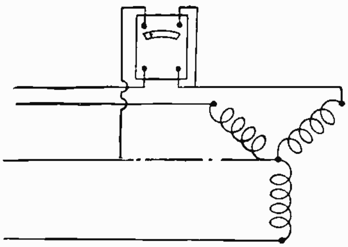


Fig. 55.

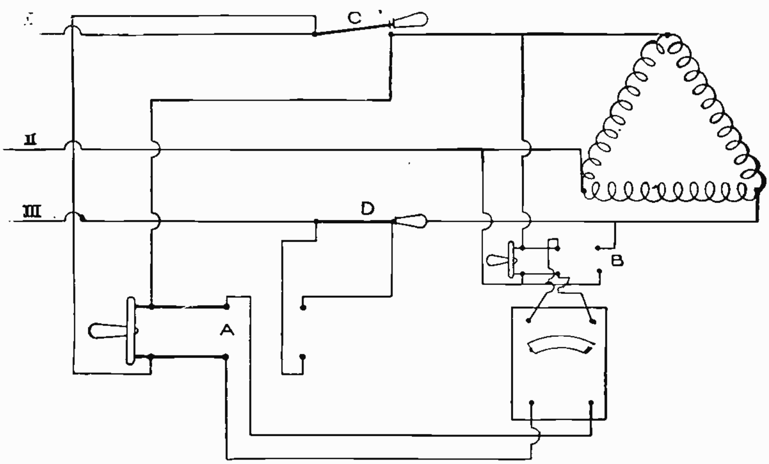


Fig. 56.

To measure the power of a balanced 4-wire 3-phase system, one wattmeter may be connected as shown in Fig. 55, and the wattmeter reading multiplied by 3. Usually, however, a 4-wire 3-phase system is unbalanced; and to determine the power supplied under this condition, three wattmeters should be employed, one for each phase, the power supplied being equal to the algebraic sum of all three readings.

It is obvious that in any of the above instances one wattmeter could be employed, provided the necessary switches are furnished. Assuming, for example, the 3-phase 3-wire case, one wattmeter would require switch connections as shown in Fig. 56. A is a double-pole switch, which, when thrown to the left, places the current-coil of the wattmeter in series with the conductor of No. I, and, when thrown to the right, places it in series with No. III. Similarly, switch B changes the pressure terminals from between I and II to III and II; while switches C and D are short-circuiting switches, one of which is closed previous to removing the current-coil from one phase to the other, and the other one opened after the coil is in position as indicated.

LOCALIZATION AND REMEDY OF TROUBLES.

The promptness and ease with which any accident or difficulty with electrical machinery can be dealt with, will always have much to do with the success of a plant. The following list of troubles, symptoms, and remedies for the various types and sizes of dynamos and motors in common use, has been prepared to facilitate the detection and elimination of such difficulties.

It is evident that the subject is somewhat complicated and difficult to handle in a general way, since so much depends upon the particular conditions in any given case, every one of which must be included in the table in such a way as to distinguish it from all others Nevertheless, it is remarkable how much can be covered by a systematic statement of the matter, and nearly all cases of trouble most likely to occur are covered by the table, so that the detection and remedy of the defect will result from a proper application of the rules given.

It frequently happens that a trifling oversight, such as allowing a wire to slip out of a binding-post, will cause as much annoyance and delay in the use of electrical machinery as the most serious accident. Other troubles, equally simple but not so easily detected, are of frequent occurrence.

The rules are made, as far as possible, self-explanatory; but a statement of the general plan followed and its most important features will facilitate the understanding and use of the table.

USE OF THE TABLE OF TROUBLES.

In the use of this table, the principal object should be to separate clearly the various causes and effects from one another. A careful and thorough examination should first be made; and, as far as possible, one should be perfectly sure of the facts, rather than attempt to guess what they are and jump at conclusions. Of course, general precautions and preventive measures should be taken before any troubles occur, if possible, rather than to wait until a difficulty has arisen. For example, one should see that the machine is not overloaded or running at too high voltage, and should make sure that the oil-cups are not empty. Neglect and carelessness with any machine are usually and deservedly followed by accidents of some sort. It is usually wise to stop the machine when any trouble manifests itself, even though it does not seem to be very serious. It is often practically impossible to shut down; but even then, spare apparatus should be ready. The continued use of defective machinery is a common but very objectionable practice.

The general plan of the table is to divide all troubles that may occur to generators or motors, into ten classes, the headings of which are the ten most important and obvious bad effects produced in these machines, *viz.:*

I. Sparking at Commutator.
II. Heating of Commutator and Brushes.
III. Heating of Armature.
IV. Heating of Field Magnets.
V. Heating of Bearings.
VI. Noisy Operation.
VII. Speed not right.
VIII. Motor stops or fails to start.
IX. Dynamo fails to generate.
X. Voltage not right.

Any one of these general effects is evident, even to the casual observer, and still more so to any person making a careful examination; hence nine-tenths of the possible cases can be eliminated immediately.

The next step is to find out which particular one of the eight or ten causes in this class is responsible for the trouble. This requires more careful examination, but nevertheless can be done with comparative ease in most cases. One cause may produce two effects, and, *vice versa*, one effect may be produced by two causes; but the table is arranged to cover this fact as far as possible. In a complicated or difficult case it is well to read through the entire table and note what causes can possibly apply. Generally there will not be more than two or three; and the particular one can be picked out by following the directions, which show how each case may be distinguished from any other.

I. SPARKING AT THE COMMUTATOR.

This is one of the most common of troubles, being often quite serious because it burns and cuts the commutator and brushes, at the same time producing heat that may spread to and injure the armature or bearings. Any machine having a commutator is liable to it, including practically all direct-current and some alternating-current machines. The latter usually have continuous collecting rings not likely to spark; but self-exciting or composite-wound alternators, rotary converters, and some alternating-current motors have supplementary direct-current commutators. A certain amount of sparking occurs normally in most constant-current dynamos for arc lighting, where it is not very objectionable, since the machines are designed to stand it and the current is small.

CAUSE 1. **Armature carrying too much current,** due to (*a*) overload (for example, too many lamps fed by dynamo, or too much mechanical work done by motor; a short circuit, leak, or ground on the line may also have the effect of overloading a dynamo); (*b*) excessive voltage on a constant-potential circuit, or excessive amperes on a constant-current circuit. In the case of a motor, any friction, such as armature striking pole pieces, or a shaft not turning freely, may have the same effect as overload.

SYMPTOM. Whole armature becomes overheated, and belt (if any) becomes very tight on tension side, sometimes squeaking because of slipping on pulley. Overload due to friction is detected by stopping the machine, and then turning it slowly by hand. (See V and VI, 2.)

REMEDY. (*a*) Reduce the load; or eliminate the short circuit, leak, or ground on the line; (*b*) decrease size of driving pulley, or (*c*) increase size of driven pulley; (*d*) decrease magnetic strength of field in the case of a dynamo, or increase it in the case of a motor. If excess of current cannot satisfactorily be overcome in any of the above ways, it will be necessary to change the machine or its winding. Overload due to friction is eliminated as described under V and VI, 2.

If the starting or regulating rheostat of a motor has too little resistance, it will cause the motor to start too suddenly and to spark badly at first. The only remedy is more resistance in the box.

CAUSE 2, **Brushes not set at the neutral point.**

SYMPTOM. Sparking varied by shifting the brushes with rocker-arm.

REMEDY. Carefully shift brushes backwards or forwards until sparking is reduced to a minimum. This can be done by

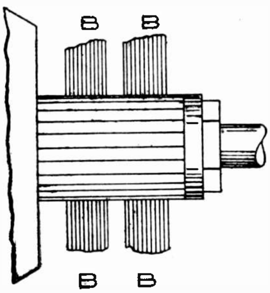


Fig. 57.

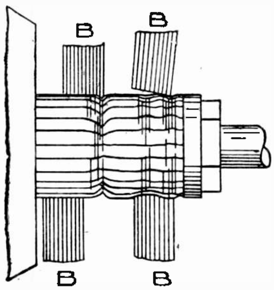


Fig. 58.

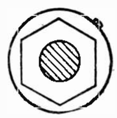


Fig. 59.

simply moving the rocker-arm. If only slightly out of position, heating alone may result, without disarrangement being bad enough to show sparking. If the brushes are not exactly opposite in a bipolar, 90° apart in a four-pole machine, and so on, they should be made so, the proper points of contact being determined by counting the commutator-bars or by careful measurement.

The usual position for brushes is opposite the spaces between the pole pieces, but in some machines they must be set in line with centers of pole pieces or at some other point. If the brushes are set exactly wrong, this will cause a dynamo to fail to generate and a motor to fail to start, and will blow the fuse or open the circuit-breaker. (See IX, 6.)

CAUSE 3. **Commutator rough, eccentric, or has one or more "high bars"** projecting beyond the others, or one or more

flat bars, commonly called **flats,** or **projecting mica,** any one of which causes the brushes to vibrate or to be actually thrown out of contact with the commutator (Figs. 58 and 59). Hard mica between the bars, which does not wear as rapidly as the copper, will prevent good contact or throw brushes off.

SYMPTOM. Note whether there is a glaze or polish on the commutator, which shows smooth working; touch revolving commutator with tip of finger nail, and the least roughness is perceptible; or feel brushes to see if there is any jar. If the machine runs at high voltage (over 250), the commutator or brushes should be touched with a stick or quill to avoid danger of shock. In the case of an eccentric commutator, careful examination shows a rise and fall of the brush when the commutator turns slowly, or a chattering of brush when it is running fast. Sometimes, by sighting in line with brush contact, one can see daylight between commutator and brush, owing to brush jumping up and down.

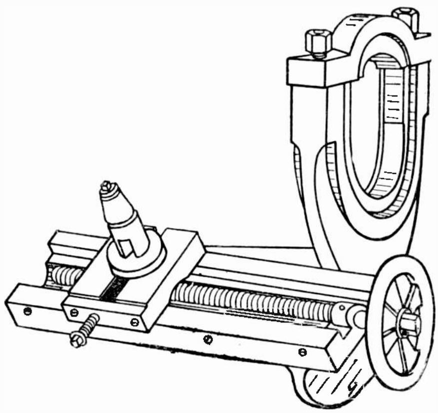


Fig. 60.

REMEDY. Smooth the commutator with a fine file or fine sandpaper, which should be applied on a block of wood that exactly fits the commutator (being careful to remove any sand remaining afterward; and *never use emery*). If commutator is very rough or eccentric, the armature should be taken out and put in a lathe, and the commutator turned off. Large machines often have a slide-rest attachment (Fig. 60), so that the commutator can be turned off without removing the armature. This is clasped on the pillow-block after removing the rocker-arm.

For turning off a commutator, a diamond-pointed tool should be used, this being better than either a round or square end. It should have a very sharp and smooth edge; and only a fine cut should be taken off each time in order to avoid catching in or tearing the copper, which is very tough. The surface is then finished by applying a "dead smooth" file while the commutator revolves rapidly in the lathe. Any particles of copper should then be carefully removed from between the bars.

To have the commutator wear smooth and work well, it is desirable to have the armature shaft move freely back and forth about an eighth of an inch in the bearings while it is running. A commutator should have a glaze of a brown or bronze color. A very bright or scraped appearance does not indicate the best condition. Sometimes a very little vaseline or a drop of oil may be applied to a commutator that is rough. Too much oil is very bad, and causes the following trouble:

CAUSE 4. **Brushes make poor contact with commutator.**

SYMPTOM. Close examination shows that brushes touch only at one corner, or only in front or behind, or there is dirt on surface of contact. Sometimes, owing to the presence of too much oil or from other cause, the brushes and commutator become very dirty, and covered with smut. They should then be carefully cleaned by wiping with oily rag or benzine, or by other means.

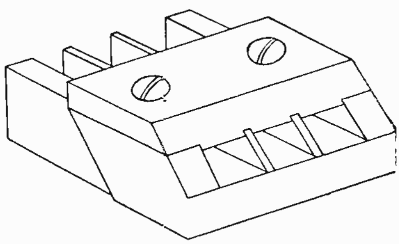


Fig. 61.

Occasionally a "glass-hard" carbon brush is met with. It is incapable of wearing to a good seat or contact, and will touch at only one or two points. Some carbon brushes are of abnormally high resistance, so that they do not make good contact. In such cases new brushes should be substituted.

REMEDY. Carefully fit, adjust, or clean brushes until they rest evenly on commutator, with considerable surface of contact and with sure but not too heavy pressure. Copper brushes require a regular brush jig (Fig. 61). Carbon brushes can be fitted perfectly by drawing a strip of sandpaper back and forth between them and the commutator while they are pressing down. A band of sandpaper may be pasted or tied around the commutator, and the armature then slowly revolved by hand or by power while the brushes are pressed upon it.

It sometimes happens that the brushes make poor contact because the brush-holders do not work freely.

CAUSE 5. **Short-circuited or reversed coil or coils in armature.**

SYMPTOM. A motor will draw excessive current, even when running free without load. A dynamo will require considerable power, even without any load. For reversed coil, see III, 5.

The short-circuited coil is heated much more than the others, and is liable to be burnt out entirely; therefore the machine should be stopped immediately. If necessary to run machine in order to locate the trouble, one or two minutes is long enough; but this may be repeated until the short-circuited coil is found by feeling the armature all over.

An iron screw-driver or other tool held between the field magnets near the revolving armature, vibrates very perceptibly as the short-circuited coil passes. Almost any armature, particularly one with teeth, will cause a slight but rapid vibration of a piece of iron held near it; but a short circuit produces a much stronger effect only *once* per revolution. Care should be taken not to let the piece of iron be drawn in and jam the armature.

The current pulsates and torque is unequal at different parts of a revolution, these being particularly noticeable when several coils are short-circuited, or reversed and the armature is slowly turned. If a large portion of the armature is short-circuited, the heating is distributed and is harder to locate. In this case a motor runs very slowly, giving little power but having full field magnetism. A short-circuited coil can also be detected by the drop-of-potential method. For dynamos, see IX, 3.

REMEDY. A short circuit is often caused by a piece of solder or other metal getting between the commutator-bars or their connections with the armature; and sometimes the insulation between or at the ends of these bars is bridged over by a particle of metal. In any such case the trouble is easily found and corrected. If, however, the short circuit is in the coil itself, the only effective remedy is to rewind the coil.

One or more "grounds" in the armature may produce effects similar to those arising from a short circuit. (See Cause 7.)

CAUSE 6. **Broken circuit in armature.**

SYMPTON. Commutator flashes violently while running, and commutator-bar nearest the break is badly cut and burnt; but in this case no particular armature coil will be heated as in the last case; and the flashing will be very much worse, even when turning slowly. This trouble, which might be confounded with a bad case of "high bar" in commutator (Cause 3), is distinguished therefrom by slowly turning the armature, when violent flashing will continue if circuit is broken; but not with "high bar" unless it is very bad, in which case it is easily felt or seen. A very bad contact has almost the same effect as a break in the circuit.

Remedy. A break or bad contact can be located by the "drop" method (page 63) or by a continuity test (page 68). The trouble is often found where the armature wires connect with the commutator, and not in the coil itself, and the break may be repaired or the loose wire properly fastened. It the trouble is due to a broken commutator connection, and cannot be fixed, the disconnected bar may be temporarily connected to the next by solder, or the brushes may be "staggered," that is, one put a little forward and the other back so as to bridge over the break (Fig. 62). It may be impracticable to "stagger" radial and some other arrangements of brushes, but usually a brush is thick enough to make contact with more than one commutator bar. If the break is in the coil itself, rewinding is generally the only cure. But this may be remedied temporarily by connecting together by wire or solder the two commutator-bars or coil-terminals between which the break exists. It is only in an emergency that armature coils should be cut out or commutator bars connected together, or other makeshifts resorted to; but it sometimes avoids a very undesirable stoppage. A very rough but quick and simple way to connect two commutator bars, is to hammer or otherwise force the coppers together across the mica insulation at the end of the commutator. This should be avoided if possible; but if it has to be done in an emergency, the crushed material can afterwards be picked out and the injury smoothed over. In carrying out any of these methods, great care should be taken not to short-circuit any other armature coil, which would cause sparking (Cause 5).

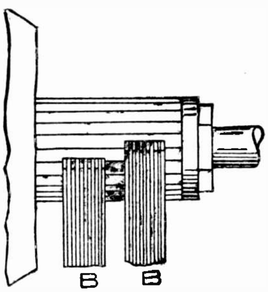
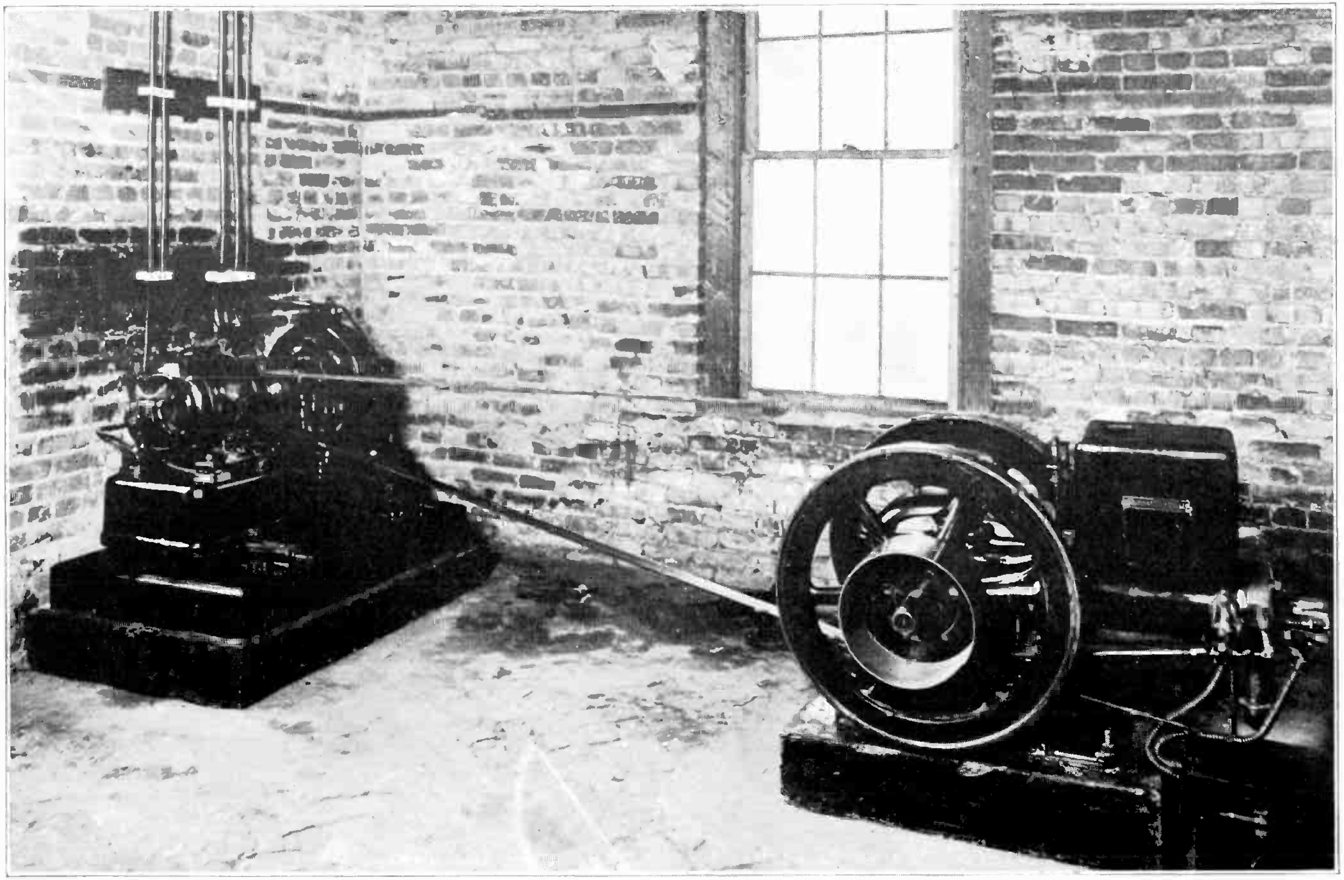


Fig. 62.

CAUSE 7. **Ground in Armature.**

SYMPTOM. Two "grounds" (accidental connections between the conductors on the armature and its iron core or the shaft or spider) would have practically the same effect as a short circuit (Cause 5), and would be treated in the same way. A single ground would have little or no effect, provided the circuit is not intentionally or accidentally grounded at some other point. On an electric-railway ("trolley") or other circuit employing the earth as a return conductor, one or more grounds in the armature would allow the current to pass directly through them, and would cause the motor to spark and have a variable torque at different parts of a revolution.

REMEDY. A ground can be detected by testing with a magneto bell (page 67). It can also be located by the drop-of-potential method (page 63). Another way to locate it is to wrap a wire around the commutator so as to make connection with all of the bars, and then connect a source of current to this wire and to the armature core (by pressing a wire upon the latter). The current will then flow from the armature conductors through the ground connection to the core, and the magnetic effect of the armature winding will be localized at the point where the ground is. This point is then found by the indications of a compass needle when slowly moved around the surface of the armature. The current may be obtained from a storage battery or from the circuit, but should be regulated by lamps or other resistance so as not to exceed the normal armature current. Sometimes the ground may be in a place where it can be corrected without much trouble, but usually the particular coil and often others must be rewound. A ground will be produced if the insulation is punctured by a spark of static electricity, which may be generated by the friction of the belt. If the frame of the machine is connected to the ground, the static charge will pass off to the ground; but such grounding is often inadvisable, and in such cases the frame may be connected to the ground through a Geissler tube, a wet thread, a heavy pencil-mark on a piece of unglazed porcelain, or other very high resistance which will carry off a static charge of very high potential and almost infinitesimal quantity, but will not permit the passage of any considerable current that might cause trouble.



WESTERN ELECTRIC COMPANY TYPICAL CHARGING OUTFIT AT DAWSON, GEORGIA

CAUSE 8. **Weak Field Magnetism.**

SYMPTOM. Pole pieces not strongly magnetic when tested with a piece of iron. Point of least sparking is shifted considerably from normal position, owing to relatively strong distorting effect of armature magnetism. Speed of a shunt motor is usually high unless magnetism is very weak or *nil*, in which case a motor may run slow, stop, or even run backwards.* A generator fails to generate the full E.M.F. or current.

The particular cause of trouble may be found as follows: A broken circuit in the field of a motor is found by purposely opening the field circuit at some point, taking care first to disconnect armature (by putting wood under the brushes, for example), and to use only one hand, to avoid shock. If there is no spark when circuit is thus opened, there must be a broken circuit somewhere. A short circuit in the field coils is found by measuring their resistance roughly to see if it is very much less than it should be. Usually a short circuit is confined to one magnet, and will therefore weaken that one more than the others; and a piece of iron held half-way between the pole pieces will be attracted to one more than to the other. The short circuit may be found by the drop-of-potential method, by testing from the joint between the field coils to each outside terminal. "Grounding" is practically identical with short-circuiting, but one ground will not produce this effect until another occurs. A double ground, through which the current finds a complete path, is equivalent to a short circuit. In the ordinary "trolley" electric-railway system, a ground return is used, and the neutral conductor of three-wire systems is often grounded. In such cases one ground may be sufficient to cut out one or more field coils.

If one field coil is reversed and opposed to the others, it will weaken the field magnetism and cause bad sparking. This may be detected by examining the field coils to see if they are all connected in the right way, or by testing with a compass needle. (See IX, 4.) The series-coil of a compound-wound dynamo or motor is ofted connected wrongly, and will have the wrong effect, that is, will reduce the voltage of the former or raise the speed of the latter with increase of load.

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* NOTE. If the motor is not loaded, it will race.

REMEDY. A broken or short circuit or a ground is easily repaired if external or accessible. If it is internal, the only remedy is to replace or rewind the faulty coil. A shunt motor will spark badly in starting if the armature is connected before the field. This can be remedied by adjusting the contacts and switch-arm. If the voltage is too low on the circuit, it may cause sparking in a shunt dynamo or motor; and if the voltage cannot be raised, the resistance of the field circuit should be reduced by unwinding a few layers of wire or by substituting other coils (See VII, VIII, IX, and X.)

CAUSE 9. **Vibration of Machine.**

SYMPTOM. Considerable vibration is felt when the hand is placed upon the machine, and sparking decreases if the vibration is reduced.

REMEDY. The vibration is usually due to an imperfectly balanced armature or pulley (see VI, 1), to a bad belt (see VI, 6), or to unsteady foundations; and the remedies described for these troubles should be applied.

Any considerable vibration is likely to produce sparking, of which it is a common cause. This sparking can be reduced by increasing the pressure of the brushes on the commutator, but the vibration itself should be overcome.

CAUSE 10. **Chatter of Brushes.**

The commutator sometimes becomes sticky when carbon brushes are used, causing friction, which throws the brushes into rapid vibration as the commutator revolves, similar to the action of a violin bow.

SYMPTOM. Slight tingling or jarring is felt in brushes.

REMEDY. Clean commutator, and oil slightly.

CAUSE 11. **Flying break in armature conductor.**

SYMPTOM. No break found by test with armature standing still, but break shown by flashing at brushes, when running, being usually due to centrifugal force.

REMEDY. Tighten connections to commutator, or repair broken wire, etc.

EXCESSIVE HEATING IN GENERATOR OR MOTOR.

General Instructions. The degree of heat that is injurious or objectionable in a generator or motor is easily determined by feeling the various parts. If the heat is bearable to the hand, it is entirely harmless; but if unbearable, the safe limit of temperature has been approached or passed, and the heat should be reduced in some of the ways that are indicated below. In testing with the hand, allowance should be made for the fact that bare metal feels much hotter than cotton at the same temperature. The back of the hand is more sensitive than the palm for this test. If the heat has become so great as to produce an odor or smoke, the safe limit has been far exceeded, and the current should be shut off immediately and the machine stopped, as this indicates a serious trouble, such as a short-circuited coil or tight bearing. The machine should not again be started until the cause of the trouble has been found and positively overcome. Of course, neither water nor ice should ever be used to cool electrical machinery, except possibly the bearings of large machines at points where they can be applied without danger of wetting the other parts.

Feeling for heat will serve as a rough test to detect excessive temperatures or in emergencies; but, of course, the sensitiveness of the hand varies, and it makes a great difference whether the surface is a good or bad conductor of heat. The proper and reliable methods for determining rise in temperature are given on page 59, Part I.

It is very important, in all cases of heating, to locate the source of heat in the exact part in which it is produced. It is a common mistake to suppose that any part of a machine that is found to be hot is the seat of the trouble. A hot bearing may cause the armature or commutator to heat, or *vice versa*. In every case all parts of the machine should be tried to find which is the hottest, since heat generated in one part is rapidly diffused throughout the entire machine. It is better to make observations for heating by starting with the whole machine cool, which is done by letting it stand for several hours.

II. HEATING OF COMMUTATOR AND BRUSHES.

Cause 1. **Heat spread from another part of machine.**

Symptom. Start with the machine cool, and run for a short time, so that heat will not have time to spread. The real seat of trouble is the part that heats first.

Remedy. (See Heating of Armature, Fields, and Bearings.)

CAUSE 2. **Sparking.** Any of the causes of sparking will cause heating, which may be slight or serious.

SYMPTOM and REMEDY. See "Sparking."

CAUSE 3. **Tendency to spark, or slight sparking hardly visible.**

Sometimes before sparking appears, serious heating is produced by the causes of sparking, such as the short-circuiting of the coils as their commutator-bars pass under the brushes.

SYMPTOM. Reduced by applying the principal remedies for sparking, such as slightly shifting rocker-arm. Fine sparks may be found by sighting in exact line with the surface of contact between the commutator and brushes.

REMEDY. (See "Sparking.") Apply the remedies with extra care. This incipient sparking may be due to excessive inductance in the armature coils, which can be corrected only by reconstruction; or it may be due to insufficient field strength, and this can be cured by increasing the ampere-turns of field winding.

CAUSE 4. **Overheated commutator will decompose carbon brush.**

The effect is to cover commutator with a black film which offers resistance and aggravates the heat.

SYMPTOM. Commutator covered with dark coating; commutator, brushes and holders show marks of abnormal heat.

REMEDY. Commutator and brushes should be carefully cleaned, and the latter adjusted to make good contact at the proper points.

CAUSE 5. **Bad connections in brush-holder, cable, etc.**

SYMPTOM. Holder, cable, etc., feel hottest; unusual resistance found in these parts by "drop method."

REMEDY. Improve the connections.

CAUSE 6. **Arcing or short circuit in commutator.**

This may occur across mica or insulation between bars or nuts.

SYMPTOM. Burnt spot between parts; spark appears in the insulation when current is put on.

REMEDY. Pick out the charred particles; take commutator apart and repair; or put on new commutator.

CAUSE 7. **Carbon brushes heated by the current.**

Carbon brushes require less attention than copper, because they do not cut the commutator, and their resistance usually reduces sparking, but it may also cause them to heat.

SYMPTOM. Brushes hotter than other parts.

REMEDY. Use carbon of higher conductivity. Let the brush-holder grip brush closer to commutator, so as to reduce the length of brush through which the current must pass. Reinforce the brush with copper gauze or sheet copper. Use larger brushes or a greater number.

III. HEATING OF ARMATURE.

CAUSE 1. **Excessive current in armature coils.**

SYMPTOM and REMEDY the same as in case of "Sparking," Cause 1.

CAUSE 2. **Short-circuited armature coils.**

SYMPTOM and REMEDY the same as in case of "Sparking;" Cause 5. See also Cause 7.

CAUSE 3. **Moisture in armature coils.**

SYMPTOM. Armature requires considerable power to run free. Armature steams when hot, or feels moist. This is really a special case of Cause 2, as moisture has the effect of short-circuiting the coils through the insulation. Measure insulation resistance of armature ; this should test at least one megohm if armature is in good condition, but would be much lowered by moisture. (See "Insulation Tests.")

REMEDY. The armature should be baked for 5 to 10 hours in an oven or other place sufficiently warm to drive out the moisture, but not hot enough to run any risk of burning or even slightly charring the insulation. A neat way to do this is to pass through the armature a current regulated to be about three quarters of the rated armature current, the armature being held still or turned over occasionally.

CAUSE 4. **Foucault currents in armature core.**

SYMPTOM. Iron of armature core hotter than coils after a short run, and considerable power required to run armature when

NOTE. Any excess of current taken by an armature when running *free*, whatever the cause, must be converted into heat by some defect in the motor; hence the "free current" is the simplest and most complete test of the efficiency and perfect condition of the machine field is magnetized and there is no load on armature. This can be distinguished from Cause 2 by absence of sparking and absence of excessive heat in a particular coil or coils after a short run. (See "Stray Power Tests.")

REMEDY. Armature core should be laminated more perfectly, which is a matter of first construction.

CAUSE 5. **One or more reversed coils on one side of armature.** This will cause a local current to circulate around armature.

SYMPTOM. Excessive current when running free, but no particular coil heated more than others. If a moderate current is applied to each coil in succession by touching wires carrying current to each two adjacent commutator-bars, a compass needle held over the coils will behave differently when the reversed coil is reached. In a motor the half of armature containing the reversed coils is heated more than the other.

REMEDY. Reconnect the coil to agree with the others.

CAUSE 6. **Heat conveyed from other parts.**

SYMPTOM. Other parts hotter than armature. Start with machine cool, and see if other parts heat first.

REMEDY. See Heating of Bearings, Field and Commutator.

CAUSE 7. **Flying cross in armature conductor.**

SYMPTOM and REMEDY similar to the case of sparking (Cause 11), except that reference here is to the insulation of the conductors.

IV. HEATING OF FIELD MAGNETS.

CAUSE 1. **Excessive current in field circuit.**

SYMPTOM. Field coils too hot to keep the hand on. Their temperature more than 50°C above that of room by resistance test or by thermometer.

REMEDY. In the case of a shunt-wound machine, decrease the voltage at terminals of field coils; or increase the resistance in field circuit by winding on more wire or putting resistance in series. In the case of a series-wound machine, shunt a portion of, or otherwise decrease, the current passing through field; or take a layer or more of wire off the field coils; or rewind with coarser wire. This trouble might be due to a short circuit in field coils in the case of a shunt-wound dynamo or motor, and would be indicated by the pole piece with the short-circuited coil being weaker than the others. This coil is cooler than the others; in fact, if completely short-circuited, it is not heated at all. This condition can be remedied only by rewinding the short-circuited coil. Measure resistance of the field coils to see if they are nearly equal. (See "drop method.") If the difference is considerable (say, more than 5 or 10 per cent), it is almost a sure sign that one coil is short-circuited or double-grounded.

CAUSE 2. **Foucault currents in pole pieces or field cores.**

SYMPTOM. The pole pieces hotter than the coils after a short run. When making the comparison, it is necessary to keep the hand on the coils some time before the full effect is reached, because the coils are insulated and the pole pieces are bare metal, and even then the coils will not feel so hot, although their actual temperature may be higher if measured by a thermometer.

REMEDY. This trouble is due to faulty design of toothed-armature machines, which can be corrected only by rebuilding, or is caused by fluctuations in the current. The latter can be detected, if the variations are not too rapid, by putting an ammeter in circuit; or rapid variations may be felt by holding a piece of iron near the pole pieces, and noting whether it vibrates. In the case of an alternating current it is necessary to use laminated fields to avoid great heating.

CAUSE 3. **Moisture in field coils.**

SYMPTOM. The field circuit tests lower in resistance than normal in that type of machine; and in the case of shunt-wound machines, the field takes more than the ordinary current. Field coils steam when hot, or feel moist to hand. The insulation resistance also tests low.

REMEDY. The same as for moisture in armature (III, 3).

V. HEATING OF BEARINGS.

The cause should be found and removed promptly, but heating of the bearings can be reduced temporarily by applying cold water or ice to them. This is allowable only when absolutely necessary to keep running; and great care should be taken not to allow any water to get upon the commutator, armature, or field-coils, as it might short-circuit or ground them. If the bearing is very hot, the shaft should be kept revolving slowly, as it might "freeze," or stick fast, if stopped entirely.

CAUSE 1. **Lack of oil.**

SYMPTOM. Oil-cup reservoir empty. Oil passages clogged. Self-oiling rings stick fast. Shaft and bearing look dry. The shaft does not turn freely.

REMEDY. Supply oil, and make sure that oil passages as well as feeding or self-oiling devices work freely, and that the oil cannot leak out. This last fault sometimes causes oil to fail sooner than attendant expects. A good quality of oil should always be used, as poor oil might be as bad as no oil.

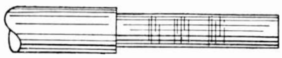


Fig. 63.

CAUSE 2. **Grit or other foreign matter in bearings.**

SYMPTOM. Best detected by removing shaft or bearing and examining both. Any grit can of course be felt easily, and will also cut the shaft.

REMEDY. Remove shaft or bearing, clean both very carefully, and see that no grit can get in. Place machine in dustless place or box it in. The oil should be perfectly clean; if not, it should be filtered. If it is not possible to stop the machine or to remove the shaft, the dirt may be washed out with kerosene or water; but these should not be allowed to get on the commutator, armature, or field coils.

CAUSE 3. **Shaft rough or cut.** (Fig. 63.)

SYMPTOM. Shaft will show grooves or roughness, and will probably revolve stiffly.

REMEDY. Turn shaft in lathe; or smooth with fine file; and see that bearing is smooth and fits shaft.

CAUSE 4. **Shaft and bearing fit too tight.**

SYMPTOM. Shaft hard to revolve by hand.

REMEDY. Turn or file down shaft in lathe, or scrape or ream out bearings.

CAUSE 5. **Shaft "sprung" or bent.**

SYMPTOM. Shaft hard to revolve, and usually sticks much more in one part of revolution than in another.

REMEDY. It is very difficult to straighten a bent shaft. It might be bent back or turned true, but probably a new shaft will be necessary.

CAUSE 6. **Bearings out of line.**

SYMPTOM. Shaft hard to revolve, but is much relieved by slightly loosening the screws that hold bearings in place, when machine is not running and when belt, if any, is taken off.

REMEDY. Loosen the bearings by partly unscrewing bolts or screws holding them in place, and find their easy and true position, which may require one of them to be moved either sideways or up or down; then file the screw-holes of that bearing, or raise or lower it, as may be necessary, to make it occupy the right position when the screws are tightened. The armature, however, must be kept in the center of the space between the pole pieces, so that the clearance is uniform all around. (See Cause 9.)

CAUSE 7. **Thrust or pressure of pulley, collar, or shoulder on shaft against one or both of the bearings.**

SYMPTOM. Move shaft back and forth with a stick applied to the end while revolving, and note if the collar or shoulder tends to be pushed or drawn against either bearing. It is usually desirable that a shaft should move freely back and forth about an eighth of an inch, to make commutator and bearings wear smoothly.

REMEDY. Line up the belt; shift collar or pulley; turn off shoulder on shaft, or file off bearing, until the shoulder does not touch when running, or until pressure is relieved.

CAUSE 8. **Too great a load or strain on the belt.**

SYMPTOM. Great tension on belt. In this case the pulley bearing will probably be very much hotter than the other, and also worn elliptical, as indicated in Fig. 64, in which case the shaft can be shaken in the bearing in the direction of the belt pull, when the belt is off, provided the machine has been running long enough to wear the bearings.

REMEDY. Reduce load or belt tension, or use larger pulleys and lighter belt, so as to relieve side strain on shaft. (See "Belting.")

CAUSE 9. **Armature too near one pole piece, producing much greater magnetic attraction on nearer side.**

SYMPTOM. Examine the clearance of armature to see if it is uniform on all sides. Charge and discharge the field magnet, the armature being disconnected (by putting wood under the brushes);

and note whether armature seems to be drawn to one side and turns very much less easily when field is magnetized.

REMEDY. This fault is due either to a defect in the original construction, or to wear in the bearings, either of which is difficult to correct; but in cases of necessity the armature can be centered exactly in the field by moving the bearings, which may be done by carefully filing the holes through which the screws pass that hold the bearings in place; or the pole piece may be filed away where it is too near the armature.

Trouble from this cause is greater in multipolar than in bipolar machines, and always tends to become aggravated, because the more the side pull the more the bearings wear in that direction. If, on the other hand, the armature is in the center of the space formed by the pole pieces, the magnetic pull is practically balanced in all directions.

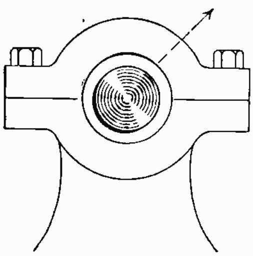


Fig. 64.

It is risky to file bolt-holes or make any such change in a machine; and this should never be attempted before consulting an experienced machinist. Very often the trouble is due to the parts being out of place merely because they have not been put together right or because there is dirt between them. If the bearing is worn, it may be rebabbitted or renewed.

CAUSE 10. **Bearing heated by hot pulley, commutator, or armature.**

SYMPTOM. Pulley, armature, or commutator hotter than bearing. The slipping of the belt on the pulley, sparking at the commutator, or heating of the armature may heat one or both bearings of the machine, in which case an examination will show that these parts are hotter than the bearing, and the real source of the trouble.

REMEDY. A slipping belt, sparking commutator, or hot armature can be cured as described under these headings, and then the bearing will probably cease to heat.

VI. NOISY OPERATION.

CAUSE 1. **Vibration due to armature or pulley being out of balance.**

Symptom. Strong vibration felt when the hand is placed upon the machine while it is running. Vibration changes greatly if speed is changed, and sometimes almost disappears at certain speeds.

Remedy. Armature or pulley must be perfectly balanced by securely attaching lead or other weight on the light side, or by drilling or filing away some of the metal on the heavy side. The easiest method of finding in which direction the armature is out of balance is to take it out, and to rest the shaft on two parallel and horizontal A-shaped metallic tracks sufficiently far apart to allow the armature to go between them (Fig. 65). If the armature is then slowly rolled back and forth, the heavy side will tend to turn downward. The armature and pulley should always be balanced separately. An excess of weight on one side of the pulley and an equal excess of weight on the opposite side of the armature will not produce a balance while running, though it does when standing still; on the contrary, it will give the shaft a strong tendency to "wobble." A perfect balance is obtained only when the weights are directly opposite, *i.e.*, in the same line perpendicular to the shaft.

Cause 2. **Armature strikes or rubs against pole pieces.**

Symptom. Easily detected by placing the ear near the pole pieces; or by examining armature to see if its surface is abraded at any point; or by examining each part of the space between armature and field as armature is slowly revolved, to see if any portion of it touches or is so close as to be likely to touch when the machine is running. In small machines, the armature may be turned by hand, noting whether it sticks at any point.

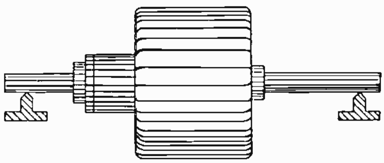


Fig. 65.

Remedy. Bind down any wire or other part of the armature that may project abnormally; or file out the pole pieces where the armature strikes; or center the armature so that there is a uniform clearance between it and the pole pieces at all points.

Cause 3. **Shaft collar or shoulder, hub or edge of pulley, or belt, strikes or scrapes against bearings.**

SYMPTOM. Rattling noise, which stops when the shaft or pulley is pushed lengthwise away from one or the other of the bearings. (See "Heating of Bearings," Cause 7.)

REMEDY. Shift the collar or pulley, turn off the shoulder on the shaft, file or turn off the bearing, move the pulley on the shaft, or straighten the belt, until there is no more striking, and the noise ceases.

CAUSE 4. **Rattling due to looseness of screws or other parts.**

SYMPTOM. Close examination of the bearings, shaft, pulley, screws, nuts, binding-posts, etc., or touching the machine while running, or shaking its parts while standing still, shows that some parts are loose.

REMEDY. Tighten up the loose parts, and be careful to keep them all properly set up. It is easy to guard against the occurrence of this trouble, which is very common, by simply examining the various screws and other parts each day before the machine is started. Electrical machinery being usually high-speed, the parts are particularly liable to shake loose. A worn or poorly fitted bearing might allow the shaft to rattle and make a noise, in which case the bearing should be refitted or renewed.

CAUSE 5. ***Singing or hissing of brushes.*** This is usually occasioned by rough or sticky commutator (see "Sparking," Causes 3 and 10), or by brushes not being smooth, or by the layers of a copper brush not being held together and in place. With carbon brushes, hissing will be caused by the use of carbon that is gritty or too hard. Vertical carbon brushes, or brushes inclined against the direction of rotation, are liable to squeak or sing. Occasionally, a new machine will make noise that is reduced after the machine has been run for some time.

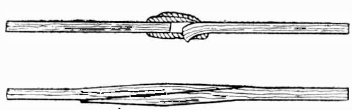


Fig. 66.

SYMPTOM. Sound of high pitch, and easily located by placing the ear near the commutator while it is running, and by lifting off the brushes one at a time, provided there are two or more in each set, so that the circuit is not opened. If there is no current there is no objection to raising the brushes.

REMEDY. Apply a *very little* oil or vaseline to the commutator with the finger or a rag. Adjust the brushes or smooth the commutator by turning or filing, or by using fine sandpaper, being careful to clean thoroughly afterwards. Carbon brushes are liable to squeak in starting up or at low speed. This decreases at full speed, and can generally be stopped by moistening the brushes with oil, care being taken not to have any drops or excess of oil. Shortening or lengthening the brushes sometimes stops the noise. Running the machine without load for some time usually reduces this trouble.

CAUSE 6. **Flapping or pounding of belt joint or lacing against pulley.** (Fig. 66.)

SYMPTOM. Sound repeated once for each complete revolution of the belt, which is much less frequent than any other generator or motor sound, and can easily be detected or counted.

REMEDY. Endless belt or smoother joint. (See "Belting.")

CAUSE 7. **Slipping of belt on pulley due to overload.**

SYMPTOM. Intermittent squeaking noise.

REMEDY. Tighten the belt or reduce the load. A wider belt or larger pulley may be required. Powdered rosin may be put on the belt to increase its adhesion ; but it is a makeshift, injurious to the belt, to be adopted only if necessary. (See "Belting.")

CAUSE 8. **Humming of armature-core teeth as they pass pole-pieces.**

SYMPTOM. Pure humming sound less metallic than Cause 5.

REMEDY. Slope or chamfer the ends of the pole pieces so that each armature tooth does not pass the edge of the pole piece all at once. Decrease the magnetization of the fields. Increase the air-gap or reduce the distance between the teeth. But these are nearly all matters of first construction and are made right by good manufacturers.

CAUSE 9. **Humming due to alternating or pulsating current.**

SYMPTOM This gives a sound similar to that in the preceding case. The two can be distinguished, if necessary, by determining whether the note given out corresponds to the number of alternations, or to the number of armature teeth passing per second.

Usually the latter is considerably greater than the former.

REMEDY. This trouble is confined to alternating apparatus, and its effects can be reduced by proper design and by mounting the machine so as to deaden the sound as far as possible.

It often happens that a generator or motor seems to make a noise, which in reality is caused by the engine or other machine with which it is connected. Careful listening with the ear close to the different parts will show exactly where the noise originates. A very sensitive method of locating a noise or vibration is to hold a short stick by one end between the teeth, and press the other end squarely against the several parts, to ascertain which particular one gives the greatest vibration.

VII. SPEED TOO HIGH OR TOO LOW.

This is generally a serious matter in either generator or motor, and it is always desirable and often imperative to shut down immediately, and make a careful investigation.

SPEED TOO LOW.

CAUSE 1. **Overload.** (See "Sparking," Cause 1.)

SYMPTOM. Armature runs more slowly than usual. Bad sparking at commutator. Ammeter indicates excessive current. Armature heats. Belt very tight on tension side.

REMEDY. Reduce the load on machine, decrease the diameter of driving pulley, or increase the diameter of driven pulley. If necessary to relieve strain of overload, temporarily decrease the voltage on either a generator or a motor.

CAUSE 2. **Short circuit or ground in armature.**

SYMPTOM and REMEDY the same as in case of "Heating of Armature, Cause 2 and Cause 6.

CAUSE 3. **Armature strikes pole pieces.**

SYMPTOM and REMEDY the same as in case of "Noise," Cause 2.

CAUSE 4. **Shaft does not revolve freely in the bearings.**

SYMPTOM and REMEDY the same as for "Heating of Bearings," all cases.

SPEED TOO HIGH OR TOO LOW.

CAUSE 5. **Field magnetism weak.**

This has the effect, on a constant-voltage circuit, of making a motor run too fast if lightly loaded, or too slow if heavily loaded, or even run backwards if the field magnet is not excited at all, as, for example, when the field circuit is broken. It makes a generator fail to "build up" or excite its field, or give the proper voltage in any case.

Symptom and Remedy the same as in case of "Sparking," Cause 8. (See the following Cause; also "Dynamo Fails to Generate ')

Cause 6. **Too high or too low voltage on the circuit.**

Symptom. This would cause a motor to run too fast or too slow, respectively. It can be shown by measuring the voltage of the circuit.

Remedy. The central station or generating plant should be notified that voltage is not right.

SPEED TOO HIGH.

Cause 7. **Motor too lightly loaded.**

Symptom. A series-wound motor on a constant-potential circuit runs too fast, and may speed up to the bursting point if the load is very much reduced or removed entirely (by the breaking of the belt, for example).

Remedy. Care should be exercised in using a series motor on a constant-potential circuit, except where the load is a fan, pump, or other machine that is *positively* connected or geared to the motor so that there is no danger of its being taken off. A shunt motor should be used if the load is likely to be thrown off.

VIII. MOTOR STOPS OR FAILS TO START.

This is an extreme case of the previous class ("Speed Too High or Too Low"), but is separated because it is more definite and permits of quicker diagnosis and treatment. This heading does not, of course, apply to generators, since any trouble in setting these in motion is usually outside of the machine itself.

Cause 1. **Great overload.**

A slight overload causes motor to run slowly, but an extreme overload will, of course, stop it entirely or "stall" it. (See "Sparking," Cause 1.)

Symptom. On a constant-potential circuit the current is excessive, and safety-fuse blows or circuit-breaker opens. In their absence or failure, armature is burnt out.

Remedy. Turn off switch instantly, reduce or take off the load, replace the fuse or circuit-breaker, if necessary, and turn on current again just long enough to see if trouble still exists; if so, take off more load.

CAUSE 2. **Very excessive friction due to shaft, bearings, or other parts being jammed, or armature touching pole pieces.**

SYMPTOM. Similar to previous case, but distinguished from it by the fact that the armature is hard to turn even when load is taken off. Examination shows that the shaft is too large or is bent or rough, that the bearing is too tight, that the armature touches pole pieces, or that there is some other impediment to free rotation. (See "Heating of Bearings" and "Noise.")

REMEDY. Turn current off instantly, ascertain and remove the cause of friction, turn on the current again just long enough to see if trouble still exists; if so, investigate further.

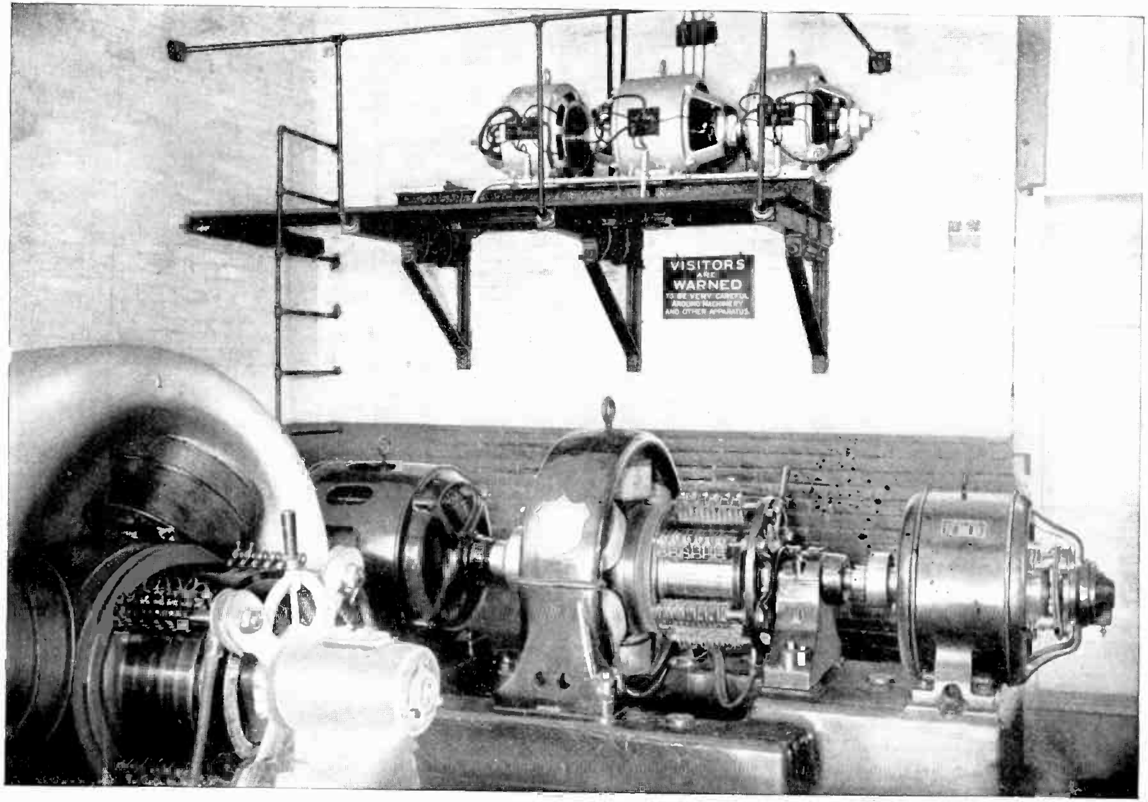
CAUSE 3. **Circuit open.**

This may be due to (*a*) safety-fuse blown or circuit-breaker open; (*b*) wire in motor broken or slipped out of connections; (*c*) brushes not in contact with commutator; (*d*) switch open; (*e*) circuit supplying motor open; (*f*) failure at generating plant.

SYMPTOM. Distinguished from causes 1 and 2 by the fact that if the load is taken off, the motor still refuses to start, and yet armature turns freely.

On a constant-potential circuit the field circuit alone of a shunt motor may be open, in which case the pole pieces are not strongly magnetic when tested with a piece of iron, and there is a dangerously heavy current in the armature; if the armature circuit is at fault, there is no spark when the brushes are lifted; and if both are without current, there is no spark when switch is opened. One should be very careful if there is no field magnetism or even if it is weak, as a motor is liable to be burnt out if the current is then thrown upon the armature.

REMEDY. Turn current off instantly. Examine safety-fuse circuit-breaker, wires, brushes, switch, and circuit generally, for break or fault. If none can be found, turn on switch again for a moment, as the trouble may have been due to a temporary stoppage of the current at the station or on the line. If motor still seems dead, test separately armature, field coils, and other parts of circuit for continuity with a magneto or a cell of battery and an electric



REGULATING BOOSTER SET
Gould Storage Battery Co.

bell, to see if there is any break in the circuit. (See "Instructions for Testing.")

One of the simplest ways to find whether the circuit has current on it and to locate any break, is to test through an incandescent lamp. Two or five lamps in series should be used on 220- and 500-volt circuits, respectively.

CAUSE 4. **Wrong connection or complete short circuit of field, armature, switch, etc.**

SYMPTOM. Distinguished from Causes 1 and 2 in the same way as Cause 3, and differs from Cause 3 in the evidence of strong current in motor.

On a constant-potential circuit, if current is very great, it indicates a short circuit. If the field is at fault, it will not be strongly magnetic.

The possible complications of wrong connections are so great that no exact rules can be given. Carefully examine and make sure of the correctness of all connections (see Diagrams of Connections). This trouble is usually inexcusable, since only a competent person should ever set up a machine or change its connections.

In the 3-wire (220-volt direct-current) system, several peculiar conditions may exist, as follows:

(*a*) The dynamo or dynamos on one side of the system may become reversed, so that both of the outside wires are positive or negative. In that case a motor fed in the usual way from the two outside conductors will get no current, but lamps connected between the neutral wire and either of the outside wires will burn as usual.

(*b*) If one of the outside wires is open by the blowing of a fuse, an accidental break, or other cause, then a motor (220-volt) beyond the break can get some current at 110 volts through any lamps that may be on the same side of the break as itself, and on the same side of the system as the conductor that is open. These lamps will light up when the motor is connected, but the motor will have little or no power unless the number of lamps is large.

(*c*) If the neutral or middle wire is open, a motor connected with the outside wires will run as usual; but lamps on one side of the system will burn more brightly than those on the other side, unless the two sides are perfectly balanced.

(*d*) If one of the outside wires becomes accidentally grounded, a 110-volt dynamo, motor, or other apparatus, also grounded and connected to the other outside wire, will receive 220 volts, which will probably burn it out.

IX. DYNAMO FAILS TO GENERATE.

This trouble is almost always caused by the inability of a dynamo to "excite" or "build up" its field-magnetism sufficiently. The proper starting of a self-exciting dynamo requires a certain amount of residual magnetism, which must be increased to full strength by the current generated in the machine itself. This trouble is not likely to occur in a separately-excited machine; and if it does it is usually due to the exciter failing to generate, and therefore amounts to the same thing.

CAUSE 1. **Residual magnetism too weak or destroyed.**

This may be due to (*a*) vibration or jar; (*b*) proximity of another dynamo; (*c*) earth's magnetism; (*d*) accidental reversed current through fields, not enough to completely reverse magnetism. The complete reversal of the residual magnetism in any dynamo will not prevent its generating, but will only make it build up of opposite polarity. Sometimes reversal of residual magnetism may be very objectionable, as in case of charging storage batteries; but, although the popular supposition is to the contrary, it will not cause the machine to fail to generate.

SYMPTOM. Little or no magnetic attraction when the pole pieces are tested with a piece of iron.

REMEDY. Send a magnetizing current from another machine or battery through the field coils, then start and try the machine; if this fails, apply the current in the opposite direction, since the magnets may have enough polarity to prevent the battery building them up in the direction first tried.

Shift the brushes backward in a generator, or forward in a motor to make armature magnetism assist field. Turn machine around or change its polarity, so that the magnetism which the earth or the adjacent machine tends to induce is in the right direction. Dynamos should be placed with their opposite poles toward each other, and the north pole of a machine should preferably be placed toward the north (which is magnetically the *south* pole of the earth); but the earth's magnetism is hardly strong enough to reverse a dynamo's residual magnetism.

CAUSE 2. **Reversed connections or reverse direction of rotation.**

SYMPTOM. When running, pole pieces show no attraction for a piece of iron. The application of external current cannot be made to start the machine, as in case of Cause 1, because, whichever way the field may be magnetized, the resulting current generated by armature opposes and destroys the magnetism.

REMEDY. (*a*) Reverse either armature connections or field connections, *but not both*. (*b*) Move brushes through 180° for 2-pole, 90° for 4-pole machines, etc. (*c*) Reverse direction of rotation. After each of the above are tried, the field may have to be built up with a battery or other current, since the causes in this case operate to destroy whatever residual magnetism may have been present.

CAUSE 3. **Short circuit in the machine or external circuit.** This applies to a shunt-wound machine, and has the effect of preventing the voltage and the field magnetism from building up.

SYMPTOM. Magnetism weak, but still quite perceptible.

REMEDY. If the short circuit is in the external circuit, opening the latter will allow the dynamo to build up and generate full voltage. If the short circuit is within the machine, it should be found by careful inspection or testing. In either of these cases, do not connect the external circuit until short circuit is found and eliminated. A slight short curcuit, such as that caused by a defective lamp socket or by copper dust on the brush-holder or commutator, may prevent the magnetism of a shunt machine from building up. (See "Sparking," Causes 5 and 8.) Too many lamps, or other load, might prevent a shunt dynamo from building up its field magnetism, in which case the load should be disconnected in starting.

CAUSE 4. **Field-coils opposed to each other.**

SYMPTOM. Upon passing a current from another dynamo of a battery the following symptom will exist: If the pole-pieces of a bipolar machine are approached with a compass or other freely suspended magnet, they both attract the same end of the magnet, showing them to be of the same polarity, whereas they should always be of opposite polarity.

For similar reasons the pole-pieces are magnetic when tested separately with a piece of iron, but show less attraction when the same piece of iron is applied to both at once, in which latter case the attraction should be stronger. In multipolar machines these tests should be applied to consecutive pole-pieces.

REMEDY. Reverse the connections of one of the coils in order to make the polarity of the pole-pieces opposite. The pole-pieces should be alternately north and south (when tested by compass).

CAUSE 5. **Open circuit.**

This may be due to (*a*) broken wire or faulty connection in machine; (*b*) brushes not in contact with commutator; (*c*) safety fuse melted or absent; (*d*) switch open; (*e*) external circuit open.

SYMPTOM. If the trouble is merely due to the switch or external circuit being open, the magnetism of a shunt dynamo may be at full strength, and the machine itself may be working perfectly; but if the trouble is in the machine, the field magnetism will probably be very weak.

REMEDY. Make very careful examination for open circuit; if not found, test separately the field-coils, armature, etc., for continuity, with magneto or cell of battery and electric bell. (See "Instructions for Testing;" also "Motor Stops," etc., Cause 3.)

A break, poor contact, or excessive resistance in the field circuit or regulator of a shunt dynamo will also make the magnetism weak and prevent its building up. This may be detected and overcome by cutting out the rheostat for a moment by connecting the two terminals of the field-coils to the two brushes respectively, care being taken not to make a short circuit.

A break or abnormally high resistance anywhere in the circuit of a series-wound dynamo will prevent it from generating, since the field-coil is in the main circuit. This may be detected and overcome by short-circuiting the machine for a moment in order to start up the magnetism.

Either of these two remedies by short-circuiting should be applied very carefully, and not until the pole-pieces have been tested with a piece of iron to make sure that the magnetism is weak.

CAUSE 6. **Brushes not in proper position.**

SYMPTOM. The magnetism and current are increased by shifting the brushes.

REMEDY. It often happens that the brushes are not set at the proper point; in fact, they may be set exactly wrong, so that the dynamo is incapable of generating any current whatever. This trouble is mainly due to the fact that the proper position for the brushes is not the same for all kinds of machines. Almost all ring armatures and many drum armatures require the brushes to be set opposite the *spaces* between the pole-pieces. But most armatures are wound so that the brushes must be set nearly 90° from this position, or opposite the center of the poles. Some multipolar machines have as many sets of brushes as there are pole pieces; while others have armatures that are cross-connected, or have the conductors arranged in series so that only two sets of brushes are required. Four-pole machines with only two brushes require them to be set at 90°; 6-pole machines, either 60° or 180°; 8-pole, either 45° or 135°; 10-pole, either 36°, 108°, or 180°; 12-pole, either 30°, 90°, or 150°; and 16-pole, either $22\frac{1}{2}$°, $67\frac{1}{2}$°, $112\frac{1}{2}$°, or $157\frac{1}{2}$°; and so on.

The fact is, that the proper position of the brushes depends upon the particular winding, internal connections, etc., and *no one should ever assume to know where to set the brushes* unless he is perfectly familiar with the particular type of machine. A blue print or other definite instructions should always be obtained and followed; and, if these are not available, the matter may be determined by careful trial. The proper position of brushes is the same for dynamos and motors, except that in the former the brushes are given a forward lead, that is, shifted a little in the direction of rotation, whereas motor brushes should be set a little backward. This shifting is necessitated by the armature reaction or the magnetizing effect of the armature current, which distorts the field magnetism.

The positions and number of brushes for each kind of armature are show in Fig. 67, which shows also the *arrangements of circuits* in each of the leading types.

A is the armature for the ordinary two-pole machine, and may be drum- or ring-wound. The current enters from the positive

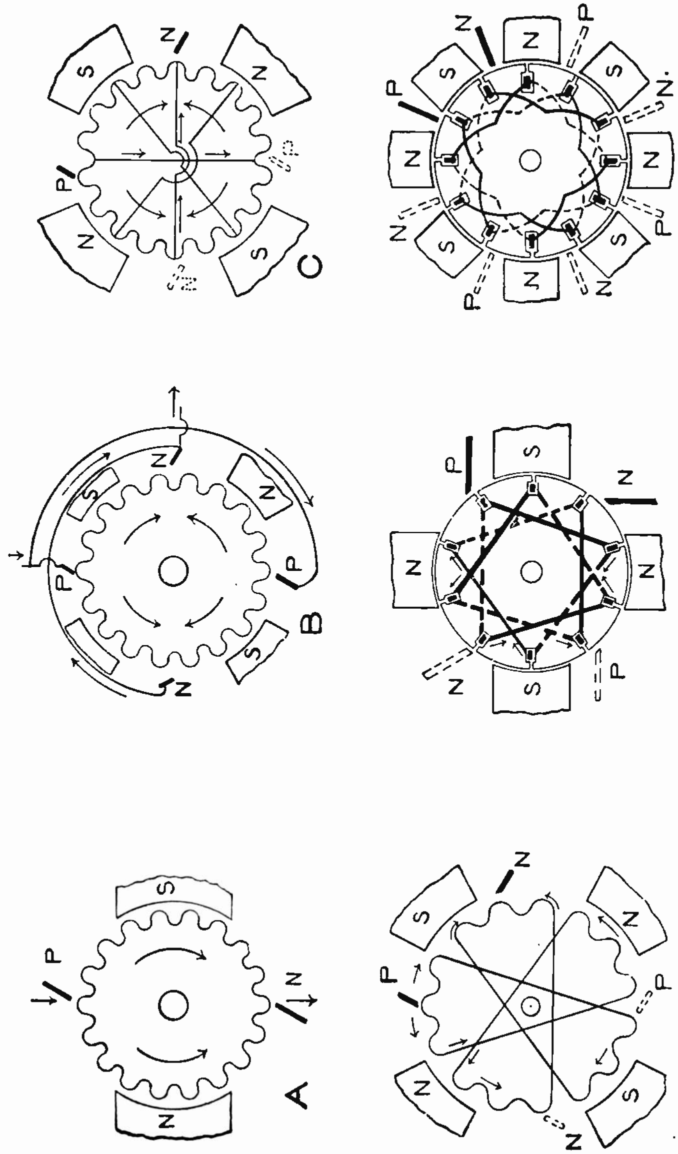


Fig. 67.

A = Two Pole, Two Circuit.
B = Four Pole, Four Circuit, Four Brushes in Multiple.
C = Four Pole, Four Circuit, Cross Connected, Two or Four Brushes in Multiple.

D = Four Pole, Two Circuit Ring, Two or Four Brushes in Multiple.
E = Four Pole, Two Circuit Drum, Two or Four Brushes in Multiple.
F = Eight Pole, Two Circuit Drum, Two, Four, Six, or Eight Brushes in Multiple.

brush, passes around both sides of the armature, and out through the negative brush. Hence this is called a "two-circuit" armature.

B is a plain armature used in a 4-pole machine. As there are here two more poles, it is necessary to use two more brushes to collect the current. This gives two brushes through which current enters, and two through which it leaves; consequently each pair of brushes must be joined in multiple in order to carry all the current to the mains.

C is a 4-pole armature in which the additional currents are carried across to the first pair of brushes by means of connections through the center of the armature. Therefore, the entire current may be taken off by these brushes; or two more may be added to divide the work, in which case they must also be connected in multiple to the first pair, as in case B above.

With either B or C, since there are two parts of the armature winding under the influence of different magnets, but running in parallel to the mains, it is evident that if the pressure of the current in one part of the winding is weaker than in the other, through inequality of the magnets or otherwise, it will short-circuit the other part of the winding and work badly.

This cannot occur in A, because both parts of the winding are influenced by the two ends of a single magnet.

D is a 4-pole armature in which the windings do not connect together in parallel but *in series*, thus overcoming the objection above. It has a ring-winding, and each coil is connected to the one diametrically opposite. An examination will show that though the poles alternate, the wire is all arranged so that the current flows in a single pair of circuits, as in A. This also permits of the use of larger wire and fewer turns, as they are connected in series instead of multiple.

E is a drum armature all in series, as in the case of D. Inspection will show that the actions of each of the four poles on all the bars harmonize, or cause the current to flow in the same direction.

To facilitate tracing the course of the current, the arrangement is represented with the smallest possible number of bars Many more are used in practice.

F is a series drum armature for eight poles. The principle is the same, but the limit of brush adjustment is smaller. The entire range from zero to full E. M. F. is covered by moving the brush one-eighth of the circumference.

As the winding is all in series, two brushes only are necessary; but as many more as desired may be added between the other poles, and then connected in multiple to the first ones. This is usually taken advantage of, because a single pair of brushes would become heated from carrying excessive current; but the difficulty of one part of the armature short-circuiting the other cannot occur, because *each part* of the winding is under the influence of all the poles.

X. VOLTAGE OF GENERATOR NOT RIGHT

VOLTAGE TOO LOW.

CAUSE 1. **Speed too low.** (See "Speed not Right.")

REMEDY. Increase speed of the prime mover, if possible; when this cannot be done, decrease the diameter of the driven pulley or increase the diameter of the driving pulley, preferably the latter.

CAUSE 2. **Field magnetism weak.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 8.)

CAUSE 3. **Brushes not in proper position.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 2.)

CAUSE 4. **Machine overloaded.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 1 and "Speed not Right," Cause 1); also increase field excitation, if possible.

CAUSE 5. **Short-circuited armature coil or coils.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 5.)

CAUSE 6. **Reversed armature coil or coils.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 5.)

VOLTAGE TOO HIGH.

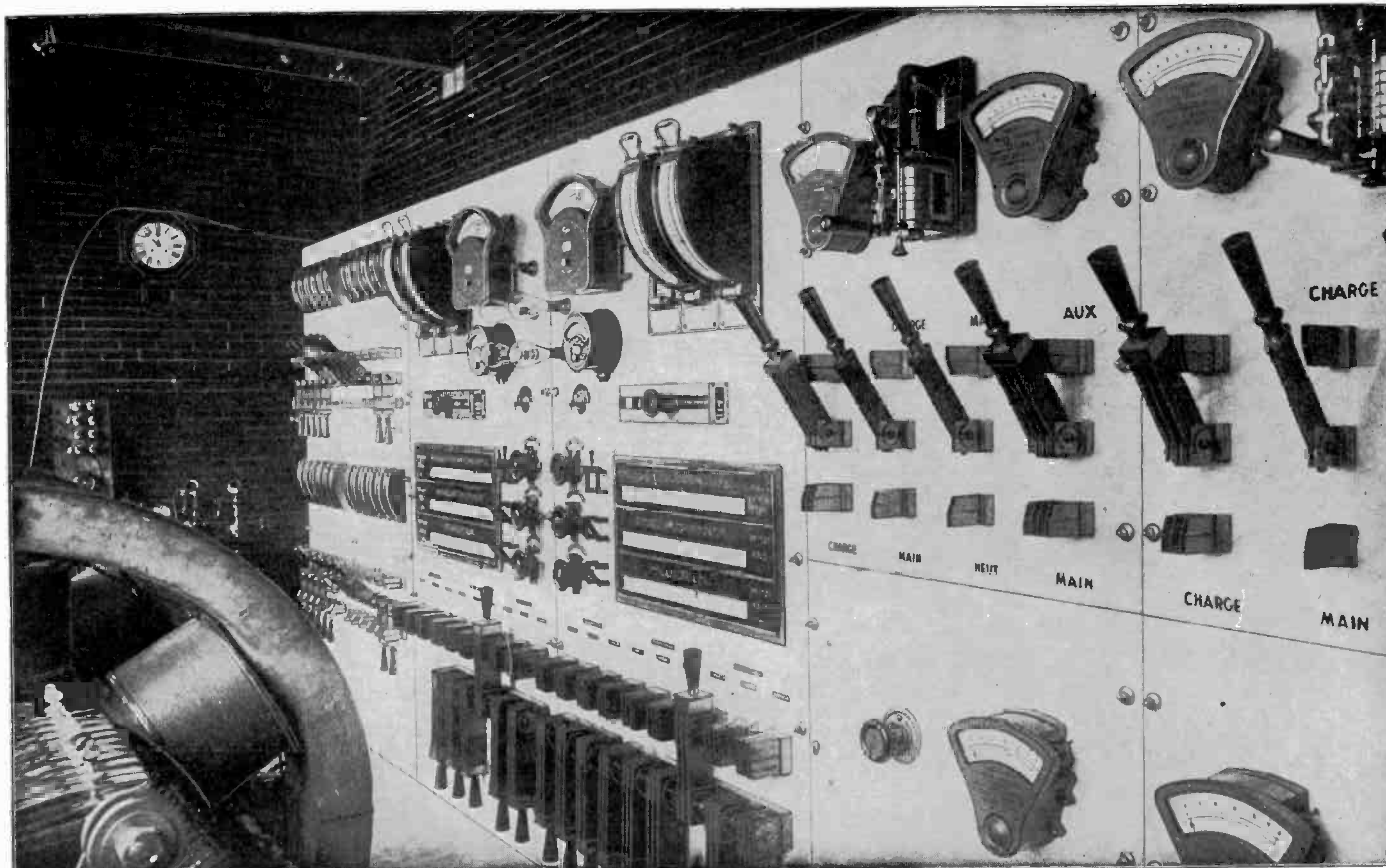
CAUSE 7. **Speed too high.**

REMEDY. Apply the reverse of treatment given in Cause 1.

CAUSE 8 **Field magnetism too powerful.**

REMEDY. Increase resistance of shunt field circuit, by means of a shunt field rheostat.

CAUSE 9. **Machine Compounds too much.**
REMEDY. Decrease resistance of series field shunt.
(See Compound-wound Dynamos, page 25, Part I.)



Storage Battery Switchboard

Detroit Edison Company

STORAGE BATTERIES

Storage or secondary batteries, also called *accumulators*, consist of cells in which a chemical change is brought about by passing an electric current through them, thereby rendering them capable of giving back electrical energy, or *discharging*, until they return to their original chemical condition.

Ordinarily a storage battery consists essentially of two sets of plates suspended in a chemical solution. The plates are of metal or metallic oxide, and the solution is incapable of acting upon them until an electric current is passed from one set of plates to the other. This current decomposes the electrolyte, one of its ions or constituents going to one set of plates and the remaining ion or constituent to the other. Thus two chemical elements or compounds are formed, having a tendency to combine or react; and when combination or reaction occurs on closing the circuit, the energy evolved appears as an electric current, which flows in a direction opposite to that of the charging current. This flow of current continues until the cell is restored to its original condition; when this occurs, the cell is said to be *discharged*.

A *Primary Cell* is one in which electrical energy is produced by the chemical action of one or two solutions on the plates of the cell. When the solutions or plates are exhausted, they are not restored to their original condition by the passage of an electric current in the same cell; but it is possible to regenerate or recover the solutions and metal by treating them electrolytically or chemically in other vessels.

An *Electrolyte* is a chemical compound capable of acting as an electrical conductor, and while so acting, undergoes chemical decomposition. This phenomenon is called *electrolysis*.

For example, when hydrochloric acid is decomposed by electrical energy, it is decomposed into the elementary gases hydrogen (H) and chlorine (Cl). The chemical formula for this action is,

$$2HCl + \text{Electrical energy} = Cl_2 + H_2.$$

When sulphuric acid is electrolyzed, it is at first split up into hydrogen (H_2) and the radical sulphion (SO_4); the latter combines with the water of solution present and reforms sulphuric acid (H_2SO_4), oxygen being liberated. The chemical equations for the above primary and secondary reactions are:

$$2H_2O + 2H_2SO_4 + \text{Electrical energy} = 2H_2 + 2SO_4 + 2H_2O$$

$$2H_2 + 2SO_4 + 2H_2O = 2H_2 + 2H_2SO_4 + O_2$$

The modern theory of electrolysis is based upon the existence of free ions in every electrolyte. For example, a metallic salt dissolved in water is partially ionized; that is, a certain percentage is dissociated into the metal constituent and the other component part of the salt. These carry respectively positive and negative electrical charges, which are neutralized when the ions reach the negative and the positive plates of the battery. The various ions have definite velocities at which they travel or migrate through the electrolyte. The conductivity of electrolytes is entirely due to the presence of these ions, as the non-ionized portion does not conduct.

In 1802, soon after the invention of the primary cell by Volta, Gautherot demonstrated the fact that platinum wires, after being used to electrolyze saline solutions, were able to produce secondary currents. Volta, Ritter, Davy, and others noted similar effects, the phenomenon being what is commonly called *polarization*. In 1859, Planté undertook a series of experiments with the object of studying and magnifying this effect, and finally developed the Planté type of storage battery. Many of the most successful types of storage batteries of the present day are based upon Planté's invention.

Types of Storage Batteries:

Planté;
Faure;
Combination of Planté and Faure;
Non-lead.

PLANTE TYPES OF BATTERY

The Planté cell was originally made by placing two plates of metallic lead in a vessel containing dilute sulphuric acid. These plates were connected to an electric generator, and a current sent through the cell, which decomposed the electrolyte and oxidized the positive plate. The cell was then discharged; but the energy obtained was very small, since the action was confined to the immediate surface of the plates. By repeated charging and discharging, first in one direction and then in the other, the oxidation penetrated deeper and deeper into both plates, thus increasing the storage capacity of the cell.

The chief difficulty with the original Planté battery was the great length of time and consumption of energy required for *forming* the plates, which process, as just explained, consists in converting the surface of the plates into active materials, by repeated charging and discharging. Planté found that he could hasten this forming process by pickling the plates in dilute nitric acid, then washing them in a 10 per cent sulphuric acid solution, after which they were electrically formed. Other methods of facilitating the forming process, or increasing the active surface, are given later.

In 1881, Faure devised the method of *pasting* the lead oxide or active material directly upon the plates. This largely avoids the tedious forming process; but the plates thus produced are not so durable as the Planté elements, being more likely to disintegrate, because the paste is not an integral part of the plate.

General Principles of the Storage Battery. Any primary battery will act as a storage battery provided its chemical action is reversible. The ordinary gravity cell, for example, may be regenerated by sending a current through it in the direction opposite to that produced by it. The zinc sulphate and the metallic copper are thus reconverted into metallic zinc and sulphate of copper respectively, the chemical action being

$$ZnSO_4 + Cu + \text{Electricity} = Zn + CuSO_4,$$

which is exactly the reverse of the action in the primary cell. There are, however, practical difficulties in the continued recharging of a spent gravity cell, due to the ultimate mixture of the sulphate solutions so that the copper salt will reach the negative electrode, where it is deposited and sets up destructive local action. In some forms of primary cells, the chemical action liberates a gas that escapes, so that the action in these cases is obviously irreversible.

Chemical Action in Lead Storage Batteries. The exact nature of the chemical changes which occur in lead batteries, is not yet fully established. Planté believed the charging action to consist in the formation of peroxide of lead (PbO_2) on the positive plate, and metallic lead on the negative, which were converted into lead oxide (PbO) on both plates by the discharge. It was shown later by Gladstone and Tribe, and corroborated by subsequent investigations, that the formation of lead sulphate plays an important part.

This reaction may be represented as follows:

	Positive Plate		Electrolyte		Negative Plate
Charged Condition	PbO_2	+	$2H_2SO_4$	+	Pb
Discharged "	$PbSO_4$	+	$2H_2O$	+	$PbSO_4$
Charging Current			⟶		
Discharging Current			⟵		

According to the above equations, the active material on both plates is converted into lead sulphate when the battery is discharged. The reasons for believing this to occur are: *first,* chemical analysis shows that lead sulphate exists in the discharged plate; *second,* the density of the electrolyte decreases during the discharge of the cell, corresponding to the consumption of sulphuric acid and the formation of water, as shown in the above reactions; *third,* on thermochemical grounds, the combination of lead and oxygen as lead oxide (PbO) does not evolve sufficient energy to account for the E. M. F. produced.

Storage Batteries of the Planté Type. It was noted that the first difficulty met with in the making of Planté plates was the inordinate length of time and cost of current necessary to form them; and it was also shown how Planté treated them with nitric acid to hasten this action. Other methods are used to facilitate the formation; these are tabulated as follows:

1. *Mechanical Action:* Laminated plates, made up of lead ribbons. The surface of the plate is grooved with some forming tool. Built up of lead wires, etc.
2. *Chemical:* Treating the plates in some pickling bath, to produce initial oxidation.
3. *Electrolytic:* Forming a plate of some compound of lead or an alloy, and either reducing the compound or eating the foreign matter away, leaving a porous lead plate.

Gould Storage Battery. This battery is made by the Gould Storage Battery Company, of New York, and the plates are produced by a combination of the first and third methods. The plates or blanks are placed in steel frames and given a reciprocating motion between two revolving shafts which carry grooving discs, giving the plates a surface as shown in Fig. 1. No lead is removed by this process; but the surface is ploughed up. It is then subjected to electro-chemical treatment to form the active material. The types manufactured range in size from a cell of three plates 3 inches by 3

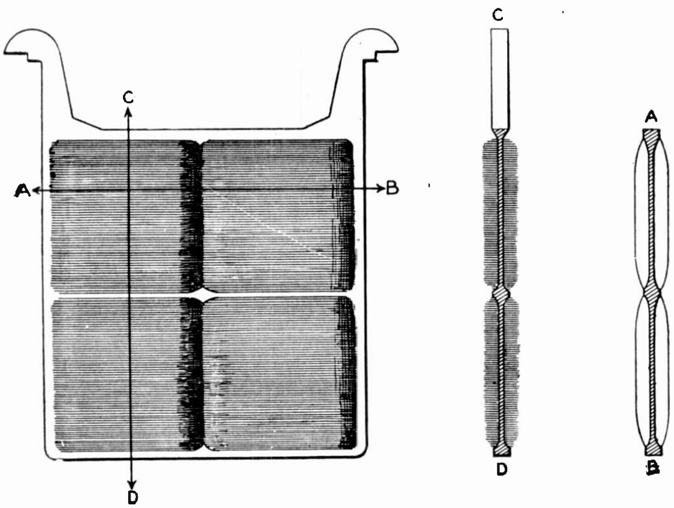


Fig. 1. Gould Storage-Battery Plate.

inches, to one of 105 plates, each 15.5 inches by 31 inches; and in capacity from 5 ampere-hours in the smallest size to 17,000 ampere-hours in the largest.

Bijur "High-Duty" Battery. Batteries of this type are manufactured by the General Storage Battery Company, of New York. They are made in standard sizes ranging from 6 ampere-hours to 12,688 ampere-hours, the smallest cell being made up of two plates, one positive and one negative, each 3 inches by 3 inches, suspended in a small glass jar. The largest type comprises 67 plates, each 15¾ inches by 31¾ inches, suspended in a lead-lined tank. Some of the standard sizes manufactured are shown in Table I.

Both positive and negative plates are of the Planté type, and are of the same general design, Fig. 2. Each plate consists of the grid or supporting frame, made up of pure lead containing a small percentage of refined antimony, producing a rigid inoxidizable supporting and conducting member for the active lead. In the openings of this rigid framework are welded gratings or *grills* of pure lead. Each grill consists of vertical strips supported by heavier horizontal

TABLE I
Data, Bijur High-Duty Battery

Type		BB	DDS	C	D		E		F		G		K		L	
Size of Plate (inches)		3x3	4⅛x8¼	3x5½	5½x5⅝		8⅛x8		10⅝x11		15¾x16		18¼x18⅝		15¾x31¾	
No. of Plates		2	2	7	5	11	5	15	7	19	11	57	21	71	19	67
Discharge Rate (in Amperes)	8 hrs.	¾	3	4.5	6	15	12	42	36	108	120	672	360	1,260	432	1,584
	5 "	1	4.2	6.5	8	21	17	59	50	151	168	942	504	1,760	605	2,218
	3 "	1½	6	9	12	30	24	84	72	216	240	1,344	720	2,520	864	3,168
	1 "	3	12	18	24	60	48	168	144	432	480	2,688	1,440	5,040	1,728	6,336
Normal Charge Rate		¾	3	4.5	6	15	12	42	36	108	120	672	360	1,260	432	1,584
Outside Dimensions of Glass Jar	Width	2⅜	3⅛	6¼	4¾	9⅛	5¼	13½	7⅜	....	....	....	....	....	....	....
	Length	3⅞	6⅛	6¼	7⅞	8⅛	9	9½	12¾	....	....	....	....	....	....	....
	Height	5⅜	12	10	10	10	12	12	16	....	....	....	....	....	....	....
Outside Dimensions of Lead-Lined Tank	Width	....	....	....	....	....	....	....	....	21¾	15⅛	54⅞	25	66½	23½	63¼
	Length	....	....	....	....	....	....	....	....	15	19¾	21½	24½	24½	22	22
	Height	....	....	....	....	....	....	....	....	17⅝	26	27½	31½	31½	48⅞	49⅞
Outside Dimensions of Glass Tanks	Width	....	....	....	....	....	....	....	....	20¼	....	....	....	....	....	....
	Length	....	....	....	....	....	....	....	....	13	....	....	....	....	....	....
	Height	....	....	....	....	....	....	....	....	18¼	....	....	....	....	....	....
Weight of Complete Cell, Incl. Acid and Containing Vessel (Pounds)		5⅝	19	25½	36	75	61	161	152	516 466	603	2,670	1,486	4,706	1,947	6,070

STORAGE BATTERIES AND SECTION OF TELEGRAPH TABLE
U. S. Telephone Company, Cleveland, Ohio.
The Dean Electric Co.

members which act as I-beams to stiffen it laterally, and which, with the vertical ribs, form the oxide cells. The active material is formed from the grill expanding as it grows in each of the minute oxide cells, thus locking itself in place.

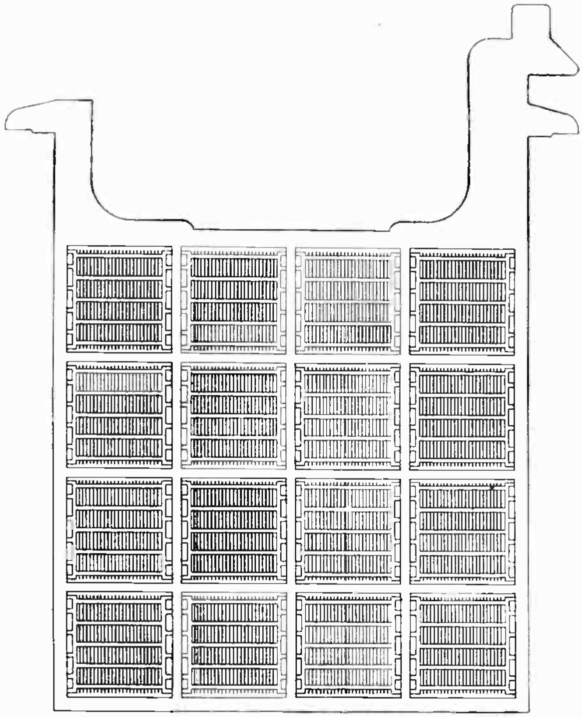


Fig. 2. Bijur High-Duty Battery Plate.

The grills have no central web; and, being open structures, a through - and - through circulation of electrolyte is obtained. The grills are held on both sides by the alloy frame to which they are welded.

A suitable space is provided between each end of the grill and grid to allow for vertical elongation, while the spacing of the strips accommodates the lateral expansion. The grills are therefore free to expand in every direction, thus avoiding the tendency to set up strains in the plates, which might cause them to buckle.

In welding the grills to the grid or frame, a heat process only is employed; no solder, flux, or foreign substance of any kind is used. Since the grill is an open structure, grown from which is a very thin layer of active material, and as this active material does not entirely close the small oxide cell, the gases evolved at high rates of charge have ready means of escape. This results in lower E. M. F.'s required for charging, and the acid diffusion thus obtained also maintains the E. M. F. when discharging at excessive rates.

With the closely adherent layers of active material in intimate contact with the metallic lead, and the absence of concentration of the electrolyte in the pores of the active mass, due to the diffusion, excessive sulphating does not occur.

The loss of negative capacity, due to shrinkage of the active material into a metallic mass, is avoided in this particular plate, by a special treatment which the plates undergo.

FAURE TYPES OF BATTERY

The difficulty with this type is the tendency to disintegrate or buckle. Various means intended to increase the permanency of adhesion of the active material have been suggested, of which the most important are as follows:

1. Plates are grooved, roughened, or *pocketed*.
2. Plates are entirely perforated, the holes being circular, or rectangular, and varying in cross-section; some have a uniform section through the grid

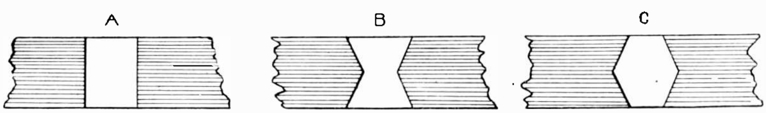


Fig. 3. Different Cross-Sections of Faure Plate Perforations.

(*A*, Fig. 3); others are contracted at the center (*B*); and again they have been expanded at the center of the grid (*C*).

3. The active materials may be enclosed in either a conducting or a non-conducting cage.
4. The plates may be made up entirely of active material.

Faure cells usually have a greater weight efficiency than those of the Planté type, because the proportion of active material may be made greater.

E. P. S. Battery. This is one of the most important of the Faure type, its name being the initials of the Electric Power Storage Company by which it is manufactured in England. It is sometimes called the "Faure-Sellon-Volckmar" cell, being based upon the work of these and several other inventors.

The plates consist of lead grids cast in an iron mould, and have the cross-section shown in Fig. 4. The later types have a thin perforated strip of lead running across each opening midway between the edges. The holes *A* in the grid are completely filled with a paste of red lead or minium (Pb_3O_4) and dilute sulphuric acid, for the positive;

while the paste for the negative consists of minium, or litharge (PbO), and dilute sulphuric acid, or a magnesium sulphate solution. These pastes are pressed into the grids and dried.

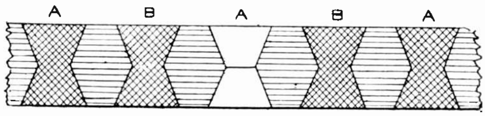


Fig. 4. Section of E. P. S. Battery Plate.

The plates are hardened in dilute sulphuric acid, after which they are ready for forming. A strong current of 48 hours' duration is required for the positive plate, and twenty-four hours is required for the formation of the negative plate. To prevent short-circuiting after the cells are set up, the plates have glass rod separators placed between them.

The E. P. S. batteries are made in many different sizes and forms, of which the L type is a good example, being used extensively in isolated plants. Data of this type are given in Table II.

TABLE II

Data, E. P. S. Accumulator, L Type

No. of Plates	Maximum Normal Charge or Discharge Rate	Capacity (Ampere-Hours)	Approximate External Dimensions			Weight Complete with Acid (Wooden Cell)
			Length	Width	Height	
7	13 amperes	130	5½ in.	13½ in. for wooden and 12 in. for glass cell	18 in. for wooden and 13½ in. for glass cell	74 lbs.
11	22 "	220	8 "			107 "
15	30 "	330	9½ "			143 "
23	46 '	500	14½ "			228 "
31	60 "	660	19 "			286 "

One of the smaller types of the E. P. S. battery is used extensively in England in electric vehicle work.

Exide Battery. This type is manufactured by the Electric Storage Battery Company, of Philadelphia, Pa., chiefly for electric vehicle duty. The plates are of the Faure type, and consist of lead-antimony grids (about 5 per cent antimony) pasted with oxides of lead.

The grid for the positive plate is of the cage type, consisting of thin vertical ribs the edges of which are flush with the faces of the plate and connected by small bars of a triangular cross-section; the bars on one face are staggered with respect to those on the other side. This finished form is then pasted up with red lead (Pb_3O_4), and formed in the usual way; the thickness of the finished plate is about $\frac{7}{32}$ inch. From this description it is evident that the plate is made up in accordance with method 3 described on page 8, the enclosing cage being of conducting material. The active material is in the form of rectangular pencils extending from the top of the plate to the bottom. The thin, flat ribs are on two sides of these pencils; and the triangular cross-pieces are imbedded in the other two sides which constitute the faces of the plates. The Exide cell is shown in Fig. 5.

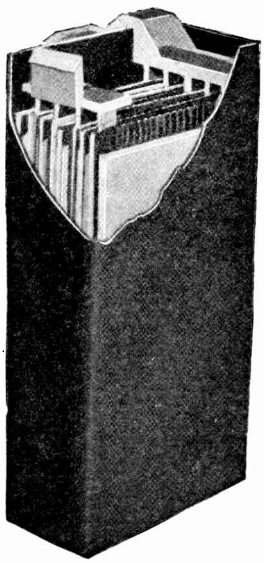


Fig. 5. Exide Battery.

The negative plate consists of a thin antimony-lead sheet, with a comparatively heavy frame of cast lead. The body of the sheet is perforated at regular points, about half an inch apart. These perforations, being made by a tool which does not remove the material, are not actual punchings; but are simply holes torn in the plate, leaving the surrounding material in ragged projections which curve back towards the sheet, forming, as it were, a series of hooks. These projections are formed on both sides of the plates.

The grid is then pasted with litharge (PbO) on both faces; it is held to the plate by the "hooks," as well as being riveted by passing through the holes which the projections surround. The thickness of this finished plate is about $\frac{3}{16}$ inch.

When assembled, the plates are placed in rubber jars of dimensions shown in Table III, and separated from one another by wooden partitions. In addition, a perforated rubber sheet is placed against the faces of the positive plates.

TABLE III

Data, Exide Cells*

Type	M. V.							P. V.			
No. of Plates.......	7	9	11	13	15	17	19	5	7	9	11
Discharge 4 Hours (Amperes)	21	28	35	42	49	56	63	12	18	24	30
Size of Plates—											
Length (inches) ...	5¾	same	same	same	same	same	same	4$\frac{13}{16}$	same	same	same
Height (inches) ...	8⅝	same	same	same	same	same	same	8⅝	same	same	same
Outside Measures of Rubber Jars—											
Width (inches)	2$\frac{7}{16}$	3¼	4¼	4$\frac{11}{16}$	5$\frac{3}{16}$	6¼	7$\frac{3}{16}$	1$\frac{13}{16}$	2$\frac{9}{16}$	3¼	4¼
Length (inches)...	6$\frac{3}{16}$	same	same	same	same	same	same	5$\frac{5}{16}$	same	same	same
Height (inches)...	11½	same	same	same	same	same	same	11½	same	same	same
Weight (lbs.)—											
Elements	15¾	20¾	25½	30¼	35	40	44¾	9¼	13¼	17¼	21⅛
Electrolyte	2½	3½	4½	6¼	7	8	8¾	1½	2¼	3	4½
Complete Cell......	19½	25½	31½	38½	44½	50	56	11½	17½	21½	27½

*Note.—For data on the "Express Type" of Exide cell, see literature of the Electric Storage Battery Company, Philadelphia, Pa.

The *brougham* or *hansom* battery of this type of cells consists of 44 cells of TV-9 size, having four positive and five negative plates. The weight of this outfit complete with tray is about 1,659 pounds; the capacity, 156 ampere-hours (4 hour, 39 ampere rate); the average voltage during discharge, about 1.98 volts per cell, or 87 volts for 44 in series; the total watt-hour output being therefore 13,572, or 8.18 per pound of battery complete including trays.

COMBINATIONS OF PLANTE AND FAURE TYPES

Chloride Battery. In the form which was manufactured until recently by the Electric Storage Battery Company and allied companies in England, France, and Germany, the Chloride Battery is a compromise between the Plante and Faure types, the positive being a Plante type and the negative of practically the Faure type.

The principal features in the manufacture of this battery are as follows: The first step is the production of finely divided lead, which is made by directing a blast of air against a stream of the molten metal, producing a spray of lead which, upon cooling, falls as a powder. The powder is dissolved in nitric acid (HNO_3) and precipitated as lead chloride ($PbCl_2$) on the addition of hydro-

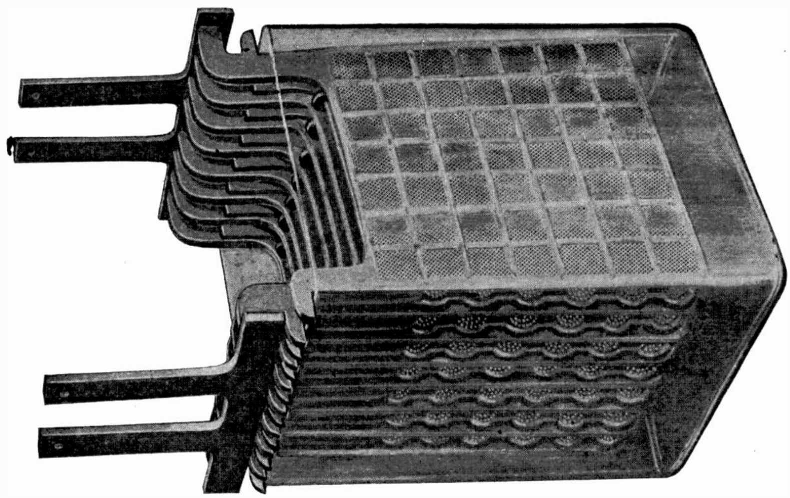
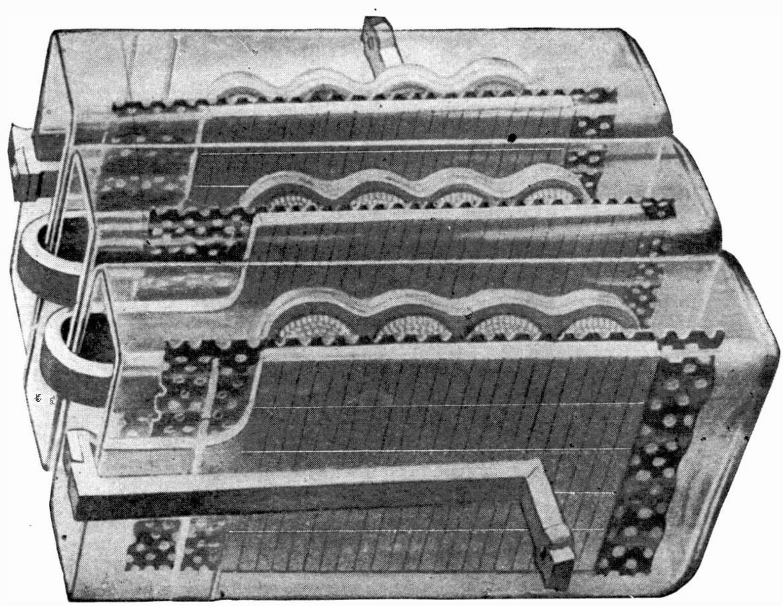


Fig. 6. The Chloride Battery.

Type F—15 Plates in Glass Jar.



B. T.—Couples in Glass Jars.

chloric acid (HCl). This chloride, washed and dried, forms the basis of the material which afterwards becomes active in the negative plate. The lead chloride is mixed with zinc chloride and melted in crucibles, then cast into small pastiles or tablets about $\frac{3}{4}$ inch square and of the thickness of the negative plate, which, according to the size of the battery, varies from $\frac{1}{4}$ inch to $\frac{5}{16}$ inch. These tablets are then put in moulds and held in place by recesses, so that they clear each other by .2 inch and are at the same distance from the edges of the mould. Molten antimonious lead is then forced into the mould under about 75 pounds pressure, completely filling the space between the tablets. The result is a solid lead grid, holding small squares of active material. The lead chloride is then reduced by stacking the plates in a tank containing a dilute solution of zinc chloride, slabs of zinc being alternated with them. This assemblage of plates constitutes a short-circuited cell, the lead chloride being reduced to metallic lead. The plates are then thoroughly washed to remove all traces of zinc chloride.

In the new form of negative plate which has replaced the chloride type just discussed, the negative consists of a pocketed grid, the openings being filled with a litharge paste; it is then covered with perforated lead sheets, which are cast integral with the grid.

The positive plate is a firm grid, composed of lead, alloyed with about 5 per cent of antimony, about $\frac{7}{16}$ inch thick, with circular holes $\frac{25}{32}$ inch in diameter, staggered so that the nearest points are .2 inch apart. Corrugated lead ribbons $\frac{7}{16}$ inch wide are then rolled up into close spirals $\frac{25}{32}$ inch in diameter, which are forced into the circular holes of the plate. These spirals are electro-chemically formed into active material. The process requires about thirty hours; at the same time, the spirals expand so that they tend to fit still more closely in the grids. This form of positive is that known as the *Manchester Plate.*

Recent types of "Chloride accumulator" are shown in Fig. 6. In setting up the cells, the plates are separated from one another by thin wood partitions having vertical grooves to facilitate the rising of the gases. These separators are stiffened by split wooden pins slipped over them. Sometimes glass tubes are used as separators.

Table IV gives data of the various types and sizes of cells. To save space, only the smallest and largest sizes of each type are given;

TABLE IV
Data, Chloride Battery

Types	B	C		BT	CT	PT	D		E		F		G		R*		H	
Size of Plate, inches...	3x3	4⅜x4		3x4	5x5	8¾x5	6x6		7¾x7¾		11x10½		15½x15⅛		18⅝x18⅝		15½x31	
No. of Plates....	3	3	7	2	2	2	3	13	5	15	9	27	11	75	25	75	21	75
Discharge in Amperes — For 8 hrs.	⅝	1¼	3¾	¾	1½	3	2½	15	10	35	40	130	100	740	360	1,110	400	1,480
Discharge in Amperes — 5	⅞	1¾	5¼	1	2	4¼	3½	21	14	49	56	182	140	1,036	510	1,550	560	2,072
Discharge in Amperes — 3	1¼	2½	7½	1½	3	6	5	30	20	70	80	260	200	1,480	720	2,220	800	2,960
Discharge in Amperes — 1	....	....	....	....	....	....	10	60	40	140	160	520	400	2,960	1,440	4,440	1,600	5,920
Normal Charge Rate..........	⅝	1¼	3¾	¾	1½	3	2½	15	10	35	40	130	100	740	360	1,110	400	1,480
Outside Dim. of Glass Jars (inches) — Width	2½	3½	5¼	1¾	2¼	2½	3¼	11	5½	11	9	No glass jars for these large sizes.						
Outside Dim. of Glass Jars (inches) — Length	4	5¼	5¼	3¾	6¼	6	7⅞	8¼	9⅛	9⅛	12⅝							
Outside Dim. of Glass Jars (inches) — Height	6½	7¼	7¼	6¾	8	12	9½	9½	11⅜	11⅜	17							
Outside Dim. of Lead-Lined Wooden Tanks — Width	....	....	....	....	....	....	....	....	....	....	13⅜	28⅜	15⅛	69⅞	24¾	24¾	25⅛	69⅞
Outside Dim. of Lead-Lined Wooden Tanks — Length	....	....	....	....	....	....	....	....	....	....	15	15	19¾	21½	28⅜	69⅞	21½	21½
Outside Dim. of Lead-Lined Wooden Tanks — Height	....	....	....	....	....	....	....	....	....	....	20¼	20¼	26	27⅞	31½	32½	48¾	49¾
Weight of Cell Complete (lbs.)	5½	10½	19	3½	7½	13½	19½	64	48¾	112	175	....	....	....	....	....	....	...
Ditto. Lead-Lined Tanks...	....	....	....	....	....	....	....	....	....	....	250	615	561	3,260	1,641	4,616	1,885	5,986

* This size of cell is listed by its manufacturers on the 6, 2 and 1 hour rates; but for purposes of comparison it is brought to the same basis as the other sizes.

but in all cases intermediate sizes are made with every odd number of plates. The capacities, weights, etc., are of course nearly proportional to the number of plates.

The smaller sizes are provided with either rubber or glass jars, and the larger ones, from F up, with lead-lined tanks.

Tudor Cell. This type is very extensively used in Europe, and to some extent in this country, although it is no longer manufactured here. The American patent rights are controlled by the Electric Storage Battery Company.

The plates consist of rolled, grooved sheets as shown in Fig. 7, *A* being the hollows or grooves into which the paste is set, and *B* the lead frame. The thickness of the plate between opposite grooves is about .12 inch for the positive and about .06 inch for the negative. The width of grooves on the positive plate is also about .12 inch, while on the negative it is about .08 inch. The grooves are first coated with a thin layer of peroxide of lead (PbO_2) by electrolysis, and then packed with the oxides as required; the plates are then rolled to *fix* the paste. This treatment of the grid with an electrolytic bath before applying the active material, is covered by United States patent No. 413,112.

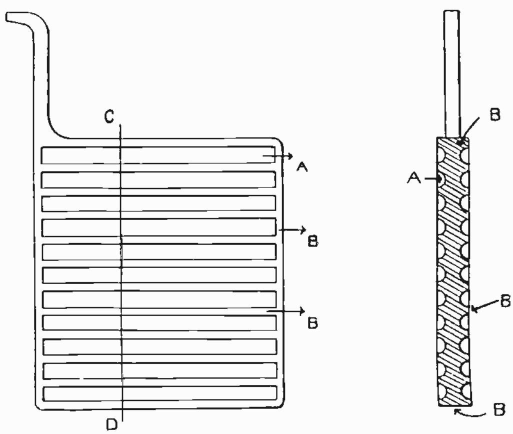


Fig. 7. The Tudor Battery Plate.

TABLE V
Tudor Cells

Type	Available Capacity	Maximum Current (in amperes)		Dimensions of Cells (in centimeters)			Total Weight
	Amp.-Hours	Charge	Discharge	Length	Width	Height	Kgms.
I	26	6	8	12	21	35	10
V	91	21	28	30	21	35	30
X	270	54	72	42	42	55	110
XIV	630	126	168	74	42	55	230

In addition to the sizes given in this table, all the intermediate sizes are made.

Lithanode. Mr. Desmond Fitzgerald has made storage batteries with a positive plate consisting entirely of active materials made up of litharge (PbO) mixed with ammonium sulphate $(NH_4)_2 SO_4$ which he pressed into the required shapes. This plate is converted into peroxide by chemical treatment. The negative consists of the ordinary lead plate. While this cell has an exceedingly high weight efficiency, it is not of much commercial importance, though used considerably in laboratory work.

It is the tendency in Europe to make the positive plate of the Planté form, and the negative of the Faure or pasted type. The reason for this is that the Planté form is hard to make; and as the activity is small on the negative, the pasted plate is good enough.

The practice in lead batteries is to make the negative plate of greater capacity than the positive, as the charging and discharging of a cell in service tends to produce or form more active material on the positive plate, whereas the negative plate is made to decrease, so that allowance for this is made as above stated. A still further allowance is made to cover this action, by always having one more negative than positive plate in a cell.

Storage Batteries Containing Metals Other than Lead. It has already been stated that almost any primary cell will act more or less as a secondary cell; as, for example, the common gravity battery. A great many have been devised in which the lead in one or both of the plates has been replaced by some other metal. For example, Reynier made the negative plate of zinc instead of lead, this zinc in discharging being converted into zinc sulphate, which dissolved in the electrolyte. The substitution of zinc for lead secures an increase in initial E. M. F. from 2.2 to 2.5 volts, and also allows of a considerable reduction in weight, since for the storage of a given amount of energy the weight of the zinc required is much less than that of the equivalent lead. A difficulty with this type of cell is the formation of *trees* of zinc on the negative plate during the charging process, which are likely to fall off or extend across to the positive plate, thus short-circuiting the cell.

Another difficulty is the difference in density of the solution between the top and bottom of the plates, the tendency being to exhaust the zinc sulphate from the upper portion of the liquid during charging. In order to avoid this trouble, the plates have been arranged horizontally, so that the density would be uniform for each plate; but the difficulty then arises that the gases which form to a certain extent in almost all batteries collect between the plates and interfere with the chemical action and the passage of the current.

A similar type of cell has been manufactured by the Union Electric Company of New York, in which the negative plates consist of thin sheet copper covered with an amalgam of zinc, and the positive plates are made up of laminæ of lead held together by leaden rivets and perforated with numerous small holes, these positives being formed by the Planté process.

Waddell-Entz Accumulator. The copper alkali-zinc primary battery of Lalande, Chaperon and Edison being reversible in action, can be used as a storage battery. Waddell and Entz have constructed accumulators on this principle. When discharged, the positive plate consists of porous copper; on charging, the electrolyte is decomposed, metallic zinc being deposited on the negative plate; the porous copper of the positive plate is oxidized, and the liquid becomes converted into a solution of caustic potash (potassium hydrate).

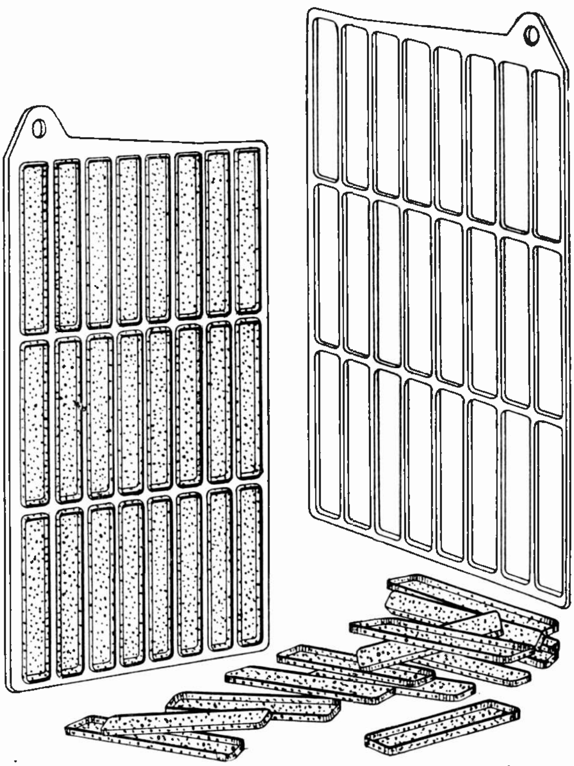


Fig. 8. Plates and Receptacles of the Edison Cell.

This storage battery was formerly used with considerable success for traction purposes; but its E. M. F. is so low, being only about .7 volt, that it would require 170–180 cells for the ordinary 110-volt electric-lighting circuit, allowing for loss of potential in the battery and conductors. This number is three times as great as is required with the lead battery. This is a serious objection to this or any other low-voltage cell.

Edison Storage Battery. The standard cells of this type are 13 inches high, 5.1 inches wide, and vary in length according to their rating, the various capacities being obtained by simply increasing the number of plates. The positive and negative plates are alike in appearance, and consist of rectangular grids, of nickel-plated iron, each about 9½ by 5 inches by .025 inch, punched with three rows of rectangular holes, eight holes to the row (Fig. 8), each hole being filled by a shallow perforated box of nickel-plated steel, the perforations being very fine, about 2,500 per square inch.

The difference between the positive and negative plates is entirely in the contents of the perforated receptacles; those for the positive plate containing a mixture of oxide of nickel and pulverized carbon, the latter being employed to increase the conductivity of the active material. The compartments of the negative plates contain a finely divided oxide of iron and pulverized carbon. When filled, these receptacles are secured to the grid by placing them in the openings of the same, and subjecting the assembled plate to a pressure of about 100 tons, which expands the pockets and fixes them firmly in the grid. A set of assembled plates as employed in a complete battery, is shown in Fig. 9.

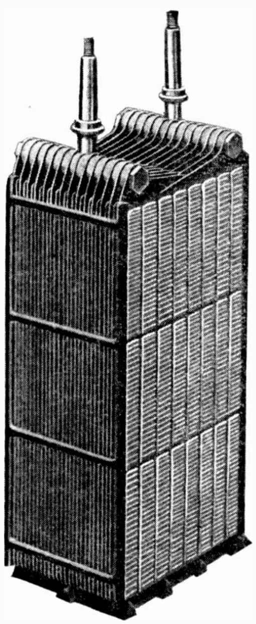


Fig. 9.
Complete Edison Cell.

The electrolyte consists of a 20 per cent solution of caustic potash, which, however, undergoes no chemical change during the process of charge or discharge, acting simply as a conveyor of oxygen between the plates. The charging current, entering at the positive plates, oxidizes the nickel compound to the peroxide state, and reduces the iron compound in the negative plates to a spongy iron mass. The containing vessel consists of nickel-plated steel; and the plates are strong individually and close together, being separated by thin strips of vulcanized rubber, thus forming a compact mass. The terminals of the plate pass through the cover of the cell, from which they are insulated by vulcanized rubber bushings.

The electrical features of the Edison cell are as follows:

Average voltage of charge at normal rate, 1.68.
Average voltage of discharge at normal rate, 1.24.

A set of charge and discharge curves of a 180-ampere-hour cell is shown in Fig. 10. This battery is rated at 30 amperes for a period of six hours. The various cells have a weight efficiency of 11.5 to

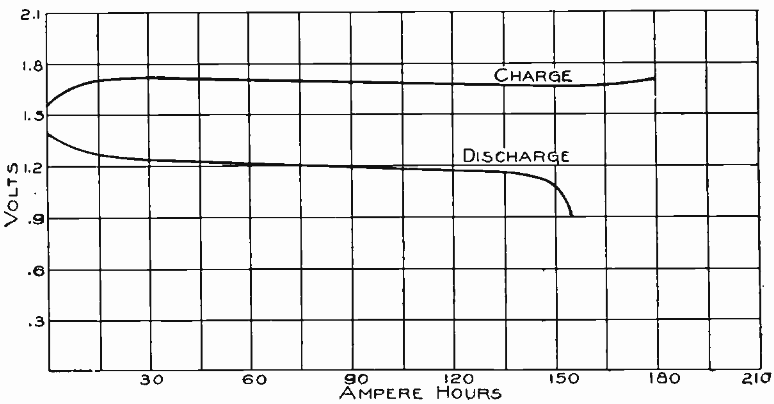


Fig. 10. Charge and Discharge Curves of Edison Cell.

13.2 watt-hours per pound, depending upon the size. The watt efficiency under normal working conditions is about 60 per cent. The charging and discharging rates are alike, and cover wide ranges. A cell may be charged at a high rate in one hour, without apparent detriment except lowering the efficiency slightly. It is not appreciably influenced by temperature changes, and may be fully discharged to the zero-point of E. M. F., or even charged in the reverse direction, and then recharged to normal conditions, without suffering loss in storage capacity or other injury. The best results are obtained when twice as many positive as negative plates are employed; and the standard cells are made up on this basis. This type is intended especially for electric automobile service, by virtue of its high weight efficiency and its ability to endure rough mechanical as well as electrical treatment. The same qualities would also adapt it to portable electric-lighting purposes.

MANAGEMENT OF STORAGE BATTERIES

In describing the handling of storage batteries, the various types of lead cells will be considered, as they constitute a very large majority of the cells in commercial use.

Battery Room. In the installation of a battery, the first point to be considered is its location. The room for this purpose should be dry, well ventilated, and of a moderate temperature; otherwise, not only will the evaporation of the electrolyte be excessive, but if the temperature be very high, the plates themselves will be affected and their life shortened. The floor, walls, and ceiling must be of some acid-proof material, brick or tile being preferable, and the floor so made as to drain readily, an outlet being provided to the drainage system. If the room should be an old one, and have a wooden floor, the floor should be coated with asphaltum paint, and lead trays placed below the batteries; any woodwork or ironwork in the room should be likewise treated.

The room should be sealed from the rest of the building, and located near the generating machinery and distribution switchboard, so that the copper cables may be low in cost. The windows in the battery room should be of either ground or painted glass, so that no direct rays of the sun may strike the cells, as the heat might crack the cells (glass) or increase the activity of the acid, which is not desirable.

In case the battery installation is in a cold climate, some device for keeping the electrolyte at a moderate temperature must be used.

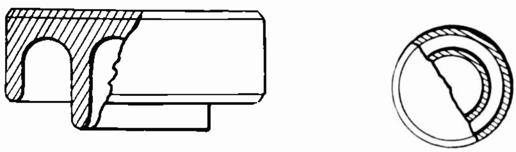


Fig. 11. Glass Insulator for Battery Support.

Setting Up the Cells. The battery is usually placed on the floor, or upon strong wooden shelves; Fig. 11 shows a form (made of glass or porcelain) adapted to cells of medium size. Iron stands are sometimes used for large and heavy cells, but they must be protected from acid fumes and drip by several coats of an acid-proof paint. Wooden stands should be varnished, painted, or soaked in paraffin for the same reason. It is important to have every cell accessible for inspection, cleaning, and removal, it being desirable to reach both sides of the cell. There should also be sufficient head-room between shelves so that the elements may be lifted out.

It is highly important that the cells be thoroughly insulated from one another, to avoid leakage of current. This is accomplished by standing each cell on four insulators of porcelain or glass of the design shown in Fig. 11. Glass is now almost universally employed because porcelain is frequently found to deteriorate gradually as a result of the action of the acid fumes.

Lead-lined tanks for 500-volt installations are usually set as follows: The floor is covered with a layer of glazed tile or brick; on this are placed two wooden stringers about 3 by 4 inches, carefully painted with asphaltum varnish or some acid-proof paint. Under each tank are set four or more insulators held in place by wooden pegs which are kept in position by pouring melted sulphur around them. Sometimes the insulators have short, threaded projections on the top, which are screwed into the bottoms of the tanks. On top of these are placed the battery tray and battery as indicated in Fig. 11.

In the case of 125-volt installations, the insulators are sometimes set directly on the tile flooring, which has been leveled by running molten sulphur under the tiling.

Oil insulators were at first used; but oil collects and holds dust, and, as dust is likely to cause leakage, they are no longer employed. For very large lead tank outfits, a double system of the supporting construction shown in Fig. 12 is used, but with individual stringers for each cell.

Glass cells are often set on wooden trays, which are filled with sand to distribute the strains and absorb the drip. Sawdust was formerly also used; but it becomes carbonized by the acid drip, and, as this is likely to cause leakage, it has been abandoned.

In connecting the cells, which are usually put in series, great care should be taken to join the positive terminal of one cell to the negative of the next, and so on. The color of the plate is the best indication of its polarity, the positive plate being a light brown when discharged and a chocolate color when charged, while the negative varies from a light to a dark slate color.

It may be noted at this point, that the nomenclature concerning storage batteries is different from that of primary cells. The positive

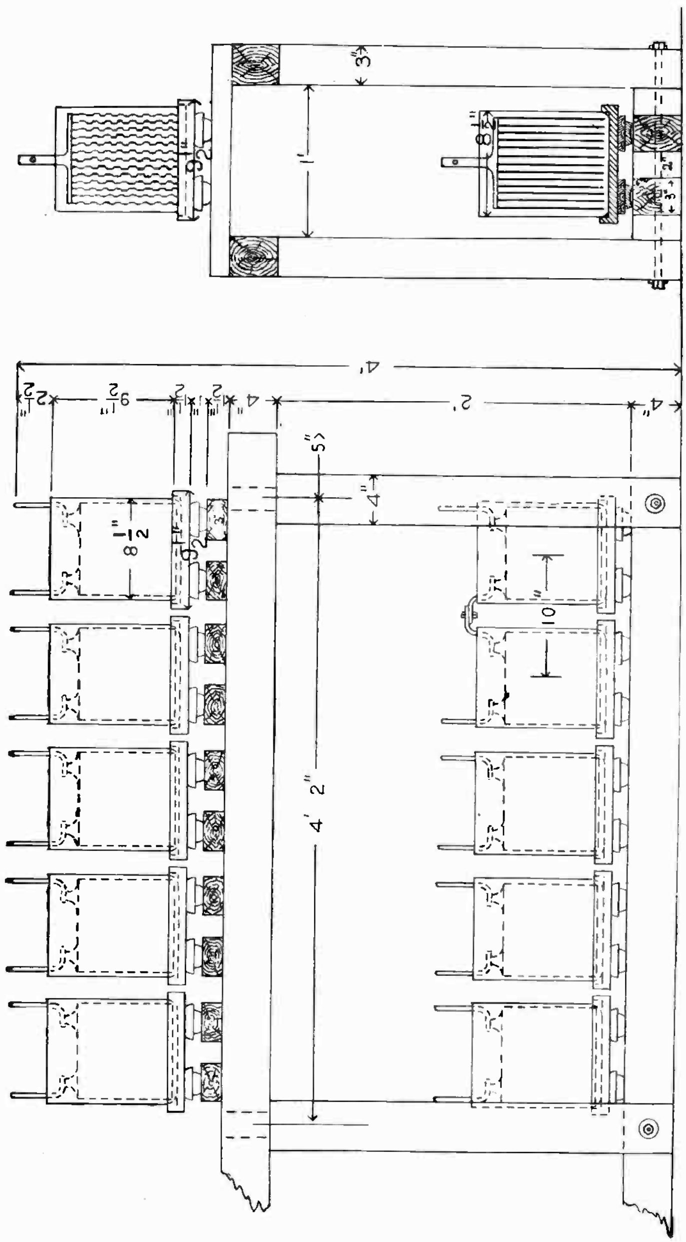
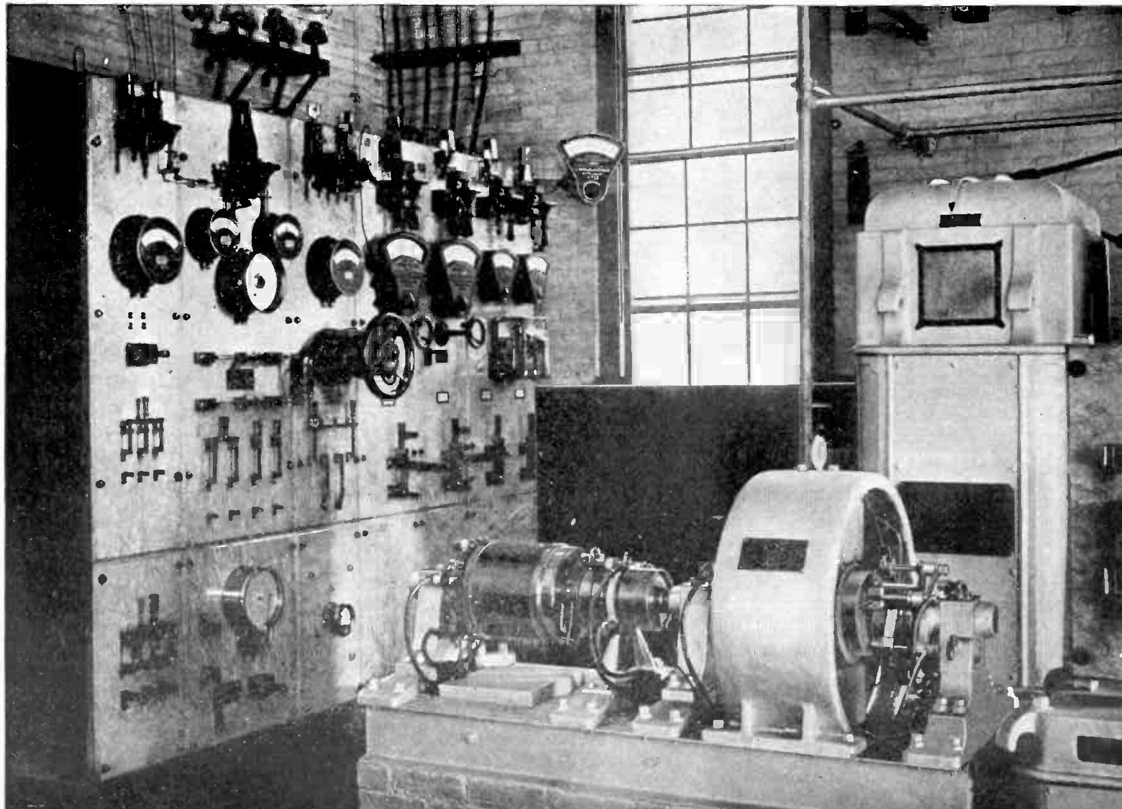


Fig. 12. Shelf Construction for Battery Support.



ROTARY RECTIFIER AND SWITCHBOARD PANELS
Gould Storage Battery Co.

plate in the former is the peroxide plate (brown), and is that one from which the current flows out in discharging; whereas that would be the negative plate of a primary battery.

The positive pole or terminal in a storage battery is an extension of the positive plate, and is connected to the positive terminal of the dynamo in charging; consequently there is much less cause for confusion of terms than there is in the primary cell.

It is well to test the polarity of each cell and of the circuit, before making connections. This may be done with any form of pole-tester, or by the positive expedient of dipping the two terminals in dilute sulphuric acid, the one from which the most bubbles arise being negative. The connections should be scraped clean and screwed up very tight, then coated with acid-proof paint to avoid corrosion. The most satisfactory way to connect up a cell is to weld or *burn* the positive terminal to the negative terminal of the next cell, though soldered connections are good.

This soldering is done as follows: Two strips of lead and the terminals to be connected are very carefully cleansed; the lead strips are then clamped to the terminals, a mould placed around the joints, and molten lead poured into it.

The Electrolyte. Practice varies considerably as to the strength of solution to use. Chemically pure sulphuric acid is poured into water until its density becomes about 1.2, and then the mixture is allowed to cool before pouring it into the cells. The electrolyte *should completely cover* the plates. Cells for vehicle work use an electrolyte with density as high as 1.3. It is important to use perfectly pure acid and water, as impurities will cause local actions and ultimately destroy the plates.

It is well to remember that *water should never be poured into sulphuric acid*, as it is likely to cause the liquid to be thrown out violently.

The advantage of a strong solution is its lower resistance; but it is likely to produce the very objectionable effect of *sulphating*.

The density of the electrolyte falls immediately after filling a cell, since some of the acid is taken up by the plates; but it rises again in charging—for example, from 1.17 to 1.2. It is convenient to keep a hydrometer in several cells to observe the density of the electrolyte, not only at the beginning, but as a permanent indicator of the amount of charge and general working conditions.

The hydrometer is an instrument for determining the specific gravity of a liquid, and consists of a weighted bulb and an upright glass rod, bearing a scale, the unit point being fixed by the distance to which it sinks in pure water at 4°C. Readings above this point are for solutions of lower specific gravity than water, and those below it are for solutions of a higher specific gravity. For storage battery work, the specific gravity of the electrolyte is always between 1.1 and 1.3; hence we require only a certain portion of the scale as represented in Fig. 13.

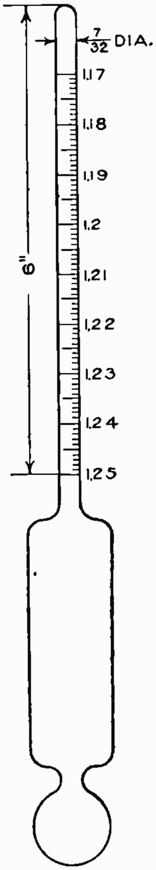


Fig. 13. Hydrometer.

Charging. The charging should begin immediately after a new cell is filled with the electrolyte; otherwise the plates are likely to become sulphated. The first charge differs from subsequent regular charges in that it should be at a rate (lower than normal) that will not cause the temperature of the cell to reach 100°F.; but in all other respects it is the same.

Indications of Amount of Charge in a Storage Battery. There are various methods of ascertaining the amount of charge in a storage battery. The following are the indications that will serve the purpose:

1. The E. M. F. rises from 2.1 volts, at the beginning of the charging of a lead cell, after it has been discharged, to approximately 2.5 volts when fully charged, although this value may be made a trifle higher or lower, depending upon the rate of charge and temperature of cell. The rise is quite gradual, but more rapid near the beginning and end of the charge, as indicated in Fig. 14. When the cell is fully charged, the E. M. F. becomes constant, and the curve approaches a horizontal line as shown. The charging should then be stopped, as any more energy passed through the cell is simply wasted in producing gases. The external voltage is higher in charging than in discharging, because of the internal resistance of the cell and resulting IR drop, which must be overcome in charging.

The measurements of voltage should always be made when the current is flowing either in charging or discharging.

The E. M. F. on open circuit has little practical significance, since a cell, no matter how low it may have been discharged, will show about 2.1 volts after standing on open circuit a short while.

2. *If a record is kept* of the exact number of ampere-hours of charge and discharge, the actual amount of energy in the battery at any time is known, due allowance being made for leakage and other losses. For this purpose any integrating instrument, such as the Thompson recording wattmeter, may be used.

3. *The density of the electrolyte* gradually rises during the charging operation (Fig. 14), the density when charged being about .025 higher than when discharged. There is a lag in the change

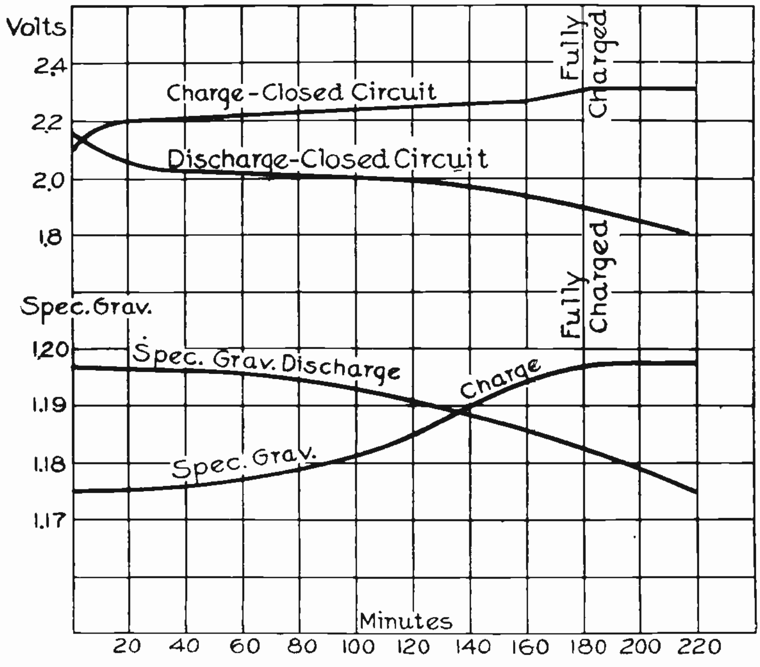


Fig. 14. Curves Showing Variations in Specific Gravity and Voltage in a Storage Battery during Charge.

of the density of the electrolyte, the acid not being absorbed or given off at once by the plates; hence a little time should be allowed before taking any hydrometer reading as final. It is also advisable to agitate the electrolyte to insure complete diffusion, as the electrolyte at the bottom of the cell is otherwise denser than at the top.

4. *Bubbles of gas are given off* freely when the battery is fully charged, since the material of the plates is then no longer able to take up the oxygen and hydrogen which tend to be set free by the electrolysis; these bubbles give the electrolyte the appearance of boiling, and often they are so fine that the liquid looks almost milky white, particularly in a cell which has not been very long in use.

5. *The color of the positive plates* varies from a light brown on active parts to a chocolate color when fully charged, and to nearly black when overcharged. The negatives vary from pale to dark slate color, but they always differ in color from the positives. This indication of the amount of charge is acquired by experience, but is quite definite after one becomes familiar with a particular battery.

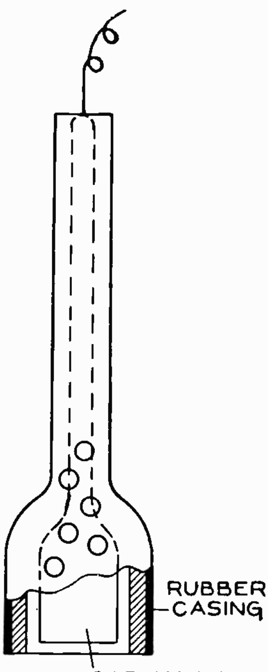


Fig. 15. Cadmium Test-Piece.

6. *Cadmium Test.* The apparatus for making this test consists of a small piece of cadmium, say $\frac{5}{8}$ by $\frac{5}{8}$ by $\frac{1}{32}$ inch, contained in a perforated hard rubber casing (shown in Fig. 15), the rubber covering being employed to prevent short-circuiting of the cell during the test (see Fig. 15). A rubber sleeve contains the conducting wire, wax being used to protect the soldered joint of copper and cadmium. Cadmium is used because it will give reliable readings of the E. M. F. of the positive and the negative plates, with respect to itself. In this way a relative condition of the battery and also of each plate can be determined.

With normal conditions of cell, when fully charged and in open circuit, the difference of potential between the positive and the cadmium piece immersed in the liquid is 2.5 volts or nearly so, and between the cadmium and the negative plates is zero or nearly so. In fact it is sufficient if the sum of the readings is about 2.5 volts.

To avoid false conclusions in making a cadmium test, hydrometer, temperature, and charge data should be noted. The cadmium test is usually made by inserting the tester at the center of the cell to get a uniform current distribution. This test gives readings the sum of which is less than 2.50 volts, when hydrometer tests, temperature, and charge data show that the cell is not fully charged. If the hydrometer, temperature, and other data show the charge to be completed, and the cadmium test gives .1 volt or more below 2.5 volts, one or more plates are defective and may be found by individual cadmium readings. For example, suppose we have a cell in which all the other conditions tend to show full charge, but the potential difference is low. A cadmium test is made; and the set of plates which shows the falling off from normal reading is the defective one, and should be examined for some of the troubles that will be discussed later.

In some cases the cadmium reading with respect to both positive and negative plates may approach zero; this is caused by a short circuit in the cell, which should be found and removed immediately.

In practice it is advisable to have the cadmium wet before the test is made, as the readings increase when cadmium is first placed in the electrolyte. The simplest way to accomplish this is to keep the cadmium tester in a beaker of distilled water when not in use. All foreign matter should be carefully removed from the cadmium, as it might affect the results. If gas bubbles collect on the cadmium, they should be taken off, as they tend to lower the readings.

The proper rate of charge depends upon the size and type of cell, and is usually specified by the manufacturer in each case, since it is merely an empirical fact, being determined by the construction of the plates.

The current for charging is ordinarily obtained from a direct-current dynamo, but any other direct-current source may be employed. The potential required for charging must exceed that of the battery, which, during the operation, acts as a counter-E. M. F., the expression being $I = \frac{P-e}{R}$, in which I is the current, P the potential applied to battery terminals, e the counter-E. M. F., and R the internal resistance of the cell. Usually P is 5 to 10 per cent greater than e, in order to cause the necessary charging current to flow through the resistance R of the cell.

In practice, P is regulated until the required charging current I is obtained.

The above equation, put into form of $R = \frac{P-e}{I}$, enables the internal resistance R to be calculated; but, as this varies considerably with the temperature and with different states of charge, its exact value is not often considered.

Another form of the above equation, $e = P - IR$, shows that the true E. M. F. of the battery is less than the charging voltage by an amount equal to the product of the charging current and the internal resistance. Conversely, in discharging, the total E. M. F. of cell is greater than the difference of potential P between its terminals, by the same amount; that is, $e = P - IR$. Hence it is necessary to know I and R, in order to find the real E. M. F. of cell. This applies to each individual cell, as well as to the entire battery, and is important in determining the amount of charge or working condition of a particular cell.

If the charging voltage P be kept constant, it is evident from the above equations that the current I will gradually decrease, since the C. E. M. F. or e of the cell steadily rises as shown in Fig. 16. This effect is counteracted somewhat by the fact that the inter-

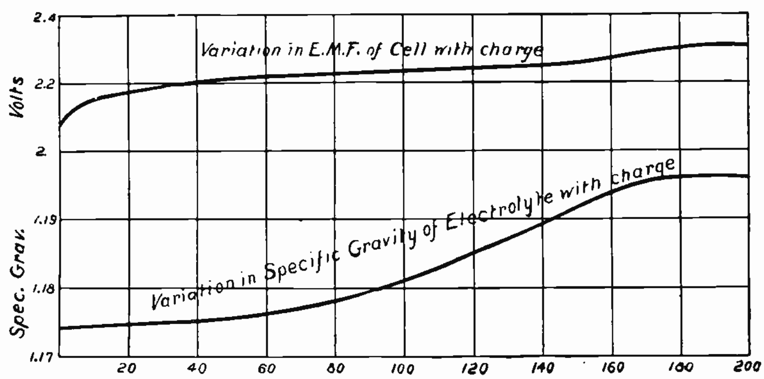


Fig. 16. Curve Showing Increase of E. M. F. in a Charging Cell.

nal resistance R also diminishes, owing to the density of the electrolyte increasing. This gradual reduction in the strength of the charging current is considered desirable by some authorities, since it enables the cell to take a greater charge than if the current were maintained at full strength. On the other hand, this diminishing charge makes it difficult to keep account of the exact number of ampere-hours supplied to the cell; hence, in ordinary commercial work, it is considered simpler to charge with a constant current, and if it is desired to keep the cell temperature down, the current is decreased near the end of the charge. The charging operation may be continued until the battery is fully charged as shown by the indications already stated. Since most types of cells are not injured by a slight overcharging at a moderate rate, it may even be carried a little beyond the charged point, as it tends to remove sulphating. A considerable overcharge should be avoided, as it causes excessive formation of gas bubbles in the active materials and is likely to heat the cell and even to cause disintegration and buckling of the plates.

Discharging. A storage battery is in most cases discharged within a few hours after being charged, as, for example, in electric lighting, when the engine and dynamo are run during the day for charging the battery which supplies current to the lamps during the night. But a portable battery for feeding lamps or a vehicle battery might be required to retain its charge for several days. The loss of charge in any battery standing on open circuit is about 25 per cent in one week, but for one day or less it is quite small.

Even when the discharge occurs immediately, the average voltage and the ampere-hours obtained are less than for the charge, as explained under "Efficiency." The loss referred to is additional, depending upon the time.

The operation of discharging is naturally the converse of charging, the changes which have been described as occurring in the latter take place also in the former, but in the reverse order. The normal rate of discharging is usually equal to that of charging, but may be somewhat greater. In some cases it is necessary to discharge at higher rates; but, by so doing, a percentage of the capacity in ampere-hours is sacrificed.

For example, a cell whose normal or eight-hour discharge rate is 100 amperes, can easily be discharged at 400 amperes for one hour, but only 50 per cent of the cell's capacity in ampere-hours is obtained at the latter rate. Under these latter conditions, there is not a large loss of energy, as is shown by the fact that to recharge a cell thus discharged requires only about 50 per cent of the normal charge.

TABLE VI

Percentage of Capacity Variation at Different Discharge Rates

Rate in Hours	Percentage of Capacity at 8-Hour Rate		
	Planté	Planté (+) Faure (−)	Faure
8	100	100	100
7	99	97	96
6	96½	93½	92
5	93	89	86
4	88	83	80
3	80	75	72
2	70	65	61
1	55	50	40

An excessive discharge rate is injurious to most types of storage-battery plates, since it tends to disintegrate the plates, and abnormally heats the electrolyte, which hastens the disintegration. It is therefore advisable to protect the battery with fuses or a circuit-breaker.

A storage battery *should never be discharged completely*, as it is very likely to become sulphated or otherwise injured; and moreover the voltage falls so rapidly towards the end of discharge that the current would be of no practical value. The limit of discharge is usually considered to be the point at which the voltage drops to 1.75, though when cells are used at the one-hour rate the limit of discharge is 1.6 volts.

A battery should never be allowed to stand in a discharged condition, but should be recharged immediately.

The charge usually left in a storage battery is from 10 to 30 per cent of the total capacity, depending on the rate of discharge; but this involves no considerable loss of energy or efficiency, since it remains in the battery each time, and the charging begins at that point.

Efficiency of Storage Batteries. The efficiency of any apparatus is the ratio between output and input. In a storage battery it is the ratio of the amount of discharge to what is required to bring the battery back to its original condition after a discharge.

The *ampere efficiency*—or, more properly, the *ampere-hour efficiency*—which is the ratio of current in ampere-hours drawn from the battery to current in ampere-hours put into the battery, is quite different from the *watt-hour efficiency*. The latter is the *real efficiency* since it considers the energy, and includes the voltage as well as the ampere-hours. The former may be used either through ignorance or intention to give a false idea, since the ampere efficiency is often 15 per cent higher than the watt efficiency.

Another difficulty is the fact that it is possible to obtain an apparent efficiency of over 100 per cent from a storage battery. Since a certain amount (about 25 per cent) of charge is always left in the cell, it is possible to draw more ampere-hours than were put in during the last charge, by simply discharging the cell more than usual.

This matter has been investigated by Ayrton, who says:

> "If an E. P. S. accumulator be over and over again carried around the cycle of being charged up to 2.4 volts, and discharged down to 1.8 per cell, the charging and discharging currents being the maximum allowed by the makers—namely, .026 ampere per square inch of surface in charging, and .029 ampere per square inch in discharging—the working efficiency thus obtained may be 97 per cent for the ampere-hours, and 87 per cent for the watt-hours. If, on the contrary, the cell be constantly charged up before being tested, then for the first few charges and discharges between the above limits, and with the same current density in charging and discharging, even the energy efficiency may be as high as 93 per cent; whereas, if the accumulator has been left for some weeks, then, although it was left charged, the energy efficiency for the first few charges and discharges will be as low as 70 per cent."

In general practice it has been found that the watt-hour efficiency of storage-battery plants, when in good condition, varies from 75 to 80 per cent. For instance, referring to the battery plant at the Edison Electric Company station in Boston, a series of tests made there show the battery installation to have an efficiency of 75 per cent.

Depreciation of Accumulators. The depreciation is claimed to be as low as 4 or 5 per cent per annum; but 7 per cent is a safer allowance to cover depreciation and renewals extending over long periods of time. During the first few years the depreciation may be practically nothing; but after five or ten years it will be considerable. These statements apply to *stationary* batteries in central stations or isolated plants. For *traction* or *automobile* service, which is much more severe, the life of storage batteries in some instances has not exceeded six months; and 3,000 to 5,000 miles total run is considered a good result in actual practice. For either stationary or vehicle storage batteries, the life of the positive plates is only half as great as that of the negatives. The figures given are based upon an average of the two.

It has been the practice of several storage battery manufacturers to insure their stationary battery equipments for 6 per cent per annum of their first total cost. This insurance is a maintenance contract calling for inspection and any repairs necessitated through normal use of cells.

TROUBLES AND REMEDIES

The most serious troubles which occur in storage batteries are *sulphating*, *buckling*, *disintegrating*, and *short-circuiting* of the plates. These can usually be avoided, or cured by proper treatment if they have not gone too far.

Sulphating. The normal chemical reaction which takes place in storage batteries is supposed to produce lead sulphate ($PbSO_4$) on both plates when they are discharged, their color being usually brown and gray, as already stated. But under certain circumstances a whitish scale forms on the plates, probably consisting of $Pb_2\ SO_5$. Plates thus coated are said to be *sulphated*. This term is therefore somewhat ambiguous, since the formation of a certain proportion of ordinary lead sulphate ($PbSO_4$) is perfectly legitimate; but the word has acquired a special significance in this connection.

A plate is inactive, and practically incapable of being charged, when it is covered with this white coating or sulphate, which is a non-conductor.

The conditions under which this objectionable sulphating is likely to occur are as follows:

(*a*) A storage battery may be overdischarged—that is, run below the limits of voltage specified—and left in that condition for several hours.

(*b*) A storage battery may be left discharged for some time, even though these limits have not been exceeded.

(*c*) The electrolyte may be too strong.

(*d*) The electrolyte may be too hot (above 125° F.).

(*e*) A short circuit may cause sulphating, because the cell becomes discharged (on open circuit), and, when charging, it receives only a low charge compared with the other cells of the series. A battery may become overdischarged or remain discharged a long time, on account of leakage of current due to defective insulation of the cells or circuit; or the plates may become short-circuited by particles of the active material or foreign substances falling between them.

Sulphating may be removed by carefully scraping the plates. The faulty cells should then be charged at a low rate (about one-half normal) for a long period. In this way, by fully charging and only partially discharging the cells for a number of times, the unhealthy sulphate is gradually eliminated. When the cells are only slightly sulphated, the latter treatment is sufficient without scraping; when the cells are very badly sulphated, the charge should be at about one-quarter the normal rate for three days.

Adding to the electrolyte a small quantity of sodium sulphate, or carbonate, which latter is immediately converted into sodium sulphate, tends to hasten the cure of sulphated plates by decomposing or dissolving the unhealthy sulphate. This is not often used in practice, as a cell must be emptied and thoroughly washed, and fresh electrolyte added after the plates have been restored to their proper condition, before the cell can be used to advantage.

Sulphating not only reduces the capacity of lead storage batteries, but also uses up the active material by forming a scale which falls off or has to be removed. It also produces the following troubles:

Buckling. Buckling or warping of a plate, is caused by uneven action on the two surfaces; for example, a patch of white sulphate on one side of a plate will prevent the action from taking place there, so that the expansion and contraction of the active material on the other side, which occurs in normal working, will cause the plate to buckle. This might be so serious that it would be impossible to straighten the plate without breaking or cracking it; but, if taken in time, this may be accomplished by placing the warped plate between boards, and subjecting it to pressure in a screw or lever press. Striking the plate is objectionable, because it cracks or loosens the active material; but, if it should be necessary to straighten a plate in this way, a wooden mallet should be used very carefully, with flat boards laid under and over the plate. Buckling may be caused by an excessive rate of charging or discharging, as well as by sulphating.

Disintegration. Some of the material may become loosened or entirely separated from the plates, as a result of various causes.

The chief of these is sulphating, which forms scales or blisters that are likely to fall off, thus gradually reducing the amount of active material and the capacity of the cell. Buckling also tends to disintegrate the plates. Contraction and expansion of the active material take place in normal working, and are increased by excessive rates or limits of charging and discharging. This constitutes another cause of disintegration, particularly in plates of the Faure type containing plugs or pellets of lead or lead oxide paste.

The fragments which fall from the plates not only involve a loss of material, but are also likely to extend across or gather between the plates, and cause a short circuit.

The positive plates are far more susceptible to and injured by these troubles than the negatives. The former are also more expensive to make; therefore it is to them that special attention should be directed in the management of storage batteries.

Short-Circuiting. Short-circuiting of a cell may be caused by conditions previously stated, and also by the collection of sediment at the bottom of the containing cell. The short-circuiting caused by the dropping in of foreign matter, or the bridging of the active materials, is prevented by the use of glass, rubber, or wooden separators.

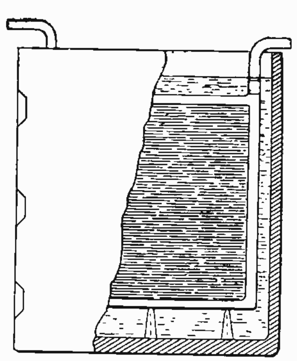


Fig. 17. Glass Frame Support Used to Prevent Short-Circuiting by Sediment.

The short-circuiting of plates by the formation of sediment is prevented, or the chances of it are decreased, by raising the plates so that they clear the bottom of the containing cell. In small batteries this clearance is about an inch; in very large cells it is considerable, being about 6 inches; and large-sized plates, on account of their weight, are supported at the bottom by glass frames running lengthwise through the cell, as shown in Fig. 17.

This sediment should be watched carefully; and when it reaches a depth of 1 inch or more at the center of the cells, it should be removed. The usual method is to take out the plates, siphon the electrolyte off carefully, and then flush out the tanks until all the sediment is removed. If siphoning cannot be resorted to because of the absence of drop, a pump may be used, either of glass or of the bronze rotary type.

Troubles from Acid Spray. A storage battery gives off occasional bubbles of gas at almost any time or condition; but when nearly charged, the evolution becomes more rapid. These bubbles, as they break at the surface, throw minute particles of acid into the air, forming a fine spray which floats about. This spray not only corrodes the metallic connections and fittings in the battery room, but is also very irritating to the throat and lungs, causing an extremely disagreeable cough.

Glass covers are sometimes placed over cells to prevent the escape of fumes; but this is not advisable, as the glass becomes moist and will collect dust, thus forming a conducting surface over the cell.

Attempts have been made to do away with this spraying by placing an oil film (thin layer of oil) over the electrolyte; but this has the objection of interfering with hydrometers; in addition, it sticks to the surface of the plates when they are removed, and interferes with their conductivity on replacing them.

Another plan consists in spreading a layer of finely granulated cork over the surface of the liquid; but while this does not interfere with the hydrometer, it makes the cell look dirty.

The general practice is to depend almost entirely upon ventilation to get rid of the acid fumes; in fact, even forced ventilation is used. A blower forces fresh air into the room, which is provided with a free exhaust.

In connecting up the cells, it is advisable to use lead-covered copper cables, and to paint all connections with an acid-resisting paint, as these coverings protect the copper and prevent the formation and the dropping of copper salts into the cell.

Purity of the Electrolyte. This is very important, and great care should be taken to insure it. The electrolyte may have nitric acid present when formed (Planté) plates are used; and some chlorine, when Chloride negatives are used. In addition, iron may be present, due to the water or acid if the sulphuric acid is made from iron pyrites; it may also be present owing to the corrosion of iron fittings near the cells, some of the scale falling into the electrolyte. Similarly, some of the copper salt formed from the connections by this corrosive action may fall into the cell. Mercury may also be present as a result of the breakage of hydrometers or thermometers.

Other foreign substances might be present, but those named are the most harmful. Nitric acid, even in exceedingly small quantities, will cause disintegration of plates, as the supporting material is destroyed. Chlorine has a similar effect. Iron, mercury, and copper produce local action, and thus decrease the efficiency and ultimately the life of the cells. The electrolyte should be tested about once a week for these impurities; and if any of them are present, it should be drawn off and renewed. If nitric acid is present, it is even advisable to flush the cell with pure water.

TESTS

1. **Test for Chlorine.** Take a sample of the electrolyte, acidulate with nitric acid, and add a few drops of silver nitrate solution. If a curdy white precipitate forms, which is soluble in ammonium hydrate, chlorine is present in some of its compounds.

2. **Test for Iron.** Iron may appear in one of two forms, namely, ferrous or ferric salts. A small sample is taken, and some concentrated hydrochloric acid added, and then some potassium ferric cyanide; if a heavy blue precipitate forms, ferrous iron is present; if in very minute quantities, a deep blue-green discoloration results.

3. **Test for Ferric Salts.** To a sample of the electrolyte, add some hydrochloric acid and a few drops of ammonium thiocyanite; if a blood-red solution or precipitate is the result, ferric salts are present.

4. **Test for Copper.** To a sample of electrolyte, an excess of ammonium hydrate is added; if a rich blue solution is the result, copper is present. It is advisable to check the test by taking another sample and adding some potassium hydrate to it; if a blue precipitate is found which turns black upon boiling, it is additional proof of the presence of copper.

5. **Nitric Acid or its Compounds.** As these are injurious, even in very small quantities, it is advisable to make the following test, which is very sensitive: Some diphenylamine in concentrated sulphuric acid is added to the sample; if a deep blue color is the result, nitrates or nitrites are present.

6. **Test for Mercury.** Mercury may be present in two forms, mercurous or mercuric compounds. The *mercurous* compounds give a black precipitate with lime water, and a greenish precipitate with potassium iodide. The *mercuric* compounds give a yellow precipitate with lime water, and a red or scarlet precipitate with potassium iodide.

On account of possible difficulties with these various impurities, the following are recommended:

1. Test every carboy of sulphuric acid before using.
2. Concentrated sulphuric acid should not be kept around, as it may be used by mistake, which would ruin the plates.
3. Only distilled water from carboys should be used, and not from barrels, as in the latter case it may be contaminated by organic matter.
4. Water from the city mains is never to be used unless the amount of impurities which it contains is very small.
5. When testing with hydrometer for specific gravity, the battery should be fully charged, and tests *always made at the same temperature, or temperature changes should be corrected for,* because the specific gravity of the electrolyte falls with increase of temperature. The specific gravity changes due to temperature are given in Table VII.

TABLE VII

Specific Gravity of Dilute Sulphuric Acid at Various Temperatures

Temperatures	30° F.	40° F.	50° F.	60° F.	70° F.	80° F.	90° F.	100° F.	110° F.
Sp. gr.	1.1593	1.1562	1.1531	1.1500	1.1469	1.1438	1.1407	1.1376	1.1345
"	1.2096	1.2064	1.2032	1.2000	1.1968	1.1936	1.1904	1.1872	1.1840
"	1.2620	1.2590	1.2530	1.2500	1.2470	1.2440	1.2410	1.2380	1.2350
"	1.3090	1.3060	1.3030	1.3000	1.2990	1.2940	1.2910	1.2880	1.2850
"	1.3620	1.3580	1.3540	1.3500	1.3460	1.3420	1.3380	1.3340	1.3300
"	1.4144	1.4076	1.4048	1.4000	1.3952	1.3904	1.3856	1.3808	1.3768

Putting the Battery out of Commission. If, for any reason, the battery is to be but occasionally used, or the discharge is to be at a very low rate, a weekly freshening charge to full capacity at normal rate should be given.

It frequently happens in practice that a storage battery equipment is put out of commission for a lengthy period (for instance, in most summer or winter resorts, the battery may be used for one-half of the year only). In such cases the procedure is as follows: First give the battery a complete charge at normal rate, then siphon off the electrolyte into carefully cleaned carboys (as it may be used again); and, as each cell is emptied, *immediately* refill it with pure water, to prevent the charged negative from heating in the air, as this would result in loss of capacity. When the acid has been drawn from all cells and replaced with water, begin discharging the battery, and continue until the voltage falls to or below one volt per cell at normal load (rate); when this point has been reached, the water should be drawn off. In this condition the battery may stand without further attention until it is to be put again into service; and to do this, proceed in the same manner as when the battery was originally put into use.

If, during discharge, when water has replaced electrolyte, the battery shows a tendency to get hot (100°F.), add colder water.

COMMERCIAL APPLICATIONS

The function of a storage battery is to receive electrical energy at one time or place, and to give it out at some other time or place. The principal uses are the following:

1. To furnish portable electrical apparatus with power.
2. To make up for fluctuations, and thus steady the voltage and load on the generator.
3. To furnish energy during certain hours of the day or night, and enable the generating machinery to be stopped.
4. To aid the generating plant in carrying the maximum load (peak), which usually exists for only an hour or two.
5. To make the load on engines or prime movers more uniform, by charging the battery when the load is light.
6. To transform from a higher to a lower potential by charging the cells in series, and discharging them in parallel, or *vice-versa*.
7. To subdivide the voltage, and enable a three- or a five-wire system to be operated from a single generator.
8. To supply current from local centers or substations.
9. To supply current to electrically-driven vehicles.
10. As sources of current in telephone and telegraph systems.
11. For car-lighting purposes.
12. As sources of constant potential and current in electrical laboratories.

Portable Storage Batteries. The storage or the primary battery is practically the only means of supply for portable electric lamps or for those not connected to a dynamo even when they are not portable.

The various manufacturers furnish portable forms of storage batteries. The Gould Storage Battery Company's portable battery

(Fig. 18) is arranged in a case made as a hard rubber jar, lead-lined box, or glazed earthenware jar, over which is placed a rubber gasket, and then a wooden cover clamped in place by U-shaped straps passing around the containing vessel. For ventilation in charging, the cover has threaded holes, which, when the battery is in use, are closed with hard rubber stoppers. The usual number of cells in a case is from one to five, although they are made up in larger numbers if desired. The batteries are rated at 2 volts per cell.

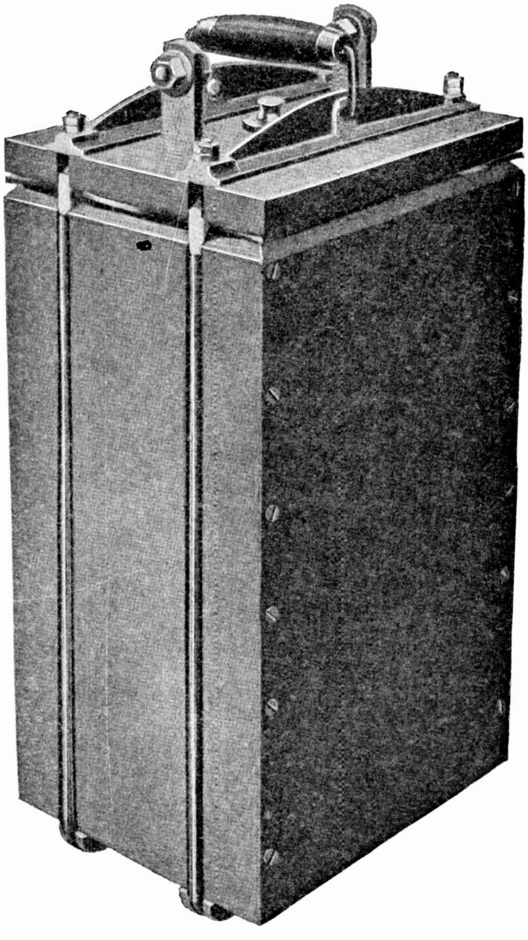


Fig. 18. Gould Portable Storage Battery.

A serious objection to portable storage batteries is their great weight. For example, a standard size weighing 100 lbs. yields 5 amperes at ten volts, or fifty watts, for ten hours—just enough to feed a 16-candle-power lamp. The total discharge is 500 watt-hours or two-thirds of one horse-power-hour. The special forms of battery used in automobiles give about twice this output for the same weight.

This weight is almost prohibitive to portability, except for automobiles, railway train lighting, and special purposes.

Portable batteries, for example, are used for feeding small motors, lamps, etc., for medical or dental purposes, in which cases their weight is not a serious difficulty, in view of the importance of the work and the small amount of energy required. Another special field for very small batteries is the theatrical application, for which they are carried by performers. Storage batteries are also extensively used as sources of power to drive small fan and kinetoscope motors.

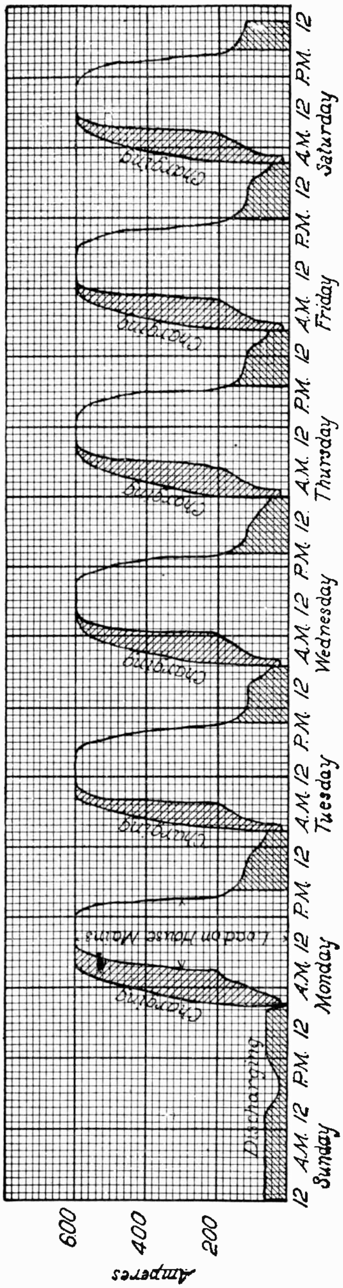


Fig. 19. Load Curve of Astor Building, New York City.

Storage Batteries for Preventing Fluctuations due to unsteadiness in the driving power or in the load, as with elevators, are often applied successfully. A dynamo driven by a gas engine for example, may vary periodically in speed because of the explosive action of the gas in the cylinder; and a battery connected in parallel with the dynamo will have the effect of steadying the voltage. A storage battery is generally installed in connection with a small gas-engine or steam-engine lighting plant, to enable the engine to be stopped for a considerable portion of the time, and thus save labor and attention, in which case the battery may also act to prevent fluctuations. A windmill electric-lighting plant must have an accumulator or some other means of storing energy, not only to eliminate fluctuations in speed, which are continually occurring, but also to bridge over the considerable periods of calm weather.

To Furnish Energy during Certain Portions of the Day or Night. In almost every electric-lighting plant, there are long periods during the day and late at night when the number of lamps lighted is so small that it may not pay to run the generating machinery.

For example, Fig. 19 is a load diagram showing the weekly output of the electric plant of the Astor Building in New York City. The generator plant runs from 3 a.m. to 8 p.m. each day, the battery being charged from 3 a.m. to 11 a.m.; and when the generating plant is shut down at 8 p.m. the battery carries the entire load from then until 3 a.m., when the plant is started up again. Saturday nights the plant is shut down at eight o'clock, and the battery furnishes all the power required from then until Monday morning at 3. This enables the plant to be operated by two gangs or shifts, practically no labor being required for the remaining seven hours, as the battery carries the load, and the machinery is stopped entirely all day Sunday, giving a stretch of thirty-one hours once a week, and seven hours each night for cleaning and repairs. In a hotel or residence, or on board

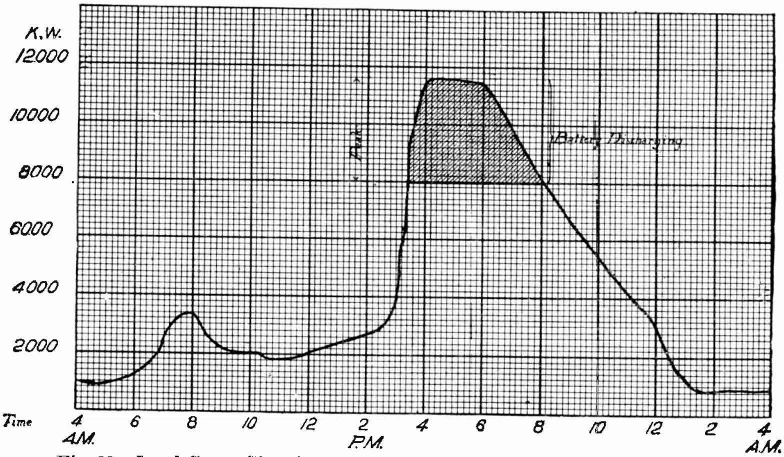


Fig. 20. Load Curve Showing "Peak" of Load Carried by Storage Battery.

a yacht, it may be desirable to stop the machinery and avoid the vibration and noise during the night.

Storage Batteries to Aid in Carrying the Maximum Load. Assume, in the case of the load diagram shown in Fig. 20, that the generating machinery is capable of supplying 8,000 kilowatts, and that a storage battery is used to furnish the remaining 3,600 kilowatts at the time of maximum load—that is, the *peak* of the load diagram. This simply means that batteries are substituted for a certain portion of the machinery plant, and the question is whether or not the substitution is of any advantage.

The first cost of a battery for a given rate of output depends simply upon the time of discharge. Batteries usually have a normal period of discharge of about 8 hours, at which rate the price of accumulators to furnish a given number of watts would be 3 to 5 times as great as that of the equivalent boilers, engines, and dynamos combined; but if the time of discharge is reduced to about 2 or 3 hours, the costs are about equal; and with a still higher rate, the cost of batteries would be less.

As a matter of fact, the storage battery secures other advantages, so that the total gain may be very important. For example, there is a reserve supply in case of accident; and the load may be made more uniform, as will now be explained.

Storage Batteries to Maintain Uniform Loads on Engines. Steam engines are very inefficient at light loads, and this fact often causes serious losses, especially in electric-lighting plants. Judicious selection of the number and sizes of the engines enables them to be worked in most cases at a considerable fraction of their full capacity nearly all the time. Nevertheless the storage battery gives greater flexibility to the plant, and renders it easy to increase the economy of the engines by making their loads still more uniform and nearer to their full capacities while they are running. The engines can be made to have a uniform full load, the battery being charged when the external load is light, and the battery taking the peak of the load when it is heavy.

Storage Batteries Used as Transformers. If the cells of a battery are arranged in series while being charged, and in parallel for discharging, a high voltage will be required for charging, and a low voltage will be given out. The amounts of energy measured in watt-hours are the same, less the loss of about 25 per cent which always occurs in accumulators; the result is similar to that obtained by an alternating-current transformer or motor-dynamo, but is less efficient. As an example, the equipment used at the Brooklyn Navy

Yard may be mentioned. It consists of about 250 small cells connected up in series parallel of 5 sets of 50 cells each and charged on a 110-volt circuit. When discharged, they are connected up all in series, and give about 500 volts, but with very small current. This equipment is used to furnish 500 volts for the *insulation test* of cables, and therefore requires little or no current.

Storage Batteries Used for Subdividing Voltage. The most important practical case is that in which a dynamo of 220 volts charges a battery of corresponding potential, a three-wire system being supplied from the battery, the neutral wire of which is connected to the middle point of the battery, as represented in Fig. 21.

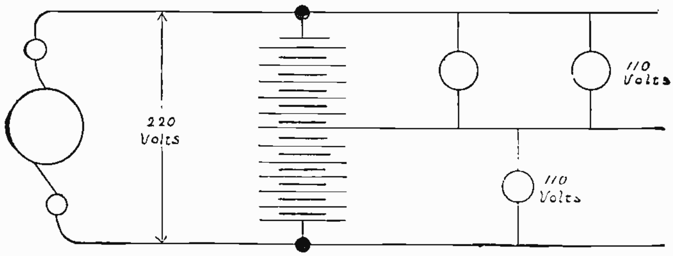


Fig. 21. Battery Used to Subdivide Voltage.

This arrangement avoids the necessity of running two dynamos, and allows the battery to be placed in a substation near the district to be supplied, so that it is necessary to run only two conductors to that point instead of three. The same principle may be applied to the five-wire system. When used in this manner, each side of the system requires its individual end cells and regulators.

The Hartford Electric Light Company was one of the first in this country to introduce the modern method of high-tension transmission, with low-tension 3-wire distribution.

The auxiliary battery used in connection with this equipment consists of 130 Chloride accumulators (65 on a side), each cell containing 31 negatives and 30 positive plates, each $15\frac{1}{2}$ by 31 inches, placed in lead-lined tanks measuring $58\frac{1}{4}$ by $21\frac{1}{2}$ by $43\frac{7}{8}$ inches. Fig. 22 is a diagram showing the general plan of the system. The power is transmitted 10.8 miles from the Farmington River Power Station to the Pearl Street Station, in Hartford, by means of step-up transformers, a 10,000-volt transmission line, and step-down transformers for distribution. From Pearl Street Station to State

Street, a distance of 3,000 feet, the current is transmitted at 2,400 volts, at which latter point, by means of step-down transformers and rotary converter, the storage battery is charged and the current distributed over a low-tension three-wire system.

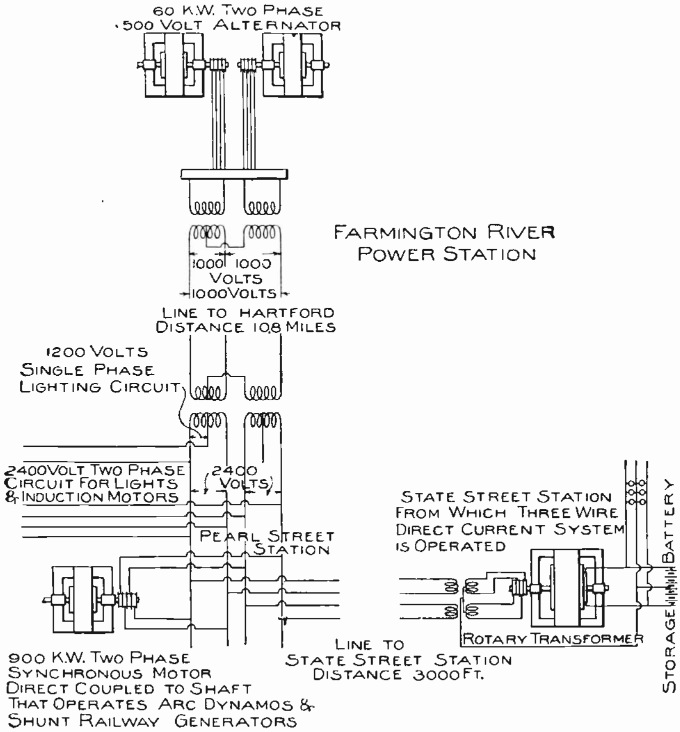


Fig. 22. Plan of Farmington River-Hartford Distribution System.

Storage Battery for Substations. The plan of installing battery plants at local centers, which are charged from the main station, enables some of the conductors to be saved in a three- or five-wire system, as already stated. It also makes it possible to reduce the size of these conductors, because the current which flows over them can be kept practically constant, so that it is not necessary to have them large enough to carry the maximum current consumed by the lamps, etc., which may be several times its average value. The generating machinery has the same steady load as if the battery were located near it.

The batteries at the various substations may be connected and charged in series or in parallel. The former plan would require far less copper in the conductors, since the voltage is multiplied by the number of batteries in series, and the current is the same as for a single battery. On the other hand, this great difference of potential would exist between the first and the last batteries of the series; and if either of these became grounded, any person connected to the earth and touching a wire supplied by the other battery would receive a shock due to the total voltage.

An excellent example of a storage battery substation is the Bowling Green Plant of the New York Edison Company. The Bowling Green Station furnishes an auxiliary supply of current directly from the battery, enabling the feeders, extended as tie-feeders into the Bowling Green building, to be used as distributing feeders to the system from both the Duane Street and Bowling Green Stations. While acting as an auxiliary supply to the general system, the battery also takes care of the distribution of current to the extensive installation in the Bowling Green building itself. The supply of current to charge the battery is taken from the Duane Street Station, about a mile distant, over four tie-feeders equipped with controllable disconnective switchboxes on the Bowker-Van Vleck system. This enables them to be used as tie-feeders by disconnecting them from the general system during the hours of light load, and as distributing feeders during the hours of maximum load, when they feed current into the system from each end. A considerable saving is thus effected in the investment, because costly feeders are not required to supply the maximum load to a distant part of the system.

This installation of an auxiliary source of current supply in the lower district makes it possible to shut down the generators in the Duane Street Station during the hours of minimum load, the supply of current to the district below 8th Street being derived from the battery plants at Bowling Green and 12th Street Stations, supplemented, if desired, by the supply of current from the 26th Street Station, over the tie-lines to 12th Street Station, whence the current is distributed through boosters raising it to the required potential, over the tie-feeders to the Duane Street Station switchboard. The battery and operating rooms of the Bowling Green

Station are located in the sub-basement of the Bowling Green Office Building. Vitrified hollow tile for conducting the feeder cables are laid under the battery-room floor, which consists of glazed white tile. Drains to carry off the water or acid run in the aisles between the cells, and lead to small cesspools which discharge into a lead drain-pipe.

The battery consists of 150 Chloride cells, 75 in series on each side of the three-wire system. The cells consist of wooden tanks, $40\frac{3}{4}$ by $21\frac{1}{2}$ by $30\frac{1}{2}$ inches, treated with an acid-proof paint and lead-lined, each containing 14 positive and 15 negative plates $15\frac{1}{2}$ inches wide by 31 inches high. Each tank is supported on four petticoat porcelain insulators resting upon 6-inch glazed tiles.

The plates are suspended in the tanks by shoulders resting upon sheets of heavy glass, which stand upon lead saddles in the bottoms of the tanks. The cells are connected by welding the plate terminals to lead bus-bars, no mechanical connections being used.

Twenty of the end cells on each side of the system are used for regulating, being separately connected to contact points on the regulating switches, which carry movable contacts operated by a screw. The potential is raised or lowered by cutting in or cutting out the regulating cells. Two regulating switches are connected in multiple on the positive, and two on the negative, side, to permit of discharging at two potentials, or to enable the battery to be charged and discharged simultaneously. The conductors between each series of cells, and between the regulating cells and the regulating switches, consist of copper bars 3 inches wide by $\frac{1}{2}$ inch thick. These bars are supported on porcelain insulators resting in hangers. The connections of this equipment are shown in Fig. 23.

The capacities of the battery at various rates of discharge are:

2,000 amperes per side for 1 hour.
1,000 amperes per side for 3 hours.
400 amperes per side for 8 hours.

Provision has been made in the battery-room, for the installation of a duplicate battery, which can be placed over the present plant. The booster is used to raise the voltage from that of the system to that required for charging the battery. The booster can be used also to raise the voltage of discharge for feeding some distant point of the system at a higher potential than would normally be required. The machine consists of one positive and one negative dynamo at each end of a common shaft driven by two motors. Each dynamo

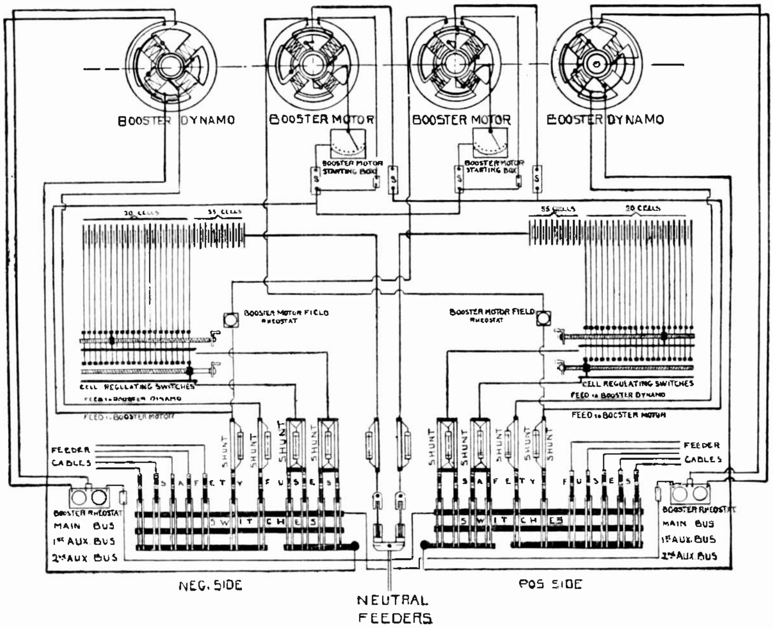


Fig. 23. Connections of the Bowling Green Storage Battery Substation.

has a capacity of 1,200 amperes, and a range of pressure up to 60 volts.

Storage Batteries Used for Two or More of the Above=Named Purposes. Each of the different uses has been considered separately to avoid confusion, but in most cases the storage battery is adopted in order to secure several advantages. By thus combining different applications, the plant is rendered not only more economical, but also more flexible. For example, the battery may be utilized to help out the generating machinery at times of heavy load, or when the latter is partially or wholly disabled. It often happens that it is difficult to produce or maintain sufficient steam pressure, owing to poor draft or other conditions, in which event a battery enables the boilers to be temporarily relieved of some or all of the drain upon them while the pressure is being raised to the proper point. It may also be necessary or desirable to shut down the machinery or a portion of it, temporarily, in order to make some repair or adjustment. It is also possible to feed some of the circuits from the battery while the others may be supplied at a higher or lower voltage by the machinery. In these and many other ways the storage battery may be a convenient adjunct to an electrical system. The fact that it is so radically different from the machinery in its nature and action, makes it very unlikely that the entire plant will be crippled at any one time, since the two sources of current are not exposed to the same dangers. An accident to the steam piping, for instance, might shut down all the machinery, but probably it would not affect the battery; and, *vice-versa,* an accident to the latter is not likely to extend to the former.

As an example of this application of the storage battery to several purposes, the following case may be cited:

The installation of storage batteries at the power house of the Woronoco Street Railway Company, in Westfield, Mass., presents features of special interest. After considering various methods of increasing the power-house capacity, rendered necessary by the construction of an extension of the line, it was decided that the storage battery offered the greatest advantages.

The station equipment consists of two 75-kilowatt multipolar generators belted to two 120-horse-power, high-speed, simple, non-condensing engines, steam being furnished by two 90-horse-power return tubular boilers.

The battery consists of 264 Chloride Accumulator cells, Type F–11, in glass jars of Type F–13, permitting an increase of 20 per cent by the addition of one pair of plates in each cell, and is installed in a small brick extension to the power house. The cells are located in one tier, each cell being supported on a sand tray resting on four glass insulators. The foundation for each row of cells consists of two stringers of wood suitably braced and supported on brick piers. This battery was not installed as a voltage regulator, the feeder system being so designed that the drop on the line is only a small amount.

By means of the battery, the load on the machinery is reduced within the capacity of one unit, leaving the second one as a reserve in case of an accident or an unusually heavy load. Without the battery, both machines would be needed nearly all the time.

The economy of operation due to using one unit instead of two, is clearly shown by the following station records:

	Date, 1899.	Lbs. coal.	Output kw.-hrs.	Lbs. coal. per kw.-hr.
With battery	Oct. 25–27	16,250	3,032	5.36
Without battery	Oct. 28	6,250	981	6.37

This shows an increase in the coal consumption, of 19 per cent, on the day when the operation of the battery was discontinued. The plant is also noteworthy from the fact that the station attendance is reduced to one man per shift, the engineer doing his own firing. This arrangement could not have been continued under the conditions of increased load, had it not been for the improved regulation and reduction of coal handling, and especially the increased reliability of operation secured by the battery.

On several occasions the battery has been called upon to carry the entire load of the system for an hour or so, during a temporary shut-down of the rest of the plant, as well as early in the morning or late at night, when only one or two cars are in operation.

Storage Batteries for Propelling Vehicles and Boats. The storage battery is usually about 35 per cent of the total weight in the modern electric automobile; and even with this great proportion, the distance run on one charge is seldom more than from 20 to 40 miles at a speed of about ten miles per hour, and that only on comparatively smooth roads. The ordinary battery equipment consists of about 44 cells of 108 ampere-hours capacity with an average discharge voltage of about 1.9.

In cities or where the roads are good, with charging stations close at hand, the electric automobile is superior to the gasoline types on account of the absence of explosive vapors, with the accompanying odor and noise. But for general touring they are not so handy, on account of the limited capacity of the battery.

The application of the storage battery to the street-car, while presenting such great advantages as the entire absence of poles and overhead wires, has not been a commercial success, mainly on account of the mechanical weakness of the plates, which are not able to stand the jolting and jarring or the rush of current due to frequent starts and stops. Another objectionable feature is the escape of acid fumes into the car, producing throat irritations and coughs among the passengers, although this is overcome by the use of fans.

The storage battery has been comparatively successful as a source of power in submarine boats, being charged while the vessel is on the surface, and discharged to run electric motors and lights when the vessel is manœuvering under the surface.

Storage Batteries in Telephone and Telegraph Systems. Since the adoption of the central battery systems by telephone companies, the use of the storage battery for this purpose has become very common, its advantages over the primary cell being as follows: Lower first cost; smaller space required (about ¼ of that occupied by an equivalent primary battery); greater constancy of E. M. F. and lower internal resistance; absence of the annoying *creeping salts;* and rapidity of recharge. The cost of storage-battery maintenance is about ⅓ that of the primary cell.

In telephone work, the battery is installed in the district station, and charged when the line is not in use, from either a street connection or a generator in the station. When the line is in use for conversation, the charging current is automatically cut off, and the battery alone switched into service.

The storage battery in telephone work has become so important that the following description of a typical installation is given.

In the Filbert Street Exchange of the Philadelphia Bell Telephone Company, there are two generating units, forming a duplicate plant, each consisting of one engine, directly connected to a 30-kilowatt, 110-volt dynamo. These machines are run on alternate days, and are used for lighting the building and for furnishing power at 110 volts to various motor-generators. The latter comprise two 1.5-kilowatt machines for charging a 20-volt battery, one 1.5-kilowatt machine for charging an 8-volt battery; one 500-watt machine for charging a 4-volt battery; and two ¼-horse-power 75-volt alternating-current motor-dynamos for ringing call bells. Only one machine is installed for the 8-volt battery, and one for the 4-volt battery. Both batteries are in duplicate. To avoid a possible breakdown, a rheostat is furnished, so that the batteries of lower voltage can be charged from batteries or motor-generators of higher voltage. All machines are protected by automatic cut-outs.

The 20-volt battery consists of ten Chloride Accumulators having a capacity of about 1,000 ampere-hours, which furnish all the current needed by the subscribers for talking and for calling up the central office. The 8-volt batteries, in duplicate, consist of four cells, each having a capacity of 2,400 ampere-hours. This battery furnishes current for the "disconnect" signals on theoperator's cords, and for the relays which cut out the subscriber's lamp signal when the operator answers his call, by plugging into the jack corresponding to the lamp signal.

Half the drop in potential of the 8-volt battery is in the 4-volt lamp, and the other half in the cut-out relay. This battery is in duplicate, so that one can be charged while the other is being discharged. This avoids danger of burning out the lamps, as the voltage of the battery is raised from 8 to 10 volts during charging.

Each of the duplicate 4-volt batteries comprises six 13-cells arranged in two sets. One of these sets consists of four cells, two in series, two in multiple; the other of two cells. The two extra cells are needed on one of the batteries to supply current for the operator's transmitters. The latter is arranged to furnish a current of four volts or two volts as desired. The 4-volt battery also furnishes all current for the lamp signals, which light when a subscriber takes his telephone off the hook. This lamp is put out when the operator answers the call. This battery also is made in duplicate, one being charged while the other is discharged, to avoid burning out the lamp from the higher voltage during charge.

Storage Batteries for Train Illumination. When cars are lighted by oil or gas lamps, these, owing to their size, and the heat produced by them, can be installed only in certain places, so that the distribution of light is not general, besides which, the heat and odor given off by the lamps are objectionable. The inflammable character of the illuminants involves great danger of explosion or fire in case of a train wreck. The absence of these disagreeable and dangerous features in electric lighting, is what has made its application so desirable in traction work.

Several methods of electric illumination have been tried on railroad trains. In one of the simplest of these, a small dynamo on the locomotive truck, or one perched above the boiler, is driven by a small steam turbine. While this is an economical method, it has the objection, that when the locomotive is uncoupled, the cars must be illuminated by some other means.

For this reason, the storage-battery system of supply has been adopted. One of the most successful methods is the "Axle Light" system. This, as its name implies, derives the motive power for its dynamo from the car axle. The mechanism is suspended from the bottom of the car, and is completely encased, so as to be dust-proof and waterproof. It comprises a small dynamo driven from a pulley on the axle of the car by means of a friction coupling.

The dynamo and driving mechanism are shown in Fig. 24. The former generates from 32 to 40 volts, depending upon the speed

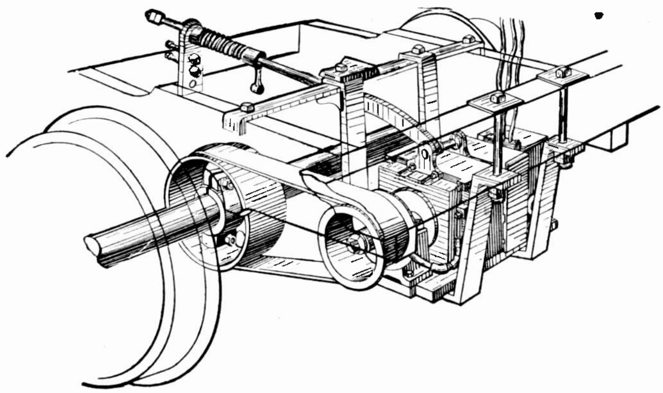


Fig. 24. Method of Suspension Used by the "Axle Light" System.

of the train, provided that it exceeds 15 miles per hour, the dynamo being then automatically connected to the battery and lamp circuit. An automatic device rectifies the direction of current, so that even though the direction of rotation is reversed, the battery is always charged in the proper direction. A variable resistance in series with the field coils is automatically adjusted by a small motor, so that even at high speed the normal limit of voltage is not exceeded.

The lamps are 16-candle-power at 30 volts, the filaments being short and heavy so that they are not injured by vibration.

After the storage battery has been charged, it acts in parallel with the dynamo, and avoids fluctuations in voltage. When the car stops, the dynamo is automatically cut out, and the full supply of current is furnished by the battery, which is large enough for a ten-hour supply at full load.

Storage Batteries for Electrical Laboratories. The great advantage of this source of power in electrical laboratories, is the fact that any variation in the voltage is very gradual, and by the simple regulation of a rheostat in series with the battery, the operator can keep his voltage and current absolutely constant while a test or calibration is being made. When a large current is wanted, as in the case of ammeter calibration, the cells may be connected in parallel and discharged through a low resistance, thus cutting down the energy required for the test. A storage battery may also be used to step up the voltage, the cells being connected in parallel groups for charging, and in series for discharging.

The special arrangement shown in Fig. 25 consists of a storage battery *S.B.*, the charging current for which is regulated by a bank of incandescent lamps *L*. Where a large-capacity battery is employed, a rheostat or motor-dynamo can be substituted for the lamps. In the instance shown, four distinct operations may be carried on simul-

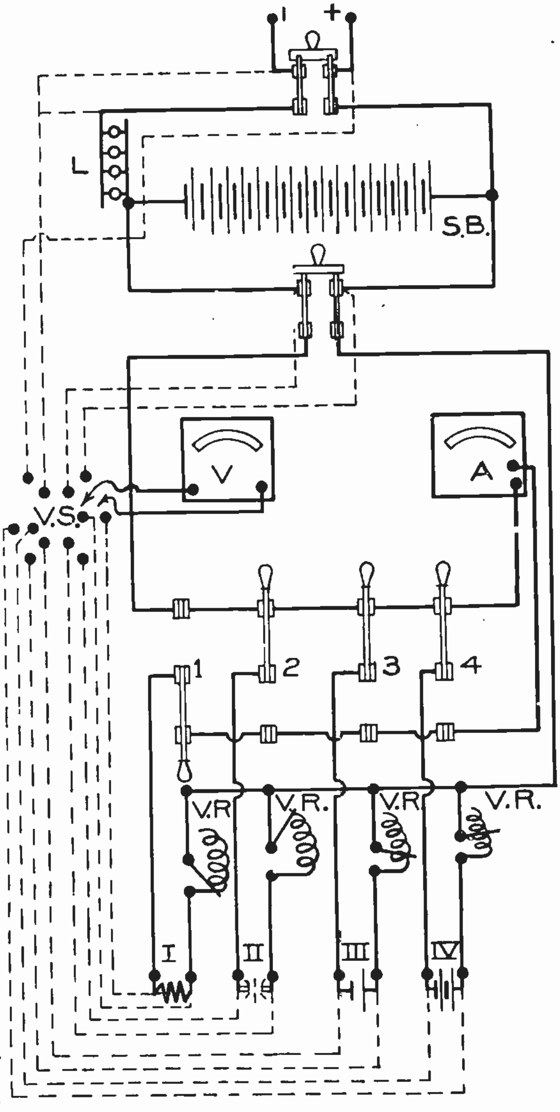


Fig. 25. Diagram of Connections of a Laboratory Equipment Arranged to Supply Current for Four Independent Operations.

taneously, without having one interfere with the other. Each one of the circuits is supplied with a regulating device *V. R.*, so that any desired current density is obtainable at the electrodes of the experimental devices I, II, III, and IV. The arrangement of the voltmeter circuits is such that the voltage of each individual circuit can be readily obtained through the use of the twelve-point voltmeter switch at *V. S.* The switching arrangement is such that by means

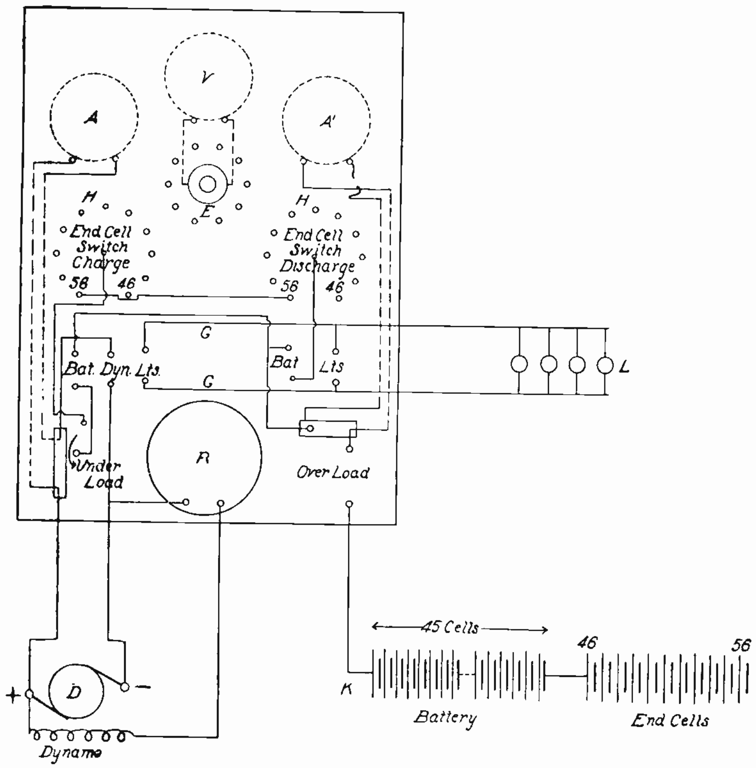


Fig. 26. Switchboard, Dynamo, and Battery Connections.

of one ammeter *A*, separate readings of the current in each branch circuit may be made, or the total current read. For example, with the switches as shown in the figure, the current flowing through the first apparatus consisting of a resistance furnace is being measured. If switch 1 were thrown in the opposite direction, and switch 2 had its position reversed, the current of group II would be shown by the ammeter. If all the switches were placed in the same position as switch 1, the ammeter would indicate the total current drawn by the four pieces of experimental apparatus.

Connection and Regulation of Storage Batteries. The complete control of a battery in an electric-lighting plant requires provision to be made for feeding the lamps, etc., from either the dynamo or battery separately, or from the two working in parallel; and it should be possible to charge the battery at the same time that lamps

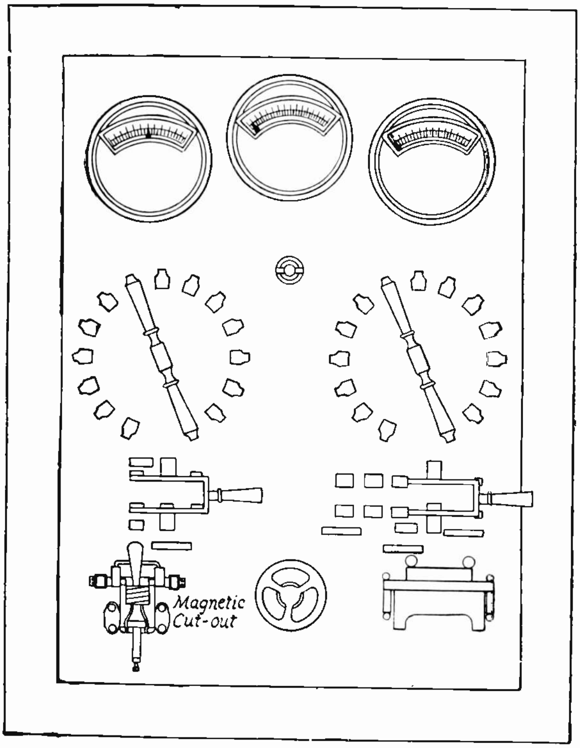


Fig. 27. Face of Switchboard.

are being supplied. To accomplish these results requires three switches—one to connect the battery to the dynamo, one to connect the lamps to the dynamo, and one to connect the lamps to the battery. In some plants the second switch is omitted, because the lamps are always fed by the battery alone, the latter being charged during the day, when no lamps are in use. However, it would seem desirable to have all three switches in every plant in order to be able at least to supply lamps and charge the battery at any time. In the battery circuit, there should be an ampere-meter having a scale on both sides of zero, so that it shows whether the battery is being charged or discharged, as well as the value of the current. Another similar ampere-meter is required in the circuit between the dynamo and the battery, to show the direction and amount of current. A third ampere-meter is desirable in the lamp circuit, to show the total current supplied to the lamps; but it need indicate only on one side of zero, since the current there always flows in the same direction. A voltmeter is required with a three-way switch, which enables it to be connected to the dynamo, battery, or lamps respectively.

An automatic overload switch must be inserted in the battery circuit so as to open or introduce resistance into the circuit when the current becomes excessive. An automatic cut-out is required between the dynamo and the battery to open the circuit when the charging current falls below a certain value, and thus avoid any danger of the battery discharging through the dynamo, if from any cause the E. M. F. of the latter drops below that of the former. This completes the ordinary measuring and circuit-controlling apparatus employed in connection with storage batteries. The arrangement is shown diagrammatically in Fig. 26, in which *A* and A^1 are the two ampere-meters, the third one being omitted in this case; *V* is the voltmeter; *E* the voltmeter switch to connect to the dynamo, battery, or lamps as desired; *G* the bus-bars; *L*, lamps; *D*, dynamo; *R*, rheostat in field-circuit of dynamo.

The regulating device consists of eleven end-cells, which are connected to corresponding contacts on the end-cell switches (Fig. 26). But as the drawing of these connections would complicate the figure, they have been omitted. Fig. 27 shows the switchboard with these devices mounted upon it.

Parallel Charge, Series Discharge. With batteries of small capacity, where it is not advisable or convenient to raise the generator voltage in order to charge all the cells in a single series, it is usual to divide the battery into two parts and charge each half of the battery individually, through a resistance from the main lines. This method is inefficient, however, and should be employed only with small equipments. Fig. 28 shows a diagram of connection for charging in this manner, and coupling the two halves of the battery in series during discharge, the discharge voltage being also regulated by resistance, there being no end cells employed.

Regulation of Storage Batteries. This is one of the most troublesome problems involved in the practical use of storage batteries. It arises from the fact that the voltage falls continually from the begin-

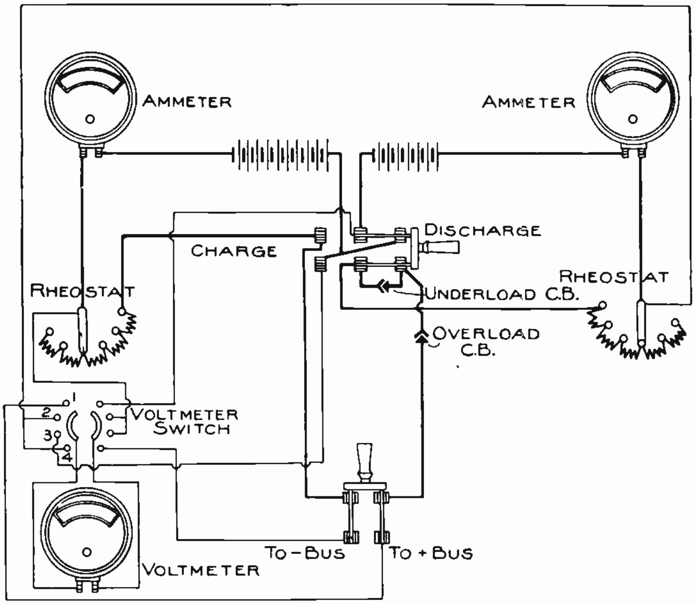


Fig. 28. Connections for Parallel Charge, Series Discharge.

ning to the end of discharge. To be sure, this decline is gradual; but its total value is large, being from about 2.2 to about 1.8 volts, which is a decrease of nearly 18 per cent.

In order to maintain a constant voltage, the usual plan is to have a number of extra cells, which are successively switched into circuit as the potential falls. These reserve cells and the switches which control them are represented in Fig. 26.

The contact-pieces of these switches must be made in such a way that they do not short-circuit the cells as they pass from one point to the next. This is accomplished by splitting the movable contact arm into two parts, between which a certain amount of resistance is introduced, so that when the two parts happen to rest on two adjacent contact-points, the resistance prevents the cell which is connected to these two points from being short-circuited, and also avoids breaking the circuit.

The number of extra cells depends upon conditions; for 110-volt lamps, it would require 51 cells to obtain 112.2 volts when fully charged and giving 2.2 volts each, assuming the drop on the conductors at 2 per cent. When the battery becomes discharged, and its potential falls to 1.8 volts per element, 10 additional cells, or 61 in all, would be needed. These would yield 111.8 volts, assuming the average potential of the reserve cells to be 2 volts, since they have not been discharged to the same extent as the original battery. If the drop on the conductors is 10 per cent of the lamp voltage, the potential at the battery will have to be 110 + 11 = 121. This will necessitate 4 more elements, or a total of 65, when the 51 original cells are fully discharged to 1.8 volts, and the 14 extra cells give 2 volts each.

For a three-wire system, the above figures should, of course, be doubled. This switching of extra cells into and out of the circuit obviously results in discharging them unequally; hence they require to be charged to a corresponding extent. This is accomplished by successively cutting the cells out of circuit as soon as they become fully charged, the last cell which was put into the circuit being fully charged in the shortest time, and so on. The amount of charge is determined by the methods already given. If the cells employed are not injured by overcharging, they may be left in circuit until the entire battery is fully charged. This saves the trouble of operating the switch; but it is wasteful of energy, since the full counter-E. M. F. and resistance of the charged cells must be overcome, which requires about 2.5 volts more per element. The switches might be operated automatically by a voltage regulator or by clockwork.

REGULATION OF GENERATOR IN CHARGING STORAGE BATTERIES

The variation in E. M. F. which occurs in accumulators renders it somewhat difficult to regulate the generators employed to charge them. A constant potential will give a decreasing rate of charge, owing to the gradual rise in counter-E. M. F. This is advantageous in that it enables the cells to receive a larger charge; but the increase in their voltage is so great that it is practically necessary to regulate the charging potential. In practice it is customary to maintain the charging current approximately constant for considerable periods of time; otherwise it would be difficult to determine the quantity of energy put into the battery, and its efficiency. When extra cells are used, they facilitate the regulation of the generator, since they are gradually cut out as the E. M. F. rises.

If the lamps are supplied at the same time that the battery is being charged, some provision must be made for the fact that it may be necessary for the voltage of the dynamo to be considerably higher than that required by the lamps. One plan is to have two separate switches connected to the reserve cells, as shown in Fig. 26, the charging current from the dynamo being led in through one, and the current for the lamps passing out through the other, so that the potential can be independently controlled in the two circuits. Another method is to insert counter-E. M. F. cells (without active material) in the circuit between the dynamo and the lamps, in order to bring down the voltage of the former to suit the latter. The number of these cells is varied in accordance with the excess of the potential of the dynamo.

Simple resistance coils may be used in place of the counter-E. M. F. cells to reduce the pressure; but the cells have the great advantage, that they have an effect practically independent of variations in the current. All these methods, however, involve a waste of power, the value of which in watts is the product of the current in amperes and the number of volts by which the potential is cut down. In small plants this loss is not serious, but in large plants or central stations it may become very considerable.

Booster Methods of Regulation. The best plan is to make use of a *booster*, in which case the main dynamos are run at the proper voltage to supply the lamps directly, and the additional pressure required to charge the battery is furnished by the booster. This is connected in series with the dynamo, being inserted in the circuit between the latter and the battery.

When a battery is placed at the end of a long feeder to compensate for line drop, and at light loads to act as a storage reservoir, it is not usual to equip this *floating battery* with any regulating device. In such cases the battery is simply connected across the line, and the charge and discharge are determined by the feeder drop. For instance, when a small load is on the line, the drop is small, and the potential applied across the battery terminals is high enough to send a charging current into the battery; if the load on the line increases, the drop naturally increases, the pressure at the end of the line falls, and, if it falls below the battery voltage, the battery discharges in parallel with the generator, carrying a certain portion of the load. The floating battery has the advantages of simplicity, and acts immediately, as it has no time lag, which is always present in any apparatus depending upon changes in magnetization. Usually the variations in voltage and the fluctuations in load are too great for successful operation of a floating battery on any but an electric railway or power circuit, and a booster is required if incandescent lighting is a part of the load.

The duty of a booster is to vary the voltage at the battery terminals with variation in load, causing charging or discharging of current as conditions may require. The booster is an auxiliary dynamo, the E. M. F. of which is used to raise or lower the voltage in the battery circuit. These machines are classified as *series, shunt, compound, differential,* and *constant-current* boosters.

Shunt Booster. This is a shunt dynamo, driven by any source of power, having its armature circuit in series with the line from generator to battery. This form is used in plants where the bat-

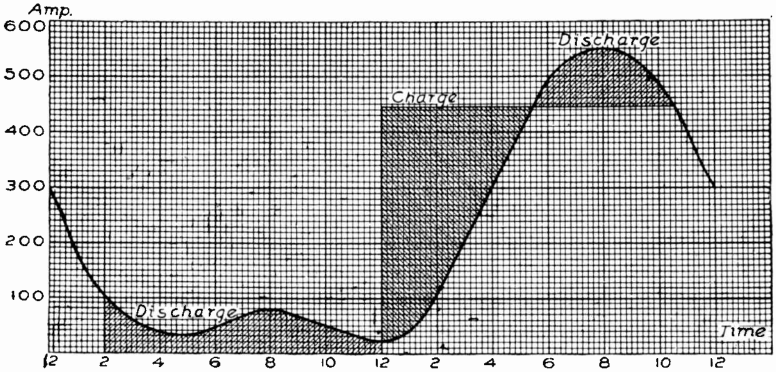


Fig. 29. Load Diagram of Case in which a Shunt Booster is Applicable.

tery is not designed to take up load fluctuations, but is in service only to carry the peak of the load, being charged during periods of light load, and discharged in parallel with the generator. It acts to increase the voltage applied to the battery so that the charging current will flow into the latter. As a rule, the battery used in conjunction with a shunt booster is made large enough to carry the entire load during the light-load period. As the battery discharges and its voltage drops, the end-cells (regulation cells) are cut in and the proper voltage maintained. Fig. 29 shows a load diagram to which this system is applicable, and Fig. 30 shows diagrammatically

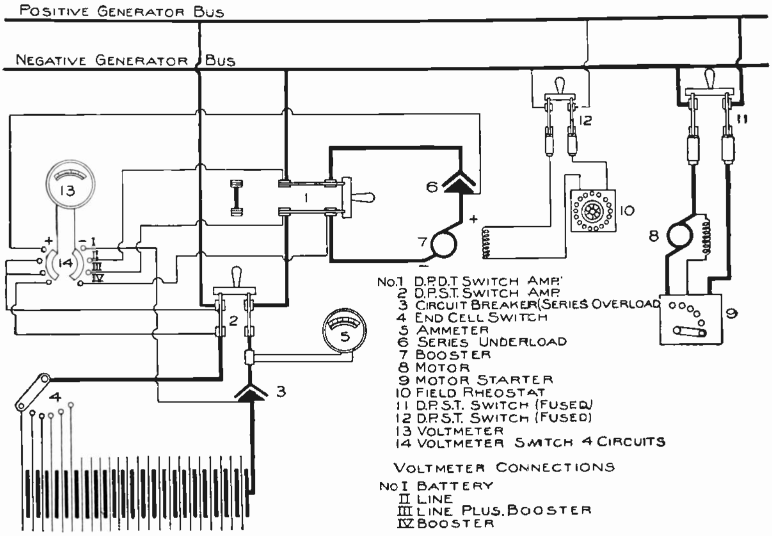


Fig. 30. Shunt Booster Connections.

the connections of this system. The booster (7) is direct-connected to and driven by a shunt-covered motor (8), which takes current from the main bus-bars. The field of the booster is provided with a single winding excited from the generator circuit. This winding has a rheostat (10) in series with it so as to be able to regulate to booster E. M. F. It is to be noted that the shunt booster is not applicable where there are sudden fluctuations which are great compared with the capacity of the generator, and that it is not automatic in changing from charge to discharge, the switching being performed by hand.

Series Booster. The connections are like those of the shunt booster with the battery and booster in series across the line; but the field of booster being in series with the battery circuit, its E. M. F. is zero when no current is flowing in or out of the battery. Should the voltage of the line rise, due to a decrease of load, and a charging current flow into the battery, the E. M. F. of the booster would increase, and thus tend to increase the rate of charge. The reverse occurs when the battery discharges, as an increase of load on the line increases the current through the series field of the booster, thus raising the voltage of discharge so that the battery carries a larger part of the load.

This booster acts to compound the battery on discharge, and tends to maintain a constant voltage on the line. It depends on the fact that the generator voltage falls when the load increases; hence it is used with a shunt generator or equivalent source of supply.

This system is applicable to power, but not to lighting purposes, and is similar in its operation to a floating battery. It is not so extensively used as the compound and differential booster arrangements, which give better regulation under similar conditions.

Compound Booster. This system is used on railway and power circuits with great fluctuations in load, the battery action to prevent excessive drop and to assist the generating machinery in carrying the load, relieving it from the strain of sudden rushes of current. The connections of this system are indicated in Fig. 31, and the operation

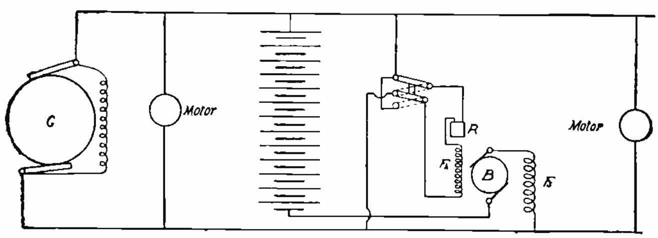


Fig. 31. Compound Booster Connections.

is as follows: Under normal load conditions the shunt field F_h of the booster creates an E. M. F. in the same direction as the battery, tending to discharge it. Calling E_g the generator E. M. F.; E_a the booster E. M. F.; and E_b the battery E. M. F., we have $E_g - E_a = E_b$ when no current is flowing into or out of the battery. In this case the generator carries the whole external load.

If the load increases, E_g decreases, so that $E_b - E_a$ is greater than E_g, and the battery begins to discharge. In discharging, the current passes through the series field F_s of the booster and produces a proportional E. M. F., acting with the shunt field to raise E_a, thus increasing the battery discharge and shifting more of the load from the generator, until the system becomes balanced.

If the load on the external circuit be light, the generator voltage E_g rises and current flows into the battery. In this case the series field acts against the shunt field and decreases E_a, so that the generator voltage is greater than booster and battery voltage combined, thus increasing the rate of charge of the battery, until the load causes the generator voltage to drop to normal and the system is again balanced. The battery and booster can be placed at the power house or at the point at which the greatest drop is likely to occur.

A battery can also be used to help out the generators at the peak of the load, by increasing the shunt-field current and thus causing E_a–E_b to be greater than E_g.

Since this system also depends for its action upon the drop of voltage with increase of load, it is only applicable to shunt-wound generators or equivalent source.

Differential Boosters. The differential booster system most commonly used is shown in Fig. 32. The compensating field S_1

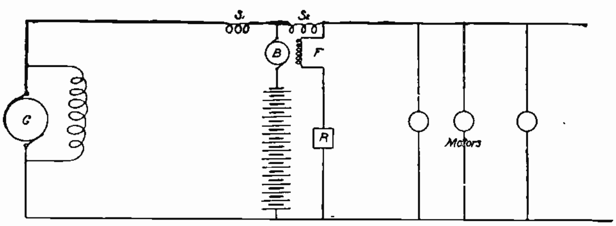


Fig. 32. Differential Booster Connections.

prevents the variation of the battery E. M. F. from disturbing the equilibrium of the system. If the battery E. M. F. be lower than normal, it will not discharge rapidly enough to relieve the generator from overload fluctuations, unless the booster E. M. F. be increased; and the generator will therefore have to supply a current of greater than its normal value. If, however, a current of greater value than the normal flows through S_1, the value of f–S_1 is decreased, and S_2 still further overpowers the resultant of f–S_1 and causes a higher booster E. M. F., tending to discharge the battery, thus bringing down the generator load to normal. Should the battery E. M. F. be above its normal value, the battery would discharge too rapidly and carry more than its share of the load; in this case f–S_1 is greater than it should be, and the booster E. M. F. causes the load to become evenly distributed between the battery and generator.

In operating this system, the varying load must be beyond the booster equipment. If desired, the coils S_1 and S_2 may be short-circuited so that the battery may be charged more rapidly.

Constant-Current Booster. In systems having short lines and small drop, it is often desirable to have the voltage fall on sudden application of an overload, so that the rush of excessive current is prevented. This rush of current occurs in buildings where elevator and power motors constitute a large percentage of the load; and to prevent it, the *constant-current booster* system is used.

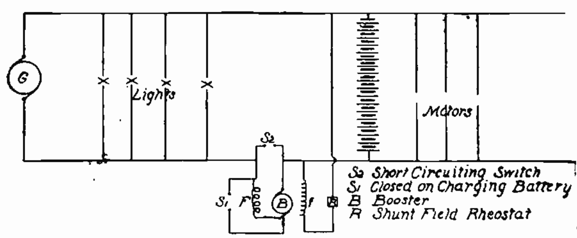


Fig. 33. Constant-Current Booster Connections.

Fig. 33 represents a constant-current booster system, in which the main current passes through the armature and series field of the booster; and this current does not reverse.

The voltage impressed on a fluctuating load of motors, on the right, is greater than that impressed on a non-fluctuating load of lamps on the left, by the amount of the booster voltage.

The shunt-coil f creates an E. M. F. in the same direction as that of the generator; while the series-coil F opposes it.

Should a load come in the motor portion of the circuit, the generator sends a greater current through the series coil S, the action of which reduces the booster E. M. F. in direct proportion to this rush of current, and causes the booster E. M. F. to vary inversely as the motor load, thus tending to maintain an almost constant current delivery from generator. If it is desired to have the battery furnish power to both lights and motors, at periods of light load, and not to use the generator, this can be done by simply opening the generator switch and short-circuiting the booster by closing switch S_2.

The switch S_1 is closed in charging the battery, as the rate of charge can be controlled by varying the shunt-field resistance R.

This is often done, when the battery has been carrying a heavy load for some time and the recharging must be hurried.

In the automatic booster systems already described, the regulation is obtained by two or more field windings acting differentially or cumulatively.

Systems of External Control. In the following systems of booster control, only a single field winding is provided, and this winding is excited from the main bus-bars through an automatic field regulator which varies the field current to produce the necessary booster E. M. F. as the load on the line changes. The booster armature is connected

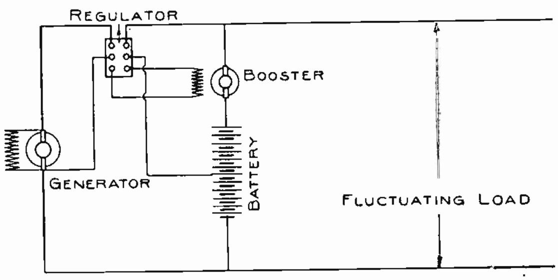


Fig. 34. External Control Differential Booster System.

in series with the battery and generator as heretofore. Figs. 34 and 35 show diagrammatically the connections of the differential and constant-current systems arranged on this plan.

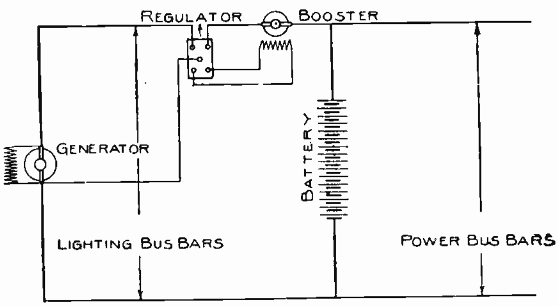
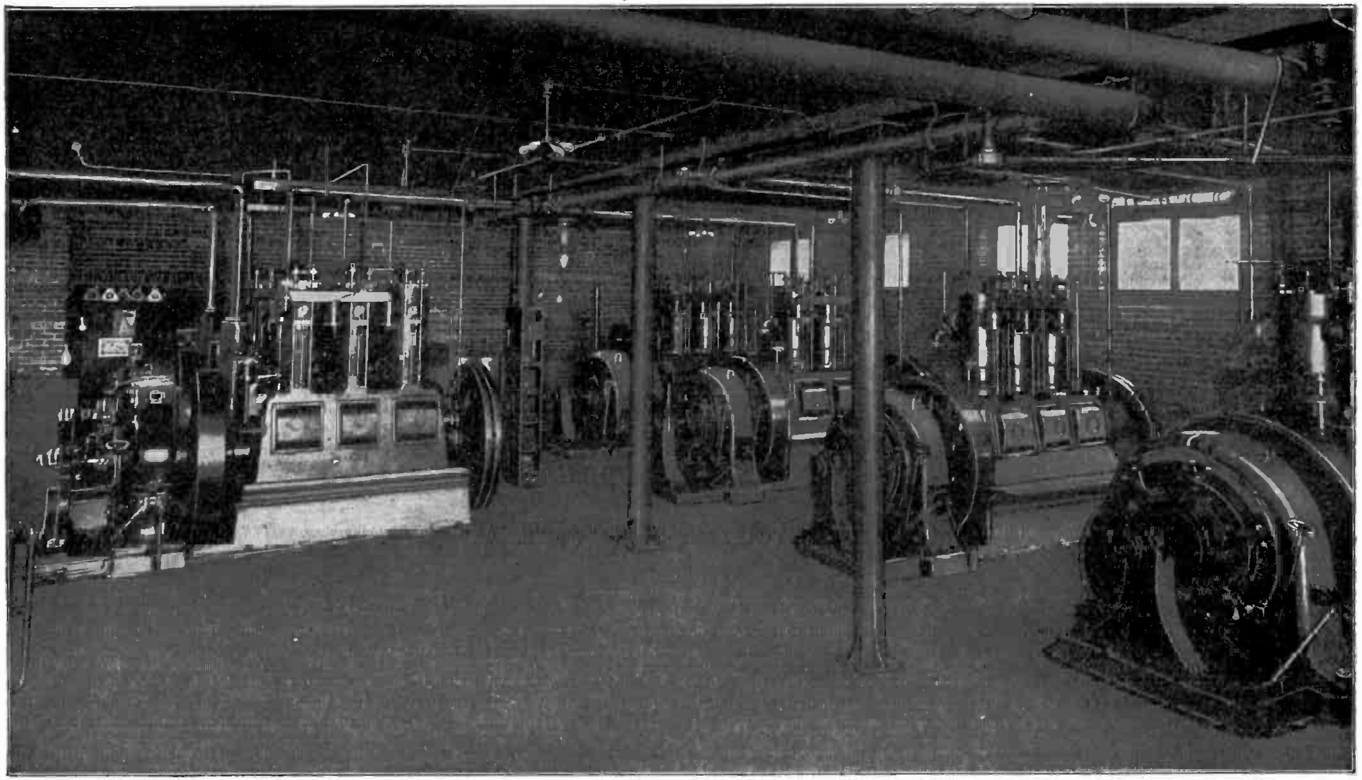


Fig. 35. External Control Constant-Current System.

These externally controlled booster equipments are the system employed by the General Storage Battery Company, and in one of these constant-current systems the following excellent regulation was obtained: The load across the power bus-bars was a rapidly fluctuating one, varying instantly from zero to 2,500 amperes, while the average current required amounted to only 150 amperes. With no load across the power bus-bars, the booster passed 150 amperes from the generator to the battery, tending to charge the latter; with a sudden increase of power demands from zero to 2,500 amperes, the generator current rose to a value of only 159 amperes. This example brings out the definition of a constant-current booster—that is, it should be one which maintains a practically constant power load on the generator.



WALRATH GAS ENGINES DIRECT CONNECTED TO GENERATORS
In Diamond Light & Power Company's Plant, Pittsburg

ELECTRIC LIGHTING

HISTORY AND DEVELOPMENT

The history of electric lighting as a commercial proposition begins with the invention of the Gramme dynamo, by Z. J. Gramme, in 1870, together with the introduction of the Jablochkoff candle or light, which was first announced to the public in 1876, and which formed a feature of the International Exposition at Paris in 1878. Up to this time, the electric light was known to but few investigators, one of the earliest being Sir Humphrey Davy who, in 1810, produced the first arc of any great magnitude. It was then called the *voltaic arc*, and resulted from the use of two wood charcoal pencils as electrodes and a powerful battery of voltaic cells as a source of current.

From 1840 to 1859, many patents were taken out on arc lamps, most of them operated by clockwork, but these were not successful, due chiefly to the lack of a suitable source of current, since all depended on primary cells for their power. The interest in this form of light died down about 1859, and nothing further was attempted until the advent of the Gramme dynamo.

The incandescent lamp was but a piece of laboratory apparatus up to 1878, at which time Edison produced a lamp using a platinum spiral in a vacuum, as a source of light, the platinum being rendered incandescent by the passage of an electric current through it. The first successful carbon filament was made in 1879, this filament being formed from strips of bamboo. The names of Edison and Swan are intimately connected with these early experiments.

From this time on, the development of electric lighting has been very rapid, and the consumption of incandescent lamps alone has reached several millions each year. When we compare the small amount of lighting done by means of electricity twenty-five years ago with the enormous extent of lighting systems and the numerous applications of electric illumination as they are to-day, the growth and development of the art is seen to be very great, and the value of a study of this subject may be readily appreciated. While in many cases electricity is not the cheapest source of power for illumination, its admirable qualities and convenience of operation make it by far the most desirable.

CLASSIFICATION

The subject of electric lighting may be classified as follows:

1. The type of lamps used.
2. The methods of distributing power to the lamps.
3. The use made of the light, or its application.
4. Photometry and lamp testing.

The types of lamps used may be subdivided into:

1. Incandescent lamps: Carbon, metallic filament, Nernst.
2. Special lamps: Exhausted bulb without filament, such as the Cooper-Hewitt lamp and Moore tube lamp.
3. Arc lamps: Ordinary carbon, flaming arc.

INCANDESCENT LAMPS

The *incandescent lamp* is by far the most common type of lamp used, and the principle of its operation is as follows:

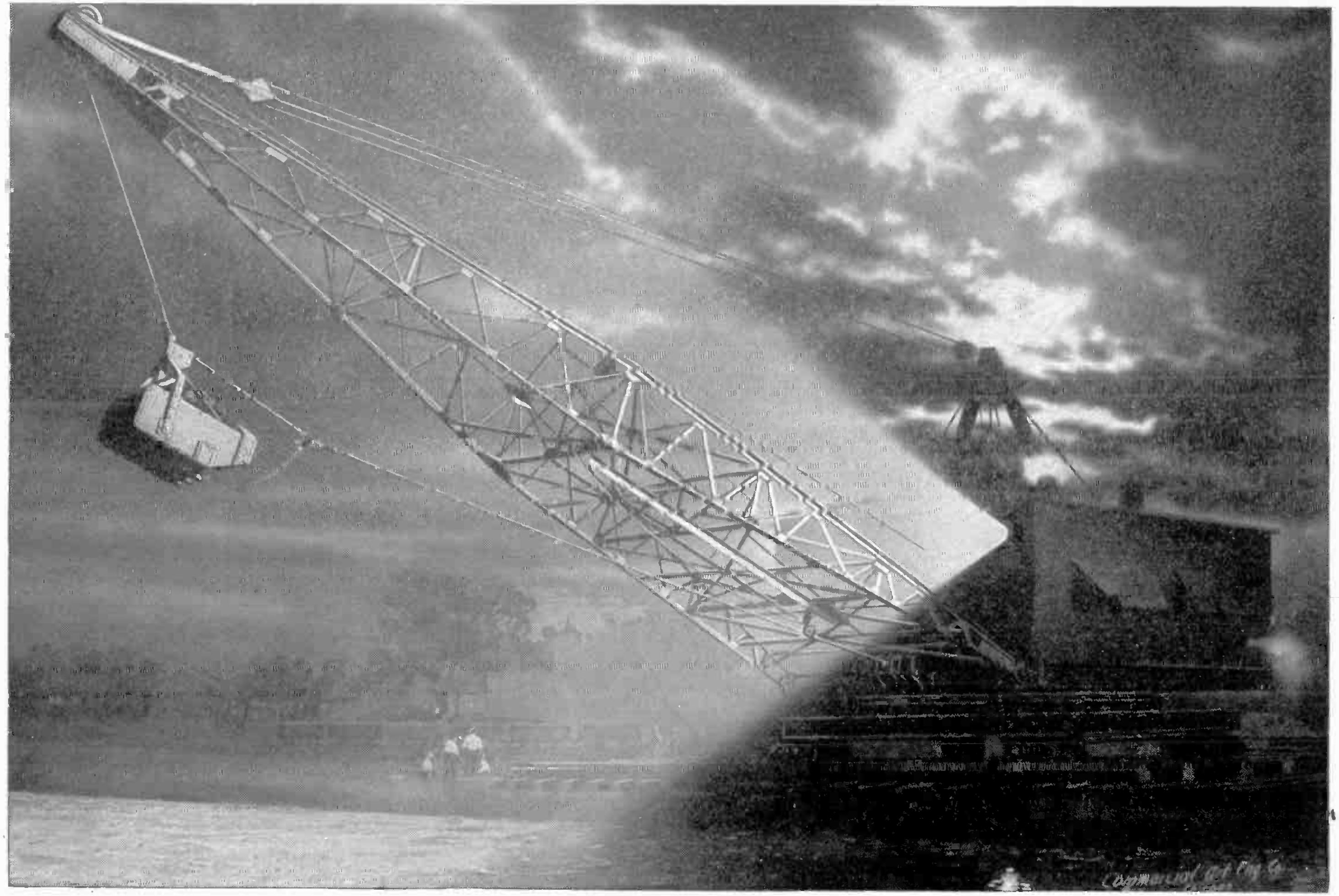
If a current I is sent through a conductor whose resistance is R, for a time t, the conductor is heated, and the heat generated = $I^2R\ t$, $I^2R\ t$ representing joules or watt-seconds.

If the current, material, and conditions are so chosen that the substance may be heated in this way until it gives out light, becomes incandescent, and does not deteriorate too rapidly, we have an incandescent lamp. Carbon was the first successful material to be chosen for this conductor and for ordinary lamps it is formed into a small thread or filament. Very recently metallic filament lamps have been introduced commercially with great success but the carbon incandescent lamp will continue to be used for some time, especially in the low candle-power units operated at commercial voltages. Carbon is a successful material for two reasons:

1. The material must be capable of standing a very high temperature, 1,280° to 1,330° C., or even higher.

2. It must be a conductor of electricity with a fairly high resistance.

Platinum was used in an early stage of the development, but, as we shall see, its temperature cannot be maintained at a value high enough to make the lamp as efficient as when carbon or a metal



EXCAVATING BY NIGHT

Illuminated by a Powerful Searchlight, Work Need not be Interrupted by the Coming of Darkness. A Lidgerwood-Crawford Excavator at Work.

having a melting point higher than that of platinum, is used. Nearly all attempts to substitute another substance in place of carbon have failed until recently, and the few lamps which are entirely or partially successful will be treated later. The nature of the carbon employed in incandescent lamps has, however, been much improved over the first forms, and owing to the still very great importance of this lamp, the method of manufacture will be considered.

Manufacture of Carbon Incandescent Lamps. *Preparation of the Filament.* Cellulose, a chemical compound rich in carbon, is prepared by treating absorbent cotton with zinc chloride in proper proportions to form a uniform, gelatine-like mass. It is customary to stir this under a partial vacuum in order to remove bubbles of air which might be contained in it and destroy its uniformity. This material is then forced, "squirted," through steel dies into alcohol, the

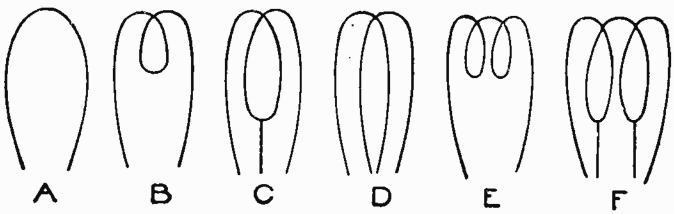


Fig. 1. Forms of Filaments now in Use.

alcohol serving to harden the soft, transparent threads. These threads are then thoroughly washed to remove all trace of the zinc chloride, dried, cut to the desired lengths, wound on forms, and carbonized by heating to a high temperature away from air. During carbonization, the cellulose is transformed into pure carbon, the volatile matter being driven off by the high temperature to which the filaments are subjected. The material becomes hard and stiff, assuming a permanent form, shrinking in both length and diameter—the form being specially constructed so as to allow for this shrinkage. The forms are made of carbon blocks which are placed in plumbago crucibles and packed with powdered carbon. The crucibles, which are covered with loosely fitting carbon covers, are gradually brought to a white heat, at which temperature the cellulose is changed to carbon, and then allowed to cool. After cooling, the filaments are removed, measured, and inspected, and the few defective ones discarded.

In the early days, these filaments were made of cardboard or bamboo, and later, of thread treated with sulphuric acid.

A few of the shapes of filaments now in use are shown in Fig. 1, the different shapes giving a slightly different distribution of light. As here shown they are designated as follows: A, U-shaped; B, single-curl; C, single-curl anchored; D, double-loop; E, double-curl; F, double-curl anchored.

Mounting the Filament. After carbonization, the filaments are mounted or joined to wires leading into the globe or bulb. These wires are made of platinum—platinum being the only substance, so far as known, that expands and contracts the same as glass, with change in temperature and which, at the same time, will not be melted by the heat developed in the carbon. Since the bulb must remain air-tight, a substance expanding at a different rate from the glass cannot be used. Several methods of fastening the filament to the *leading in* wires have been used, such as forming a socket in the end of the wire, inserting the filament, and then squeezing the socket tightly against the carbon; and the use of tiny bolts when cardboard filaments were used; but the pasted joint is now used almost exclusively. Finely powdered carbon is mixed with some adhesive compound, such as molasses, and this mixture is used as a paste for fastening the carbon to the platinum. Later, when current is sent through the joint, the volatile matter is driven off and only the carbon remains. This makes a cheap and, at the same time, a very efficient joint.

Flashing. Filaments, prepared and mounted in the manner just described, are fairly uniform in resistance, but it has been found that their quality may be much improved and their resistance very closely regulated by depositing a layer of carbon on the outside of the filament by the process of *flashing.* By flashing is meant heating the filament to a high temperature when immersed in a hydrocarbon gas, such as gasoline vapor, under partial vacuum. Current is passed through the filament in this process to accomplish the heating. Gas is used, rather than a liquid, to prevent too heavy a deposit of the carbon. Coal gas is not recommended because the carbon, when deposited from this, has a dull black appearance. The effects of flashing are as follows:

1. The diameter of the filament is increased by the deposited carbon and hence its resistance is decreased. The process must be

discontinued when the desired resistance is reached. Any little irregularities in the filament will be eliminated since the smaller sections, having the greater resistance, will become hotter than the remainder of the filament and the carbon is deposited more rapidly at these points.

2. The character of the surface is changed from a dull black and comparatively soft nature to a bright gray coating which is much harder and which increases the life and efficiency of the filament.

Exhausting. After flashing, the filament is sealed in the bulb and the air exhausted through the tube *A* in Fig. 2, which shows the lamp in different stages of its manufacture. The exhaustion is accomplished by means of mechanical air pumps, supplemented by Sprengle or mercury pumps and chemicals. Since the degree of exhaustion must be high, the bulb should be heated during the process so as to drive off any gas which may cling to the glass. When chemicals are used, as is now almost universally the case, the chemical is placed in the tube *A* and, when heated, serves to take up much of the remaining gas. Exhaustion is necessary for several reasons:

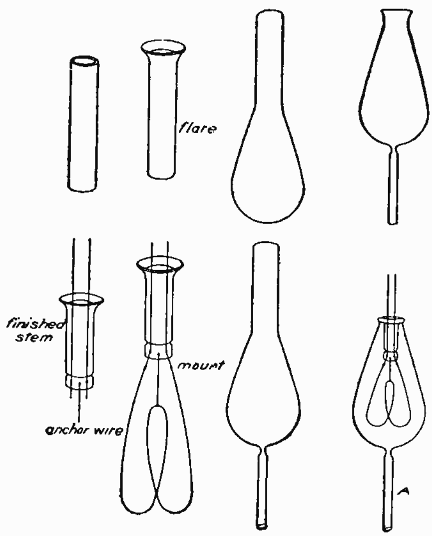


Fig. 2. Different Stages in Lamp Manufacture.

1. To avoid oxidization of the filament.
2. To reduce the heat conveyed to the globe.
3. To prevent wear on the filament due to currents or eddies in the gas.

After exhausting, the tube *A* is sealed off and the lamp completed for testing by attaching the base by means of plaster of Paris. Fig. 3 shows some of the forms of completed incandescent lamps.

Voltage and Candle-Power. Incandescent lamps of the carbon type vary in size from the miniature battery and candelabra lamps to those of several hundred candle-power, though the latter are very seldom used. The more common values for the candle-power are

8, 16, 25, 32, and 50, the choice of candle-power depending on the use to be made of the lamp.

The voltage will vary depending on the method of distribution of the power. For what is known as *parallel distribution,* 110 or 220 volts are generally used. For the higher values of the voltage, long and slender filaments must be used, if the candle-power is to be low; and lamps of less than 16 candle-power for 220-volt circuits are not practical, owing to difficulty in manufacture. For series distribution, a low voltage and higher current is used, hence the filaments may be quite heavy. Battery lamps operate on from 4 to 24 volts, but the vast majority of lamps for general illumination are operated at or about 110 volts.

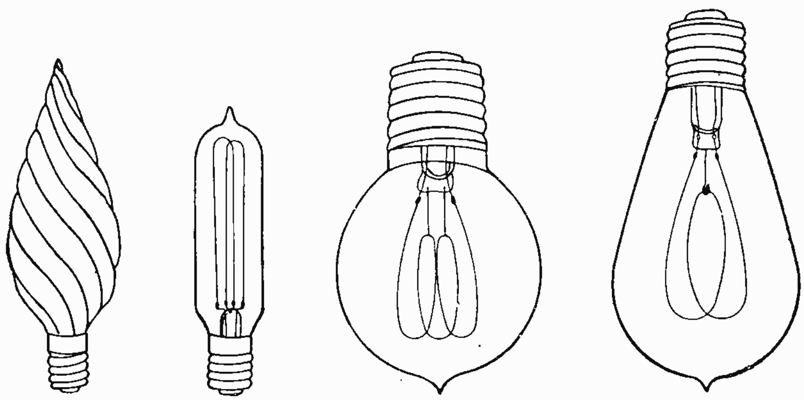


Fig. 3. Several Forms of Completed Lamps.

Efficiency. By the efficiency of an incandescent lamp is meant the power required at the lamp terminals per candle-power of light given. Thus, if a lamp giving an average horizontal candle-power of 16 consumes $\frac{1}{2}$ an ampere at 112 volts, the total number of watts consumed will be $112 \times \frac{1}{2} = 56$, and the watts per candle-power will be $56 \div 16 = 3.5$. The efficiency of such a lamp is said to be 3.5 watts per candle-power, or simply watts per candle. *Watts economy* is sometimes used for *efficiency.*

The efficiency of a lamp depends on the temperature at which the filament is run. In the ordinary lamp this temperature is between 1,280° and 1,330° C, and the curve in Fig. 4 shows the increase of efficiency with the increase of temperature. The temperature attained by a filament depends on the rate at which heat is radiated and the amount of power supplied. The rate of radiation of heat is proportional to the area of the filament, the elevation in temperature, and the emissivity of the surface.

By emissivity is meant the number of heat units emitted from unit surface per degree rise in temperature above that of surrounding bodies. The bright surface of a flashed filament has a lower emissivity than the dull surface of an unheated filament, hence less energy is lost in heat radiation and the efficiency of the filament is increased.

As soon as incandescence is reached, the illumination increases much more rapidly than the emission of heat, hence the increase in

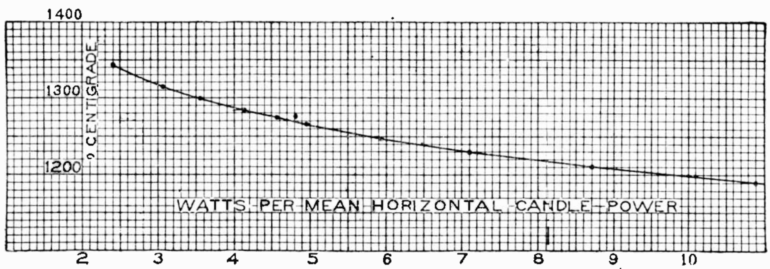


Fig. 4. Efficiency Curve for Incandescent Lamp.

efficiency shown in Fig. 4. Were it not for the rapid disintegration of the carbon at high temperature, an efficiency higher than 3.1 watts could be obtained.

By a special treatment of the carbon filaments, the nature of the carbon is so changed that the filaments may be run at a higher temperature and the lamps still have a life comparable to that of the 3.1-watt lamp. Lamps using these special carbon filaments are known as *gem metallized filament lamps*, or merely as *gem lamps*, and they will be described more fully later.

Relation of Life to Efficiency. *Ordinary Carbon Lamp.* By the useful life of a lamp is meant the length of time a lamp will burn before its candle-power has decreased to such a value that it would be more economical to replace the lamp with a new one than to continue to use it at its decreased value. A decrease to 80% of the initial candle-power of carbon lamps is now taken as the point at which a lamp should be replaced, and the normal life of a lamp is in the neighborhood of 800 hours. To obtain the most economical results, such lamps should always be replaced at the end of their useful life.

In Table I are given values of efficiency and life of a 3.5-watt, 110-volt carbon lamp for various voltages impressed on the lamp. These values are plotted in Fig. 5. The curves show that a 3% increase of voltage on the lamp reduces the life by one-half, while an increase of 6% causes the useful life to fall to one-third its normal value. The effect is even greater when 3.1-watt lamps are used, but not so great with 4-watt lamps. From this we see that the regulation of the voltage used on the system must be very good if high efficiency lamps are to be used, and this regulation will determine the efficiency of the lamp to be installed.

Selection of Lamps. *Ordinary Carbon Type.* Lamps taking 3.1 watts per candle-power will give satisfaction only when the regulation of voltage is the best—practically a constant voltage maintained at the normal voltage of the lamp.

TABLE I

Effects of Change in Voltage

Standard 3.5-Watt Lamp

Voltage Per Cent. of Normal	Candle-Power Per Cent. of Normal	Watts Per Candle-Power	Life Per Cent. of Normal	Deterioration Per Cent. of Normal
90	53	5.36		
91	56	5.09		
92	61	4.85		
93	65	4.63		
94	69	4.44	394	25
95	73	4.26	310	32
96	78	4.09	247	44
97	83	3.93	195	51
98	88	3.78	153	65
99	94	3.64	126	79
100	100	3.5	100	100
101	106	3.38	84	118
102	111	3.27	68	146
103	116	3.16	58	173
104	123	3.05	47	211
105	129	2.95	39	253
106	137	2.85	31	316
107	143	2.76	26	380
108	152	2.68	21	474
109	159	2.60	17	575
110	167	2.53	16	637

Lamps of 3.5 watts per candle-power should be used when the regulation is fair, say with a maximum variation of 2% from the normal voltage.

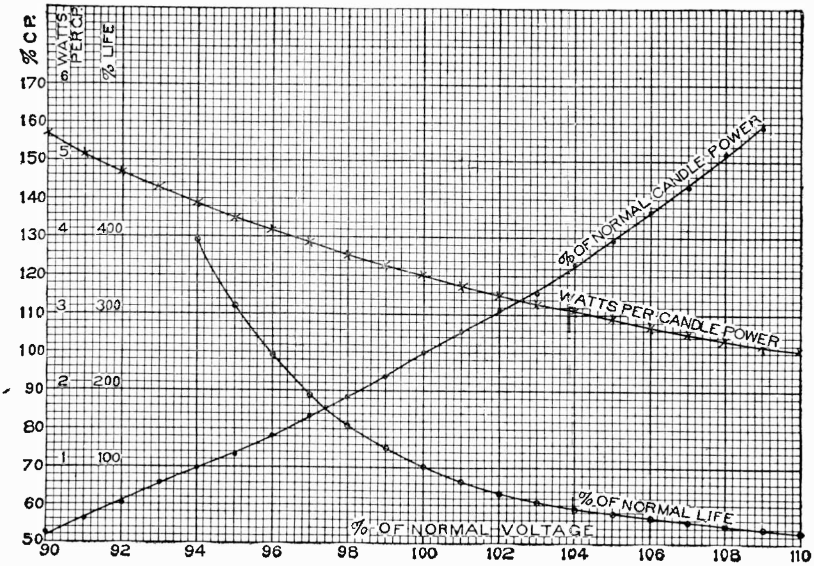


Fig. 5. Curves of Efficiency and Life of Carbon Filament Lamps.

Lamps of 4 watts per candle-power should be installed when the regulation is poor. These values are for 110-volt lamps. A 220-volt lamp should have a lower efficiency to give a long life. This is on

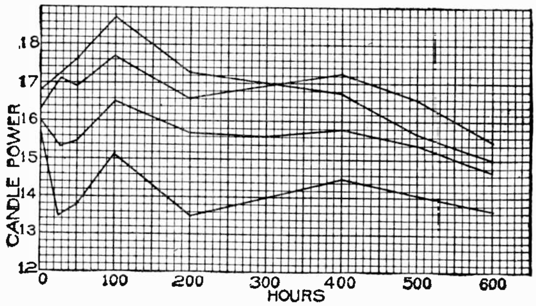


Fig. 6. Life Curves of Incandescent Lamps.

account of the fact that, for the same candle-power, the 220-volt lamp must be constructed with a filament which is long and slender compared to that of the 110-volt lamp, and if such a filament is run at a high temperature its life is short. The 220-volt lamp is used to some considerable extent abroad but it is not employed extensively in the United States. It is customary to operate such lamps at an efficiency of about 4 watts per candle-power.

Lamps should always be renewed at the end of their useful life, this point being termed the *smashing-point,* as it is cheaper to replace the lamp than to run it at the reduced candle-power. Some recommend running these lamps at a higher voltage, but that means at a reduced life, and it is not good practice to do this.

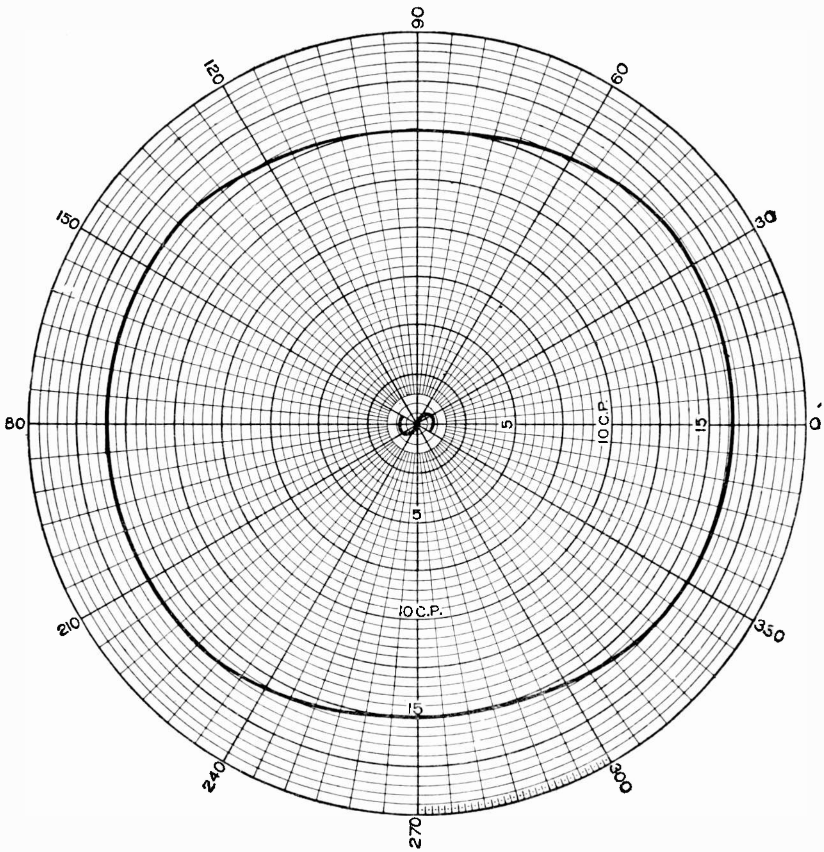


Fig. 7. Horizontal Distribution Curve for Single-Loop Filament.

Fig. 6 shows the life curves of a series of incandescent lamps. These curves show that there is an increase in the candle-power of some of the lamps during the first 100 hours, followed by a period during which the value is fairly constant, after which the light given by the lamp is gradually reduced to about 80% of the initial candle-power.

Distribution of Light. In Fig. 1 are shown various forms of filaments used in incandescent lamps, and Figs. 7 and 8 show the distribution of light from a single-loop filament of cylindrical cross-section. Fig. 7 shows the distribution of light in a horizontal plane, the lamp being mounted in a vertical position, and Fig. 8 shows the dis-

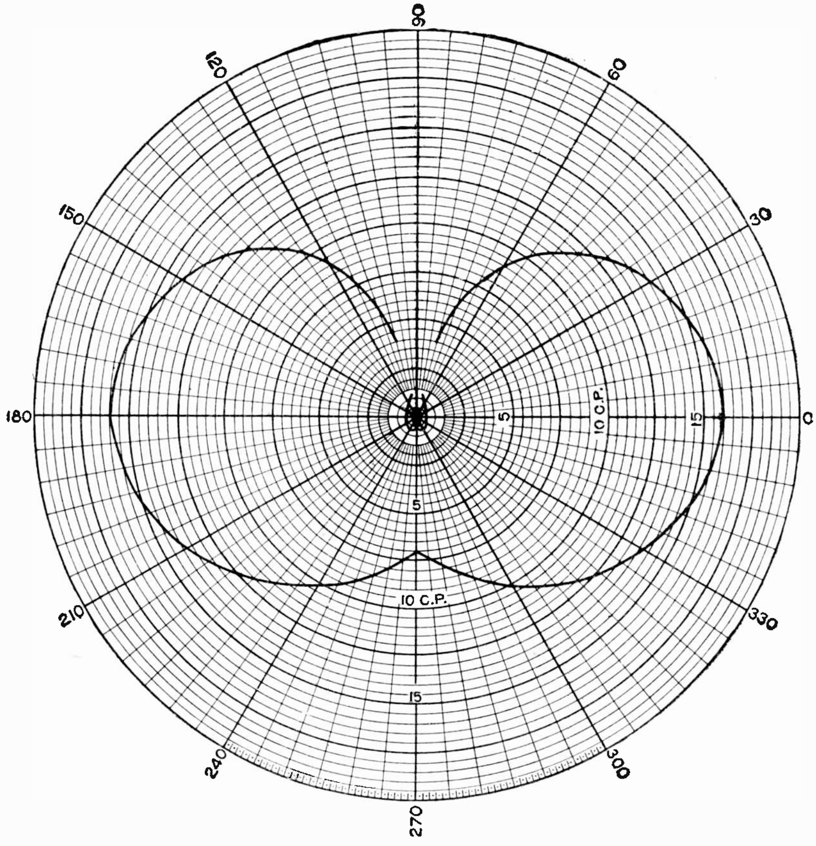


Fig. 8. Vertical Distribution Curve for Single-Loop Filament.

tribution in a vertical plane. By changing the shape of the filament, the light distribution is varied. A mean of the readings taken in the horizontal plane forms the *mean horizontal candle-power,* and this candle-power rating is the one generally assumed for the ordinary incandescent lamp. A mean of the readings taken in a vertical plane gives us the mean vertical candle-power, but this value is of little use.

Mean Spherical Candle-Power. When comparing lamps which give an entirely different light distribution, the mean horizontal candle-power does not form a proper basis for such comparison, and the mean spherical or the mean hemispherical candle-power is used instead. By *mean spherical candle-power* is meant a mean value of the light taken in all directions. The methods for determining this will be taken up under *photometry*. The mean hemispherical candle-power has reference, usually, to the light given out below the horizontal plane.

The Gem Metallized Filament Lamp. When the incandescent lamp was first well established commercially, the useful life of a unit, when operated at 3.1 watts per candle, was about 200 hours. The improvements in the process of manufacture have been continuous from that time until now, and the useful life of a lamp operated at that efficiency to-day is in the neighborhood of 500 hours. Experiments in the treatment of the carbon filament have led to the introduction of the *gem metallized filament lamp.* This lamp should not be confused with the metallic filament lamps, to be described later, because the material used is carbon, not a metal. As a result of special treatment the carbon filament assumes many of the characteristics of a metallic conductor, hence the term *metallized filament.* The word *graphitized* has been proposed in place of metallized.

TABLE II

*** Data on the Gem Metallized Filament Lamp**

Watts	Horizontal C. P.	Watts per Candle	†Spherical Reduction Factor	§ Useful Life
40	16	2.5	.816	450 hrs.
50	20	2.5	.825	450 "
80	32	2.5	.816	450 "
100	40	2.5	‡	460 "
125	50	2.5	‡	450 "
187.5	75	2.5	‡	450 "
250	100	2.5	‡	450 "

* These lamps are normally rated at three voltages, 114, 112, and 110 volts, but data referring to the highest voltage only are given.

† By spherical reduction factor is meant the factor by which the horizontal candle-power must be multiplied to obtain the mean spherical candle-power.

‡ The larger units are almost invariably used with reflectors, hence no spherical reduction factor is given.

§ The life of the lamps when operated at the lower voltage is increased to about 950 hours, and the efficiency is changed to 2.83 watts per candle.

When a filament, as treated in the ordinary manner, is run at a high temperature in a lamp there is no improvement of the filament, but it was discovered that, if the treated filaments were subjected to the extremely high temperature of the electric resistance furnace—3,000 to 3,700 degrees C.—at atmospheric pressure, the physical nature of the carbon was changed and the resulting filament could be operated at a higher temperature in the lamp and a higher efficiency,

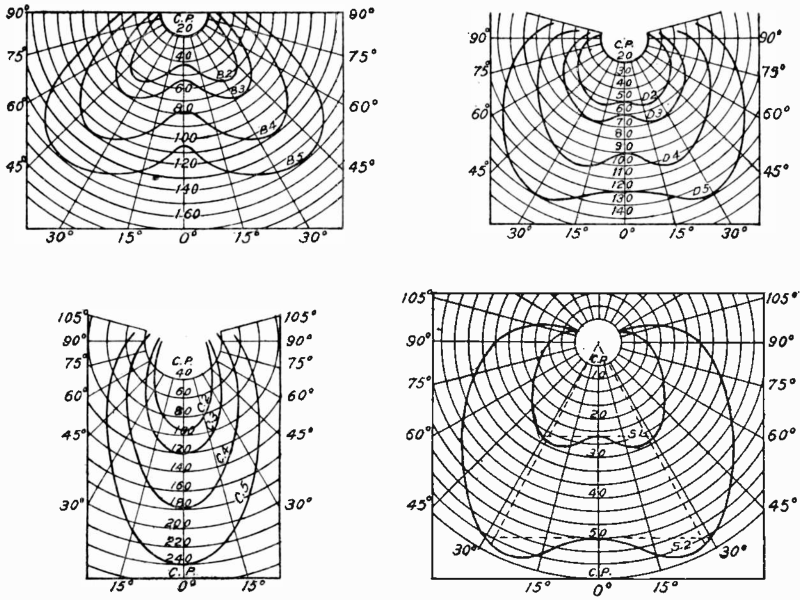


Fig. 9. Typical Distribution Curves of Gem Lamp with Different Types of Reflectors.

and still maintain a life comparable to that of a 3.1-watt lamp. This special heating of the filament, which is applied to the base filament before it is flashed, as well as to the treated filament, causes the cold resistance of the carbon to be very materially decreased and the filament, as used in the lamp, has a positive temperature coefficient—rise in resistance with rise in temperature—a desirable feature from the standpoint of voltage regulation of the circuit from which the lamps are operated. The high temperature also results in the driving off of considerable of the material which, in the ordinary lamp, causes the globe to blacken after the lamp has been in use for some time. The blackening of the bulb is responsible to a considerable degree for the decrease in candle-power of the incandescent lamp. The metallized filament lamp is operated at an efficiency of 2.5 watts per candle with a useful life of about 500 hours. The change in candle-power with change in voltage is less than in the ordinary lamp on account of the positive temperature coefficient of the filament. These lamps are not manufactured for very low candle-powers, owing to the difficulty of treating very slender filaments, but they are made in sizes consuming from 40 to 250 watts. Table II gives some useful information in connection with metallic filament lamps. The filaments are made in a variety of shapes and the distribution curves are usually modified in practice by the use of shades and reflectors. The general appearance of the lamp does not differ from that of the ordinary carbon lamp. Fig. 9 shows typical distribution curves of the metallized filament lamp as it is installed in practice.

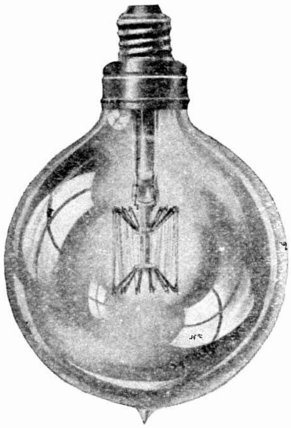


Fig. 10. Round Bulb Tantalum Lamp.

Metallic Filament Lamps. *The Tantalum Lamp.* The first of the metallic filament lamps to be introduced to any considerable extent commercially was the tantalum lamp. Dr. Bolton of the Siemens & Halske Company first discovered the methods of obtaining the pure metal tantalum. This metal is rendered ductile and drawn into slender filaments for incandescent lamps. Tantalum has a high tensile strength and high melting point, and tantalum filaments are operated at temperatures much higher than those used with the carbon filament lamp. On account of the comparatively low specific resistance of this material the filaments for 110-volt lamps must be long and slender, and this necessitates a special form of support. Figs. 10, 11, and 12 show some interesting views of the tantalum lamp and the filament. This lamp is operated at the efficiency of 2 watts per

Fig. 11. Tantalum Filament Before and After 1,000 Hours' Use.

candle-power, with a life comparable to that of the ordinary lamp. By special treatment it is possible to increase the resistance of the filaments so that they may be shorter and heavier than those used in

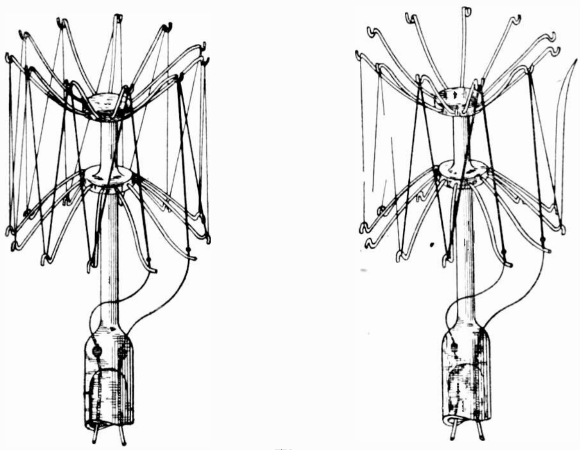


Fig. 12.

Appearance of Filament After Having Been Used.

Filament Frame Showing Broken Filament.

the first of the tantalum lamps. It should be noted that the life of this type of lamp on alternating-current circuits is somewhat uncertain; it is much more satisfactory for operation on direct-current circuits. Tables III and IV give some general data on the tantalum lamp, and Figs. 13 and 14 show typical distribution curves for the units as installed at present.

TABLE III

Data on Tantalum Lamp

GENERAL ELECTRIC CO., MFTRS.

Size of Bulb		Diameter of Bulb in Inches	Estimated Life	
Regular	Round		on A. C.	on D. C.
40 watt		$2\frac{5}{16}$	350	800
50 "		$2\frac{5}{16}$	350	800
80 "		$3\frac{1}{8}$	400	800
	40 watt	$3\frac{3}{4}$	350	800
	80 "	5	400	800

TABLE IV

Data on the Life of a 25-C. P. Unit

No. of Hours Burned	Candle-Power	Watts per Candle
0	19.8	2.17
25	23.6	1.865
50	23.1	1.90
125	22.3	1.98
225	22.4	1.96
350	22.3	1.97
450	22.2	1.98
550	21.2	2.05
650	19.6	2.20

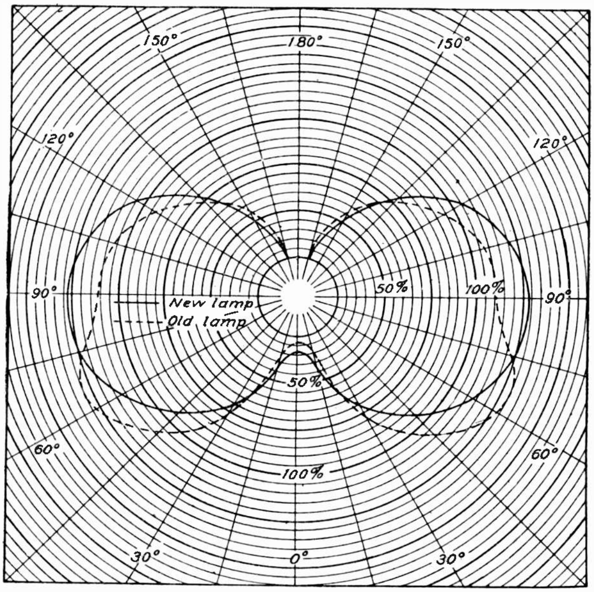


Fig. 13. Vertical Distribution Curve Without Reflector.

The Tungsten Lamp. Following closely upon the development of the tantalum lamp came the tungsten lamp. Tungsten possesses a very high melting point and an indirect method is employed in forming filaments for incandescent lamps. There are several of these methods in use. In one method a fine carbon filament is flashed in an atmosphere of tungsten oxychloride mixed with just the proper proportion of hydrogen, in which case the filament gradually changes to one of tungsten. A second method consists of the use of powdered tungsten and some binding material, sometimes organic and in other cases metallic. The powdered tungsten is mixed with the binding material, the paste squirted into filaments, and the binding material is then expelled, usually by the aid of heat. Another method of manufacture consists of securing tungsten in colloidal form, squirting it

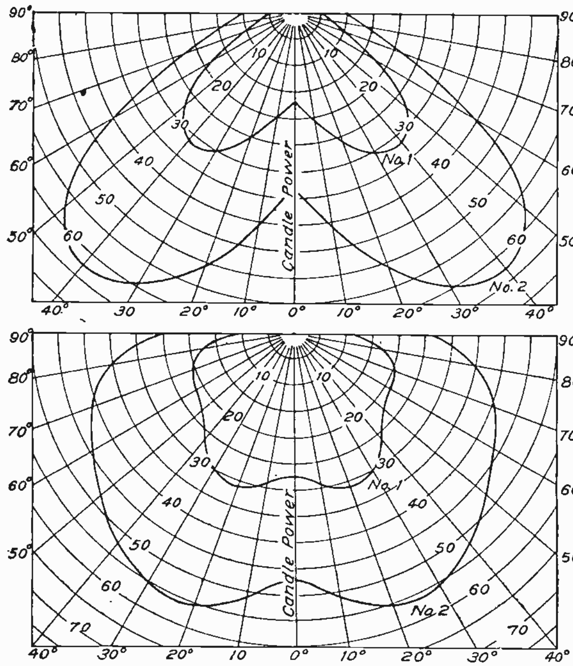


Fig. 14. Distribution Curves for Tantalum Lamp. No. 1, 40 Watts; No. 2, 80 Watts.

into filaments, and then changing them to the metallic form by passing electric current through the filaments.

The tungsten lamp has the highest efficiency of any of the commercial forms of metallic filament lamps now in use, about 1.25 watts per candle-power when operated so as to give a normal life, and lamps for 110-volt service and consuming but 40 watts have recently been put on the market. A 25-watt lamp for this same voltage appears to be a possibility. The units introduced at first were of high candle-power because of the difficulty of manufacturing the slender filaments required for the low candle-power lamps.

The advantages of these metals, tantalum and tungsten, for incandescent lamps are in the improved efficiency of the lamps and the good quality of the light, white or nearly white in both cases. In either case the change in candle-power with change in voltage is less than the corresponding change in an ordinary carbon lamp. The disadvantage lies in the fact that the filaments must be made long and slender, and hence are fragile, for low candle-power units to be used

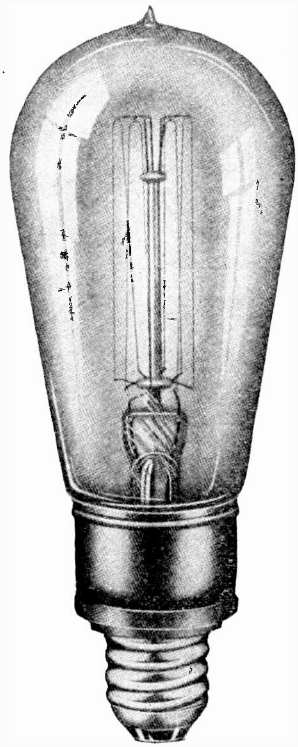


Fig. 15. Multiple Tungsten Lamp.

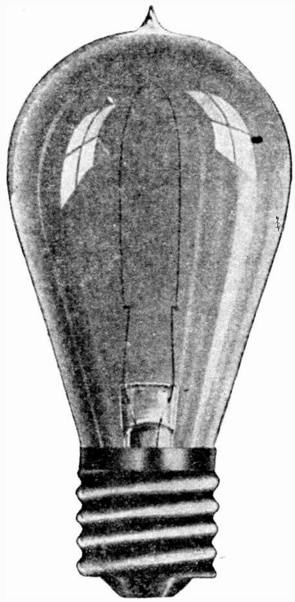
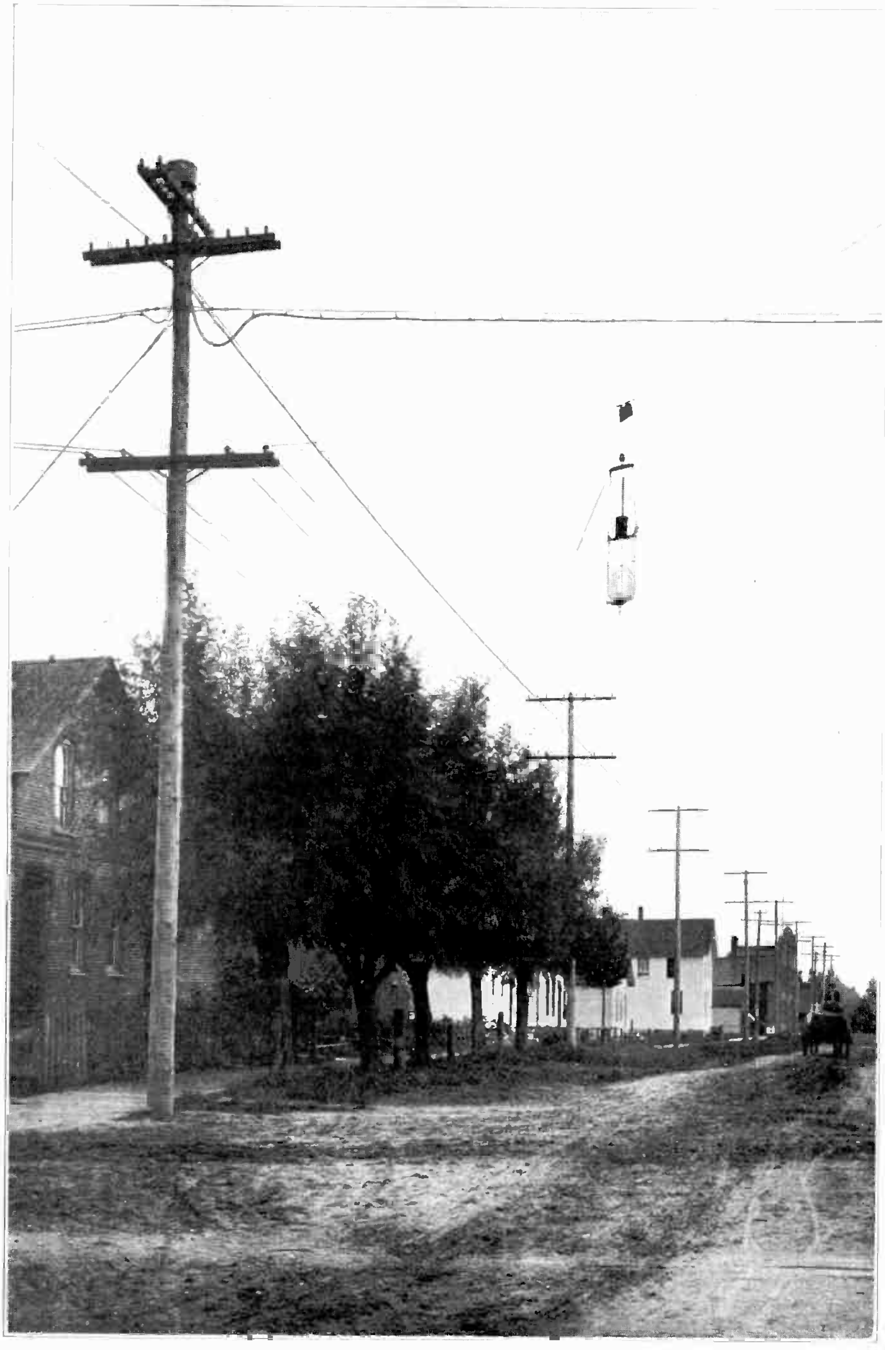


Fig. 16. Series Tungsten Lamp.

on commercial voltages. In some cases tungsten lamps are constructed for lower voltages and are used on commercial circuits through the agency of small step-down transformers. Improvements in the process of manufacture of filaments and of the method of their support have resulted in the construction of 110-volt lamps for candle-powers lower than was once thought possible. Figs. 15 and 16 show the appearance of the tungsten lamp, and Figs. 17 and 18 give some



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typical distribution curves. Tables V and VI give data on this lamp as it is manufactured at present. One very considerable application

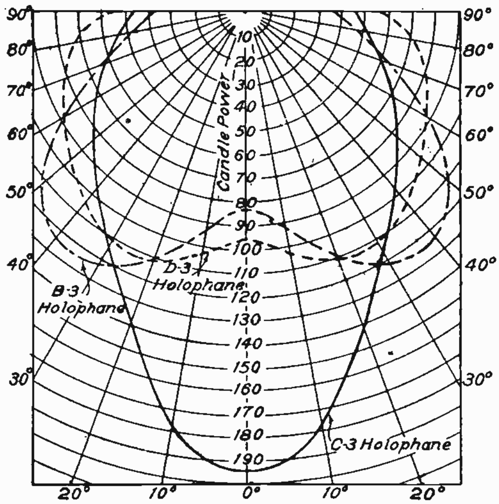


Fig. 17. C. P. Distribution Curves of 100-Watt Gen. Elec. Tungsten Incandescent Units with B-3, C-3, and D-3 Holophanes.

of the tungsten lamp is to incandescent street lighting on series circuits, in which case the lamp may be made for a low voltage across its terminals and the filament may be made comparatively short and

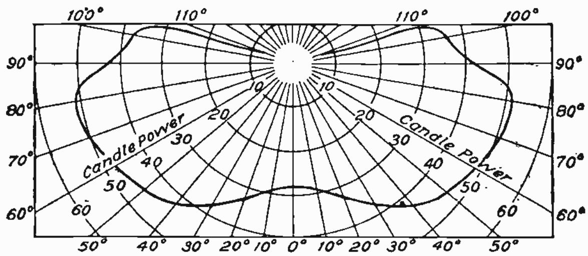


Fig. 18. Candle-Power Distribution Given with 40 c. p Gen. Elec. Tungsten Series Lamp and Radial Wave Reflector.

heavy. The tungsten lamp is also being introduced as a low voltage battery lamp.

The Just lamp, the Z lamp, the Osram lamp, the Zircon-Wolfram lamp, the Osmin lamp, etc., are all tungsten lamps, the filaments being prepared by some of the general methods already described or modifications of them.

TABLE V
Tungsten Lamps
MULTIPLE

Watts	Volts	Candle-Power	Watts per C. P.	Tip Candle-Power	Spherical Reduction Factor
40	100	32	1.25	5	76.3
60	125	40	1.25	5.6	76.3

TABLE VI
Tungsten Lamps
SERIES

Amperes	Volts	Candle-Power	Watts per C. P.
4	13.5 20.25	40 60	1.35
5.5	9.8 14.7	40 60	1.35
6.6	8.2 12.3	40 60	1.35
7.5	7.2 10.8	40 60	1.35

The Osmium Lamp. Very efficient incandescent lamps have been constructed using osmium for the filament. An indirect method is resorted to in the formation of these filaments. Osmium lamps have not been successful for commercial voltages because the filament is too fragile if it is made to have a high resistance, so these lamps must be operated in series or through the agency of reducing transformers if they are to be applied to 110-volt circuits. At 25 volts, lamps are constructed giving an efficiency of about 1.5 watts per candle-power with a life comparable to that of a 3.5-watt carbon lamp. Owing to the introduction of the tungsten lamp, the osmium lamp will probably never be used to any great extent.

Other Metallic Filament Lamps. Table VII gives the melting points of several metals which are highly refractory and those already mentioned are not the only ones which have been successfully used in incandescent lamps. Titanium, zirconium, iridium, etc., have been successfully employed, but the tantalum and tungsten lamps are the only ones which are used to any extent in the United States.

TABLE VII

Melting Point of Some Metals

Metal	Approximate Melting Point in Degrees C.
Tungsten	3080–3200
Titanium	3000
Tantalum	2900
Osmium	2500
Platinum	1775
Zirconium	1500
Silicon	1200
Carbon (not a metal)	3000

The Helion Lamp. The helion lamp, which gives considerable promise of commercial development, is a compromise between the carbon lamp and the metallic filament lamp. A slender filament of carbon is flashed in a compound of silicon (gaseous state) and a filament composed of a carbon core more or less impregnated with silicon and coated with a metallic layer is formed. The emissivity of such a filament is high, the light is white in color, and the filament is strong. The efficiency of the helion filament as far as it has been developed is higher than that of a carbon filament when operated at the same temperature. At 1,500 degrees C. the efficiency of the helion filament is 2.15 watts per candle-power, while for a carbon filament it is about 3.5 watts per candle-power. Filaments of this type have been made which may be heated to incandescence in open air without immediate destruction. This lamp is not yet on the market.

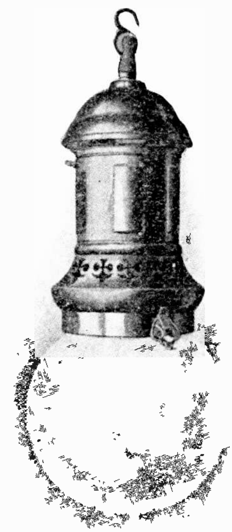


Fig. 19. Westinghouse Nernst Multiple-Glower Lamp.

The Nernst Lamp. The Nernst lamp is still another form of incandescent lamp, several types of which are shown in Figs. 19, 20, 21, and 22. This lamp uses for the incandescent material certain oxides of the rare earths, the oxides being mixed in the form of a paste, then squirted through a die into a string which is subjected to a roasting process forming the filament or *glower* material of the lamp as represented by the lower white line in Fig. 23. The more recent glowers are made hollow instead of solid. The glowers are cut to the desired length and platinum terminals attached. The attachment of these terminals to the glowers is an important process in the manufacture of the lamp. The recent discovery of additional oxides has led to the construction of glowers which show a considerable gain in efficiency over those previously used. The glowers are heated to incandescence in open air, a vacuum not being required.

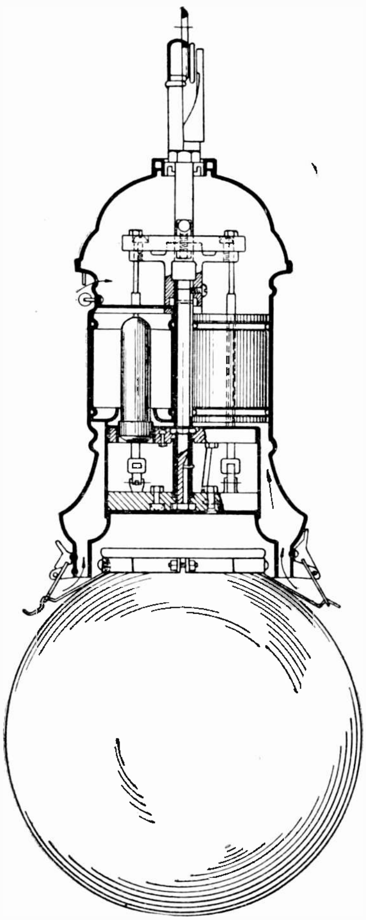


Fig. 20. Sectional View of Multiple-Glower Westinghouse Nernst Lamp.

As the glower is a non-conductor when cold, some form of *heater* is necessary to bring it up to a temperature at which it will conduct. Two forms of heater have been used. One of them consists of a porcelain tube shown just above the glower, Fig. 23, about which a fine platinum wire is wound; the wire is in turn coated with a cement. Two or more of these tubes are mounted directly over the glower, or glowers, and serve as a reflector as well as a heater. The second form of heater consists of a slender rod of refractory material about which a platinum wire is wound, the wire again being covered with a cement. This rod is then formed into a spiral which surrounds the glower in the vertical glower type, or is formed into the *wafer heater*, Fig. 24, now universally employed in the Westinghouse Nernst lamp with horizontal glowers. The wafer heater is bent so that it can be mounted with several sections parallel to the glower or glowers.

The heating device is connected across the circuit when the lamp is first turned on, and it must be cut out of circuit after the glowers become conductors in order to save the energy consumed by the

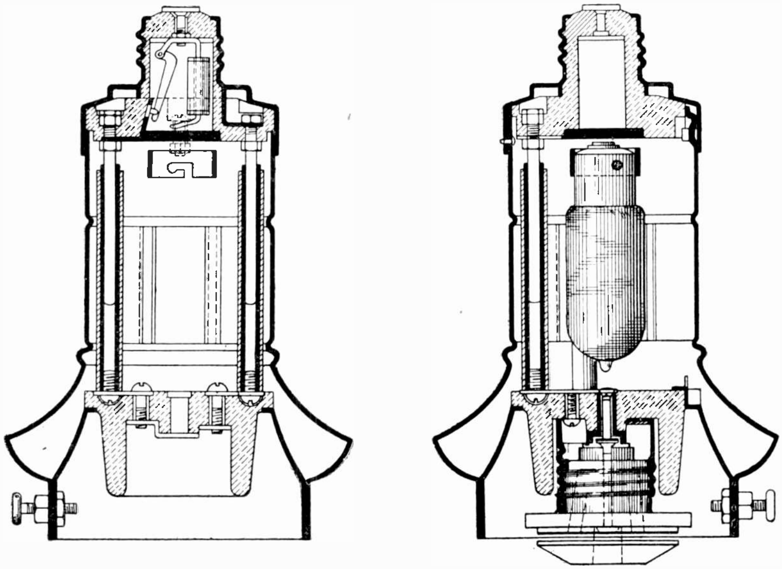


Fig. 21. Sectional Views of Single-Glower Westinghouse Nernst Lamp.

heater and to prolong the life of the heater. The automatic *cut-out* is operated by means of an electromagnet so arranged that current flows through this magnet as soon as the glower becomes a conductor, and contacts in the heater circuit are opened by this magnet. The contacts in the heater circuit are kept normally closed, usually by the force of gravity.

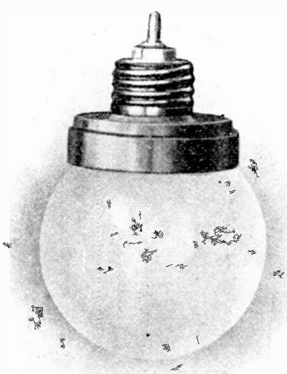


Fig. 22. Westinghouse Nernst Screw Burner.

The conductivity of the glower increases with the increase of temperature—the material has a negative temperature coefficient—hence if it were used on a constant potential circuit directly, the current and temperature would continue to rise until the glower was destroyed. To prevent the current from increasing beyond the desired value, a *ballast resistance* is used in series with the glower. As is well known, the resistance of iron wire increases quite rapidly with increase in temperature, and the resistance of a fine pure iron wire is so adjusted that the resistance of the combined circuit of the glower and the ballast becomes constant at the desired temperature of the glower. The iron wire must be protected from the air to prevent oxidization and too rapid temperature changes, and, for this reason, it is mounted in a glass bulb filled with hydrogen. Hydrogen has been selected for this purpose because it is an inert gas and conducts the heat from the ballast to the walls of the bulb better than other gases which might be used.

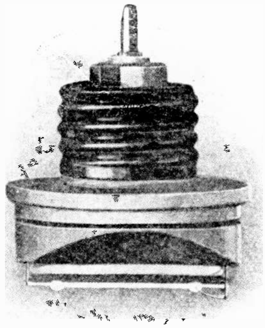


Fig. 23. Westinghouse Nernst Screw Burner with Globe Removed, Showing Glower and Tubular Heater.

All of the parts enumerated, namely, glower, heater, cut-out, and ballast, are mounted in a suitable manner; the smaller lamps have but one glower and are arranged to fit in an incandescent lamp socket, while the larger types are constructed at present with four glowers

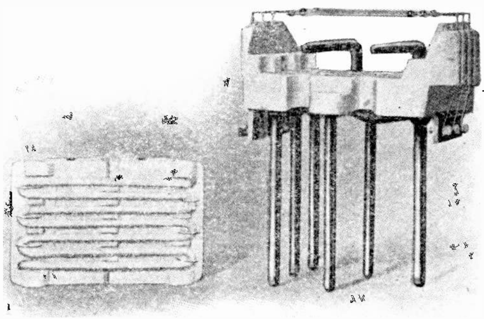


Fig. 24. Wafer Heater and Mounting.

and are arranged to be supported in special fixtures, or the same as small arc lamps. All parts are mechanically arranged so that renewals may be easily made when necessary and it is not possible to insert a part belonging to one type of lamp into a lamp of a different type.

The advantages claimed for the Nernst lamp are: High efficiency; a good color of light; a good distribution of light without the use of reflectors; a long life with low cost of maintenance; and a complete series of sizes of units, thus allowing its adaption to practically all classes of illumination.

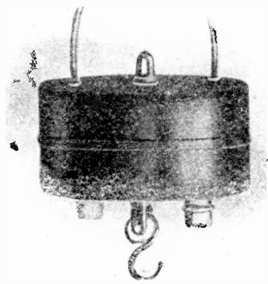


Fig. 25. Converter Coil.

The lamp is constructed for both direct- and alternating-current service and for 110 and 220 volts. When the alternating-current lamp is used on a 110-volt circuit a small transformer, commonly called a *converter coil*, Fig. 25, is utilized to raise the voltage at the lamp terminals to about 220 volts.

Data on the Nernst lamp in its present form are given in Table VIII, and Figs. 26 and 27 show the form of distribution curves.

TABLE VIII

General Data on the Nernst Lamp

Lamp Rating in Watts	Voltage	Current in Amperes	Max. Candle-Power	Mean Hemispherical c. p.	Watts per M. H. S. c. p. from Test		
66	110	.6	74	50	1.38	1-Glower	A.C. or D.C.
88	220	.4	105	77	1.2	1-Glower	A.C. or D.C.
110	110 220	1.0 .5	131	96.4	1.2	1-Glower	A.C. or D.C.
132	110 220	1.2 .6	156	114	1.2	1-Glower	A.C. or D.C.
264	220	1.2	345	231	1.2	2-Glower	A.C. or D.C.
396	220	1.8	528	359	1.15	3-Glower	A.C. or D.C.
528	220	2.4	745	504	1.09	4-Glower	A.C. or D.C.

Comparison of the Different Types of Incandescent Lamps. A direct comparison of the different types of incandescent lamps cannot be made but it is desirable at this time to note the following points: The lamps which are considered commercial in the United States at the present time are the carbon, gem, tantalum, tungsten, and Nernst lamp. The efficiencies ordinarily accepted run in the order given, approximately 3.1, 2.5, 2, 1.25, and 1.2 watts per candle respectively. The figure of 1.2 watts per candle for the Nernst lamp is based upon the mean hemispherical candle-power and it should not be compared directly with the other efficiencies. The color of the light in all of the above cases is suitable for the majority of classes of illumination, the light from the higher efficiency units being somewhat whiter than that from the carbon lamp. All of these lamps are constructed for commercial voltages and for either direct or alternating current. The use of the tantalum lamp on alternating current is not

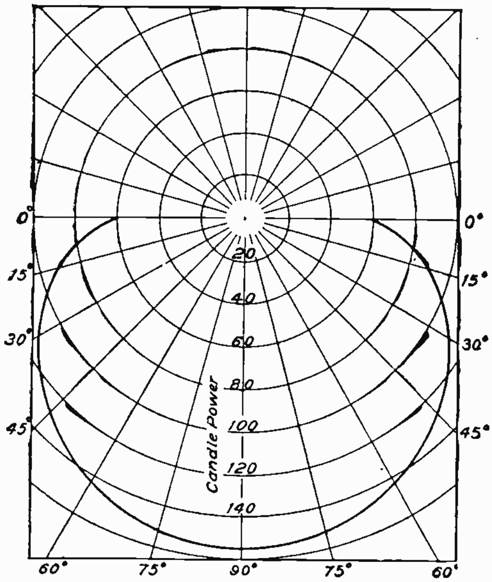


Fig. 26. Distribution Curve of 132-Watt Type Westinghouse Nernst Lamp. Single Glower.

always to be recommended as the service is unsatisfactory in some cases. The minimum size of units for 110 volts is about 4 candle-power for the carbon lamp, 20 candle-power for the metallic filament lamp, and 50 candle-power (mean hemispherical) for the Nernst lamp. Some of the metallic filament lamps are constructed for a consumption of as high as 250 watts, while the largest size of the Nernst lamp uses 528 watts. The light distribution of any of the units is subject to considerable variation through the agency of reflectors, but the Nernst lamp is ordinarily installed without a reflector. Practically all of the other units of high candle-power use reflectors and only a few of the typical curves of light distribution curves with reflectors have been shown in connection with the description of the lamps. The life of all of the commercial lamps described is considered as satisfactory. The minimum life is seldom less than 500 hours and the useful life is generally between 500 and 1,000 hours. On account of the slender filaments employed in the metallic filament

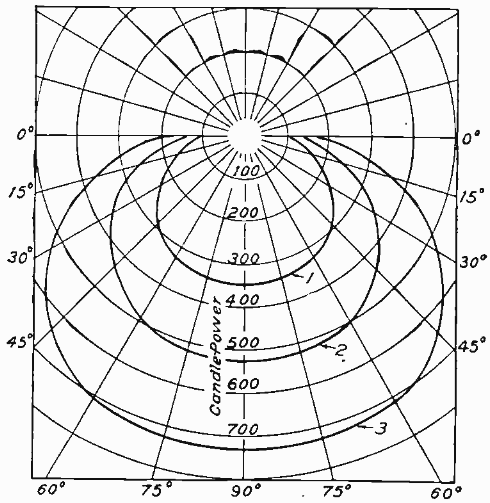


Fig. 27. Distribution of Light from Multiple-Glower Westinghouse Nernst Lamps with 8″ Clear Globes. No. 1, 2 Glower; No. 2, 3 Glower; No. 3, 4 Glower.

lamps they are not made for low candle-powers at commercial voltages. The introduction of transformers for the purpose of changing the circuit voltage to one suitable for low candle-power units has not become at all general as yet in this country.

SPECIAL LAMPS

The Mercury Vapor Lamp. The mercury vapor lamp in this country is put on the market by the Cooper-Hewitt Electric Company and it is being used to a considerable extent for industrial illumination. In this lamp mercury vapor, rendered incandescent by the passage of an electric current through it, is the source of light. In its standard form this lamp consists of a long glass tube from which the air has been carefully exhausted, and which contains a small amount of metallic mercury. The mercury is held in a large bulb at one end of the tube and forms the negative electrode in the direct-current lamp. The other electrode is formed by an iron cup and the connections between the lamp terminals and the electrodes are of platinum where this connection passes through the glass. Fig. 28 gives the general appearance of a standard lamp having the following specifications:

Total watts (110 volts, 3.5 amperes) = 385
Candle-power (M. H. with reflector) = 700
Watts per candle = 0.55
Length of tube, total = 55 in.
Length of light-giving section = 45 in.
Diameter of tube = 1 in.
Height from lowest point of lamp to ceiling plate = 22 in.
For 220-volt service two lamps are connected in series.

The mercury vapor, at the start, may be formed in two ways: First, the lamp may be tipped so that a stream of mercury makes contact between the two electrodes and mercury is vaporized when the stream breaks. Second, by means of a high inductance and a quick break switch, a very high voltage sufficient to pass a current from one electrode to the other through the vacuum, is induced and the conducting vapor is formed. The tilting method of starting is preferred and this tilting is brought about automatically in the more recent types of lamp Fig. 29 shows the connections for automatically starting two lamps in series. A steadying resistance and reactance are connected as shown in this figure.

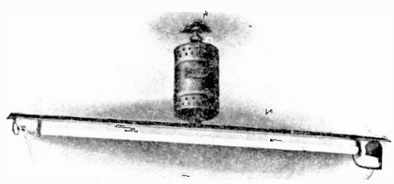


Fig. 28. Cooper-Hewitt Mercury Vapor Lamp.

The mercury vapor lamp is constructed in rather large units, the 55-volt, 3.5-ampere lamp being the smallest standard size. The color of the light emitted is objectionable for some purposes as there is an entire absence of red rays and the light is practically *monochromatic.* The illumination from this type of lamp is excellent where sharp contrast or minute detail is to be brought out, and this fact has led to its introduction for such classes of lighting as silk mills and cotton mills. On account of its color the application of this lamp is limited to the lighting of shops, offices, and drafting rooms, or to display windows where the goods shown will not be changed in appearance by the color of the light. It is used to a considerable extent in photographic work on account of the actinic properties of the light. Special reactances must be provided for a mercury arc lamp operating on single-phase, alternating-current circuits.

The Moore Tube Light. The Moore light makes use of the familiar Geissler tube discharge—discharge of electricity through a vacuum tube—as a source of illumination. The practical application of this discharge to a system of lighting has involved a large amount

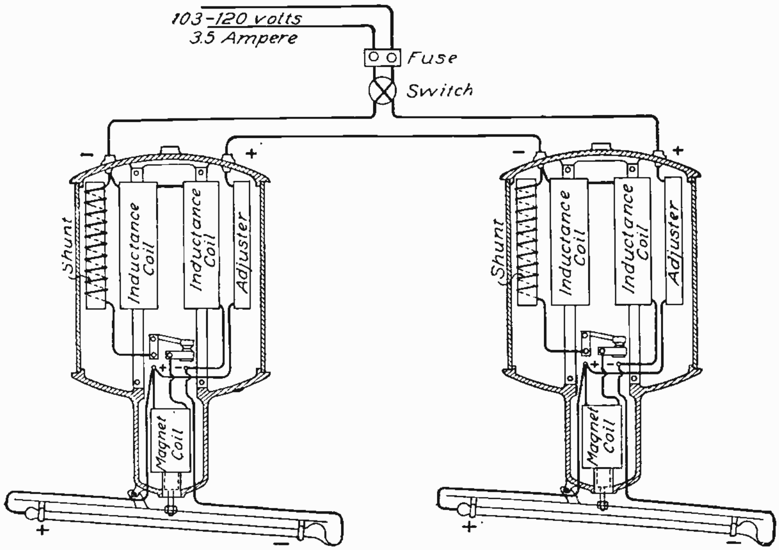


Fig. 29. Wiring Diagram. Two H Automatic Lamps in Series.

of consistent research on the part of the inventor and it has now been brought to such a stage that several installations have been made. The system has many interesting features.

In the normal method of installation, a glass tube $1\frac{3}{4}$ inches in diameter is made up by connecting standard lengths of glass tubing together until the total desired length is reached, and this continuous tube, which forms the source of light when in operation, is mounted in the desired position with respect to the plane of illumination. In many cases the tube forms a large rectangle mounted just beneath the ceiling of the room to be lighted. The tube may be of any reasonable length, actual values running from 40 to 220 feet. In order to provide an electrical discharge through this tube it is customary to lead both ends of the tube to the high tension terminals of a transformer, the low tension side of which may be connected to the alternating-current lighting mains. This transformer is constructed so that the high tension terminals are not exposed and the current is led into the tube by means of platinum wires attached to carbon electrodes. The electrodes are about eight inches in length. The ends of the tube and the high tension terminals are enclosed in a steel casing so as to effectually prevent anything from coming in contact with the high potential of the system. As stated, the low tension side of the transformer is connected to the usual 60-cycle lighting mains. If direct current is used for distribution, a motor-generator set for furnishing alternating current to the primary of the transformer is required. Any frequency from 60 cycles up is suitable for the operation of these tubes. At lower frequencies there is some appreciable variation of the light emitted. One other device is necessary for the suitable operation of this form of light and this is known as the *regulator*. In order to maintain a constant pressure inside the tube, and such a constant pressure is necessary for its satisfactory operation, there must be some automatic device which will allow a small amount of gas to enter the tube at intervals while it is in operation. The regulator accomplishes this purpose. Fig. 30 shows a diagram of the very simple connections of the system and gives the relative positions occupied by the transformer, tube, and regulator. Fig. 31 gives an enlarged view of the regulator, a description of which and its method of operation is given as follows:

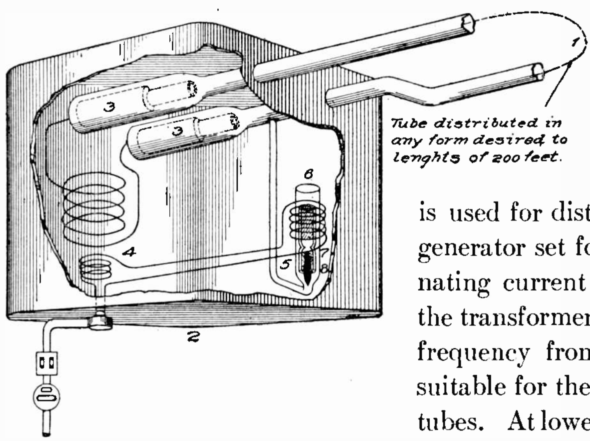


Fig. 30. Diagram Showing Essential Features of the Moore Light. 1. Lighting Tube; 2. Transformer Case; 3. Lamp Terminals; 4. Transformer; 5, 6, 7, 8, Regulators.

A piece of $\frac{7}{8}$-inch glass tubing is supported vertically and its bottom end is contracted into a $\frac{3}{8}$-inch glass tube which extends to the main lighting tube.

At the point of contraction at the bottom of the ⅞-inch tube there is sealed by means of cement a ¼-inch carbon plug, the porosity of which is not great enough to allow mercury to percolate through it but which will permit gases easily to pass, due to the high vacuum of the lighting tube connected to the lower end of the plug, and approximately atmospheric pressure above it. This carbon plug is normally completely covered with what would correspond to a thimbleful of mercury which simply seals the pores of the carbon plug, and therefore has nothing whatever to do with the conducting properties of the gas in the main tube which produces the light. Partly immersed in the mercury and concentric with the carbon plug, is another smaller and movable glass tube, the upper end of which is filled with soft iron wire, which acts as the core of a small solenoid connected in series with the transformer. The action of the solenoid is to lift the concentric glass tube partly out of the mercury, the surface of which falls and thereby causes the minute tip of the conical shaped carbon plug to be slightly exposed for a second or two.

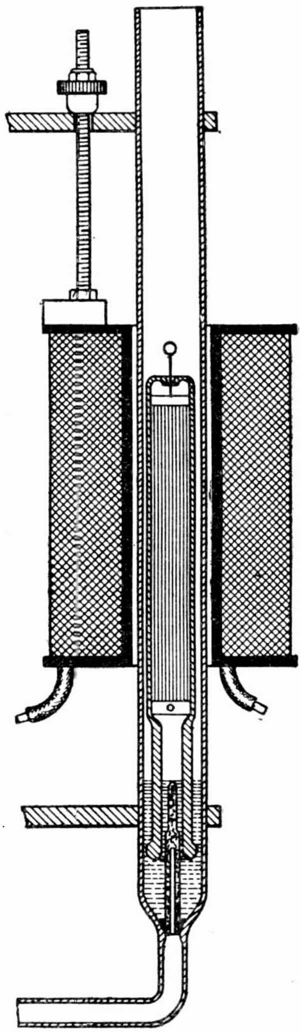


Fig. 31. Regulating Valve.

This exposure is sufficient to allow a small amount of gas to enter the tube, the current increases slightly, and the carbon plug is again sealed. The process above described takes place at intervals of about one minute when the tube is in operation.

The color of the light emitted by the tube depends upon the gas used in it. The regulator is fitted with some chemical arrangement whereby the proper gas is admitted to it when the tube is in operation. Nitrogen is employed when the tube gives the highest efficiency and the light emitted when this gas is used is yellowish in color. Air gives a pink appearance to the tube and carbon dioxide is employed when a white light is desired.

Table IX gives general data on the Moore tube light. The advantages claimed for this light are: High efficiency, good color, and low intrinsic brilliancy.

TABLE IX

Data on the Moore Tube Light

Length of Tube	Transformer Capacity	Power Factor of Circuit	Voltage at Lamp Terminals
40–70 ft.	2 kw.	65–84%	3,146 for 40-ft. tube, at 12 hefners per ft.
80–125 "	2.75 "		
130–180 "	3.5 "		
190–220 "	4.5 "		12,441 for 220-ft. tube, at 12 hefners per ft.

Pressure in tube, about $\frac{1}{10}$ m.m.
Watts per hefner, 3.2 for 20-foot tube including transformer.
Watts per hefner, 1.4 for 180-foot tube including transformer.
Hefner per foot, normal, 12.
Note that one hefner equals 0.88 candle-power.

ARC LAMPS

The Electric Arc. Suppose two carbon rods are connected in an electric circuit, and the circuit closed by touching the tips of these rods together; on separating the carbons again the circuit will not be broken, provided the space between the carbons be not too great, but will be maintained through the arc formed at these points. This phenomenon, which is the basis of the arc light, was first observed on a large scale by Sir Humphrey Davy, who used a battery of 2,000 cells and produced an arc between charcoal points four inches apart.

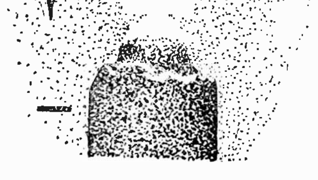


Fig. 32. The Electric Arc between Carbon Terminals.

As the incandescence of the carbons across which an arc is maintained, together with the arc itself, forms the source of light for a large portion of arc lamps, it will be well to study the nature of the arc. Fig. 32 shows the general appearance of an arc between two carbon electrodes when maintained by direct current.

Here the current is assumed as passing from the top carbon to the bottom one as indicated by the arrow and signs. We find, in the direct-current arc, that the most of the light issues from the tip of the positive carbon, or electrode, and this portion is known as the *crater* of the arc. This crater has a temperature of from 3,000° to 3,500° C., the temperature at which the carbon vaporizes, and gives fully 80 to 85% of the light furnished by the arc. The negative carbon becomes pointed at the same time that the positive one is hollowed out to form the crater, and it is also incandescent but not to as great a degree as the positive carbon. Between the electrodes there is a band of violet light, the *arc proper*, and this is surrounded by a luminous zone of a golden yellow color. The arc proper does not furnish more than 5% of the light emitted when pure carbon electrodes are used.

The carbons are worn away or consumed by the passage of the current, the positive carbon being consumed about twice as rapidly as the negative.

The light distribution curve of a *direct-current arc*, taken in a vertical plane, is shown in Fig. 33. Here it is seen that the maximum amount of light is given off at an angle of about 50° from the vertical, the negative carbon shutting off the rays of light that are thrown directly downward from the crater.

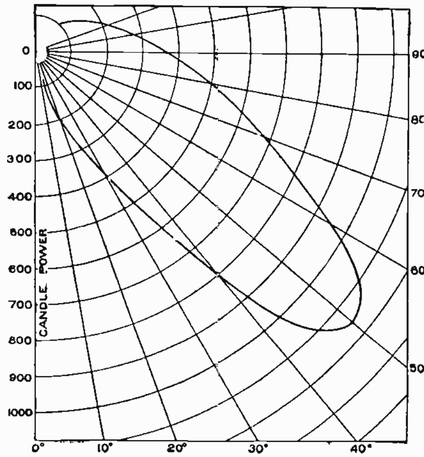


Fig. 33. Distribution Curve for D. C. Arc Lamp (Vertical Plane).

If alternating current is used, the upper carbon becomes positive and negative alternately, and there is no chance for a crater to be formed, both carbons giving off the same amount of light and being consumed at about the same rate. The light distribution curve of an *alternating-current arc* is shown in Fig. 34.

Arc-Lamp Mechanisms. In a practical lamp we must have not only a pair of carbons for producing the arc, but also means for supporting these carbons, together with suitable arrangements for leading the current to them and for maintaining them at the proper distance apart. The carbons are kept separated the proper distance by the operating mechanisms which must perform the following functions:

1. The carbons must be in contact, or be brought into contact, to start the arc when the current first flows.

2. They must be separated at the right distance to form a proper arc immediately afterward.

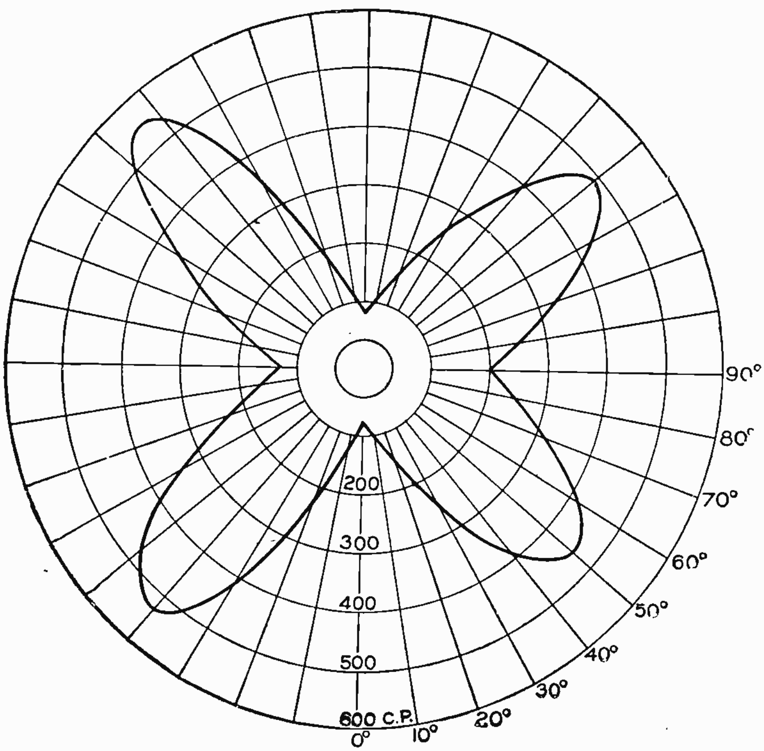


Fig. 34. Distribution Curve for A. C. Arc Lamp (Vertical Plane).

3. The carbons must be fed to the arc as they are consumed.

4. The circuit should be open or closed when the carbons are entirely consumed, depending on the method of power distribution.

The feeding of the carbons may be done by hand, as is the case in some stereopticons using an arc, but for ordinary illumination the striking and maintaining of the arc must be automatic. It is made so in all cases by means of solenoids acting against the force of gravity or against springs. There are an endless number of such mechanisms,

MOORE VACUUM-TUBE LIGHT.

Designed to Actually Imitate Daylight with a Better Efficiency than the Incandescent Lamp

but a few only will be described here. They may be roughly divided into three classes:

1. Shunt mechanisms.
2. Series mechanisms.
3. Differential mechanisms.

Shunt Mechanisms. In shunt lamps, the carbons are held apart before the current is turned on, and the circuit is closed through a solenoid connected in across the gap so formed. All of the current must pass through this coil at first, and the plunger of the solenoid is arranged to draw the carbons together, thus starting the arc. The pull of the solenoid and that of the springs are adjusted to maintain the arc at its proper length.

Such lamps have the disadvantage of a high resistance at the start—450 ohms or more—and are difficult to start on series circuits, due to the high voltage required. They tend to maintain a constant voltage at the arc, but do not aid the dynamo in its regulation, so that the arcs are liable to be a little unsteady.

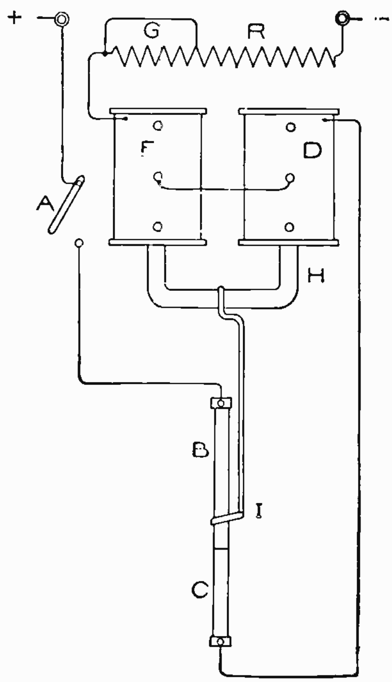


Fig. 35. Series Mechanism for D. C. Arc Lamp.

Series Mechanisms. With the series-lamp mechanism, the carbons are together when the lamp is first started and the current, flowing in the series coil, separates the electrodes, striking the arc. When the arc is too long, the resistance is increased and the current lowered so that the pull of the solenoid is weakened and the carbons feed together. This type of lamp can be used only on constant-potential systems.

Fig. 35 shows a diagram of the connection of such a lamp. This diagram is illustrative of the connection of one of the lamps manufactured by the Western Electric Company, for use on a direct-current, constant-potential system. The symbols + and − refer to the terminals of the lamp, and the lamp must be so connected that the current flows from the top carbon to the bottom one. *R* is a series resistance, adjustable for different voltages by means of the shunt *G*. *F* and *D* are the controlling solenoids connected in series with the arc. *B* and *C* are the positive and negative carbons respectively, while *A* is the switch for turning the current on and off. *H* is the plunger of the solenoids and *I* the carbon clutch, this being what is known as a *carbon-feed lamp*. The carbons are together when *A* is first closed, the current is excessive, and the plunger is drawn up into the solenoids, lifting the carbon *B* until the resistance of the arc lowers the current to such a value that the pull of the solenoid just counterbalances the weight of the plunger and carbon. *G* must be so adjusted that this point is reached when the arc is at its normal length.

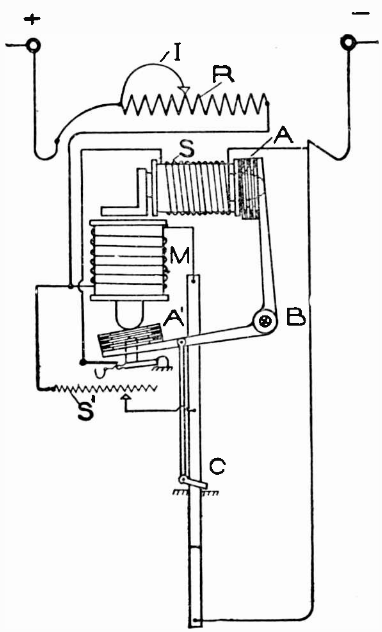


Fig. 36. Differential Mechanism for D. C. Arc Lamp.

Differential Mechanisms. In the differential lamp, the series and shunt mechanisms are combined, the carbons being together at the start, and the series coil arranged so as to separate them while the shunt coil is connected across the arc, as before, to prevent the carbons from being drawn too far apart. This lamp operates only over a low-current range, but it tends to aid the generator in its regulation.

Fig. 36 shows a lamp having a differential control, this also being the diagram of a Western Electric Company arc lamp for a direct-current, constant-potential system. Here *S* represents the shunt coil and *M* the series coil, the armature of the two magnets *A* and *A′* being attached to a bell-crank, pivoted at *B*, and attached to the carbon clutch *C*. The pull of coil *S* tends to lower the carbon while that of *M* raises the carbon, and the two are so adjusted that equilibrium is reached when the arc is of the proper length. All of the lamps are fitted with an air dashpot, or some damping device, to prevent too rapid movements of the working parts.

The methods of supporting the carbons and feeding them to the arc may be divided into two classes:

1. Rod-feed mechanism.
2. Carbon-feed mechanism.

Rod-Feed Mechanism. Lamps using a rod feed have the upper carbons supported by a conducting rod, and the regulating mechanism acts on this rod, the current being fed to the rod by means of a sliding contact. Fig. 37 shows the arrangement of this type of feed. The rod is shown at *R*, the sliding contact at *B*, and the carbon is attached to the rod at *C*.

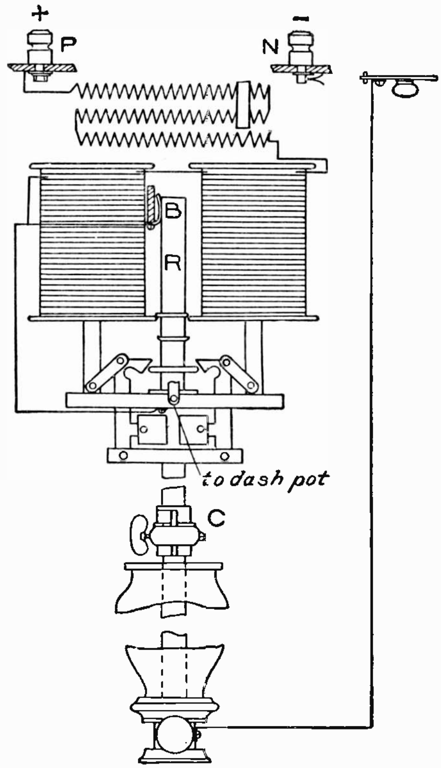


Fig. 37. Rod-Feed Mechanism.

These lamps have the advantage that carbons, which do not have a uniform cross-section or smooth exterior, may be used, but they possess the disadvantage of being very long in order to accommodate the rod. The rod must also be kept clean so as to make a good contact with the brush.

Carbon-Feed Mechanism. In carbon-feed lamps the controlling mechanism acts on the carbons directly through some form of clutch such as is shown at *C* in Fig. 38. This clamp grips the carbon when it is lifted, but allows the carbon to slip through it when the tension is released. For this type of feed the carbon must be straight and have a uniform cross-section as well as a smooth exterior. The current may be led to the carbon by means of a flexible lead and a short carbon holder.

TYPES OF ARC LAMPS

Arc lamps are constructed to operate on *direct-current* or *alternating-current* systems when connected in *series* or in *multiple*. They are also made in both the *open* and the *enclosed* forms.

By an *open arc* is meant an arc lamp in which the arc is exposed to the atmosphere, while in the *enclosed arc* an inner or enclosing

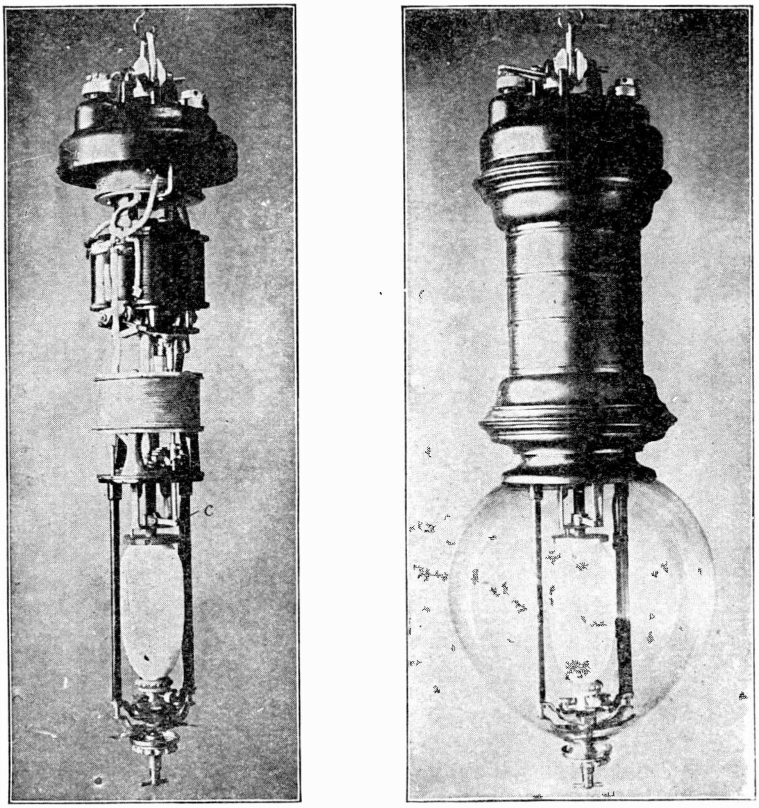


Fig. 38. Enclosed Arc Lamp with Carbon-Feed Mechanism.

globe surrounds the arc, and this globe is covered with a cap which renders it nearly air-tight. Fig. 38 is a good example of an enclosed arc as manufactured by the General Electric Company.

Direct-Current Arcs. *Open Types of Arcs* for direct-current systems were the first to be used to any great extent. When used they are always connected in series, and are run from some form of special arc machine, a description of which may be found in "Types of Dynamo Electric Machinery."

Each lamp requires in the neighborhood of 50 volts for its operation, and, since the lamps are connected in series, the voltage of the system will depend on the number of lamps; therefore, the number of lamps that may be connected to one machine is limited by the maximum allowable voltage on that machine. By special construction as many as 125 lamps are run from one machine, but even this size of generator is not so efficient as one of greater capacity. Such generators are usually wound for 6.6 or 9.6 amperes. Since the carbons are exposed to the air at the arc, they are rapidly consumed, requiring that they be renewed daily for this type of lamp.

Double-carbon arcs. In order to increase the life of the early form of arc lamp without using too long a carbon, the double-carbon type was introduced. This type uses two sets of carbons, both sets being fed by one mechanism so arranged that when one pair of the electrodes is consumed the other is put into service. At present nearly all forms of the open arc lamp have disappeared on account of the better service rendered by the enclosed arc.

Enclosed arcs for series systems are constructed much the same as the open lamp, and are controlled by either shunt or differential mechanism. They require a voltage from 68 to 75 at the arc, and are usually constructed for from 5 to 6.8 amperes. They also require a constant-current generator or a rectifier outfit if used on alternating-current circuits.

Constant-potential arcs must have some resistance connected in series with them to keep the voltage at the arc at its proper value. This resistance is made adjustable so that the lamps may be used on any circuit. Its location is clearly shown in Fig. 38, one coil being located above, the other below the operating solenoids.

Alternating-Current Arcs. These do not differ greatly in construction from the direct-current arcs. When iron or other metal parts are used in the controlling mechanism, they must be laminated or so constructed as to keep down induced or eddy currents which might be set up in them. For this reason the metal spools, on which the solenoids are wound, are slotted at some point to prevent them from forming a closed secondary to the primary formed by the solenoid winding. On constant-potential circuits a reactive coil is used in place of a part of the resistance for cutting down the voltage at the arc.

Interchangeable Arc. Interchangeable arcs are manufactured which may be readily adjusted so as to operate on either direct or alternating current, and on voltages from 110 to 220. Two lamps may be run in series on 220-volt circuits.

The distribution of light, and the resulting illumination for the different lamps just considered, will be taken up later. Aside from the distribution and quality of light, the enclosed arc has the advantage that the carbons are not consumed so rapidly as in the open lamp because the oxygen is soon exhausted from the inner globe and the combustion of the carbon is greatly decreased. They will burn from 80 to 100 hours without retrimming.

TABLE X

Rating of Enclosed Arcs

D. C. Lamp	Current	Watts Consumed: In Lamp	Watts Consumed: In Arc	Watts Consumed: Mechanism	Mean Intensity in H. U.: Spherical: Opal Outer	Mean Intensity in H. U.: Spherical: Clear Outer	Mean Intensity in H. U.: Lower Hemi-spherical: Clear Outer	Mean Watts: Spherical H. U.: Opal Outer	Mean Watts: Spherical H. U.: Clear Outer	Mean Watts: Lower Hemi-spherical: Clear Outer
						235	332		2.37	1.66
1	5.01	551	401	150	172	256*	362*	3.10	2.18*	1.52*
3	5.08	559	406	252	195	216	282	2.85	2.60	1.99
4	4.76	524	381	143	127	139	208	4.12	3.76	2.52
5	4.16†	458	333	125	154	174	221	2.96	2.63	2.07
7	4.76	524	381	143	203	333	317	2.63	2.20	1.65
9	4.84	532	387	145	182	226	281	2.83	2.38	1.89
10	4.99	549	399	150	202	242	309	2.74	2.24	1.77
12	4.87	536	390	146	178	195	230	3.05	2.66	2.33
Mean	4.9	529	384	144	176	207	272	3.03	2.60	1.98

A. C. Lamp	Current	In Lamp	Power Factor Lamp	In Arc	Power Factor Arc	Mechanism	Spherical: Opal Outer (H. U.)	Spherical: Clear Outer (H. U.)	Lower Hemi-spherical: Clear Outer (H. U.)	Mean Watts: Opal Outer	Mean Watts: Clear Outer	Mean Watts: Lower Hemi-spherical Clear Outer
101	6.40	448	.63	340	.82	108	127	141	206	3.52	3.17	2.17
								203	236		2.26	1.94
102	6.79	459	.61	375	.73	84	146	176†	226†	3.31	2.60†	1.72†
103	5.89	424	.65	344	.75	80	116	130	147	3.66	3.15	2.88
105	6.20	414	.61	382	.80	32	128	187	219	3.24	2.20	1.89
								153	169		2.56	2.23
106	6.12	378	.56	298	.70	80	132	182†	284	2.82	2.19†	1.48†
108	6.48	457	.64	383	.80	74.5	133	175	211	3.20	2.61	2.16
110	6.18	339	.49	276	.72	63	140*	126	143	2.41*	2.68	2.37
Mean	6.29	417	.60	342	.76	74.5	130	159	190	3.31	2.66	2.23

*Condition of no outer globe. †Condition with shade on lamp. H.U. Hefner Units.

Rating of Arc Lamps. Open arcs have been classified as follows:

Full Arcs, 2,000 candle-power taking 9.5 to 10 amps. or 450–480 watts.
Half Arcs, 1,200 candle-power taking 6.5 to 7 amps. or 325–350 watts.

These candle-power ratings are much too high, and run more nearly 1,200 and 700, respectively, for the point of maximum intensity and less than this if the mean spherical candle-power be taken. For this reason, the ampere or watt rating is now used to indicate the power of the lamp. It is now recommended that specifications for street lighting should be based upon the illumination produced. This point is considered later under the topic of street lighting. Enclosed arcs use from 3 to 6.5 amperes, but the voltage at the arc is higher than for the open lamp. Table X gives some data on enclosed arcs on constant-potential circuits.

Efficiency. The efficiency of arc lamps is given as follows:

Direct-Current Arc (enclosed) 2.9 watts per candle-power.
Alternating-Current Arc (enclosed) 2.95 watts per candle-power.
Direct-Current Arc (open) .6–1.25 watts per candle-power.

Carbons for Arc Lamps. Carbons are either moulded or forced from a product known as *petroleum coke* or from similar materials such as *lampblack*. The material is thoroughly dried by heating to a high temperature, then ground to a find powder, and combined with some substance such as pitch which binds the fine particles of carbon together. After this mixture is again ground it is ready for moulding. The powder is put in steel moulds and heated until it takes the form of a paste, when the necessary pressure is applied to the moulds. For the forced carbons, the powder is formed into cylinders which are placed in machines which force the material through a die so arranged as to give the desired diameter. The forced carbons are often made with a core of some special material, this core being added after the carbon proper has been finished. The carbons, whether moulded or forced, must be carefully baked to drive off all volatile matter. The forced carbon is always more uniform in quality and cross-section, and is the type of carbon which must be used in the carbon-feed lamp. The adding of a core of a different material seems to change the quality of light, and being more readily volatilized, keeps the arc from wandering.

Plating of carbons with copper is sometimes resorted to for moulded forms for the purpose of increasing the conductivity, and, by protecting the carbon near the arc, prolonging the life.

The Flaming Arc. In the carbon arc the arc proper gives out but a small percentage of the total amount of light emitted. In order to obtain a light in which more of the source of luminosity is in the arc itself, experiments have been made with the use of electrodes impregnated with certain salts, as well as with electrodes of a material different than carbon. The result of these experiments has been to place upon the market the flaming arc lamps and the luminous arc lamps—lamps of high candle-power, good efficiency, and giving various colors of light. These lamps may be put in two classes: One class uses carbon electrodes, these electrodes being impregnated with certain salts which add luminosity to the arc, or else fitted with cores which contain the required material; the other class covering lamps which do not employ carbon, the most notable example being the magnetite arc which uses a copper segment as one electrode and a magnetite stick as the other electrode.

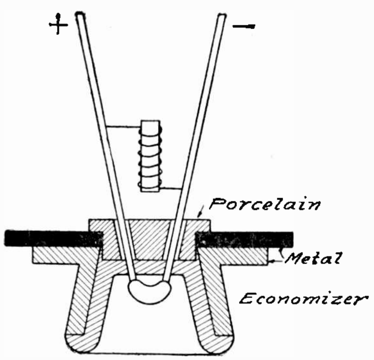


Fig. 39. Diagram of Bremer Flaming Arc.

Flaming arcs of the first class are made in two general types: One in which the electrodes are placed at an angle, and the other in which the carbons are placed one above the other as in the ordinary arc lamp. The term luminous arc is usually applied to arcs of the flaming type in which the electrodes are placed one above the other. The minor modifications as introduced by the various manufacturers are numerous and include such features as a magazine supply of electrodes by which a new pair may be automatically introduced when one pair is consumed; feed and control mechanisms; etc. The flaming arc presents a special problem since the vapors given off by the lamp may condense on the glassware and form a partially opaque coating, or they may interfere with the control mechanism.

Bremer Arc. The Bremer flaming arc lamp was introduced commercially in 1899, and since some of its principles are incorporated in many of the lamps on the market to-day, it will be briefly described here. The diagram shown in Fig. 39 illustrates the main features of this lamp. The electrodes are mounted at an angle and an electromagnet is placed above the arc for the purpose of keeping the arc from creeping up and injuring the economizer, and also for the purpose of spreading the arc out and increasing its surface. The vapor from the arc is condensed on the economizer and this coating acts as a reflector, throwing the light downward. The economizer serves to limit the air supplied to the arc and thus increases the life of the electrodes. The inclined position of the carbons was suggested by the fact that in the impregnated carbons a slag was formed which gave trouble when the electrodes were mounted in the usual manner. By using the electrodes in this position there is little if any obstruction to the light which passes directly downward from the arc.

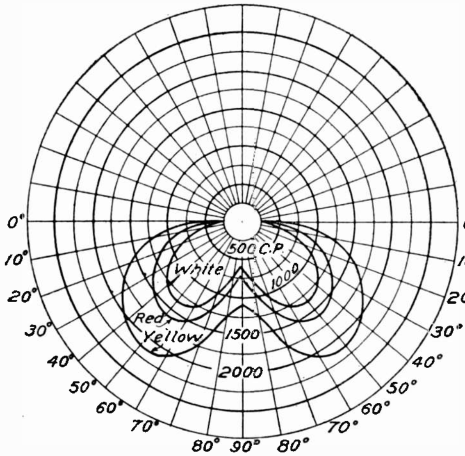


Fig. 40. Distribution Curves of a Luminous Arc.

Bremer's original electrodes contained compounds of calcium, strontium, magnesium, etc., as well as boracic acid. Electrodes as employed in the various lamps to-day differ greatly in their make-up. Some use impregnated carbons, others use carbons with a core containing the flaming materials, and metallic wires are added in some cases. The life of electrodes for flaming lamps is not great, depending upon their length and somewhat upon the type of lamp. The maximum life of the treated carbons is in the neighborhood of 20 hours.

The color of the light from the flaming arc is yellow when calcium salts are used as the main impregnating compound, and the majority of the lamps installed use electrodes giving a yellow light. By employing more strontium, a red or pink light is produced, while if a white light is wanted, barium salts are used. Calcium gives the most efficient service and strontium comes between this and barium. The distribution curves in Fig. 40 illustrate the relative economies of the different materials. Modern electrodes contain not more than 15% of added material and it is customary to find the salts applied as a core to the pure carbon sticks. The electrodes are made of a small diameter in order to maintain a steady light and this partially accounts for their short life.

The feeding mechanisms employed differ greatly. They may be classified as: Clock, gravity-feed, clutch, motor, and hot-wire mechanisms. Fig. 41 illustrates a clock mechanism. This is a differential mechanism in which the shunt coils act to release a detent *f* which allows the electrodes to feed down and when they come in contact the series coils separate them to the proper extent for maintaining a suitable arc. In the gravity feed an electromagnet is used to operate one carbon in springing the arc and the other carbon is fed by gravity, it being prevented from dropping too far by means of a special rib formed on the electrode which comes in contact with a part of the lamp structure. Gravity feed is also employed in the clutch mechanism but here the carbons are held in one position by an electrically operated clutch which releases them only when the current is sufficiently reduced by the lengthening of the arc. In the

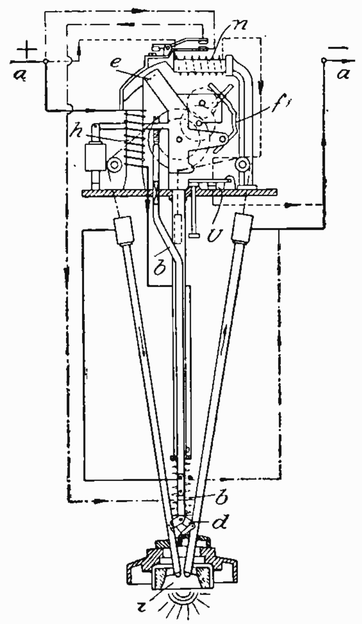


Fig. 41. Clock Feeding Mechanism for Luminous Arc Lamp.

hot-wire lamp, the wire is usually in series with the arc; the contraction and expansion of this wire is balanced against a spring and the arc is regulated by such contraction or expansion of the wire. Such a lamp is suitable for either direct or alternating current. In the motor mechanism, as applied to alternating-current lamps, a metallic disk is actuated by differential magnets and its motion is transmitted to the electrodes to lengthen or shorten the arc accordingly as the force exerted by the series or shunt coils predominates.

Magnetite Arc. The magnetite arc employs a copper disk as one electrode; and a magnetite stick—formed by forcing magnetite, to which titanium salts are usually added, into a thin sheet steel tube—is used as the other electrode. This lamp gives a luminous arc of good efficiency and the magnetite electrode is not consumed as rapidly as the treated carbons with the result that magnetite lamps do not require trimming as frequently. The life of the magnetite electrode as at present manufactured is from 170 to 200 hours. A diagram of the connections of this lamp as manufactured by the General Electric

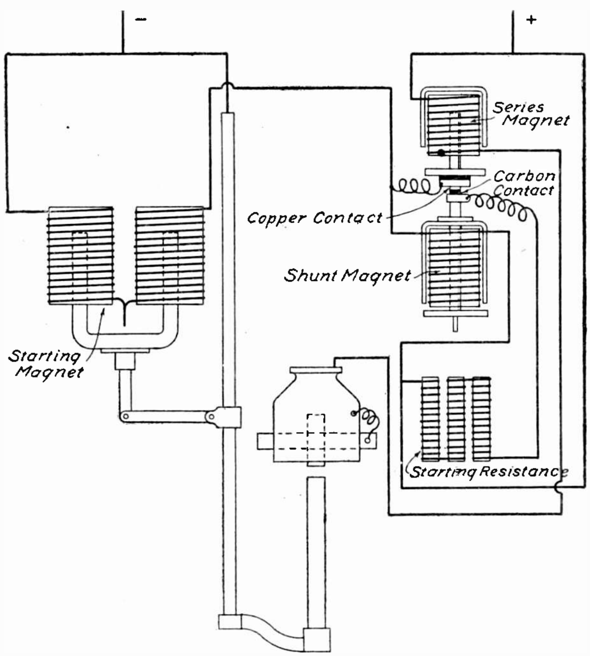


Fig. 42. Diagram of Connections for Magnetite Arc Lamp.

Company is shown in Fig. 42. The magnetite electrode is placed below. The copper electrode has just the proper dimensions to prevent its being destroyed by the arc and yet it is not large enough to cause undue condensation of the arc vapor. Direct current must be used with this lamp, the current passing from the copper to the magnetite.

Table XI gives some general data on the flaming arc, while Figs. 43 and 44 give typical distribution curves. The advantages of the flaming arc over lamps using pure carbon electrodes are: High efficiency; better light distribution; and better color of light for some purposes. A greater amount of light can be obtained from a single unit than is practical with the carbon arc. The disadvantages lie in the frequent trimming required and the expense of electrodes. Flaming arcs have been introduced abroad, especially in Germany, to a much greater extent than in the United States.

TABLE XI

General Data on Flaming Arcs

Volts	Amperes	Watts	Mean Spherical Candle-Power	Watts per Mean Spherical C. P.
55	6	330	480	.68
	8	440	800	.55
	10	550	1100	.5
	12	660	1300	.5
	15	825	1700	.49
	20	1100	2250	.48

POWER DISTRIBUTION

The question of power distribution for electric lamps and other appliances is taken up fully in the section on that subject, therefore it will be treated very briefly here. The systems may be divided into:

1. Series distribution systems.
2. Multiple-series or series-multiple systems.
3. Multiple or parallel systems.

They apply to both alternating and direct current.

The Series System. This is the most simple of the three; the lamps, as the name indicates, are connected in series as shown in Fig. 45. A constant load is necessary if a constant potential is to be used. If the load is variable, a constant-current generator, or a special regulating device is necessary. Such devices are constant-current transformers and constant-current regulators as applied to alternating-current circuits.

The series system is used mostly for arc and incandescent lamps when applied to street illumination. Its advantages are simplicity and saving of copper. Its disadvantages are high voltage, fixed by the number of lamps in series; the size of the machines is limited since they cannot be insulated for voltage above about 6,000; a single open circuit shuts down the whole system.

Alternating-current series distribution systems are being used to a very large extent. By the aid of special transformers, or regulators, any number of circuits can be run from one machine or set of bus bars, and apparatus can be built for any voltage and of any size. It is not customary, however, to build transformers of this type having a capac-

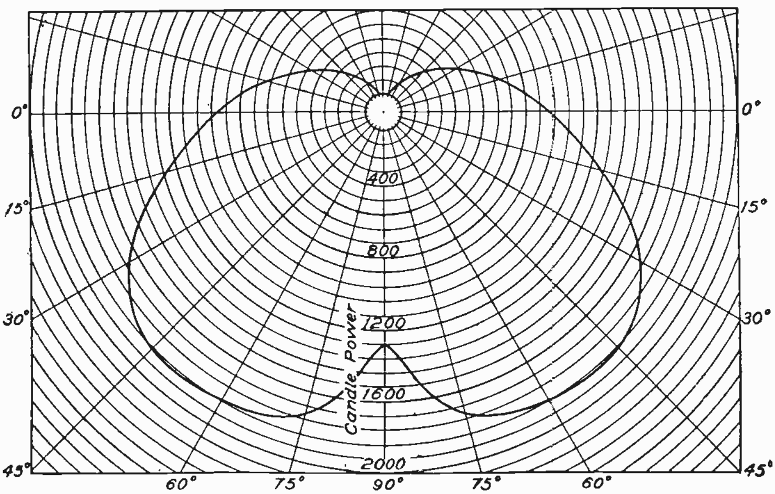


Fig. 43. Distribution Curve for Flaming Arc Lamp.

ity greater than one hundred 6.6-ampere lamps because of the high voltage which would have to be induced in the secondary for a larger number of lamps.

Fig. 45 gives a diagram of the connection of a single-coil transformer in service. The constant-current transformer most in use for lighting purposes is the one manufactured by the General Electric Company and commonly known as a *tub transformer*. Fig. 46 shows such a transformer (double-coil type) when removed from the case.

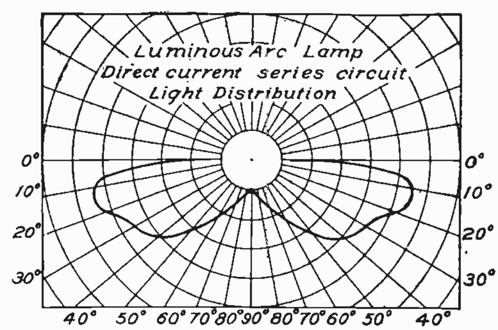


Fig. 44. Distribution Curve for a 4-Ampere, 75-Volt, Magnetite Luminous Arc Lamp.

Referring to Fig. 46, the fixed coils A form the primaries which are connected across the line; the movable coils B are the secondaries connected to the lamps. There is a repulsion of the coils B by the coils A when the current flows in both circuits and this force is balanced by means of the weights at W, so that the coils B take a position such that the normal current will flow in the secondary. On light loads, a low voltage is sufficient, hence the secondary coils are close together near the middle of the machine and there is a heavy magnetic leakage. When all of the lamps are on, the coils take the position shown when the leakage is a minimum and the voltage a maximum. When first starting up, the transformer is short-circuited and the secondary coils brought close together. The short circuit is then removed and the coils take a position corresponding to the load on the line.

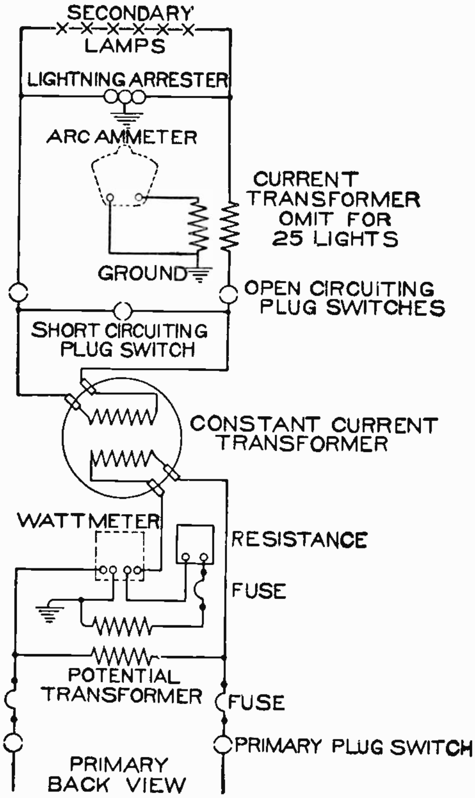
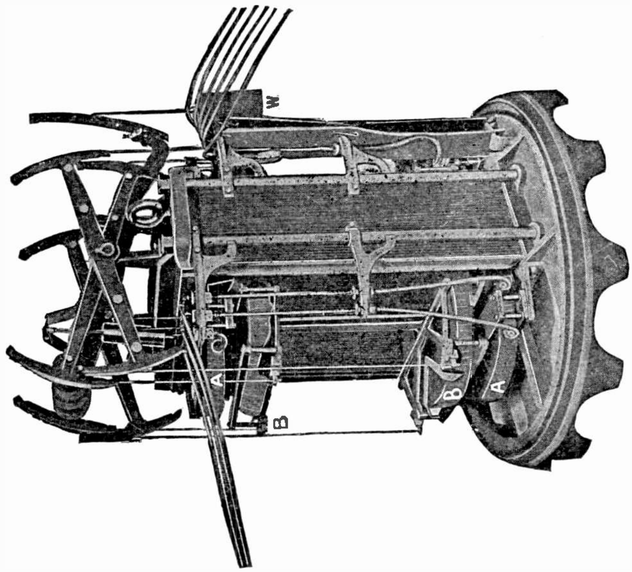


Fig. 45. Wiring Diagram for Single-Coil Transformer.

These transformers regulate from full load to $\frac{1}{3}$ rated load within $\frac{1}{10}$ ampere of normal current, and can be run on short circuit for several hours without overheating. The efficiency is given as 96% for 100-light transformers and 94.6% for 50-light transformers at full load. The power factor of the system is from 76 to 78% on full load, and, owing to the great amount of magnetic leakage at less than full load—the effect of leakage being the same as the effect of an inductance in the primary—the power factor is greatly reduced, falling to 62% at $\frac{3}{4}$ load, 44% at $\frac{1}{2}$ load, and 24% at $\frac{1}{4}$ load.

Standard sizes are for capacities of 25-, 35-, 50-, 75-, and 100-6.6 ampere enclosed arcs, and they are also made for lower currents in



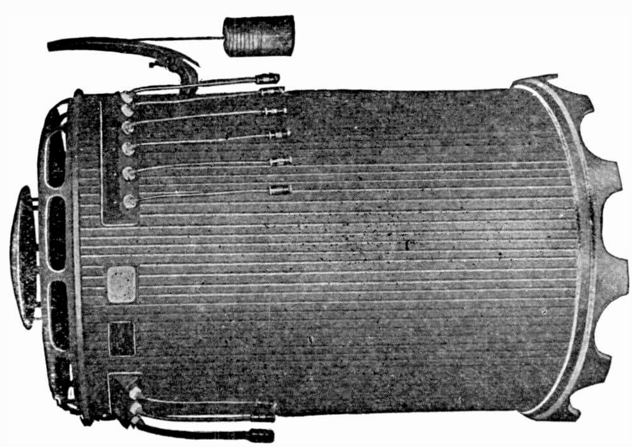


Fig. 46. Double-Coil Transformer (second view with case removed).

the neighborhood of 3.3 amperes for incandescent lamps. The low power factor of such a system on light loads shows that a transformer should be selected of such a capacity that it will be fully or nearly fully loaded at all times. The primary winding can be constructed for any voltage and the open circuit voltages of the secondaries are as follows:

25 light transformer,	2,300 volts.		75 light transformer,	6,900 volts.
35 " "	3,200 "		100 " "	9,200 "
50 " "	4,600 "			

The 50-, 75-, and 100-light transformers are arranged for multiple circuit operation, two circuits used in series, and the voltages at full load reach 4,100 for each circuit on the 100-light machine.

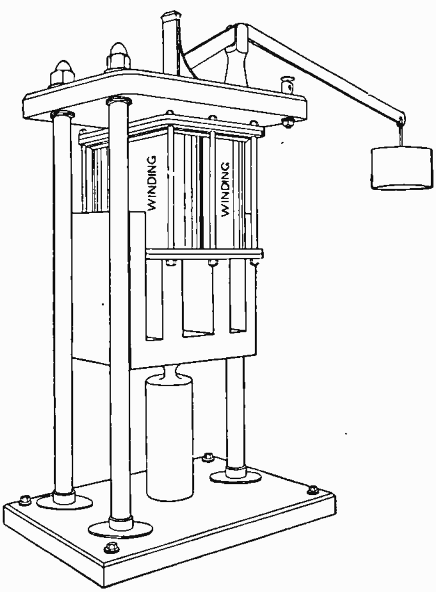
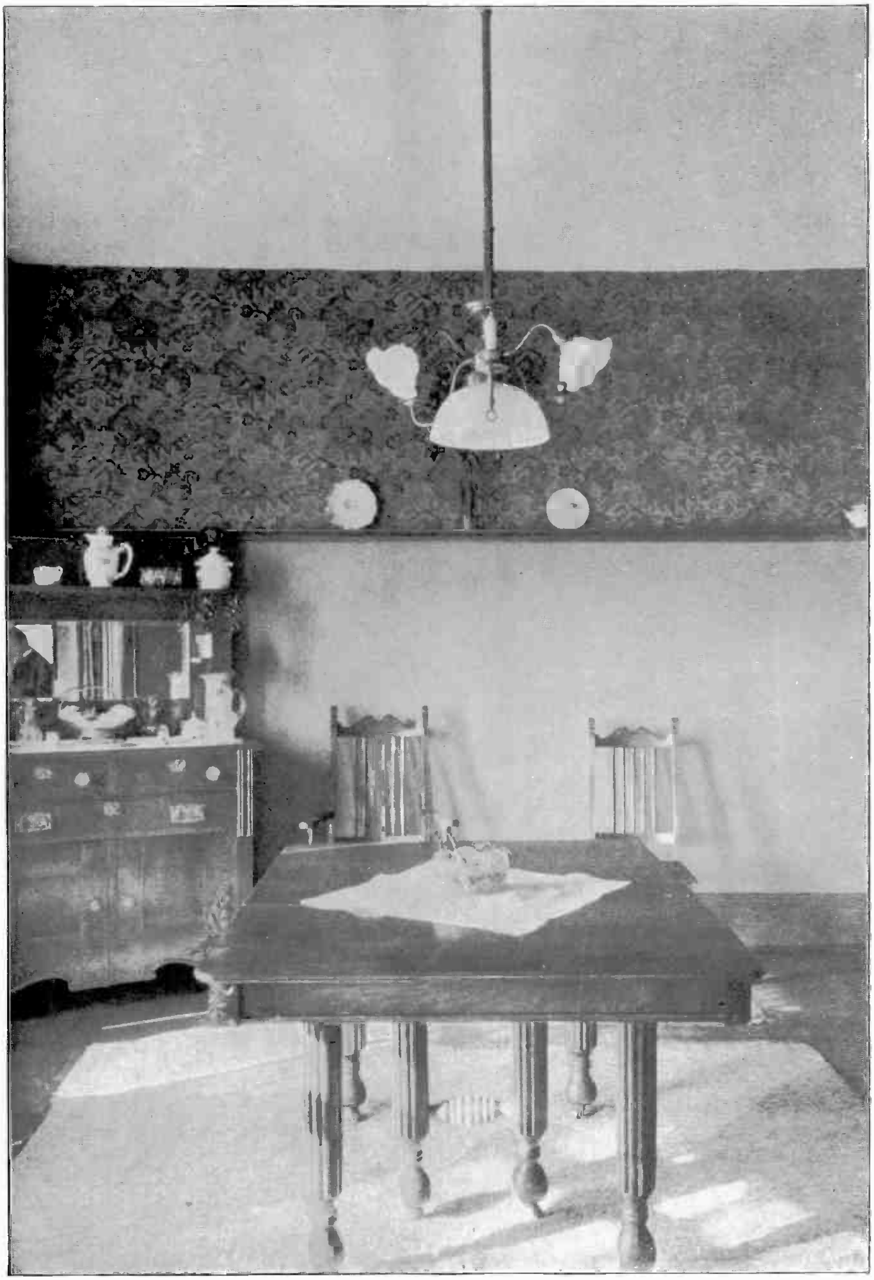


Fig. 47. Current Regulator for A. C. Series Distribution Systems.

The second system, used for series distribution on alternating-current circuits consists of a constant-potential transformer, stepping down the line voltage to that required for the total number of lamps on the system, allowing 83 volts for each lamp, and in series with the lamps is a reactive coil, the reactance of which is automatically regulated, as the load is increased or decreased, in order to keep the current in the line constant. Fig. 47 shows such a regulator and Fig. 48 shows this regulator connected in circuit. The inductance is varied by the movement of the coil so as to include more or less iron in the magnetic circuit. Since the inductance in series with the lamps is high on light loads, the power factor is greatly reduced as in the constant-current transformer; and the circuits should, preferably, be run fully loaded. 60 to 65 lamps on a circuit is the usual maximum limit.

While used primarily for arc-light circuits, the same systems,



SIMPLE COMBINATION GAS AND ELECTRIC FIXTURE IN A DINING ROOM designed for lower currents, are very readily applied to series incandescent systems.

The introduction of certain flaming or luminous arcs requiring direct current for their operation has led to the use of the *mercury arc rectifier* in connection with series circuits on alternating-current systems. A constant-current transformer is used to regulate for the proper constant current in its secondary winding, and this secondary current is rectified by means of the mercury arc rectifier for the lamp circuit. In the recent outfits the rectifier tubes are immersed in oil for cooling. While this rectifier was first introduced for the operation of luminous arc lamps, there is no reason why it should not be used with any series lamp requiring direct current, provided the system is designed for the current taken by such lamps. With this system any commercial frequency may be used. Sets are constructed for 25-, 50-, and 75-light circuits. They have a combined efficiency, transformer and rectifier tube, of 85% to 90%, and operate at a power factor of from 65% to 70%. Fig. 49 gives a diagram of the circuit and rectifier connections used with a single-tube outfit.

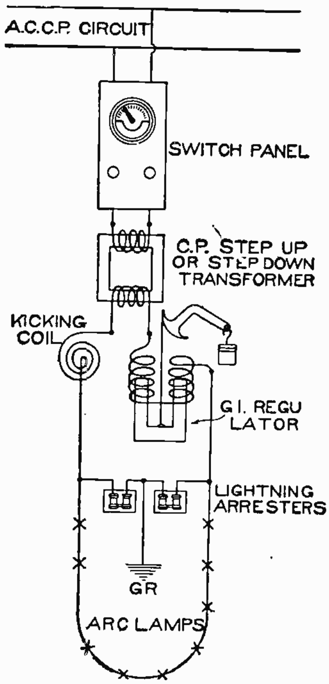


Fig. 48. Wiring Diagram Showing Introduction of the Current Regulator.

Multiple-Series or Series-Multiple Systems. These combine several lamps in series, and these series groups in multiple, or several lamps in multiple and these multiple groups in series, respectively. They have but a limited application.

Multiple or Parallel Systems of Distribution. By far the largest number of lamps in service are connected to parallel systems of distribution. In this system, the units are connected across the lines leading to the bus bars at the station, or to the secondaries of constant-potential transformers. Fig. 50 shows a diagram of ten lamps connected in parallel. The current delivered by the machine depends directly on the number of lamps connected in service, the voltage of the system being kept constant.

Inasmuch as the flow of current in a conductor is always accompanied by a fall of potential equal to the product of the current flowing into the resistance of the conductor, the lamps at the end of the system shown will not have as high a voltage impressed upon them as those nearer the machine. This drop in potential is the most serious obstacle that we have to overcome in multiple systems, and various schemes have been adopted to aid in this regulation. The systems may be classified as:

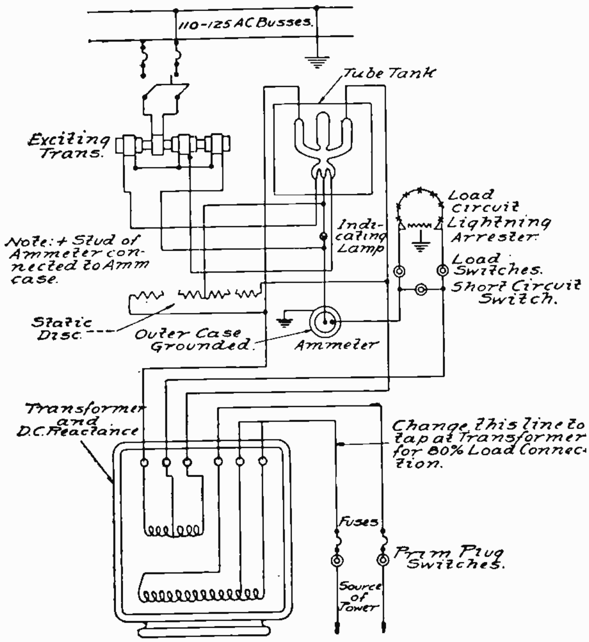


Fig. 49. Wiring Diagram for A. C. System Showing Introduction of Mercury Arc Rectifier.

1. Cylindrical conductors, parallel feeding.
2. Conical " " "
3. Cylindrical " anti-parallel feeding.
4. Conical " " "

In the cylindrical conductor, parallel-feeding system, the conductors, *A*, *B*, *C*, *D*, Fig. 50, are of the same size throughout and are fed at the same end by the generator. The voltage is a minimum at the lamps *E* and a maximum at the lamps *F;* the value of the voltage at any lamp being readily calculated.

By a *conical* or *tapering conductor* is meant a conductor whose diameter is so proportioned throughout its length that the current, divided by the cross-section, or the current density, is a constant quantity. Such a conductor is approximated in practice by using smaller sizes of wire as the current in the lines becomes less.

In an anti-parallel system, the current is fed to the lamps from opposite ends of the system, as shown in Fig. 51.

Multiple-Wire Systems. In order to take advantage of a higher voltage for distribution of power to the lighting circuits, three- and five-wire systems have been introduced, the three-wire system being used to a very large extent. In this system, three conductors are used, the voltage from each outside conductor to the middle neutral conductor being the same as for a simple parallel system. Fig. 52 gives a diagram of this. By this system the amount of copper required for a given number of lamps is from five-sixteenths to three-eighths of the amount required for a two-wire distribution, depending on the size of the neutral conductor. The saving of copper together with the disadvantages of the system is more fully treated in the paper on "Power Transmission."

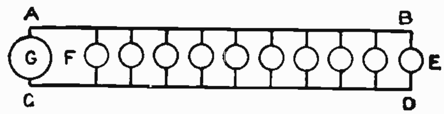


Fig. 50. Parallel Feeding System.

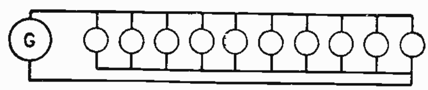


Fig. 51. Anti-parallel Feeding System.

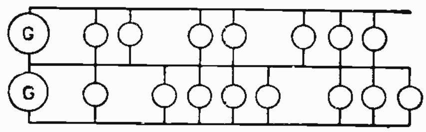


Fig. 52. Three-wire System.

ILLUMINATION

Illumination may be defined as the quality and quantity of light which aids in the discrimination of outline and the perception of color. Not only the quantity, but the quality of the light, as well as the arrangement of the units, must be considered in a complete study of the subject of illumination.

Unit of Illumination. The unit of illumination is the *foot-candle* and its value is the amount of light falling on a surface at a distance of one foot from a source of light one candle-power in value. The law of inverse squares—namely, that the illumination from a given source varies inversely as the square of the distance from the source—shows that the illumination at a distance of two feet from a single candle-power unit is .25 foot-candles. For further consideration of the law of inverse squares, see "Photometry."

Illumination may be classified as *useful*—when used for the ordinary purposes of furnishing light for carrying on work, taking the place of daylight; and *scenic*—when used for decorative lighting such as stage lighting, etc. The two divisions are not, as a rule, distinct, but the one is combined with the other.

Intrinsic Brightness. By intrinsic brightness is meant the amount of light emitted per unit surface of the light source. Table XII gives the intrinsic brightness of several light sources.

TABLE XII

Intrinsic Brilliancies in Candle-Power per Square Inch

Source	Brilliancy	Notes
Sun in zenith	600,000	Rough equivalent values, taking account of absorption
Sun at 30 degrees elv.	500,000	
Sun on horizon	2,000	
Arc light	10,000 to 100,000	Maximum about 200,000 in crater
Calcium light	5,000	
Nernst "glower"	1,000	Unshaded
Incandescent lamp	200–300	Depending on efficiency
Enclosed arc	75–100	Opalescent inner globe
Acetylene flame	75–100	
Welsbach light	20 to 25	
Kerosene light	4 to 8	Variable
Candle	3 to 4	
Gas flame	3 to 8	Variable
Incandescent (frosted)	2 to 5	
Opal shaded lamps, etc.	0.5 to 2	

Regular Reflection. Regular reflection is the term applied to reflection of light when the reflected rays are parallel. It is of such a nature that the image of the light source is seen in the reflection. The reflection from a plane mirror is an example of this. It is useful in lighting in that the direction of light may be changed without complicating calculations aside from deductions necessary to compensate for the small amount of light absorbed.

Irregular Reflection. Irregular reflection, or diffusion, consists of reflection in which the reflected rays of light are not parallel but take various directions, thus destroying the image of the light source. Rough, unpolished surfaces give such reflection. Smooth, unpolished surfaces generally give a combination of two kinds of reflection.

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(63) Civil Engineering	$68.00	$140.00
(44) Railroad Engineering	47.00	100.00
(42) Municipal Engineering	47.00	100.00
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Occupation ______________ **Age** ______________

COURSES AND FEES

The amount given under Cost of Textbooks covers the cost of Matriculation, Textbooks, and Postage; the difference between this amount and the Regular Price represents Tuition, which is free to the bearer of this Scholarship. The number of Textbooks in each course is shown by the figures before the title.

Electrical Engineering

	Cost of Textbooks	Regular Price
(67) Electrical Engineering	$60.00	$125.00
(61) Electro-Mechanical Engineering	58.00	120.00
(61) Hydro-Electric Engineering	58.00	120.00
(49) Operating Engineering	47.00	100.00
(30) Telephone Practice	33.00	70.00

Fire Prevention and Insurance

(30) Fire Prevention and Insurance	$33.00	$70.00
(21) Fire Prevention	26.00	55.00
(19) Fire Insurance	23.00	50.00

Law

(58) Complete Law	$72.00	$150.00
(22) Real Estate Law	29.00	60.00
(20) Business Law	29.00	60.00

Mechanical Engineering

(58) Mechanical Engineering	$55.00	$115.00
(47) Steam Engineering	47.00	100.00
(27) Shop Practice	26.00	55.00
(19) Automobile Course	23.00	50.00

Sanitary Engineering

(37) Heating and Ventilation Eng.	$37.00	$75.00
(14) Heating, Ventilating, Plumbing	17.00	35.00

Textile Manufacturing

(42) Complete Textile Mfg.	$39.00	$85.00
(30) Woolen and Worsted Mfg.	26.00	55.00
(29) Cotton Manufacturing	26.00	55.00
(28) Knit Goods Manufacturing	26.00	55.00

NOTE — A discount of 10% from the Cost of Textbooks is allowed for cash with enrollment. If you wish to take advantage of this discount, but cannot send the full amount today, send $3.00 with your acceptance and the balance of the cash price any time during the next 30 days. Always send remittance by check, post office or express money order, payable to American School of Correspondence.

Diffused reflection is very important in the study of illumination inasmuch as diffused light plays an important part in the lighting of interiors. This form of reflection is seen in many photometer screens. Light is also diffused when passing through semi-transparent shades or screens.

In considering reflected light, we find that, if the surface on which the light falls is colored, the reflected light may be changed in its nature by the absorption of some of the colors. Since, as has been said, in interior lighting the reflected light forms a large part of the source of illumination, this illumination will depend upon the nature and the color of the reflecting surfaces.

Whenever light is reflected from a surface, either by direct or diffused reflection, a certain amount of light is absorbed by the surface. Table XIII gives the amount of white light reflected from different materials.

TABLE XIII

Relative Reflecting Power

Material	%
White blotting paper	82
White cartridge paper	80
Chrome yellow paper	62
Orange paper	50
Yellow wall paper	40
Light pink paper	36
Yellow cardboard	30
Light blue cardboard	25
Emerald green paper	18
Dark brown paper	13
Vermilion paper	12
Blue-green paper	12
Black paper	5
Black cloth	1.2
Black velvet	.4

From this table it is seen that the light-colored papers reflect the light well, but of the darker colors only yellow has a comparatively high coefficient of reflection. Black velvet has the lowest value, but this only holds when the material is free from dust. Rooms with dark walls require a greater amount of illuminating power, as will be seen later.

Useful illumination may be considered under the following heads:

1. Residence Lighting.
2. Lighting of Public Halls, Offices, Drafting Rooms, Shops, etc.
3. Street Lighting.

RESIDENCE LIGHTING

Type of Lamps. The lamps used for this class of lighting are limited to the less powerful units—namely, incandescent or Nernst lamps varying in candle-power from 8 to 50 per unit. These should always be shaded so as to keep the intrinsic brightness low. The intrinsic brilliancy should seldom exceed 2 to 3 candle-power per square inch, and its reduction is usually accomplished by appropriate shading. Arc lights are so powerful as to be uneconomical for small rooms, while the color of the mercury-vapor light is an additional objection to its use.

Plan of Illumination. Lamps may be selected and so located as to give a brilliant and fairly uniform illumination in a room; but this is an uneconomical scheme, and the one more commonly employed is to furnish a uniform, though comparatively weak, ground illumination, and to reinforce this at points where it is necessary or desirable. The latter plan is satisfactory in almost all cases and the more economical of the two.

While the use of units of different power is to be recommended, where desirable, lights differing in color should not be used for lighting the same room. As an exaggerated case, the use of arc with incandescent lamps might be mentioned. The arcs being so much whiter than the incandescent lamps, the latter appear distinctly yellow when the two are viewed at the same time.

Calculation of Illumination. In determining the value of illumination, not only the candle-power of the units, but the amount of reflected light must be considered for the given location of the lamps. Following is a formula based on the coefficient of reflection of the walls of the room, which serves for preliminary calculations:

$$I = \frac{c.p. \quad \dfrac{1}{1-k}}{d^2}$$

I = Illumination in foot-candles.
c.p. = Candle-power of the unit.
k = Coefficient of reflection of the walls.
d = distance from the unit in feet.

Where several units of the same candle-power are used this formula becomes:

$$I = c.p. \left(\frac{1}{d^2} + \frac{1}{d^2_1} + \frac{1}{d^2_2} + \text{---------}\right)\frac{1}{1-k}$$

or,

$$c.p. = \frac{1}{\left(\frac{1}{d^2} + \frac{1}{d^2_1} + \frac{1}{d^2_2} + \text{---------}\right)\frac{1}{1-k}}$$

where d, d_1, d_2, etc., equal the distances from the point considered to the various light sources. If the lamps are of different candle-power, the illumination may be determined by combining the illumination from each source as calculated separately. An example of calculation is given under "Arrangement of Lamps."

The above method is not strictly accurate because it does not take account of the angle at which the light from each one of the sources strikes the assumed plane of illumination. If the ray of light is perpendicular to the plane, the formula $I = \frac{c.p.}{d^2}$ gives correct values. If a is the angle which the ray of light makes with a line drawn from the light source perpendicular to the assumed plane, then the formula becomes $I = \frac{c.p. \times \text{cosine } a}{d^2}$. Therefore, by multiplying the candle-power value of each light source in the direction of the illuminated point by the cosine of each angle a, a more accurate result will be obtained.

It is readily seen that the effect of reflected light from the ceilings is of more importance than that from the floor of a room. The value of k, in the above formula, will vary from 60% to 10%, but for rooms with a fairly light finish 50% may be taken as a good average value.

The amount of illumination will depend on the use to be made of the room. One foot-candle gives sufficient illumination for easy reading, when measured normal to the page, and probably an illumination of .5 foot-candle on a plane 3 feet from the floor forms a sufficient ground illumination. The illumination from sunlight reflected from white clouds is from 20 foot-candles up, while that due to moonlight is in the neighborbood of .03 foot-candles. It is not possible to produce artificially a light equivalent to daylight on account of the great amount of energy that would be required and the difficulty of obtaining proper diffusion.

The method of calculating the illumination of a room that has just been described is known as the *point-by-point* method and it gives very accurate results if account is taken of the angle at which the light from each source strikes the plane of illumination and if the light distribution curves of the units, and the value of k, have been carefully determined. Under these conditions the calculations become extended and complicated and methods only approximate, but simpler in their application, are being introduced. One method, which gives good results when applied to fairly large interiors, makes the flux of light from the light sources the basis of calculation of the average illumination.

Flux of light is measured in lumens and a *lumen* may be defined as the amount of light which must fall on one square foot of surface in order to produce a uniform illumination of an intensity of one foot-candle. A source of light giving one candle-power in every direction and placed at the center of a sphere of one foot radius would give an illumination of one foot-candle at every point in the surface of the sphere and the total flux of light would be 4π, or 12.57, lumens since the area of the sphere would be 4π, or 12.57, sq. ft. A lamp giving one mean spherical candle-power gives a flux of 12.57 lumens and the total flux of light from any source is obtained by multiplying its mean spherical candle-power by 12.57. In calculating illumination it is customary to determine the illumination on a plane about 30 inches from the floor for desk work, and about 42 inches from the floor for the display of goods on counters. If we determine the total number of lumens falling on this plane and divide this number by the area of the plane, we obtain the average illumination in foot-candles. This of course tells us nothing about the maximum or minimum value of the illumination and such values must be obtained by other methods if they are desired. Reflected light, other than that covered by the distribution curve of the light unit including its reflector, is usually neglected in this method of calculation.

We may assume that in large rooms the light coming from the lamp within an angle of 75 degrees from the vertical reaches the plane of illumination. In smaller rooms this angle should be reduced to about 60 degrees. In order to determine the flux of light within this angle a Rousseau diagram, which is described later, should be drawn. By the means of this diagram the average candle-power of the light source within the angle assumed may be readily determined and this mean value, multiplied by 12.57, will give the flux of light in lumens. This method of calculation, together with some guides for its rapid application, is described by Messrs. Cravath and Lansingh in the "Transactions of the Illuminating Engineering Society, 1908." The same authorities give the following useful data:

To determine the watts required per square foot of floor area, multiply the intensity of illumination desired by the constants given as follows:

INTENSITY CONSTANTS FOR INCANDESCENT LAMPS

Tungsten lamps rated at 1.25 watts per horizontal candle-power; clear prismatic reflectors, either bowl or concentrating; large room; light ceiling; dark walls; lamps pendant; height from 8 to 15 feet	.25
Same with very light walls	.20
Tungsten lamps rated at 1.25 watts per horizontal candle-power; prismatic bowl reflectors enameled; large room; light ceiling; dark walls; lamps pendant, height from 8 to 15 feet	.29
Same with very light walls	.23
Gem lamps rated at 2.5 watts per horizontal candle-power; clear prismatic reflectors either concentrating or bowl; large room; light ceiling; dark walls; lamps pendant; height from 8 to 15 feet	.55
Same with very light walls	.45
Carbon filament lamps rated at 3.1 watts per horizontal candle-power; clear prismatic reflectors either bowl or concentrating; light ceiling; dark walls; large room; lamps pendant; height from 8 to 15 feet	.65
Same with very light walls	.55
Bare carbon filament lamps rated at 3.1 watts per horizontal candle-power; no reflectors; large room; very light ceiling and walls; height from 10 to 14 feet	.75 to 1.5
Same; small room; medium walls	1.25 to 2.0
Carbon filament lamps rated at 3.1 watts per horizontal candle-power; opal dome or opal cone reflectors; light ceiling; dark walls; large room; lamps pendant; height from 8 to 15 feet	.70
Same with light walls	.60

INTENSITY CONSTANTS FOR ARC LAMPS

5-ampere, enclosed, direct-current arc on 110-volt circuit; clear inner, opal outer globe; no reflector; large room; light ceiling; medium walls; height from 9 to 14 feet	.50

Arrangement of Lamps. An arrangement of lamps giving a uniform illumination cannot be well applied to residences on account of the number of units required, and the inartistic effect. We are limited to chandeliers, side lights, or ceiling lights, in the majority of cases, with table or reading lamps for special illumination.

When ceiling lamps are used and the ceilings are high, some form of reflector or reflector lamp is to be recommended. In any case where the coefficient of reflection of the ceilings is less than 40%, it is more economical to use reflectors. When lamps are mounted on chandeliers, the illumination is far from uniform, being a maximum in the neighborhood of the chandelier and a minimum at the corners of the room. By combining chandeliers with side lights it is generally possible to get a satisfactory arrangement of lighting for small or medium-sized rooms.

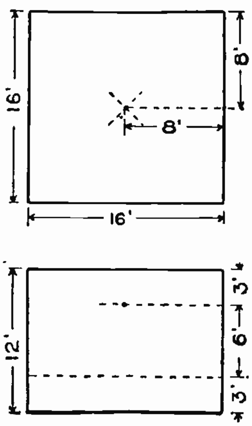

Fig. 53. Diagram Showing Method of Calculating Room Illumination.

As a check on the candle-power in lamps required, we have the following:

For brilliant illumination allow one candle-power per two square feet of floor space. In some particular cases, such as ball rooms, this may be increased to one candle-power per square foot.

For general illumination allow one candle-power for four square feet of floor space, and strengthen this illumination with the aid of special lamps as required. The location of lamps and the height of ceilings will modify these figures to some extent.

As an example of the calculation of the illumination of a room with different arrangements of the units of light, assume a room 16 feet square, 12 feet high, and with walls having a coefficient of reflection of 50%. Consider first the illumination on a plane 3 feet above the floor when lighted by a single group of lights mounted at the center of the room 3 feet below the ceiling. If a minimum value of .5 foot-candle is required at the corner of the room, we have the equation (first method outlined):

$$.5 = c.\ p. \frac{1}{12.8^2} \times \frac{1}{1 - .5}$$

Since $d = \sqrt{8^2 + 8^2 + 6^2} = 12.8$ (see Fig. 53)

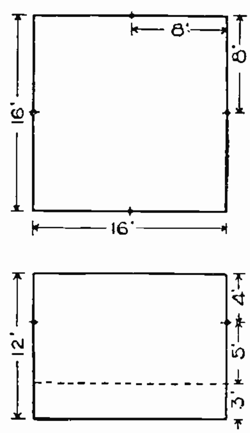

Fig. 54. Diagram for Four 8-c. p. Lamps on Side Wall.

Solving the above for the value of *c. p.*, we have

$$c.\,p. = \frac{.5}{\frac{1}{164} \times \frac{1}{.5}} = .5 \times 82 = 41$$

Three 16-candle-power lamps would serve this purpose very well.

Determining the illumination directly under the lamp, we have:

$$I = 48 \times \frac{1}{6^2} \times \frac{1}{1-.5} = \frac{48}{36} \times 2 =$$

2.7 foot-candles, or five times the value of the illumination at the corners of the room.

Next consider four 8-candle-power lamps located on the side walls 8 feet above the floor, as shown in Fig. 54. Calculating the illumination at the center of the room on a plane three feet above the floor, we have:

$$I = 8\left(\frac{1}{89} + \frac{1}{89} + \frac{1}{89} + \frac{1}{89}\right)\frac{1}{1-.5}$$

$$d^2 = 8^2 + 5^2 = 64 + 25 = 89$$

$$\therefore I = 8 \times \frac{4}{89} \times 2 = .72 \text{ foot-candles}$$

The illumination at the corner of the room would be:

$$I = 8\left(\frac{1}{89} + \frac{1}{89} + \frac{1}{345} + \frac{1}{345}\right)\frac{1}{1-.5}$$

$$= 8\left(\frac{2}{89} + \frac{2}{345}\right) \times 2 = .45 \text{ foot-candles.}$$

In a similar manner the illumination may be calculated for any point in the room, or a series of points may be taken and curves plotted showing the distribution of the light, as well as the areas having the same illumination. Where refined calculations are desired, the distribution curve of the lamp must be used for determining the candle-power in different directions. Fig. 55 shows illumination curves for the Meridian lamp as manufactured by the General Electric Company. This is a form of reflector lamp made in two sizes, 25 or 50 candle-power. Fig. 56 gives the distribution curves for the 50-candle-power unit. Similar incandescent lamps are now being manufactured by other companies.

Table XIV gives desirable data in connection with the use of the Meridian lamp.

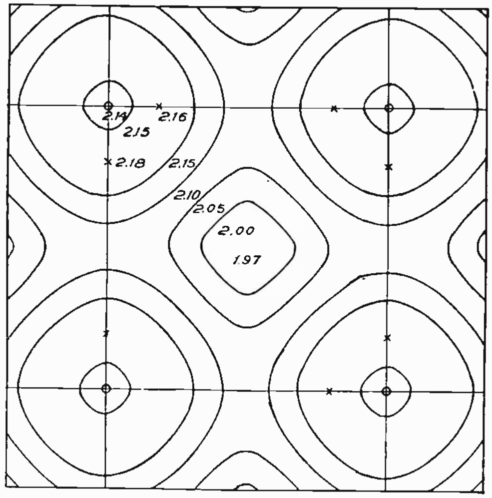

Fig. 55. Illumination Curves for a G. E. Meridian Lamp.

TABLE XIV

Illuminating Data for Meridian Lamps

Class Service	Light Intensity in Foot-candles	No. 1 Lamp (60 Watts)		No 2 Lamp (120 Watts)		Watts per Sq. Ft. of Area Lighted with either Lamp
		Height of Lamp and Diameter of Uniformly Lighted Area	Distance between Lamps when Two or more are Used	Height of Lamp and Diameter of Uniformly Lighted Area	Distance between Lamps when Two or more are Used	
Desk or Reading Table	3	2.9 feet	4.9 feet	4 feet	7 feet	2.50
	2	3.5 "	6 "	5 "	8.5 "	1.66
	$1\frac{1}{2}$	4 "	7 "	5.75 "	9.8 "	1.25
General Lighting	1	5 "	8.5 "	7 "	12 "	0.83
	$\frac{3}{4}$	5.75 "	9.8 "	8.2 "	13.9 "	0.62
	$\frac{1}{2}$	7 "	12 "	10 "	11 "	0.41

By means of the Weber, or some other form of portable photometer, curves as plotted from calculations may be readily checked after the lamps are installed. When lamps are to be permanently located, the question of illumination becomes an important one, and it may be desirable to determine, by calculation, the illumination curves for each room before installing the lamps. This applies to the lighting of large interiors more particularly than to residence lighting. The point-by-point method of calculation is used for very accurate work when the system of illumination admits of this method. Other methods are often simpler and sufficiently accurate for practical work.

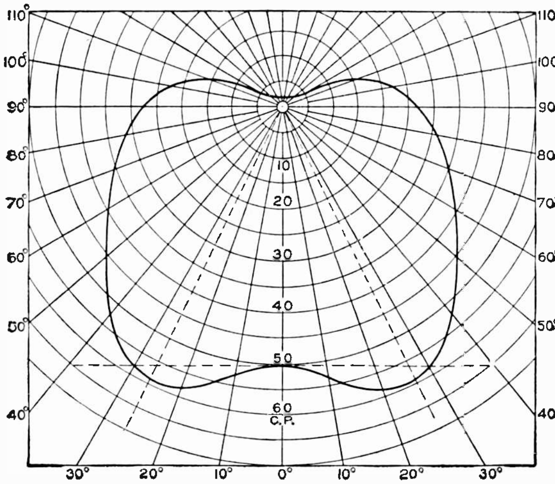

Fig. 56. Distribution Curve for a G. E. 50-c. p. Meridian Lamp.

Dr. Louis Bell gives the following in connection with residence lighting:

TABLE XV
Residence Lighting Data

Room	8 C. P.	16 C. P.	32 C. P.	Sq. ft. per C.P.	Remarks
Hall, 15′ × 20′	8			4.7	
Library, 20′ × 20′	12		1	3.1	8-c.p. reflector lamps
Reception room, 15′ × 15′	4			7.0	
Music room, 20′ × 25′	12		2	3.0	
Dining room, 15′ × 20′	14			2.7	8 reflector lamps
Billiard room, 15′ × 20′			4	2.3	32-c.p. with reflectors
Porch			1		
Bedrooms (6), 15′ × 15′		14		7.0	
Dressing rooms (2), 10′×15′		4		4.7	
Servants' rooms (3), 10′×15′		3		9.4	
Bathrooms (3), 8′ × 10′		3		5.0	
Kitchen, 15′ × 15′; Pantry, 10′ × 15′		3			
Halls; Cellar	10	3			
Closets (4)	4				Reflector lamps
Total	64	30	8		

LIGHTING OF PUBLIC HALLS, OFFICES, ETC.

Lighting of public halls and other large interiors differs from the illumination of residences in that there is usually less reflected light, and, again, the distance of the light sources from the plane of illumination is generally greater if an artistic arrangement of the lights is to be brought about. This in turn reduces the direct illumination. The primary object is, however, as in residence lighting, to produce a fairly uniform ground illumination and to superimpose a stronger illumination where necessary. An illumination of .5 foot-candle for the ground illumination may be taken as a minimum.

In the lighting of large rooms it is permissible to use larger light units, such as arc lamps and high candle-power Nernst or incandescent units, while for factory lighting and drafting rooms, where the color of the light is not so essential, the Cooper-Hewitt lamp is being introduced. High candle-power reflector lamps, such as the tungsten lamp, are being used to a large extent for offices and drafting rooms.

The choice of the type of lamp depends on the nature of the work. Where the light must be steady, incandescent or Nernst lamps are to be preferred to the arc or vapor lamps, though the latter are often the more efficient. When arcs are used, they must be carefully shaded so as to diffuse the light, doing away with the strong shadows due to portions of the lamp mechanism, and to reduce the intrinsic brightness. Such shading will be taken up under the heading "Shades and Reflectors." Arcs are sometimes preferable to incandescent lamps when colored objects are to be illuminated, as in stores and display windows.

In locating lamps for this class of lighting, much depends on the nature of the building and on the degree of economy to be observed. For preliminary determination of the location of groups, or the illumination when certain arrangement of the units is assumed, the principles outlined under "Residence Lighting" may be applied. It has been found that actual measurements show results approximating closely such calculated values.

When arcs are used they should be placed fairly high, twenty to twenty-five feet when used for general illumination and the ceilings are high. They should be supplied with reflectors so as to utilize the light ordinarily thrown upwards. When used for drafting-room work, they should be suspended from twelve to fifteen feet above the floor, and special care must be taken to diffuse the light.

Incandescent lamps may be arranged in groups, either as side lights or mounted on chandeliers, or they may be arranged as a frieze running around the room a few feet below the ceiling. The last named arrangement of lights is one that may be made artistic, but it is uneconomical and when used should serve for the ground illumination only. Reflector lights may be used for this style of work and the lights may be entirely concealed from view, the reflecting property of the walls being utilized for distributing the light where needed.

Ceiling lights should preferably be supplied with reflectors, especially when the ceilings are high.

Indirect lighting is employed to some extent. By indirect lighting we mean a system af illumination in which the light sources are concealed and the light from them is reflected to the room by the walls, or ceilings, or other surfaces; or in which the light sources are placed above a diffusing panel. In the latter case the diffusing plate appears to be the source of light. In some cases the walls themselves are shaped and constructed so as to form the reflectors for the light units (cove lighting), but in others all of the reflecting surfaces, except the side walls and ceiling, are made portions of the lamp fixtures.

Tables XVI and XVII give data on arc and mercury-vapor lamps for lighting large rooms. Table XVII refers to arc lights as actually installed.

TABLE XVI

Cooper-Hewitt Lamps

Service	Height of Lamp	C. P. of Unit	Av. Area per Lamp in Square Feet
Foundry	10-15 ft.	300	900
"	20-25 "	700	2250
Machine shop	10-15 "	300	500
Erecting shop	20-30 "	700	1250
Drafting room	15 "	300	300
" "	20 "	700	400
Offices	10-15 "	300	400
"	20-25 "	700	750
Ordinary labor	10-15 "	300	1100
" "	20-25 "	700	2750

TABLE XVII

Lighting Data for Arc Lamps

Place Lighted	Clothing Store	Weave Room	Erecting Room	Machine Shop	Drafting Room	Drafting Room	Ship Shed	Cataloging Dept.	Jewelry Store
No. of sq. ft. place lighted	4000	14400	281600	42250	6275	5690	69000	4136	4000
No. lamps used	12	50	200	42	27	24	50	17	6
Circuit	A. C. Mult.	D. C. Mult.	D. C. Mult.	D. C. Mult.	A. C Series	D. C. Mult.	D. C. Mult.	D. C. Mult.	D. C. Mult.
Cycles	60	......	......	......	60	......	......	......	......
Volts line	104	110	120	120	......	120	220	110	110
Amperes	6	3¼	6.2	6.2	7.5	4	6	4½	5
Volts at arc	72	75	80	80	72	80	80	80	80
Power factor of lamp	.69	......	......	......	.86	......	......	......	......
Watts per lamp	430	357	744	744	490	480	660	495	550
Watts per sq. ft. (term.)	1.29	1.24	.53	.74	2.11	2.02	.478	2.03	.825
Kw. at term. (whole installation)	5.16	17.8	148.8	31.25	13.22	11.52	33	8.42	3.3
Kw. at arc (whole installation)	4.62	12.28	99.2	20.8	12.42	7.68	24	6.12	2.4
Sq. ft. lighted per lamp	333	288	1408	1006	232	237	1380	243	667
Sq. ft. lighted per amp	55.6	88.6	227	162	31	59.2	230	54.1	133.5
Enclosing globe	Opal.		Opal.	Opal.	Opal.	Opal.		Opal.	Opal.
Height and style of ceiling	12′ white steel	Saw Toothed	Trussed	Trussed	12′ White	Trussed	160′ Trussed	13′ 9″ Maroon	16′ 10′ White
Reflector system used	Concentric Diffuser	Adjust. Diffuser	9″ Mirror	9″ Mirror	Concentric Diffuser	16 Adj.Dif. 8 Con.Dif.	12″ Mirror	Concentric Diffuser	Concentric Diffuser
Height of arc from floor	9′ 6″	12′ to 15′	46′	47′	9′	15′	150′	10′ 7″	13′ 2″
Distance between lamps	14′ to 18′	24′	32′ to 38′	30′ 9″	15′	12′ to 25′	17′ to 20′	14′ to 18′	16′ to 25′

Measurements taken in well-lighted rooms having a floor space of from 1,000 to 5,000 square feet show an average of 3 to 3.5 square feet per candle-power. About 2.5 square feet per candle-power should be allowed when brilliant lighting is required or the ceilings are very high, while 3.75 square feet per candle-power will give good illumination when lights are well distributed and there is considerable reflected light.

In factory and drafting room lighting, the lamps must be arranged to give a strong light where most needed, and located to prevent such shadows as would interfere with the work.

STREET LIGHTING

In studying the lighting of streets and parks, we find that, except in special cases, such as narrow streets and high buildings, there is no reflected light which aids the illumination aside from that due to special shades or reflectors on the lamp itself. Such reflectors are necessary if the light ordinarily thrown above the horizontal plane is to be utilized.

In calculating the illumination due to any type of lamp at a given point it is necessary to know the distribution curve of the lamp used and the distance to the point illuminated. The approximate illumination of a plane normal to the rays of light is given by the formula,

$$I = \frac{c.p.}{h^2 + d^2}$$

when I = illumination in foot-candles.

c.p. = candle-power of the unit, determined from the distribution curve of the lamp.

h = distance the lamp is mounted above the ground, in feet, and *d* = distance from the base of the pole supporting the lamp to the point where the illumination is being considered, Fig. 57.

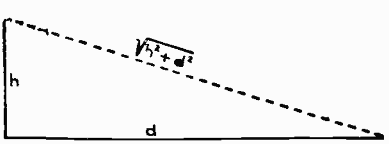

Fig. 57. Street Light Illumination Diagram.

While this will give the illumination in foot-candles, the nature of the lighting cannot be decided from this alone, but the total amount of light must also be considered. Thus, a street lighted with powerful units and giving a minimum illumination of .05 foot-candles would be considered better illuminated than one having smaller units so distributed as to give the same minimum value.

Since a uniform distribution of light is desirable, for economic reasons, the ideal distribution curve of a lamp for street lighting would be a curve which shows a low value of candle-power thrown directly downward, but with the candle-power increasing as we approach the horizontal. Such an ideal distribution curve is shown in Fig. 58.

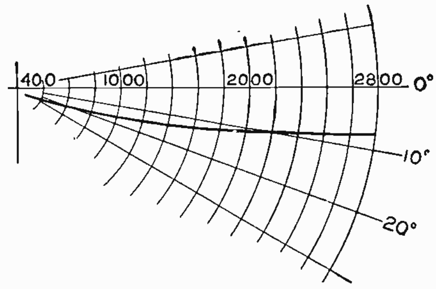

Fig. 58. Ideal Distribution Curve for a Street Light.

Actual distribution curves taken from commercial arc lamps are given in Fig. 59, in which

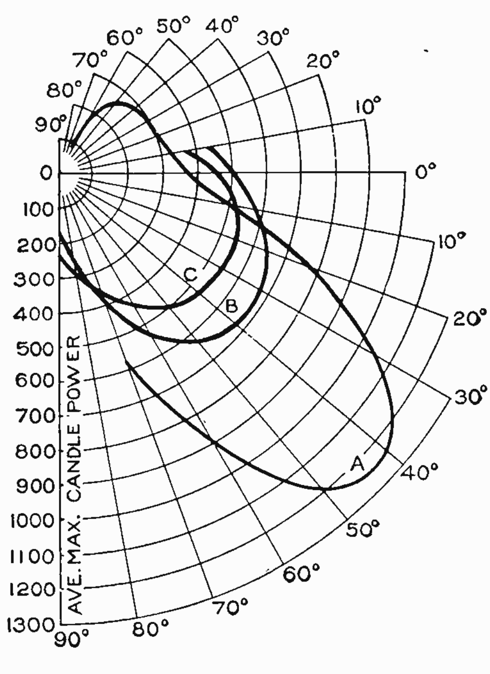

Fig. 59. Distribution Curves for Commercial Arc Lamps Used in Street Lighting.

Curve *A* shows distribution curve for a 9.6-ampere, open, direct-current arc.

Curve *B* shows distribution curve for a 6.6-ampere, D.C. enclosed arc

Curve *C* shows distribution curve for a 7.5-ampere, A.C. enclosed arc.

Globes used with *B* and *C* are opal inner globes, clear outer globes.

Globes used with *A* are clear outer globes.

A street reflector was used with the enclosed arcs.

Typical curves for flaming and luminous arc lamps are shown in Figs. 40, 43, and 44.

A series of curves known as *illumination curves* may be readily calculated showing the illumination in foot-candles at given distance from the foot of the pole supporting the lamp. Illumination curves corresponding to the distribution curves in Fig. 59 are given in Fig. 60 where *A′*, *B′*, and *C′* correspond to *A*, *B*, and *C* in Fig. 59. These curves correspond to actual readings taken with commercial lamps. Similar curves for incandescent lamps fitted with suitable reflectors are shown in Fig. 61. A value of .03 foot-candles is about the min-

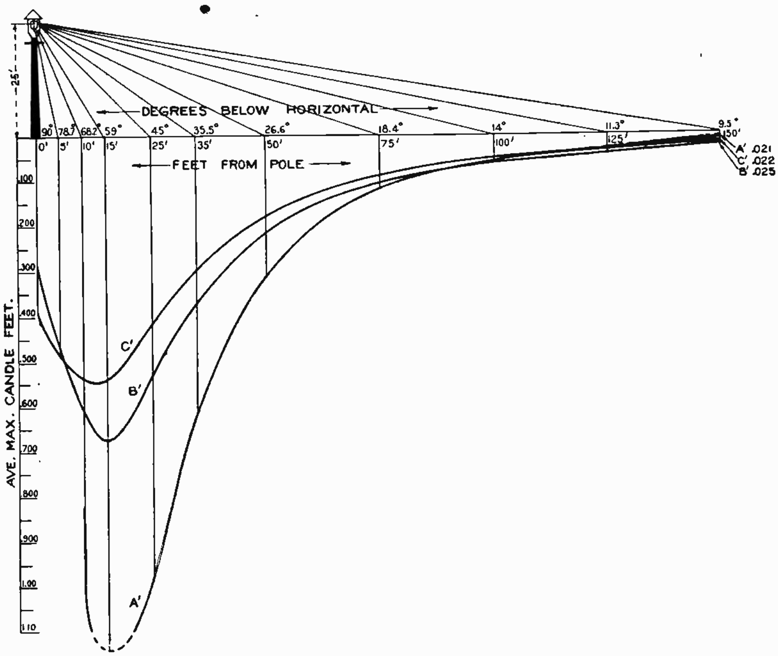

Fig. 60. Illumination Curves Drawn to Data given in Fig. 59.

imum for street lighting. Open arcs should be placed at least 25 feet above the ground; 30 to 40 feet is better, especially if the space to be illuminated is quite open. With enclosed arcs it is often advantageous to place them as low as 18 to 20 feet from the ground. Table XVIII gives the distance between lights for different types of arcs for fair illumination.

In considering the type of arc light to be used we must turn to the illumination curves as shown in Fig. 60. These curves show that the illumination from a direct-current open arc in its present form is superior to that from a direct-current enclosed arc, taking the

TABLE XVIII

Kind of Light	Distance Between Lights	Lights per Mile
6.6-ampere enclosed D.C. arc	340 feet	15
9.6-ampere open D.C. arc	315 "	17
6.6-ampere enclosed A.C. arc	275 "	19
6.6-ampere open D.C. arc	260 "	20

same amount of power, in the vicinity of the pole; but at a distance of 100 feet, the illumination from the enclosed arc is better. This illumination is still more effective on account of the absence of such strong light as is given by the open arc near the pole. The pupil of the eye adjusts itself to correspond to the brightest light in the field of vision, and we are unable to see as well in the dimly-lighted section as when the maximum intensity is less. The characteristics of the open and enclosed direct-current arc lamps are as follows:

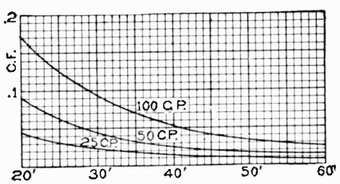

Fig. 61. Illumination Curves for Street Incandescent Lamps.

The mean spherical candle-power and energy required at the arc are variable with the open arc.

Fluctuations of light are marked, due to wandering of the arc, flickering due to the wind and lack of uniformity of the carbons.

Dense shadows are cast by the side rods and the lower carbon, while the light is objectionably strong in the vicinity of the pole.

With the enclosed arc the mean spherical candle-power and the watts consumed at the arc are fairly constant.

No shadows are cast by the lamps, and the illumination is not subject to such wide variations. The enclosed arc is much superior to the open arc using the same amount of energy. This applies to the open arc as it is now used. With proper reflection and diffusion of the light such as might be accomplished by extensive or special shading, we ought to be able to get as good distribution from the open arc with a greater total amount of illumination.

In comparing the direct-current with the alternating-current enclosed arc, we see that the direct-current arc gives slightly more light than the alternating lamp, but this may be more than counterbalanced by the better distribution of light from the alternating-current lamp. The selection of A.C. or D.C. enclosed lamps will usually depend on other conditions, such as method of distribution of power, efficiency of plant, etc.

TABLE XIX

Street-Lamp Data

Lamp	Amperes	Approx. Watts at Lamp Terminals	Approx. Value of X as Proposed
D. C. Series, open arc, clear globe	6.6	330	3.5
	9.6	450	4
D. C. Series, enclosed, clear outer globe	5.0	370	3.5
	6.6	480	4
Opalescent inner globe, street reflectors	5.5	345	3
	6.6	430	3.5
A. C. Series as above	7.5	480	4
D. C. Series "Magnetite"	4.0	310	5.5

The question of street lighting has been given considerable attention by the National Electric Light Association and this society recommends the following form of specification for street lights:

1. Under ordinary conditions of street lighting, with lamps spaced 200 to 600 feet apart, specifications for street lamps should define the mean illumination thrown by the individual lamp, in position in the street, as measured at the height of the observer's eye and perpendicular to the rays, at some point not less than 200 feet nor more than 300 feet distant, along a level street, from a position immediately below the lamp, with all extraneous light screened off and with no reflection from surrounding objects not forming part of the lamp equipment.

2. When using smaller units of light, such as series incandescent lamps spaced shorter distances apart, a correspondingly shorter distance from the lamp should be chosen in measuring the illumination.

3. The lamp contracted for should give a mean normal illumination at the test point (selected as in Sections 1 and 2) not less than the illumination given by the stationary standard incandescent lamp of 16 candle-power at 1/X of the distance. The said standard incandescent lamp should be a standardized seasoned lamp having a determined candle-power in a fixed direction.

4. When the lamp tested fluctuates in intensity, a number of observations of the maximum normal illumination should be made at a distance of not less than 200 feet horizontally from beneath the lamp, and the average of these measurements should be taken as the average maximum illumination. A similar number of observations of the minimum normal illumination should be made, the average of which should be taken as the average minimum illumination. The arithmetical mean of the said average maximum and minimum illuminations should be taken as the mean normal illumination called for in Section 1.

5. A reasonable number of the lamps covered by the contract should be tested.

6. For measuring the mean normal illumination of a lamp, comparison with the standard incandescent lamp may be made either with a suitable portable

photometer or with a reading distance instrument, such as the so-called *luminometer*.

7. The unobstructed mean normal illumination must not be less at shorter distances than at the point of test.

8. An approximate value of the mean normal illuminations thrown by street lamps of standard manufacture, at horizontal distances within the 200–300-foot range, hung approximately 20 feet above the observer's eye, may be determined from Table XIX.

Series incandescent lamps are used considerably for lighting the streets in residence sections of cities or where shade trees make it impracticable to use arcs. These vary in candle-power from 16 to 50 or even higher, and are usually constructed so as to take from two to four amperes. The best arrangement of these is to mount them on brackets a few feet from the curb, with alternate lamps on opposite sides of the street. The distance between the lamps depends on their power. 50 candle-power lamps spaced 100 feet between lamps, give a minimum illumination of .02 foot-candle. 25 candle-power lamps spaced 75 feet between lamps will serve where economy is necessary.

TABLE XX

	Per Cent
Clear glass	10
Alabaster glass	15
Opaline glass	20–40
Ground glass	25–30
Opal glass	25–60
Milky glass	30–60
Ground glass	24.4
Opal glass	32.2
Opaline glass	23

SHADES AND REFLECTORS

Lamps, as ordinarily constructed, do not always give a suitable distribution of light, while the intrinsic brightness is often too high for interior lighting. Shades are intended to modify the intensity of the light, while reflectors are used for the purpose of changing its direction. Frequently the two are combined in various ways. Shades are also used for decorative purposes, but, if possible, these should be of such a nature as to aid illumination rather than to reduce its efficiency.

A considerable amount of light is absorbed by the material used for the construction of shades. Table XX shows the approximate amount absorbed by some materials.

Of the great number of styles of shades and reflectors in use, only a few of the more important will be considered here.

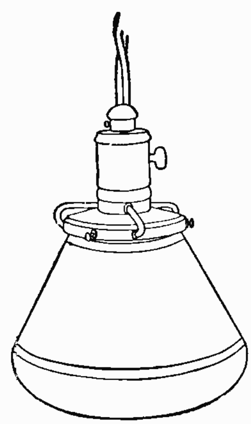

Fig. 62. McCreary Shade.

Frosted Globes. One of the simplest methods of shading incandescent lamps is by the use of frosted bulbs. These serve to reduce the intrinsic brightness of the lamp, and should be freely used for residence lighting when separate shades are not installed. Frosted globes are also used in connection with reflectors for the purpose of diffusing the reflected light. The *McCreary shade* as shown in Fig. 62, is an example of such a combined shade and reflector. Fig. 63 shows the distribution curve taken from an incandescent lamp using a McCreary shade. Fig. 64 shows the distribution of light from a conical shade. Fig. 56 shows the distribution of light brought about by means of a spiral filament and a reflector as used in the Meridian lamp.

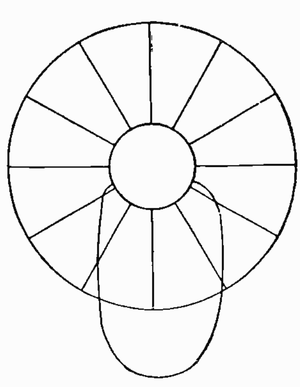

Fig. 63. Distribution Curve for Incandescent Lamp Provided with McCreary Shade.

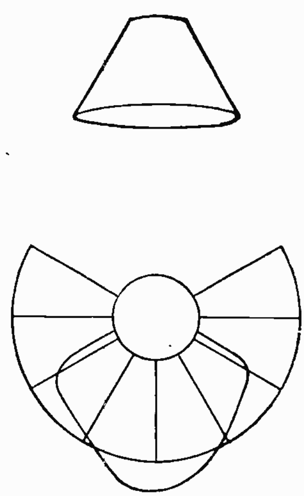

Fig. 64. Distribution Curve for Incandescent Lamp Provided with Conical Shade.

Holophane Globes. These are made for both reflecting and diffusing the light, and they can be made to bring about almost any desired distribution with but a small amount of absorption of light. These consist of shades of clear glass having horizontal grooves forming surfaces which change the direction of light by refraction or total reflection as is necessary. The diffusion of light is effected by means of deep, rounded, vertical grooves on the interior surface of the globe. While these globes are of clear glass and absorb an amount of light corresponding to clear glass, the light is so well diffused that the filament of the lamp cannot be seen, and the globe appears as if

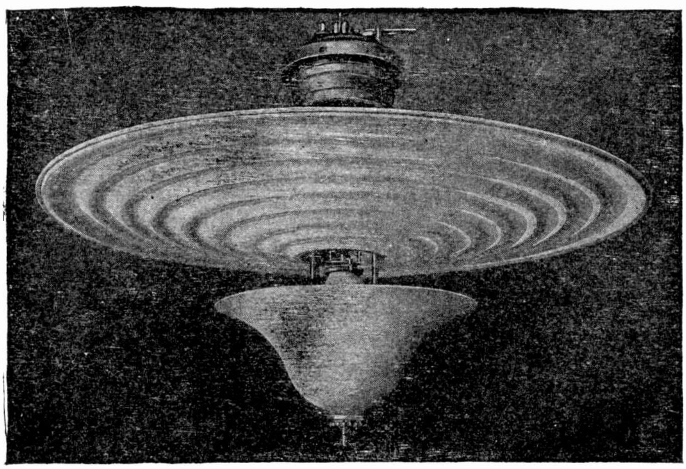

Fig. 65. Enclosed Arc Lamp Fitted with Shade and Concentric Diffuser.

made of some semi-transparent material. The holophane glassware is made in a large variety of artistic designs and for all types of incandescent lamps. By the proper selection of a reflector the distribution of the light of the unit used may be made that which is best suited to the particular case of lighting in hand. Figs. 9, 13, 14, 15, 16, 17, and 18 give some idea of what can be accomplished by these shades.

Fig. 65 shows an enclosed arc lamp fitted with a shade and a concentric *diffuser*. The effect of this combination is best shown in Fig. 66. Fig. 67 shows the change in the illumination curve produced by such shading. Inverted arcs have some application where

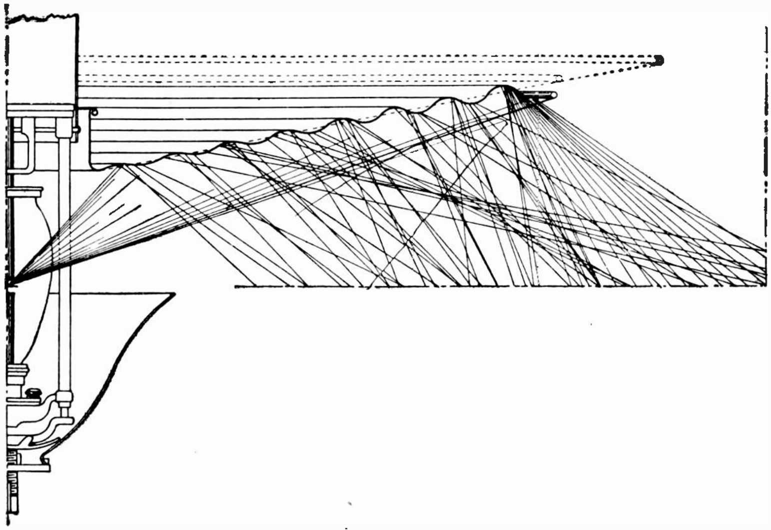

Fig. 66. Diagram Showing Effect of the Concentric Diffuser.

the light may be readily reflected and diffused as in lighting large rooms with light finish. Reflectors of this general type are now being manufactured in such a form that they may be built in and become part of the ceiling of the room to be illuminated.

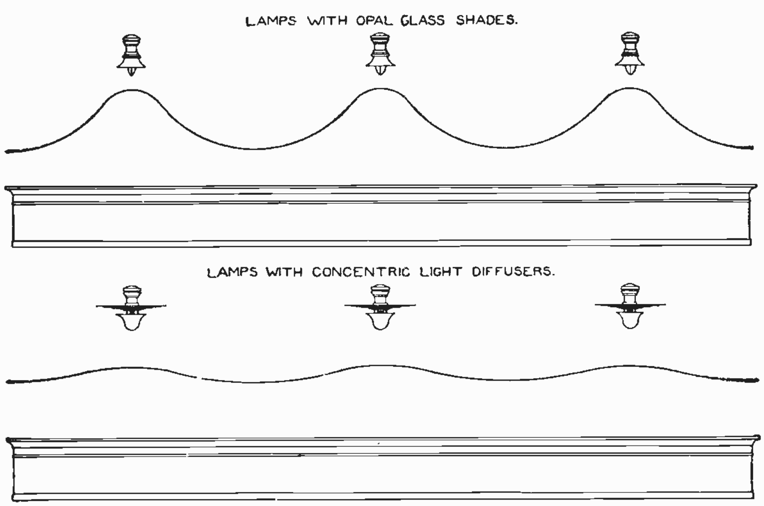

Fig. 67. Illumination Curves for Lamps with and without Light Diffusers.

Opal Enclosing Globes. The use of opal enclosing globes is recommended for arc lamps used for street lighting for the reason that they change the distribution of the light so that it covers a greater area, and the light is so diffused as to obliterate shadows in the vicinity of the lamp. Table XXI gives the efficiency of different globe combinations for street lighting assuming the opal inner and the clear outer globes as 100%.

TABLE XXI

Opal enclosing and clear outer	100 per cent
Clear " " clear "	91.2 "
" " " opal "	85.1 "
Opal " " opal "	82.7 "

PHOTOMETRY

Photometry is the art of comparing the illuminating properties of light sources, and forms one branch of scientific measurement. Its use in electric illumination is to determine the relative values of different types of lamps as sources of illumination, together with their efficiency; also by means of the principles of photometry, we are able to study the distribution of illumination for any given arrangement of light sources.

LIGHT STANDARDS

Inasmuch as sources of light are compared with one another in photometry, we must have some standard, or unit, to which all light sources are reduced. This unit is usually the candle-power and the rating of most lamps is given in candle-power.

While the candle-power remains the unit and is based on the standard English candle, other light standards have been introduced and are much more desirable.

The English Candle. The English candle is made of spermaceti extracted from crude sperm oil, with the addition of a small quantity of beeswax to reduce the brittleness. Its length is ten inches, and its diameter .9 inch at the bottom and .8 inch at the top, and its weight is one-sixth of a pound. Great care is taken in the preparation of the wick and spermaceti. This candle burns with a normal height of flame of 45 millimeters and consumes 120 grains per hour when burning in dry air at normal atmospheric pressure. Under these conditions, the light given by a single candle is one candle-power.

When used for measurements, the candle should be allowed to burn at least fifteen minutes before taking any readings. At the end of this period the wick should be trimmed, if necessary, and when the flame height reaches 45 millimeters, readings can be taken. The candle should not require trimming when the proper height of flame has been reached. It is best to weigh the amount of material consumed by balancing the candle on a properly arranged balance when the first reading is taken, and again balancing at the end of a suitable period—ten to fifteen minutes. The candle-power of the unit is then, practically, directly proportional to the amount of the material consumed.

The objections to the candle as a unit are that it burns with an open flame which is subject to variation in height and to the effect of air currents. The color of the light is not satisfactory, being too rich in the red rays, and the composition of the spermaceti is more or less uncertain.

The German Candle is made of very pure paraffine, burns with a normal flame height of 50 millimeters, and is subject to the same disadvantages as the English candle. It may be necessary to trim the wick to keep the flame height at 50 millimeters. The light given is a trifle greater than for the spermaceti candle.

The Carcel Lamp is built according to very careful specifications and burns colza (rape seed) oil. It has been used to a large extent in France, but its present application is limited.

The Pentane Lamp is a specially constructed lamp burning pentane, prepared by the distillation of gasoline between narrow limits of temperature. This standard is not extensively used.

The Amyl Acetate Lamp. This lamp, known also as the *Hefner lamp*, is at present the most desirable standard. It is a lamp built to very careful specifications, especially with regard to the dimension of the wick tube. It burns pure amyl acetate and the flame height should be 40 millimeters. This flame height must be very carefully adjusted by means of gauges furnished with the lamp. Amyl acetate is a colorless hydrocarbon prepared from the distillation of amyl alcohol obtained from fusil oil, with a mixture of acetic and sulphuric acids, or by distillation of a mixture of amyl acetate, sulphuric acid, and potassium acetate. It has a definite composition, and must be pure for this use.

The most serious disadvantage of this standard is the color of the light, inasmuch as it has a decidedly red tinge and is not readily compared with whiter lights. Its value is affected somewhat by the moisture in the air and the atmospheric pressure, but it excels all other standards in that it is quite readily reproduced.

Table XXII gives the value of the candle-power units of different laboratories in terms of the unit of the Bureau of Standards and also the values of the units of the Carcel and Vernon-Harcourt in terms of the Hefner, as accepted by the International Photometric Commission.

TABLE XXII

Photometric Units

Bureau of Standards Unit, United States	1.000
Reichsanstalt Unit, Germany	0.998 × 0.88
National Physical Laboratory Unit, England	0.984
Laboratoire Central Unit, France	0.982

	Carcel	Hefner	Vernon-Harcourt
Carcel	1.00	10.75	0.980
Hefner	0.0930	1.00	0.0915
Vernon-Harcourt (pentane)	1.020	10.95	1.0

The above values are at a barometric pressure of 760 mm. of mercury and a humidity for the Carcel and Vernon-Harcourt standards of 10.0 liters of water per cubic meter of dry air. The humidity for the hefner unit is 8.8 liters of water to one cubic meter of dry air.

Working Standards. *Incandescent Lamp.* The units just described, together with some others, form reference standards, but an incandescent lamp is generally used as the working standard in all photometers. An incandescent lamp, when used for this work, should be burned for about two hundred hours, or until it has reached the point in the life curve where its value is constant, and it should then be checked by means of some standard when in a given position and at a fixed voltage. It then serves as an admirable working standard if the applied voltage is carefully regulated. Two such lamps should always be used—the one to serve as a check on the other; the checking lamp to be used for very short intervals only.

PHOTOMETERS

Two light sources are compared by means of a photometer which, in one of its simplest forms, consists of what is known as a *Bunsen screen* mounted on a carriage between the two lights being compared, with its plane at right angles to a line passing through the light sources, and arranged with mirrors or prisms so that both sides of the screen may be observed at once. The Bunsen screen consists of a disk of paper with a portion of either the center, or a section around the center, treated with paraffine so as to render it translucent. If the light falling on one side of this screen is in excess, the translucent spot will appear dark on that side of the screen and light on the opposite side. Care must be taken to see that the two sides of the screen are exactly alike, otherwise there will be an error introduced in using the screens. It is well to reverse the screen and check readings whenever a new lot of lamps are to be tested. When the light falling on the two sides of the screen is the same, the transparent spot disappears. The values of the two light sources are then directly proportional to the square of their distances from the screen. As an example, consider a 16 candle-power lamp being compared with a standard candle on a photometer with a 300-centimeter bar. Say the translucent spot disappears when the screen is distant 60 centimeters from the standard candle, we then have the proportion,

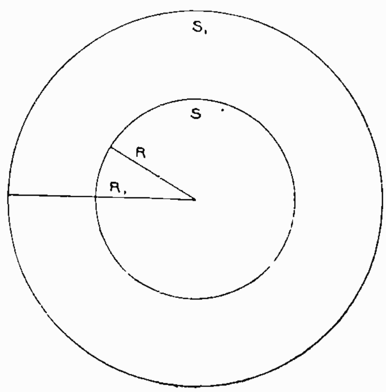

Fig. 68. Proof of the Law of Inverse Squares by the Method of Concentric Spheres.

$$x : 1 = (240)^2 : (60)^2 = 16 : 1,$$

showing that the lamp gives 16 candle-power.

The above law is known as the law of inverse squares, and holds true only when the dimensions of the light sources are small compared with the distance between them, and when there are no reflecting surfaces present as when the readings are taken in a dark room.

The proof that the light varies inversely with the square of distance from the source is as follows:

Consider two spherical surfaces, Fig. 68, illuminated by a source of light at the center. The same quantity of light falls on both surfaces.

Area of $S = 4\pi R^2$ sq. ft. (R is in feet.)
Area of $S_1 = 4\pi R^2_1$ sq. ft.

Let Q = total quantity of light and q = light falling on unit surface. Then,

$$q = \frac{Q}{4\pi R^2}$$

$$q_1 = \frac{Q}{4\pi R^2_1}$$

$$q : q_1 = \frac{Q}{4\pi R^2} : \frac{Q}{4\pi R^2_1}$$

$$= 4\pi R^2_1 : 4\pi R^2$$

$$\frac{q}{q_1} = \frac{R^2_1}{R^2}$$

Fig. 69 shows the relation in another way. The area of C. distant two units from the source of light A, is four times that of B which is distant one unit.

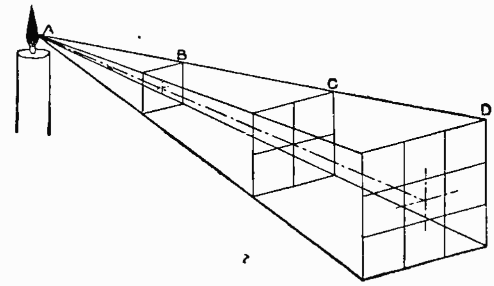

Fig. 69. Proof of the Law of Inverse Squares by Method of Screen Shadow.

The Lummer-Brodhun Photometer. In addition to the Bunsen screen described, there are several other forms of photometers, the most important of which is the Lummer-Brodhun. The essential feature of this instrument is the optical train which serves to bring into contrast the portions of the screen illuminated by the two sources of light. Referring to Fig. 70 the screen S is an opaque screen which reflects the light falling upon it from L, to the mirror M, when it is again reflected to the pair of glass prisms A, B. The surfaces sr are ground to fit perfectly and any light falling on this surface will pass through the prisms. Light falling on the surface ar or bs will be reflected as shown by the arrows. We see then that the light from L, which falls on ar and bs, is reflected to the eye piece or telescope T, while that falling on sr is transmitted to and absorbed by the black interior of the containing box. Likewise, the light from the screen

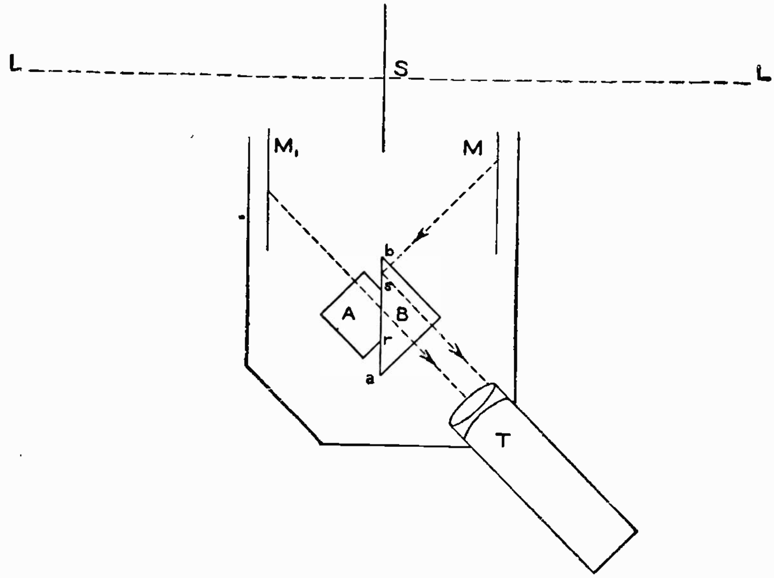

Fig. 70. Diagram of Lummer-Brodhun Screen.

L_1 is reflected by the screen M_1 to the pair of prisms A, B. The rays falling on the surface sr pass through to the telescope T, while the rays falling on ar and bs are reflected and absorbed by the black lining of the case. The field of light, as then viewed through the telescope, appears as a disk of light produced by the screen L_1, surrounded by an annular ring of light produced by L. When the illumination on the two sides of the screen is the same, the disk and ring appear alike and the dividing circle disappears.

In using this screen, it is mounted the same as the Bunsen screen and readings are taken in the same manner. The screen and prisms are arranged so that they can be reversed readily and two readings should always be taken to compensate for any inequalities in the sides of the screen and the reflecting surfaces, a mean of the two readings

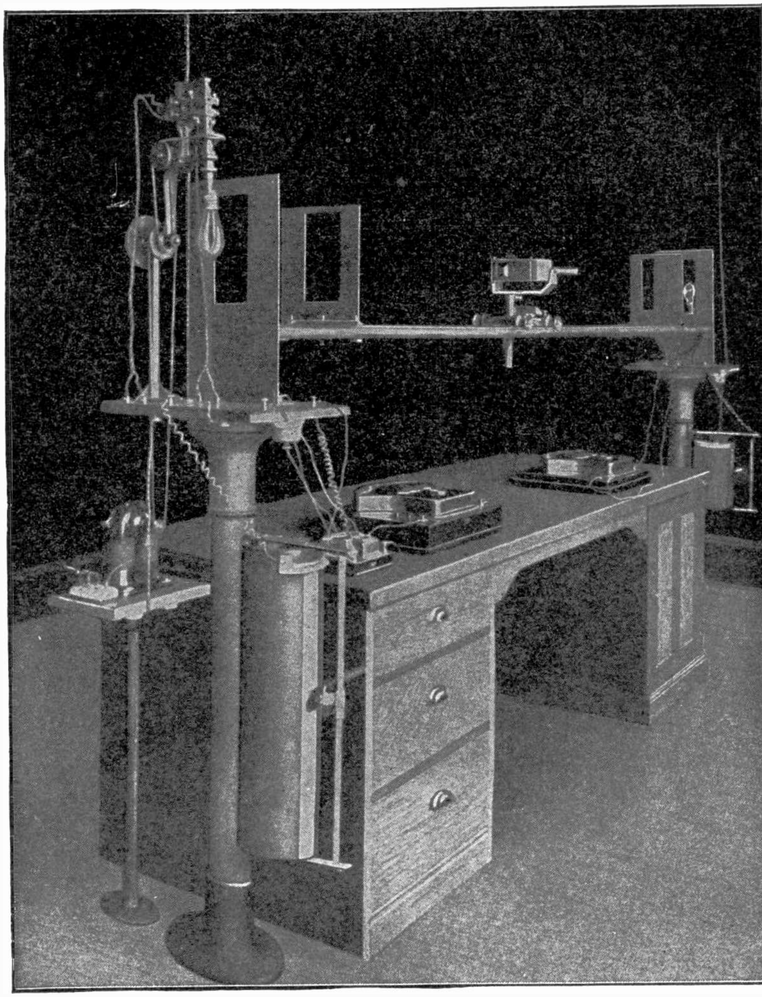

Fig. 71. Complete Photometer with Lummer-Brodhun Screen.

serving as the true reading. This form of screen is used when especially accurate comparisons are required.

Fig. 71 shows a complete photometer with a Lummer-Brodhun screen, while Fig. 72 shows a Bunsen screen and sight box. In Fig. 71, the lamps are shaded by means of curtains so as to leave only a small opening toward the screen. If the lights are properly screened photometric measurements may be made in rooms having light-colored walls.

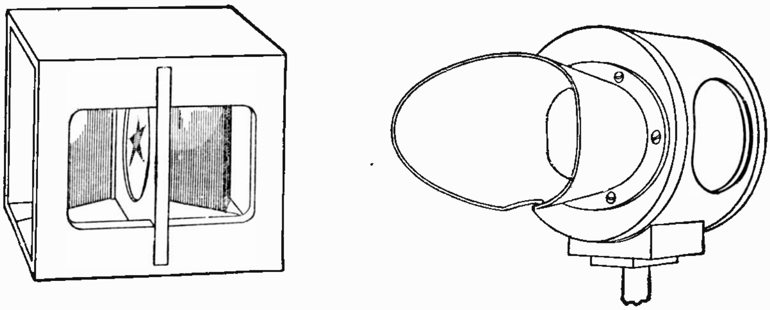

Fig. 72. Bunsen Screen and Sight Box.

The Weber Photometer. As an example of a portable type of photometer, we have the Weber. This photometer, shown in Fig. 73, is very compact and is especially adapted to measuring intensity of illumination as well as the value of light sources; it may be used for exploring the illumination of rooms or the lighting of streets.

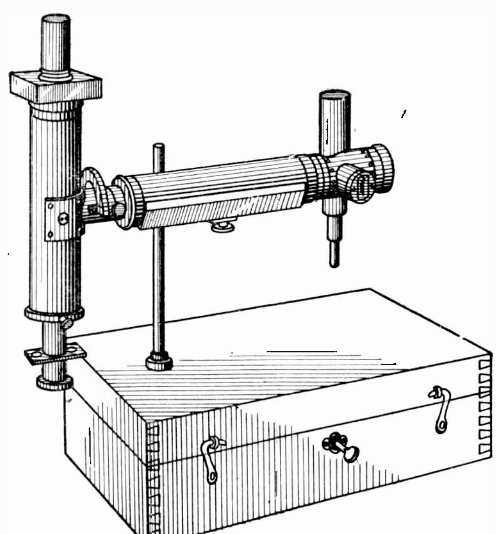

Fig. 73. Weber Portable Photometer.

This apparatus consists of a tube *A*, Fig. 74, which is mounted horizontally and contains a circular, opal glass plate *f*, which is movable by means of a rack and pinion. To this screen is attached an index finger which moves over a scale attached to the outside of the tube. A lamp *L*, burning benzine, is mounted at the end of this tube. The benzine used should be as pure as possible, and the flame height should be carefully adjusted to 20 mm. when taking readings. At right angles to the tube A is mounted the tube B which contains an eye piece at O, a Lummer-Brodhun contrast prism at p, and a support for opal or colored glass plates at g.

Operation. The tube B is turned toward the source of light to be measured, the distance from the light to the screen at g being noted. The light from this source is diffused by the screen at g, while that from the standard is diffused by the screen f. By moving the screen f, the light falling on either side of the prism p can be equalized. The value of the unknown source can be determined from the reading of the screen f, the photometer having previously been calibrated by means of a standard lamp in place of the one to be measured. The calibration may be plotted in the form of a curve or it may be denoted by a constant C, when we have the formula,

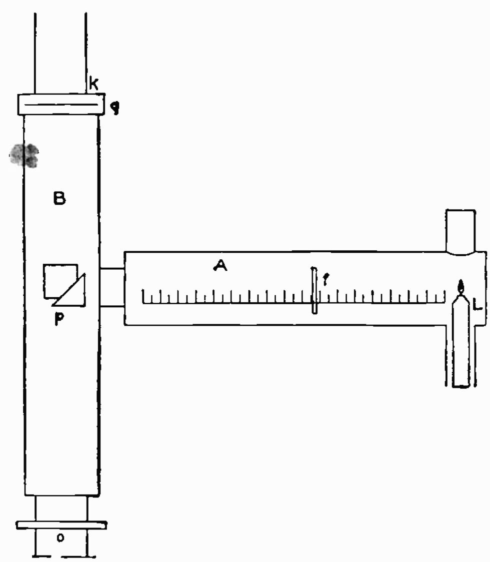

Fig. 74. Diagram of Weber Photometer.

$$I' = C\,\frac{L^2}{l^2}$$

C corresponds to a particular plate at g, l = distance of screen f from the benzine lamp, and L = distance from the screen g to the light source being measured. Screens of different densities may be used at g, depending on the strength of the light source.

When used for measuring illumination, a white screen is used in connection with this photometer. The screen is mounted in front of the opening at g, and turned so that it is illuminated by the source being considered. Readings of the screen f are taken as before. A calibration curve is plotted for the instrument, using a known light source at a known distance from the white screen when the instrument is mounted in a dark room.

Portable Photometers. There is a large variety of portable photometers available and giving more or less satisfactory results. An instrument especially designed with a view to portability and to overcoming some of the defects of instruments already on the market has recently been introduced. The instrument referred to is called a *Universal photometer* but it is more commonly known as the *Sharp-Millar photometer* from the names of its inventors. Views of this instrument are shown in Figs. 75 and 76. It is adapted to the measurement of the intensity of light sources as well as to the illumination at any point, as is the Weber photometer. The photometer screen or photometric device is shown at *B*, and consists of a special form of

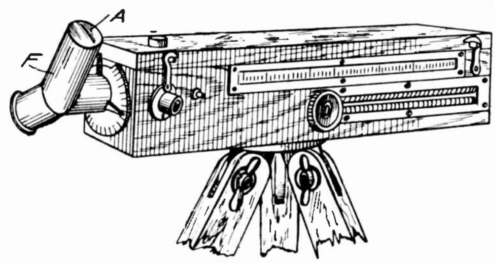

Fig. 75. Universal Photometer.

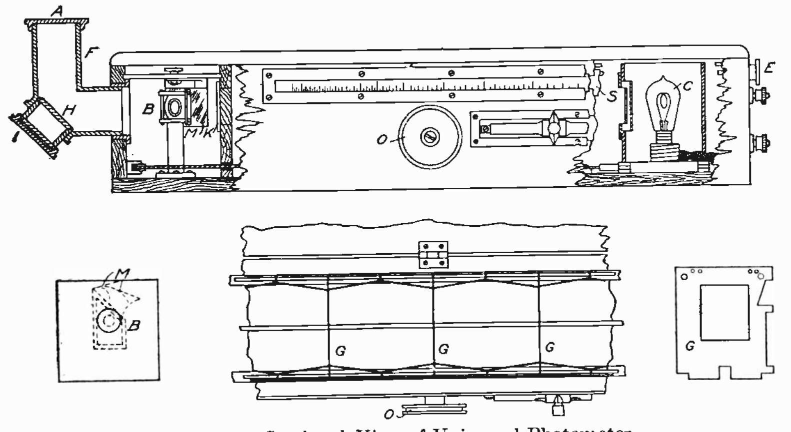

Fig. 76. Sectional View of Universal Photometer.

Lummer-Brodhun optical screen. A standardized incandescent lamp *C* is used as the photometric standard and this may be connected to a battery, or be adapted to use on the mains supplying the lamps in the room where measurements are to be taken. All stray light is carefully screened from the interior of the box by a series of screens *G*. The instrument scale is calibrated in foot-candles and in candle-powers.

When illumination is to be measured, a specially selected trans-luscent screen is placed at A and the illumination of this plate, which is placed at the point and in the plane where the value of the illumination is desired, is reflected to the photometric device by the mirror at H. A second plate K is mounted so as to be illuminated by the standard lamp and the photometer is balanced by making the illumination of A and K the same. When the intensity of a light source is to be determined, the screen at A is replaced by a small aperture and a diffusing surface I is put in place of the mirror H. The illumination of I is now compared with the illumination of K, and when the two are made equal, the photometer reads the candle-power of the light source, or some multiple of this candle-power. The range of this instrument is increased by the use of suitably arranged absorbing screens which may be readily inserted or removed, and as ordinarily equipped, the range in foot-candles is approximately from .004 to 2,000. The variety of uses which can be made of such a photometer is large, and some idea of its portability can be obtained from the dimensions of the box, 24″ x 4½″ x 5″, and its weight, fully equipped, of 8 pounds. It is very accurate considering its compactness.

Integrating Photometers. *Matthews.* This photometer is used to some extent and a very good idea of its construction can be obtained from Fig. 77. By means of a system of mirrors, the light given by the lamp in several directions may be integrated and thrown on the photometer screen for comparison with the standard, the result giving the mean spherical candle-power from one reading. By covering all but one pair of screens, the light given in any one direction is easily determined.

Another type of integrating photometer is known as the *integrating sphere* or *globe photometer*. If a light source is placed within a sphere, the interior walls of which are coated with a white diffusing surface, the illumination of that surface at any point is due partly to the light falling on it directly, and partly to the light reflected from the remainder of the surface of the sphere. The reflected light is proportional to the total flux of light from the light source and so, if the direct light is screened from the point considered, its illumination is proportional to the total flux of light, and hence to the mean spherical candle-power of the light source.

The practical application of this principle is to so arrange our properly coated sphere that the lamp to be tested may be readily inserted; to replace a small portion of the sphere by a piece of unpolished white glass; to shut off the direct rays of the lamp to be

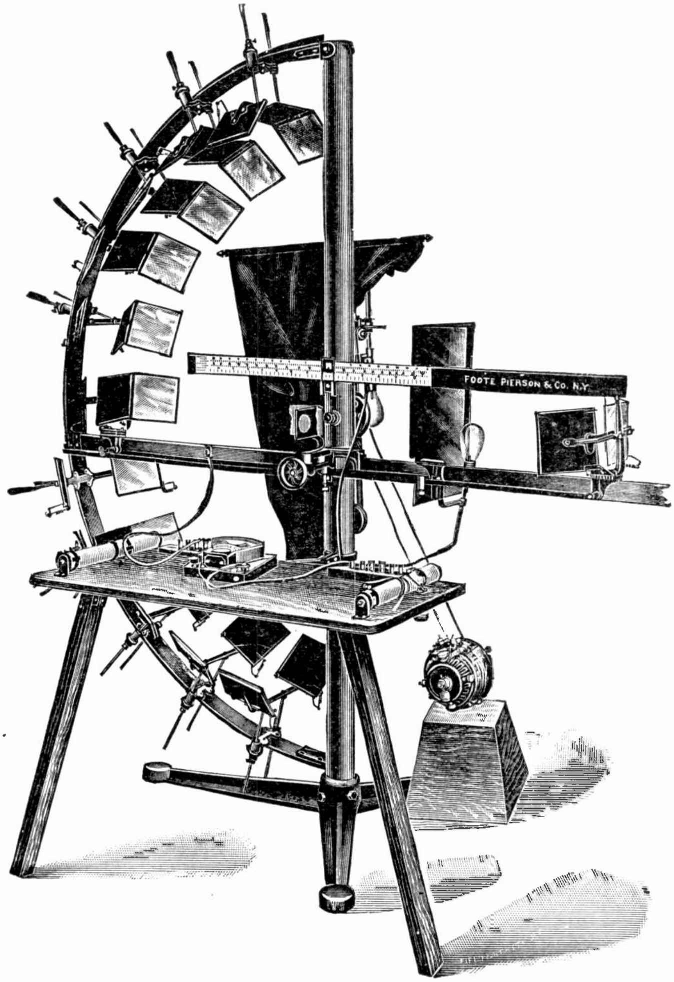

Fig. 77. Integrating Photometer.

measured from this glass surface; and to so mount a photometer screen and standard lamp that the illumination of the glass section can be measured. Under these conditions the illumination of the glass screen is proportional to the mean spherical candle-power of the lamp under test. A substitution method is used in practice. A standardized lamp of the general type of the one to be tested is mounted in the sphere and the constant of the instrument for this type of lamp is determined. The unknown lamps are then put in place and their candle-power is readily determined, once the constant of the instrument is known. Figs. 78 and 79 give some views of the integrating

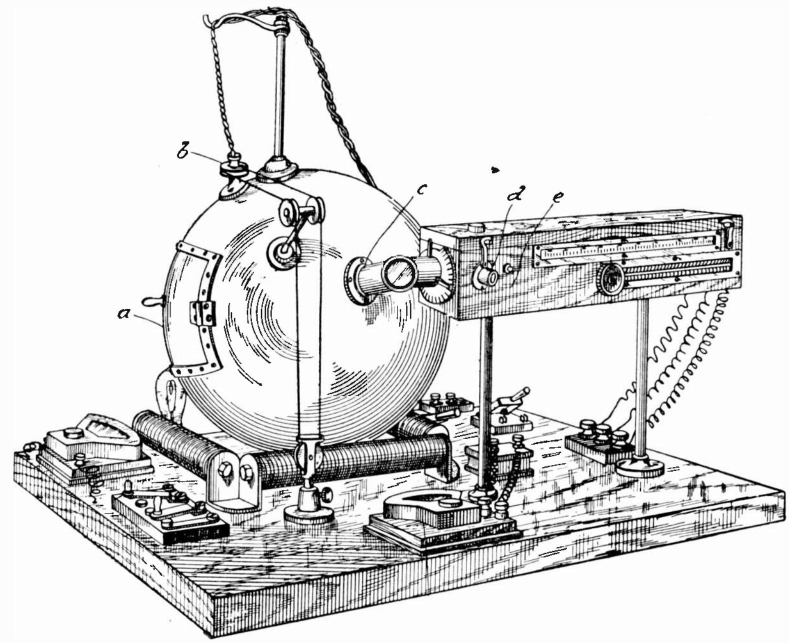

Fig. 78. Eighteen-Inch Integrating Sphere Equipped with Photometer.

sphere and indicate the range of the sizes in which it may be constructed.

INCANDESCENT LAMP PHOTOMETRY

Apparatus. Some sort of screen, either the Bunsen type or the Lummer-Brodhun screen preferred, should be mounted on a carriage moving on a suitable scale, and the lamp holders, one for the standard, the other for the lamp to be tested, are mounted at the ends of this scale. There are several types of so-called station photometers arranged so as to be very convenient for testing incandescent lamps. Fig. 80 shows one form of station photometer manufactured by Queen & Co. The controlling rheostats and shielding curtains are not shown here. Fig. 81 shows a form of portable photometer for incandescent lamps. The length of scale should not be less than 100 centimeters, and 150 to 200 centimeters is preferred. This scale may be divided into centimeters or, for the purpose of doing away with much of the calculation, the scale may be a *proportional scale.* This scale is based on the law of inverse squares and reads the inverse ratio of the squares of the distances from the two lights being compared.

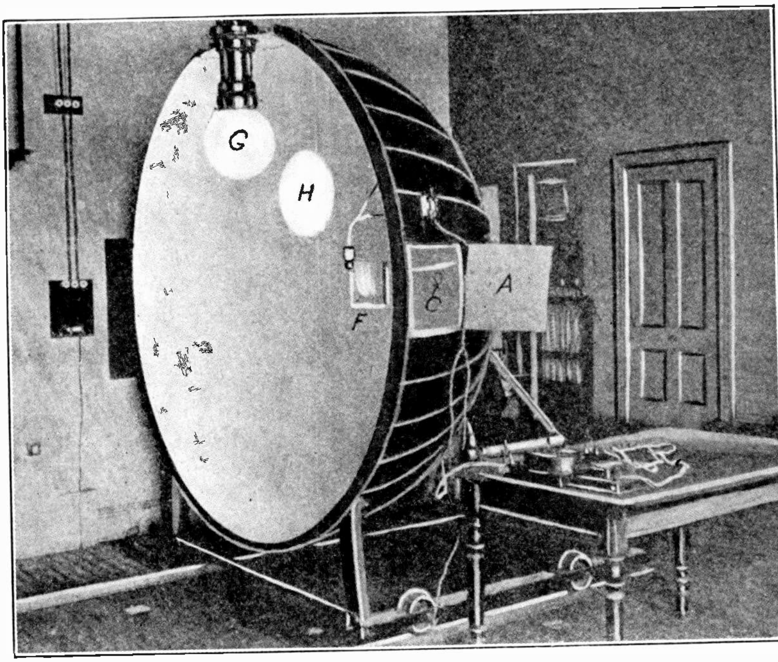

Fig. 79. Interior of 80-Inch Integrating Sphere.

If the standard used always has the same value, the scale may be made to read in candle-powers directly.

For mean horizontal candle-power measurements, the lamp should be rotated at 180 revolutions per minute, when mounted in a vertical position.

For distribution curves a universal lamp holder which will allow the lamp to be placed in any position, and which indicates this position, is used.

For mean spherical candle-power, the following method is used when the Matthews photometer is not available:

The lamp is placed in an adjustable holder and readings taken with the lamp in thirty-eight positions, as follows:

The measurement of the spherical intensity. For convenience the tip of the lamp and its base may be termed the north and south poles respectively.

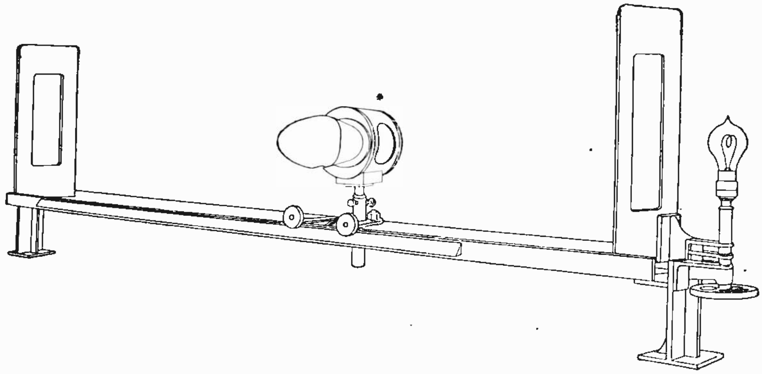

Fig. 80. Station Photometer.

The mean of 13 readings taken at intervals of 30°, is taken to give the mean horizontal candle-power.

Beginning again at 0° azimuth, thirteen readings are made in the prime meridian or vertical circle, the interval again being 30°, and the last reading checking the first.

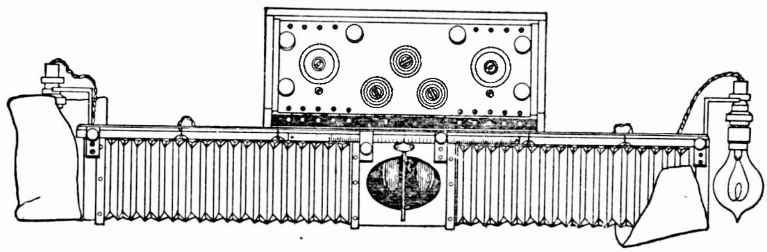

Fig. 81. Portable Photometer for Incandescent Lamps.

It will be noticed that four readings, two being check readings, have been made at 0° azimuth in each case. The mean of the four is taken as the *standard reading*, it being the value of the intensity, in this position, should the lamp be used as a standard.

Additional sets of thirteen readings each—the last reading checking the first one—are similarly made on each of the vertical circles through 45°, 90°, and 135° azimuth.

In combining the readings for the mean spherical intensity, a note is taken of the repetitions.

Neglecting the repetitions, which may also be omitted in part, in the practice of the method, there remain thirty-eight points, as follows:

	Distributed Values
The mean of four measurements at the north pole of the lamp.........	1
Four measurements on each of the vertical circles through 0° and 90° azimuth at vertical circle readings of 60°, 120°, 240°, and 300°....	8
Four measurements on each of the vertical circles through 0°, 45°, 90°, and 135° azimuth at vertical circle readings of 30°, 150°, 210°, and 330°..........	16
Twelve measurements 30° apart at the equator....................	12
Four null values at the south pole of lamp..........................	1
Total number of effective measurements..........................	38

The points thus laid off on the reference sphere are approximately equidistant, being somewhat closer together at the equator than at the poles.

When the lamp is rotated, readings are taken for each 15° or 30° in inclination, from 0° to 90°, and from 0° to 270°. These are integrated values for their corresponding parallels of latitude on the unit sphere.

The mean spherical candle-power from these readings may best be obtained by plotting a distribution curve from the readings, determining the area of this closed curve by means of a planimeter and taking the radius of an equivalent circle as the value for the mean spherical candle-power.

The *Rousseau diagram* may be used for determining the mean spherical candle-power of a lamp when its vertical distribution curve is known. Fig. 82 shows such a diagram made up for a *gem lamp* with a bowl reflector. Where the horizontal distribution curve of the lamp is not uniform the values for the vertical distribution curve should be taken with the lamp rotating so as to give average values at each angle. One-half of the distribution curve is drawn to scale *A* and a circle *B* is drawn with the source of light *O* as a center. Radii *C* are drawn at equal angles about the light source and extended until they intersect the circle *B*. The points of intersection of these lines with the circle are projected upon the straight line *D E*. Distances from this line are laid off on the verticals *F* equal to the distances from the center of the circle to the points where the corresponding radii cut the distribution curve. The area enclosed between the straight line *D E* and a curve drawn through the points just determined, *G H*, divided by the base line, is equal to the mean spherical candle-power of the lamp. If the mean candle-power of the lamp within a certain angle is desired, it is only necessary to find the area of the diagram within the space indicated by that angle and divide by the corresponding base.

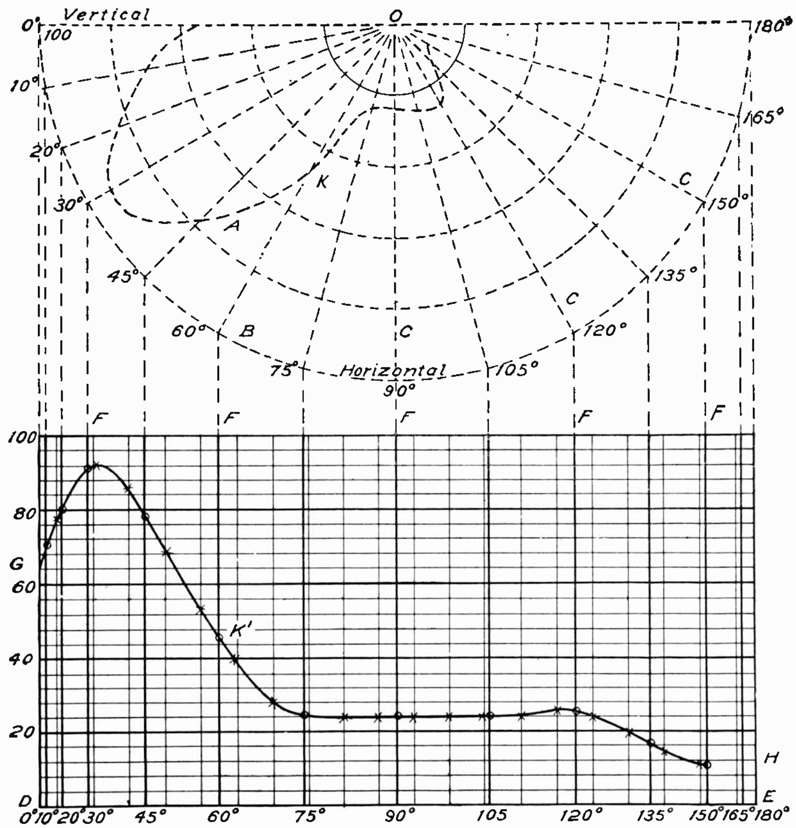

Fig. 82. Rousseau Diagram for Gem Lamp with Bowl Reflector.

In all tests the voltage of the lamp must be very closely regulated. A storage battery forms the ideal source of current for such purposes. In testing incandescent lamps, a standard similar to the lamp being tested is desirable and it should, preferably, be connected to the same leads. Any variation in the voltage of the mains then affects both lamps and the error introduced is slight.

ARC LIGHT PHOTOMETRY

Owing to the variation of the amount of light given out by an arc lamp in one direction at any time, due to variation of the qualities of the carbons, position of the arc, and also on account of the color of the light, etc., the photometry of arc lamps is much more difficult than that of incandescent lamps. The curves shown in Figs. 33 and 34 are average distribution curves taken from several lamps and will vary considerably for any one lamp. If the arc is enclosed, this variation is not so great.

The working standard should be an incandescent lamp run at a voltage above the normal so that the quality of the light will compare favorably with that of the arc. Since an incandescent lamp deteriorates rapidly when run at over voltage, the standard can be used only for short intervals and must be frequently checked.

Since an arc lamp can be mounted in one position only, mirrrors must be used to obtain distribution curves. A mirror is used mounted at 45° with the axis of the photometer, and arranged so as to reflect the arc when in different positions. A mirror absorbs a certain per cent of the light falling upon it and this percentage must be determined by using lamps previously standardized. The length of the photometer bar must include the distance from the mirror to the arc.

The Weber photometer is well adapted to arc-light measurements inasmuch as appropriate screens may be used to cut down the intensity of the light.

A special form of the Matthews photometer is also used for testing arc lamps.

For the comparison of the illumination from arc lamps as installed in service, an instrument known as an *illuminometer* is sometimes used. This consists of a light wooden box, readily portable, having a black interior and arranged with two openings. One of these openings is for the purpose of admitting light from the source being considered, to a printed card. The other opening is for the purpose of viewing this card when illuminated by the light source. The printing on the card is made up from type of different sizes, and the smallest size which is legible, together with the distance from the light source, is noted. Another method of application is to select some definite size of type and then to move the instrument from the light source to a point where this type is just legible and note the distance. From similar measurements taken on different lamps a good comparison may be obtained. Such an instrument is very convenient to use, and results obtained by different observers check very closely.

The *flicker photometer* is used for the comparison of different colored lights, the basis for comparison being that each light, though different in color, shall produce light sensations equally intense for the purpose of distinguishing outlines. It consists, in one form, of an arrangement by means of which a sectored disk is rotated in front of each light source, these disks being so arranged that the light from one source is cut off while the other falls on the screen, and *vice versâ*, any form of screen being used for making the comparison. The disks must be revolved at such a rate that the light, viewed from the opposite side, will appear continuous. When the illumination of the two sides of the screen, under these conditions, is not the same, there will be a perceptible flicker and the screen should be so adjusted that this flicker disappears. The value of the light source can then be calculated from the screen reading in the usual manner. Another device consists of the use of a special lens mounted in front of a wedge-shaped screen, the lens being constructed so as to reverse the image of the two sides of the screen, as viewed by the eye, when such lens is in front of the screen. The lens is so mounted that it can be oscillated rapidly in front of the screen, giving the same result as would be obtained were it possible to reverse the screen at such a rapid rate as to cause the illumination on the two sides to appear continuous. The setting of this screen is accomplished as with the more simple forms.

Still another flicker photometer, the Simmance-Abady, makes use of a rotating wheel. This wheel is made of a white material having a diffusing surface, and its edge is so beveled that during part of a revolution a surface illuminated by one of the light sources is viewed through the eye-piece of the instrument, and during the other part of the revolution a surface viewed by the second light source is observed. The flicker occasioned by this change disappears when the screen is brought to a point where it is equally illuminated by the two light sources.

By the use of such forms of photometers it is found that results with different colored lights can be obtained, which are comparable with results obtained with lights of the same color.

REVIEW QUESTIONS

REVIEW QUESTIONS

ON THE SUBJECT OF

DIRECT-CURRENT MOTORS

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1. State briefly the fundamental principle of the motor.

2. What is meant by the *torque* of a motor? How is it related to the power? If the field and armature current are constant, how is the torque related to the speed?

3. If the output of a motor is 60 horse-power, and the armature makes 490 revolutions per minute, what is the torque?

4. If the pulley of the motor in the preceding question is 22 inches in diameter, what is the effective pull upon the belt?

5. What is the commercial efficiency of a 500-volt motor which takes 120 amperes and delivers 71.6 horse-power?

6. What is meant by the counter-electromotive force of a motor? What relation does it bear to the efficiency?

7. The current in the armature of a shunt motor is 50 amperes; and the E.M.F. at the brushes, 240 volts. If the armature resistance is 0.38 ohm, what is the counter-E.M.F.?

8. Upon what does the speed of a motor depend?

9. Explain briefly the different methods used to vary the speed of shunt motors.

10. What disadvantages are there in controlling the speed of a shunt motor by a rheostat in the armature circuit?

11. A 230-volt shunt motor takes 55 amperes at full load, the speed being 760 revolutions per minute. What resistance must be inserted into the armature circuit to give half the full-load torque at two-thirds speed? How many watts are lost in this resistance under these conditions?

12. A shunt generator is to be used as a motor. What changes are necessary? Should the brushes be shifted, and, if so, to what point?

13. What limits the range of speed by varying the field resistance?

14. Make a sketch of Fig. 19, showing the connections for rotation in the opposite direction.

15. Why cannot the starting resistance be used as a speed-controller?

16. In stopping a shunt motor, why should the main switch be opened before the armature circuit is broken?

17. What is the general advantage of shunt motors?

18. What is the objection to reversing a motor while running?

19. Explain why the speed of a series motor on constant-potential circuit increases when the load is removed. Does this call for any special precautions?

20. What is the especial advantage of the series motor?

21. What is a cumulative compound motor, and for what is it used?

22. If the fields of a series motor were magnetized nearly to saturation with half the full-load current, what effect would this have upon speed variations in the neighborhood of full load?

23. Explain the effect of the series coil of a differential motor on the speed. Is this property of any value? Has it any disadvantages?

24. Why cannot an enclosed motor be rated at the output it would have if open?

25. What is the *Multi-Voltage System*, and what are its advantages? Would you use it for a single motor?

26. What is a *balancer?* Why may it be of relatively small capacity compared with the main generator?

REVIEW QUESTIONS

ON THE SUBJECT OF

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

PART I.

---

1. Why is the steam turbine well adapted for direct connection?

2. On a three-wire system is it better to use 110-volt or 220-volt motors? Explain why.

3. Describe construction and operation of the Fort Wayne self-starting synchronous motor.

4. What methods are used for controlling the speed of induction motors? Which one is preferable?

5. How can the friction of brushes and bearings be tested roughly?

6. What points should be considered in the selection of a machine?

7. Give a sketch of the connections of a compound-wound motor.

8. What is the advantage of a synchronous motor when its field is over excited? Explain.

9. Give a safe rule to follow for personal protection when handling electrical circuits of a sufficiently high voltage to be dangerous.

10. What precautions must be taken in fixing a direct-connected set?

11. Why should starting boxes always be furnished with direct-current motors?

12. (a) How are small induction motors started? (b) Why cannot large sizes be started in the same way?

13. If a machine is to be taken apart for the purpose of cleaning or inspecting it, what precautions should be taken?

14. Describe the method of lacing a belt.

REVIEW QUESTIONS

ON THE SUBJECT OF

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

PART II.

---

1. In measuring resistance with the Wheatstone bridge, what is the objection of using a ratio of 1000 : 1 or 100 : 1 ?

2. Describe a tachometer. What advantage has this over the speed counter ?

3. What is the torque of a 20 horse-power motor running at the rate of 600 r.p.m. ?

4. When the armature of a machine becomes overheated and the belt is tight on the tension side, to what would you ascribe the cause and how would you remedy it ?

5. Explain how to true up the commutator in case it becomes rough or uneven.

6. Describe a method of testing to see if the armature is centered between the pole pieces.

7. What is the pull in pounds in the case of a 40 horse-power motor if the speed is 550 r.p.m. and the pulley is 3 feet in diameter ?

8. What do you understand to be meant by a ground in the armature ?

9. If the speed of a generator is too high, what effect does this have on the voltage ?

10. Describe with formula the direct-deflection method of measuring insulation resistance.

11. Describe a method of determining the current in a circuit if you have a voltmeter but no ammeter at hand.

12. How does eddy-current loss vary with the speed ?

REVIEW QUESTIONS

ON THE SUBJECT OF

STORAGE BATTERIES.

---

1. What is the lowest voltage to which a lead battery should be discharged?

2. What means may be employed to make up for the drop in potential of storage batteries during discharge?

3. What causes sulphating?

4. What plate of a storage battery is the positive?

5. Describe the several indications by which the amount of charge in a storage battery can be determined.

6. How is the capacity of a storage battery usually expressed?

7. What is an electrolyte?

8. What is meant by a floating battery, and when is it applicable?

9. How must a storage battery room be arranged?

10. What causes buckling?

11. Why are there always more negative plates than positive plates in a storage battery?

12. Give several applications of storage batteries.

13. When a storage battery is charged, what is found on the positive plate? What is found on the negative plate? What occurs when the cell is discharged?

14. What is the maximum voltage obtainable from a lead storage cell?

15. How may sulphating and buckling be prevented?

16. How would you put a battery out of commission for a long period, and how would you place it in service again?

17. What is the difference in construction between Faure and Planté plates?

18. What is the essential difference between a primary and a storage battery?

19. What instruments are required on a storage battery switchboard, and how are they connected?

20. If a battery be discharged at a greater rate than its normal, how does it temporarily affect the capacity of the cell?

21. What impurities in the electrolyte must be guarded against? How is their presence caused, and how determined?

22. Which type of cell has the larger storage capacity per lb. of cell, the Faure or the Planté? Why?

23. Why is the storage battery useful in electrical laboratories?

24. What is the specific gravity of the electrolyte of a lead cell when fully charged, and about what when discharged?

25. What is the constant-current booster system, and where is it most applicable?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC LIGHTING

---

1. Define what is ordinarily meant by the term *efficiency of an incandescent lamp,* and give the values accepted at present for the efficiency of the carbon, gem, tantalum, and tungsten types.

2. What are the essential features of the Nernst lamp? Why is the ballast necessary?

3. What use is made of the flicker photometer?

4. How may the color of the flaming arc lamp be changed? With what color of light is the efficiency of this lamp the highest?

5. What is the object of shades and reflectors?

6. Describe the globe photometer and give its use.

7. What is the relation between the *hefner* and the *candle-power?*

8. What do you understand by the term *indirect lighting?*

9. Give your understanding of the Rousseau diagram and its use.

10. Name the advantages and disadvantages of the mercury vapor lamp and outline the two methods used in starting this type of lamp.

11. Explain the terms *mean spherical candle-power; mean hemispherical candle-power; mean horizontal candle-power.*

12. Define a *lumen;* a *foot-candle.*

13. In what way does the treatment of the filament of the gem lamp differ from that of the ordinary carbon filament?

14. Why are enclosed arc lamps preferable to open arcs? What is the approximate difference in the voltage at the terminals of these two types of lamps when connected in series circuits?

15. What use is made of the mercury arc rectifier in connection with lighting?

16. Explain how constant-current transformers work and tell why they should be fully loaded, or nearly so, when in use.

17. Why does an incandescent lamp decrease in candle-power with use? What is meant by the *useful life of an incandescent lamp?*

18. How much power will be required to properly illuminate a room (average illumination one foot-candle) having 400 sq. ft. of floor space if 3.1-watt carbon-filament lamps are used with opal cone reflectors, the lamps to be in pendant position and placed from 10 to 12 feet above the floor; the room to have light ceilings and walls?

19. Prove that the illumination of a plane surface perpendicular to the rays of light varies inversely with the square of the distance of the surface from the source of light.

20. Draw a sketch of a three-wire system of distribution for electric lighting and give the advantages of such a system.

21. Why are arc lights unsuitable for residence lighting?

22. Describe the process of flashing filaments for incandescent lamps and give its effects.

23. A standard incandescent lamp of 16 candle-power is compared with an unknown source of light by means of a Bunsen screen on a photometer bar 300 cm. in length. A balance is obtained when the screen is 125 cm. from the standard lamp. What is the candle-power of the lamp under test?

24. What is the recommendation of the National Electric Light Association regarding the proper basis for the preparation of specifications for street lamps?

25. Why is the tungsten lamp more efficient than the other incandescent lamps on the market?

26. Explain the function of the regulator in the Moore tube system of lighting and tell how the color of the light emitted by such a tube can be controlled.

27. What methods of regulation are in common use with flaming arc lamps?

28. Describe the magnetite arc lamp.

29. Define *photometry; illumination; intrinsic brilliancy.*

30. An arc lamp 20 feet above the ground gives 600 candle-power in the direction of a point on the street 150 feet distant from the lamp-post measured along the ground. How much illumination is received at this point on a plane perpendicular to the rays of light?

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