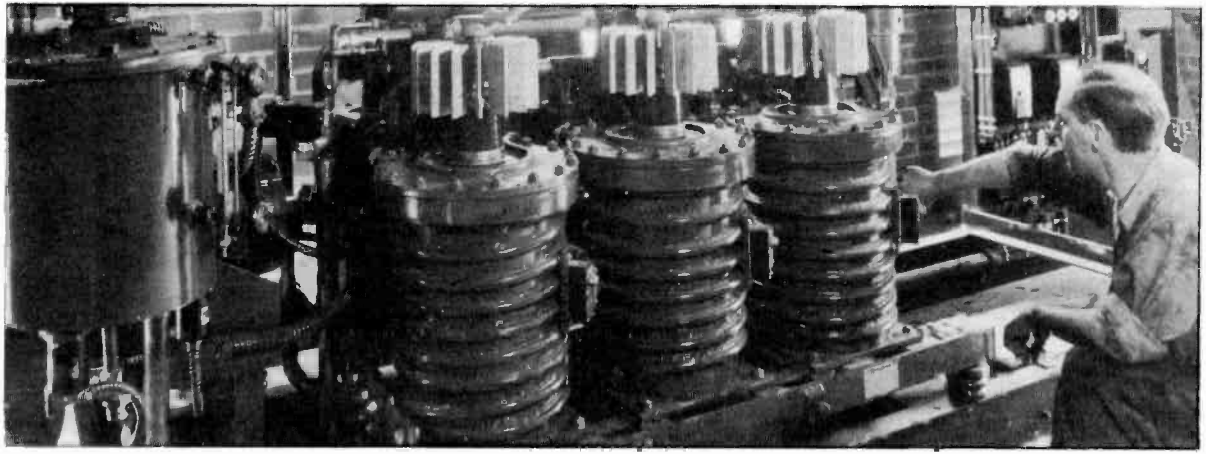
COYNE
PRACTICAL APPLIED ELECTRICITY



Many industries are turning to electronic developments for supplying direct current power. For example, this ignitron installation in a mine for changing alternating current into direct current provides efficient conversion, is compact and light weight; has high overload capacity and low maintenance.

COYNE PRACTICAL APPLIED ELECTRICITY

A Set of Complete Practical Books

For Home Study

and

Field Reference

On

Electrical principles, telephones, wiring, meters, D.C. and A.C. motors, controls, and equipment, household appliance repair, Rural Electrification, Armature winding, Generators, Diesel Electric Plants, Automotive Electricity, Batteries, Electrical Refrigeration and Air Conditioning, Industrial Electronics, Radio Electric Welding — laws, rules, etc. — Over 3,000 subjects, 5,000 Electrical facts, thousands of photos and diagrams.

By

THE TECHNICAL STAFF

of the

COYNE ELECTRICAL SCHOOL

Printed in United States of America

FOREWORD

ELECTRICITY is the greatest force known to **mankind.**

ELECTRICITY is leaping ahead at an unbelievable rate. It is moving into practically every part of the world and has become **the most important factor in modern civilization.** Practically every month the Kilowatt hour demand sets a new high —it has been doing this for the past 25 years. ELECTRICITY, even though it is one of America's youngest industries, already employs directly and indirectly over 3 million people.

All of our marvelous developments in Radio, Television, Electronics, Radar, etc., employ **electrical** power and the principles of **Electricity.** It is truly **one of the world's greatest industries.**

Because of the tremendous opportunity in the field of **Electricity,** there have been many books written on the subject. Most treat with **one** specific phase of **Electricity.** This set of books — Coyne Practical Applied Electricity (of which this volume you now read is an integral part)—covers the entire field.

This set is NEW. It includes the very latest methods and explanations of Electrical installation, operation and maintenance.

COYNE PRACTICAL APPLIED ELECTRICITY WRITTEN BY A STAFF OF EXPERTS

Most Electrical publications are written by **one man** and can therefore **only** cover **his** own specific knowledge of a subject. COYNE PRACTICAL APPLIED ELECTRICITY, however, represents the combined efforts of the **entire Coyne Electrical School Teaching Staff and the assistance of other authorities on the subject.** These men have a wide field and teaching experience and practical knowledge in **electricity** and its allied branches.

HOW THIS SET WAS DEVELOPED

In submitting any material for these books these experts kept two things in mind—1. MAKE IT SIMPLE ENOUGH FOR THE "BEGINNER"—2. MAKE IT COMPLETE, PRACTICAL and VALUABLE FOR THE "OLD TIMER". All material that was submitted for these books by any individual was then rewritten by an editorial group so that added explanations for the benefit of clarity and easier understanding could be included.

Coyne Practical Applied Electricity can pay you big dividends every day "on the job". However, if you only use the set occasionally when you MUST BE SURE before going ahead on a job—the set **will pay for itself many times over.**

Coyne Practical Applied Electricity is to an electrician what a set of complete law books is to a lawyer or a set of medical books is to a doctor. Regardless of whether a lawyer or a doctor is "just starting out" or is an "old timer" and has been practicing his profession for many years **he has many occasions to refer to his reference books. Many doctors and lawyers spend thousands of dollars on complete sets of reference books—they find it a very wise investment.**

In ELECTRICITY the need for good reference books is just as great. So, when you make a purchase of this set you are not just buying a set of books—you are making an investment in your future that can pay dividends all your life.

PRESIDENT
COYNE ELECTRICAL SCHOOL

CONTENTS

ACKNOWLEDGMENTS

We wish to acknowledge and express our appreciation for the assistance and co-operation given by the following companies, in supplying data and illustrations for the preparation of this Electrical Set.

GENERAL ELECTRIC COMPANY
WESTINGHOUSE ELECTRIC & MFG. CO.
ALLIS CHALMERS MFG. CO.
POWER PLANT ENGINEERING JOURNAL
AMERICAN BROWN BOVERI CO.
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WELSH SCIENTIFIC CO.
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You will note that in some places in this Set we have explained and shown illustrations of some of the earlier types of Electrical equipment.

WE HAVE A DEFINITE REASON FOR DOING THIS, namely, many of the earlier units are much easier to understand. An important point to keep in mind is that the BASIC PRINCIPLES of these earlier machines are the same as those of the modern equipment of today.

Modern equipment has not materially changed in principle — IT IS MERELY REFINED AND MODERNIZED. It is from the earlier basic theories and simple beginnings that the complicated mechanisms of today have been developed. IT IS TO THESE EARLY BEGINNINGS WE MUST OFTEN TURN IN ORDER TO GET A FULL UNDERSTANDING OF THE PRESENT ADVANCED TYPES OF EQUIPMENT.

In the early days many of the parts and mechanism of Electrical equipment were visible whereas today much of it is not. However, the PRINCIPLES OF THE EARLY EQUIPMENT ARE SIMILAR TO THOSE OF MODERN ELECTRICAL APPARATUS.

SO IN VARIOUS PLACES IN THIS SET. WE SHOW YOU SOME OF THIS EARLIER EQUIPMENT BECAUSE ITS CONSTRUCTION IS SIMPLER AND EASIER TO UNDERSTAND AS YOU STUDY THE MODERN EQUIPMENT. THEN FROM THESE EARLIER TYPES OF EQUIPMENT WE CARRY YOU ON TO THE VERY LATEST DEVELOPMENTS IN THE FIELD.

HOW TO USE THIS SET OF BOOKS

Coyne Practical Applied Electricity will be of use and value to you in exact proportion to the time and energy you spend in studying and using it.

A Reference Set of this kind is used in two distinct ways.

FIRST, it is used by the fellow who wishes to make Electricity his future work and uses this Reference Set as a home training course.

SECOND, it is especially valuable to the man who wishes to use it strictly as a Reference Set. This includes electricians, mechanics or anyone working at any trade who wishes to have a set of books so that he can refer to them for information in Electrical problems at any time.

You, of course, know into which group you fall and this article will outline how to properly use this Set to get the most value for your own personal benefit.

How To Use This Set As A Home Training Course In Electricity

The most important advice I can give the fellow who wishes to study our set as a home training course in Electricity is to start from the beginning in Volume 1, and continue in order through the other 6 volumes. Don't make the mistake of jumping from one subject to another or taking a portion of one volume and then reverting back to another. Study the set as it has been written and you'll get the most out of it.

Volume 1 is one of the most important of the entire Set. Every good course of training must have a good foundation. Our first volume is the foundation of our course and is designed to explain in simple language terms and expressions, laws and rules of Electricity, upon which any of the big installations, maintenance and service jobs are based. So, become thoroughly familiar with the subjects covered in the first volume and you will be able to master each additional subject as you proceed.

One of the improvements we made in this set was to add "review" questions throughout the books. You will find these questions in most cases at the end of a chapter. They are provided so "beginners" or "old timers" can check their progress and knowledge of particular subjects. Our main purpose in including the "review" questions is to provide the reader with a "yardstick" by which he can check his knowledge of each subject. This feature is a decided improvement in home study material.

Above all, do not rush through any part of these books in order to cover a large amount at one time. You should read them slowly and understand each subject before proceeding to the next and in this way you will gain a thorough understanding as you read and think it out.

For the special benefit of the fellow desiring to learn Electricity at home, we have prepared a great number of diagrams and illustrations. Refer to these pictures and diagrams in our books regularly.

How To Use Coyne Practical Applied Electricity Strictly As A Reference Set

The man who is interested in using these books mainly for reference purposes will use it in a little different way than the fellow who is trying to learn Electricity as a trade. Some of the types of fellows who use this set strictly for reference purposes are: home owners, electricians or mechanics, garage owners or workers, hardware store owners, farmers or anyone who has an occasional use for electrical knowledge. Those types of fellows should use this set in the following manner.

If some particular type of electrical problem presents itself, **refer immediately to the Index**—it will give you the section in which the subject is covered.

Then, turn to that section and carefully read the instructions outlined. Also read any other sections of the set mentioned in the article. As an example, in checking over some information on electric motors, some reference might be made to an electrical law of principles contained in Volume 1 of the Set. In order to thoroughly understand the procedure to follow in working out the electrical problem, you should refer to Volume 1 and get a better understanding of the electrical law on principles involved.

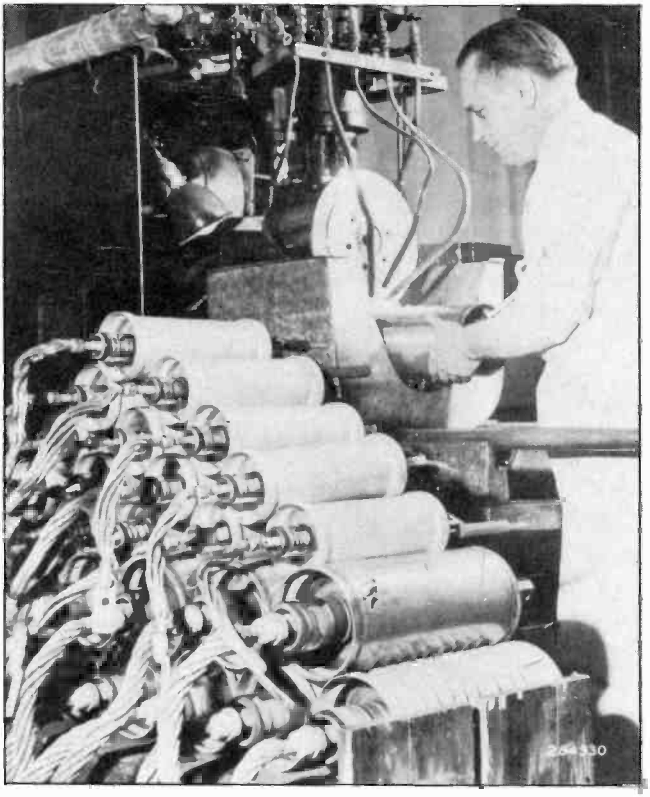
Use The Master Index To Locate Electrical Subjects

Thousands of men use this Set in their daily problems, both on the job and around the home as well. If you follow the instructions outlined you will be able to locate any information you may want at any time on your own electrical problems.

And here's a very important point. Although this set of books starts in Volume 1 and proceeds through the other 6 volumes in order, it makes an ideal home study course—nevertheless, **any individual book in the series is independent of the others and can be studied separately.** As an example, Volume 3 covers D.C. motors and equipment. If a man wanted to get some information on D.C. machines **only** he could find it **completely covered in this volume** and it would not be essential to refer to any other volume of the set unless he wanted some additional information on some other electrical principle that would have a bearing on his problem.

This feature is especially beneficial to the "old timer" who plans to use the set mainly for field reference purposes.

We believe, however, that the entire set of 7 volumes should be read completely by both the "beginner" or the expert. In this way you get the greatest benefit from the set. In doing so the experienced Electrician will be able to get very valuable information on subjects that he may have thought he was familiar with, but in reality he was not thoroughly posted on a particular subject.



"Ignitrons", like these metal-encased devices, convert alternating current into direct current needed to make aluminum for American fighting planes. The workman is shown seam-welding the metal jacket in which the tube mechanism is enclosed.

ARMATURE WINDING

This section covers one of the most interesting and important branches of practical electricity. There are many thousands of new motors and generators built each year which must be wound and tested by experts at the factories. There are also many millions of electric motors in use in this country which have to be maintained, tested, operated, and occasionally completely rewound.

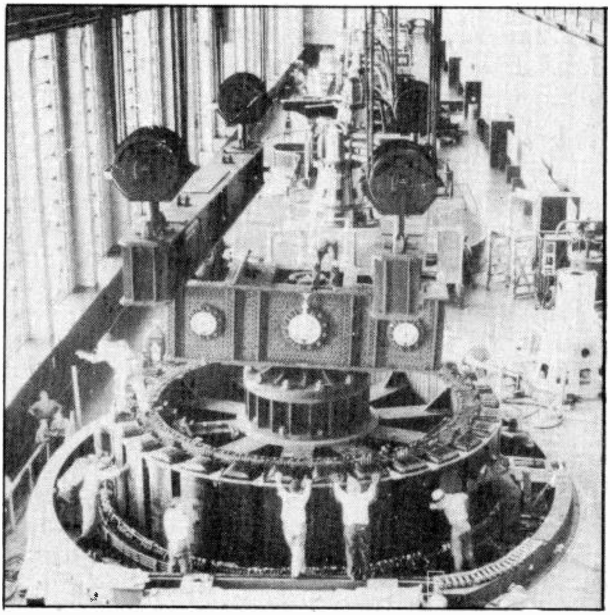
Power companies have expert armature winders to repair their great generators when their windings develop trouble. Industrial plants and factories, some of which have thousands of motors in one plant, require armature winders to repair the motors that burn out. Then there are the small companies which have only a few motors and don't have their own electrician, so they must send their machines to some armature shop for repairs.

Numerous smaller factories that do not keep a regular armature winder, much prefer to have a maintenance electrician who can wind armatures when necessary. So in many cases we find that the general electrician, who does the wiring and repairing around the plant, is also called upon to test and rewind armatures in emergencies. So a thorough knowledge of this subject will often enable you to land a good job easier, and to advance into greater responsibility and higher pay than you could without it.

We have mentioned armature **testing,** as well as winding, and wish to emphasize the importance of obtaining a good knowledge of **testing** and **trouble shooting** so that you will be able to locate troubles and faults in the windings of motors and generators.

In many cases some small fault, such as an open circuit, short circuit, or "ground," right at the leads or connections of an armature winding, will seriously interfere with the operation of the machine. Many times such faults that don't require a complete rewinding can be quickly repaired, and the machine put right back in service with very little lost time.

Because of a shortage of trained electricians there are actually thousands of untrained men in the field today who do not know how to locate and repair such faults, and instead must take motors out of service and send them out to be repaired. In many cases windings are pulled apart unnecessarily to find troubles that would have been easily located by a test, without even removing the armature from the machine. It is needless to say that the main-



Hydroelectric Power Station, present capacity, of 297,500 H.P. General interior view showing (in foreground) wound revolving field (weighing 300 tons, and supported by 2 cranes) partly inserted in bore of stationary armature of G-E vertical synchronous single-phase A-C waterwheel generator, 35,000 KVA, 100 RPM, 13,300 volts, 60 cycles, type ASI-W, 30-pole (7th unit).

tenance electrician who knows how to systematically test for and locate these troubles, and can make quick repairs and put a machine back in service with the least delay, is the man who gets the best jobs and the best pay.

A good knowledge of armature construction and windings not only makes it easier to understand testing and rewinding, but is also a great help to you in thoroughly understanding the motors and generators covered in the later lessons. So make a careful and thorough study of armature winding, and you will find it very interesting and valuable.

1. GENERATORS AND MOTORS

In order to properly understand armature winding it is necessary to first know something of the construction and principles of motors and generators, and the function of the armature in these machines.

An electric generator is a machine used to convert mechanical energy into electric energy.

An electric motor is a machine used to convert electric energy into mechanical energy.

In actual construction these two machines are practically the same, the difference in them being merely in the way they are used. In fact, in many cases a generator can be used for a motor, or a motor used as a generator, with very slight changes and adjustments.

The more important parts of a D.C. motor or generator are the **Frame, Field Poles, Armature** and **Commutator.** In addition to these, the brushes, bearings, and a number of other small parts are needed to complete the machine.

Fig. 3 shows a machine with the front bearing plate removed. The field poles can be seen at "B," securely attached to the inside of the frame. The armature is shown resting inside the field poles, where it is rotated during operation. The commutator can be seen on the front end of the armature. The extra poles shown at "A" in this view will be explained later.

2. FIELD POLES

The field poles are made of iron, either in the form of solid cast blocks or in many cases built up of thin strips or **Laminations,** pressed and bolted tightly together. These iron cores are then wound with a great many turns of insulated wire, forming what are called **Field Coils.** These coils may consist of from a few hundred to several thousand turns, according to the size and voltage of the machine. We find then that the completed field pole is simply a large electro-magnet, and its purpose is to supply a strong flux or field of magnetic lines of force for the armature conductors to rotate in.

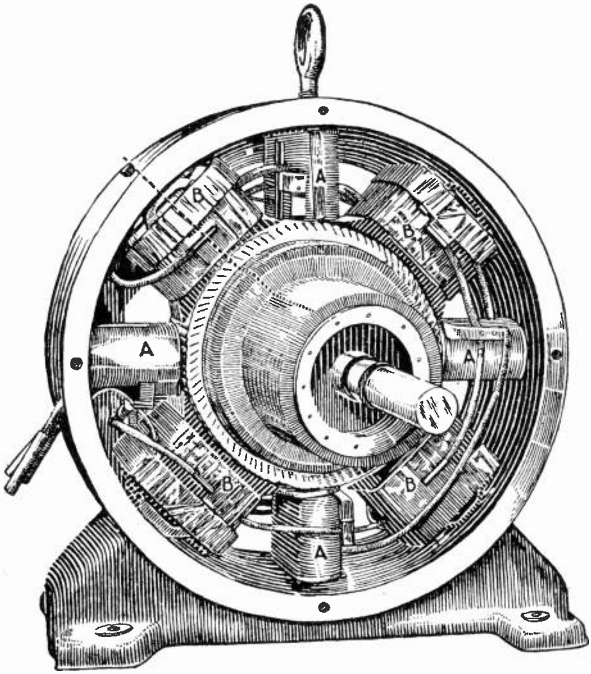


Fig. 3. This view of a D.C. generator with the front bearing bracket removed shows the field poles, armature, and frame very clearly.

The field frame is not only to provide a support for the field poles, but also provides a flux path for the complete magnetic circuit between the outer ends of the poles. The field coils are connected together in such a manner that each one will produce a magnetic pole opposite to the one next to it. They are then supplied with direct current to maintain constant polarity at the pole **Shoes** or **Faces.**

3. ARMATURES

The armature is also made of iron and is always of laminated construction, or built up of thin iron sheets pressed tightly together. The laminated construction is used to prevent the flow of induced **Eddy Currents** in the armature core. The core has a number of slots around its entire outer surface, in which the armature coils are mounted. See Fig. 5. The iron armature core provides a magnetic path for the flux of the field poles, and also carries the coils which are rotated at high speed through the field flux.

In a generator, it is the cutting of these coils through the flux which produces the voltage. In a motor, it is the reaction between the field flux and the flux around the armature conductors which causes the **Torque** or turning effort.

Small armatures are often constructed of laminations in the form of complete disks which merely have a hole through their center for the shaft, and possibly bolt holes for clamping them. This makes a core which is solid clear to the shaft. In the larger

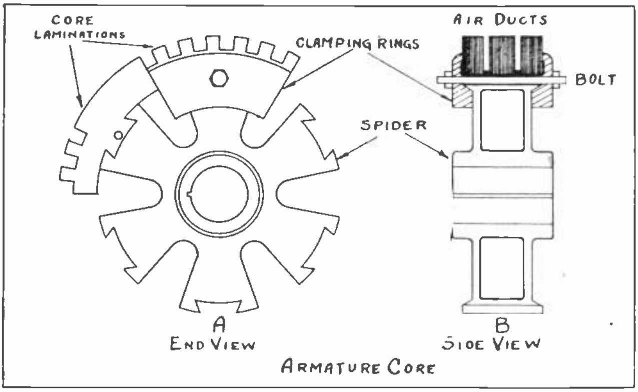


Fig. 4. The view at "A" shows the manner in which core laminations are assembled on a spider to make up the large armatures. At the right is a sectional view, showing the manner in which the laminations are assembled and clamped to the spider rim, and the air ducts which are left for ventilation and cooling.

machines it is not necessary to have the entire core solid, so the laminations are assembled like the rim of a wheel, on the outside ends of short spokes, as shown in Fig. 4-A. This wheel or center framework is called the **Spider**, and the sections of core laminations are dovetailed into the spider, as shown in the figure. Heavy clamping rings at each end of the group, and drawn tight by bolts, hold the entire core in a solid, rigid unit.

Fig. 4-B shows a sectional view through such a spider and core. Note the spaces or air ducts that are left between the laminations, for ventilation and cooling of the core and windings.

Fig. 6 shows a complete armature with the winding in place and the commutator shown at the left end. Note how the coils are neatly fitted into the slots and held in place by wedges in the top of the slots. The ends of the coils are tightly banded with steel banding wire to prevent them from being thrown outward when rotated at high speed.

4. ARMATURE SLOTS

There are several different types or shapes of slots used for holding the coils in armature cores. Several of these are shown in Fig. 7. This figure shows end views of the slots and sectional views of the coils in them. The one at "A" is called an "open type slot," and is used where the coils are completely wound and formed before being placed in the slots. This type of slot has the advantage of being very easy to place the coils in. Bands around the core must be used to hold the coils in slots of this shape when the armature is rotated.

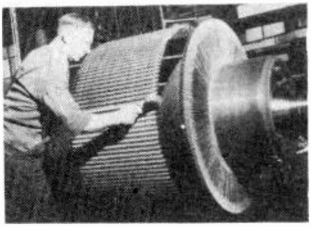


Fig. 5. Revolving armature being wound fo. large D-C motor, G-E S.henectady Works.

"B" and "C" show slightly different types of partly closed slots, which are used with armatures on which the coils are wound directly into them. This type of slot gives a better distribution of flux from the field poles to the armature than the open ones do. This is due to the projecting lips which reduce the broad air gap over the top of the slot. With these partly closed slots the coils are held

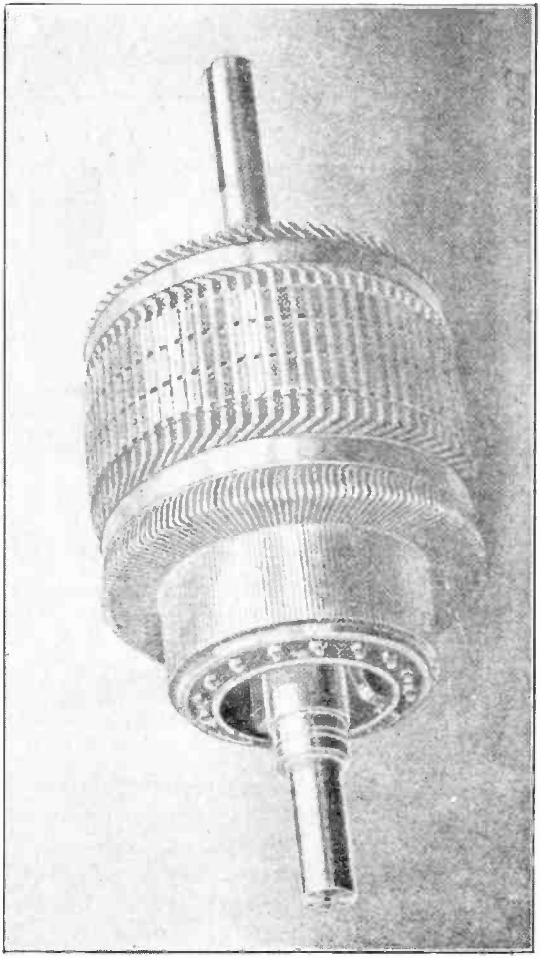


Fig. 6. This photo shows a large D.C. armature for a 150 KW, belt driven generator. The commutator is at the left and the bars or segments can be plainly seen. Note how the armature coils are held in the slots by wedges and by the band wires around each end of the armature. (Photo Courtesy Crocker-Wheeler Electric Company.)

securely in place by wedges slipped over their top edges and under the iron lips.

"D" shows an open type slot which has a groove in each side of its top, through which the slot wedge is driven.

5. COMMUTATORS

Commutators are constructed of a number of segments or copper bars, mounted in the form of a cylinder around the shaft. They are mounted near to

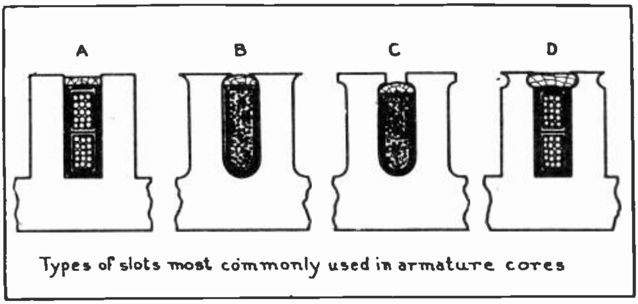


Fig. 7. The above diagram shows four common types of armature slots. Note carefully the manner in which the coils are arranged and insulated, and also the wedges which hold them in the slots. The wedge in the slot at "A" would be held in place by band wires around the armature.

the end of the armature core, so the coil ends can be connected to each of the bars. Between each bar and the next is placed a thin mica strip or segment, which keeps them entirely insulated from each other.

See Fig. 8-A, which is an end view of such a commutator. B— and B+ are the brushes which rest on the commutator surface F. The black lines at "M" are mica insulating strips.

At "B" is shown a sectional view cut endwise through a commutator, showing the shape of the bars or segments and the notches cut in each end, so they can be held securely together by the heavy **Clamping Rings.** When the bars are all fitted in place by the clamping ring "V" is drawn up tightly by the clamping nut "R", this locks the segments to the commutator core or center, in a sort of dovetail construction. The raised part of the segment at "L" is called the **Riser** or **Neck.** At "U" are shown slots in the segments where the coil leads are attached.

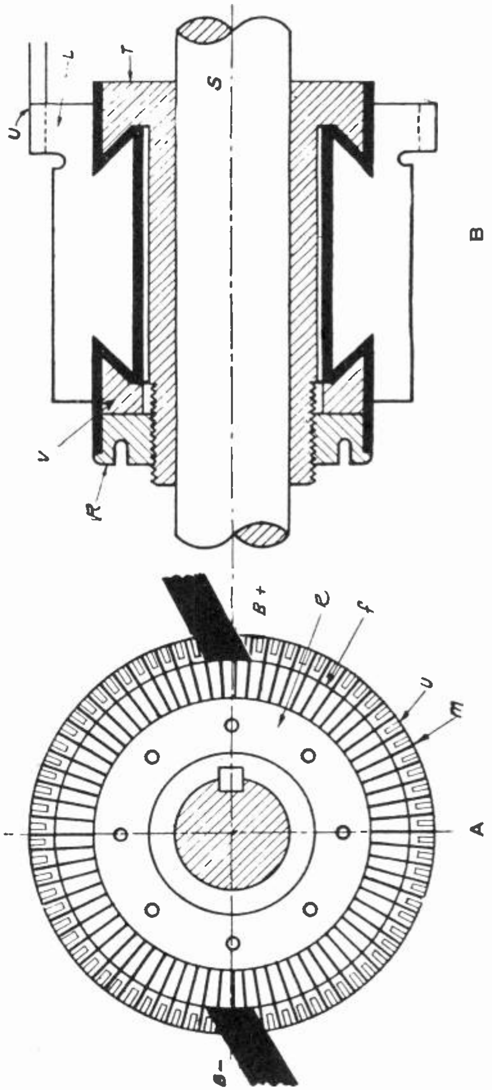


Fig. 8. At "A" is shown an end view of a commutator, illustrating the manner in which the bars or segments are assembled and kept separated by strips of insulation between them. At "B" is a sectional view showing how the commutator segments are clamped and held in place by clamping rings which fit in their grooves.

The heavy black lines represent mica insulation which keeps all bars well insulated from the clamping rings, core, and shaft. Examine this diagram carefully as it shows the typical construction features of small and medium sized commutators.

On very large machines where the commutators have a large diameter, they are sometimes mounted on a spider similar to those described for large armatures. Commutators are held in place on the shaft by use of keys and slots, or special locknuts, in each end.

On some of the very small armatures of fractional horsepower machines, the commutators are tightly pressed on to the shaft, and held in place by the extremely tight fit.

Fig. 10 shows a large engine-driven D.C. generator from the commutator end. This commutator is mounted on a spider and you can note the brushes resting on its outer surface. Part of the field poles can also be seen around the left side of the frame. Machines of this type are made in sizes ranging from less than 100 horsepower to many thousands of horsepower, and small motors are made in sizes down to 1/50 horsepower and less.

Keep in mind, however, that regardless of the size of the machine the **general operating principles are the same**; so if you obtain a thorough understanding of the purpose of the important parts and the fundamental operating principles of one type or size, these things will apply equally well to all others.

6. OPERATING PRINCIPLES OF GENERATORS AND MOTORS

So far we have only discussed the mechanical parts and construction of generators and motors. It is also very important that you have a good understanding of the electrical features and operating principles of these machines, for two reasons. It will help you understand armature windings much easier, and also provide a foundation for your study of these machines in the later sections.

The operating principles of generators and motors are not nearly as complicated, when properly explained, as many men without training think they are.

GENERATION OF VOLTAGE

We have learned that a generator is a machine which when driven by mechanical power will generate voltage or electro motive force, and supply electric energy to the circuit or load to which it may be connected.

You will also recall from early lessons that a generator operates on the principle of magnetic induction, and that **the voltage is produced by the wires or conductors cutting magnetic lines of force**

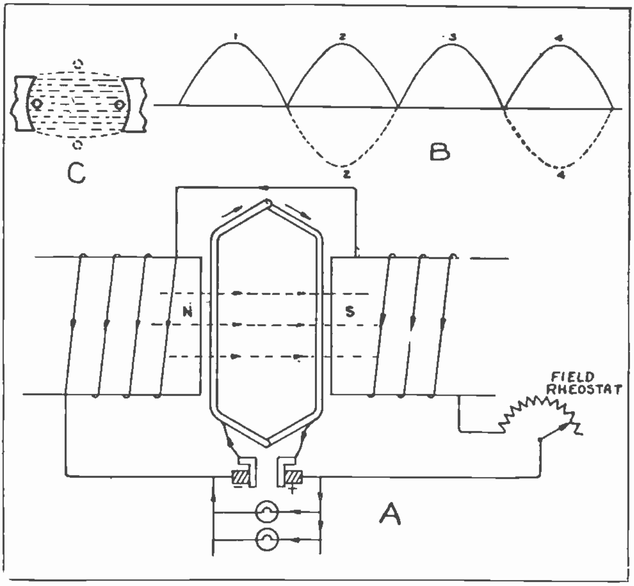


Fig. 9. The above diagram shows the principles of a simple D.C. generator. Note the manner in which the field coils are connected to the brushes, and the rheostat used for controlling the amount of field current.

Fig. 9 shows a diagram of a very simple form of D.C. generator, consisting of two field poles marked "N" and "S", and one armature coil connected to two commutator segments, which are in contact with the positive and negative brushes. These brushes are to collect the current from the commuator bars as the coil and the commutator revolve on the armature. If we revolve the coil rapidly through the magnetic flux between the north and south poles, a voltage will be generated in the coil; and if there is a complete external circuit through the lamps or load as shown, this voltage will cause current to flow out through this circuit and back through the armature coil continuously, as long as the rotation continues and the circuit remains closed. As the coil revolves, either side of it passes first the north pole and then the south pole, and cuts through the lines of force first in one direction and then the other. Therefore, the

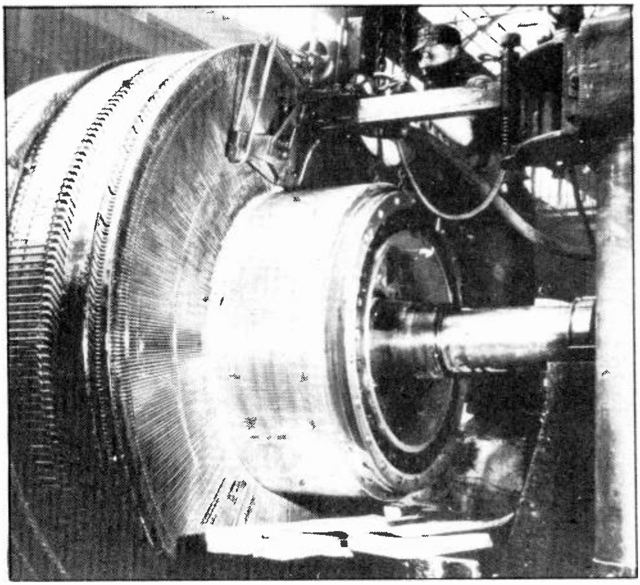


Fig. 10. When completed this generator armature will be part of the system supplying power to the most heavily powered strip mill in operation at Westinghouse Electric and Manufacturing at East Pittsburgh, Pa., this workman is undercutting the mica on the commutator.

voltage generated in the coil will be continually reversing or alternating in direction.

If this coil was provided with collector rings instead of commutator bars the entire circuit would be supplied with alternating current. Always remember that **alternating current is generated in the windings of any ordinary D.C. generator.**

8. COMMUTATOR ACTION

Now we come to **the purpose of the commutator, which is to rectify this alternating current or change it to direct current,** as it flows out to the external circuit. This is accomplished in the following manner:

The field poles and brushes are, of course, held rigidly in one position and always keep about the same position with regard to each other. Thus the positive brush will always be at the right place to collect current from the coil side which is passing by the south pole, and the negative brush will always be at the proper position to connect with coil sides passing the north pole. So the **current will always flow out at the positive brush and back in at the negative brush,** regardless of the speed of the armature.

9. VOLTAGE CURVES. PULSATING DIRECT CURRENT

We learned in a previous section that the voltage or current of any circuit can be conveniently represented by curves, as shown at "B" in Fig. 9. These curves show the variation and direction of the voltage that would be produced by this simple generator.

The combined solid and dotted line curves 1, 2, 3, and 4, represent the alternating impulses that are produced in the armature coil. Curves 1 and 3 above the line indicate voltage in one direction, while 2 and 4 below the line indicate voltage in the opposite direction. The vertical distance, from the center line, to any point along these curves, indicates the value of the generated voltage at that particular point of the coil revolution.

The rise and fall of the curves is due to the coil approaching and leaving the strong field flux directly under the poles. When the conductors of the coil are in the position shown by the dotted circles at "C", and are practically out of the effective field and moving parallel to the few lines of force, they do not generate any voltage. This position between two field poles is called the **Neutral Plane.** As the coil rotates back into the stronger field of the poles, the voltage gradually builds up higher until it reaches a maximum when the conductors are in the strong field at the center of the poles, as shown by the solid line curves. If we ignore the dotted curves 2 and 4 below the line at "B", and consider them to be placed above the line, the curves will then represent the **pulsating direct current** which exists in the external circuit due to the action of the commutator.

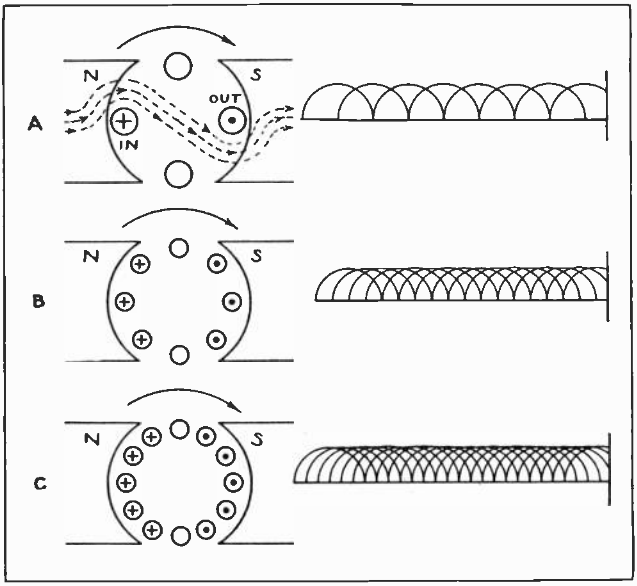


Fig. 11. The above diagram shows the voltage curves for three simple generators with different numbers of conductors in their armatures. Note how the greater number of conductors produces direct current of a more constant value.

Large generators are never constructed with only one coil on the armature, but usually have a considerable number of coils placed in the slots around the armature surface, and connected to as many commutator segments. The use of this greater number of coils produces impulses closely following each other, and in fact overlapping, so that the variation or pulsation of current, as shown in Fig. 9, is considerably reduced.

Fig. 11-A, B, and C illustrates approximately the voltage curves for three simple generators, each with a different number of coils on its armature. The one shown at "A" has two coils placed 90 degrees apart. One of these coils will be passing through dense flux directly under the center of the poles, while the other coil is at right angles to the poles and moving parallel to the flux. Therefore, the voltage induced in one coil will be at maximum value, while that in the other is at zero value. The result is shown by the curves, and we can see that the current flow in the external circuit will be much steadier. By comparing this with the number of coils in "B" and "C," and also observing the curves representing their voltage, we find that the greater number of coils we use the less pulsation there will be in the current flowing to the external circuit; and the closer it approaches to true direct current. The curves shown in this figure are not of the exact shape that would be produced by such a generator, but will serve to illustrate the effect of greater numbers of coils in a generator armature.

10. FACTORS THAT DETERMINE MACHINE VOLTAGE

We may recall that in an earlier lesson on magnetic induction we learned that **a single conductor must cut 100,000,000 lines of force per second to generate one volt**, and that **the voltage produced by any generator depends on the speed with which lines of force are cut.**

This, in turn, depends on three principle factors as follows—strength of the field or **number of lines of force** per pole, **speed of armature rotation, and number of turns in series** between the brushes.

We can readily see that the stronger the field, the more lines of force will be cut per revolution of the coil. If we strengthen or weaken the field of any generator its voltage will increase or decrease proportionately. The voltage of generators while in operation is usually controlled by varying their field strength.

The faster an armature turns, in revolutions per minute, the greater will be the speed of movement of its conductors and the greater the number of lines of force cut per second. So we find that the voltage of a generator will also vary directly with the speed.

If a simple generator, such as shown in Fig. 9, has one volt produced in each side of its coil, then the pressure at the brushes will be 2 volts; because the two sides of the coil are in series, and their voltage adds together. If we were to increase the number of turns in this coil from one to ten, the pressure at the brushes would be 20 volts, because all ten turns would be in series and their voltages would add. So we find that the number of turns per coil in an armature winding will regulate the voltage produced.

11. ARMATURE FLUX AND ITS ACTION IN GENERATORS

When a generator is connected to an external circuit on which we have a load of lamps or motors, the amount of connected load and **the resistance of the external circuit will determine the current which flows.** This current, of course, must all flow through the armature winding continuously, and it sets up magnetic lines of force around the armature conductors, as shown in the upper view in Fig. 12. The reaction between this flux and that of the field poles causes the field flux to be distorted or pushed out of its straight path as shown.

When the magnetic lines from the north field pole strike the counter-clockwise lines around the left armature conductor, they deflect downward, and travel with them to a certain extent. Then as they encounter the clockwise lines around the right hand conductor they are deflected upwards.

These lines, of course, have a tendency to try to straighten or shorten their path, and thereby exert considerable force against the movement of the armature conductors, and in opposition to the force applied by the prime mover which drives the generator.

This force will, of course, depend upon the amount of current flowing in the armature conductors and the strength of the flux which they set up. For this reason **the greater load we have connected to the external circuit, the more power will be required from the prime mover, to drive the generator.**

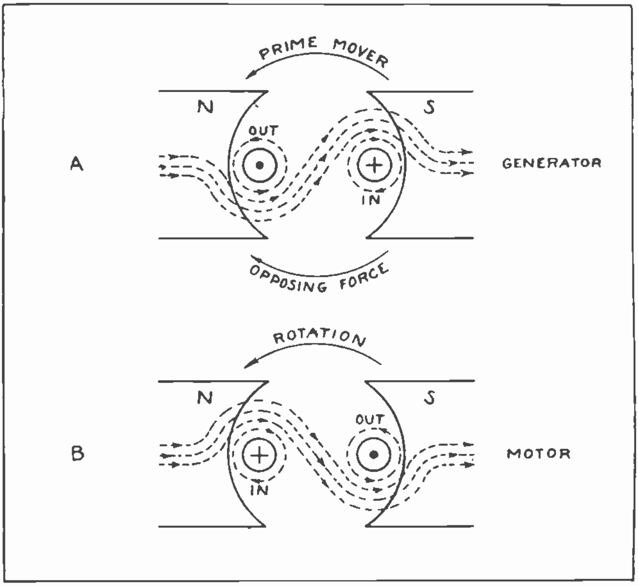


Fig. 12. This sketch shows the manner in which motor torque is produced by the reaction between the flux of the armature conductors and the field flux. Examine both "A" and "B" very carefully, and check the direction of current in the conductors, the direction of flux around them, and the direction of the resulting movement.

12. MOTOR PRINCIPLES

If we take this same machine which has been used as a generator, and send current through its armature and field coils from a line and some other source of electric supply, the reaction between the lines of force of the field and those of the armature conductors will set up **Torque** or twisting effort to rotate the armature, as shown in the lower view in Fig. 12.

You will note that, in order to obtain rotation of the motor in the same direction the armature formerly turned as a generator, we must reverse the current through the armature coils. Use the right hand rule for magnetic flux around a conductor, and check carefully the direction of the flux set up, with the direction of current flow through these conductors. The current is flowing in at the conductor nearest the north pole, and, therefore, sets up a clockwise flux around this conductor. In the other conductor the current is flowing out and sets up a counter-clockwise flux. The lines of force of the field coming from the north pole in striking those around the left conductor will be deflected upwards over the top of this conductor, and as they continue across and strike the lines in the opposite direction on the right hand conductor, they will be deflected downward and under it. Their tendency to shorten and straighten their path will then cause this force or torque to rotate the armature counter-clockwise. With a pulley or gear connected to the shaft of such a motor we can thus derive mechanical power from electric energy.

13. COUNTER E. M. F. IN MOTORS

We must remember that as the motor rotates its armature conductors will still be cutting lines of force of the field. As the conductors of the motor in Fig. 9 are revolving in the same direction they did in the generator, this voltage induced in the coils will be in the opposite direction to the applied line voltage. This voltage, which is always generated in the coils of any motor during operation, is therefore called **Counter Electro-Motive Force,** and usually referred to as counter E. M. F., or counter voltage.

The applied voltage is equal to the counter E.M.F. plus the voltage drop in the armature or, $E = C.E.M.F. + I.R.$

As the counter voltage opposes the applied line voltage it regulates the amount of current the line will send through the armature. The resistance of the armature winding is very low, being only about ¼ of an ohm in the ordinary 5 horsepower, 110 volt motor. From this we can see that if it were not for the counter voltage an enormous current would flow through this armature.

Applying Ohms law, or $E \div R = I$, we find that $110 \div \frac{1}{4} = 440$ amperes. Actually a motor of this size would ordinarily draw only about 10 amperes when operating without mechanical load; so we can see to what a large extent the current must be controlled by the counter voltage.

This counter voltage can be determined in the following manner. We know that $I \times R = E$, so $10 \times \frac{1}{4} = 2\frac{1}{2}$ volts, or the voltage required to force 10 amperes through the armature resistance. If we subtract this from the applied voltage we find the counter voltage, or $110 - 2\frac{1}{2} = 107\frac{1}{2}$ volts, counter E. M. F.

14. GOVERNOR EFFECT OF COUNTER E. M. F.

When a load is applied to a motor it tends to slow down a little, and as the conductors then cut through the field flux at less speed, the generated counter E. M. F. will be less, and will allow the applied voltage to send a little more current through the armature. This additional current increases the motor torque and enables it to carry the increased mechanical load. If the mechanical load is entirely removed from a motor it will tend to speed up; and as the speed increases the armature conductors move through the field flux faster. This increases the counter E. M. F. which will immediately reduce the current flow, by its opposition to the applied line voltage. So we find that **The Counter E. M. F. of a Motor Armature Acts Like a Governor to Control Its Speed.**

We should also remember that if a motor is loaded to a point where the armature slows down too much, or stops entirely, the counter voltage will fall too low and allow the applied voltage to send excessive current through the armature and possibly burn out its windings. The counter voltage in a motor armature, of course, depends upon the number of turns in the coils, the speed of rotation, and the field strength, the same as the voltage in a generator does.

Counter voltage plays a very important part in the starting of motors, and will be further discussed in the lesson on D.C. motors but be sure you have a thorough understanding of its principles as covered in this lesson.

15. ARMATURE COILS

Armature windings merely consist of a number of coils of wire, arranged uniformly in the slots of the armature core, and connected to the commutator bars to form series or parallel circuits between the brushes. Many untrained electricians think armature windings are very complicated. This is not necessarily true. The windings are the heart of the machine, and its operation depends on them, but there is nothing so mysterious or complicated about these windings that a trained man cannot easily understand.

The Important Things to Know Are the Manner of Constructing the Coils, Insulating Them, Placing Them in the Slots, and **Making the Connections to the Commutator.**

These things are all very easy to learn, for one who already knows the principles of electricity and series and parallel circuits.

We are now ready to take up coil construction and insulation, and the connections will be explained a little later.

16. NUMBER OF TURNS AND SIZE OF WIRE

We have found that the number of turns in the coils of a generator winding has a definite effect on the voltage it will produce; and that in a motor the number of turns regulates the counter voltage, and thereby determines the line voltage which can be applied to the motor.

The size of the conductors has no effect on the voltage generated in these machines, but does determine the current their windings can carry. The larger the conductors or the more of them which are connected in parallel, the more current the windings can stand without overheating. It is this conductor area that determines the current capacity of generators, or the full load current ratings of motors. So in general, high voltage machines use more turns of smaller sized wire and more coils connected in series; while low voltage, heavier current capacity machines, use fewer turns of larger wire.

The shape of wires used for armature coils depends on the kind of machine and the shape of the slots. Round wires are most commonly used for small armatures, except those for the starting motors of automobiles and such very low voltage machines. These are usually wound with one or two turns of square or rectangular wires or bars.

Windings for large size motors and generators generally use square or rectangular conductors in order to utilize all the space in the slots.

17. WIRE INSULATION

Armature coils of more than one turn must have all turns well insulated from each other. Round magnet wire, and also the smaller square wires, are usually supplied with the insulation already on them.

The more common forms of insulaion used on magnet wires are enamel, cotton, and silk coverings. The silk and cotton covered wires can be obtained with either single or double layers of this insulation. Combinations of enamel and cotton, or enamel and silk are also used.

In specifying or buying magnet wire we usuall refer to its insulation by the first letters coverings used, as follows: E. for enam S.C. for single cotton; D.C. for dou for single silk; D.S. for dou single cotton and enamel;

The plain enamel insulation is generally used only on the very small wires, but combined enamel

Size B.&S. Gauge	Diam. bare wire in in.	Metric equiv in. M.M.	Diam. enam. wire in in.	Diam. S.C.E in in.	Diam. S.S.E. in in.	Diam. S.C.O. in in.	Diam. D.C.C. in in.	Diam. S.S.O. in in.	Diam. D.S.C. in in.	Area Cir. Mils.	Ohms per 1,000 ft.	Ohms per pound	Feet per ohm	Feet per pound
14	.0641	1.628	.0661	.0711	.0681	.0691	.0741	.0661	.0681	4107	2.521	.2028	396.6	80.44
15	.0571	1.450	.0590	.0640	.0610	.0621	.0671	.0591	.0611	3257	3.179	.3225	314.5	101.4
16	.0508	1.291	.0526	.0576	.0546	.0558	.0608	.0528	.0548	2583	4.009	.5128	249.4	127.9
17	.0453	1.150	.0471	.0521	.0491	.0503	.0543	.0473	.0493	2048	5.055	.8153	197.8	161.8
18	.0403	1.025	.0419	.0469	.0439	.0453	.0493	.0423	.0443	1624	6.374	1.296	156.9	203.4
19	.0359	.9116	.0375	.0425	.0395	.0409	.0449	.0379	.0399	1288	8.038	2.061	124.4	256.5
20	.0320	.8118	.0335	.0385	.0355	.0370	.0410	.0340	.0360	1022	0.14	3.278	98.66	323.4
21	.0285	.7229	.0299	.0344	.0319	.0330	.0370	.0305	.0325	810.1	12.78	5.212	78.24	407.8
22	.0253	.6438	.0267	.0310	.0287	.0296	.0336	.0273	.0293	642.4	16.12	8.287	62.05	512.3
23	.0226	.5733	.0239	.0282	.0259	.0269	.0309	.0246	.0266	509.5	20.32	13.18	49.21	648.4
24	.0201	.5106	.0213	.0256	.0233	.0244	.0284	.0221	.0241	404.0	25.63	20.95	39.02	817.6
25	.0179	.4547	.0191	.0234	.0211	.0222	.0262	.0199	.0219	320.4	32.31	33.32	30.95	1031
26	.0159	.4049	.0170	.0210	.0190	.0199	.0239	.0179	.0199	254.1	40.75	52.97	24.54	1300
27	.0142	.3606	.0152	.0192	.0172	.0182	.0222	.0162	.0182	201.5	51.38	84.23	19.46	1639
28	.0126	.3211	.0135	.0175	.0155	.0166	.0206	.0146	.0166	159.8	64.79	133.9	15.43	2067
29	.0113	.2859	.0122	.0162	.0142	.0153	.0193	.0133	.0153	126.7	81.70	213.0	12.24	2607
30	.0100	.2546	.0108	.0148	.0128	.0140	.0180	.0120	.0140	100.5	103.0	338.6	9.707	3287
31	.0089	.2268	.0097	.0137	.0117	.0129	.0169	.0109	.0129	79.70	129.9	538.4	7.698	4145
32	.0080	.2019	.0087	.0127	.0107	.0120	.0160	.0100	.0120	63.21	163.8	856.2	6.105	5227
33	.0071	.1798	.0077	.0117	.0097	.0111	.0161	.0091	.0111	50.13	206.6	1361	4.841	6591
34	.0063	.1601	.0069	.0109	.0089	.0103	[illegible]	.0083	.0103	39.75	260.5	2165	3.839	8311
35	.0056	.1426	.0062	.0102	.0082	.0096	.0136	.0076	.0096	31.52	328.4	3441	3.045	10480
36	.0050	.1270	.0055	.0095	.0075	.0090	.0130	.0070	.0090	25.00	414.2	5473	2.414	13210
37	.0045	.1131	.0050							19.83	522.2	8702	1.915	16650
38	.0040	.1007	.0044							15.72	658.5	13870	1.519	21010
39	.0035	.0897	.0039							12.47	830.4	22000	1.204	26500
40	.0031	.0799	.0035							9.888	1047	34980	.9550	33410
41	.0028	.0711	.0031							7.845	1333	56000	.7630	42000
42	.0025	.0633	.0028							6.250	1680	87400	.6050	52800
43	.0022	.0564	.0025							4.850	2120	132000	.4670	66400
44	.0020	.0502	.0023							4.000	2670	212500	.3850	82600

The above tables show average diameters which are subject to variations as follows:

Bare Wire—Sizes No. 30 and larger, 1% plus or minus. Sizes No. 31 and finer .0001" plus or minus.

Enameled Wire—Varying from .0001" plus or minus on the fine sizes to .0005" plus or minus on the heavy sizes.

Fabric covered Wire—Will take approximately the same variation as the bare and enameled wire.

Thickness of insulation can be varied to meet special space or dielectric requirements.

and cotton or silk coverings are used on quite large wires.

The enamel used for insulating magnet wires is of a very good grade, being of very high dielectric strength, and flexible enough to allow the wire to be bent in a curve around a wire of its own size without damaging the enamel insulation.

Very small motors of the fractional horsepower portable types often use windings with only enamel insulation, because of the very small space this ...tion occupies, and the ease with which it ...heat to the outside of the coils.

...se Wires With Sufficient Insulation ...rom Short Circuits in the Fin-

ished Coils. However, we must also remember that the **Thicker Insulations Require More Space and, Therefore Allow Fewer Turns in a Slot of Any Given Size.**

Winding Data Based on Actual Winding Space

Size Wire	Low Tension Coils		High Tension Coils
	Turns per sq. in.	Ohms per cu. in.	Turns per sq. in.
14	177	.037	
15	225	.060	
16	282	.098	
17	348	.146	
18	431	.229	
19	528	.354	
20	647	.547	653
21	793	.845	800
22	980	1.315	988
23	1297	2.195	1205
24	1590	3.400	1465
25	1970	5.31	1810
26	2395	8.15	2200
27	2980	12.75	2680
28	3990	21.50	3270
29	4870	33.10	3930
30	5960	51.20	4750
31	7330	79.40	6240
32	8960	122.3	7650
33	11920	205.5	9350
34	14500	315.0	11150
35	17600	482.0	13800
36	21700	750.0	16700
37	28700	1250	21300
38	34100	1870	25300
39	43000	2980	32600
40	52000	4490	41700
42	91700	12600	72500
44	130600	28300	106500

Method of Determining Actual Winding Space

Let D = outside diam. finished coil

d = inside diam. finished coil

L = overall length finished coil

An = Actual winding space low tension coil without cotton tape

At = Actual winding space low tension coil taped with cotton tape.

Ab = Actual winding space high tension coil

Then

$$An = (L - \tfrac{1}{8})\left[\frac{(D - \frac{1}{16})^2 - (d + \frac{1}{16})^2}{2}\right]$$

$$At = (L - \tfrac{1}{8})\left[\frac{(D - \frac{1}{16})^2 - (d + \frac{1}{8})^2}{2}\right]$$

$$Ab = (L - \tfrac{1}{8})\left[\frac{(D - \frac{1}{16})^2 - (d + \frac{1}{16})^2}{2}\right]$$

Round magnet wires can usually be obtained in sizes from No. 46 to No. 6 B. & S. gauge.

The table on page 22 gives the diameters of magnet wires from No. 14 to No. 44 B. & S. gauge. These diameters are given for the bare wires and also for wires with various insulations. The table also gives the areas and weights of these wires. The table on page 23 gives some additional data which is very convenient in calculating and winding various coils. Examine these tables carefully to note the convenient data they contain, and then remember where to find them when you need such information.

EXAMINATION QUESTIONS

1. a. Give a brief definition for an electric generator.
   b. A Motor.

2. Name 4 important parts of a D. C. Motor or generator.

3. Why are armature cores generally of laminated construction?

4. What is the purpose or function of the commutator on a D. C. generator?

5. Explain briefly, how voltage is produced in a generator.

6. a. Upon what several factors does the voltage of a generator depend?
   b. How many lines of force must be cut per second to devolop one volt?

7. Explain briefly how torque or turning effort is developed in a D. C. Motor.

8. a. What is meant by the term counter E.M.F.?
   b. What important part does counter E.M.F. play in the operation of a D.C. Motor?

9. a. How does the number of turns and size of wire in an armature coil or winding affect the voltage?
   b. How do they affect the current?

10. What kinds of insulation are commonly used on wires for winding armatures?

TYPES OF COILS

There are two general methods of winding armature coils. The proper number of turns can be wound directly into the armature slots, as is generally done on the small machines; or the coils can be wound and formed complete before inserting them in the slots, which is the more common method with larger armatures.

Fig. 1-A shows a **Diamond Type Coil** before and after pulling or shaping. The unfinished loop coil consists of three wires wound in parallel the desired number of turns, and after the coil is wound a layer of cotton tape is wound over it, with each turn lapping over the last by half its width. The coil is then pulled with a coil spreader into the shape shown in the lower view at "A".

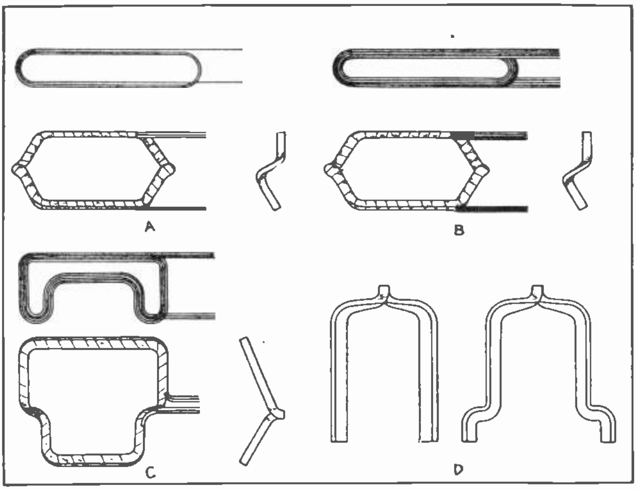


Fig. 1. This diagram shows several of the more common types of armature coils, both in the rough loop form and in the finished taped form.

At "B" is shown a coil of the same type wound with five wires in parallel instead of three. Coils are often wound with several wires in parallel in this manner because several small wires are more flexible than one large one. In other cases they are wound in this manner so their ends can be connected to a greater number of commutator bars.

One loop or coil connected between two commutator bars is called an **element**. So coils wound with three wires in parallel are called **Three Element Coils**.

The coil at "A" is called a three element coil, while the one at "B" is a five element coil. The coil shown at "C" in Fig. 1 is known as the Eickemeyer type. The upper view shows it before taping, and the lower view after it has been taped and shaped. At "D" is shown a single turn coil of copper ribbon on bar, shaped into a wave coil with a diamond twist on the back end.

1. COIL AND SLOT INSULATION

In addition to the insulation on the wires themselves it is also necessary to insulate the coils and entire winding from the slots and armature core.

The insulations used for this purpose serve both to protect the coils from mechanical injury from contact with slot edges, and also to electrically insulate them from the slots.

The materials commonly used for **Mechanical Protection** are as follows: **Hard Fibre, Fish Paper, Manila Paper, Vulcanized Fibre**, and **Press Board.**

2. FIBRE AND PAPER INSULATIONS

Hard fibre, vulcanized fibre, and pressboard or fullerboard, are made of dense hard paper or pulp layers tightly packed under hydraulic pressure, and have a dielectric strength or voltage breakdown test of about 200 volts per mil (1/1000 inch), at thicknesses from 50 to 150 mils.

These materials are used wherever insulating material of exceptional mechanical strength is needed, as for armature slot wedges, etc.

Fish paper is made from rag stock and by a treating process becomes a hard fibre-like paper which is very strong and tough. It is very commonly used for lining armature slots.

Manila paper is made from linen or manila fibre, producing a tough, strong paper which when dry has very good insulating properties.

Fish paper and manila paper are commonly made in thicknesses from 4 to 28 mils. These materials give considerable electrical insulation, as well as mechanical protection to the coils.

3. VARNISHED CLOTH INSULATIONS

The materials particularly for **Electrical Insulation** are as follows. **Yellow Varnished Cambric, Black Varnished Cambric, Varnished Silk, Oiled Muslin,** and **Yellow Oiled Canvas.**

Yellow varnished cambric is a strong, closely woven cloth having an especially soft finish, and is treated with high-grade insulating varnish. The varnish is baked into the cloth, producing a tough, flexible material with a very high dielectric strength and a smooth glossy surface. This can be obtained either by the yard, or in standard width tape, and is used for insulating slots and for wrapping coils. It is commonly made from 7 to 12 mils thick.

Black varnished cambric is also a varnished cloth and is used in the form of straight cut tape for insulating wires and cables, and in a bias cut tape (cut at an angle to the weave) for taping armature coils.

Varnished silk is made of Japanese silk treated with a very highgrade insulating varnish and oven cured. This material is very light and thin, and has very high dielectric strength per mil. It is commonly used in 3 and 5 mil thickness, where light weight and minimum thickness are required.

Oiled muslin is a linen finish cloth, coated with oil and oven-cured to set the film to a hard smooth surface. It is a very flexible cloth of good insulating properties, and does not deteriorate much with age or vibration.

Yellow oiled canvas is a high grade duck cloth, treated with oil to produce a flexible water-proof material. It is commonly used for insulating field coils and for pads under railway motor field coils, etc. It can be obtained in 45 mils thickness and either by the yard in 36″ width, or in standard width tapes.

4. HEAT-RESISTING INSULATION

For **Heat Resisting** and **High Quality Electrical**

Insulation we use **Mica, Micanite, Mica Paper,** and **Mica Cloth.**

Mica is a mineral which is mined in flake or sheet form, and is one of the very few materials which will maintain a high dielectric strength at high temperatures. It is not very strong mechanically in its original form, but is is generally made up in sheets by cementing numerous thin flakes together. This is called micanite, and is used for insulating armature slots, between high voltage coils, and for commutator insulation. Flexible sheets are made by cementing mica splittings or flakes to paper or cloth.

A little thought and good judgment will enable you to select the proper insulating material from the foregoing list, according to the requirements for flexibility, space, insulation, and mechanical strength.

The following examples can be used as suggestions, however:

Typical insulation for 220 volt D. C. armature winding, with coils wound with D.C.C. round wire:

1. Slot insulation, fish paper .004″ thick.
2. Slot insulation, a layer of varnished cambric .008″ thick.
3. Coils taped with "half lapped" cotton tape .004″ to .007″ thick.
4. Entire coil dipped in insulating compound and baked.

Typical insulation for 500 volt armature winding, with coils wound with D.C.C. round wire:

1. Slot insulation, fish paper .004″ thick.
2. Slot insulation, fish paper and mica .012″ thick, made up of fish paper .004″ thick, 3 layers of mica splittings .002″ to .003″ thick, one layer of Japanese paper .001″ thick; all cemented together.
3. Coils taped with "half lapped" cotton tape .007″ thick.
4. Entire coil dipped in insulating compound and baked.

5. WINDING COILS

After the proper size of wire and the number of turns for the coils have been determined, either from the old winding in cases of rewinding, or from the designer's data on new machines, the next step is to wind the coils.

We should be very careful to get the proper number of turns and the right size of wire, as well as proper wire insulation.

When winding the coils care should be used to get them the correct length to fit the armature slots. If they are wound too short they will be very difficult or perhaps impossible to place in the slots. If they are too long, they will make the winding too bulky at the ends, and possibly cause it to rub the machine frame or end plates

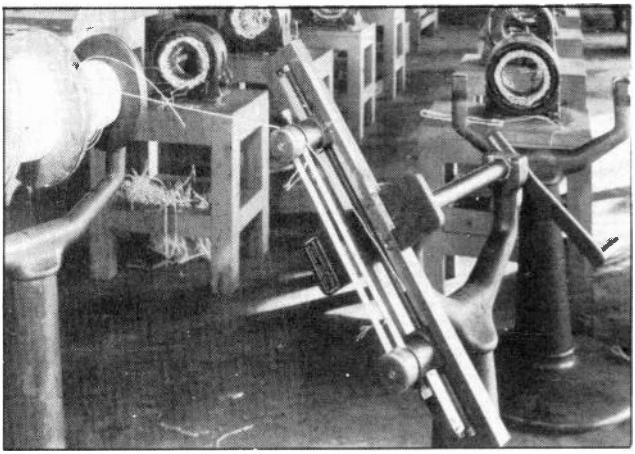


Fig. 2. The above view shows a coil winder which can be used for winding coil loops of different sizes, by adjusting the end pins along the slide. When the crank is turned the wire is wound directly from the spool into the slots on these end pins.

When rewinding an armature it is a good plan to pattern the new coils carefully after one of the old ones which has been removed, both in size and shape.

In winding an armature on which there are no coils to compare with, and no coil measurements given, it is well to make the first coil from your own measurements of the armature, and then try this finished coil in the proper slots before making the others.

Special machines can be obtained for winding and shaping coils of various sizes, and these are generally used in large repair or manufacturing shops. Fig. 2 shows an adjustable coil winder, for making coil loops of various sizes.

For the small shop or the occasional rewinding job to be done by the maintenance electrician, simple coil winding forms can be made up at very low cost.

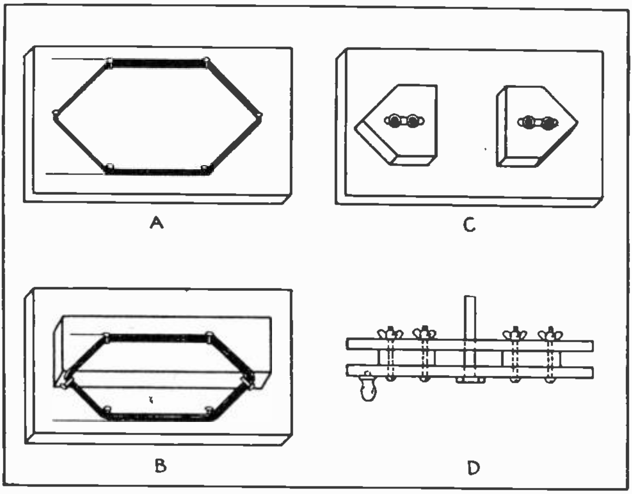


Fig. 3. Simple board forms can be made as shown above for winding coils of various sizes. These are very economical and easy to make, and a very handy device for the small repair shop to have.

Fig. 3 shows several of these forms which can easily be made from pieces of board. At "A" is shown a flat board with 6 nails or wood pins driven in the proper shape to make a plain diamond coil. by moving the nails or pins, coils of most any desired size and shape can be made.

In Fig. 3-B is shown a method of placing another thick piece of board on the first one and driving the nails for the points of the coil, in the edge of this board at an angle. When the wires are wound over the corner of this board and down under these end nails, it shapes the twist in the coil ends as shown.

Fig. 3, C and D, show how an adjustable winding form can be made, which can be rotated on a large center bolt by means of a crank. This enables a coil to be rapidly wound, by allowing the wire to run directly from a spool into this form as it is rotated; similarly to the coil winder shown in Fig. 2.

The two center blocks can be fitted with slots so they are adjustable for making coils of different sizes. When adjusted to the proper size for the coils to be wound, the other side-board can be put in place and the whole form clamped together by the bolts and wing nuts shown.

6. TAPING AND SHAPING OF COILS

Coils that are wound on forms of this kind can be tied together with short pieces of wire as they are removed from the form, removing these tie wires, however, before taping the coil.

If the coils are to go in open type slots, they can be completely taped before inserting them. If they are to go into partly closed slots with narrow top openings, the wires must be fed into the slots a few at a time until the coil is all in place. Then the ends of the coil can be taped, and twisted in shape to fit compactly together in the smallest possible space. With the coils in the slots, the points can be gripped with duck bill pliers and twisted to just the right curve.

If desired, the coil ends can be twisted before placing them in open type slots, by hooking a spike or bolt through the coil end and giving it a pulling twist, while the coil is held spread out on four pins or a block.

Remember that to make a neat and well balanced winding it is very important to **get all coils of the same size and shape,** and the ends twisted uniformly and evenly. Fig. 4 shows a coil shaping machine used for shaping and twisting the coils before they are placed in open type slots.

Fig. 5 shows several coils in various stages of completion. The first coil at the left is just a plain coil loop of the proper length, before taping or

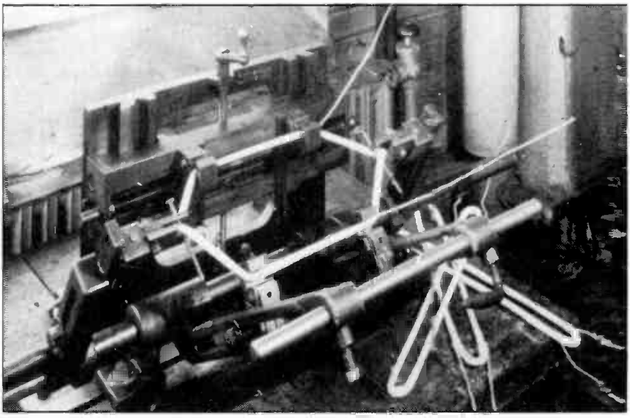


Fig. 4. This photo shows a coil shaping machine, which is used for pulling diamond coils into the proper shape and putting the twist in the ends as shown. This machine is adjustable to shape coils of different sizes.

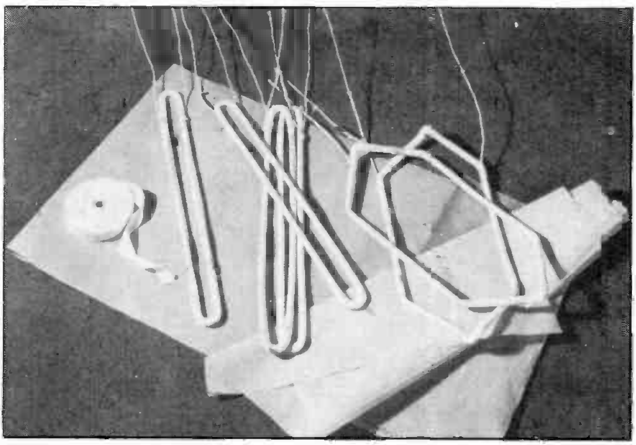


Fig. 5. Above are shown several armature coils, both in the unfinished loops and the completely taped coils. Also note the ro l of cotton tape and the varnished cambric used for insulating the coils and slots.

shaping. In the center are three of these coil loops already taped. The two coils at the right are completely taped and shaped. Note the sleeving placed on the coil leads for marking and protection. A roll of cotton tape such as used for these coils is also shown, and underneath the tape and coils are shown a sheet of fish paper and a roll of varnished cambric such as used for slot insulation.

LAP AND WAVE WINDINGS

Armature windings can be divided into two general classes, according to the methods of connecting the coils to the commutator. They are called **Lap** windings and **Wave** windings. These names are derived from the appearance of the coils when they are traced through the winding.

Fig. 6 shows a section of a lap winding. Starting with the coil at the left, trace the path of current through this coil as shown by the arrows, and then on through the next coil, etc. The coils are all alike but the one on the left is drawn with heavier lines to make it easier to trace the first one. Examining this diagram, we find that each coil overlaps the next as we trace the circuit through them; thus the name **Lap Winding.**

Fig. 6-B shows the method of connecting coils for a wave winding. Starting at the left lead, trace the path of current through the two coils shown by the heavy lines. Note the location of the north and south field poles, which are shown by the dotted rectangles and marked "N" and "S." We find, by tracing the circuit through, that each coil in this circuit is separated from the last by the distance of one pair of poles, and you will note the wave-like appearance of the two coils traced in heavy lines, and from this appearance the name **Wave Winding** is derived.

Lap Windings are known as parallel windings and are generally used for lower voltages and machines which must carry heavy currents.

Wave Windings are known as series windings and are generally used for machines of higher voltage and smaller currents.

Lap and Wave Windings

In tracing through a lap winding from one brush to the next, we find a number of coils or circuits in parallel between these brushes; while in tracing a circuit of a wave winding, we find a number of coils are in series between the positive and negative brushes.

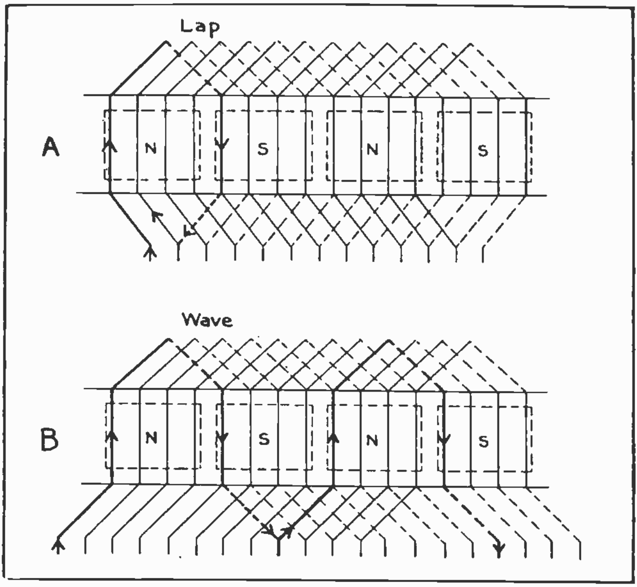


Fig. 6. The two above diagrams show the connections for a lap winding at "A", and a wave winding at "B". Observe carefully the manner in which the leads are brought out from the coils to the commutator bars.

Both lap and wave windings are used in armatures from fractional horse power sizes to those of hundreds of horse power. The type of winding selected by the designer depends on several factors in the electrical and mechanical requirements of the machine. Wave windings require only two brushes on the commutator, while lap windings must have as many brushes as there are field poles. Wave windings are quite commonly used on motors for street cars and electric locomotives, because these machines are generally used on quite high voltage. Another advantage of wave-wound machines for this class of work is that their two sets of brushes can be located at adjacent poles and also on whichever side of the commutator they may be most convenient and accessible for inspection and repairs.

The table in Fig. 7 gives the number of brushes, brush spacing, and the number of circuits for lap and wave windings with different numbers of poles. These figures are given for **Simplex** windings, which will be explained later.

TYPE	POLES	BRUSHES	SPACING	CIRCUITS
LAP	2	2	180°M.	2
	4	4	90°	4
	6	6	60°	6
	8	8	45°	8
	10	10	36°	10
	12	12	30°	12
WAVE	4	2	90°	2
	6	2	60°	2
	8	2	45°	2
	10	2	36°	2
	12	2	30°	2

Fig. 7. This convenient table gives the number of brushes and circuits, and the brush spacing for lap and wave windings with different numbers of poles.

7. CURRENT FLOW THROUGH A LAP WINDING

Fig. 8 shows a complete four-pole winding of the lap simplex type. This diagram shows the position of the field poles by the dotted lines and markings "N" and "S." It also shows the direction of current flow through the armature conductors under each pole and the position of the brushes with relation to those of the poles. Note that the two negative brushes are connected together in parallel and the two positive brushes connected the same. This winding is drawn out in a flat plan view so that you can more conveniently trace the entire circuit and see all the coils. The last six slots on the right have only one coil side in each, while all the other slots have two coil sides in each.

If these coils were wound in a round armature with 24 slots as represented here, the first six coil sides on the left would overlap the last six on the right; and the top sides of coils A, B, C, D, E, F, would go in the same slots respectively with coil sides, A′, B′, C′, D′, E′, F′. The current flow through this winding can be easily traced by starting at the negative brush G, and entering the left lead of coil A, coming around this coil and leaving at its right lead. As there is no brush on segment 2 of the commutator, we must re-enter at the left lead of the coil B, following this coil around and out at its right-hand terminal; then through coils C, D, E, and F in the same manner, going out of the right lead of coil F, to the positive brush H. This completes one circuit.

Next trace the other circuit from the same brush G through coil lead B, which continues through the coil at the far right end of the winding. Trace this current counter-clockwise through coils F′ E′, D′, C′, B′, and A′, leaving at positive brush J.

The other two circuits from the negative brush I can be traced through in the same manner by starting with leads C and D. Thus we find we have four circuits in parallel, or the same number as there are poles.

Note that there are six coils in series in each circuit, and that the number of coils per circuit is equal to the total number of coils divided by the number of circuits.

By comparing this winding with the sketch at A in Fig. 6, we can see that it is nothing more than a number of coils all connected in series, with the finish of one coil attached to the start of the next, etc.

All coils for any given winding are connected the same as the first one. The two ends of each coil are connected to adjacent commutator bars, and this connection is known as the **Simplex Connection.**

Each coil lies in two slots and spans over the intervening slots. They are placed in the slots, one after the other, completely around the armature. In order to arrange the coil ends more compactly and in less space, one side of each coil is placed in the bottom of the slot, and the other side in the top of its slot. This permits the ends of the coils to fit closely together without crossing each other unnecessarily.

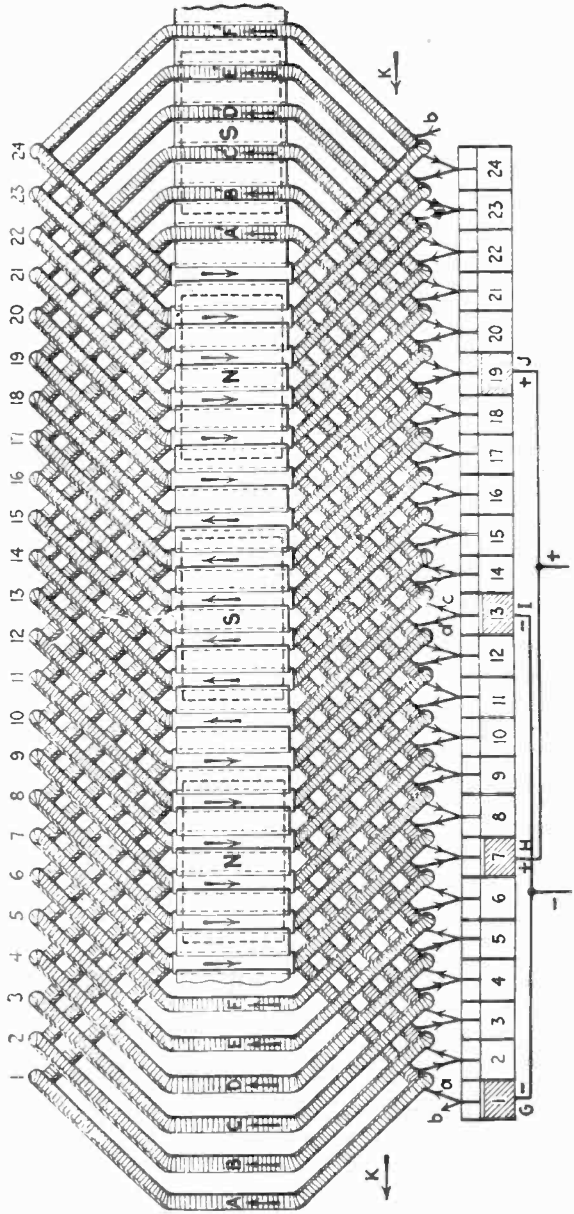


Fig. 8. The above diagram shows a complete four-pole lap winding of the Simplex type. Note the manner in which the coils are laid in the slots, with one side of each coil in the bottom of a slot and the other side in the top of its slot. Also trace out this winding carefully with the instructions given on these pages.

8. COIL SPAN

The number of slots spanned by one coil is known as the **Coil Span.** The two factors which govern this coil span are the number of slots in the core and the number of poles. When we know the number of slots and the number of poles of any machine, the correct full pitch coil span for its armature winding can be found as follows: **Divide the total number of slots by the number of poles,** and **the next whole number above this answer will be the number of slots the coil should span.**

For example, if we have an armature with 21 slots and for a machine with 4 poles, then $21 \div 4 = 5\frac{1}{4}$. The coil span. of course, cannot be a whole number and a fraction, and therefore the next whole number above $5\frac{1}{4}$ is selected. So the coil span will be 6 slots.

The top side of coil No. 1 will lie in slot No. 1, and the bottom side in slot No. 6.

In another case, we have a 28-slot armature to be wound for a four-pole machine. Then $28 \div 4 = 7$; and the next whole number above this being 8, we will use a coil span of 1 to 8.

9. PREPARING AN ARMATURE FOR WINDING

Now that we know how to make the connections for a lap or wave winding and how to determine the correct coil span for a given number of slots and poles, our next step will be the actual placing of the coils in the slots. Before this is done, however, the slots must be prepared and insulated to protect the coils from grounding against the sides or corners of them. The slots should be smoothed out carefully with a flat file, to remove the sharp edges and burrs which are often found in the bottom and sides of slots. The commutator should also be prepared by making a slot in the **Neck** or **Riser** of each bar, in which the coil leads will be placed. We should also test across each pair of bars or segments with a 110-volt test lamp to make sure that no bars are shorted together, due to defective mica insulation between them. A test should also be made from the segments to the shaft, to be sure that no part of the commutator is grounded to it. This should always be done before starting a winding, because if the commutator is defective the armature will not operate properly when the winding is in.

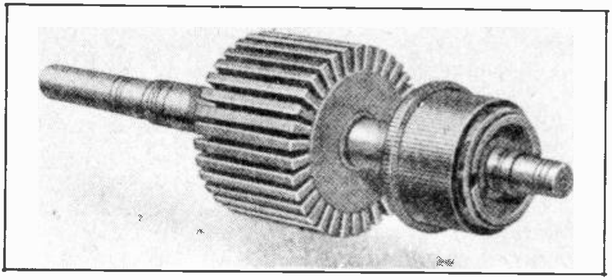


Fig. 9. The above photo shows a D.C. armature prepared for winding. The slots are cleaned and smoothed out, and the necks of the commutator bars have been slotted to receive coil leads.

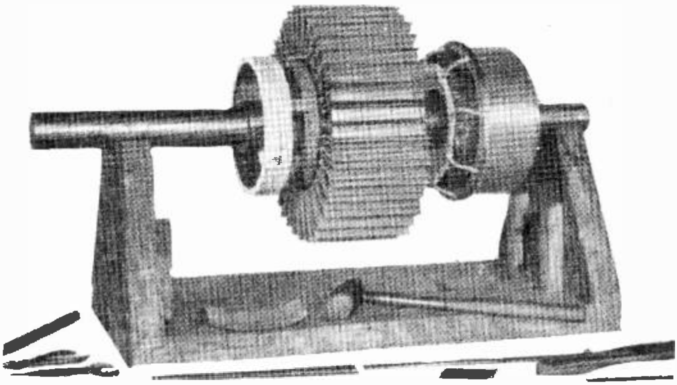


Fig. 10. This armature has the slot insulation in place ready to receive the coils, and you will also note that the coil support ring at the left end has been wrapped with insulating tape. The armature is mounted in a stand and free to revolve so it will be more convenient to place the coils in all the slots.

Fig. 9 shows an armature with the core and commutator prepared for winding, and in Fig. 10 is shown an armature with the insulation placed in the slots. Note that this slot insulation is allowed to project slightly at the ends of each slot, to protect the coils at these sharp edges; and also out of the tops of the slots a short distance, to make it easier to slide the coils in, and to protect them from scratching or damaging the insulation while they are being placed in the slots. Also note the insulation wrapping on the coil support ring at the left end of the armature. All such metal parts against which the coils may rest should be thoroughly insulated by wrapping with fish paper or varnished cambric and tape, before any coils are placed in the slots.

10. INSERTING COILS FOR A LAP WINDING

By referring to the several sketches in Fig. 11, the method of laying coils in place in the slots can be observed. In the three views at "A" the coils are wound in from the left to right, as shown by the arrow. Note carefully the manner in which each coil overlaps the last, and the manner in which the diamond shaped ends of the coils allow them to fit closely and neatly together, if they are properly shaped and twisted at the ends. In order to obtain a satisfactory winding job, it is essential that all coils be exactly the same size, and uniformly fitted in the slots and at their ends. Care and practice on these points are necessary to make a rugged and well-balanced winding.

The coils at "B" in Fig. 11 are wound into the slots in the opposite direction around the armature, or to the left when facing the commutator end. Armatures may be wound in either direction, as it makes no difference in their operation. The direction in which the coils are placed in depends on the shape of the twist or curl at their ends, and the important point to remember is that if the coils are shaped as shown at "A," they must be laid in the slots to the right, in order to get their ends to fit together compactly. If the twists on the coil ends are made in the opposite direction, as at "B," then the coils must be laid in the armature to the left.

Sometimes coils fit very tightly in the slots and it is necessary to use a driver of some kind to force them down to the bottom of the slots. Such a coil driver can be easily made from a piece of hard fibre about three inches wide and six inches long, and just thin enough to slide easily through the top of the slot. After the coil is started in the slot, this driver is laid on top of it, and by tapping the top of the driver with a mallet the coil can be driven down in place. Extreme care should be used, however, not to apply too much force, as it may result in broken or cut insulation on the coil.

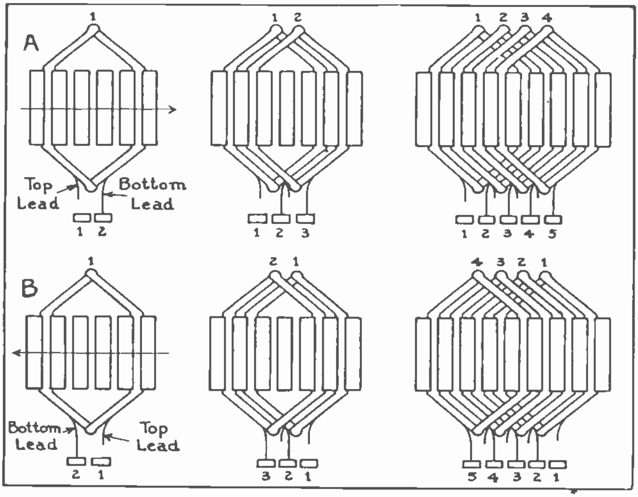


Fig. 11. The above diagrams show the method of laying coils of a lap winding in the slots. Note the direction the coils are laid in or progress around the core, according to the shape of the twist at their ends.

After the bottom side of the first coil is in place in the slot, (leave the top of this coil out for the present), the lower coil lead should be brought out to the commutator and driven into the slot in the proper segment. The angle of this lead, or whether it connects to a segment in line with the center of the coil as in Fig. 11, or is connected straight out to a bar in line with the side of the coil, depends upon the position of the brush with relation to the field poles.

An explanation of these two different methods of connecting the coil leads is given a little later.

Now the first coil is in place and its lower side in the slot, the bottom lead connected to the commutator segment but the top side of the coil left out of its slot, and the top lead left unconnected. The second coil should be placed in the next slot and its bottom lead connected to the next adjacent commutator segment, but the top side of this coil and its top lead should also be left out, as with the first one. The next two coils are placed in the slots in the same manner. When the fifth coil is inserted both sides can be placed in the slots, as the coil span is one to five, and the top side of the fifth coil will lie in the slot with the bottom side of the first coil. The top lead of the fifth coil should be left disconnected from the commutator.

11. CONNECTING THE COILS

From this point on, both sides of all the other coils can be placed in the slots as the winding progresses, but all of their top leads should be left unconnected until all coils are in, and the bottom leads all in place.

A layer of varnished cambric should then be wound tightly around the bottom leads, and should be wide enough to extend from the ends of the coils to the commutator; so it will thoroughly insulate the bottom leads from the top ones. The top leads can then be connected to the commutator segments as follows:

The top lead of coil No. 2 in Fig. 11 will connect to segment No. 2, with the bottom lead of coil No. 1.

After carefully making this first connection, all the other leads can be connected in the same manner: the top lead of coil No. 3 to bar No. 3; the top lead of coil No. 4 to bar No. 4; etc.

After all the top leads are in place, the winding should be carefully tested for shorts, opens, and "grounds." This should always be done before soldering the leads to the commutator. The method of making these tests is explained in a later article.

We are now ready to trim off the excess insulation at the top of the slots. Fold in the edges neatly over the coil and place the slot wedges over it to hold the coils in. If the slots are not equipped with lips or grooves to hold the wedges in place, the armature should be banded with steel wires. The top leads are also quite often banded with steel wire or heavy twine to hold them rigidly in place and prevent their being thrown outward by centrifugal force when the armature is run at high speed.

If steel wire is used for banding these leads, they should first be well wrapped with several layers of fish paper or varnished cambric, to prevent any possible short circuits between them and the steel banding wire.

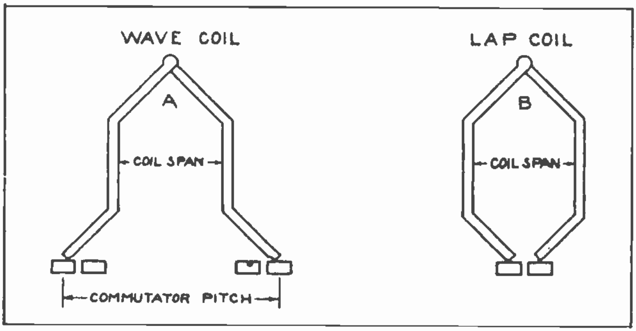


Fig. 12. At "A" is shown a coil for a wave winding and at "B" a coil for a lap winding. Note the difference in the way their ends or leads are brought out to the commutator bars, and the manner in which either side of the wave coil is braced in two directions by the angle of its front and back connections.

12. WAVE WINDINGS

The shape of wave-wound coils, their connections, and the manner in which they differ from lap windings, has already been explained. Wave windings have the advantage of their coils being more securely braced and held in place by the way they are arranged in the armature. This is due to the manner in which the coil ends are bent in the opposite direction from the coil side in the slot, while those of the lap winding are bent in the same direction as shown in Fig. 12.

When an armature is in operation there is considerable centrifugal stress, which tends to throw the windings out of the slots; so the more rugged the winding can be made the better it is.

Automobile starting motors frequently use wave windings in open type slots, and even without bands on the armature. This is because the strength of the heavy wave coils is sufficient to hold the winding in place. Large A.C. machines which have wound rotors very often use wave windings, because of the greater mechanical strength of these windings when completed.

Wave Winding

Fig. 14 shows a diagram of a complete wave winding. By tracing the coils, we find that there are only two circuits in parallel betwen the positive and negative brushes, but that there are eight coils

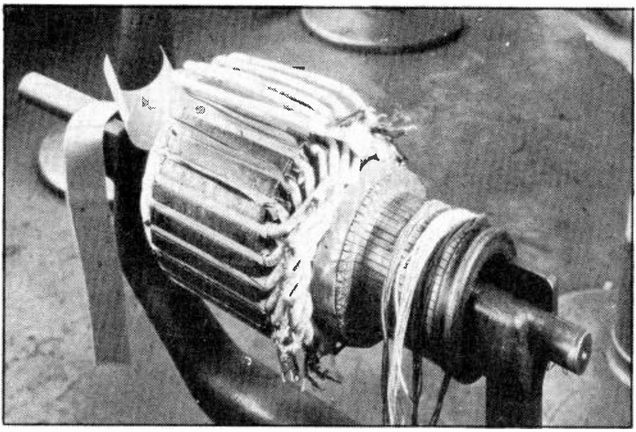


Fig. 13. This photo shows an armature completely wound, with the exception of laying in the last top coil sides, and connecting the leads to the commutator.

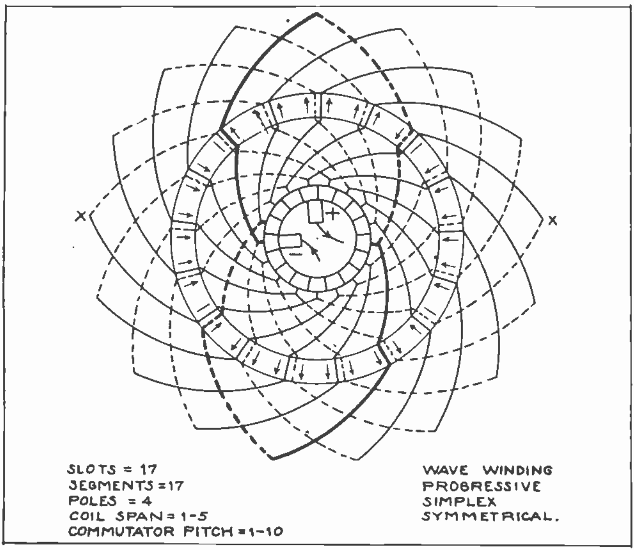


Fig. 14. This diagram shows a complete four-pole wave winding for an armature with 17 slots. Note the coil span and commutator pitch, and trace out the two coils shown with heavier lines.

in series. Two brushes are all that are needed to complete the circuits through all coils, but more brushes may be used, if desired, in order to reduce the current intensity in each brush. There can be as many brush groups as there are poles.

In Fig. 14, the two coils indicated by X and X are at present short circuited by the positive brush. Each pair of coils must reverse in polarity as they move from one pole to the next, and this current should reverse when the segments connecting these coils are shorted by the brush or, in other words, the brush should short circuit the coil as it passes through the neutral plane in the center of the space between two poles.

13. PROCEDURE FOR WAVE WINDINGS

Wave windings are made much the same way as lap windings, and the coil span will be the same for a given armature regardless of which winding is used. The coils are laid from the bottom of one slot to the top of the other, the same as described for a lap winding, and they may also be wound either to the right or to the left. There is a difference, however, in the manner of making connections of their coil leads to the commutator bars, and in the distance between leads of any one coil. This distance between the coil leads is expressed by the number of commutator bars between them, and is known as **Commutator Pitch.** After this commutator pitch has been determined the coils are placed in the slots much the same as with a lap winding.

Commutator pitch for wave windings can be determined by the following formulas.

For a progressive wave windings—

$$\text{Pitch} = \frac{\text{Segments} + \text{plex}}{\tfrac{1}{2}\text{ the number of poles}}\text{, plus 1}$$

The term **Plex** refers to the methods of connection of the coils to the commutator, known as simplex, duplex, and triplex. These will be explained later.

In this formula simplex equals 1, duplex equals 2, triplex equals 3.

For retrogressive wave windings—

$$\text{Pitch} = \frac{\text{Segments} - \text{plex}}{\tfrac{1}{2}\text{ the number of poles}}\text{, plus 1}$$

14. PROGRESSIVE AND RETROGRESSIVE

In Fig. 14 the coil sides which lie in the tops of the slots are shown by solid lines, while those which lie in the bottoms of the slots are shown by dotted lines. If we start at the negative brush and trace the top lead of the upper coil shown in the heavy lines, we find that the bottom lead of the second coil in this circuit connects to a commutator bar just to the right of the one at which we started, and if we trace on around the next pair of coils we arrive at a bar one more step to the right. This is known as a **Progressive Winding,** and applies to either lap or wave windings.

If, after tracing through two coils, the bottom lead of the second coil connects to a bar to the left of the one at which we started, it is called a **Retrogressive Connection.**

15. INSERTING COILS OF A SYMMETRICAL WAVE WINDING

Fig. 15 shows the procedure of laying in the coils for a winding such as shown in Fig. 14. At "A" the first coil is placed in the slots and the bottom lead brought out to its commutator segment. The proper point for this first connection can be found by locating a commutator segment that is in line with the center of the coil as shown at "A." Then divide by 2 the commutator pitch which has previously been determined, and count off this number of bars to the right of the center bar, which has been located. This will locate the proper bar to connect the bottom lead of the first coil to. This distance is shown from "A" to "B" in Fig. 15-A.

Sometimes a mica segment will be in line with the center of the coil and in this case we start to count with the next bar to the right as No. 1. If the commutator pitch happens to be an odd number, dividing this by 2 will give a whole number and a fraction, in which case we should use the next larger whole number.

After the first coil is in place but with its top side and top lead left out, the second coil is inserted in the next slot to the right and the bottom lead will be connected to the next bar to the right of the first one. The third and fourth coils are inserted in the same manner, leaving their top sides and leads out. The fifth coil can have both sides placed in the slots, but its top lead should still be left unconnected, as should all the other top leads, until all coils are in place.

When the winding is completed around the armature and the bottom sides of the last four coils are in their slots, then the top sides of the first coils can be placed in on top of these. After all coil sides and bottom leads are in place, the top leads are then connected to the commutator bars.

16. DETERMINING COMMUTATOR PITCH AND CONNECTING THE COILS ON WAVE WINDINGS

The armature shown in Fig. 14 has 17 slots and 17 commutator segments and is connected simplex. We will use it for an example to determine the commutator pitch.

We have learned that for a wave winding:

$$\text{Commutator pitch} = \frac{\text{Segments} + \text{plex}}{\tfrac{1}{2}\text{ number of poles}}\text{, plus 1,}$$

$$\text{or:— pitch} = \frac{17 + 1}{2}\text{, plus 1}$$

In which:

17 = slots
1 = simplex
2 = ½ of 4 poles

With a commutator pitch of 10, the coil lead from the top side of one coil will connect to bar No. 1, and the lead from the bottom of the same coil to bar No. 10, counting toward the coil that is being checked. After the first top lead is connected all the others are connected in the same way.

The completed winding is then wedged and banded if necessary, as was done with the lap winding.

We should remember that some armatures cannot be wound wave, except by using dead coils or bars. The commutator pitch formula determines whether a winding can be connected wave or not.

When a commutator pitch is a whole number and a fraction the winding cannot be connected wave without using dead coils or bars.

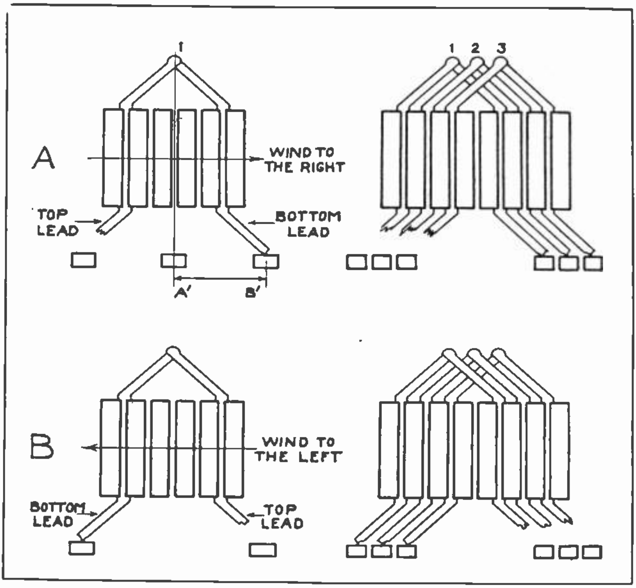


Fig. 15. The above views show the method of laying the coils of a wave winding in the slots. One side of each coil should go in the bottom of the slots, and the other sides in the tops of slots, and the coils should be laid in the directions as shown and according to the shape of the twist on their back ends.

17. ELEMENT WINDINGS

That part of the armature winding which is connected between two commutator bars is called a **Winding Element.** A simple winding element would consist of one complete turn of wire. Each side of this turn or coil is referred to as an armature conductor or sometimes as an "inductor." Each element, therefore, will have at least two conductors, and may have many more, according to the number of turns per coil.

In many armatures the coils are wound with several conductors in parallel and the ends of each of these conductors can be connected to separate commutator bars. This will, of course, require a greater number of commutator bars than there are slots in the armature. But many machines are designed in this manner to reduce the voltage between bars.

It is not good practice to have too high a voltage across adjacent commutator bars, because of the greater liability of puncturing the mica insulation and the increased tendency to flash over or arc between bars while the machine is in operation.

Carbon particles from the brushes and metallic dust from the commutator tend to start small sparks or arcs of this kind; and if the voltage between bars is too high, the arcs will be maintained and possibly burn the mica insulation between the bars. If this mica becomes charred or deeply burned, it results in a short circuit between bars, which will cause the coils of the windings to heat up and possibly burn out.

On larger machines the voltage between bars usually doesn't exceed about 25 volts. On smaller machines it may range from 2 to 10 volts. So we can readily see that the higher the voltage the machine is to be operated at, the greater number of commutator bars it will usually have. This number of bars is determined by the designer or manufacturer in building machines on any give voltage.

The number of slots in an armature is determined by the number of poles and the practical number of slots which can be used per pole. The slots, of course, cannot be too numerous or close together, or there will not be sufficient iron between the coils to provide a good magnetic path through the armature for the field flux.

The number of slots is generally considered in determining the exact number of commutator bars, as the number of bars is usually a multiple of the number of slots. For example, an armature with 24 slots might have 24, 48 or 72 commutator bars. In the latter case the coils would be wound with three conductors in parallel, and the three leads from each coil connected to three adjacent bars.

So we find that armature windings can be called single element, double element, or three element windings, according to the number of conductors in parallel in the coils, and the number of bars in proportion to the number of slots.

EXAMINATION QUESTIONS

1. What is one loop of wire connected between two commutator bars called?

2. a. Is the wave winding known as a series or a parallel winding?

   b. Is it used on high or low voltage machines?

3. What do we mean by the expression "coil span?"

4. What would be the correct full pitch coil span on an armature with 15 slots to be used in a two pole motor?

5. What is meant by the expression "commutator Pitch?"

6. What would be the commutator pitch on a simplex progressive, wave wound, two pole motor using a commutator with 29 segments?

7. What is the difference between a progressive winding and a retrogressive winding?

8. What is the average voltage range between bars on small motors?

9. How many brushes are needed on a 4 pole lap wound machine?

10. How many brushes are needed on an 8 pole wave wound machine?

ARMATURE WINDING

Armature winding may at first seem to be difficult, but it is not at all difficult when one has an opportunity to work out some of the simple rules which govern armature. winding procedure. One cannot expect, however, to grasp and understand all of the details in a few moments, without practice. That is why we recommend that the student do real jobs as he studies the subject. It is advisable to first practice winding a small armature with ordinary string. We do not mean that you should attempt to do a finished job with a string, but merely practice winding the string in the slots until you understand how the wire is to be wound on the armature. After you have a good understanding of the method of following thru from one set of slots to the next, then you may wind the armature with real magnet wire.

1. WINDING SMALL ARMATURES

Many automobiles are equipped with hot water heaters, which make use of a small 6 volt, D. C. motor. The following information is taken from a motor of this kind. Assuming that the winding is defective and we have checked up on the motor and found the following data.

2 poles
11 slots on armature
11 commutator bars
16 turns per coil of No. 24 S. C. E. Wire

The armature is wound lap. The coil span is 1 to 5. About 2 ozs. of wire will be needed. All the old wire should be removed from the armature, and the slot insulation carefully checked to see if it is O. K. for use. The commutator should also be carefully tested to make sure no shorts exist between the commutator bars, or between the commutator and the shaft. The little grooves in the commutator risers should also be thoroughly cleaned in order to make it easy to do a good job of soldering the wire to the commutator bars.

2. WINDING PROCEDURE

We have found the coil span to be 1 to 5 and the wire size No. 24 S. C. E. Therefore, we obtain the proper wire and go to work. See Fig. 1. We may start with any slot and call it No. 1. Insert the wire in No. 1 slot, leaving about 4″ extending out on the commutator end so that we will have plenty wire for making the connection to the commutator. We then wind in 16 turns of wire in slots one and five, and as we return toward slot No. 1 with the 16th turn, we stop at slot No. 2 and make a loop about 4″ long, for connection to the commutator. Then we wind 16 turns in slots 2 and 6 and as we return toward slot No. 2 with the 16th turn we again stop at the next slot to the right which will be No. 3. Then wind 16 turns in slots 3 and 7, etc. This operation is continued, and as each coil is finished the next is placed one slot further around the armature until there are two coil sides in each slot. When the last coil is finished the end of the wire is connected to the single wire at slot No. 1. You then have one loop or two wires coming from each slot. Now since there is only one commutator segment for each slot the loop or pair of wires should be connected to one segment. The two wires from slot No. 1 are pulled straight out and soldered to the commutator segment which is in a direct line with the slot. Be sure, of course, to first scrape the insulation from the wire at the point of connection to the commutator. The surplus wire may then be cut off and discarded. After completing the first connection, you simply take each loop in turn and connect it to the next commutator bar to the right. You will find that the bars all line up with the slots so that all loops extend straight out from the slot to the commutator bar.

Small armatures of this kind do not always use wedges to hold the wire in the slots, but if you desire, you may cut wedges from thin fibre and drive them in over the wire and beneath the flanges on the armature bars.

Be sure to follow all rules given so far, for winding armatures, and take your time and do a good job.

The above winding is for operation on 6 volts D. C. and it will operate very well on from 8 to 12 volts A. C. It may also be wound for operation on other voltages. When winding the motor for any of the following voltages, you may follow the same winding procedure as given for the six volt winding. The main difference will be in the size of wire and the number of turns.

3. 110 VOLT WINDING—

Wind the armature with 180 turns per coil of No. 36 magnet wire. The field poles will have to be rewound with 415 turns of No. 30 magnet wire per

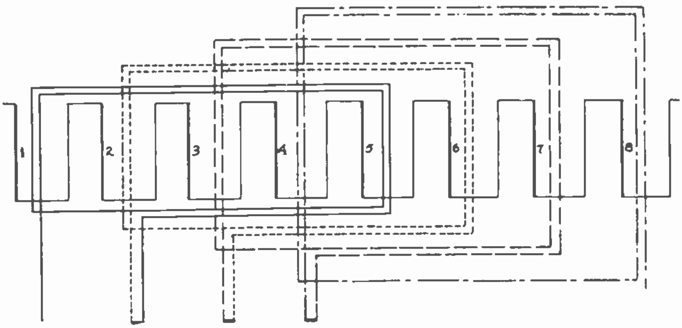


Fig. 1. This diagram shows how the first 4 coils are placed on a 11 slot armature with a coil span from 1 to 5. The following coils are placed on the armature in the same order until there are two coil sides in each slot.

pole. (The 6 volt field coils were originally wound with 45 turns of No. 21 magnet wire on each pole.)

The same slot insulation may be used, but you should also add a piece of .007 varnished cambric to each slot to increase the insulation for 110 volts. This winding will enable you to operate the motor on either D. C. or A. C.

4. 3 VOLT WINDING

Wind the armature with 8 turns per coil of No. 21 magnet wire. The two field poles may be connected in parallel so as to lower the resistance enough for operation on 3 volts without rewinding.

5. 32 VOLT D. C. WINDING

Rewind the armature with 85 turns per coil of No. 31 wire.

The field poles should be rewound with 250 turns of No. 28 wire per coil.

6. SMALL TWO ELEMENT WINDING

In the following paragraphs we will explain in detail the methods of winding a small two pole, two element, non-symmetrical armature having 12 slots and 24 segments.

The slots should first be lined with fish paper about 7 to 10 mils thick, and varnished cambric about 7 mils thick. The fish paper is placed in the slot, next to the iron core, and the varnished cloth or cambric is placed inside the fish paper. To complete the insulation of the core we generally use at each end a fibre lamination which is shaped the same as the iron core laminations and has the same number of slots stamped in it. This protects the coils at the corners of the slots.

The armature should be held or clamped with the commutator end next to the winder.

In winding the first coil the number of turns will depend on the size of the armature and its voltage rating. If this number is taken from coils in an old winding, the turns in one or more of the old coils should be very carefully counted. When winding an armature that has twice as many bars as slots, we wind two coils in each slot, thereby providing enough coil leads for all bars.

The first coils for this armature will go in slots 1 and 7, winding to the right of the shaft, at both the front and back ends of the core. After winding in one coil, a loop about 4 inches long should be made at slot No. 1. Then continue and wind the same number of turns again, still in slots 1 to 7. When the last turn is finished, run the wire from the 7th slot over to the 2nd, and make a loop at slot No. 2. Next wind a coil in slots 2 and 8, and again make another loop at slot No. 2. Then place another coil in the same slots 2 and 8, and finish with a loop at slot 3, etc. This places two coils and two loops in each slot, and the same procedure should be followed until there are two coils and two loops in every slot.

The slot insulation should then be folded over the tops of the coils, and the wedges driven in.

The loops are next connected to the commutator, one loop to each segment, and they should be connected in the same way that they were made in the winding. That is, **the first and last single wires are brought together and connected to a segment straight out from the first slot.** The second loop in the first slot is connected to the next bar, and the first loop in the second slot connected to the next, etc.

To avoid mistakes these loops should be marked with cotton sleeving which is slipped on over them as they are made. Red sleeving could be used on the first loop of each slot, and white sleeving on the second, which will make it easy to locate the first and second loops for each slot. This winding would be used in a two pole frame, and has two circuits with 12 coils in each. If 110 volts were applied to this winding the voltage between adjacent commutator segments would be 110 ÷ 12, or 9⅙ volts, which is not too high between adjacent bars. If this same armature had a commutator of only 12 segments, the voltage between bars would be

110 ÷ 6, or 18⅓ volts, which is a little high for this sized armature.

7. ELEMENT WINDINGS FOR LARGE ARMATURES

In winding large armatures having twice or three times as many segments as there are slots, the coils are made up specially for the type of armature and wound with two or more wires in parallel.

In Fig. 2-A are shown the coils for two-element armatures. These coils are wound with two wires in parallel; and when the coil is completed, two small coils or elements are in each bundle. These two elements are taped together with cotton tape. The top and bottom leads of one element are marked with sleeving of one color, and those of the other element are both marked with sleeving of another color.

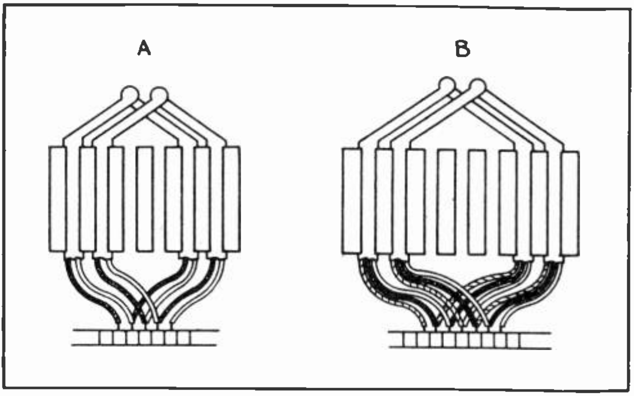


Fig. 2. The diagram at "A" shows the connections of lap coils for a two element winding. At "B" are shown the connections for a three element winding. Note how the separate windings in each coil are connected to two separate commutator bars.

These coils are placed in the slots the same way as single element coils, the only difference being that there are two bottom leads to connect instead of one. When connecting the bottom leads a definite system should be followed in the colors. If black and red sleeving are used to identify the two elements, first connect a black lead and then a red.

When the second coil is placed in, again connect a black lead and then a red one.

In order to avoid mistakes in the connections, all coils should be connected in a similar manner. When the top leads are connected use the same system, and connect around the armature in the same direction. This method can be used on any armature, regardless of the combination of slots and segments.

Fig. 2-B shows the coils for a three-element winding having three wires wound in parallel in each coil, and the leads marked with three separate colors. These colors are alternated when the bottom leads are connected in, each succeeding coil being connected similarly. The top leads are connected around the armature in the same direction as the bottom leads were, and the colors alternated in the same manner.

A wave winding may be of 2, 3, 4, or more wave elements, and the system for connecting these coils is the same as for a single element wave winding, only more than one lead is connected to the commutator from each coil. The leads are marked with sleeving and the colors are alternated as in the lap windings.

Many 2 and 3 element wave-windings have dead coils which are not connected in the armature circuit. They occur when the number of segments in the commutator is less than a multiple of the number of slots. When a winding has one dead coil it should be left in the slots to mechanically balance the armature; but if more than one dead coil occurs in a winding they may be left out, provided they are at equally distributed points around the armature core.

6. CHANGING AN OLD MOTOR FOR NEW CONDITIONS

It is often desired to change the voltage or speed at which a motor may operate, and in such cases some change is usually made in the windings. We have already learned that the voltage of an armature winding depends on the number of turns per coil. So it is evident that if any change is made in the number of turns between brushes it will have a direct effect on the voltage. The voltage of a winding will vary directly with the number of turns.

For example, a winding has 10 turns per coil, of wires 4000 C.M. in area and operates on 110 volts. If we wish to rewind this machine for 220 volts we can do it by using 20 turns per coil of wire with 2000 C.M., area. This rewound armature would operate on 220 volts with the same speed and horse power as it formerly did on 110 volts.

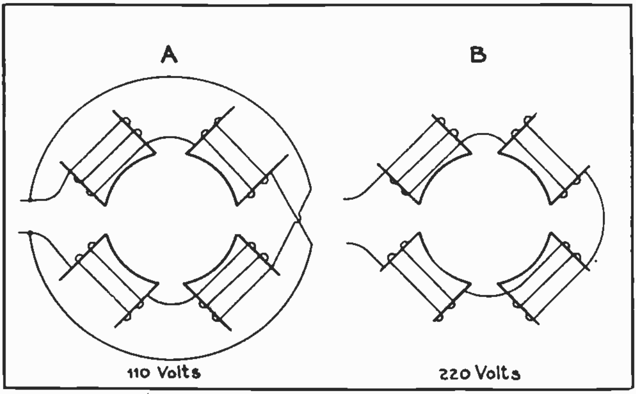


Fig. 3. The above diagram shows the methods of changing the field pole connections from parallel to series to be able to operate them on higher voltage.

It will be necessary, however, to change the field coil connections also. If they were formerly connected two in series and two in parallel, as in Fig. 3-A, they could be reconnected all in series, as shown in Fig. 3-B, and would then operate satisfactorily on 220 volts.

If the field coils are all connected in series on 110 volts, they cannot be changed for 220-volt operation without rewinding. To rewind them for double voltage, we should use approximately twice as many turns of wire, of a size one-half as large as the wire with which they were formerly wound.

The resistance of the field coils will have to be increased to stand the increased voltage. This, of course, will reduce the amount of current flowing, but the additional number of turns will maintain approximately the same ampere-turn strength of the field magnets. **If we change the number of turns in the winding of an armature and leave the applied**

voltage the same, its speed will vary inversely with the number of turns.

For example, if an armature is wound with 25 per cent more turns, the speed will decrease about 25 per cent if the machine is left on the same voltage.

9. MULTIPLEX WINDINGS

In some cases, where armature windings are designed to carry very **heavy currents and at lower voltages,** the connections can be arranged to provide a greater number of circuits in parallel through

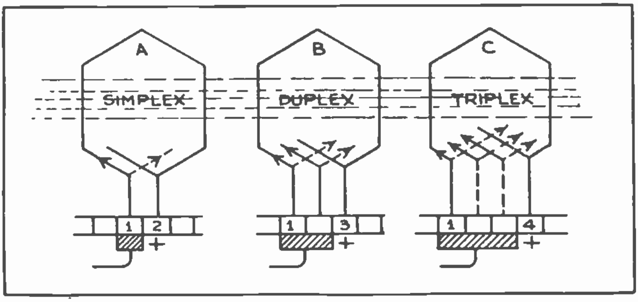


Fig. 4. "A" shows the connections for a coil of a simplex lap winding. "B" shows the connections for a duplex lap winding, and "C" those for a triplex lap winding.

the windings. Windings connected in this manner are called **Multiplex Windings.** Those which we have covered so far have been **Simplex Windings;** and, in the case of the lap windings described, they have had the start and finish leads of each coil connected to adjacent bars of the commutator. Fig. 4-A shows a coil of a lap winding connected in this manner. With simplex connections a lap winding will have only as many circuits in parallel as there are field poles.

If we simply move the finish lead of a coil one segment further from the starting lead, and use a wider brush to span two bars instead of one, we have provided twice as many circuits through the winding, or two circuits for each pole. This is called a **Duplex Connection** and is shown in Fig. 4-B.

If we move the leads one more segment apart, we provide 3 circuits per pole, and have what is known as a **Triplex Connection,** as shown in Fig.

4-C. In this case the brush must be wide enough to span three commutator segments.

Fig. 5 illustrates the difference between simplex and duplex connections, with simplified winding diagrams. These sketches are laid out to show the winding in a straight form. On the actual armature the ends of this winding would come together at the points marked X and X.

In Fig. 5-A is shown a simplex connection with the start and finish leads of each coil connected to adjacent segments. If we start at the positive brush and trace the circuit to the left to the negative brush, we will pass through 12 coils in series; and the same will be true of the other circuit traced to the right from the positive brush to the point X, which in reality connects back to the negative brush in the actual winding. So we find we have two circuits in parallel between the brushes, and each of these circuits consists of 12 coils in series. If we assume that each coil is wound with a sufficient number of turns to produce 10 volts and with wire of a size that will carry 5 amperes, then this winding will produce 120 volts between brushes and have a total capacity of 10 amperes.

This is easily understood by recalling our laws of series and parallel circuits. We know that when coils are connected in series their voltages are added. So 12 coils with 10 volts each will produce 12 × 10, or 120 volts.

Connecting circuits in parallel does not increase their voltage, but does increase the current capacity; so with two circuits each having five amperes capacity and connected in parallel, the total current capacity will be 10 amperes.

In the lower sketch of Fig. 5-B, we have simply moved the start and finish leads of each coil one bar farther apart, which in effect makes two separate windings, or 4 circuits in parallel between the positive and negative brushes. In this diagram we have lengthened the coils of one section simply to make them easier to trace separately from the other. Tracing through any one of these four circuits from the positive to negative brush, we now find there are only six coils in series. So the voltage of this winding will be 10 × 6, or 60 volts.

But as we now have four circuits in parallel between the positive and negative brushes, the current capacity of this winding will be 4 × 5, or 20 amperes. The wattage of either winding will be the same, however.

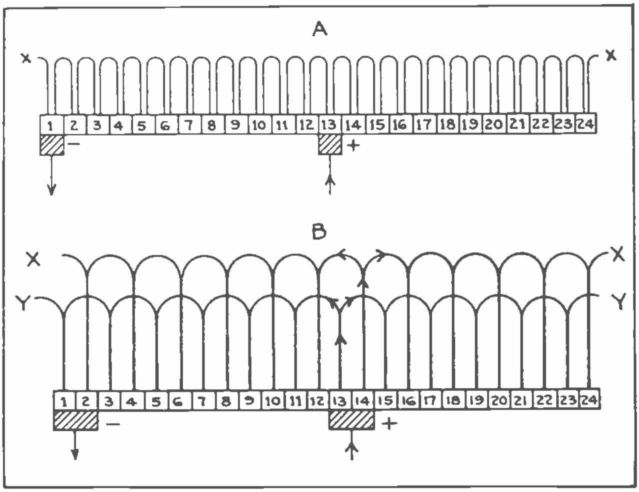


Fig. 5. At "A" is shown a simplified diagram of the circuit in a winding connected simplex lap. At "B" the winding is connected duplex, doubling the number of circuits from positive to negative brush.

The brush span for a simplex winding is generally equal to the width of one to 1¾ segments, while for a duplex and triplex winding it must be increased proportionately.

Wave windings can also be connected duplex or triplex if the commutator pitch is a whole number. So the surest way to determine whether a wave wound armature can be connected duplex or triplex, is to calculate the commutator pitch; and if this number is a whole number and fraction the winding cannot be connected multiplex.

10. NEUTRAL PLANE—IMPORTANT TO COMMUTATION

We have learned that the coils of a motor or generator winding must have their polarity reversed as the coil sides move thru the **neutral plane** between two field poles. As the armature rotates and the segments slide under the brushes, the brushes repeatedly short circuit the coils which are connected to adjacent brushes. In order to avoid bad sparking at the brushes this short circuit must occur at the time the coil is dead, or passing thru a neutral point where no voltage is induced in it. This means that the brushes must always be in the correct position with regard to field poles, in order that they may short circuit the coils at the right time. This point is of great importance to good commutation, and will be more fully discussed later.

11. SYMMETRICAL AND NON-SYMMETRICAL CONNECTIONS

The angle at which the coil leads are brought out from the slots to the commutator segments depends upon the position of the brushes with respect to the poles. If the brushes are placed in line with the centers of the field poles, then each coil lead comes out from the slots at the same angle, to two bars directly in the center of the coil. This is called a

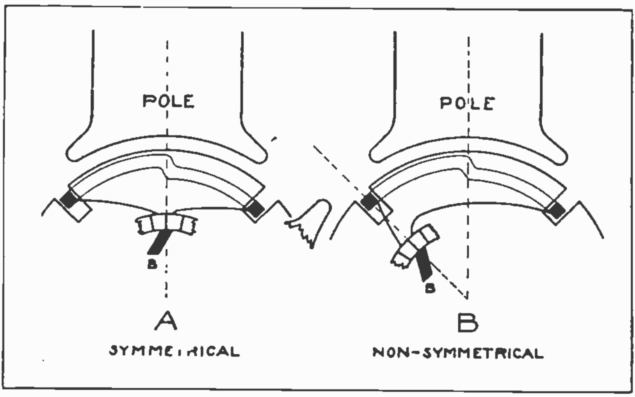


Fig. 6. Note the position of the brushes with respect to the poles, and also the shape of the end connections of the above lap winding coils for symmetrical and non-symmetrical windings.

Symmetrical Connection, as it leaves the coil and leads in a symmetrical diamond shape.

Fig. 6-A shows this condition on a machine which has the brush located in line with the center of the field pole, and you will note that the leads are of equal length and brought out from the slots to the two bars in the center of the coil span. If

the brushes of the machine are located at a point between the field poles, the coil leads must be carried to one side in order to be connected to the segments at the time they are short circuited by the brush.

Fig. 6-B illustrates this condition. One lead is brought straight out from the slot to the segment, while the lead from the other side of the coil is carried clear across to the adjacent segment. This is called a **Non-Symmetrical Connection,** because of the lengths and unbalanced shape of the coil leads.

Whether the brushes are located in line with the center of the field poles or in line with the neutral plane depends, to quite an extent, on the mechanical design of the machine. In some cases the brushes are much easier to get at for adjustment and replacement, if they are located as in Fig. 6-B.

In small fractional-horse-power motors there is generally very little space between the centers of the field coils and the end shields. So the brush holders are frequently bolted to the end shields at a point between the poles. This makes necessary the use of a non-symmetrical connection on the armature coil leads.

On larger machines, where there is plenty of space for the brush holders, they are usually placed in line with the centers of the field poles, and the coil leads of the armature are connected symmetrically.

12. COLLECTING DATA FROM OLD WINDINGS

When rewinding any armature, care should be taken to collect sufficient data while dismantling the old winding to enable you to put in the new winding correctly. It is a very good plan to mark the slots and commutator segments from which the first coil and leads are removed. This can be done with a prick-punch or file, as shown in Fig. 7. One small punch mark can be placed under the slot that held the top coil side, and two dots under the slot that holds the bottom side of the same coil. The top leads are then traced out to the commutator, and each bar that they connect to should be marked with one dot. Next trace the bottom leads to the commutator, and each of the bars they connect to should be marked with two dots. This can be done with both lap and wave windings, and is a positive way of keeping the core and commutator marked, to be sure to replace the coils and connections properly.

If necessary, you can also make a sketch or diagram of the first few coils removed. This sketch can be made similar to the ones in Fig. 7, and can show the exact coil span, commutator pitch, etc.

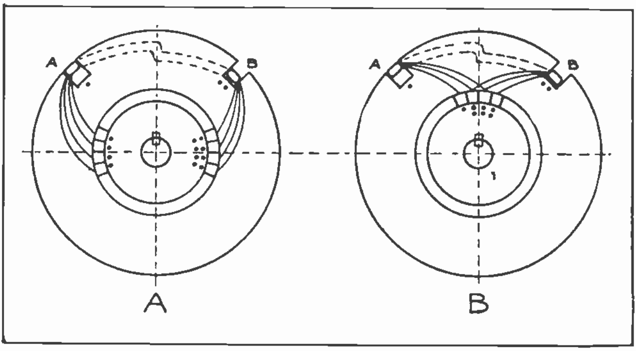


Fig. 7. A very simple and sure way of marking the commutator and armature when removing an old winding is shown above. Compare these sketches carefully with the instructions given, so you will be able to replace windings correctly.

In addition to marking the core and commutator and keeping a diagram of the winding and connections, the following data should be carefully collected as the old winding is removed.

1. Turns per element.
2. Size of conductor.
3. Insulation on conductor.
4. Coil insulation.
5. Slot insulation (layers, type, and thickness.)
6. Extension of slot insulation from each end of core.
7. Extension of straight sides of coils from each end of the core.
8. Over-all extension of the winding from the core, both front and back.

If these things are carefully observed and recorded, you should have no difficulty in properly replacing most any type of winding and getting it back in the same space, and with the same connections. It will, of course, require a little practice to be able to make your coils exactly the proper size and shape so they will fit neatly and compactly in the armature.

13. BANDING ARMATURES

Wire bands, as previously mentioned, are generally used on large armatures having heavy coils, to hold the coil ends securely in place. If the core has open slots, bands are often used over the core to hold the wedges in place. High-grade steel piano wire is commonly used for this purpose and can be obtained in rolls in various sizes. This wire is usually tinned at the factory.

When a banding machine is not available, a lathe can be used to hold the armature while the bands are wound on. A layer of paper or cloth is usually placed under the band. Cloth makes the best foundation for bands placed on the coil ends, as the cloth tends to keep the bands from slipping off. A layer of fuller board or fish paper can be used under bands placed around the core. Grooves about 1/32 of an inch deep are usually provided for the bands on cores with open slots.

The paper should be cut carefully to the exact width of this groove, so it will fit snugly and without sticking out at either side. The banding wires should be wound on under tension, so they will be firm and tight when completed. A simple tension clamp or brake can be made by cutting two strips of fibre ¼ inch by 1½ by 6 inches, and bolting these together with two small bolts, using wing nuts on each end. Place these pieces of fibre in the tool post of the lathe and run the wire between them. Then, by adjusting the two wing nuts, any desired tension may be obtained.

To start the first band, make a hook of heavier wire and attach the band wire securely to this hook. Then slip the hook under the ends of a couple of coils close to the ends of the slots and start winding the band wire on the core. Make two or three gradual turns around the core to get the band wire over to the first slot. As the first turn is wound in the slot, narrow strips of tin should be placed in the

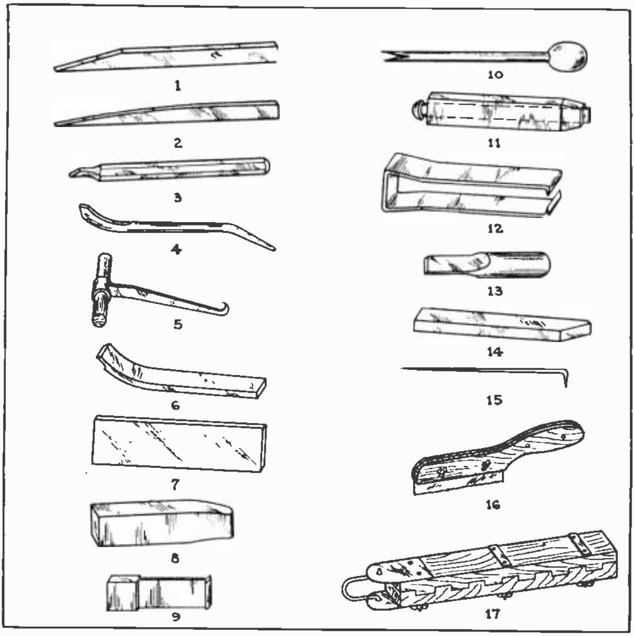


Fig. 8. Above are shown a number of the more common tools used in armature windings. No 1 is a stripping tool for stripping open slot armature and stators. No. 2—coil lifter for lifting coils from the slots. No. 3—lead lifter for lifting coil leads from commuator risers. No. 4—lifting tool for prying tight coils from slots. No. 5—coil hook to break coil ends loose from insulating varnish. No. 6—coil puller for sliding top sides of coils into slots. No. 7—fibre slot drift for driving coils into slots. (4 thicknesses needed: 3/16", 5/16", 7/16", 9/16") No. 8—fibre coil shaper for shaping coil ends after coils are in slots. No. 9—steel slot drift for driving coils to the bottom of partly closed slots. No. 10—push cutter for trimming edges of slot insulation. No. 11—wedge driver for driving wedges into partly closed slots. No. 12—wire scraper for removing insulation from ends of coil leads. No. 13—lead drift for driving coil leads into commutator risers. No. 14—one sided chisel to cut off leads at risers. No. 15—commutator pick for picking out short circuits between segments. No. 16—under cutting saw for under cutting commutator mica. No. 17—banding clamp for placing tension on banding wires while winding them.

slot under it, and every few inches apart around the core. Drawing the first turn tight will hold these strips in place, and other turns are then wound on over them. Wire should be wound with the turns tightly together until this groove is full. Then fold up the ends of several of the tin strips to hold these wires in place, run the wire across to the next groove with a couple of gradual turns around the core, and start the next band without cutting the wire. Continue in this manner until all the bands are on. Then, before releasing the tension on the wire, run a thin layer of solder across each group of band wires in several places, to keep them from loosening when the end wires are cut.

After cutting the wires between the bands, cut these ends off to the proper length, so that they will come directly under one of the tin clamping strips. Then fold in the ends of all these strips tightly and solder them down with a thin layer of solder.

These tin strips are usually about 15 mils thick, and ¼ inch wide, and should be cut just long enough so that their ends will fold back over the bands about ¼ inch.

14. ARMATURE TESTING

We have already mentiond the importance of being able to systematically test armatures to locate faults and troubles in their windings. One of the most common devices used for this purpose is known as a **Growler,** and sometimes also called a "bug" or "mill."

A growler is constructed of laminated iron in the form of a core, around the center of which a coil of insulated wire is wound, as shown in Fig. 9. When this coil is connected to an alternating current supply it sets up a powerful alternating magnetic field at the two poles of the growler.

Growlers are made with poles shaped at an angle, as shown in the illustration at "A", so that small and medium sized armatures can be laid in these poles. Growlers are also made with poles shaped as shown in Fig. 9-B, so they can be conveniently used on the inside of large alternating current windings, as will be explained later.

The growler shown at "B" has its windings arranged in two separate coils and the leads are connected to a double-throw, double-pole switch, so that the coils can be used either in series or parallel by changing the position of the switch. This permits the growler to be used on either 110 or 220 volts, and also makes possible an adjustment of growler field strength for testing windings with different numbers of turns and high or low resistance.

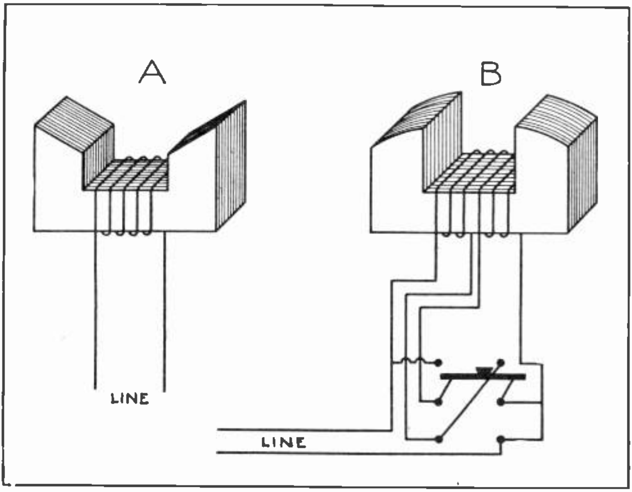


Fig. 9. Two types of "growlers". The one at "A" is for testing armatures, and the one at "B" for use inside of stator cores. Note the switch and double coil arrangement of the growler at "B", which can be used to connect the coils in series or parallel to vary the strength of the growler flux.

15. GROWLER OPERATION AND USE

When an armature is placed in a growler and the current turned on in the coil, the flux set up between the poles of the growler builds up and collapses with each alternation; thus cutting across the armature coils and inducing a voltage in them, in a manner similar to the action in a transformer. If there are no faults of any kind in the armature winding, no current will flow in the coils from the voltage induced by the growler; but, if there is a short circuit between two of the commutator segments or within the turns of a coil, an alternating current will flow in this shorted coil when it is placed at right angles to the growler flux. This secondary current, which is flowing in the armature coil will set up alternating flux around it and in the teeth or edges of its slots.

Now, if we hold over the opening of this slot a thin piece of steel, such as a hacksaw blade, the steel will vibrate rapidly. A short circuit is the only fault that will give this indication, so we see that this method is a very simple one for locating shorted armature coils.

It is best to make all tests with a growler on coils that are in the same plane of the growler flux; so, as we test from one slot to the next, the armature should be rotated, in order to make the tests on all coils in the same position. Sometimes it is difficult to rotate the armature without turning off the current from the growler coil.

A low-reading ammeter, with a scale ranging from 2½ to 10 amperes, is quite commonly used with a growler. A rheostat should be connected in series with a meter and a pair of test leads, as shown in Fig. 10. These test leads consist of two pieces of flexible wire several feet long to the ends of which are attached a pair of sharp test points or spikes. Sometimes these points are made of flat spring steel or brass and are attached to a wood or fibre handpiece in a manner that permits them to be adjusted close together or farther apart. This makes it convenient to test adjacent commutator bars or bars farther apart.

If these test leads are placed across a pair of adjacent commutator bars which connect to a coil lying in the growler flux, we will obtain a definite reading on the ammeter. If we continue around the commutator, testing pairs of adjacent bars while rotating the armature to make the test on coils which are in the same plane, each pair of bars should give the same reading. In the case of a faulty coil the reading may either increase or decrease, depending on the nature of the fault.

16. GROWLER INDICATIONS ON WAVE WINDINGS

When testing wave-wound armatures, if one coil is shorted the indication will show up at four places around the armature. Fig. 11 shows a winding for a four-pole wave armature in position for testing in a growler. The heavy lines represent two

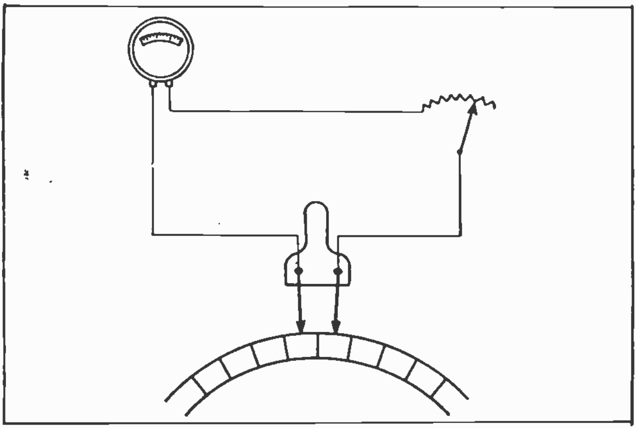


Fig. 10. This sketch shows connections of an ammeter and rheostat with test points on a "hand-piece". Meter and test leads of this sort are used for locating faults in armature windings.

coils which complete a circuit between adjacent commutators bars, 1 and 2. The top side of one of these coils and the bottom side of the other connect at bar 10. It will be seen from this diagram that a short circuit between bars 1 and 2 would cause our steel strip to vibrate over the four slots shown by the small double circles.

Practically all four-pole automotive armatures are wave-wound so it is well to remember that a short between any two of their bars will be indicated at the four places around the armature.

17. COMMON ARMATURE TROUBLES

In addition to short circuits a number of the other common troubles are as follows: **grounded coils or commutator bars, open coils, shorts between commutator bars, and reversed coil-leads.** In addition to the growler, which can be used to locate any of these faults, we can also use a galvanometer and dry cell to locate several of these troubles by testing at the commutator bars. This method will be explained a little later.

Fig. 12 is a simplified drawing of a two-pole, 24-coil, lap winding in which are shown a number of the more common faults which might occur in armature windings, as follows:

Coil 1 is short-circuited within the turns of the coil.

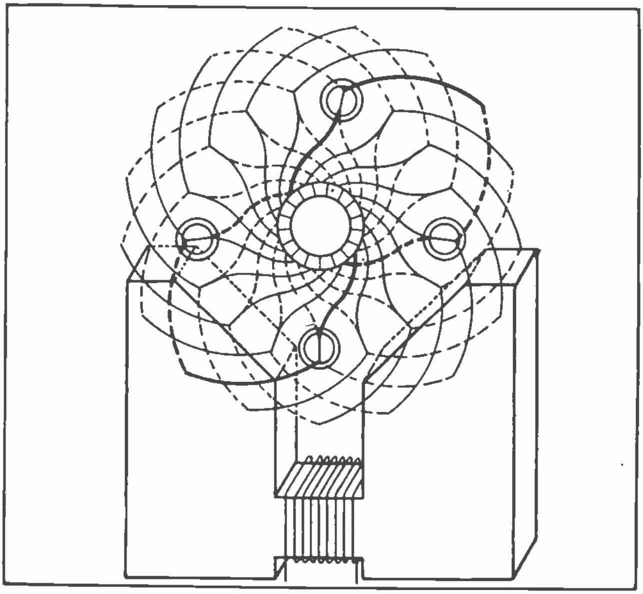


Fig. 11. The above diagram shows the coils of a four-pole wave armature which is in place in a growler for testing.

Coils 20 and 21 have their terminals loose in the commutator bars.

Coil 19 has an open circuit.

Coil 5 is connected in reverse order.

Coil 12 is grounded to the shaft or core of the armature.

Coils 6 and 9 are shorted together.

Coils 15, 16 and 17 are properly connected in in relation to each other, but have their leads transposed or connected to the wrong commutator bars.

Coil 13 has a short between its commutator bars.

The commutator bar to which coils 2 and 3 are attached is grounded to the shaft.

Now let's cover in detail each of these faults and the exact method of testing and locating them.

18. SHORT CIRCUITS

In Fig. 12 we found that coil 1 had a short circuit within the coil, which is probably the result of broken or damaged insulation on the conductors. To test for this fault, we will place the armature on the growler and close the switch to excite the growler coil. Place the steel strip over an armature slot which is at least the distance of one coil span from the center of the growler core. Now turn the armature slowly, keeping the steel parallel with and over the slots. When the slot containing coil 1 is brought under the steel, the induced current flowing in this local short circuit will set up flux between the teeth of this slot, which will attract and repel the steel strip, causing it to vibrate like a buzzer. This indicates that that coil is short circuited. Mark this slot with a piece of chalk and proceed with the test. Again rotate the armature slowly and test each slot, at all times keeping the strip over slots that are in the same position with respect to the growler. When the slot which contains the other side of the shorted coil is brought under the steel strip, it will again vibrate. Mark this slot. The two marked slots should now show the span of the exact coil which is shorted.

If we find no other slots which cause the steel to vibrate, we know there is only one short in the armature. This test will apply to armatures of any size, regardless of the number of poles in their winding, and whether they are wound lap or wave.

In order to locate on the commutator the bars to which the leads of the shorted coil are attached, adjust the test points of the hand-piece so they will span adjacent commutator bars. Place these test points on two adjacent bars, and adjust the rheostat until the meter reads about ¾ of its full scale reading. Note this reading carefully and, by rotating the armature, check the readings of all the other bars in this same position.

When the test leads are placed on the bars that connect to the shorted coil, the reading will be lower than the other readings obtained. How low will depend on how many turns of the coil are short circuited. If the short is right at the leads or commutator bars and is of very low resistance, no reading will be obtained between these bars.

19. LOOSE COIL LEADS

In testing for loose coil leads, such as shown on coils 20 and 21 in Fig. 12, the steel strip would not vibrate at any slot due to this fault; but, in testing

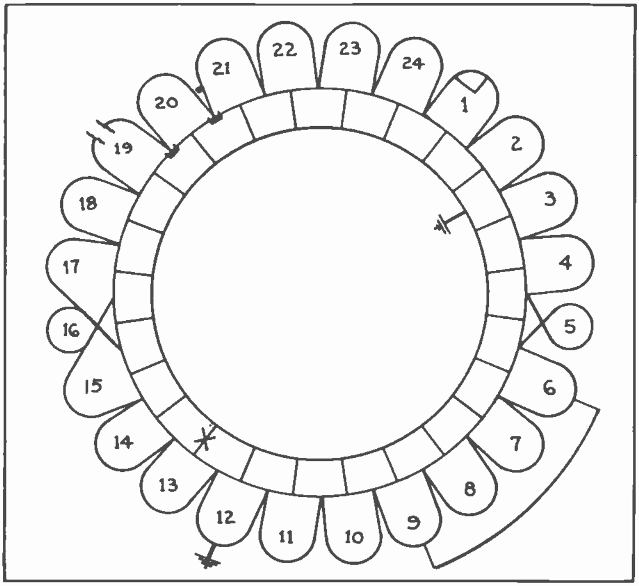


Fig. 12. This diagram of a two-pole lap winding shows a number of the more common faults which may occur in armature coils and at the commutator segments.

between commutator bars with the hand-piece, when the ammeter leads are placed on the commutator bars to which these coils are connected, the reading between them and adjacent bars would drop to zero, indicating an open circuit.

20. OPEN CIRCUIT

In testing for an open circuit, such as shown in coil 19 in Fig. 12, the steel strip would, of course, give no indication of this fault. So we must locate it by again testing around the commutator with the hand-piece. When these leads are placed across the bars to which the open coil is connected, we will get a very low reading. The reason that any reading at all is obtained is because there are always two paths for the current to travel through the winding, unless it is open at some other coil also.

With an open circuit only at coil 19, we would still have a circuit through all the other coils in series. The voltages induced in the coils which lie in the active position for the growler flux would tend to neutralize each other, but there is often a slightly unbalanced condition in the windings which would allow a little current to flow through the ammeter.

If there are three coils of the armature in the active flux of the growler and one side of coil 19 is one of these, then there will be three good coil sides working against two good coil sides with their induced voltages; and, since coil 19 is open circuited, the reading would be about ⅓ normal. The exact amount of this reading, however, will depend upon the pitch of the coils and the size of the armature. The main point to note is that one open circuit in an armature does not necessarily give a zero reading, unless the coil sides on each side of the test points are perfectly balanced electrically.

21. REVERSED COIL

In testing for a reversed coil such as No. 5 in Fig. 12, the steel strip will not vibrate at any slots, and testing from bar to bar with the ammeter leads on adjacent bars will not show up this fault either; because the induced current is alternating and the meter will not indicate the reversed polarity of the coil. So, in testing for reversed coils, we should spread the test points on the hand-piece far enough apart so they will touch bars 1 and 3. In this manner we will get a reading of two coils in series. Then, when we place the test points on bars which are connected to coils 4 and 5, or 5 and 6, two coils will be in series in each case; but, as the voltage in one will be opposite in direction to that in the other, the reading will be zero.

So, in testing for reversed coils we test two coils at a time by spreading the test leads apart to span an extra commutator segment, and the indication for the reversed coils will be a zero reading.

22. GROUNDED COILS

Coil 12 in Fig. 12 is grounded. The steel strip or vibrator will not indicate this fault, nor will the bar to bar test with the ammeter leads. To locate a ground we should place the test leads one on the commutator and one on the shaft or core of the armature. If the first test is made between the bar of coil 8 and the shaft, we would obtain a very high reading on the ammeter, because this would give the reading of the 4 coils in series between the grounded coil and this bar.

As we test bars closer to the grounded point the reading will gradually decrease, and the two bars that give the lowest reading should be the one connected to the grounded coil. The sum of the readings from these two bars to the shaft should equal the reading of a normal coil.

23. SHORTS BETWEEN COILS

In Fig. 12 coils 6 and 9 are shorted together, which places coils 6, 7, 8, and 9 in a closed circuit, through the short and the coil connections to the commutator bars. In this case the steel strip will vibrate and indicate a short circuit over each of the slots in which these coils lay. A bar to bar test with the ammeter leads would not give a definite indication, but the readings on these bars would be lower than normal.

24. REVERSED LOOPS

In the case of coils 15, 16, and 17 in Fig. 12, which are properly connected to each other but have their leads transposed or placed on the wrong commutator bars, the steel strip will not vibrate or give any indication. The bar to bar test with the ammeter leads would, however, show double readings between bars 1 and 2, normal readings on bars 2 and 3, and double reading again on bars 3 and 4. This indicates that the coils are connected in the proper relation to each other, but that their leads are crossed at the commutator bars.

25. SHORTED COMMUTATOR SEGMENTS

In the case of coil 13 in Fig. 12, which is short circuited by a short between its commutator bars, the steel strip would vibrate and indicate a short circuit over both slots in which this coil lies. The bar to bar test of the ammeter will give a zero or very low reading across these two bars, depending upon the resistance of the short circuit between them.

If the winding is connected lap, the short would be indicated in two places on the core; and if it is connected wave for four poles, it would be indicated in four places on the core.

26. GROUNDED COMMUTATOR SEGMENTS

The commutator bar to which coils 2 and 3 are connectd in Fig. 12, is grounded to the shaft. The steel strip will not indicate this fault. Testing with the ammeter leads between other commutator bars and the shaft would show high readings on the meter; but, as we test bars that are closer to the grounded one, the reading falls lower and lower, and will be zero when one test lead is on the grounded bar, and the other on the shaft.

If an absolute zero reading is obtained it indicates the ground is at the commutator bar.

27. GALVANOMETER TESTS ON ARMATURES

We have mentioned that a galvanometer and dry cell can be used to test armature windings for open circuits and short circuits in coils. You will recall, from the description of a galvanometer in an earlier lesson, that this instrument is simply a very sensitive voltmeter which will read a fraction of one volt. Fig. 13 shows a method of making galvanometer tests on armatures. Two leads from a dry cell should be held against bars on opposite sides of the commutator and kept in this position as the armature is rotated. This will send a small amount of direct current through the coils of the winding in two paths in parallel.

If the positive lead in Fig. 13 is on the right, a current will flow from this lead through the commutator bar to the right side of the winding. If all coils of the winding were closed and in good condition, the current would divide equally, part flowing through the top section of the winding to bar 3 and the negative lead, and the other part flowing through the lower section of the winding to the same bar and lead. When this current is flowing through the armature and we test between adjacent bars with the galvanometer, the instrument reads the voltage drop due to the current flowing through the resistance of each coil. So the galvanometer test is quite similar to that with the ammeter leads and growler.

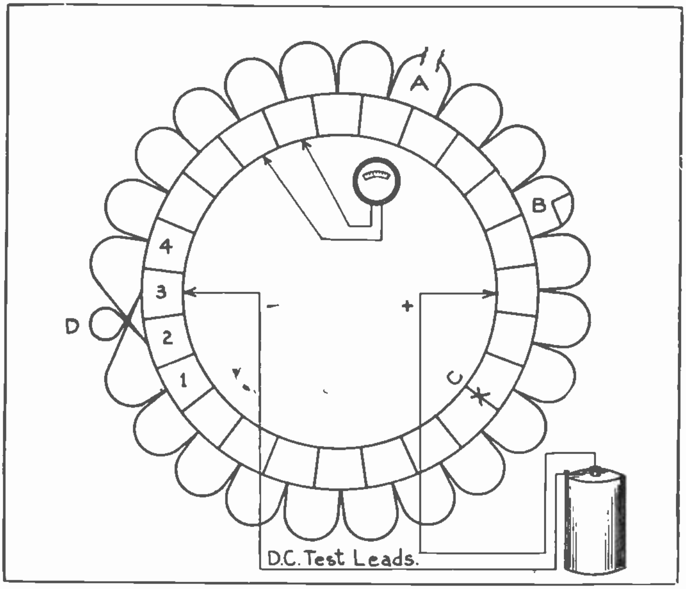


Fig. 13. This diagram shows the method of testing with a galvanometer and dry cell to locate various faults in an armature.

In testing for an open circuit with the galvanometer leads placed on adjacent bars connected to good coils, there will be no reading in the section of the winding in which the open coil is located; but when these leads are placed across the bars connected to the open coil, the needle will probably jump clear across the scale, because at this point it tends to read practically the full battery voltage. Of course, if there are two open circuits in this half of the armature, no reading will be obtained at any pair of bars. This is a good indication that there is more than one open. If a test is made all the way around the commutator and no open circuits are present, the galvanometer should read the same across any pair of bars. You should be careful, however, to secure at all times a good contact between these test leads and the bars, and also be sure that the battery leads make good connection to the commutator as the armature is rotated. Otherwise variations in the readings will be obtained.

A lower reading than normal between any two bars will indicate a shorted coil, and a zero reading indicates a short between two commutator bars. When galvanometer leads are placed on bars 2 and 3, which are connected to coils with their leads transposed, the reading will be normal; but in testing between bars 1 and 2, or 3 and 4, the reading will be double. This indicates that the leads at bars 2 and 3 are the ones reversed.

The methods and indications described for each of the foregoing tests should be carefully studied until you are quite sure you understand the principles in each case. It is not expected that you will be able to remember each of these tests until you have actually tried them a number of times. However, with the instructions given in the foregoing paragraphs, you need not hesitate to undertake any of these tests, if you have this material on hand to refer to during the first few times you make them.

28. CUTTING OUT FAULTY COILS

In many cases when a machine develops some fault in the coils of its armature, it is inconvenient to take it out of service for complete rewinding or for the amount of time required to replace the defective coils with new ones. At times like this, when it is extremely important that a machine be kept in service in order not to stop or delay production on the equipment it operates, **a quick temporary repair can be made by cutting the faulty coils out of the armature circuit.** This is done **by using a jumper wire of the same size as the conductors in the coils,** and which should be soldered to the same two bars to which the defective coil was connected. This jumper will then complete the circuit through this section of the armature, and will carry the current that would normally have been carried by the defective coil.

Fig. 14 shows the manner in which an open circuit coil can be cut out with such a jumper. For each coil that is cut out of a winding a slightly higher current will flow through the other coils of that circuit. The number of coils that can safely be cut out will depend on the position in which they occur in the armature.

In some cases several coils may be cut out, if they are equally distributed around the winding; but if several successive coils became defective and were all cut out with a jumper, it might cause the rest of the coils in that circuit to burn out.

Other factors that determine the number of coils which can be cut out in this manner are: the number of coils per circuit, the amount of load on the motor or generator, and the size of the machine. If the defective coil is grounded, its two ends should be disconnected from the commutator bars before the jumper is soldered in place. Shorted coils should be cut at the back end of the armature and these

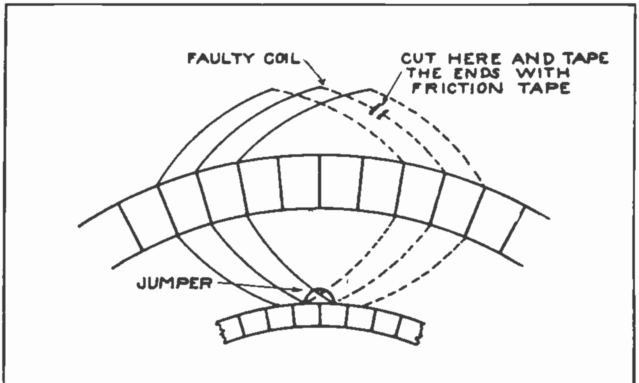


Fig. 14. The above diagram shows the method of cutting out a defective coil, and completing the circuit through the winding with a jumper at the commutator bars to which this connects.

cut ends well taped. The jumper wire should be well insulated from the leads of other coils.

Repairs of this type should be considered as only temporary and, as soon as the machine can be conveniently taken out of operation, the defective coils should be replaced with new ones; or the armature rewound, if necessary.

Keep well in mind this method of making temporary repairs, as there are frequent cases on the job when the man who knows how to keep the machinery running through important periods of production or operation can make a very favorable impression on his employer by demonstration of this ability.

If you have carefully studied the material in this lesson, the knowledge you have obtained of the principles of D. C. machines and their windings will be of great value to you.

You should wind armatures at every opportunity, until you are able to confidently put into practice the important knowledge gained from this lesson. By carefully following the instruction in this lesson, you should be able to quite easily locate trouble and repair or rewind armatures of all kinds.

Important things to remember are to use the proper number of turns of correct sized wire per coil, proper coil and slot insulation, and correct connections to the commutator. Also remember the importance of doing thorough, neat, and careful work. Your next lessons will take you into the field of A. C. winding.

EXPERIMENTS

As explained in article 27, it is possible to make several armature trouble tests by the use of a dry cell and a meter. The best type of a meter for this purpose is a sensitive galvanometer, but quite satisfactory tests may be made by using a 0 to 10 D. C. Voltmeter, or any other good low reading volt meter.

If your volt meter does not give sufficient readings to make good comparisons on the tests when using one dry cell, you can try 2 or 3 dry cells in series to increase the readings.

We suggest that several tests be made using this method: Various troubles such as shown by the diagram in Fig. 13 may be placed in the armature and tests made so that the results are fully understood and well fixed in mind.

Suggestions for constructing a growler will be included in one of the following lessons on A. C. Armature Winding.

EXAMINATION QUESTIONS

1. Assuming that on a certain motor designed for operation on 220 volts we find the armature coils wound with 30 turns of wire with an area of 1288 C. M. (No.19). What size wire and how many turns would you use in rewinding the coils for operation on 110 volts?

2. What advantage is there in using multiplex windings?

3. In what position with relation to the field poles must the armature coils be at the time they are short circuited by the brushes?

4. What is the difference between a symmetrical and a non-symmetrical connection to the commutator?

5. What kind of current must be used in operating a growler?

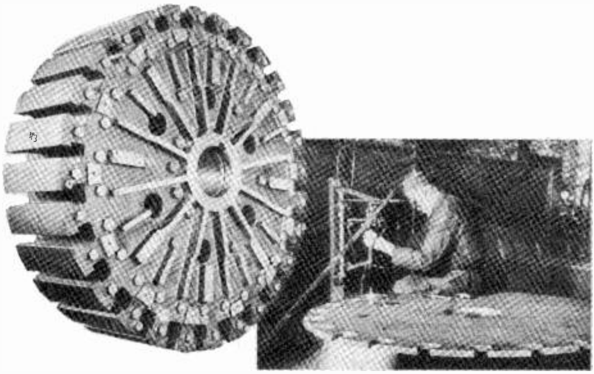
6. Name four common troubles which may develop in an armature?

7. What quick temporary repair can be made when faulty coils develop in an armature?

8. Describe the method of testing for a reversed coil?

9. When making a growler and meter test, why do we obtain a low meter reading when testing across commutator bars connected to an open coil?

10. Name five very important items to check when collecting data from an old armature for rewinding.



• 23,600 FEET PER MINUTE . . .

The 38-ton rotor spider shown to the left is for one of the highest peripheral speed salient-pole rotors ever built. Ten feet in diameter from póle tip to pole tip, this 28-pole rotor was built to withstand an overspeed of 750 rpm . . . equal to a peripheral velocity of 23,600 feet per minute (268 miles per hour). Centrifugal force on each pole at 750 rpm is 660,000 lbs.

To insure no stresses exceeding ⅔ the elastic limit of the material used, thorough stress analysis both analytically and by photo-elastic methods was required. The spider lamination plates are special high tensile strength chrome steel.

The rotor spider is for a 5,000 kva, 257 rpm water wheel driven synchronous generator at Bonneville Dam, Bonneville, Ore. The oxy-acetylene torch was used to cut the T-tail pole-fastening slots in the spider end-plates.

ARMATURE WINDING

Alternating current is very extensively used for light and power purposes, and most of the large power plants generate alternating current because it is so much more economical than D. C. to transmit over long lines. The reason for this will be explained in later lessons on alternating current.

The general use of A. C. in industrial plants and power plants makes it very important for one to know these principles of A. C. machines and the methods of winding, connecting, and testing them.

1. PRINCIPLES OF A. C. GENERATORS

We have learned that voltage can be generated in a conductor by moving it through a magnetic field, and that alternating current will always be generated in the windings of a D. C. generator, because during rotation the conductors are continuously passing alternate N. and S. poles.

Let us review this principle briefly, to be sure we have it well in mind as we start the study of A. C. machines.

In Fig. 1-A and B we have another illustration of this principle. At "A" the lines of force from the field poles are passing downward and the conductor is being moved to the right. This will induce in the wire a voltage that will tend to cause current to flow in at the end we are facing, or away from us, if this conductor is part of a closed circuit. Check this with the right-hand rule for induced E. M. F. in generators.

This rule is here repeated for your convenience. **Hold the thumb, forefinger, and remaining fingers of your right hand, all at right angles to each other. Then, with your fore-finger pointing in the direction of the flux, and your thumb in the direction of the conductor movement—the remaining fingers will point in the direction of the induced E. M. F.**

Try this rule also with Fig. 1-B, where the conductor is moving in the opposite direction, through the same magnetic field; and you will find the induced voltage has reversed with the direction of the conductor movement.

The circular arrows around the conductors indicate the direction of the lines of force which will be set up around them by their induced currents. Check this also by the method mentioned in an earlier section, of considering the field lines as moving rubber bands rubbing the conductors, and setting up the new or induced lines in the direction the bands would revolve a pulley, etc. Also note the symbols used to indicate the direction of induced E. M. F. in the conductors: + for voltage in, and the dot for voltage out.

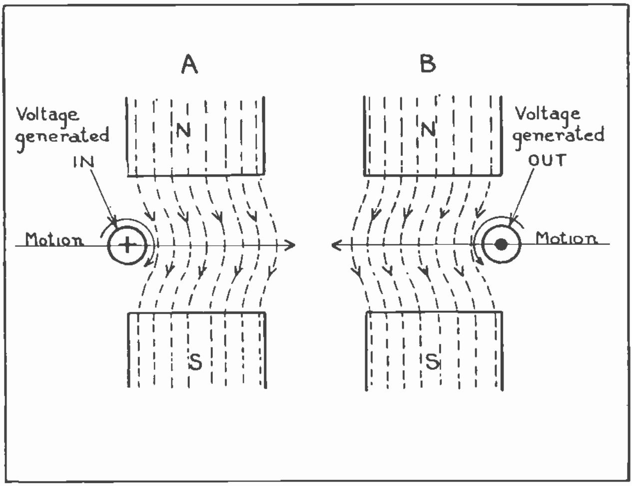


Fig. 1. This diagram illustrates the method of producing E.M.F. in conductors by cutting them through magnetic lines of force. Note carefully the direction of the induced voltage at both "A" and "B".

In Fig. 2-A we have two conductors of a coil, mounted in slots of an armature and revolving clockwise. In their position at "A" the conductors are not generating any voltage, as they are in the neutral plane and are not cutting across the lines of force. At "B" the direction of induced voltage will be "in" at conductor "F" and "out" at "G"; so if the conductors are connected together at the back of the armature their voltages will add together.

In Fig. 2-C the conductors are both in the neutral plane again, so their induced voltage once more falls to zero.

At "D" conductor "G" is passing the north pole and conductor "F" is passing the south pole, so they are both moving through the field flux in opposite directions to what they were at "B" and their induced voltage will be reversed. At "E" both conductors are again back in the neutral plane, or at the point they started from.

A curve indicating the voltage generated is shown under these various steps of generation in Fig. 2. At "A" the voltage curve is starting at the zero line, as the conductors start to enter the field flux. At "B," where the conductors are cutting through the dense field directly under the poles, the curve shows maximum positive voltage. From this point it falls off gradually as the conductors pass out of the flux at the poles, until it again reaches zero at "C." Then, as the conductors each start to cut flux in the opposite direction, the curve shows negative voltage in the opposite direction or below the line, reaching maximum value at "D." At "E" the negative voltage has again fallen to zero.

2. CYCLES AND ALTERNATIONS

Upon completion of one revolution with the simple two-pole generator we also complete what we term one **Cycle** of generated voltage. The single positive impulse produced by the conductor passing one complete pole, and shown by the curve from "A" to "C," is called one **Alternation.** It takes two alternations to make one cycle. Therefore, each time a conductor passes one north and one south pole it produces one cycle.

There are 360 **Mechanical Degrees** in a circle, or in one revolution of a conductor on an armature; and in generators we say that a conductor travels **360 Electrical Degrees** each time it passes two alternate field poles and completes one cycle. So **One Cycle consists of 360 Electrical Degrees,** and **One Alternation consists of 180 Electrical Degrees.**

In a machine having more than two poles, it is not necessary for a conductor to make a complete revolution to complete a cycle, as **One Cycle is produced for each pair of poles passed.** So a four-pole generator would produce two cycles per revolution; a 12-pole generator, 6 cycles per revolution; etc..

3. FREQUENCY OF A. C. CIRCUITS

Alternating current circuits have their **frequency** expressed in cycles per second, the most common frequencies being 25 and 60 cycles per second.

If frequency is expressed in cycles per second and if a conductor must pass one pair of poles to produce a cycle, then the frequency of an A. C. generator depends on the number of its poles and the speed of rotation.

For example, if a four-pole machine is rotated at 1800 R. P. M. (Revolutions Per Minute), the frequency of the current it produces will be 60 cycles per second. Its conductors will pass two pairs of poles per revolution, or $1800 \times 2 = 3600$ pairs of

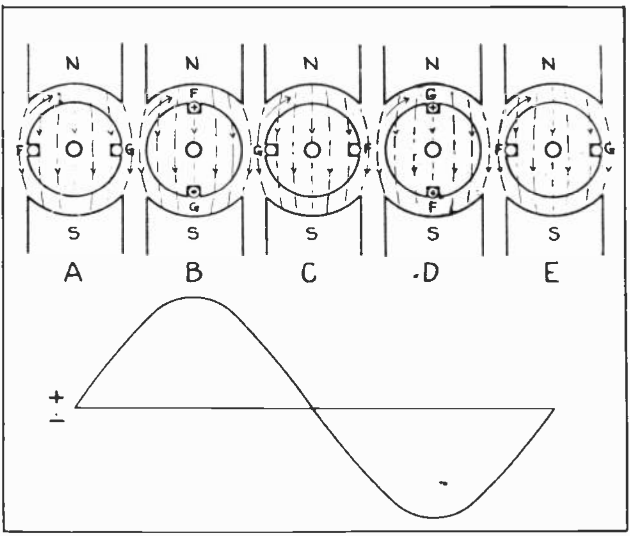


Fig. 2. The above diagram shows step by step the development of a complete cycle of alternating current voltage. Compare each of the generator sketches with the voltage of the curve directly beneath it.

poles per minute. Then, as there are 60 seconds in a minute, $3600 \div 60 = 60$ cycles per second.

A generator with 12 poles would only need to rotate at 600 R. P. M. to produce 60 cycles per second. The conductors in such a machine would pass six pairs of poles per revolution; or at 600 R. P. M. they would pass 6 × 600 or 3600 pairs of poles per minute. And again, 3600 ÷ 60 = 60 cycles per second.

The symbol for frequency is a small double curve like a sine wave, or ∼. Thus 60 ∼ means 60 cycles per second.

The **speed at which A. C. motors will operate depends on the frequency of the circuit they are connected to and the number of their poles.** This will be more fully discussed later.

4. REVOLVING FIELD ALTERNATORS

Alternating current generators are commonly called **Alternators**. So far we have discussed generators with their conductors revolving on an armature through stationary field flux. Now, why wouldn't it work equally well to have the armature conductors stationary and revolve the field, causing the lines of force of the moving field poles to cut across the conductors?

This is exactly what is done with a great number of A. C. generators or alternators; and, while some of the smaller ones are made with revolving armatures, most of the larger ones are of the **revolving field** type.

This type of construction has two very important advantages for large power plant alternators. The first of these advantages is that if the armature conductors are stationary **the line wires can be permanently connected to them and it is not necessary to take the generated current out through brushes or sliding contacts.** This is quite an advantage with the heavy currents and high voltages produced by modern alternators, many of which are designed to supply from several hundred to several thousand amperes, at voltages from 2300 to 13,200 and higher.

Of course, it is necessary to supply the current to the revolving field with slip rings and brushes, but this field energy is many times smaller in amperes and lower in volts than the main armature current.

The other big advantage is that the armature conductors are much larger and heavier than those of the field coils, and much more difficult to insulate because of their very high voltage. It is, therefore, much easier to build the armature conductors into a stationary element than it is in a rotating one.

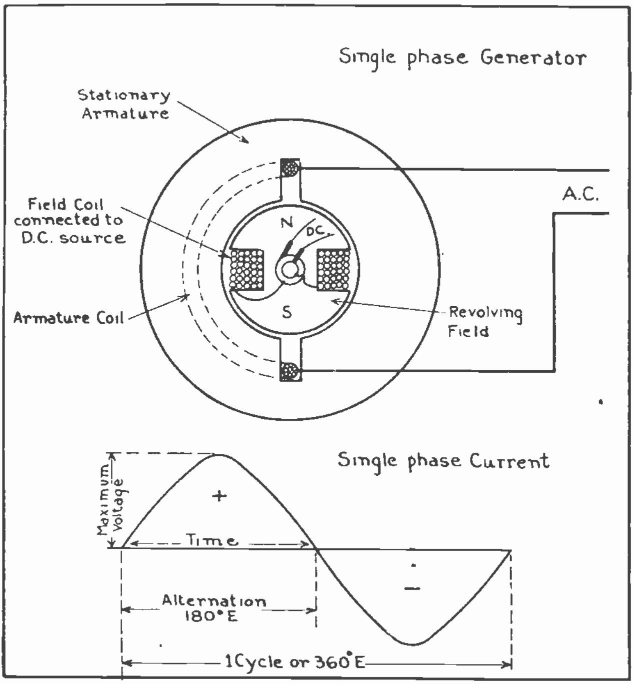


Fig. 3. Sketch of a simple single-phase alternator of the revolving field type, showing a single coil in the stator slots. The curve at the bottom of the sketch shows the single-phase alternating current which will be produced when the field revolves past the stator coil.

The field, being the lighter and smaller element, is also easier to rotate and reduces bearing friction and troubles, as well as air friction at high speeds.

With large revolving field alternators, the stationary armature is commonly called the **Stator**, and the rotating field is called the **Rotor.**

5. SINGLE PHASE CURRENTS

Fig. 3 shows a sketch of a simple revolving field alternator, with one coil in the slot of the stator or stationary armature. The circles in the slots show the ends of the coil sides, and the dotted portion is

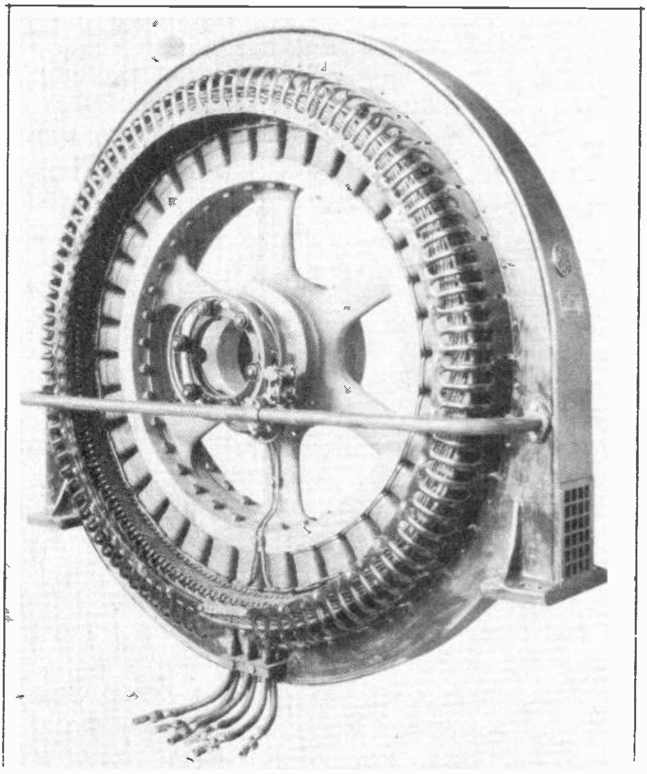


Fig. 4. This photo shows a large 36-pole alternator of the revolving field type. Examine its construction carefully as you study the explanation given on this page.

the connection between them at the back end of the stator. Inside the stator core is a two-pole field core with its coil, mounted on a shaft so it can be revolved.

When direct current is supplied to the field core through the slip rings and brushes shown, the core becomes a powerful electro-magnet with flux extending, from its poles into the stator core. Then, as the field is revolved the lines of force from its poles revolve with them and cut across the conductors in the stator slots.

As each coil side is passed first by the flux of a north pole and then a south, the induced E. M. F. and current will be alternating, as it was with the revolving armature type previously shown. The curve underneath the generator shows the complete cycle which will be produced by one revolution of the two pole field; so this machine would have to revolve at 3600 R. P. M. to produce 60-cycle energy.

Revolving fields are made with four or more poles. to produce 60-cycle energy at lower speeds.

Fig. 4 shows a large alternator of the revolving field type, with 36 poles. Each revolution of this field will bring 18 pairs of poles past any given coil, and so produce 18 cycles per revolution. Then, if its speed is 200 R. P. M., $200 \times 18 = 3600$ cycles per minute, or 60 cycles per second.

Note carefully in this figure the slip rings, brushes, and wires which carry the D. C. from the rings to the field coils. Also note the armature coils arranged in the slots of the stator, and at the bottom the cables by means of which the line leads are attached to these coils.

The generator shown in Fig. 3 will produce what is known as **Single Phase** alternating current, as shown by the curve in this same figure.

Single-phase A. C. flows in a simple two-wire circuit, and consists of alternations 180 degrees apart, or current that continuously reverses in direction and varies in amount.

This current first flows out in the top wire of the line and back in the lower one; then dies down, reverses, and flows out in the bottom wire and back in the top one. Or, we might say, it consists of continuously recurring alternations.

Even if the generator in Fig. 3 had a number of stator coils connected in series and just two leads connected to the group, it would still deliver single-phase current.

6. TWO PHASE CURRENTS

Generators are also made to produce **2-phase** and **3-phase** currents. Circuits supplied by 2 and 3-phase energy are often called **polyphase** circuits, meaning that their currents are divided into more than one part.

Fig. 5 shows a sketch of a simple 2-phase alternator, which has two separate coils placed in its stator at right angles to each other; or displaced 90 degrees from each other.

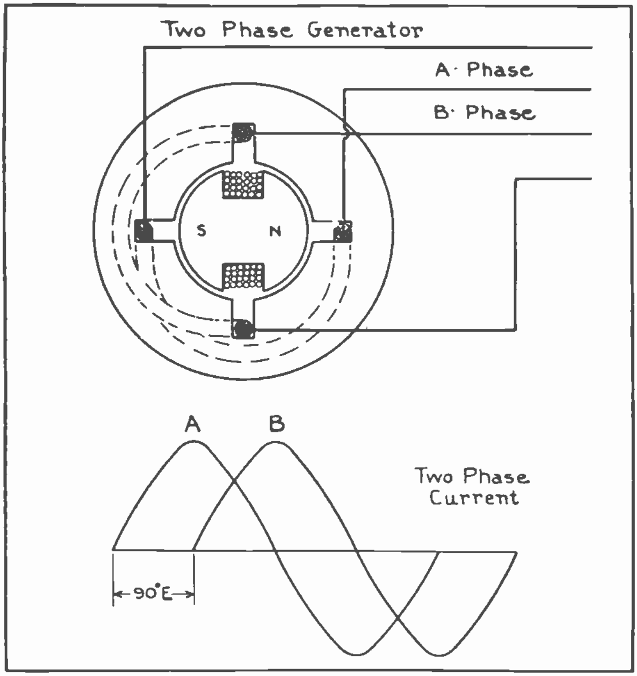


Fig. 5. Sketch of a simple two-phase A.C. generator or alternator. The curve at the bottom of the sketch shows the two-phase current that will be produced when the field revolves past the two coils in the stator.

As the field of this generator revolves it will induce voltage impulses in each of these coils, but these impulses will not come at the same time, because of the position of the coils.

Instead, the voltages will come 90 electrical degrees apart, as shown in the curves in Fig. 5. The curve "A" shows the voltage generated in coil "A" as the poles pass its sides. As these poles rotate 90° farther their flux cuts across coil "B" and produces the voltage impulses shown by curve "B," which are all 90° later than those in curve "A."

These two separate sets of impulses are each carried by their own two-wire line circuits as shown in the diagram.

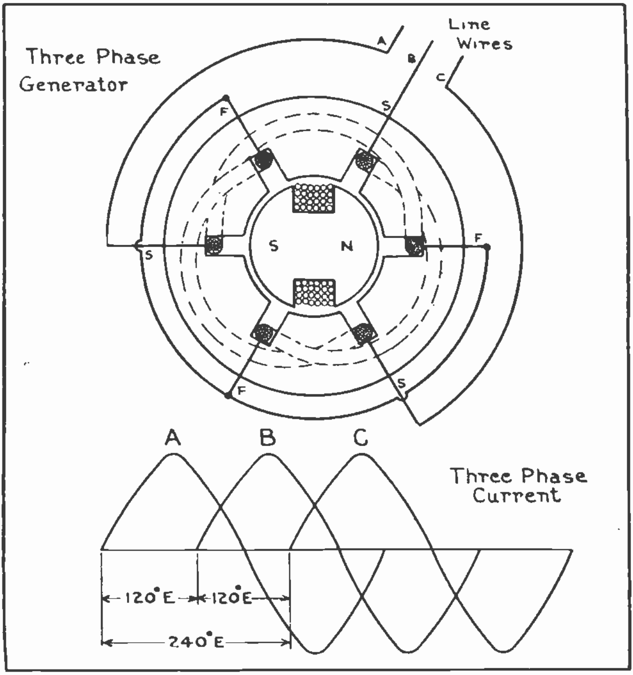


Fig. 6. This sketch shows the arrangement of the stator coils in a simple three-phase alternator and beneath it the curves for three-phase energy.

So we see that a two-phase circuit is simply a circuit of two parts, or having two sets of alternations occurring 90 degrees apart. In the curve you will note that these alternations or impulses overlap each other, and that while one is at zero value the other is at maximum value. So with a circuit of this type there is always current flowing in one phase or the other as long as the circuit is alive.

120 electrical degres apart.

As the field poles revolve past coils "A," "B," and "C" in succession, they induce voltage impulses which are also 120 degrees apart, as shown in the curves in the figure.

The line leads are taken from the coils at points 120 degrees apart and the other ends of the coils are connected together at "F." This type of connection is known as **a Star** connection of the coils to the line. Another common connection for three-phase widings is known as the **Delta** connection. Both of these will be explained later.

This feature is quite an advantage where the energy is used for power purposes, as these overlapping impulses produce a stronger and steadier torque than single-phase impulses do.

For this same reason **three-phase** energy is still more desirable for motor operation and power transmission, and is much more generally used than two-phase.

7. THREE-PHASE CURRENTS

Fig. 6 shows a sketch of a simple three-phase alternator, with three coils in its stator, and spaced

The principal points to note are that a three-phase circuit is one with three parts, or three separate sets of alternations occurring 120° apart and overlapping each other. These impulses are carried on three line wires, and the current flows first, out on wire "A" and in on wires "B" and "C"; then out on wire "B" and in on wires "A" and "C"; then, out on wire "C" and in on wires "A" and "B"; etc.

Additional features of single-phase and polyphase circuits and machines will be covered later. But now that you know the difference betwen these forms of alternating current, you will be able to understand the various A. C. windings much easier.

8. CONSTRUCTION OF A. C. MOTORS

The most common type of A. C. motor is known as an **Induction Motor.** This name comes from the

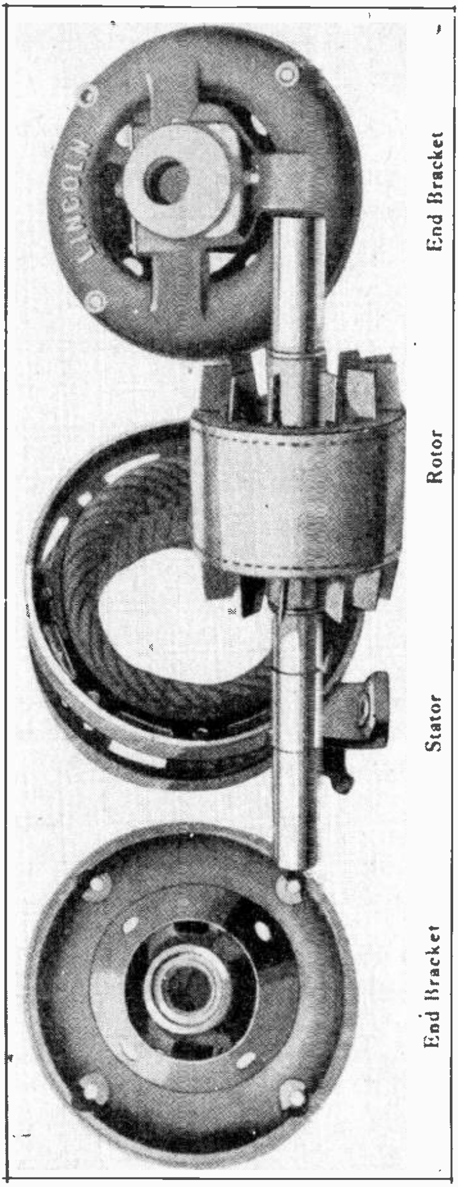


Fig. 7. Above are shown the more essential parts of an A.C. induction motor. Note carefully the construction of each part and the names by which they are called.

fact that the currents in the rotor are induced in it by the flux of the stator coils.

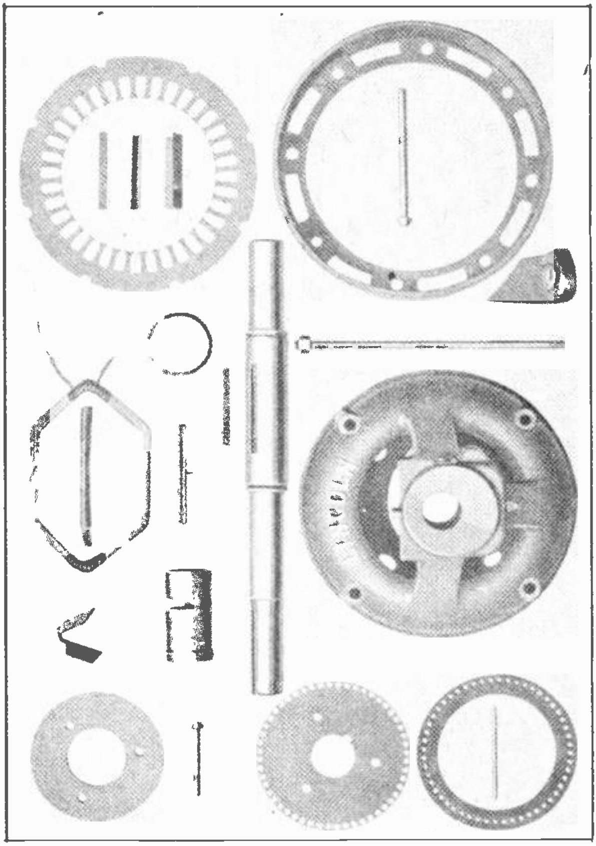


Fig. 8. Here are shown a number of the smaller parts used in the construction of A. C. motors of the induction type. Note the shape of the laminations for both the rotor and stator cores, and compare each of these parts with their explanations given on these pages.

Fig. 7 shows the more important parts of an A. C. induction motor, with the names of each. Note that the stator coils are placed in the slots around the inside of the stator core very much as the coils of a D. C. armature are placed in slots around the outside of the armature.

9. ROTORS

A. C. induction motors have two common types of rotors, known as **Squirrel-Cage** rotors and **Phase-wound** rotors.

The rotor shown in Fig. 7 is of the squirrel-cage type; and, instead of having wire windings, it has heavy copper bars buried in closed slots around its surface and all connected together by rings at each end.

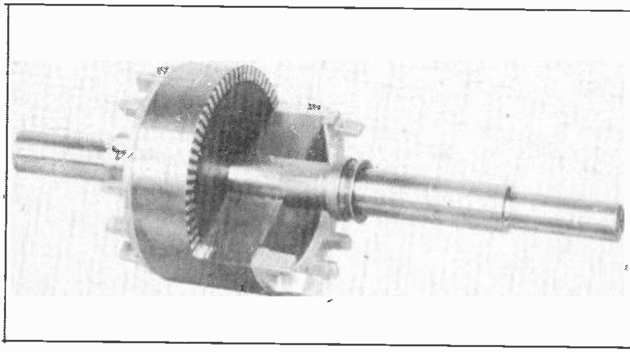


Fig. 9. This view shows a sectional view of a squirrel-cage rotor for an A.C. induction motor. Note the manner in which the copper bars are imbedded in the surface of the core.

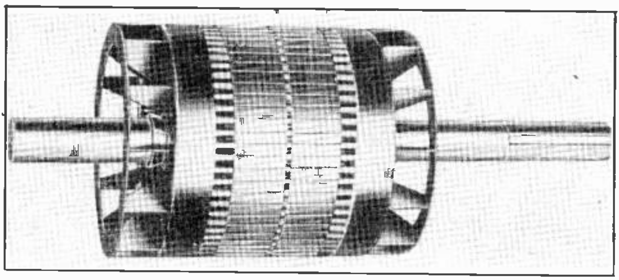


Fig. 10. Another style of squirrel-cage rotor showing the bars of the winding and also the ventilating fans.

Fig. 9 is a cut view of such a rotor, showing how the bars are imbedded in the core iron. The end rings are made of copper or brass; or, in some cases, of aluminum. The short blades on the end rings act as fans and set up an air draft to cool the rotor and machine windings while the motor is in operation.

Fig. 10 shows a slightly different type of squirrel-cage rotor, in which the ends of the bars can be seen projecting from the core ends. This rotor is also equipped with fan blades for ventilating the machine, and you can note the air space left between the laminations of the core. These spaces are also for cooling purposes.

The purpose of the end brackets shown in Fig. 7 is to support the bearings in which the rotor shaft turns. These bearings must always be in such condition, and the brackets so lined up, that they will support the rotor so that it does not rub or touch the stator core.

Fig. 8 shows in greater detail some of the smaller parts used in the construction of A. C. motors. In the center is shown the shaft to which the rotor core is keyed; and above this are a bearing sleeve, shaft key, oil ring, and stator coil. At the left end of the shaft is shown a rotor lamination, and beneath it an end ring and rotor bar. In the upper right-hand corner is a stator lamination, showing the shape of the slots and teeth; and below this is one of the frame rings used for clamping together and supporting the stator core lamiations.

Phase-wound rotors for A. C. induction motors have windings placed in the slots of their cores, similarly to D. C. armatures. Their windings are generally connected wave.

10. STATORS

Stators for A. C. motors are constructed of laminations which are stamped from soft iron. One of these was shown in Fig. 8. The slots are cut on the inside of the stator cores, instead of on the outside as with D. C. armatures.

Two types of these slots are shown in Fig. 11. This view also shows the slot insulation and method of protecting the coils and wedging them into the slots.

In large stators, the groups of laminations are spaced apart to leave an air duct every few inches for cooling the windings and core.

The partly closed slots shown at "A" in Fig. 11 are used on small stators where the wires are fed into the slots a few at a time. The open-type slots as shown at "B" are used on large stators which have their coils wound and insulated before they are placed in the slots.

11. TYPES OF A. C. WINDINGS

Three of the commonly used types of windings for A. C. stators are the **Spiral Type, Lap,** and **Wave** windings.

The spiral-type winding is used very extensively on small single-phase motors.

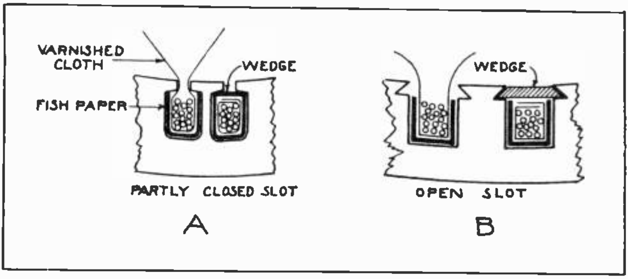


Fig. 11. The above diagram shows two common types of stator slots with the slot and coil insulation in place around the coils. Also note the wedge used for holding the finished coils in place.

The poles are wound in a spiral form, as shown in Fig. 12. The wire is started in the two slots to be used as the center of a pole, and after winding the desired number of turns in this coil we continue right on in the same direction in the next pair of slots, with the same wire. In this manner we build up the coils for one pole, working from the center to the outside. Sometimes more than one slot is left empty in the center as the first winding is placed in.

12. SKEIN WINDINGS

Another method, which uses what is known as the **Skein Coil** for making spiral windings, is illustrated in Fig. 13.

In this method the long skein coil is first made up of the right number of turns and the proper length to form the several coils. The end of this skein is then laid in the center slots as shown at "A" in Fig. 13, and the long end given one-half twist near the ends of the slots, as shown at "B." The remaining end is then laid back through the next two slots—at "C"—and again twisted one-half turn so its sides cross near the first coil end.

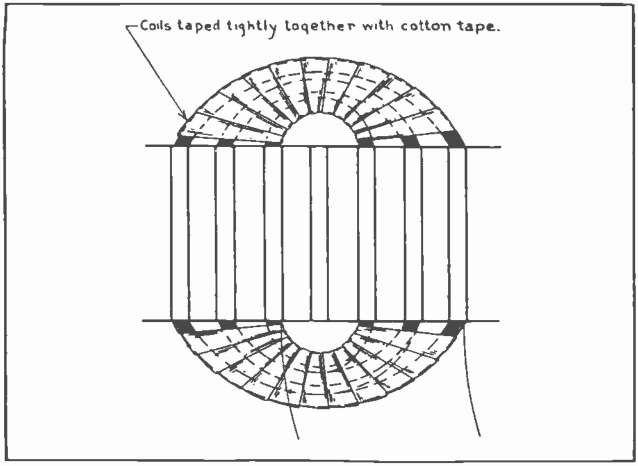


Fig. 12. This diagram illustrates the method of winding the coils for a spiral-type stator winding. Note how the wire continues from one coil to the other, as shown by the dotted lines under the tape at the lower end.

Then the last loop is laid back through the outer two slots to complete the coils for this pole.

Trace the circuit through this finished coil, starting at the left lead, going through each coil, and coming out at the right-hand lead.

This skein method of winding is quite a timesaver where a number of stators of the same size and type are to be wound. After carefully measuring to get the first skein coil the right length, the balance of the coils can be made on the same form, and the stator poles wound very rapidly.

If there are only two or three small stators to be wound, the first method described is generally best.

13. RUNNING AND STARTING WINDINGS FOR SINGLE-PHASE MOTORS

Single-phase A. C. Motors of these small induction types generally have two windings called the

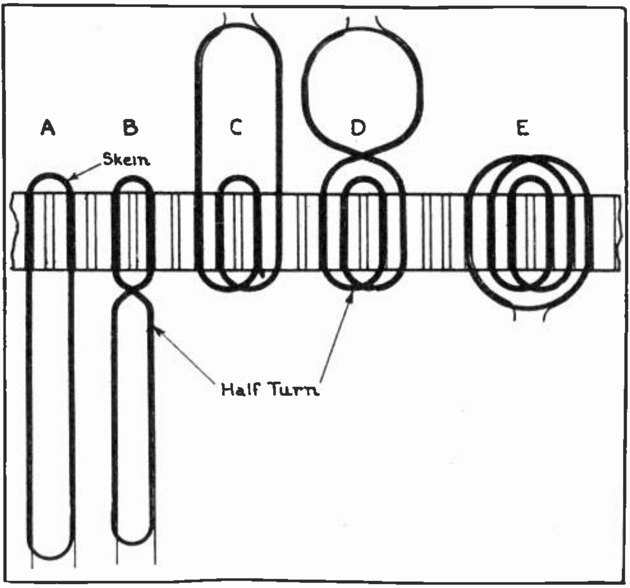


Fig. 13. Skein type windings as shown above are often used to save considerable time when winding a number of stators which are all alike. Note carefully the various steps of twisting the coil and laying it in place in the slots.

Running Winding and Starting Winding. The first winding placed in the slots as we have just described is the running winding. The starting winding is always placed in the slots over the running winding coils after they are all in the slots. This starting winding is usually wound with wire about one-third as large as that used for the running winding, and with about half as many turns. The starting winding coils are displaced 90°, or exactly one-half the width of one pole, from the coils of the running winding.

In starting to wind these coils, their centers are located where the edges of the running coils meet. This brings the edges of the starting coils together

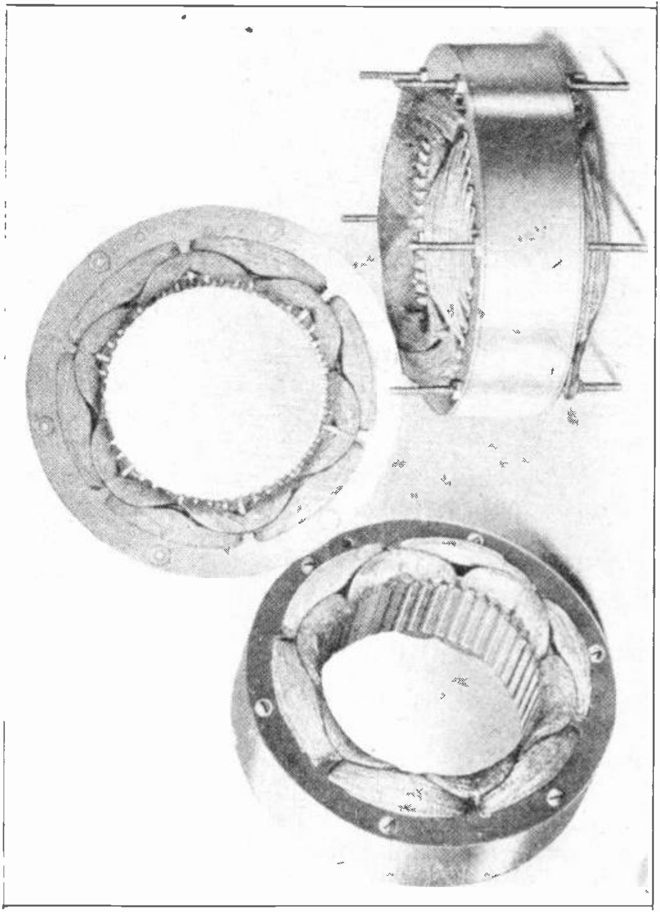


Fig. 14. On the right are shown several views of small single-phase stators for A.C. induction motors. Both the starting and running windings can be clearly seen in each of these views. Note how the starting winding overlaps the coils of the running winding about one-half their width or 90 degrees. This type of winding is known as a single-phase split-phase.

at the center of the running coils, and very often in the slots which were left empty when the running coils were wound. Windings of this type are known as single-phase, split-phase windings. The term "split phase" is used because the different numbers of turns in the starting and running windings cause them to be of different inductance, which makes the alternating current impulses in one winding lag slightly behind those in the other winding. This produces around the stator a sort of shifting or rotating magnetic field, which in turn cuts across the bars of the rotor, inducing current in these bars.

The reaction between the flux of the stator currents and rotor currents is what produces the torque or turning effect of this type motor.

The principles of inductance and split-phase operation will be more fully covered in a later section.

Fig. 14 shows several small stators and the positions of their starting and running windings.

14. CONNECTIONS OF STARTING WINDING

The starting and running windings are connected in parallel to the single-phase line, but a centrifugal switch is connected in series with the starting winding as shown in Fig. 15. This switch is arranged so that when the motor is idle it is held closed by springs.

When current is applied to the windings, both the starting winding and running winding are in use while the motor is starting and getting up to speed; but as soon as it reaches full speed, the switch, mounted to revolve on the shaft of the motor, is thrown open by centrifugal force, thereby opening the circuit of the starting winding. The motor then runs on the running winding only.

The starting winding must never be left in the circuit longer than just the few seconds required to start the motor. If it is left connected longer than this it will overheat and probably burn out.

Fig. 16 shows a simple sketch illustrating the method of connection of the starting and running windings to the line, and also the connection of the

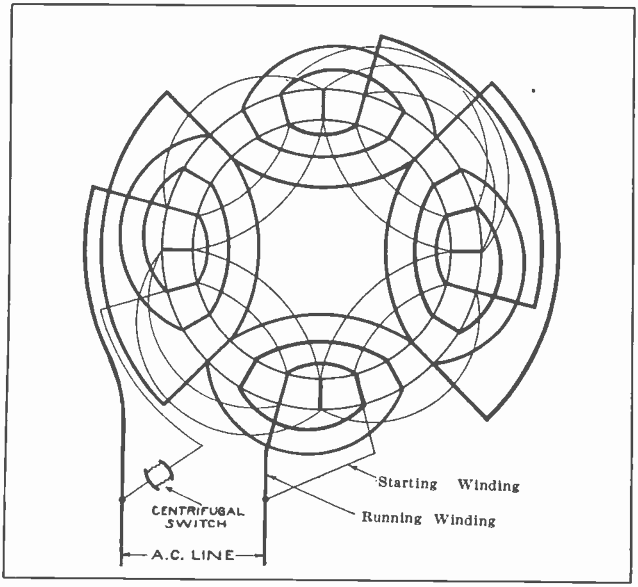


Fig. 15. The above diagram shows the complete circuits through both the starting and running windings of a single phase stator. Trace out each winding carefully and note how the coils are connected to produce alternate north and south poles around the stator.

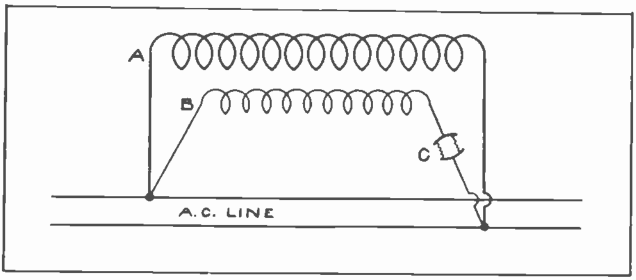


Fig. 16. This is a simplified diagram showing the manner in which the starting and running windings of a single phase motor are connected in parallel to the line. The centrifugal switch "C" is connected in series with the starting winding as shown.

centrifugal switch. Remember that this switch must always be connected in series with the starting widings.

15. CENTRIFUGAL SWITCHES

There are many different types of centrifugal switches used on single-phase motors; but the general principle of all of them is the same, in that they open the circuit of the starting winding by centrifugal force when the motor reaches nearly full speed.

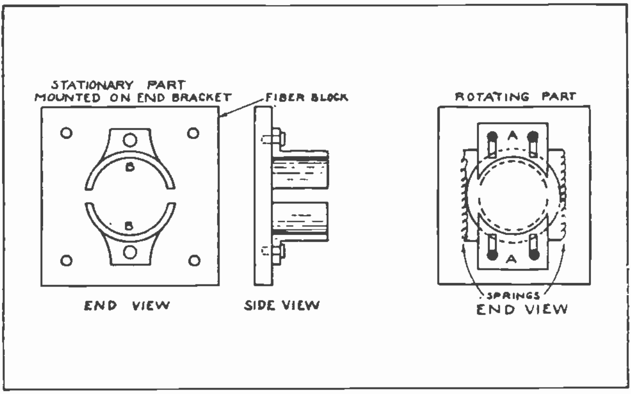


Fig. 17. These sketches illustrate the principle of a simple centrifugal switch, such as used for starting single phase motors. Examine each part closely as you read the explanation given on these pages.

Fig. 17 shows a sketch of one of the common types of these switches. The two views on the left show the stationary element, which is mounted on the end bracket of the motor; and the view on the right shows the rotating element, which is mounted on the shaft of the rotor. On the stationary element we have two terminals, "B" and "B," to which the line and starting winding leads are connected. These semi-circular metal pieces are separated from each other; so that there is no circuit between them except when the metal pieces "A" and "A" are drawn together over the cylinder formed by "B" and "B." This closes a circuit between them when the motor is idle. When the motor starts and begins to revolve at high speed the weight of the pieces "A" and "A" causes them to be thrown outward to the ends of their slots, thus disconnecting them from "B" and "B" and opening the circuit of the starting widing.

EXAMINATION QUESTIONS

1. Give the right hand rule for induced voltage in generators.

2. How many cycles would be produced for each revolution in an eight pole generator?

3. What would be the frequency output of a two pole generator operating at a speed of 3600 R. P. M.?

4. Why are large A. C. Generators designed with the field as the revolving element?

5. What is the spacing in degrees between phase currents of a three phase circuit? Of a two phase circuit?

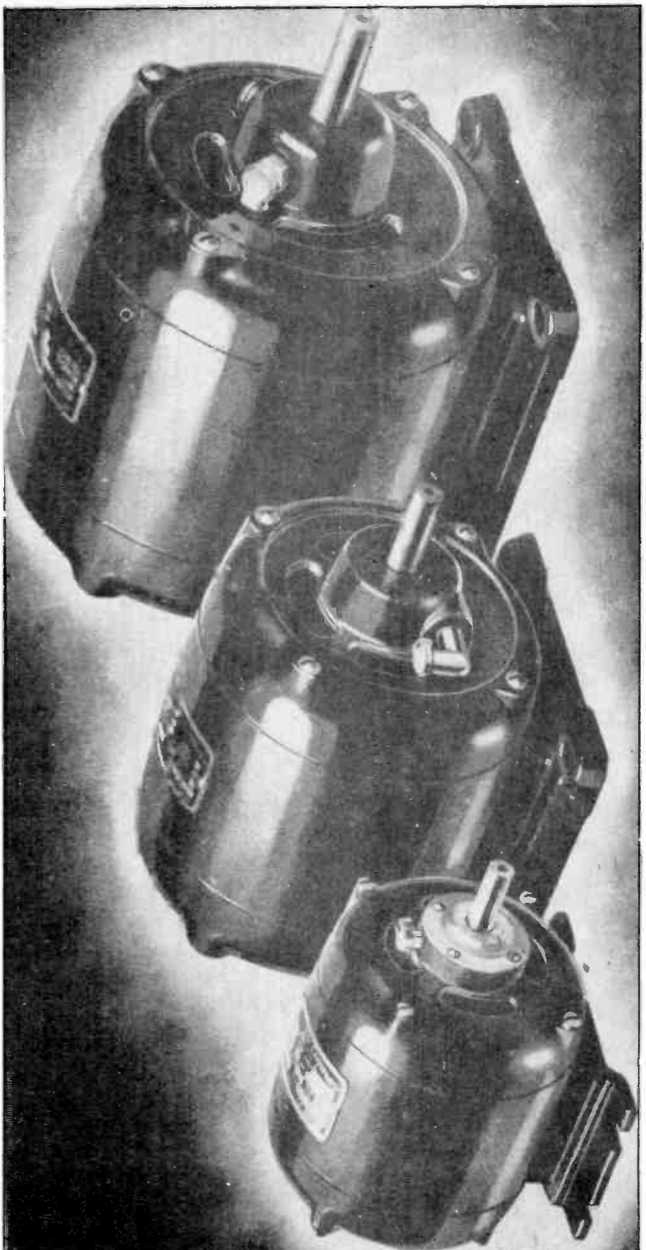
6. What are three important parts of an A. C. induction motor?

7. A. Briefly describe the construction of a squirrel cage rotor? B. How does the current get into the rotor of a squirrel cage motor?

8. How far apart are the starting and running windings spaced on a single phase split-phase motor?

9. A. What is the purpose of the centrifugal switch on a single phase split-phase motor? B. What is likely to happen if this switch fails to operate?

10. Name the two common types of rotors used in A. C. induction motors.



TWO-PHASE MOTORS

Two-phase motors are designed to operate on two-phase alternating current and have two windings, each covering one-half of each pole, or spaced 90° apart, similarly to the starting and running windings of a single-phase motor.

Each of the windings in a two-phase machine, however, is of the same size wire and has the same number of turns. Instead of being wound with spiral coils, two-phase windings are generally made with diamond-shaped coils similar to those used in armatures. A section of a two-phase winding is shown in the lower left view of Fig. 1, and you will note the manner in which the three coils of each phase overlap in forming the winding for one pole of the motor.

In the upper view of this figure are shown the curves for two-phase current with alternations 90° apart. When this current flows through the two windings, it sets up poles that progress step by step around the stator so rapidly that it produces what is practically a revolving magnetic field. The progress of this field and the magnetic poles can be observed by tracing out and comparing the several views in Fig. 1. The dotted lines running vertically through the curves in the upper view indicate the polarity of the curves at that instant. These will be referred to as "positions."

For example, in position 1, "A" and "B" are both positive; and, referring to position 1 at the leads of the windings, we find that curent will flow in at the starting leads of the two windings which are marked "S" and "S." The polarity set up will be as shown by the positive and negative marks in the sketch above these coils and at position 1.

At this instant we find that the current flows in at all of the six wires on the left and out at all six on the right. See Fig. 1B, lower line. This will set up a magnetic flux or polarity as shown in the sketch of the magnetic circuit, position No. 1 shown at D. This shows that the center of the pole at this instant will be in the exact center of the coils, and that a north pole will be produced at this point on the inside of the stator teeth.

At position No. 2 in the current curves, "B"-phase is still positive but "A" is changed to negative; so the current in the starting lead of "A"-phase will reverse as shown at position No. 2 and cause a reversal of the polarity around the "A" group. As this group covers the first half of the pole, these three slots will change in polarity. The first three slots of the second pole will also change and cause the pole to move three slots to the right, as shown in position No. 2 of the field rotation sketch.

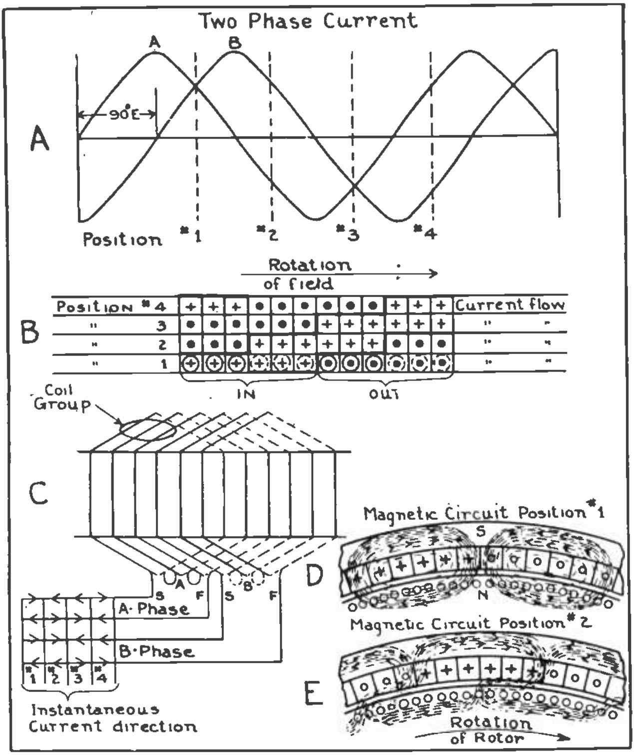


Fig. 1. The above diagrams show step by step the manner in which a revolving field is produced in a two-phase motor winding. Refer to each of the above sketches frequently when reading the descriptions in these columns. This figure illustrates a very important principle of induction motors and is well worth considerable study.

This shift of the magnetic pole is also illustrated in position 2 of the magnetic circuit sketch. At position 3 on the current curves, "B" has changed to negative and the current in the leads of the "B"-phase coil will reverse, causing the last three slots in each pole to change in polarity so the center of the pole moves three more slots to the right, as shown in position 3 of the field rotation sketch B.

We find that as the currents in the coil groups reverse in this manner and keep shifting the magnetic poles to the right, a corresponding change or movement of the field takes place in the stator, as we have seen in positons 1 and 2 of the magnetic circuit. As this flux moves to the right and cuts across the rotor bars, it induces currents in them and the reaction between the flux of this secondary current in the rotor and the stator flux causes the field of the stator poles to be distorted from its natural shape, as shown in position 2 of the magnetic circuit. It is from this field distortion that the torque or twisting force is produced and causes the rotor to turn.

It may be necessary to read the preceding paragraphs and trace the diagrams several times in order to thoroughly understand this principle, but it is well worth the time.

1. OPERATING PRINCIPLES OF THREE-PHASE MOTORS

The rotating action of the field in a three-phase motor is very much the same as that of two-phase machines, with the exception that only one-third of the pole, or in this case two slots, reverse at a time. In the two-phase machine one-half of the pole, or three slots, change at each reversal of current. The coil groups of the three-phase winding should be placed in the slots in such a manner that they alternate in the same order as the currents change in the three-phase system.

If we observe the three-phase current curves in Fig. 2 we find that the alternations change polarity or cross the center line in the order A, C, B; A, C, B; etc. The coil groups should be wound in to correspond with these current changes, or in the order A, C, B; etc., as shown in Fig. 2.

A very interesting fact to know about three-phase systems is that at any given time the voltage or current curves above the zero line will exactly equal those below the line. For example, in Fig. 2 at position 1, A and B are each at about half their maximum positive value, while "C" is at full maximum negative value. A vertical line through these curves at any point will show the same voltage relation.

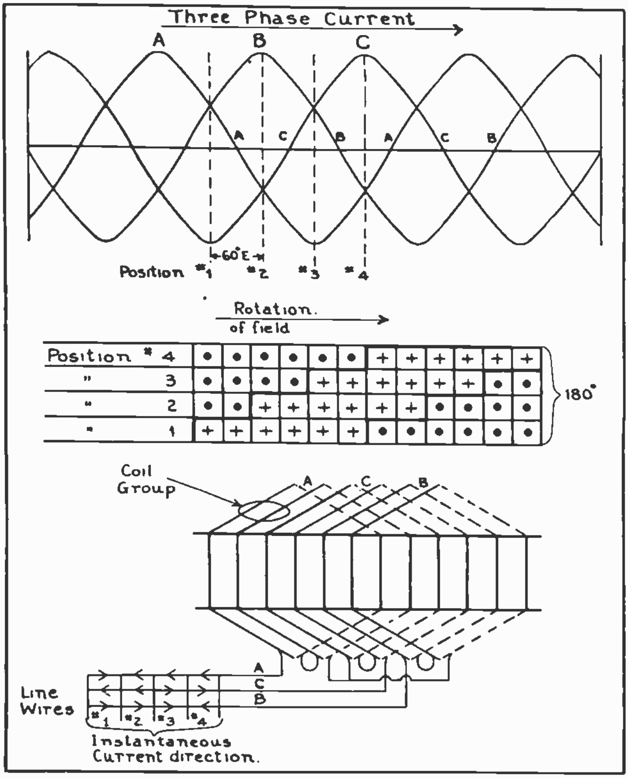


Fig. 2. The above diagrams show the development of the rotating field of a three-phase alternating current motor. Compare carefully the top, center, and lower diagrams and note the manner in which the field poles gradually advance in the slots as the current alternates in the three phases A, C, and B.

There is another condition that always exists in three-phase windings, and with which you should be familiar. You will notice that when tracing current in towards the winding on the line wires, the center group, or "C"-phase, will be traced around the coils in the opposite direction to "A" and "B." This should be the case in any three-phase winding, and will be if the coils are properly connected. This may seem confusing at first, but keep in mind that the three currents never flow toward the winding at the same time and that there will always be a return current on one of the wires. At any time when all three wires are carrying current, there will either be two positives and one negative or two negatives and one positive

When these three currents flow through a three-phase winding, as shown in Fig. 2, three consecutive coil groups will be of the same polarity, and the next three groups will be of opposite polarity, thus building up alternate poles, N.S., N.S., etc.

Trace out and compare each of the positions 1, 2, 3, and 4 in Fig. 2 as was done in Fig. 1, and you will find how the field poles progress around the stator to produce a revolving magnetic field in a three-phase motor.

2. TERMS AND DEFINITIONS FOR A. C. WINDINGS

The folowing terms and definitions should be studied carefully, in order that you may more easily understand the material in the following pages.

A **Coil Group** is the number of coils for one phase for one pole.

The formula for determining a coil group is:

$$\frac{\text{Slots} \div \text{poles}}{\text{phase}}$$

The term **Full Pitch Coil Span** refers to coils that span from a slot in one pole to a corresponding slot or position in the next pole.

The formula for determining full pitch coil span is:

$$(\text{Slots} \div \text{poles}) + 1$$

NOTE: Full pitch is also known as 100% pitch. In some cases a winding may be more than full pitch, but should never exceed 150% pitch.

The term **Fractional Pitch** applies to coils which span less than full pitch. A fractional pitch should never be less than 50% of full pitch.

We have already learned that there are 360 electrical degrees per pair of poles; so, in the study of the following material be sure to keep in mind that any single pole, regardless of size, has 180 electrical degrees.

The term **Electrical Degrees Per Slot** is commonly used to express the portion of the pole which one slot covers, and is abbreviated E° per slot.

The formula for determining the electrical degree per slot is:

$$\frac{180}{\text{Slots} \div \text{poles}}$$

Some of the material just covered may seem to you to be somewhat technical or theoretical, but a thorough study of the principles and terms on these preceding pages will help you obtain a better understanding of many of the most important and practical features in the winding and testing of alternating current machines.

3. LAP WINDING FOR A. C. MACHINES

Both lap and wave windings are used for A.C. motors and generators, but some of the rules which were given for these windings on D.C. machines do not apply to A.C. machines.

Instead of classing them as parallel and series windings, as we did for D.C., they are defined for A.C. as follows:

A lap winding is one in which all coils in a pole group can be traced through before leaving that group.

A wave winding is one in which only one coil in each pole group can be traced through before leaving that group.

Lap and wave windings are practically the same as to polarity and general characteristics.

We learned that on D.C. machines the wave winding gave the highest voltage. This is not true of A.C. windings, as the A.C. wave winding gives no higher voltage than the lap. A single circuit A.C. lap winding puts all possible coils in series, so it gives just as high voltage as the wave.

The wave winding is stronger mechanically than the lap winding, and for that reason it is generally used for phase-wound rotors, as there is often considerable stress on their windings due to centrifugal force and starting torque.

Stators are generally wound with lap windings. In the design of A.C. stators, the number of slots is determined by their size and the number of poles, and is selected for convenience in connecting the type of winding desired for the purpose of the machine.

4. TWO PHASE A.C. WINDING EXAMPLE

When the total number of slots is evenly divisible by the product of the number of poles and the number of phases, there will be an equal number of coils in each group and the same number of groups in each phase. This is known as an equal coil grouping.

For example: if we have a machine with 72 slots and we wish to wind it for 6 poles and 2 phase operation, then, to determine the coils per group, we use the formula:

$$\text{Coil group} = \frac{\text{Slots} \div \text{poles}}{\text{phase}}$$

or, in this case,

$$\text{Coil group} = \frac{72 \div 6}{2}, \text{ or } 6.$$

Then there would be 6 coils in series in each group and twelve groups in the winding. These twelve groups are divided into six parts for the six poles, and each part is again divided in two for the two phase-groups. Then these small groups of six coils each are connected into a two-phase winding.

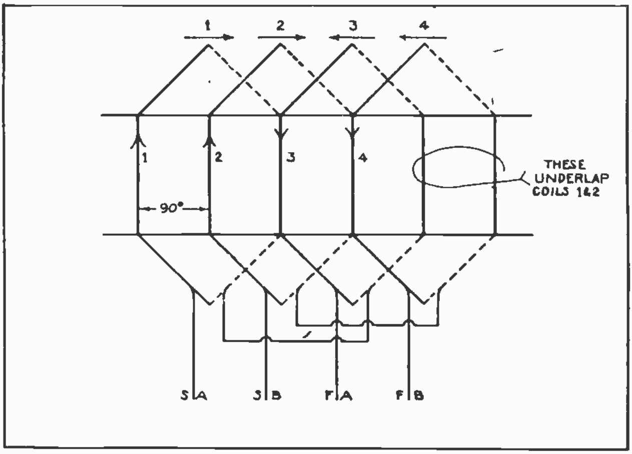


Fig. 3. This sketch shows the coils and connections of a simple two-pole, two-phase winding. Examine the connections of the coils carefully and note the direction of current in each coil.

A simple form of two-phase lap winding for two poles is illustrated in Fig. 3.

The starting leads of the coils for the "A" and "B" phases are marked "S A" and "S B," while the finish leads are marked "F A" and "F B." This winding could not be connected for three phase because the coils in each pole are not evenly divisible by three.

Note that the starts of each coil are 90° apart, or displaced from each other by one-half the width of one pole.

This should be remembered when connecting any two-phase winding, as the starts for these windings must always be spaced this distance apart.

5. COIL POLARITY IMPORTANT

When there is more than one coil per group the coils must be very carefully connected, as **all coils**

of the same group must be connected for the same polarity, or, so that current flows in the same direction through all coils of this group. This is a very important rule to remember and is illustrated in Fig. 4.

The two coils in the group at "A" are properly connected; that is, the finish of one is connected to the start of the next; so that the flux will unite around the sides of these coils, as it should to produce the pole. The coils in group "B" are improperly connected, with the finish of one to the finish of the other. So in this case the current in the right hand coil is reversed. This causes the flux

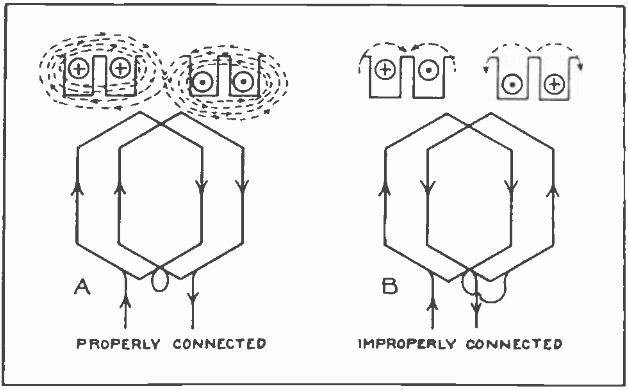


Fig. 4. Above are shown both the right and wrong methods of connecting stator coils to obtain the right polarity. Note the conditions of magnetic flux set up in the slots wih each connection.

of the two coils to oppose and neutralize each other and therefore they cannot build up a strong magnetic pole in the stator core.

Check the connections of these two groups of coils carefully, so you will know the right and wrong methods.

Fig. 5 shows a simple two-pole, three-phase winding with one coil per phase group and three groups per pole. This winding only has one coil per group. Observe very carefully the method of connecting the coil groups together. You will note that they are connected to give alternate polarity —N, S, etc. Also note that there are two coil sides per slot, one lying on top of the other.

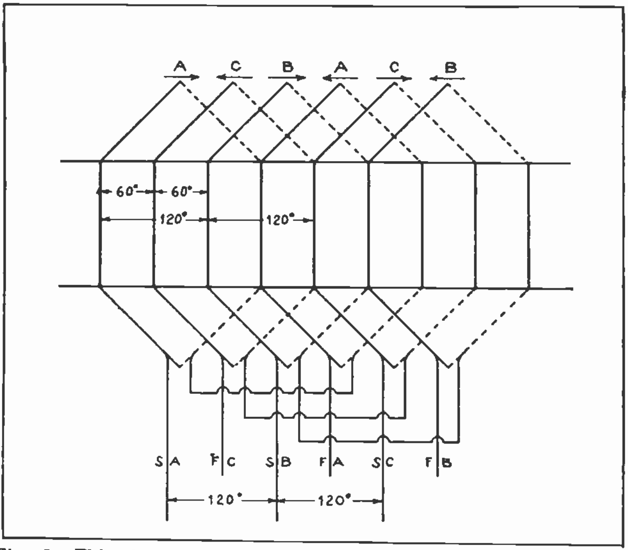


Fig. 5. This sketch shows a two-pole, three-phase winding. Note the spacing in degrees between the coil sides and line leads, and also the arrangement of the coil connections.

The leads from the coil ends are referred to as **top** and **bottom** leads, the one from a coil side lying in the top of the slot being called the **top lead,** and the one from a bottom coil side is called the **bottom lead.**

In making the connections from one group to the next of the same phase, always connect like leads together; that is, bottom leads together and top leads together. This rule should be followed strictly, in order to produce the alternate poles which are necessary in the winding to make the machine operate. If any of these coils is connected wrong the coils will overheat, as their self-induction will be neutralized and too much current will flow through them. This principle will be explained in a later section.

6. TYPES OF COILS FOR STATOR WINDINGS

Stators of 15 h. p. and under, and for less than 550 volts, usually have partly closed slots and are commonly wound with **"fed in"** or **"threaded in"** windings. For this type of winding we can use either the threaded-in diamond coil or what is known as a **basket coil.** Fig. 6 shows a coil of each type.

The diamond coil is wound, shaped, and the ends taped with half lapped cotton tape before the coil is fed in the slots. The basket coil is simply wound to the approximate shape, and to the proper length and size; but is left untaped except for little strips of tape at the corners just to hold the wires together until they are placed in the slots. The ends of these coils are taped after they are placed in the slots, or in some cases on small stators the coil ends are left untaped. After placing the coils in the slots, their ends are shaped with a fibre drift and a rubber or

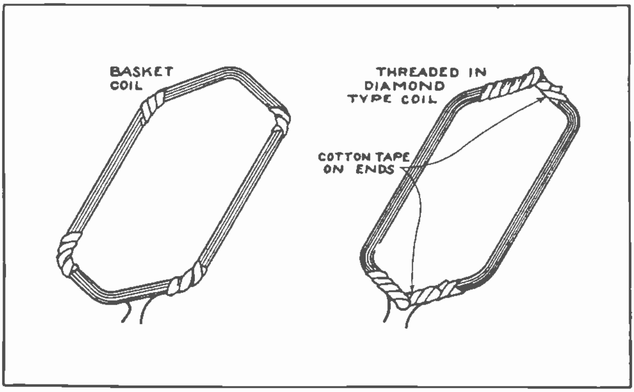


Fig. 6. Two common types of coils used in winding small stators with partly closed slots. These coils can be easily fed into the narrow slot openings.

rawhide mallet, so the coil ends can pass over each other.

These basket coils are generally used only for the smaller machines, and the diamond coils are usually more desirable for the larger machines.

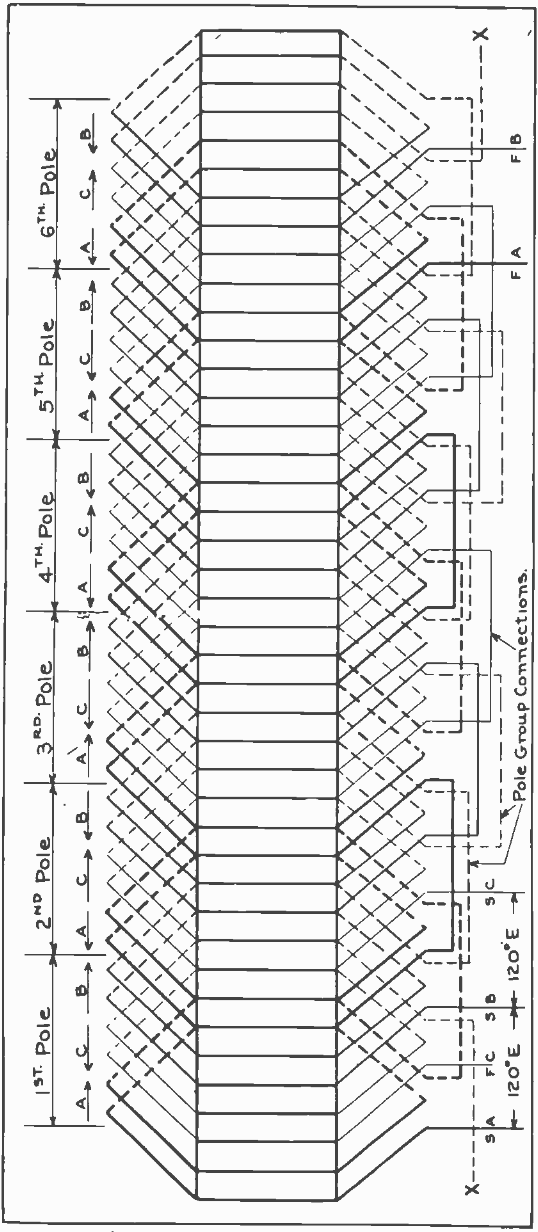


Fig. 7. Complete diagram of a three-phase, six-pole winding for a machine with 36 slots. The coils of each phase are shown in lines of different thickness in order that they may be easily traced through the winding. Trace these circuits very carefully and note the manner in which the coils are connected to obtain alternate N. and S. poles. Also note how the coil groups of each phase overlap to complete the three phases of each pole of the winding. Refer to this diagram frequently while studying the accompanying pages, and also at any time you may need it when connecting a three-phase winding.

The untaped sides of either of these types of coils makes it possible to feed the wires one or two at a time into the narrow slot openings. Thus the name "fed in" coils.

7. PROCEDURE FOR WINDING A THREE PHASE STATOR

The following paragraphs describe in detail the procedure of winding a three-phase stator of 36 slots and 6 poles.

Let us apply the formula:

$$\text{Coil group} = \frac{\text{slots} \div \text{poles}}{\text{phase}}$$

or, in this case,

$$\text{Coil group} = \frac{36 \div 6}{3}, \text{ or 2 coils per group.}$$

The full pitch coil span will then be found by the coil span formula:

$$\text{Coil span} = \frac{\text{slots}}{\text{poles}} + 1$$

or, in this case,

$$\text{Coil span} = \frac{36}{6} + 1 = 7:$$

The first coil will then span or lie in slots one and seven.

After the slots have been insulated, begin by placing one side of the first coil in any slot, with the leads of the coil toward the winder, as shown in Fig. 8.

One side of the next coil is then placed in the slot to the left of the first, which will make the winding progress in a clockwise direction around the stator. Four more coils are then placed in the slots in a similar manner. leaving the top sides of all of them out.

When the bottom side of the seventh coil is placed in the seventh slot, its top side is laid on top of the first coil, as shown in Fig. 9. The bottom of eighth coil is placed in the eighth slot and its top is placed on top of the bottom side of the second coil.

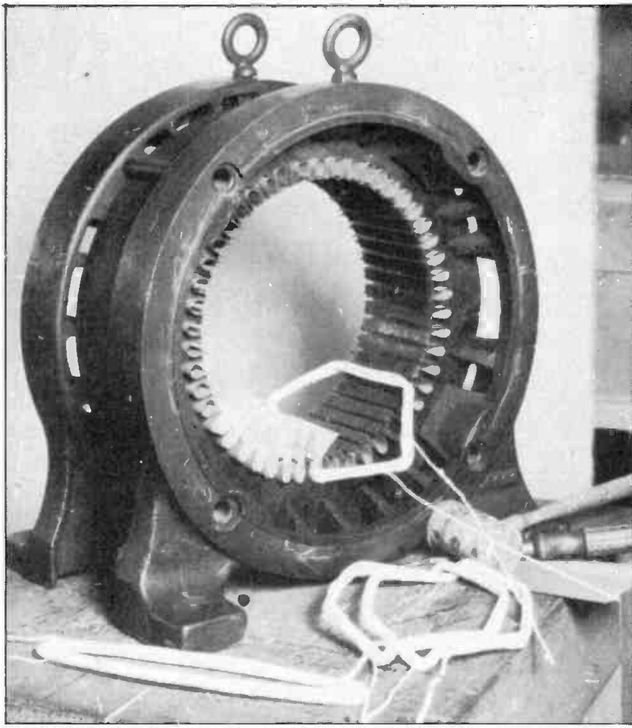


Fig. 8. This view shows a method of starting the first coil for a stator winding. The fish paper insulation is in all slots and the varnished cambric has been placed in several.

This procedure is followed until all the coils are in place, the bottom sides of the last six coils being slipped in under the first six coils, the top sides of which were left out of the slots. Fig. 10 shows a view of a stator from the back end, after the last coils have been laid in under the top sides of the first coils. These top sides are now ready to be inserted in the slots and then the slot insulation can be trimmed, folded in over the coils, and the slot wedges put in place.

While the coils of the winding just described were laid in to the left of the first, or clockwise around the stator, they can be laid either clockwise

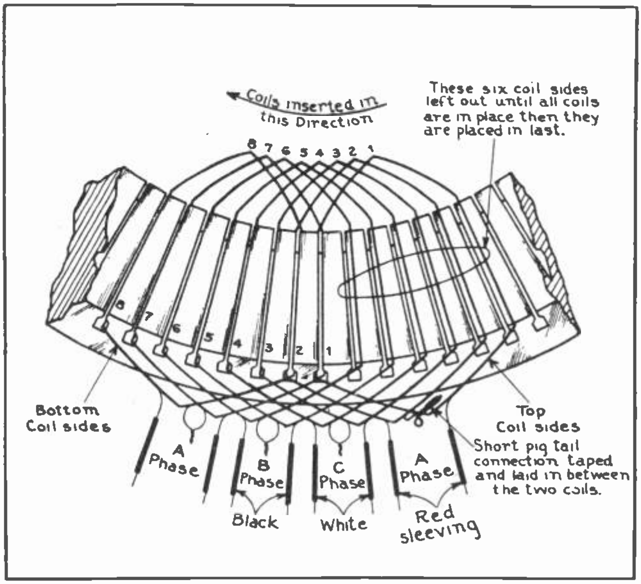


Fig. 9. This diagram illustrates the method of placing the first coils in a stator and the proper rotation for inserting them. Note the sleeving used for marking the leads of the different phase groups, and also the several coil sides which are left out of the slots until those of the last coils are inserted under them.

or counter-clockwise, according to the shape of the end twist of the coils.

8. MARKING AND CONNECTING COIL LEADS

In winding stators of small size it is general practice to connect the coils into groups as they are fed in the slots. You will notice in Fig. 9 that the bottom lead of the first coil is connected to the top lead of the second. The top lead of the first coil and the bottom lead of the second are identified or marked with sleeving of the same color. All of the following groups are connected together the same as the first; but the unconnected leads of the second group are marked with a different colored sleeving than the first, and the third group with still another color. For the fourth group we again use the same color as for the first, and from there on the colors are alternated on the other groups, the same as on the first three.

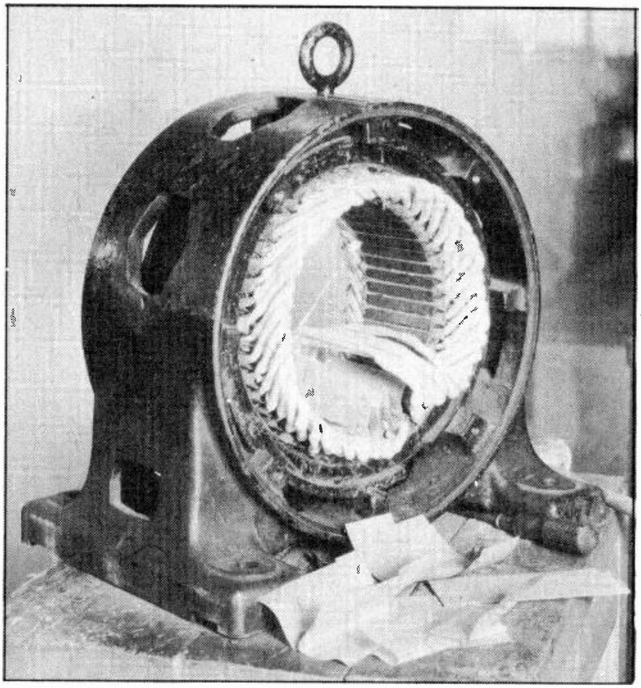


Fig. 10. This photo shows a stator winding nearly completed and ready for the top sides of the first coils to be placed in on the bottoms of the last coils which were inserted. The insulation has been neatly folded down over the coils in most of the slots.

When all the coils of this 36-slot winding are in place there will be five more poles similar to the one in Fig. 9.

After the wedges are in the slots the pole group connections are made as shown in Fig. 7. This diagram shows the connections of the groups into a three-phase winding.

Careful observation of the starting leads of A, B, and C phases will show that there are three separate windings spaced two-thirds of a pole, or 120 electrical degrees, apart.

You will note, however, that the windings are placed in the stator, in the order A, C, B, from left to right; thus actually making the effective spacing 60 degrees for certain connections.

After selecting the top lead of any convenient coil in the winding for the start of A phase and connecting all groups of a corresponding color into one winding, the second start, or B phase, is selected. This lead **must be taken from the top of the third group**, counting A phase as number one. All groups for B phase are then conected and, last of all, those for C phase are connected. The C phase should start at the top lead of the fifth coil group, which would be the same distance from B as B is from A.

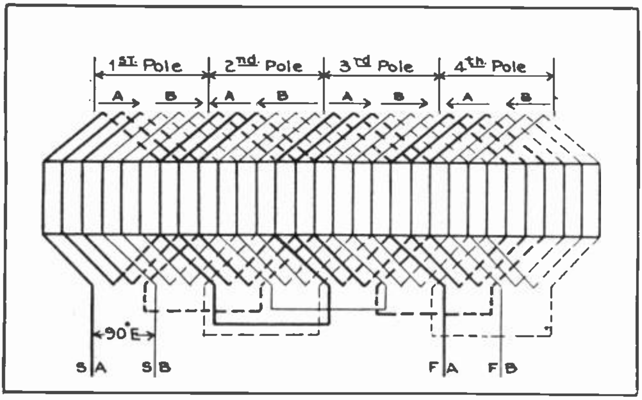


Fig. 11. Complete two-phase winding for a four-pole machine with 24 slots. Note the similarity between this diagram and the one in Fig. 7, as to the arrangement of coils and connections between pole groups; but also note that there are only two phase groups per pole, and the different spacing in electrical degrees between the leads in this winding and the three-phase winding in Fig. 7.

There will then be six leads left, three starts and three finish leads. In Fig. 7, these leads are marked SA, FC, SB, SC, FA, and FB, and you will note that they are all from top sides of coils. In selecting the starting leads for such a winding, we choose three groups which are close to the opening for the line leads in the frame or end-bracket.

Fig. 11 shows a complete connection diagram for a two-phase, four-pole winding with 24 slots. The coils are laid in the slots the same as for a three-phase winding. There are three coils per group and two groups in each pole. The coils are also connected into groups the same as for a three-phase winding, and the pole group connections made similarly, except with two groups per pole instead of three.

9. PROCEDURE FOR CONNECTING A 3 PHASE WINDING

Fig. 12 shows complete four-pole, three-phase

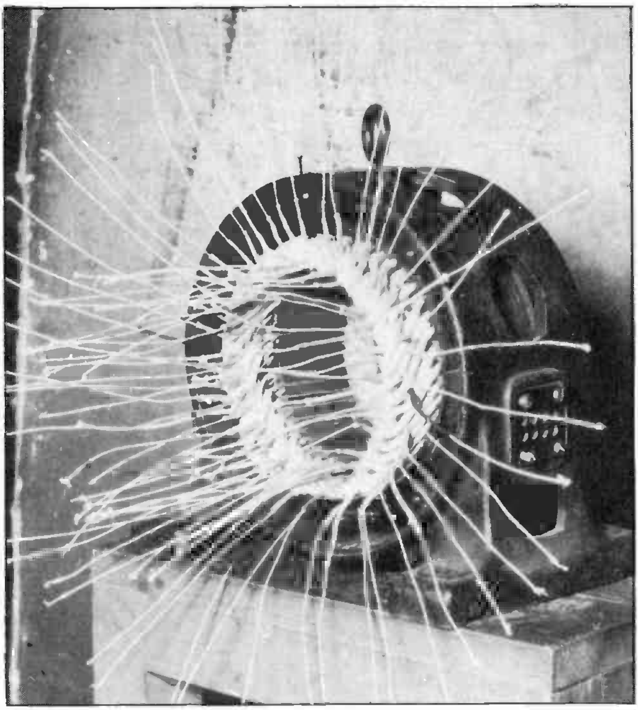


Fig. 12. The above photo shows a stator with 48 slots wound for four poles, three phase. The coils are all in the slots and the leads are marked with sleeving and ready for the connections to be made.

winding in a stator with 48 slots. The coils are all in place, but no group connections have been made.

You will note that all top and bottom leads are brought out at the points or ends of the coils, and all in the same position on the coils, in order to make a neat and systematic arrangement of the leads and to simplify the making of connections.

The bottom leads of all coils are bent out around the edge of the frame, and all top coil leads are arranged straight out from the stator core. The next step would be to strip the ends of these leads and temporarily connect them in bunches for making a ground test from the coil leads to the stator. This test can be made with a 110-volt test lamp, and it should always be done before connecting any coils, to make sure that none of them are grounded because of damage to their insulation while they were being placed in the slots.

To make sure that no coils in any group are open, the start and finish leads of each group should also be tested by placing one wire of the 110-volt line on a start and the test lamp on the finish lead.

Note that all coil leads are marked with sleeving and that every fourth bottom lead and also every 4 th top lead are marked with longer sleeving, as these leads are those of the start and finish of each pole group.

10. MAKING "STUB" CONNECTIONS

The next step will be to cut off all leads of the coil groups that are marked with the short sleeving, about 3 inches long. Strip the insulation from about 1½ inches of their ends; then connect them together, the bottom lead of one coil to the top of the next. This is shown in Fig. 13, and the pigtail splices of these coil groups can be plainly seen.

The bottom leads of the pole group are still shown sticking out around the frame, and the top pole group leads are projecting out from the center of the core.

11. POLE AND PHASE CONNECTIONS

In Fig. 14 the coil-group connections have been soldered, taped, and folded down between the coil ends and the pole group leads have been connected together. The bottom lead of one group is connected to the bottom lead of the next group of the same phase and color. The top lead of one group is also

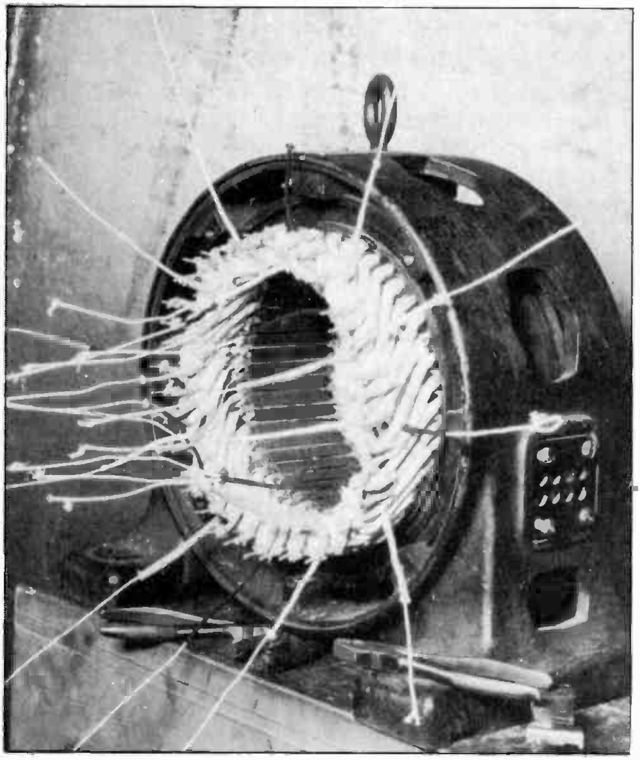


Fig. 13. This view shows the same stator as in Fig. 12, except that the coil group connections have been made. By looking carefully you can see the bare pig-tail splices of these connections around the winding. The pole group leads are not yet connected.

connected to the top lead of the next group of the same phase. This places all pole groups of each phase in series in the winding. These pole-group leads are commonly called **jumpers.**

You will note that the three starts for the phases which are marked SA, SB, and SC are taken from the first, third, and fifth pole groups, near the line-lead opening in the frame.

The three finish leads marked FA, FB, and FC, are shown at the top of the winding.

In Fig. 15 the three finish leads are shown connected together at the top of the machine, and the three start leads are connected to heavy rubber covered wires for the line leads.

The pole-group leads are now folded or pressed

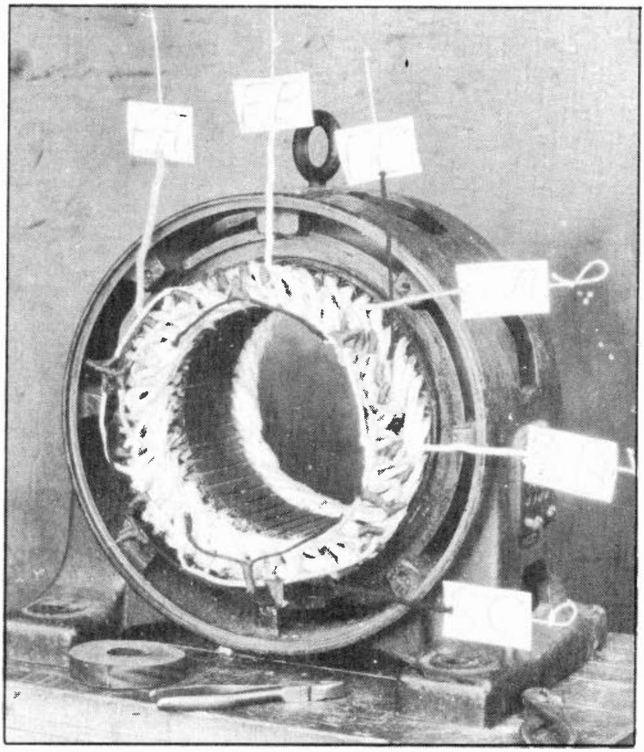


Fig. 14. Again we have the same stator as in the last two figures, but in this case the connections are one step farther along. The coil group connections have been soldered and taped, and the pole group connections are made, leaving only the start and finish leads of each phase. These are marked by the tags as shown.

down around the outside of the coil ends to make them clear the end bracket and rotor, and the winding is then ready for the insulating compound and baking.

12. UNEQUAL COIL GROUPING

The lap windings previously covered have all had equal coil grouping, that is, the same number of coils in consecutive groups. In some cases it is

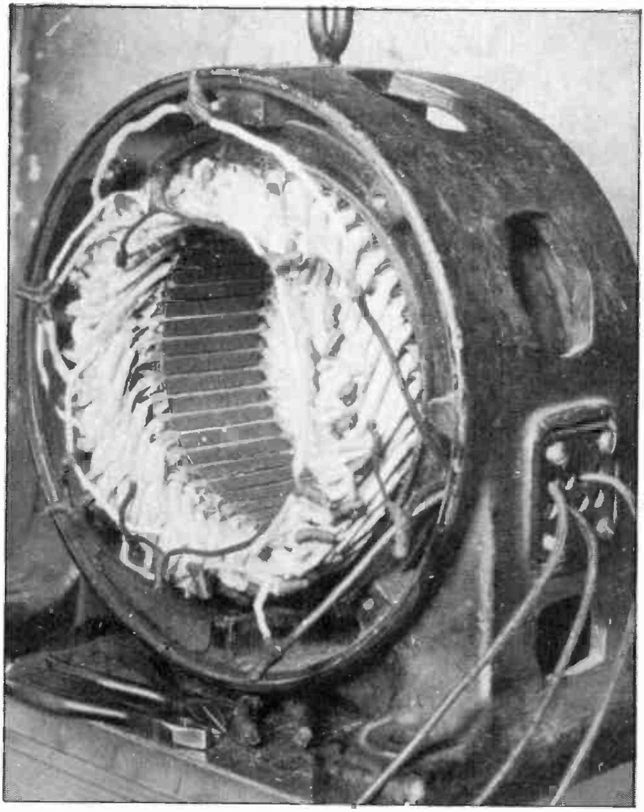


Fig. 15. The last step in the connections has now been completed and the starts and finishes of the first groups are connected to the line wires which are brought out through the right side of the frame.

necessary to wind a stator with unequal coil groups in the winding. This is because the number of slots does not happen to be evenly divisible by the product of the number of poles and the number of phases. The unequal coil grouping to be used in such a case will have two or more groups in each pole, with unequal numbers of coils.

For example, suppose we have a 48-slot machine to wind for 6 poles and 3-phase. In this case the product of the poles and phase, is 6×3, or 18. The number of slots, or 48, is not evently divisible by 18 so we cannot use equal coil grouping.

	A		B
POLE # 1	3	3	2
" 2	3	2	3
" 3	2	3	3
" 4	3	3	2
" 5	3	2	3
" 6	2	3	3

48 SLOTS 6 POLES
3 PHASE

	A	C	B
POLE # 1	4	5	4
" 2	5	4	5
" 3	4	5	4
" 4	5	4	5

54 SLOTS 4 POLES
3 PHASE

	A	C	B
POLE # 1	3	2	2
" 2	2	3	2
" 3	2	2	3
" 4	2	2	2
" 5	3	2	2
" 6	2	3	2
" 7	2	2	3
" 8	2	2	2

54 SLOTS 8 POLES
3 PHASE

POLE # 1	5	4
" 2	4	5
" 3	5	4
" 4	4	5
" 5	5	4
" 6	4	5

54 SLOTS 6 POLES
2 PHASE

Fig. 16. The above table shows unequal coil groups which can be used for two and three phase windings. Note how this arrangement of coils places an equal number in each phase when the winding is complete, even though there is not the same number in each phase of any one pole.

This stator can, however, be wound satisfactorily for three-phase by using the following coil grouping: Three coils in group "A," three coils in group "C," then two coils in group "B," which completes the first pole.

For the second pole the small group should be shifted to another phase; so we will place three coils in group "A," two in group "C," and three in group "B," etc. Thus we keep alternating or shifting the small group from one phase to the next throughout the winding.

The tables in Fig. 16 show the manner in which this grouping will even up the coils per phase in the complete winding. These tables show unequal groupings which are commonly used in two and three-phase motors.

The horizontal lines or rows show the number of coils per group in each phase, for each of the poles. The vertical columns show the number of coils per group throughout the entire winding. By adding the columns for each phase you will find that the number of coils per phase is the same in all three phases.

EXAMINATION QUESTIONS

1. a. What is a coil group?

   b. Give the formula for determining the coils per group.

2. Define a lap winding as used on A.C. motors or generators.

3. What is the advantage in using a wave winding for A. C. machines?

4. Assuming that on a 72 slot stator you wish to place a three phase winding for 6 poles, what would be the number of coils per group, and what would be the coil span?

5. When there are two or more coils in one group, are they connected for like or unlike polarity?

6. Name the two types of coils that are used in partly closed slots for stators of 15 horse power or less.

7. How are coil leads often marked to simplify their connection?

8. What important test should be made on all coils before they are finally connected?

9. Why is it sometimes necessary to use unequal coil grouping in certain A.C. machines?

10. Why are the top sides of the first set of coils left out of the slots until the last part of the winding job?

STAR AND DELTA CONNECTIONS

After the coil groups and pole-group connections in a three-phase winding have been completed, six leads remain to be connected for line leads.

The two methods of connecting these are known as **Star** and **Delta** connections. These connections are very important, as they determine to quite an extent the voltage rating of an A. C. generator or motor.

The left view in Fig. 1 shows the star connection for an A. C. winding. The three coils—A, B, and C — represent the three-phase windings of the machine and are spaced 120° apart. The center connection of this star is the point at which all three of the finish leads of the winding are connected together. The three outer ends of the coils are the starts, and are connected to the line wires.

The sketch at the right in this figure shows the method of making the star connection right on the leads of a winding.

The symbol for the star connection is a mark consisting of 3 small lines 120° apart and connecting at the center. The letter Y is also commonly used.

The left view in Fig. 2 shows the delta connection for an A. C. winding. The three coils—A, B, and C—again represent the three-phase winding of the machine, and are connected together in a closed circuit with the start of "A" to the finish of "C," start of "C" to finish of "B," and start of "B" to finish of "A."

The line leads are then taken from these points at which the windings are connected together.

The sketch at the right in Fig. 2 shows the method of making the delta connection right on the leads of a winding.

The symbol for the Delta connection is a small triangle, $\triangle$.

1. VOLTAGE OF STAR AND DELTA CONNECTIONS

By carefully comparing these two forms of connections in Figures 1 and 2, you will note that the delta connection has only half as many turns of wire in series between the line leads of any phase, as does the star connection. We know that the number of turns or coils in series directly affects the voltage, so we can see that for a given voltage per phase the star connection for a generator will

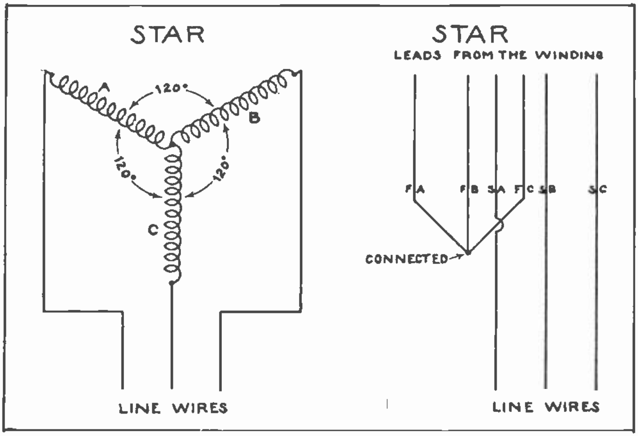


Fig. 1. The above two sketches illustrate the method of making star connections with alternating current windings. Note the phase displacement between the three windings on the left and also the manner in which two windings are placed in series between any pair of phase wires. The sketch at the right will be convenient for reference when connecting machine windings in this manner.

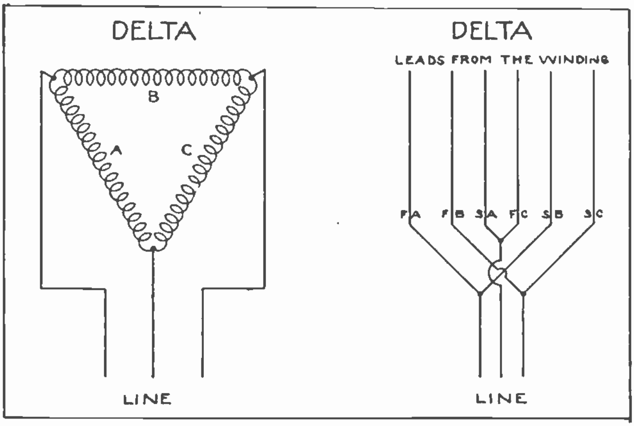


Fig. 2. These diagrams show the method of making delta connections for alternating current windings. The sketch on the left shows that with this delta connection two windings are in parallel between any pair of phase wires. The sketch on the right shows the manner of making a delta connection to the leads of a machine winding.

produce higher voltage than the delta, and that the star connection when used on a motor will enable the motor to be used on higher line voltage.

The delta connection, however, has two windings in parallel between any two line or phase leads, so it will have a greater current capacity than the star connection.

As the star connection places twice as many coils in series between line wires as the delta connection, it might at first seem that it would give double the voltage of a delta connection. The voltage increase, however, will not be quite double, because the spacing of the two windings in the machine is 120° apart and consequently their maximum voltages occur at slightly different periods of time. The placing of the C phase winding between the windings of A and B phases, as explained in Art. 8, Lesson No. 30, actually reverses its phase relation to the other two windings by 180 degrees; and in the star connection this produces voltages in series which are only 60 degrees displaced. So when two equal voltages which are 60 degrees apart are connected in series, their total voltage at any instant will not be double, but will be approximately 1.73 times the voltage of either one.

This value is obtained by vectorial addition instead of numerical addition. Fig. 3 shows how this can be done graphically or with lines drawn to scale and at the proper angles to represent the voltages to be added. The line from "B" to "A" represents 100 volts of one winding, and the line from "B" to "C" represents 100 volts of another winding 120° out of phase with the first. However, as one of the phases is reversed with respect to the other, we will draw a line in the opposite direction from B to D, to represent the voltage 180° displaced, or in the reverse direction to that shown by line B A. This voltage will then be 60° displaced from that in the other phase, shown by line B C.

By completing our parallelogram of forces as shown by the light dotted lines we can now determine the vectorial sum of the two phase winding voltages in series, by measuring the diagonal line B. E. If the lengths of the lines "B C" and "B D" are each allowed to represent 100 volts by a scale of 1/8 inch for each 10 volts, we find by measuring the length of the line "B E" that it is 1.73 times as long as either of the others, so it will represent about 173 volts.

Observation of Fig. 3 will show that a straight line drawn from A to C would be exactly the same length as the line from B to E. In many cases these vector diagrams are drawn in this manner by merely reversing the arrow on line A B and leaving off lines B D, C E, and B E.

This same method can be applied to find the sum or combined force of two separate mechanical forces acting at an angle. If we have a force of 100 lbs., acting in a direction from "B to C," and another equal force acting from "B" to "D," then the combined force "B to E" will be approximately 173 lbs.

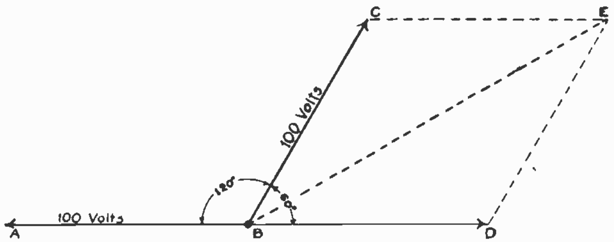


Fig. 3. The above diagram illustrates the method of adding together two voltages of windings connected in series but out of phase with each other 60°. The dotted line gives the correct sum of the two voltages shown by the solid lines.

Another method of calculating the sum of voltages which are out of phase will be given in a later section; and the use of vectors, or lines and angles for such problems will also be more fully explained in that lesson.

The important fact to remember is that the star connection always gives 1.73 (or, to be exact, 1.732) times the voltage of the delta connection. So, in **changing from delta to star we multiply the delta voltage by 1.732**; and **in changing from star to delta we divide the star voltage by 1.732,** or multiply it by .5774, to get the delta voltage.

2. FRACTIONAL-PITCH WINDING

Fractional-pitch windings, also known as short-chord windings, are those in which the coil span is less than full pitch. There are several reasons for making windings with fractional pitch coils. **The shorter coils used in these windings provide greater mechanical strength of the winding,** and they also produce a lower voltage than full-pitch coils. Fractional-pitch windings are also used to improve the power factor of alternating-current machines, as will be explained in a later lesson.

By referring to Fig. 4, you will note that the length of the coil between its ends or points is reduced by making the coil span less than full pitch. In this figure the large coil which spans from slot 1 to slot 7 is assumed to be a full-pitch coil, so a coil laid in slots 1 and 6 will be a fractional-pitch coil and will have 83⅓% pitch. The shorter the coil ends are, the greater the mechanical strength of the coil.

Most two and three-phase motor windings use a coil span of less than full pitch, and generally about 75 to 85 per cent of full pitch. If a generator winding is changed from full pitch to fractional pitch, the coils which are thus shortened will not span from the center of one pole to the center of the next. Thus the generator voltage will be decreased. This voltage reduction will vary with the sine of an angle of one-half the electrical degrees spanned by the coil.

For example, if a machine has 54 slots and 6 poles, the full-pitch coil span would be (54 ÷ 6) plus 1, or 10. The coils for this winding would then span from slots 1 to 10 and this full pitch would, of course, be 180 electrical degrees. Such a coil will span from the center of one pole to the center of the next, and the voltage generated in it will be maximum or 100%.

If we use a fractional pitch coil which lies in slots 1 and 7, it would in this case span only 120 electrical degrees, instead of 180. Since 54 ÷ 6, or 9 slots represent 180 degrees, one slot will represent 20 de-

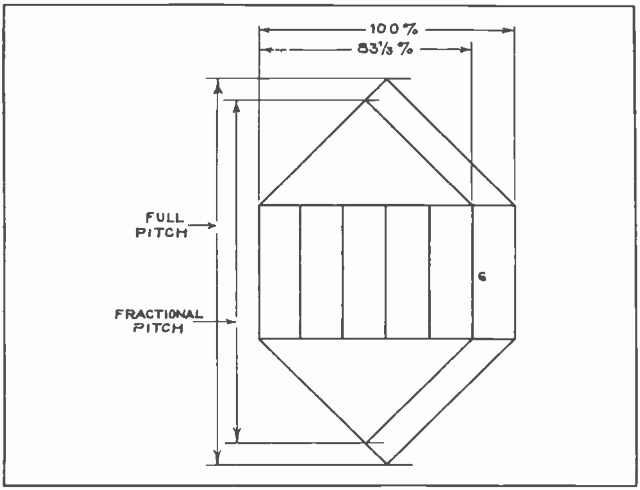


Fig. 4. Note how fractional-pitch windings make the coils shorter as their pitch is decreased. The shorter coils will have greater mechanical strength, which is one of the advantages of this type of winding.

grees and 6 slots 120 degrees. One-half of 120 degrees is 60 degrees, and the sine of an angle of 60 degrees is .866. So a fractional-pitch coil spanning 6 slots instead of 9 would only generate a little over 86% of the voltage that would be produced by a full-pitch coil, and this would apply to the entire winding of the machine. The sines of various angles can be found in tables given in a later lesson on A. C. and will be more fully explained in that section.

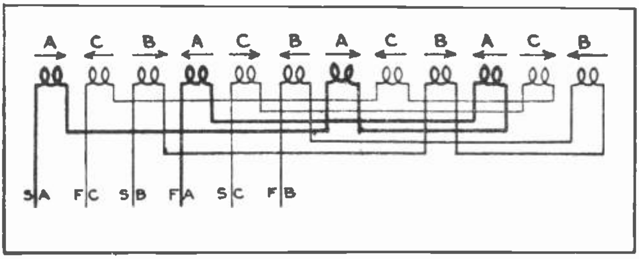


Fig. 5. This diagram shows a different method of connecting together the pole groups of the winding to allow a more compact arrangement of the leads on heavy windings. This method simply connects every other pole of one phase in a straight series group without crossing the leads; then connects back to get the remaining poles of those phases which were skipped the first time. These are connected in another straight series group and to the first group in a manner to produce alternate N. and S. poles throughout that phase.

30. SPECIAL POLE GROUP CONNECTION

Fig. 5 shows a system of connections very often used on three-phase motors. This system of connections will give the same result as the one previously described and can be used on any two or three-phase winding. You will note that instead of connecting from the finish of a certain coil group to the finish of the next coil group of that phase, this finish lead is carried over to the start of the third coil group of that phase, skipping the second one and leaving it to be connected when the counter-clockwise connections are made. This produces the same polarity as though all coils of a certain phase were connected together in succession from finish to finish, start to start, etc.

Compare this method with that shown in Fig. 11, Lesson 30. One of the advantages of this system is that on heavy windings it allows the end connections to fit more compactly against the coils and in a small space in the machine.

4. ROTOR WINDINGS

We have previously mentioned that some alternating current machines have wound rotors using windings similar to those of a D. C. armature, but instead of these coils being connected to the bars of the commutator, they are connected together for two or three-phase the same as stator coils are. The main leads are then connected to slip rings on the rotor shaft. Such windings are used for machines for variable speed duty and machines where extra-heavy starting torque and certain power factor characteristics are required.

Fig. 6 shows a diagram of a "phase-wound" rotor of four poles and 24 slots, wave wound. This type of winding is used very extensively on large rotors which have heavy coils made of copper bars, and the connecting system is practically the same as for all wave windings. This rotor can be used satisfactorily with either a two or three-phase stator winding.

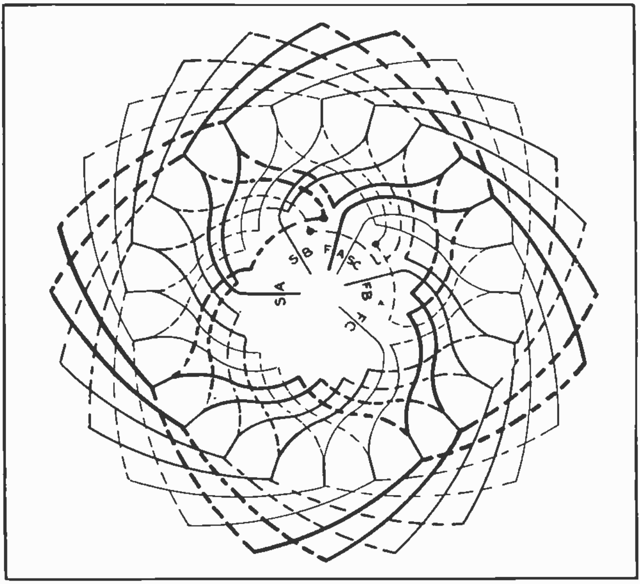


Fig. 6. This sketch shows a complete winding diagram of a 24-slot wave-wound rotor. Rotors with windings of this nature are sometimes called "phase-wound" rotors.

The actual winding procedure for such rotors is practically the same as for D. C. armatures, except for the difference in the connections.

5. CHANGING OPERATING VOLTAGE OF INDUCTION MOTORS

Very often the maintenance man is confronted with a problem of changing the operating voltage of induction motors to permit them to be operated on a different line voltage, in case they are moved to a new locality where the original operating voltage is not obtainable.

The voltage of any individual motor winding varies directly with the number of turns it has connected in series.

If you remember this simple rule it will help you solve many problems in making voltage changes on equipment. There are, of course, certain practical limits beyond which this change of voltage should not be carried. For example, if we have a winding operating at 220 volts we might be able to increase the number of turns to a point where the winding would stand 2300 volts, but it is doubtful whether the insulation would stand so high a voltage.

It is almost always permissible to reconnect a winding to operate on a lower voltage than it has been designed for; but, **when reconnecting a machine to increase its operating voltage, the insulation should always be considered.** The usual ground test for the insulation of such equipment is to apply an alternating current voltage of twice the machine's rated voltage, plus one thousand volts. This voltage should be applied from the winding to the frame for at least one minute and a test should be made after the winding is reconnected, or on any new winding before it is placed in operation. **When a winding is changed for a different voltage it should be arranged so that the voltage on each coil group will remain unchanged.**

Fig. 7 illustrates the manner in which this can be done. In the diagram at "A," 220 volts are applied to four coil groups in series, which places 55 volts on each group, and we will assume this voltage will cause 5 amperes to flow. The same winding is shown again at "B," reconnected for 110 volts, with two groups in series in each of two parallel circuits. When 110 volts are applied to these two parallel groups we will still have 55 volts per coil, and the same amount of current will flow. The rotating

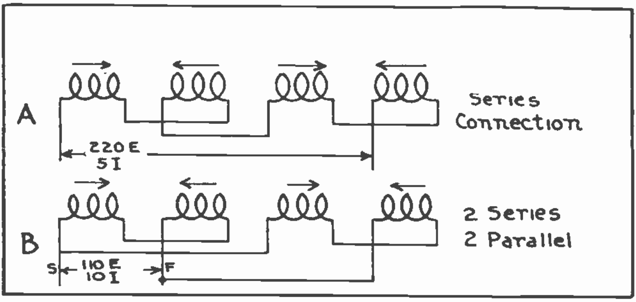


Fig. 7. The above diagram shows the method of reconnecting poles of the winding from series to series-parallel to be operated on a lower voltage.

magnetic field will not be affected any differently as long as the amount of current per coil is not changed and the polarity of the coils is kept the same. This explains why it is not necessary to change the rotor winding when the winding in the stator is reconnected for a different voltage.

In reconnecting two or three-phase windings all phases must be connected for the same number of circuits, and when connecting the groups for a winding having several circuits, extreme care should be taken to obtain the correct polarity on each group.

6. TEST FOR CORRECT POLARITY

In changing the connections of a three-phase winding one must be very careful not to connect the phases in a 60° relation instead of 120° as they should be. By referring to Fig. 8 we can see that it would be easy to connect the wrong end of the B-phase to the star point. This would reverse the polarity of the entire B-winding, and cause the stator winding to fail to build up the proper rotating field. The result would be that the motor would not develop proper torque, and the winding would heat up and burn out if the reverse connection were not located and corrected at once.

To avoid making a mistake of this kind, trace through each winding, starting from the leads or terminals and proceeding to the star connection at the center of the winding. As each successive coil group is traced through, place an arrow showing the direction in which that group was passed through. When all three phases have been traced through in this manner and the arrows on the groups are inspected, the sketch or connection is correct if the arrows on adjacent groups reverse.

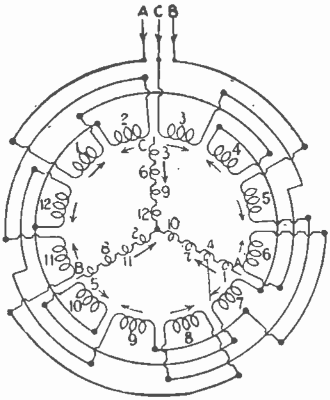


Fig. 8. This diagram shows a 3-phase, four-pole winding in which the pole groups in each phase are all four connected in series, and the three series groups connected star as illustrated by the diagram in the center. Don't confuse the inner and outer diagrams as they are entirely separate and each shows the same winding merely in a differnt manner.

That is, they should point alternately clockwise and counter-clockwise around the winding.

7. EFFECT ON CURRENT WHEN CHANGING THE VOLTAGE

It is common practice among most manufacturers to design machines that can readily be connected for either of two common voltages. This is accomplished by a series or parallel arrangement which can be more easily understood by comparing Figs. 8 and 9. In the center of each of these diagrams is shown a small schematic sketch that illustrates in a simple manner the series or parallel arrangement of the coils. This center sketch in Fig. 8 shows that there are twice as many coil groups in series between the terminal leads as there are in the connection in Fig. 9. This means that if the winding in Fig. 8 is properly connected for 440 volts the one in Fig. 9 would be correct for 220 volts.

We know that in any motor the horse power depends on the number of watts which are used in its circuit, and we also know that the watts are equal to the product of the volts and the amperes; so, if we wish to maintain the same horse power of a motor at one-half its normal voltage, we can see that it will have to carry twice as many amperes at full load.

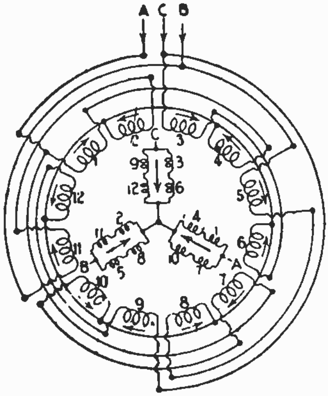


Fig. 9. This diagram shows the same three-phase, four-pole winding which was shown in Fig. 8, but in this case the four pole groups of each phase have been connected two in series and two in parallel, and then the phase groups connected star as shown by the center sketch.

By comparing the center diagrams in Figs. 8 and 9, we can see that this extra current can be carried all right by the windings as they are reconnected for the lower voltage in Fig. 9. In this connection there are two circuits in parallel which, of course, will have twice the cross-sectional area of copper that the single circuits in Fig. 8 had.

If the number of poles in the machine is evenly divisible by 4—as, for example: 4, 8, 12, 16, etc.—

the winding may be connected in four parallel circuits, as shown in Fig. 10. By comparing this with

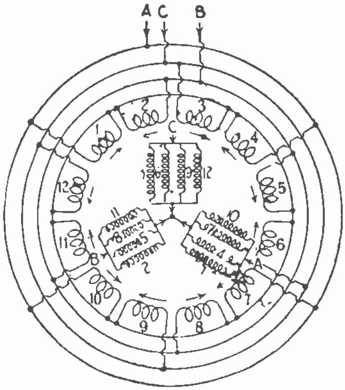


Fig. 10. Again we have the three-phase, four-pole winding. This diagram has all four poles of each phase connected in parallel and the three phase groups connected star as shown by the center sketch.

the connections and voltages of Figs. 8 and 9, we find it will be proper to operate the winding in Fig. 10 at 110 volts, and four times the current which was used in the connection in Fig. 8; which should maintain the same horse power. The increased current in this connection is again provided for by the four circuits in parallel.

On this same principle, if the number of poles of a machine can be evenly divided by 6, it will be possible to reconnect the windings for either three or six parallel groups, as shown in Figs. 11 and 12.

Before attempting to make such changes in connections, a check should be made to see if the winding can be connected for the desired number of circuits. A simple rule for this is that **the total number of poles must be evenly divisible by the number of circuits desired,** otherwise the winding cannot be changed to that connection.

8. SPECIAL CONNECTIONS FOR CONVENIENT VOLTAGE CHANGES

Inasmuch as some factories and plants may be supplied with more than one voltage for power purposes, manufacturers commonly supply motors that can easily be changed from one voltage to another; for example, 110 to 220 volts, or 220 to 440 volts; or from either of the higher voltages to the lower ones.

In most cases each winding is divided into two parts with suitable leads from each section brought outside the motor. These leads can be conveniently changed for either one or two voltages.

Practically all repulsion induction motors that use a spiral type winding are provided with this arrangement for two voltages. Fig. 13 shows the windings and terminal block of such a machine and the manner of changing the connections for either 110 or 220 volts. Two poles are connected in series with leads 1 and 4 brought out to the terminal

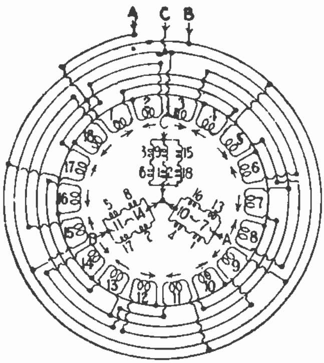


Fig. 11. This diagram shows a six-pole, three-phase winding with the six poles of each phase connected two in series and three in parallel, and then the three phase groups connected star.

block, and also two poles in series with leads 2 and 3. By simply changing the connections of the line leads and one or two short jumper wires at these terminals, the winding can be changed to operate on either of the two voltages given.

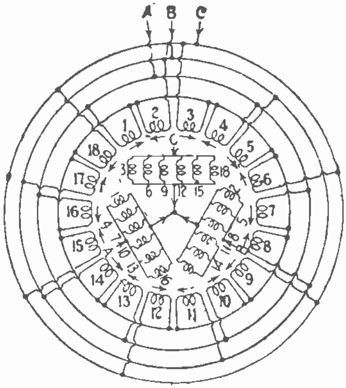


Fig. 12. In this case the six-pole, three-phase winding has all six poles of each phase connected in parallel and the three-phase groups connected star. These diagrams from 8 to 12 inclusive show aditional practical applications of series and parallel circuits to obtain different voltage and current capacities of machine windings.

A similar system is also used on two or three phase motors. Fig 14 shows the method of arranging the leads of a three-phase winding and the connections from the winding to the terminal block. The two small diagrams on the right-hand side of this figure show the method of changing the line and jumper connections to operate the motor on either 440 or 220 volts. In this figure the windings of the motor are represented by the heavy black lines arranged in the delta connection, with separate leads for each section of the winding brought out to the terminal block.

Fig. 15 shows a diagram of a star-connected stator winding, and the arrangement of the leads from the separate winding sections to the terminal block. The small sketches on the right-hand side of this figure also show the method of arranging the line leads and jumpers to change this machine for operation on either 220 or 440 volts.

9. CHANGE IN NUMBER OF PHASES

In certain emergency cases it is desirable to know how to change a motor from three-phase to two-phase operation, or vice versa. The following example will illustrate the procedure that should be used in making a change of this kind. Suppose we

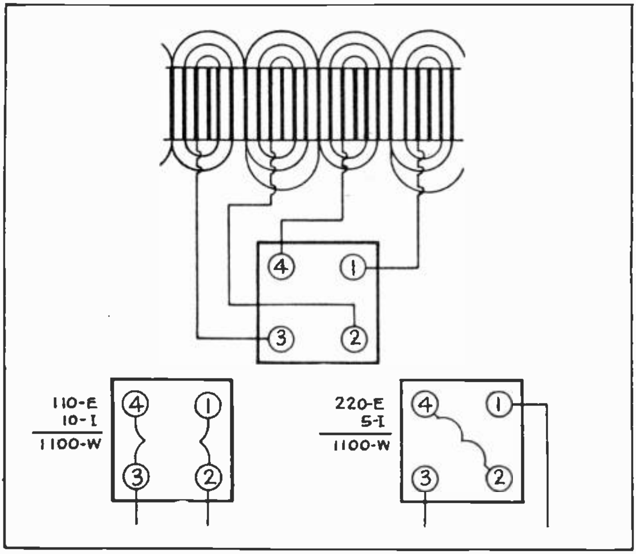


Fig. 13. This diagram shows how the terminals of a single phase winding can be arranged for convenient changing from series to parallel, so they can be operated on two different voltages.

have a machine that is connected three-phase and has 144 slots in the stator and a 24-pole winding. The coils are connected 4-parallel delta for 440 volts, and we wish to reconnect them for operation on two-phase at the same voltage. 144 coils connected for three-phase would have 144 ÷ 3, or 48, coils per phase. This would be connected for four-parallel circuits, so there would be 48 ÷ 4, or 12, coils in series across the line.

Remember that these 12 coils are connected in series on 440 volts, so we would have approximately 36⅔ volts applied to each coil in the original winding. This winding is to be regrouped for two-phase, which means that if it is connected single circuit there would be 144 ÷ 2, or 72, coils in series.

To maintain the same voltage on each coil, the same number of coils must be connected in series across the line as before; or $72 \div 12 = 6$ parallel circuits in which we must arrange the coils for the two-phase winding.

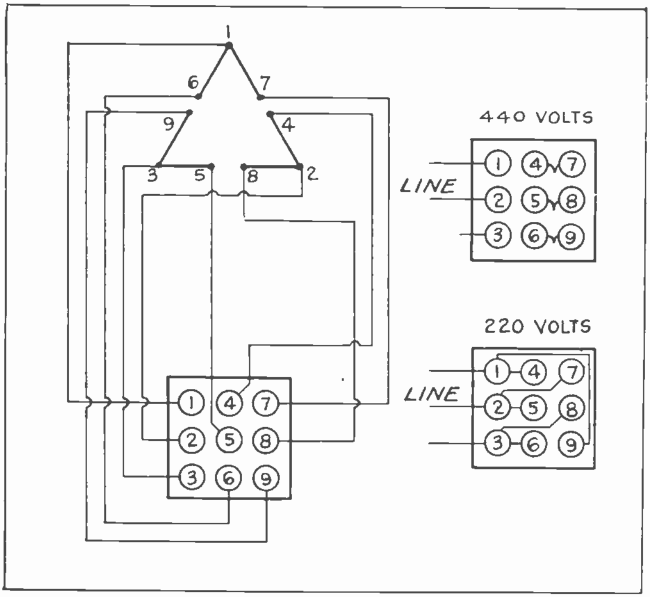


Fig. 14. Sketch showing the arrangement of the leads for a three-phase delta winding, and manner in which they can be arranged on a terminal block for convenient voltage changes.

According to the formula for determining coils per group, the three-phase winding would have $(144 \div 24) \div 3$ or 2 coils per group.

As a two-phase winding would have $(144 \div 24) \div 2$ or 3 coils per group, it will be necessary to reconnect some of the coil leads for this new grouping.

10. CHANGES IN FREQUENCY

Sometimes it is desired to change a motor which has been operating on one frequency so that it will operate on a circuit of another frequency. The most common frequency for alternating current circuits in this country nowadays is 60 cycles, but occasionally a 25-cycle circuit or one of some other odd frequency is encountered.

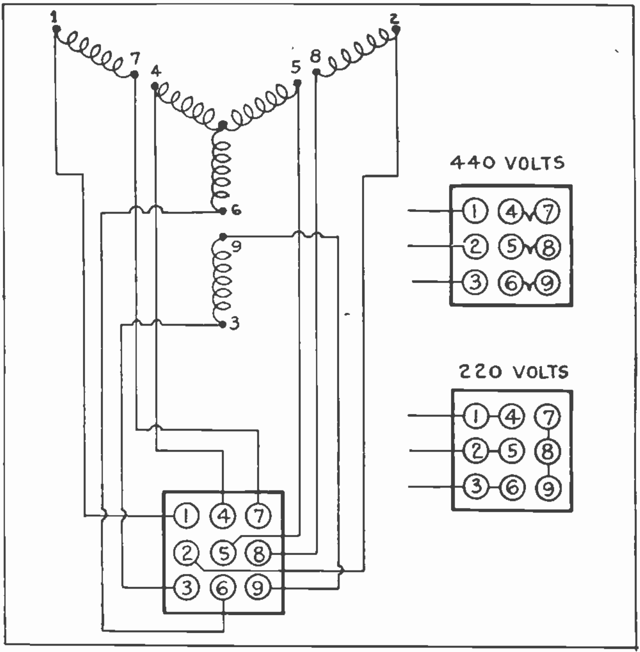


Fig. 15. The above diagram shows a winding which is connected star and has its leads all brought out to a terminal block for convenient change from 440 to 220 volts.

We have learned that when an induction motor is running, a rotating magnetic field is set up in the stator and that it is this field which induces the secondary current in the rotor and produces the motor torque; also that **this same rotating field cuts across the coils in the stator itself and generates in them a counter voltage which opposes the applied line voltage and limits the current through the winding.** The speed of field rotation governs the strength of the counter E.M.F., and therefore regulates the amount of current which can flow through the winding at any given line voltage.

There are two factors that govern the speed of rotation of this magnetic field. These are the number of poles in the winding and the frequency of the applied alternating current. The effects of changing the number of poles will be explained in a later article. **Any change that is made in the frequency of the current supplied to a motor should be offset by a change of voltage in the same direction, and in the same proportion.**

This should be done so the current through the coils will be kept at the same value. For example, if a motor is to be changed from 30 to 60 cycles, the nagnetic field will rotate twice as fast and the counter-voltage will be doubled. This means that if we are to maintain the same current value in the stator coils the line voltage should also be doubled. If the winding is to be operated on the same voltage at this higher frequency, the number of turns in each group across the line should be reduced to one-half the original number, in order to allow the same current to flow.

This procedure should, of course, be reversed when changing a motor to operate on a lower frequency.

The horse power of any motor is proportional to the product of its speed and torque or turning effort. So, when the frequency is varied and the stator flux kept constant, the horse power will vary directly with the change in speed.

11. CHANGING NUMBER OF POLES AND SPEED

It is very often desired to change the speed of motors for various jobs around manufacturing and industrial plants This can be done by changing the number of poles in the stator windings of A.C. motors.

The speed of an induction motor is inversely proportional to the number of poles; that is, if the number of poles is increased to double, the speed will decrease to one-half; or, if the poles are decreased to one-half their original number, the speed will increase to double. This rule assumes that the speed of the rotor will be the same as that of the revolving magnetic field. There is, however, a small amount of "**slip**" between the speed of the rotor and that of the revolving field. This causes the rotor to turn slightly slower than the field.

A very simple formula which can be used to determine the speed of the rotating field of such motors and the approximate speed of the rotor is as follows:

$$\frac{120 \times \text{frequency}}{\text{poles}} = \text{R.P.M.}$$

When changing the number of poles of an induction motor, if the voltage is varied in the same direction and same proportion as the change produced in the speed, the torque will remain practically the same and the horse power will vary with the speed. Therefore, the horse power increases with the higher speeds and decreases at lower speeds, in exact proportion to the change of speed.

12. SPECIAL CONNECTIONS FOR CONVENIENT SPEED CHANGES

Generally the change in the number of poles is confined to a variation of only one pair of poles, as for example, changing from 6 to 8 poles or from 10 to 12, etc. There are, however, specially built motors which have windings so connected that they can be changed from outside the motor by suitable arrangement of the leads and a switching device. Such motors can be changed to operate at either full speed or one-half of full speed.

Fig. 16 shows a lap three-phase winding which may be connected for either two or four poles by changing the connections of its leads outside the motor. This winding will produce the same torque at both speeds and will develop twice the power when running as a two-pole motor and the higher speed than it will develop as a four-pole motor and operating at the lower speed.

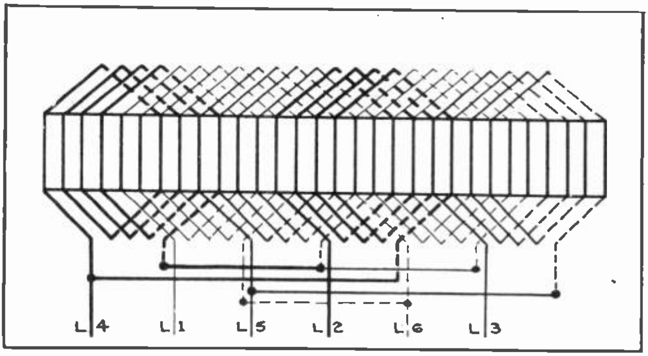


Fig. 16. A three-phase lap winding with six line leads brought out for convenient connection into either two or four poles. This enables the speed of the machine to be easily changed.

Six leads are brought outside the motor frame and the external connections should be made as follows: For two poles, connect the line leads to L 4, L 5, and L 6. Then connect L 1, L 2, and L 3 together. For four poles, connect line leads to L 1, L 2, and L 3, and leave L 4, L 5, and L 6 open or unconnected. This winding has two coil-groups per phase and when such a winding has as many groups in each phase as it has poles it is known as a **salient pole connection.**

You will notice that in the four-pole winding only two groups are used to build up four magnetic circuits in the stator. This is known as a **consequent pole connection.**

In connecting two-speed windings of this kind they are usually made fractional pitch for the high speed connection. When reconnecting windings for a different number of poles it will be necessary to change some of the group connections.

13. PROCEDURE OF RECONNECTING FOR CHANGE IN SPEED

The following example illustrates the necessary changes to make in reconnecting a machine for a different number of poles. Suppose we have a motor that has been operated at 300 R.P.M. on 25 cycles frequency. On inspecting the winding and connections we find that it is a 10-pole, 3-phase winding, connected series delta, and operating at 440 volts. We also find that the winding has 120 coils with a fractional-pitch coil-span of 1 to 12. Each group, therefore, has $(120 \div 10) \div 3$, or 4 coils. We wish to increase the speed of this motor 25% at the same voltage. 25% of 300 R.P.M., or the normal speed is 75; so the new speed should be 375 R.P.M.

To determine the number of poles that will be required for this speed we can use the formula:

$$\frac{120 \times \text{frequency}}{\text{speed}}$$

or, in this case, $$\frac{120 \times 25}{375} = 8$$

As the number of poles is to be changed, the coils per group must also be changed. This will be accomplished by reconnecting the coil leads; and, according to the formula for coil group, the number of coils for the new connection should be

$$(120 \div 8) \div 3 = 5 \text{ coils per group.}$$

After the coils have been regrouped the next factor to consider is the voltage. We have already said that the voltage will change directly with and in proportion to the speed; so that a 25% increase in speed will also produce a 25% increase over the original voltage, which in this case would be 440×1.25, or 550 volts. This would be the voltage necessary to use for the winding if it were left connected series delta. But, as we wish to operate the motor on the same voltage as before, some change must be made in the connections to permit it to be operated at 440 volts.

If we change the original connection of series delta to a two-parallel star connection, the voltage would then be $(550 \div 2) \times 1.732$, or 476 volts. If we consider the effect of the coil span on the voltage, we find that this will bring it about right with the 8 pole connection. The coil span already in the winding is 1 to 12, and, of course, will remain the same for the new connection, as we are only changing the connections and not the coils. Full pitch coil span for the 8 pole connection would be $(120 \div 8) + 1$, or a span of 1 to 16; or covering 15 slots.

Leaving the coil span at 1 to 12, makes it 4 slots less than full pitch, for the new 8 pole connection. As each pole group represents 180 degrees; then, with a coil span of 15 slots, each slot will represent $180 \div 15$, or 12 electrical degrees. The new coil span is 4 slots less than full pitch, and $4 \times 12 = 48$, the number of degrees less than full pitch. Full pitch would be 180 degrees; so $180 - 48 = 132$ electrical degrees for the new coil span.

We recall that the voltage changes with the sine of an angle of one-half the number of electrical degrees. One-half of 132 equals 66, and the sine of an angle of 66 degrees is .9135. This means that the correct voltage to apply to the new winding will be $476 \times .9135$, or 435 volts. This will be for all practical purposes near enough to the desired voltage.

EXAMINATION QUESTIONS

1. Name the two methods used in connecting the 6 leads coming from a three phase winding.

2. When connecting a three phase generator for highest voltage output would you use a Star or a Delta connection?

3. Which of the two connections, Star or Delta, has the greater current capacity? Why?

4. (a) Make a sketch showing how a star connection is made.

   (b) Also show by sketch how a Delta connection is made.

5. What is the advantage in using a fractional pitch winding?

6. What governs the limit beyond which we should not go when increasing the operating voltage of a motor by increasing the number of turns in series?

7. If the operating voltage of a motor is cut in half by reconnecting the windings, what change must take place in current carrying capacity in order to maintain the same horsepower output?

8. Give the formula for determining the speed of an induction motor.

9. What is meant by the term "slip" as applied to a motor?

10. What is the most common frequency used nowadays?

USE OF INSULATING VARNISH AND COMPOUNDS ON WINDINGS

All windings, whether D. C. or A. C., should be thoroughly impregnated with a good grade of **insulating varnish** before they are put into service.

This varnish serves several very important purposes. When properly applied it penetrates to the inner layers of the coils and **acts as extra insulation of the conductors, thereby increasing the dielectric strength of the insulation between them.** This compound within the coils and in their outer taping, **greatly reduces the liability of short circuits between conductors and of grounds to the slots or frame.**

When a winding is thoroughly saturated with insulating varnish and this varnish is properly hardened, **it adds a great deal to the strength of the coils and holds the conductors rigidly in place.** This prevents a great deal of vibration that would otherwise tend to wear and destroy the insulation, particularly in the case of alternating current windings where the alternating flux tends to vibrate the conductors when in operation.

Insulating varnish also prevents moisture from getting in the coils and reducing the quality of the insulation; and it keeps out considerable dust, dirt, and oil that would otherwise accumulate between the coils. Keeping out moisture, dust, and oil greatly prolongs the life of the insulation.

1. AIR DRY AND BAKING VARNISHES

There are many grades of insulating varnish, some of which require baking to "set" or harden them, and others which have in them certain liquids or solvents which make them dry and harden very quickly when exposed to air. The first type are called **baking** varnishes and the latter are called air **dry** varnishes.

Good air-dry insulating varnish will set or harden in from 20 to 30 minutes, but it should be allowed to dry out thoroughly for about 24 hours before the windings are put in service. Air dry varnish is not considered quite as good as the better grades of baking varnish. Therefore, the latter should be used wherever a bake oven or some means of applying heat is available.

2. METHODS OF APPLYING INSULATING VARNISH

There are three common methods by which insulating varnish can be applied to coils and windings. These are: **dipping, brushing,** and **spraying.**

Dipping is considered the best method and should be used for all small windings of stators and armatures, and for armatures and stator coils and field coils. To dip these coils or windings, a pan or tank of the proper size and depth will be required. Before dipping the windings they should be thoroughly dried out in a bake oven at about 212° F., in order to drive out all moisture and to heat the coils so that when they are dipped the varnish will rapidly penetrate to their inner layers.

The coils should be allowed to remain in the varnish until all bubbling has ceased. When they seem to have absorbed all the varnish possible they should be slowly withdrawn from the tank at about the same rate as the varnish flows from them of its own accord. This will give them a uniform coating with the least possible accumulation of varnish at the lower ends. They should then be allowed to drain until the varnish stops dripping and becomes partially set. The time required for this will depend on the size of the winding or coils.

When dipping a large number of small coils, considerable time can be saved by arranging a drip board set at an angle, so the coils can be hung above it and the varnish which drips from them will run down the board and back into the tank. With this method other coils can be dipped while the first set is draining.

After all the surplus varnish is drained from the coils they should be baked. When placing them in the oven it is a good plan to reverse their positions, so that any excess varnish on the bottom ends will tend to flow back evenly over their surface when first heated.

3. GOOD VENTILATION IMPORTANT WHEN BAKING

When a large number of coils are being baked at one time and practically fill the oven, trouble is sometimes experienced with insufficient ventilation. If the air inside the oven is not continually kept moving through the coils, and fresh air constantly

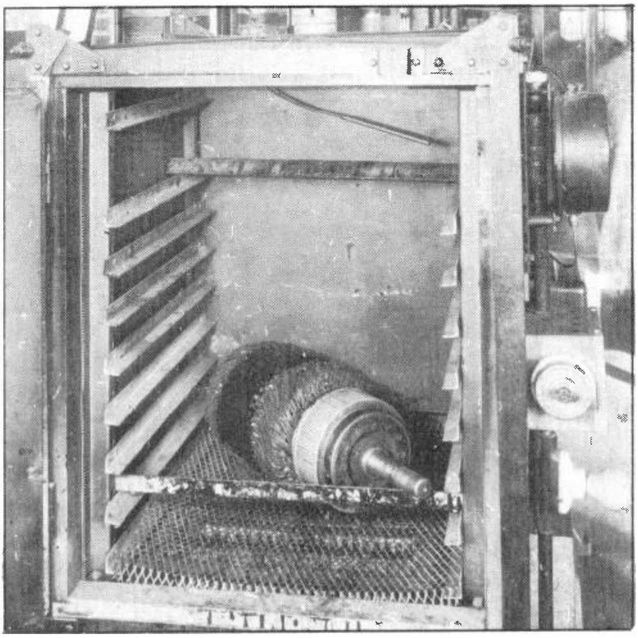


Fig. 1. This photo shows a D. C. armature in place in an electrical bake oven and ready for the insulating compound on the windings to be baked.

supplied, the vapors from the varnish will cause a green coating to form on the surface of the coils and greatly decrease the insulating qualities of the varnish. With large ovens small fans are sometimes used to force an air draft and insure good ventilation. Small ovens are usually provided with a chimney at the top and an air inlet at the bottom, so the heated air can rise and provide its own circulation.

Fig. 1 shows an electrical baking oven and a large D. C. armature to which a coat of varnish has been applied and which is ready for baking. This oven has an automatic temperature-control to keep the temperature uniform throughout the baking operation. Also note the ventilation chimney on top of the oven.

When applying the varnish with a brush, the winding should, if possible, be preheated to drive out the moisture and permit the varnish to flow deeper into the coils. Varnish can be applied with an ordinary paint brush, and this method is used where the dipping tank is not large enough to accommodate the windings, or where no dipping tank is available.

Spraying is used principally on large windings and gives a very good surface for a finishing coat.

The ends of coils should be given two or three coats of varnish as an added protection against mechanical damage and moisture, and to help prevent flash-overs to the frame of the machine.

4. PROPER TIME AND TEMPERATURES FOR BAKING

Fig. 2 shows a convenient table which gives the proper temperatures and approximate time in hours for baking insulating varnishes. You will note that when baking complete armature or stator windings more time is required to thoroughly bake the larger sizes. Also note that a slower baking produces a more elastic and better quality of insulation.

In emergency cases, where time is very important, the windings can be baked at the higher temperatures in a much smaller number of hours, but the varnish will be somewhat more brittle and inclined to crack or check when any strain is placed upon it. Never attempt to bake windings at temperatures very much higher than those given in the first column of this table, or you are likely to damage the insulation already on the coils. When a job doesn't need to be rushed, it is much better to bake it at the lower temperatures and for the longer periods given in the table, which will give a much more durable and dependable insulation.

In addition to the advantages already mentioned for this form of insulation, it also provides a smoother surface on the windings and coils, making them much easier to clean, either by means of a brush, compressed air, or by washing them with a mixture of carbon-tetra-chloride and gasoline or some such solution to remove grease and oil.

Fig. 3 shows a stator winding heavily coated with a solid mass of insulating compound applied by repeated dipping. Note the rugged protection this gives the winding. To remove a winding which has been treated in this manner it is necessary to heat it first, in order to soften the compound.

Size of Armature or Stator Core Diameter	248° F. Quick Baking	224° F. Elastic Baking	212° F. Extra Elastic Baking
Under 6 Inches	4 to 6 hrs.	6 to 8 hrs.	8 to 10 hrs.
6 to 12 Inches	12 hrs.	24 hrs.	36 hrs.
12 to 18 Inches	24 hrs.	36 hrs.	48 hrs.
18 to 24 Inches	36 hrs.	48 hrs.	60 hrs.

Fig. 2. This convenient table gives the proper temperature and time in hours for baking insulation of windings of different sizes.

5. TROUBLES OF INDUCTION MOTOR WINDINGS

By far the greater number of defects which occur in windings during service or operation are caused by **short circuits, open circuits, and grounds.** Water may have found its way into the coils, or oil from the bearings may have destroyed the quality of the insulation. Metallic dust and grit sometimes work into the windings and cause short circuits; or a static charge from a belt-driven machine may cause punctures or small pin holes in the insulation, which results in flash-overs and grounds.

Any one of the above mentioned faults is also likely to show up just after a motor has been rewound or repaired. So, if a machine doesn't operate properly after having been rewound, it is quite

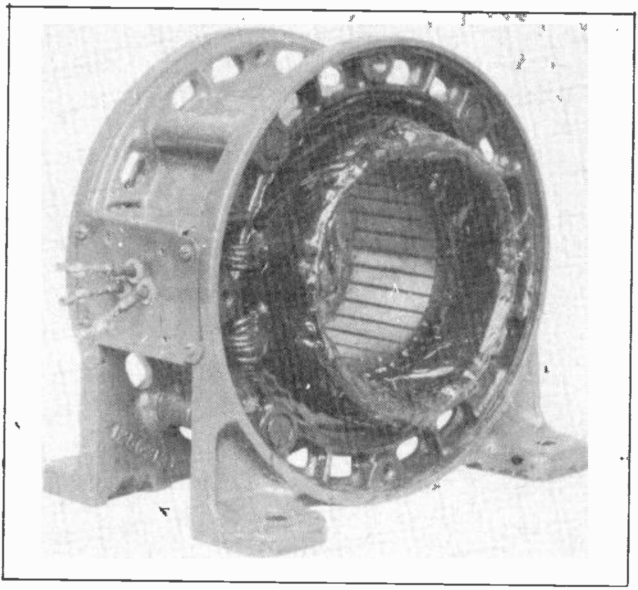


Fig. 3. The above photo shows a stator winding heavily impregnated with insulating compound. Note how insulation of this type affords mechanical strength and protection to the windings and would also prevent dirt, oil and moisture from getting in between the coils.

likely that some of the coils are connected wrong or that there is a short, open, or ground in some coils because of work carelessly done in the repair shop.

The average small induction motor when running properly is almost noiseless, and even in the larger motors only a uniform, gentle humming should be heard. This humming noise is due largely to vibration of core laminations, which are caused to vibrate slightly by the reversals of the magnetic field. This vibration will be in synchronism with the frequency of the alternating current in the windings. In addition to this humming, which is unavoidable even in the best of motors, there is also a slight whistling noise caused by the fan blades on the rotor, friction of the air with the revolving parts, and air passing through ventilation ducts. This air whistling is harmless and it will continue for a short period after the current is shut off and while the machine is still turning. If a motor is unusually noisy there is probably some defect responsible for the noise.

A deep, heavy growling is usually caused by some electrical trouble resulting in an unbalanced condition of the magnetic field in the windings.

If a shock is felt when the frame is touched it is quite definite evidence that one or more coils in the winding are grounded to the core or frame. This is a very dangerous condition with any voltage and particularly so with voltages above 220. A grounded coil on a 440-volt machine may result in a very dangerous shock, and it is for this reason that **the frames of motors should be grounded when the machines are installed.**

When the frames are grounded in this manner and a coil does become grounded, it will usually blow a fuse, thus indicating a defect at once.

Fig. 4 is a diagram of a three-phase winding in which are shown a number of the more common faults occurring in such windings. These faults are numbered and listed for your convenience in locating them.

1. The last coils in the second and fourth groups of phase "A" are grounded.

2. The last coil in the third group of phase "A" is shorted.

3. The start and finish leads of the first coil in the second group of phase "A" are shorted together at the stubs.

4. The last coil in the fourth group of phase "B" is open.

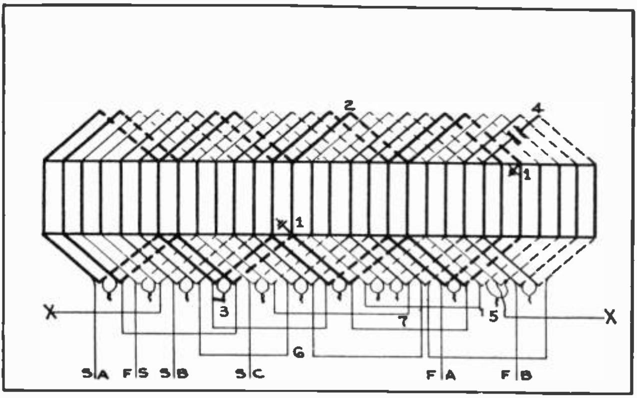


Fig. 4. The above is a diagram of a three-phase winding in which are shown a number of the more common faults that occur in stator windings.

5. The last coil in the third group of phase "C" is reversed.

6. The second coil group of phase "B" is reversed.

7. The second coil group of phase "C" and third coil group of phase "B" have wrong numbers of coils connected in them.

8. Another fault known as "reversed phase" occurs when the three starts are spaced in the wrong position. This fault is not shown in this sketch.

The following paragraphs describe in detail the methods of testing to locate these faults and also the method of correcting them.

6. GROUNDED COILS

The usual effect of one grounded coil in a winding is the repeated blowing of a fuse when the line switch is closed. That is, providing the machine frame and the line are both grounded. Two or more grounds will give the same result and will also short out part of the winding in that phase in which the grounds occur. A quick and simple test to determine whether or not a ground is present in the winding, can be made with the test outfit shown in Fig. 5. This test set consists of several dry cells connected in series with a small test lamp and pair of test leads.

In place of the dry cells and low-voltage lamp, we can use two test leads connected to a 110-volt line and with a 10-watt lamp in series. In testing with such a set, place one lead on the frame and the other in turn on each of the line wires leading from the motor. The line switch should, of course, be open before making any test. If there is a grounded coil at any point in the windings the lamp will indicate it by lighting.

To locate the phase that is grounded, test each phase separately. In a three-phase winding it will be necessary to disconnect the **star** or **delta** connections. After the grounded phase is located the

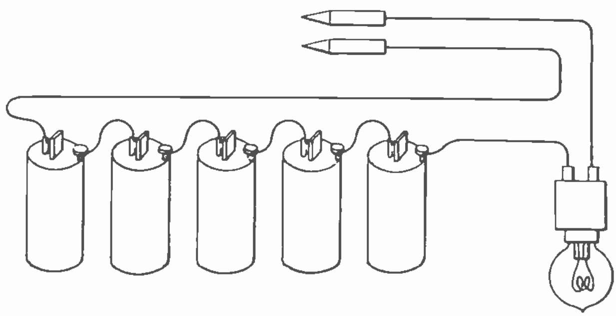


Fig. 5. Several dry cells in series with a low voltage test lamp and a pair of test leads or "points" make a very convenient test outfit for locating a number of the troubles in motor windings.

pole-group connections in that phase can be disconnected and each group tested separately. When the test leads are placed one on the frame and the other on the grounded coil group, the lamp will indicate the ground in this group by again lighting. The stub connections between the coils and this group may then be disconnected and each coil tested separately until we locate the exact coil that is grounded.

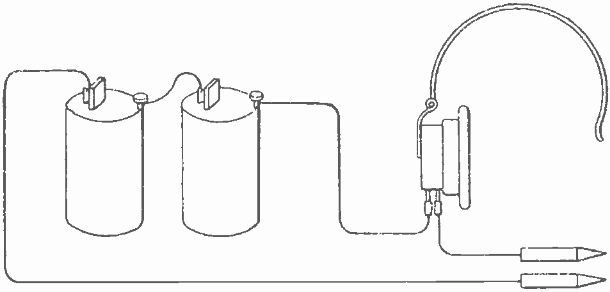


Fig. 6. A telephone receiver can also be used in series with dry cells and test leads for locating high resistance grounds occuring in windings.

7. HIGH RESISTANCE GROUNDS

Sometimes moisture in the insulation around the coils, or old and defective insulation will cause a high-resistance ground that is difficult to detect with a test lamp. In this case we can use a test outfit consisting of a telephone receiver and several dry cells connected in series, as shown in Fig. 6. Such a test set will detect a ground of very high resistance, and this set will often be found very effective when the ordinary test lamp fails to locate the trouble.

8. REPAIRS FOR GROUNDED COILS

When the grounded coil is located it should either be removed and reinsulated, or cut out of the circuit, as shown in Fig. 7. At times it is inconvenient to stop a motor long enough for a complete rewinding or permanent repairs. In such cases, when trouble develops it is often necessary to make a temporary repair until a later time when the motor may be taken out of service long enough for rewinding or permanent repairs.

The sketch in Fig. 7 shows a coil group consisting of the three coils on the left. The single coil on the right is the first one of the following group which is not all shown in this sketch. Coil 2 is de-

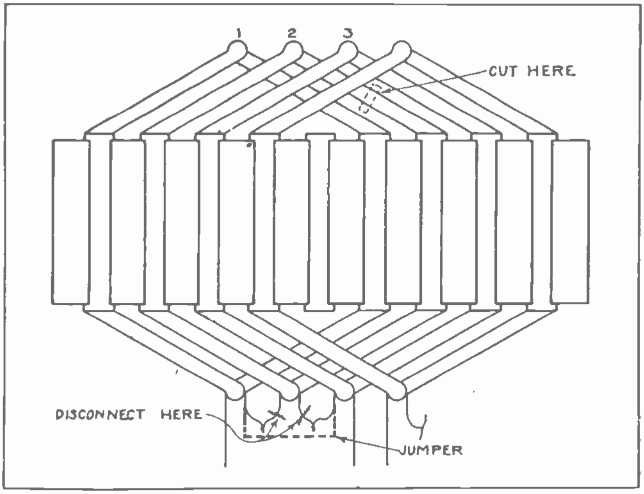


Fig. 7. This diagram illustrates the method of cutting out a defective coil with a jumper. In this manner a machine can be quickly repaired and kept in service until such time as the defective coil can be replaced.

fective and the temporary repair will be the same whether the fault is a short, an open, or a ground. A jumper wire of the same size as that used in the coils, is connected to the bottom lead of coil 1, and across to the top lead of coil 3, leaving coil 2 entirely out of the circuit. Coil 2 should then be cut at the back of the winding, as shown by the dotted lines in the sketch. If the defective coil is grounded it should also be disconnected from the other coils, as shown on the diagram.

9. ONE OR MORE TURNS SHORTED TOGETHER

Shorted turns within coils are usually the result of failure of the insulation on the wires. This is frequently caused by the wires being crossed and having excessive pressure applied on the crossed conductors when the coils are being inserted in the slot. Quite often it is caused by using too much force in driving the coils down in the slots. In the case of windings that have been in service for several years, failure of the insulation may be caused by oil, moisture, etc. If a shorted coil is left in a winding it will usually burn out in a short time and, if it is not located and repaired promptly, will probably cause a ground and the burning out of a number of other coils.

One of the most practical ways of locating a shorted coil is by the use of a growler and thin piece of steel, similar to the method described for D. C. armatures. Fig. 8 shows a sketch of a growler in use in a stator. Note that the poles are shaped to fit the curvature of the teeth inside the stator core. **The growler should be placed in the core as shown and the thin piece of steel should be placed the distance of one coil span away from the center of the growler.** Then, by moving the growler around the bore of the stator and always keeping the steel strip the same distance away from it, all of the coils can be tested.

Fig. 9 shows a photo of a growler in use on a large stator. The steel strip is held over the slot the proper distance from the growler for the size of coils or coil span used in this case.

If any of the coils has one or more shorted turns the piece of steel will vibrate very rapidly and cause a loud humming noise. By locating the two slots over which the steel will vibrate, we can find both sides of the shorted coil. If more than two slots cause the steel to vibrate, they should all be marked and all shorted coils should be removed and replaced with new ones, or cut out of the circuit as previously described.

10. SHORTED COIL GROUPS

Sometimes one coil or a complete coil group becomes short circuited at the stubs or end connections. The test for this fault is the same as that for a shorted coil. If all the coils in one group are shorted it will generally be indicated by the vibration of the steel strip over several consecutive slots, corresponding to the number of coils in the group.

The stub connections should be carefully examined and those that appear to have poor insulation should be moved during the time that the test is being made. It will often be found that when the shorted stub connections are moved during the test the vibration of the steel will stop. If these stubs are reinsulated the trouble should be eliminated.

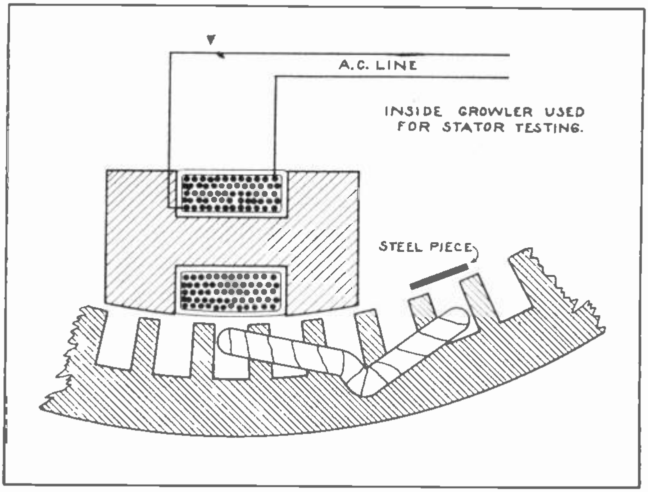


Fig. 8. The above view shows the manner in which a growler can be used to induce current in a shorted coil and indicate the short circuits by vibration set up in the steel strip at the right. This is a very simple and effective method of locating short circuits.

11. OPEN COILS

When one or more coils become open-circuited by a break in the turns or a poor connection at the stubs, they can be tested with a test lamp and dry cell such as previously shown and explained. If this test is made at the ends of each winding, an open can be detected by the lamp failing to light. The insulation should be removed from the pole-group connections and each group should be tested separately. After locating the coil group that is open, untape the coils between that group and test each coil separately. In making this test it is not necessary to disconnect the splices or connections.

In many cases the open circuits will be at the coil ends or stubs, due to a loose connection or broken conductor. If the trouble is at this point it can usually be located by careful observation and checking. If the trouble is a loose connection at the stub, it can be repaired by resoldering the splices; but if it is within the coil, the coil should either be replaced or have a jumper placed around it, as shown in Fig. 7 until a better repair can be made.

12. REVERSED CONNECTIONS

Reversed coils cause the current to flow through them in the wrong direction. This fault usually manifests itself—as do most irregularities in winding connections—by a disturbance of the magnetic circuit, which results in excessive noise and vibration. The fault can be located by the use of magnetic compass and some source of low-voltage, direct current. This voltage should be adjusted so it will send about one-fourth to one-sixth of full load current through the winding; and the D. C. leads should be placed on the start and finish of one phase. If the winding is three-phase, star-connected, this would be at the start of one phase and the star point. If the winding is delta-connected, the delta must be disconnected and each phase tested separately.

Place a compass on the inside of the stator and test each of the coil groups in that phase. If the phase is connected correctly, the needle of the compass will reverse definitely as it is moved from one coil group to another. However, if any of the coils is reversed the reversed coil will build up a field in the opposite direction to the others, thus

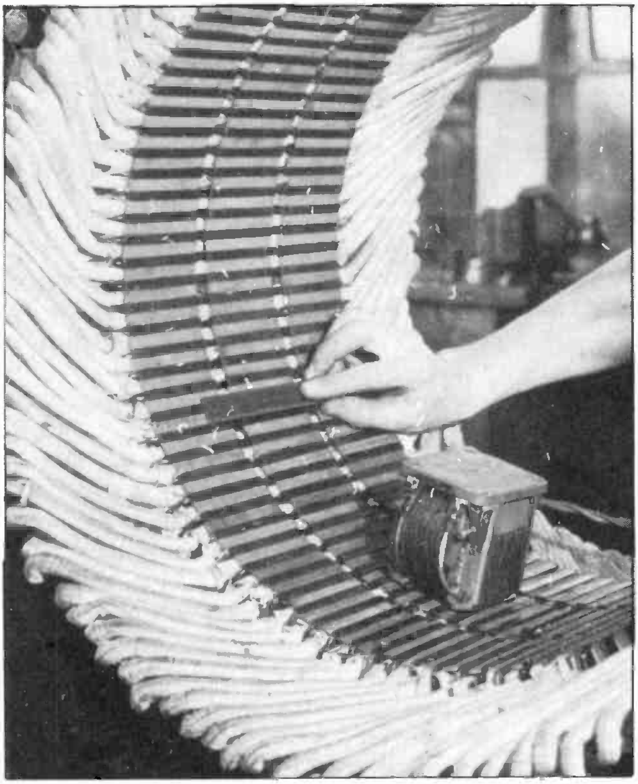


Fig. 9. This photo shows a growler in use in a large stator. Note the size and shape of these coils and the position of the steel strip which is just the width of one coil from the center of the growler.

causing a neutralizing effect which will be indicated by the compass needle refusing to point definitely to that group. If there are only two coils per group there will be no indication if one of them is reversed, as that group will be completely neutralized.

13. REVERSED COIL GROUPS

When an entire coil group is reversed it causes the current to flow in the wrong direction in the whole group. The test for this fault is the same as that for reversed coils. The winding should be magnetized with direct current, and when the compass needle is passed around the coil groups they should indicate alternately N. S., N. S., etc. If one of the groups is reversed, three consecutive groups will be of the same polarity. The remedy for either reversed coil groups or reversed coils, is to make a visual check of the connections at that part of the winding, locate the wrong connection, and reconnect it properly.

When the wrong number of coils are connected in two or more groups, the trouble can be located by counting the number of stubs on each group. If any mistakes are found they should be remedied by reconnecting properly.

14. REVERSED PHASE

Sometimes in a three-phase winding a complete phase is reversed by either having taken the starts from the wrong coils or by connecting one of the windings in the wrong relation to the others when making the star or delta connections. If the winding is connected delta, disconnect any one of the points where the phases are connected together, and pass current through the three windings in series. Place a compass on the inside of the stator and test each coil group by slowly moving the compass one complete revolution around the stator.

The reversals of the needle in moving the compass one revolution around the stator should be three times the number of poles in the winding.

In testing a star-connected winding, connect the three starts together and place them on one D. C. lead. Then connect the other D. C. lead and star point, thus passing the current through all three windings in parallel. Test with a compass as explained for the delta winding. The result should then be the same, or the reversals of the needle in making one revolution around the stator, should again be three times the number of poles in the winding.

These tests for reversed phases apply to full-pitch windings only. If the winding is fractional-pitch, a careful visual check should be made to determine whether there is a reversed phase or mistake in connecting the star or delta connections.

15. TESTING SPLIT-PHASE MOTORS

If a split-phase motor fails to start when a line switch is closed, the trouble may be due to one or several of the following faults:

1. Tight or "frozen" bearings.
2. Worn bearings, allowing the rotor to drag on the stator.
3. Bent rotor shaft.
4. One or both bearings out of alignment.
5. Open circuit in either starting or running windings.
6. Defective centrifugal switch.
7. Reversed connections in either winding.
8. Grounds in either winding or both.
9. Shorts between the two windings.

16. TIGHT OR WORN BEARINGS

Tight bearings may be caused by failure of the lubricating system; or, when new bearings are installed, they may run hot if the shaft is not kept well oiled.

If the bearings are worn to such an extent that they allow the rotor to drag on the stator, this will usually prevent the rotor from starting. The inside of the stator laminations will be worn bright where they are rubbed by the rotor. When this condition exists it can generally be easily detected by close observation of the stator field and rotor surface when the rotor is removed.

17. BENT SHAFT AND BEARINGS OUT OF LINE

A bent rotor shaft will usually cause the rotor to bind when in a certain position and then run freely until it comes back to the same position again. An accurate test for a bent shaft can be made by placing the rotor between centers on a lathe and turning the rotor slowly while a tool or marker is held in the tool post close to the surface of the rotor. If the rotor wobbles it is an indication of a bent shaft.

Bearings out of alignment are usually caused by uneven tightening of the end-shield plates. When placing end-shields or brackets on a motor, the bolts should be tightened alternately, first drawing up two bolts which are diametrically opposite. These two should be drawn up only a few turns, and the others kept tightened an equal amount all the way around. When the end shields are drawn up as far as possible with the bolts, they should be tapped tightly against the frame with a mallet and the bolts again tightened.

18. OPEN CIRCUITS AND DEFECTIVE CENTRIFUGAL SWITCHES

Open circuits in either the starting or running winding will cause the motor to tail to start. This fault can be detected by testing across the start and finish of each winding with a test lamp.

A defective centrifugal switch will often cause considerable trouble that is difficult to locate, unless one knows where to look. If the switch fails to close when the rotor stops, the motor will not start when the line switch is closed. Failure of the switch to close is generally caused by dirt, grit, or some other foreign matter getting into the switch mechanism; or by weakened springs on the switch. The switch should be thoroughly cleaned with gasoline and then inspected for weak or broken springs.

If the winding is on the rotor, the brushes sometimes stick in the holders and fail to make good contact with the slip rings. This causes sparking at the brushes. There will probably also be a certain place where the rotor will not start until it is moved far enough for the brush to make contact on the ring. The brush holders should be cleaned, and the brushes carefully fitted so they move freely with a minimum of friction between the brush and the holders. If a centrifugal switch fails to open when the motor is started, the motor will probably growl and continue to run slowly, and the starting winding will burn out if not promptly disconnected from the line by a fuse or switch. This is also likely to be caused by dirt or hardened grease in the switch.

19. REVERSED CONNECTIONS AND GROUNDS

Reversed connections are caused by improperly connecting a coil or group of coils. The wrong connections can be found and corrected by making a careful check of the connections and reconnecting those that are found wrong. The test with D. C. and a compass can also be used for locating reversed coils. Test the starting and running windings separately exciting only one winding at a time, with the direct current. The compass should show alternate poles around the winding.

The operation of a motor that has a ground in the windings will depend on where the ground is, and whether or not the frame is grounded. If the frame is grounded then when the ground occurs in the winding it will usually blow a fuse. A test for grounds can be made with a test lamp and dry cells, or a 110-volt lamp and leads. One test lead should be placed on the frame and the other on a lead to the winding. If there is no ground the lamp will not light. If it does light, it indicates a ground due to a defect somewhere in the insulation.

20. SHORT CIRCUITS

Short circuits between the two windings can also be detected by the use of a test lamp. Place one of the test leads on one wire of the starting winding and the other test lead on the wire of the running winding. If these windings are properly insulated from each other the lamp should not light. If it does light, it is a certain indication that there is a short between the windings. Such a short will usually cause part of the starting winding to burn out. The starting winding is always wound on top of the running winding; so, if it becomes burned out due to a defective centrifugal switch or a short circuit, the starting winding can be conveniently removed and replaced without disturbing the running winding.

Single phase motors are very simple to rewind, and in many localities there are a great number to be rewound or repaired each year. Many of them need only to have the centrifugal switches cleaned and adjusted, or fitted with new springs. Others have only a loose or grounded connection which can be quickly repaired.

Many students or graduates start a fine business of their own, or make considerable money in their spare time from their regular job, by repairing small motors of fans, washing machines, and others. With a few lbs. of wire and a little insulation material many men do this work right at home in their own basements or garages.

In many cases you can get old motors of both small and large sizes, that the owners have planned to discard because they did not know they could be rewound or knew no one nearby who could rewind them. Such cases are splendid opportunities for you to get additional experience and practice and to get started in this line of work if you choose.

In any case, let us again emphasize the importance of applying the instructions covered in your lessons, and keeping familiar with them by frequent reference to them for any question or problem of this nature which you may have.

You are very likely to find a knowledge of armature winding, connecting and testing very valuable on some job when you least expect it.

Welcome every opportunity to get added experience of this nature, and if you do your work properly and use your lessons frequently, you should be able to make a definite success of many profitable jobs of armature winding or testing.

21. GROWLER SPECIFICATIONS

Laminations designed for use in making small transformers may be used to good advantage in constructing a growler for use in testing armatures or stators.

Fig. 12 shows how the laminations may be trimmed and arranged for use in constructing a growler for use in testing either armatures or stators.

After the laminations are trimmed as shown by the dotted lines they are stacked as shown in Fig. 12-B so as to form the letter "H." Place the piece with the center bar attached on the work bench and then butt the "I" piece against the center bar as shown. The next two laminations are reversed so as to break joints. That is, if the "I" piece is on the right for the first layer it should be on the left for the next layer, and so on. Continue stacking the laminations alternately on first one side and then the other until you have a stack about one inch high.

The laminations must then be bound together either with bolts or by use of a clamp as shown at "C" in Fig. 12. Two pieces of fibre or wood about 3 inches long with a hole in each end may be used as a clamp. After the core is assembled it should be carefully insulated. The part of the core which will come in contact with the wire should be cov-

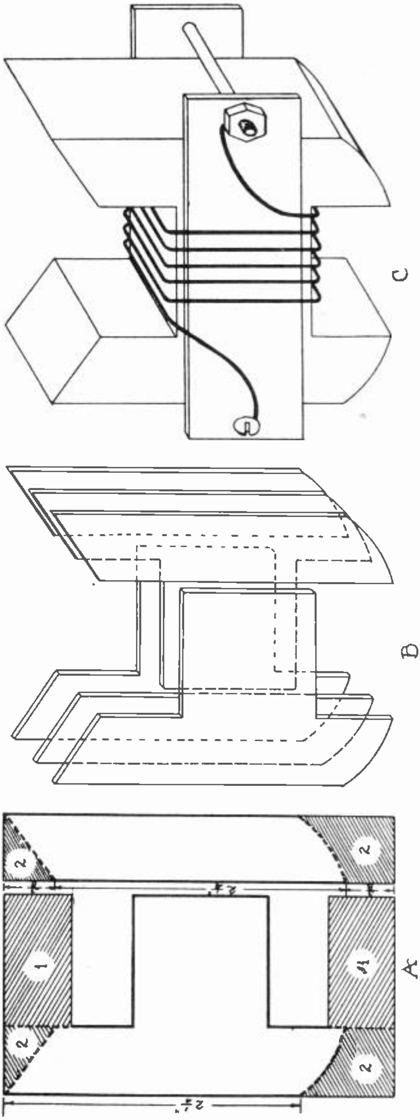


Fig. 12. This figure shows how a combination growler may be constructed from "E and I" transformer laminations. The shaded parts marked 1 are cut off first and then the shaded corners marked 2 are trimmed off.

ered with a layer of varnished cambric or oiled paper. The cambric may be wound around the core and over the fibre strips.

The 110 volt A. C. Winding consisting of No. 34 S. C. E. wire should be carefully wound on the center part of the core as shown in the Fig. 12-C. Terminals should be provided on the fibre clamp so that the ends of the coil may be attached to them, or the two binding posts may be used as terminals as shown by the drawing.

The coil should be wound with about 2,000 turns of No. 34 wire. About 2 oz. of wire will be required.

After the coil is completed it may be dipped in insulating varnish, or if varnish is not available it should be wound with tape to protect the coil.

This little growler will be very serviceable in testing small and medium sized armatures or stators.

Fig. 13 contains complete constructional data for a growler which is very desirable for use in large shops where a large number of armatures are tested.

Fig. 14 shows complete constructional data for a growler to be constructed from laminations 3½" x 4¼". The laminations are stacked together to form a stack about 1 inch high. They are then bolted together with a strip of wood on each side of both ends. These binding bolts should be ¼" x 2¼". The 4 pieces of wood may be cut from strips of wood 3¼" long by 1" wide by ½" thick. The two base supports are 5 inches long by 1¼ inches wide by 1 inch thick. The base supports are fastened to the upright strips by wood screws inserted through the bottom.

Varnished cambric or some other good grade of insulation should completely cover all parts of the iron core which will come in contact with the coil.

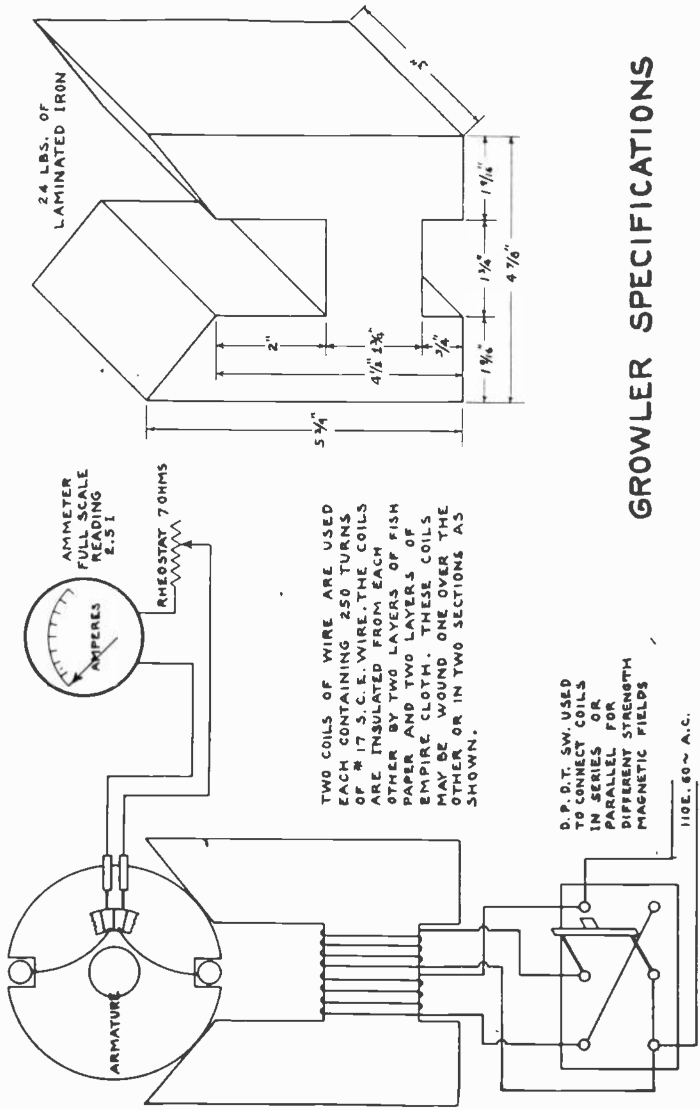

24 LBS. OF
LAMINATED IRON
5"
1 9/16"
1 3/4"
1 9/16"
4 7/8"
2"
1 3/4"
3/4"
4 1/2"
5 3/4"
GROWLER SPECIFICATIONS
AMMETER
FULL SCALE
READING
2.5 I
AMPERES
RHEOSTAT 7 OHMS
TWO COILS OF WIRE ARE USED
EACH CONTAINING 250 TURNS
OF # 17 S.C.E. WIRE. THE COILS
ARE INSULATED FROM EACH
OTHER BY TWO LAYERS OF FISH
PAPER AND TWO LAYERS OF
EMPIRE CLOTH. THESE COILS
MAY BE WOUND ONE OVER THE
OTHER OR IN TWO SECTIONS AS
SHOWN.
D.P.D.T. SW. USED
TO CONNECT COILS
IN SERIES OR
PARALLEL FOR
DIFFERENT STRENGTH
MAGNETIC FIELDS
110E. 60~ A.C.
ARMATURE

Fig. 13.

Armature Winding

The coil should be wound around the center leg of the core as shown by Fig. 14. About 2 oz. of No. 31 S. C. E. wire will be required for the coil.

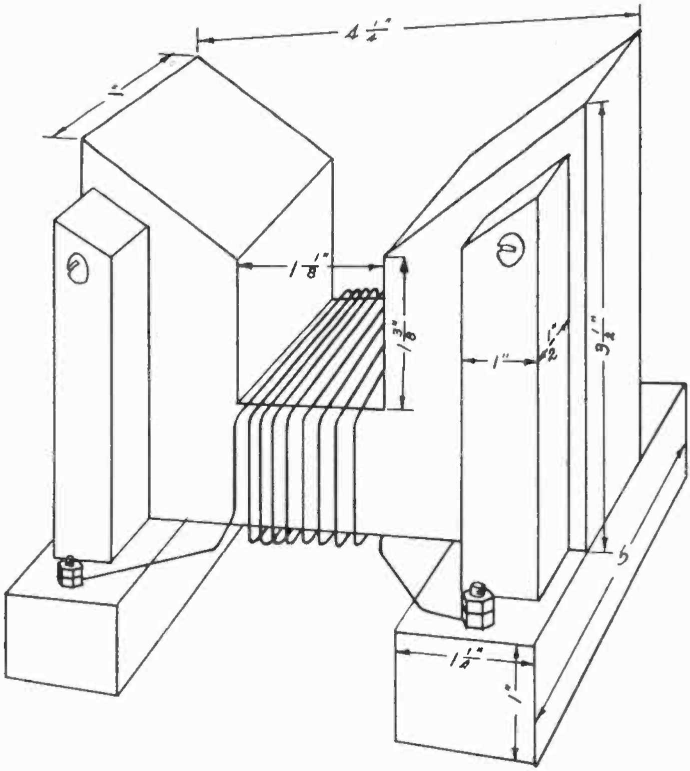


Fig. 14. A medium sized growler for armature testing.

Binding posts may be mounted on the base strips to accomodate the ends of the coil, and for connection of the 110 volt A. C. line.

EXAMINATION QUESTIONS

1. Give two advantages of using insulating varnish on armature windings

2. (a) Name three methods which may be used in applying insulating varnish.

   (b) Which method is considered best?

3. Why is good ventilation necessary when baking armatures?

4. How many hours would be required for baking a 16 inch armature in an oven with a temperature of 224°?

5. Why should motor frames be grounded?

6. What happens when a coil becomes grounded in a motor on which the frame and line are properly grounded?

7. What kind of a test outfit may be used in locating high resistance grounds?

8. When using an inside growler for locating shorts in a stator winding, where should the steel strip be located with respect to the growler?

9. Give at least three good reasons why a split-phase motor would fail to start.

10. Name two of the most common troubles which cause a centrifugal switch to fail.

ALTERNATING CURRENT METERS

Ordinary A. C. meters consist of: The moving element, which is delicately balanced and mounted in jeweled bearings and has the pointer or needle attached to it; a controlling force or spring to limit the movement of the pointer and movable element; a stationary coil or element to set up a magnetic field; a damping vane or element to prevent vibration or excessive "throw" of the pointer; and the meter scale and case.

One of the principal differences between A. C. meters and D. C. meters is that, while certain types of D. C. meters use permanent magnets for providing the field in which the moving element rotates, A. C. meters use coils instead.

Some types of A. C. meters also operate on the induction principle, which is not used in D. C. meters.

1. TYPES OF A. C. METERS

There are several different types of A. C. meters each of which uses different principles to obtain the torque for moving the pointer. Some of the most common of these types are: The moving-iron repulsion type; inclined coil and moving vane type; dynamometer type; induction type; and hot-wire type.

Some types of A. C. meters can also be used on D. C. circuits with fair results, but they are usually not as accurate on D. C.

2. MOVING IRON TYPE INSTRUMENTS

The moving-iron principle used in some makes of A. C. voltmeters and ammeters is illustrated by the several views in Fig. 1. This is one of the simplest principles used in any type of alternating current meter, and is based upon the repulsion of two soft pieces of iron when they are magnetized with like polarity.

If two pieces of soft iron are suspended by pieces of string within a coil, as shown in the upper left-hand view of Fig. 1, and current is passed through this coil, the flux set up within the turns will magnetize the two parallel pieces of iron with like poles at each end. The repulsion of like poles will cause the two iron strips to push apart, as shown in the top center view. This effect will be produced with either D. C. or A. C. flowing in the coil, because it makes no difference if the poles of the iron strips do reverse, as long as like poles are always created together at the top and bottom ends of each strip.

The view at the upper right shows the poles reversed, and the strips still repel as before. They must, of course, be made of soft iron so their polarity can reverse rapidly with the reversal of the A. C.

Now, if the two iron strips are again suspended in a horizontal coil, as shown in the lower left view, and one of the strips is in this case rigidly attached to the side of the coil and the other suspended by a string so that it is free to move, the strips will again repel each other or push apart when current is passed through the coil, as shown in the lower center view.

The view at the lower right shows how this principle can be applied to move the pointer of the meter. One small piece of soft iron is attached to the coil in a fixed position as shown. The other piece is attached to the movable element or pointer, which is mounted on a shaft and pivots, so it is free to move.

When alternating current is passed through the coil, the two iron vanes are magnetized with like poles, and the repulsion set up between them causes the movable one to rotate in a clockwise direction and move the pointer across the scale.

3. A. C. VOLTMETERS AND AMMETERS

This principle and method of construction can be used for both voltmeters and ammeters, by simply making the coil of the proper resistance and number of turns in each case.

A. C. ammeter coils usually consist of a very few turns of large wire, as they are connected in series with the load or to the secondary of a current transformer. Ammeters designed for use with shunts or current transformers, however, usually have coils of smaller wire and a greater number of turns.

Voltmeter coils are wound with a great number of turns of very fine wire, in order to obtain high

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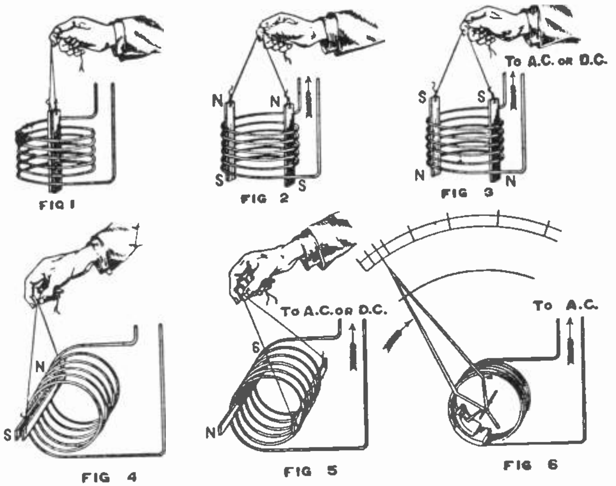


Fig 1. The above views illustrate the principle of the moving-iron type meter. Note how the iron bars repel each other when they are magnetized with like poles, by the flux of current through the coils.

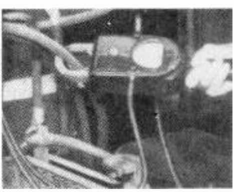


Fig. 2.A The hook-on voltammeter is a particularly handy instrument for measuring alternating current and a-c voltage.

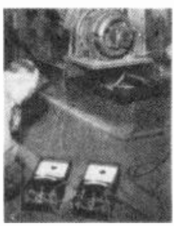


Fig. 2.B Proper position of portables for reading.

Fig. 2.C DON'T use instruments near strong fields such as the cables shown here which are connected to a generator.

enough resistance so they can be connected directly across the line.

Separate resistance coils are sometimes connected in series with the coils of voltmeters to provide sufficient resistance to limit the current through them to a very small amount. The current required to operate a voltmeter usually does not exceed a very few milli-amperes.

For damping the pointer movement some instruments use a small aluminum disk which is attached to the pointer and moves between the poles of a permanent magnet. This operates similarly to the damping disk and magnet explained for D. C. watt-hour meters, the retarding effect being produced by the eddy currents induced in the disk.

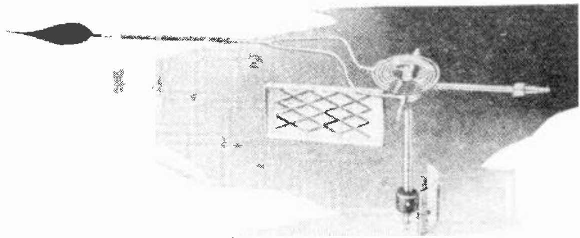


Fig. 3. Moving element of an iron-vane type meter. This view shows the shaft, iron vane, damping vane, pointer, and spring.

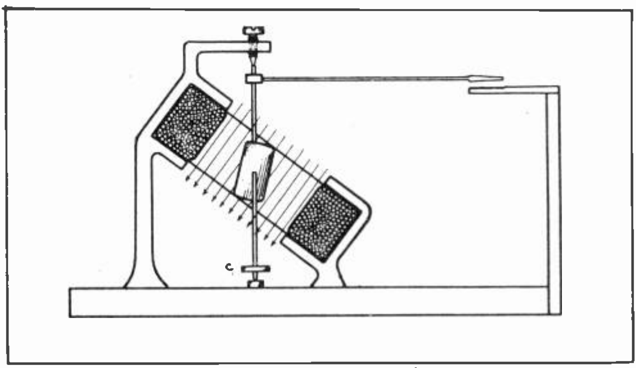


Fig 4. The above diagram shows the construction and principle of the Thompson inclined-coil meter.

Fig. 3 shows the movable assembly of the moving-iron type of instrument, on which can be seen the damping vane, mounted directly beneath the pointer, and also the movable iron vane at the lower end of the shaft, and the small coil spring which controls the pointer movement across the scale.

5. THOMPSON INCLINED COIL INSTRUMENTS

The Thompson inclined coil and moving vane type of construction is quite extensively used in some makes of A. C. voltmeters and ammeters. This type of meter uses a coil inclined at an angle of about 45 degrees with the back of the instrument, as shown in Fig. 4. This coil supplies the flux to operate a small moving vane of soft iron, which is also mounted at an angle on the shaft of the meter so that it is free to move and operate the pointer which is attached to the same shaft.

When the meter is idle and has no current flowing through the coil, the small coil spring at "C" holds the pointer at zero on the scale. When the shaft is in this position, the movable iron vane is held at an angle to the axis of the coil or to the

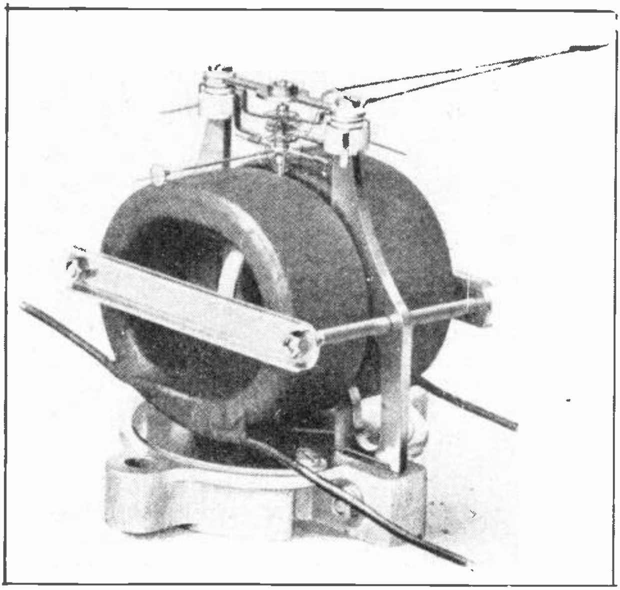


Fig. 5. This view shows the coils of an electro-dynamometer type meter.

normal path of the flux set up by the coil when it is energized.

When the coil is energized and sets up flux through its center, as shown by the arrows, the iron vane tends to move into a position where its length will be parallel to this flux. This causes the pointer to move across the scale until the magnetic force exerted is balanced by the counter-force of the spring.

This type of construction is used both for voltmeters and ammeters, by winding the coils with the proper number of turns, as previously explained.

6. DYNAMOMETER TYPE INSTRUMENTS

Dynamometer type instruments are used for voltmeters, ammeters, and wattmeters. Meters of this type have two coils, one of which is stationary and

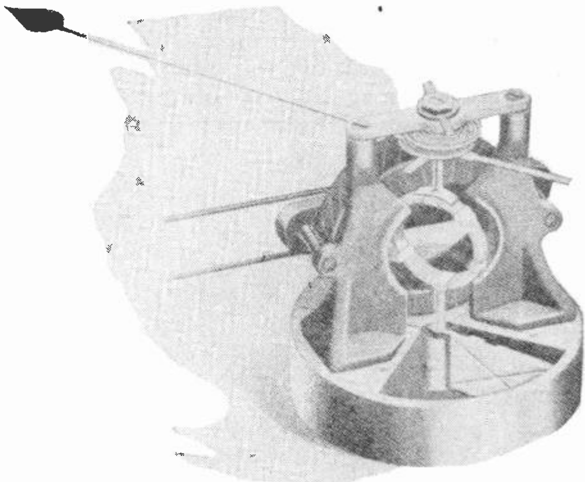


Fig. 6. Another dynamometer type meter with slightly different arrangement of the coils. Note the damping vane attached to the bottom end of the shaft so that it rotates in the damping chamber under the meter element.

the other which is movable and attached to the shaft and pointer. **The torque which moves the pointer is produced by the reaction between the fields of the two coils when current is passed through both of them.**

There is no iron used in the two elements of this meter; the moving coil being light in weight and delicate in construction, but rigid enough to exert the proper torque on the shaft.

In some meters of this type, the movable coil is mounted within two stationary coils, as shown in Fig. 5; while in other types it is mounted near to the side of one large coil, as shown in Fig. 6. In either case, the movement of the smaller coil is caused by the reaction between its flux and the flux of the stationary coil or coils.

When both the stationary and movable coils are excited or energized, the lines of force through their centers tend to line up or join together in one common path. When the pointer is at zero, the

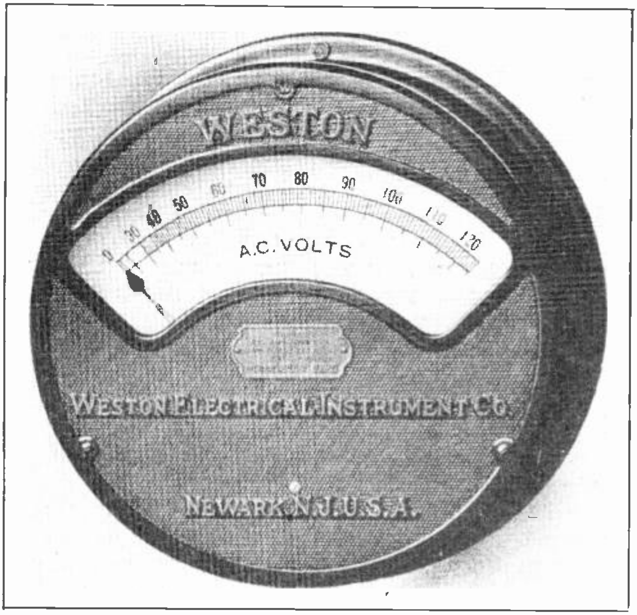


Fig. 9. Switchboard type A C. voltmeter Note the tapering graduation at the left of the scale.

movable coil rests in a position so that its axis and the direction of its flux will be at an angle to that of the stationary coils. So, when the current is applied the reaction of the two fields will cause the movable coil to force the pointer across the scale against the opposing force of the delicate coil springs, which can be seen in both Figs. 5 and 6.

These coil springs are usually made of phosphor-bronze alloy, and in some cases they carry the current to the movable coil.

Voltmeters of the electro-dynamometer type usually have the two coils connected in series with each other and also in series with a resistor, and then connected across the line.

Ammeters of this same type may have the two coils connected in series and then across an ammeter shunt which carries the main load current. In some cases the stationary coil of an ammeter may carry the full load current, while the movable coil is connected in parallel with a shunt so that it carries only a small fraction of the current.

The movable coil is not designed to carry much current in any case, because it must be light in weight and delicate in construction to obtain the proper accuracy in the operation of the meter.

7. A. C. WATTMETERS

Wattmeters using the electro-dynamometer principle have elements very similar to those shown in Fig. 5. The stationary coils are used for the current element and may be connected in series with the load or across a current transformer. The movable coil is the potential coil and is connected in series with a resistance, and then across the line.

Resistances used in connection with the coils of A. C. meters are generally of the non-inductive type, so they will not affect the reading of the meter by introducing inductive reactance in the circuit.

While shunts are used in some cases with certain types of A. C. meters, instrument transformers are also commonly used to reduce the amount of current and voltage applied to the coils of the meters. This eliminates the necessity for current coils with very heavy windings and the necessity of winding potential coils with a great number of turns to obtain high resistance to permit them to be connected across high-voltage lines. It also reduces insulation difficulties and hazards in testing high voltage circuits.

As the current coils in the wattmeter will always carry a current proportional to the amount of load, and the potential coil will carry a current proportional to the voltage applied to its terminals, the torque set up by the magnetic fields of these two coils will be proportional to the power in watts in the circuit. The scale can therefore be graduated and marked to read directly the watts or kw. of the circuit to which the meter is connected.

Since the torque acting on the movable element is proportional to the instantaneous current and voltage, the meter will register the true power of the circuit, regardless of the power factor.

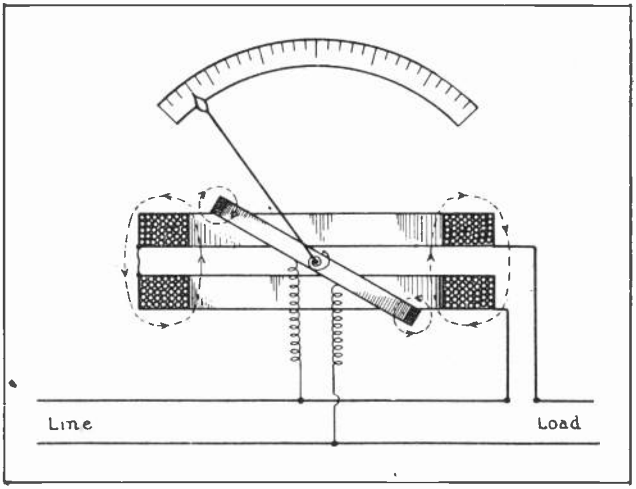


Fig. 10. This diagram illustrates the construction and principles of the dynamometer type instrument. Note the action between the flux of the moving and stationary coils.

Fig. 10 shows a sketch which further illustrates the principle of the dynamometer-type wattmeter. You will note that stationary current coils which are connected in series with the line, set up a flux which tends to repel the flux of the movable coil and will cause it to move the pointer across the scale to the right.

Electro-dynamometer type meters are somewhat more delicate and less simple in construction than the moving iron types, but the former are more accurate and therefore generally preferred where exact measurements are desired.

The scale over which the pointer of this instrument moves is not graduated with spaces of even width, because of the fact that the opposing force is a spiral or helical spring and, therefore, becomes greater as the pointer moves farther from zero.

8. INDUCTION TYPE INSTRUMENTS

Induction type A. C. meters operate on a principle similar to that of an induction motor, using the magnetic flux of stationary coils to induce currents in a rotating element in the form of a metal cylinder or drum, or in some cases a metal disk.

Fig. 14 shows a sketch of an induction meter of this type which can be used either as a voltmeter or an ammeter, according to the manner in which the coils are wound and connected.

A set of primary coils and also a set of secondary coils are wound on the upper part of the iron core.

Fig. 12. Switchboard type wattmeter which has its scale calibrated to indicate the load in kilowatts. (Photo courtesy Weston Electrical Instrument Co.)

The primary coil, being connected to the line, sets up alternating magnetic flux which magnetizes the core and also induces in the secondary coils a current which is out of phase with that in the primary.

These secondary coils are connected in series with a third set of coils wound in slots at the lower end of the core near the movable drum. The different phase relations between the currents of these coils tend to set up a flux which is out of phase with that established in the core by the primary coil, thereby producing a sort of revolving field which induces eddy currents in the drum. The reaction between the flux of these eddy currents and the flux set up by the coils then causes the drum to tend to rotate by the same principle as used in A. C. induction motors.

The pointer is attached to this drum, so that, when the drum is rotated, the pointer is moved across the scale against the action of the coil springs.

When an instrument of this type is used for an ammeter, the primary coil is wound with a few turns of heavy wire and is connected in series with

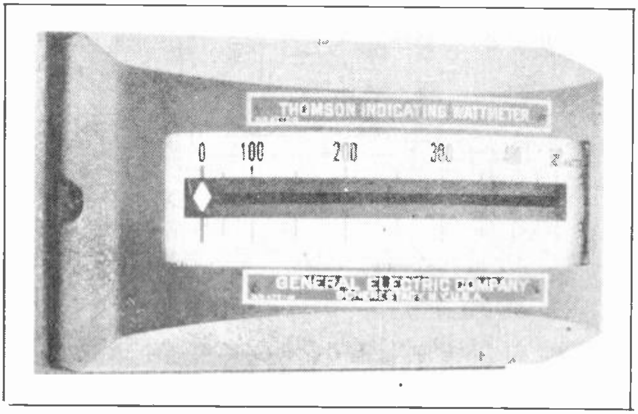


Fig. 13. Another type of switchboard meter known as the "horizontal-edgewise" type. Meters of this type are very commonly used in power plants. (Photo courtesy G. E. Company.)

the line, or it can be wound with small wire and connected in parallel with a shunt or to the terminals of a current transformer.

When used as a voltmeter, the primary coil is wound with more turns of fine wire and is connected in series with a resistance and then across the line.

9. INDUCTION TYPE WATTMETERS

This same induction principle can be applied to wattmeters, as shown in Fig. 15.

In this case, the potential element consists of the primary coils "P" which are connected in series with a reactance coil "B", and then across the line. The secondary coils "S" have current induced in them by the flux of the primary, and are connected in a closed circuit with a variable resistance "R".

In this manner, the amount of induced current which flows in the secondary coils may be varied by adjusting the resistance, so that the reaction between their flux and that of the primary coils

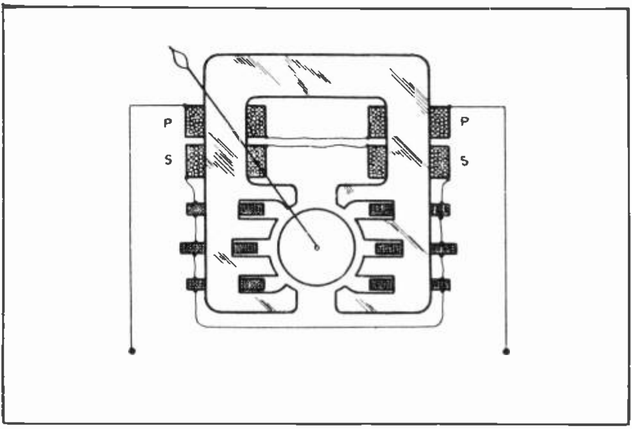


Fig. 14. The diagram shows the core and coils of an induction type meter. Study the principles of this meter thoroughly with the accompanying explanations.

will produce the proper phase relation between the flux set up in the core and the flux of the current coils "C", which are wound in slots near the movable drum.

This current element is connected in series with the line, or to the proper shunt or instrument transformer.

When both sets of coils are excited, a revolving field is set up, which induces eddy currents in the movable drum, similarly to the operation of the induction voltmeter in Fig. 14.

In this case the strength of the combined flux set up by the potential and current coils will be proportional to the product of the voltage and current of the line. So, with the proper graduation of the scale, this meter can be made to record directly in watts the power of the circuit to which the meter is attached.

10. SHADED POLE INDUCTION METERS

Another type of induction meter which uses the

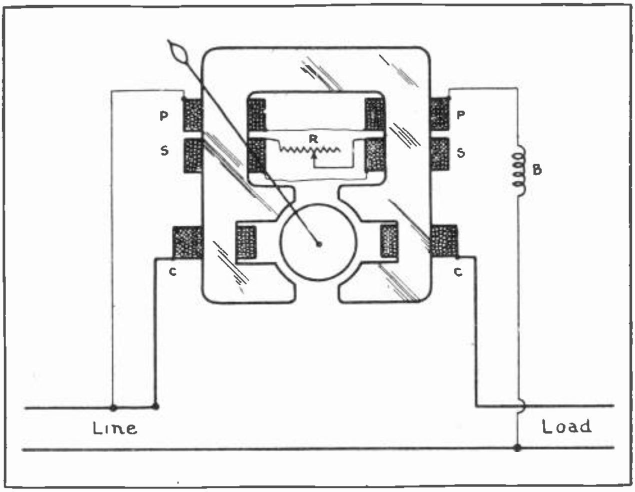


Fig. 15. Core and coils of an induction type wattmeter. Note how the current and potential coils are connected to the line.

induction disk, or **shaded pole** principle, is illustrated in Fig.17.

This type of instrument has the torque produced on a moving disk, by inducing eddy currents in the disk by means of the large exciting-coil, and small shading coils, on the soft iron core.

When alternating current is passed through the large coils it sets up an alternating flux in the iron core and induces eddy currents in the edge of the disk which is between the poles of the core. The flux also induces secondary currents in the small shading coils, which are built into slots in one side of the pole faces and are short-circuited upon themselves to make closed circuits.

The induced currents in these shading coils are out of phase with the current in the large coil, and therefore they set up flux which is out of phase with the main core flux. This causes a sort of shifting or sliding flux across the pole faces, which reacts with the flux of the eddy currents in the disk and causes the disk to tend to rotate.

The disk can rotate only part of a revolution, as its movement is opposed by a spring on the shaft. The rotating movement of the disk moves

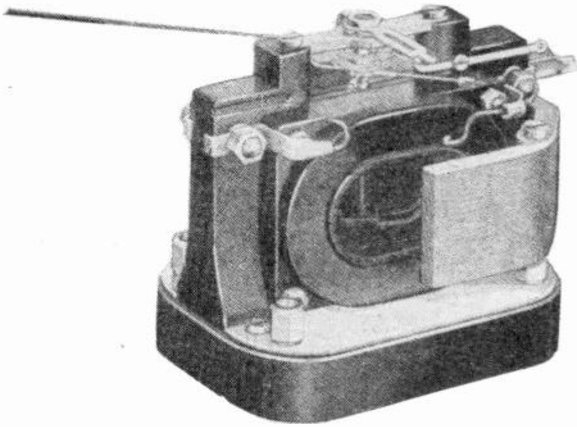


Fig. 16. This photo shows a meter element with part of the magnetic shield in place around it. These shields are made of soft-iron laminations and prevent magnetic flux from other machines or circuits from interfering with the accuracy of the meter. One-half of the shield is shown removed in this view.

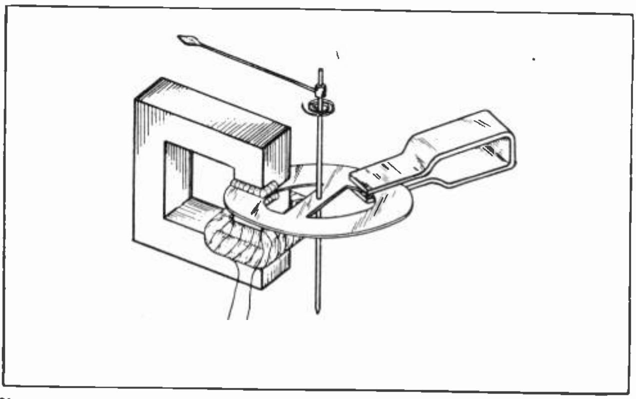


Fig. 17. Diagram illustrating the principles and construction of a disk type induction meter. The torque on the disk is produced by the action of the flux from the shaded pole.

the pointer across a scale as in any other meter.

The movement of the disk and pointer is damped by the drag magnet on the right, which induces eddy currents in the disk when it moves and thereby tends to slow its movement and prevent jumping or oscillation of the pointer.

The sides of the moving disk or ring are often cut in a slightly varying or tapered width, to obtain greater torque as the pointer moves farther against the force of the spring. This allows uniform graduation of the scale.

When instruments of this type are used for ammeters, the main coil is connected in parallel with a special alloy shunt, the resistance of which changes with temperature and load changes, to compensate for heat and increased resistance in the coil or disk.

When used as a voltmeter, the coil of the instrument is connected in series with a reactance coil to compensate for changes in frequency, and also

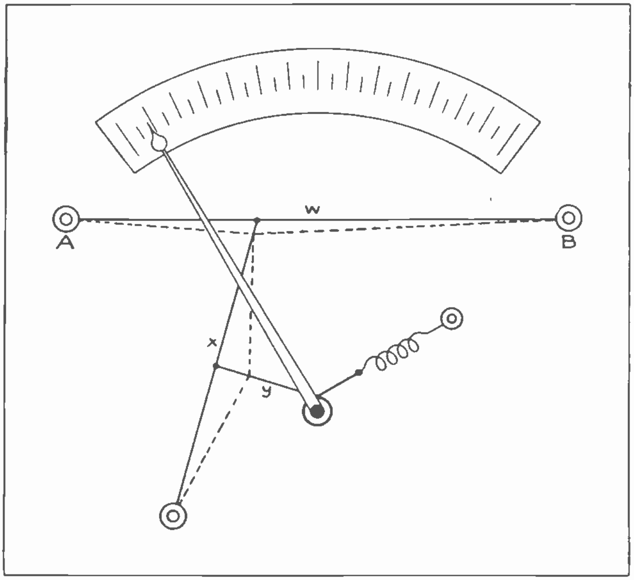


Fig. 18. This sketch shows the operation of a hot-wire meter, in which the movement of the pointer is obtained by the expansion of a wire when heated by passing current through it.

in parallel with a shunt to compensate for temperature and resistance changes.

This same principle of induction is applied to A. C. induction watthour meters, frequency meters, and various types of A. C. relays; so it is well worth thorough study to obtain a good understanding of the manner in which it produces the torque in the disk.

11. HOT-WIRE INSTRUMENTS

Hot-wire instruments are those which obtain the movement of their pointers by the expansion of a wire when it is heated by the current flowing through it.

This principle is illustrated by the diagram in Fig. 18. When the terminals "A" and "B" are connected to a line and current is passed through

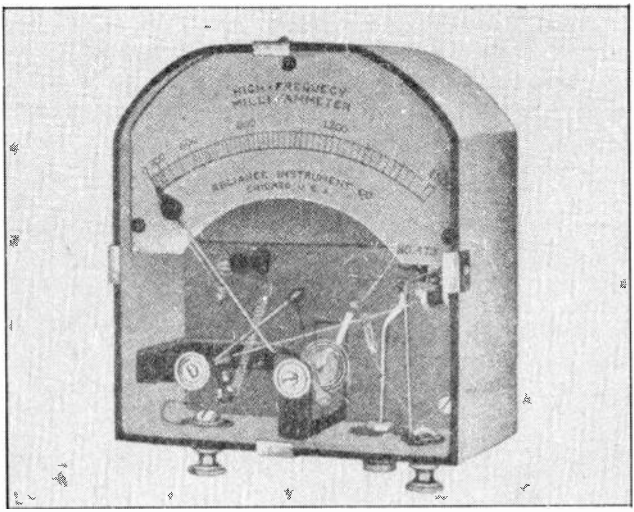


Fig. 19. This view shows the inside parts of a hot-wire meter of slightly different construction than the one illustrated in Fig. 18.

the wire "W", it becomes heated by the current and expands.

This expansion causes it to loosen and sag, and allows wire "X" to become slack. Wire "Y" is attached to wire "X" and is wrapped around a pulley on the shaft to which the pointer is attached. The other end of this wire is attached to a spring which is fastened to the meter case. This spring maintains a continual pull on wire "Y"; so that, as soon as wire "X" becomes slack, wire "Y" is drawn around the pulley and causes it to rotate and move the pointer across the scale.

When the current decreases or stops flowing through wire "W", this wire cools and contracts back to its tight condition and draws wires "X" and "Y" back against the action of the spring; thus returning the pointer to zero.

When instruments of this type are used as ammeters, the wire "W" is connected in series with the line or in parallel with a shunt which is in series with the line. When the device is used as a voltmeter, the wire "W" is connected in series with a resistance and then across the line.

Hot-wire instruments are made in a number of different forms, and with various arrangements of their wires and parts; but all of them operate on the same general principle. Fig. 19 shows the working parts of a hot-wire meter of slightly different construction from that shown in Fig. 18.

Meters of this type can be used on either D. C. or A. C. circuits; but they are particularly adaptable to high frequency A. C. circuits, such as in radio stations, X-ray work, and laboratories where very high frequencies are used. Having no coils in their construction, hot-wire meters are non-inductive and therefore offer less impedance to high frequency currents and operate more accurately on varying frequencies.

12. ELECTRO-STATIC VOLTMETERS

Electro-static voltmeters are often used for measuring very high voltages. These meters operate on the principle of the attraction between bodies with unlike charges of static or high-voltage elecricity. Fig. 20 shows an electro-static voltmeter, with the case opened to show all the working parts clearly.

This instrument consists of a set of stationary metal vanes, and a pair of movable vanes of light weight metal. In normal or zero position, the movable vanes hang free of the stationary vanes due to gravity action on a counter-weight attached to the shaft.

When the wires of a high-voltage line are connected to this instrument, one wire to the stationary vanes and one to the movable vanes, charges of opposite polarity will be set up on the vanes. This causes them to attract each other and the movable vanes will be drawn nearer to the stationary ones, or in between them. This moves the pointer across the scale a distance proportional to the voltage applied.

Electro-static voltmeters can be obtained to measure voltages as high as 50,000 volts, or even more. They can also be made to measure quite low voltages, by using a number of vanes, closely spaced. These instruments will work on either D. C. or A. C. circuits, because it makes no differ-

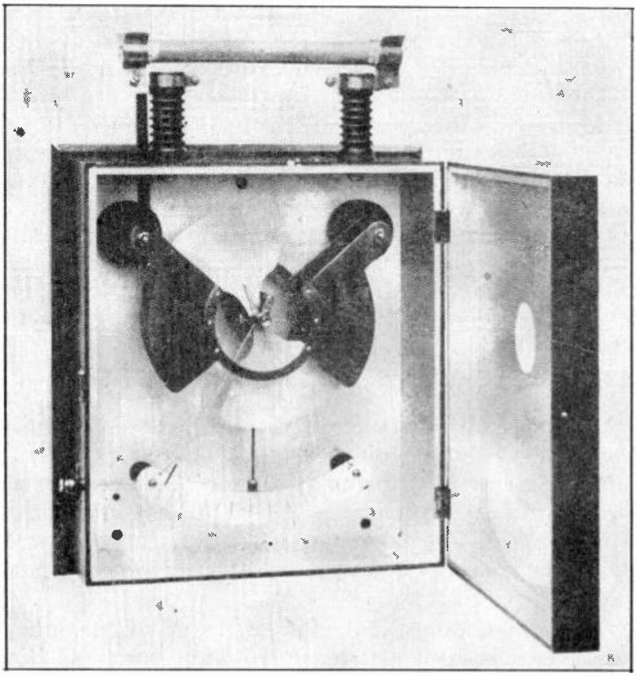


Fig. 20. This photo shows an electro-static voltmeter for measuring the potential of high voltage circuits. The pointer movement is obtained by the attraction between the moving and stationary metal vanes when they are charged with opposite polarity.

ence if the polarities reverse, as long as the movable and stationary vanes are always of opposite polarity at any instant.

13. A. C. WATTHOUR METERS

A. C. watthour meters are quite similar in many ways to those for D. C., which were explained in lesson 39 on D. C. meters. They consist of current coils and potential coils which set up flux and turning effort on the rotating element. The rotating element drives a chain of gears which operate the pointers on a row of four dials, and total up the power used in kilowatt-hours.

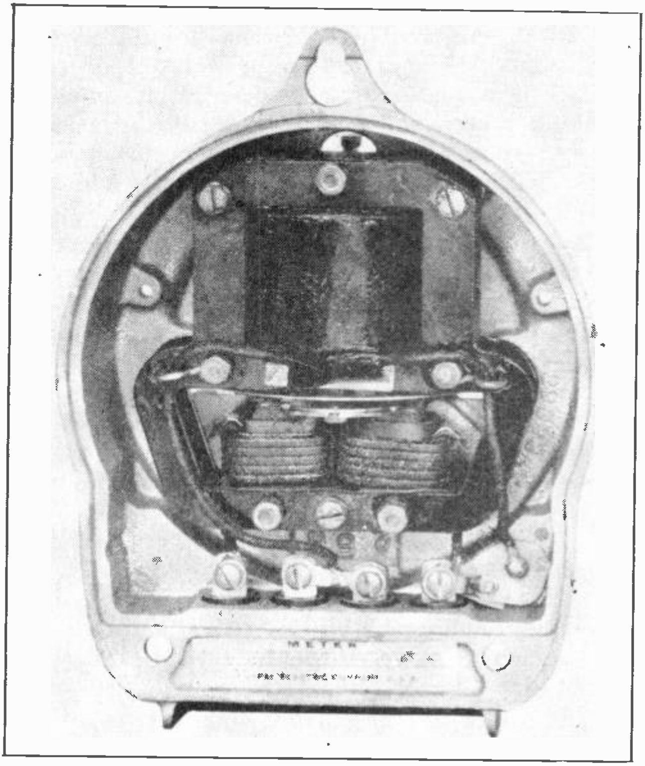


Fig. 21. Interior view of a modern watthour meter, showing the current and potential coils, and the induction disk

Some A. C. watthour meters are of the electrodynamometer type. They have the potential coil wound on the moving armature and are equipped with commutator and brushes similar to those of D. C. watthour meters. The more common type of A. C. meter uses the induction disk principle, as meters of this type are much simpler and more rugged, have fewer wearing parts, and therefore require less care than the other types.

In the induction type watthour meter, both sets of coils are stationary and the rotating element is simply a light-weight aluminum disk mounted on a vertical shaft. There are no commutators or brushes to produce friction or get out of order. Fig. 21 is a photo of a modern A. C. induction watthour meter, and it shows clearly the principal parts of such a meter, with the exception of the gears, dials, and the damping magnets, which are on the other side of the meter.

The two coils of heavy wire on the lower part of the core are the current coils, and the large coil above is the potential coil. Between these coils the rotating disk can be seen.

Fig. 22 shows a diagram of the core, coils, disk, and one damping magnet of a meter of this type, and further illustrates its operating principle.

The potential coil "P" is wound with a great number of turns of very fine wire, and on the upper leg of the soft, laminated-iron core; and the current coils "C" and "C" are wound with very few turns of heavy wire, on the two lower core legs.

The large number of turns in the potential coil make this winding highly inductive, and cause the current which flows through it to be nearly 90 degrees lagging, or out of phase with that in the current coils. As the current coils consist of only a very few turns, their circuit has very little inductance, and the current through them will be nearly in phase with the line voltage.

The potential coil is connected across the line or across the terminals of a potential transformer. The current coils are connected in series with the line on small power and lighting circuits; or to the secondary of a current transformer on heavy power circuits.

The reversing flux of the current coils alternately leaves one of these poles and enters the other;

while the flux of the voltage coil leaves its pole and splits or divides between the two poles at its sides and the two poles of the current coils under the disk.

These two different fluxes which are set up by the out-of-phase currents in the potential and current coils, create a shifting or rotating field effect, which induces eddy currents in the disk; and the reaction between the flux of these eddy currents and the main flux causes the torque and rotation of the disk. This is called the motor element.

One of the damping or "drag" magnets is shown at "D" in Fig. 22. There are two of these magnets, located one on each side of the disk; and when the edge of the disk revolves between the magnet poles, their flux induces in the disk eddy currents which tend to retard its motion. This retarding or damping force will always be proportional to the speed of the disk.

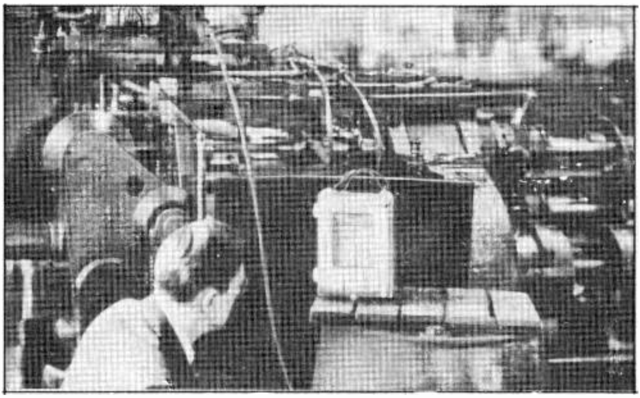
As the current and flux of the potential coil are proportional to the line voltage, and the current and flux of the current coils are proportional to the load current, the torque exerted on the disk by these fluxes will always be proportional to the product of the volts and amperes. This is also proportional to the load in watts on the line.

This force acting against the retarding effect of the damping magnets will cause the meter speed to be proportional to the power used at any time.

The upper end of the shaft on which the disk is mounted is fitted with a worm which drives the first gear of a chain of several gears, which in turn operate the pointers, exactly as described for D. C. watthour meters

14. CREEPING

Sometimes the disk of an A. C. watthour meter will continue to revolve very slowly when the load is all disconnected from its circuit. This is known as **creeping**; and it may be caused by vibration, too high line-voltage, wrong adjustment of the friction compensating device, wrong connection of the potential coil, a short circuit in the current coil; or by a high-resistance ground or leakage on the line.



Inkless strip-chart recording ammeter, equipped with a split-core current transformer, being used to check load on a motor.

The potential coil of a watthour meter is connected directly across the line; so, as long as there is voltage on the line, there will always be a very small amount of current flowing in this coil whether there is any load on the line or not.

If the meter is over-compensated for friction by the light load adjustment, this may set up enough torque to rotate the disk slowly. Vibration of the meter reduces the friction on its bearings and may be the cause of starting the creeping.

If the line voltage rises above normal, it will increase the amount of current flowing in the potential coil and thereby increase the torque set up by the light-load, friction-compensating device.

The potential coil should be connected across the line between the current coils and the service, as shown in Fig. 22; because, if it is connected on the load side of the current coils, the small current which is always flowing through the potential coils will also flow through the current coils, and may set up enough flux and torque to cause the meter to creep.

If a short-circuit occurs in the current coils, making a closed circuit of one or more turns, the flux of the potential coil will induce a current in these shorted turns. The flux of this secondary current, working on the disk with that of the potential coil, will cause the meter to creep.

High-resistance grounds or leaks on the line may cause enough current leakage to operate the meter slowly, and yet not enough current to blow a fuse.

Some watthour meters have two small holes drilled on opposite sides of the disk to prevent creeping. The nature of the eddy currents set up around these holes will tend to stop the disk when the holes come between the poles of the magnets.

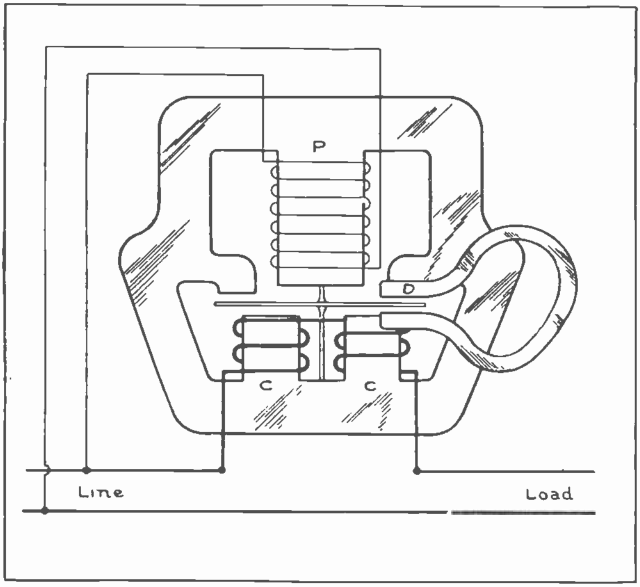


Fig. 22. This diagram illustrates the construction and principles of an induction watthour meter. Note the manner in which the current and potential coils are connected to the line.

15. A. C. WATTHOUR METER ADJUSTMENTS

The light-load adjustment, or friction compensation, on some watthour meters consists of a small coil placed near the current or potential coil and short-circuited so that it will have current induced in it by the flux of the main coil. The current and flux of this auxiliary coil are out of phase with those of the main coils and so they set up a small amount of "split-phase" or shifting flux, which adds just enough to the torque of the disk to compensate for friction at light loads.

In other meters, this adjustment consists of a small plate located between the disk and the poles of the current coil cores, to distort part of their flux and thereby produce a slight shifting flux and torque on the disk. These auxiliary coils or plates are usually adjustable by means of a screw, so that they can be accurately set to provide the right amount of compensation.

A. C. watthour meters often have another adjustment to compensate for inductive load and lagging current on the line.

On some of the latest type meters this adjustment consists of a copper punching mounted under the meter disk and directly under the pole of the potential coil.

The secondary current induced in this copper plate, or ring, sets up flux of a proper phase relation with the main field to compensate for lagging load currents.

By moving this plate back and forth by means of an adjusting screw, the meter can be adjusted properly for various inductive loads.

The **full-load adjustment** for calibrating watthour meters is made by shifting the damping magnets in or out at the edge of the disk.

If the meter runs too fast, the poles of the permanent magnets are moved farther out on the disk, to produce a greater retarding effect. If the meter runs too slowly, the damping magnets are moved farther in.

On later type meters, the damping magnets are mounted in a brass clamp which is adjustable by means of a screw.

EXAMINATION QUESTIONS

1. Why will two pieces of magnetic metal placed within a coil carrying current always push apart?

2. Name five types of A. C. Meters.

3. How is the torque produced in the Dynamometer type instrument?

4. What is the advantage of using a damping chamber in a meter?

5. On what principle does the "hot wire" meter operate?

6. On what principle does the Electro-static voltmeter operate?

7. Is the Electro-Static voltmeter used for measuring low voltages?

8. How are the potential and current coils of Wattmeters connected with relation to the line?

9. What duty does the "drag" magnet perform in a Watthour meter?

10. In case a Watthour meter runs too fast, how may it be slowed up?

Watthour Meters

TEST METERS AND POLYPHASE WATTHOUR METERS

Fig. 1 shows a portable test meter or rotating standard, used for calibrating and adjusting watt-hour meters, in the manner explained in lesson No. 39 on D. C. meters. This test instrument is connected to the same circuit or load as the meter under test, and the number of revolutions of its pointer are compared with the revolutions of the meter disk. By this comparison, and careful consideration of the watthour constant on the disk of the meter, we can determine whether the meter under test is operating accurately, or is running too fast or too slowly.

Polyphase watthour meters are used for measuring power in kw. hours in a three-phase circuit. These meters have two or three separate elements for measuring the power either by the "two meter" or "three meter" method.

Fig. 2 shows a polyphase induction watthour meter for use on a three-phase, four-wire circuit.

1. DEMAND INDICATORS

In lesson 39 on D. C. meters one type of maximum demand indicator was explained. This type, you will recall, uses the heating effect of the load current to expand the air in a glass tube, and force a liquid over into an index tube to indicate the maximum demand on the system. This same type of demand indicator can also be used on alternating current systems.

In addition to this thermo-type of demand indicator, other A. C. maximum demand indicators are used which are operated either by electro-magnets or the induction disk principle.

One of these is simply a wattmeter element which moves a pointer over a scale a certain distance proportional to the maximum load, and leaves the pointer locked in this position until a higher load advances it farther, or until it is reset by the meter reader. This type is known as an indicating demand meter.

Another type has a marker operated by a magnet so it makes a mark on a moving paper tape each

Fig. 1. Watthour test meter or rotating standard, used for calibrating watthour meters.

time the watthour meter makes a certain number of revolutions. These are called recording demand indicators.

These indicators are used in connection with a watthour meter which is equipped with a contact-making device, so that it closes the circuit to the control magnet coils of the demand indicator every time the watthour meter makes a certain number of revolutions.

On the indicating type of demand meter, the pointer or needle is advanced across the scale a distance proportional to the amount of maximum load during any period that the instrument is energized.

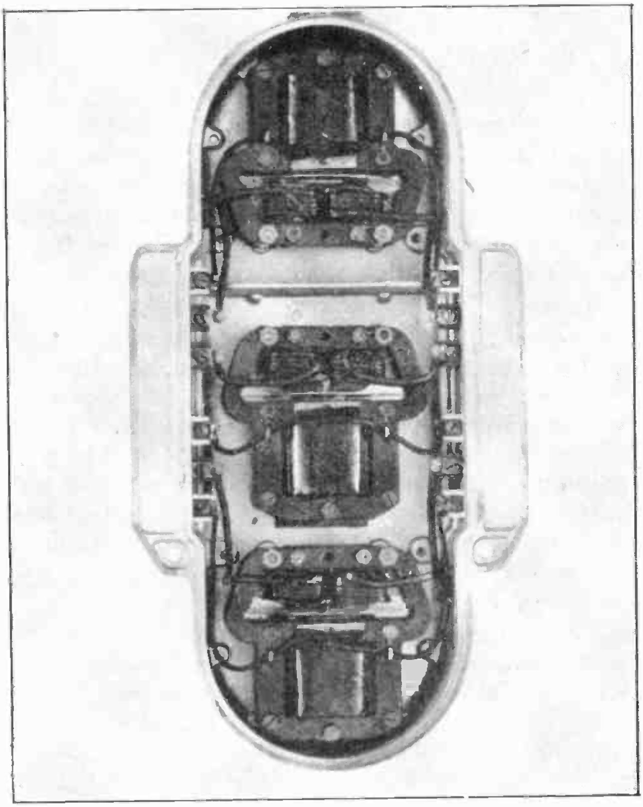


Fig. 2. This photo shows a three-phase watthour meter with three separate meter elements, one of which is connected to each phase.

On recording type demand indicators the speed of the tape is constant, so the number of marks for any given time period will vary in frequency and spacing according to the speed of the watthour meter during that period.

These marks, therefore, provide an indication of the maximum amount of power during any period.

Spring wound clocks or electric clocks are often used with demand indicators to control the time element or tape.

Some of the spring type clocks used with these meters. will run from 8 to 40 days with one winding.

2. POWER-FACTOR METERS

It has previously been mentioned that power-factor meters can be used to indicate directly the power factor of any A. C. circuit. Power-factor meters are designed to register on their scale the power factor, or the cosine of the angle of lag or lead between the current and voltage of the circuit to which they are attached.

There are a number of different types of power-factor meters. One of the very common types which operates on the electro-dynamometer principle is illustrated in Fig. 4. This instrument has two movable coils, "A" and "B", mounted at right angles to each other on the shaft to which the pointer is attached. Coil "B" is connected in series with a resistance unit, "R", and coil "A" in series with an inductance "S"; then they are connected across the line of which the power factor is to be measured.

The stationary coils, "Z" and "Z-1", are connected in series with each other and then in series with one side of the line. The current through coil "B" will be approximately in phase with the line voltage; while the current through coil "A" will lag nearly 90 degrees behind the voltage, because of the inductance which is connected in series with this coil.

As the stationary coils are connected in series with the load, their current will be in phase with the load current. At unity power factor, the current through the stationary coils will be in phase with the current through the movable coils "A" and "B", and their magnetic fields will be at maximum value at the same time.

The flux of these coils tends to line up or flow through the same axis, and therefore holds coil "B" in its present position with the needle resting at 1.00, or unity power factor.

This is also often called 100 per cent. P.F.

While the power factor is unity, the current and flux of coil "A" will be approximately 90 degrees

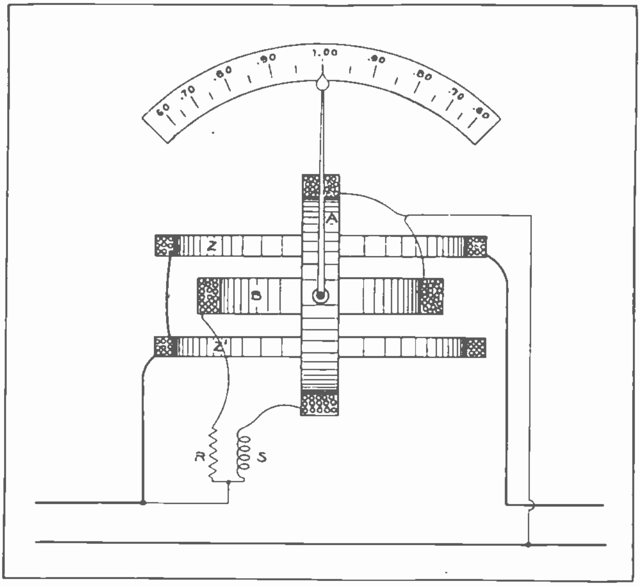


Fig. 4. This diagram shows the important parts and operating principles of a power factor meter.

out of phase with the flux of the stationary coils; therefore, there will be just as much tendency for this coil to try to turn in one direction as in the other, so it doesn't exert any definite torque in either direction and allows coil "B" to hold the pointer in an upright position.

If the line current and voltage were approximately 90° out of phase, then the current in coil "A" would be in phase with the current in the stationary coils, and its flux would tend to turn coil "A" until its axis lines up with that of the stationary coils "Z" and "Z-1". It may turn either to the right or left according to whether the current lags or leads the line voltage.

During such a period, when the line current lags the voltage nearly 90°, the flux of coil "B" would be approximately 90° out of phase with the flux of the stationary coils, and it would therefore exert no appreciable torque in either direction.

If the line current and voltage were about 45° out of phase with each other, then the flux of both coils "A" and "B" would tend to line up with the flux of the stationary coils and the needle would assume a position of balance at about 71% power factor.

In this manner, any degree of lag or lead of the line current will cause the two coils to take a corresponding position, dependent upon the angle between the currents in the stationary coils and those in coils "A" and "B".

When the instrument is used as a power-factor indicator, the scale is marked to indicate the cosine of the angle of lag or lead, so that the power factor can be read directly from the scale.

The scale of this meter can also be marked to indicate in degrees the amount of lag or lead in the current, and can then be used to indicate the phase relations between the line voltage and the current.

Fig. 5 shows a switchboard-type power-factor meter. The scales of these instruments are seldom marked lower than 45 or 50 per cent, because it is very seldom that the P.F. is found to be lower than this on any system. You will note that the needle can swing either to the right or left of unity and thereby indicate whether the power factor is lagging or leading.

Meters of this type will operate satisfactorily with voltage variations as much as 25% either below or above normal.

Single-phase power- factor indicators will not give accurate readings if the frequency of the circuit varies more than 2%. For high-voltage or heavy power circuits, current and potential transformers are used with such meters to reduce the voltage and current applied to their windings.

Power plants and large industrial plants which use considerable amounts of alternating current power are usually equipped with power-factor meters, and portable instruments of this type can often be used to make very valuable tests on machines or circuits throughout various plants.

3. FREQUENCY METERS

A frequency meter is an instrument which, when connected across the line the same as voltmeters are connected, will indicate the frequency of the alternating current in that line.

There are many cases where it is necessary to know or maintain the exact frequency of certain circuits or machines, and in such cases a frequency meter is used to conveniently determine the frequency of the circuit.

Power plants supplying A. C. usually regulate the frequency very carefully so that it will stay

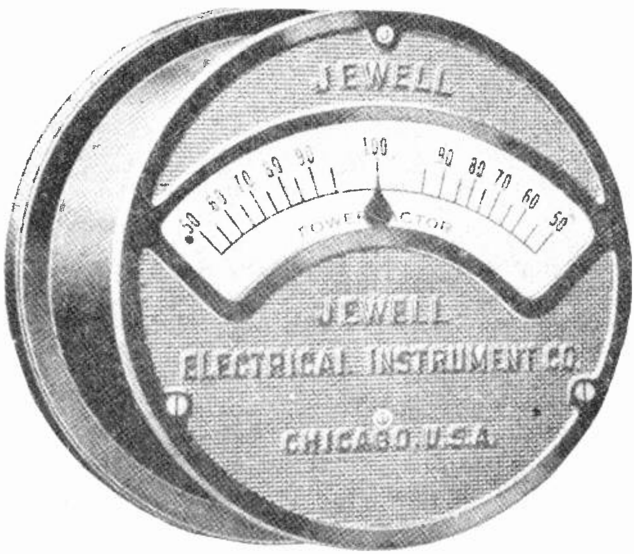


Fig. 5. Switchboard type power factor meter, such as commonly used in power plants and large industrial plants.

almost exactly at 60 cycles per second, or whatever the frequency of the generators is intended to be.

There are two types of frequency meters in common use, one known as the **vibrating-reed** type and the other of the **induction** type.

4. VIBRATING-REED TYPE INSTRUMENT

A vibrating-reed instrument is a very simple device, consisting principally of an electro-magnet which is excited by the alternating current, and a number of steel reeds which are like thin, flat springs. These reeds are caused to vibrate by the changing strength and reversing flux of the magnet.

Fig 6 illustrates the principle of this type of frequency meter. The large electro-magnet is wound

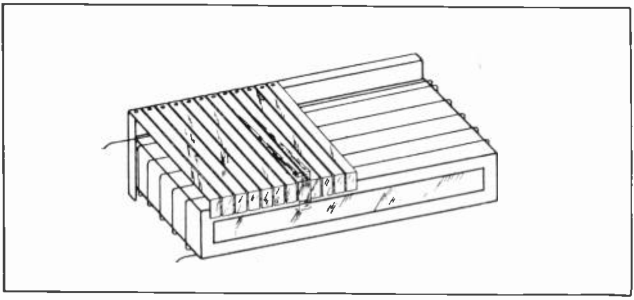


Fig. 6. Diagram of a vibrating-reed type frequency meter. Only part of the reeds are shown in this view. Note the appearance of one reed which is vibrating more than the others.

witha coil of fine wire which is connected in series with the resistor and across the line. When alternating current is passed through this coil, it magnetizes the core first with one polarity and then another.

The polarity is constantly reversing and varying in strength, in synchronism with the frequency of the current. This causes the ends of all the steel reeds to be slightly attracted each time the end of the magnet becomes strongly charged.

These reeds are about ⅛ of an inch wide and approximately 3 inches long, but they each have slightly different natural periods of vibration. In other words, they are somewhat like tuning forks which will vibrate more easily at certain frequencies, depending upon the weight and springiness of the elements.

The reeds of the frequency meter can be made to vibrate at different frequencies either by making them of slightly different thicknesses or by weighting the ends very accurately with small amounts of lead. In this manner they are graduated from one end of the instrument to the other, so that the reeds on one end have a lower rate of vibration, and

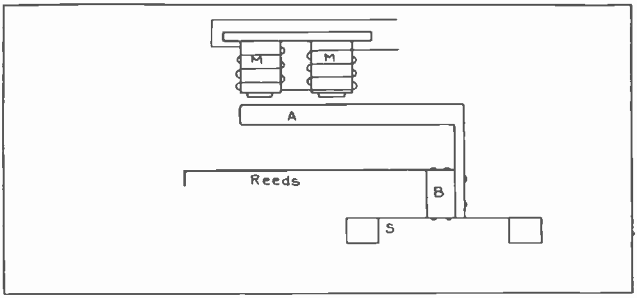


Fig. 7. This sketch shows a side-view of another type of vibrating-reed frequency meter. This instrument uses a pair of small electro-magnets to vibrate the armature to which the reeds are attached.

as they progress toward the other end each one has a slightly higher rate of vibration.

This arrangement will cause one or two of the reeds which have a natural rate of vibration closest to the frequency of the alternating current, to vibrate more than the others when the magnet coil is energized.

The vibration of most of the reeds will be barely noticeable, because the magnetic impules do not correspond with their natural frequencies. But the reed which has a natural vibration rate approximately the same as that of the alternating current, will vibate up and down from 1/8 to 1/4 of an inch or more, and perhaps one reed on each side of it will vibrate a little.

The front ends of the reeds are bent downward in short hooks to make them plainly visible and, when viewing them from the front, the end of the reed which is vibrating will appear longer than the others. Then, by reading on the scale directly under this vibrating reed, the frequency can be determined.

Another meter using this same principle, but of slightly different construction, is shown in Fig. 7. This meter has the reeds attached to a bar, "B", that is mounted on a stiff spring, "S", in such a manner that the whole bar with all of the reeds can be vibrated. There is also an iron armature, "A", attached to this bar and projecting out over the reeds beneath the poles of a pair of electro-magnets, "M".

These magnets are excited by the alternating current, the same as the large magnet shown in Fig. 6, and they cause the iron armature to vibrate and rock the bar, thereby causing the reeds to vibrate also.

This vibration of the reeds will be hardly noticeable, except on those that have a natural rate of vibration the same as the speed of the bar movement and the frequency of the alternating current which excites the magnets. These several reeds will vibrate so that their ends will be plainly noticeable, as previously explained.

This type of frequency meter has an adjusting screw for varying the distance between the electro-magnets and the armature "A". By changing this adjustment, the amount of vibration of the reeds can be regulated.

If the circuit to which a meter of this type is connected has a frequency of 60 cycles, the reed directly above the number 60 on the scale will be the one which vibrates the most.

This reed, however, will be moving at the rate of 120 vibrations per second, or once for each alternation of the 60 cycles.

5. INDUCTION-TYPE FREQUENCY METERS

The induction-type frequency meter is more commonly used than the vibrating-reed type. This meter operates on the induction-disk and shaded-pole principle, similar to that which was explained for induction voltmeters and ammeters.

Fig. 8-A shows a side view of the cores, and disk of an induction-type frequency meter.

Each of the cores, "C" and "C-1", is wound with exciting coils, one of which is connected in series with a resistor "R", and the other in series with an inductance "X".

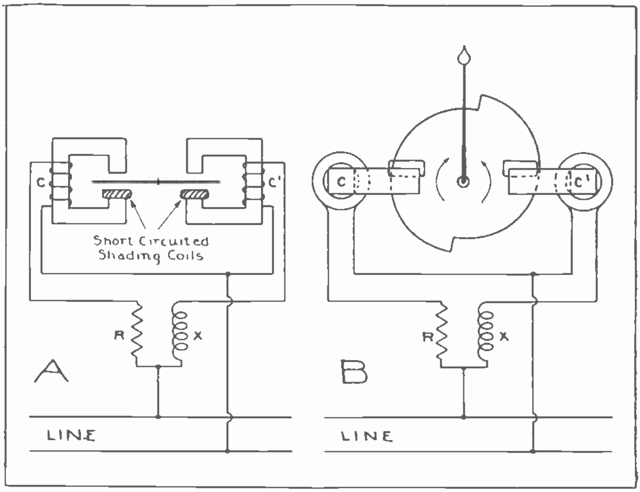


Fig. 8. "A" shows a side-view of an induction type frequency meter. This instrument uses the shaded-pole method of producing torque on the disk by induction. "B". Top view of an induction frequency meter, showing the shape and position of the disk between the poles.

These inductance coils, such as shown at "X", are sometimes called **reactors.** One end or pole of each of the magnet cores is equipped with a shading coil or small, short-circuited coils which are imbedded in one side of the pole faces.

When the coils "C" and "C-1" are excited with alternating current, the flux which is set up in the cores induces secondary currents in the short-circuited shading coils. The flux from these secondary currents in the shading coils reacts with the flux from the main coils and sets up a shifting flux across the edges of the disk.

This induces eddy currents in the disk and tends to set up torque and rotations of the disk. The position of the shading coils and the shape of the disk can be noted in Fig. 8-B.

You will also note in this view that the shading coils are placed on the same side of each magnet, so that they will both tend to exert opposing forces on the disk, each trying to revolve the disk in the opposite direction.

When the instrument is connected to a circuit of normal frequency, or 60 cycles, the current flow through each of the coils "C" and "C-1" will be balanced, and the pointer will remain in a vertical position as shown.

You will recall that the inductive reactance of any coil varies in proportion to the frequency. Therefore, if the frequency of the line increases or decreases, it will vary the amount of current which can pass through the inductance "X" and the coil "C-1".

If the frequency is increased, the inductive reactance of coil "X" will become greater and decrease the current through coil "C-1". This will weaken the torque exerted on the disk by this magnet and allow the disk to rotate a small distance to the right.

If the line frequency is decreased below normal, the inductive reactance of the coil "X" becomes less, allowing more current to flow and strengthen coil "C-1". This will cause the disk to rotate to the left a short distance.

If the disk were perfectly round it would continue to rotate; but it is so shaped that the side under the poles of coil "C" always presents the same amount of surface to the pole, while the side under the poles of coil "C-1" presents a smaller area to the pole as the disk revolves to the left. Therefore, it will turn only a short distance until the increase strength of coil "C-1" is again balanced by the decreased area of the disk under this pole.

The reverse action takes place as the disk rotates to the right, so it will always come to rest at a point corresponding to the frequency of the line to which the meter is connected. The current through coil "C" remains practically constant, because it is in series with the resistor, and the impedance of this non-inductive resistor does not vary with the changes in frequency.

Fig. 9 shows a switchboard-type frequency meter with the needle resting in the normal position, indi-

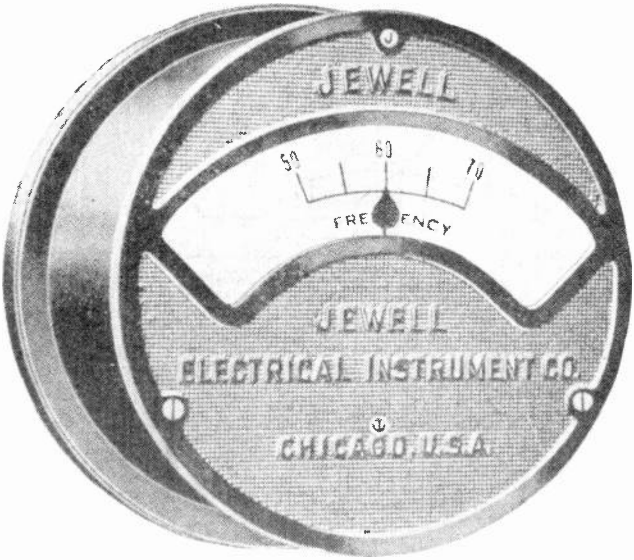


Fig. 9. This photo shows a switchboard type frequency meter, such as commonly used in power plants. The connections to instruments of this type are made to brass terminal bolts which project through the switchboard from the back of the meter.

cating 60 cycles frequency. This scale is graduated to indicate frequencies as low as 50 cycles and as high as 70 cycles per second.

Instruments of this type will operate satisfactorily on voltages either 25% below or above normal. When used on 110-volt circuits, these meters are usually connected directly across the line, the same as a voltmeter.

6. CONNECTIONS OF FREQUENCY METERS

When used on higher voltage, a potential transformer can be used to step the voltage down. In other cases a resistance box may be used in series with the meter so that it can be operated directly from lines as high as 440 volts.

Fig. 10 shows the connections of a frequency meter of this type with its resistance and reactance units which are enclosed in one box. There are

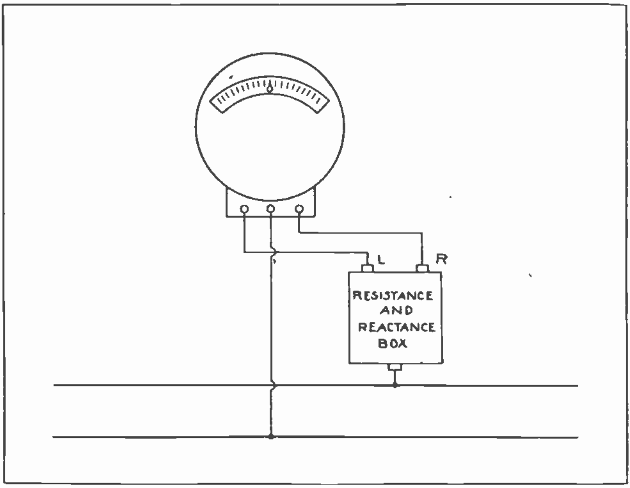


Fig. 10. This sketch shows the connections for a frequency meter and the resistance and reactance box which is used with the meter.

three terminals on the meter and three on the resistance and reactance unit.

The terminal "R" of the reactance box is connected to the right-hand terminal of the meter, while the terminal "L" from the box connects to the left-hand terminal of the meter. The center terminal of the meter connects to the line wire opposite to that to which the common wire of the reactance box is connected.

Sometimes these meters fail to register properly because of no voltage or very low voltage on the circuit, or because the moving element has become stuck. If the meter reads extremely high, it may be caused by a bent disk, a short-circuit in the resistance coil, or an open circuit in the reactor coil. Testing with a voltmeter will locate either of these faults in the resistance and reactance box.

If the meter reads too low, it may be due to the moving element having become stuck or to an open circuit in the resistance unit. If the meter reads opposite to what it should, that is, if the needle indicates a lower frequency when you know the frequency is increased, or if it indicates a higher frequency when the line frequency is decreased, then the two outside terminals at the meter or at the reactance box should be reversed.

7. SYNCHROSCOPE

When paralleling A.C. generators, it is necessary to have a device to indicate when the machines are in phase or in step with each other. For this purpose an instrument called a **synchroscope** is used.

A synchroscope will indicate the phase difference between the running generator and the one which is being brought on to the bus, and will also indicate which machine is running the fastest, so that their speeds can be properly adjusted and the machines brought into perfect step or in phase with each other. This synchronizing is absolutely necessary before paralleling any A.C. generators.

The construction and operation of the ordinary synchroscope is practically the same as that of a single-phase power-factor meter.

Fig. 11 shows the construction and connections of a common type of synchroscope. The operating principle of this type of device is similar to that of a two-pole motor. The stationary coils on the field poles, "O" and "P", are connected to the running generator. The frequency of the current supplied to these coils will therefore be constant.

The movable coils, "A" and "B", are mounted on a shaft or rotor, at right angles to each other. The coil "A" is connected in series with a resistor, and coil "B" in series with reactor. The two coils, with their resistance and reactance, are then connected in parallel and across one of the phases of the "incoming generator".

The current flowing in coil "B" will be approximately 90° out of phase with that in coil "A", because of lagging effect produced by the reactance coil in series with coil "B". This phase displacement of the currents produces a sort of revolving field around the rotor winding of the movable coils.

Let us assume that, at a certain instant, the current which is being supplied to the stationary field coils by the running generator reaches its maximum value at the same time as the current in the rotor coil "A", which is supplied from the incoming generator.

We shall assume also that at this instant these currents are both of the proper polarity to set up fluxes in the same direction, or from left to right between the field poles "O" and "P", and also from left to right through the center axis of the coil "A". Then these lines of force will tend to join together

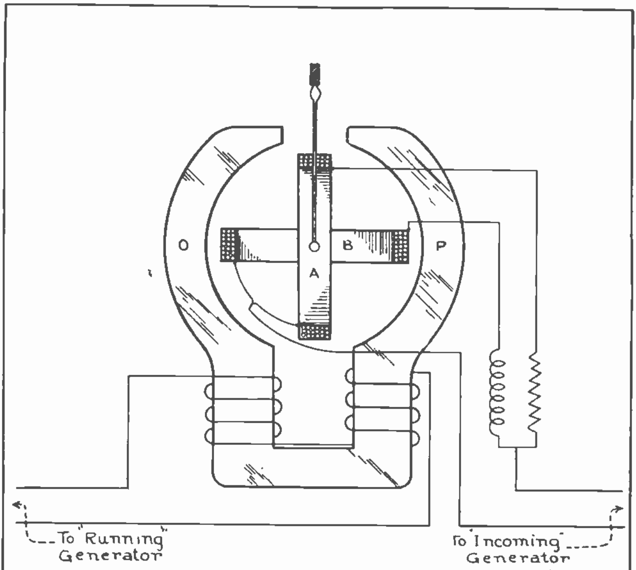


Fig. 11. The above diagram shows the important parts and illustrates the principles of a synchroscope. This diagram also shows the connections of the coils to the "running" and "incoming" generators.

or line up with each other and cause the rotor to assume the position shown in the diagram.

If the frequency of the two generators remains the same, and if they are in phase, the rotor will remain in this position and the pointer will indicate that the machines are in synchronism.

If the maximum value of the current from the running generators occurs about ¼ of a cycle or 90° later than the maximum value of the current from the incoming generator, then the current in the field poles will be in phase with the current in the rotor coil "B"; because the current through this coil is lagging approximately 90°, due to the inductance in series with it.

When the maximum flux and current occur at the same time at the field poles "O" and "P" and in the movable coil "B", this will cause the flux of coil "B" to line up with that of the field poles, and will cause coil "B" to turn into the position now occupied by coil "A" in the diagram.

If the angle of phase difference between the maximum currents of the two generators becomes still greater, the pointer will move a still greater distance from the point of synchronism.

8. SYNCHROSCOPE SHOWS WHICH MACHINE IS RUNNING TOO FAST

If the incoming generator is operated a little slower and at lower frequency than the running machine, the needle will move to the left; and when the current of the incoming machine drops 360° behind that of the running generator, the pointer will have made one complete revolution to the left.

If the incoming machine is rotating faster and producing higher frequency than the running generator, the pointer will revolve to the right, and the faster the pointer revolves, the greater is the difference in speed and frequency between the two machines.

Fig. 12 shows a synchroscope for switchboard mounting. The left side of its scale is marked "slow", and the right side marked "fast", with arrows to show the direction of rotation of the pointer for each condition. These terms marked on the scales of such instruments refer to the incoming machine.

Some types of synchroscopes have an open face or glass cover over the entire front, so that the entire pointer is in full view at all times. In other cases, the pointer moves behind a transparent scale such as shown in Fig. 12. These instruments have a small lamp located behind the scale, so that the

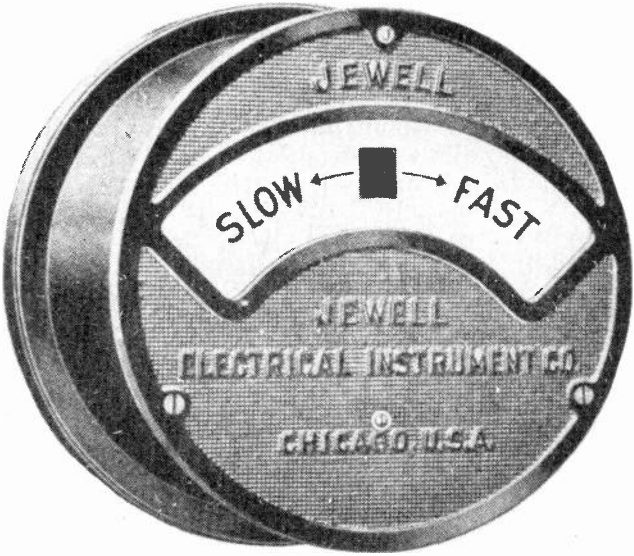


Fig. 12. Switchboard type frequency meter. With this type of instrument the pointer swings back and forth behind a transparent scale when the machines are out of phase.

pointer can be seen through the scale as it passes across the face of the meter.

This lamp, however, is lighted only when the two generators are nearly in phase with each other. This will be explained in a following paragraph.

Whether the synchroscope uses a lamp or not, it indicates that **the machines are in synchronism only when the pointer comes to rest over the dark spot at the top center of the scale.**

9. SYNCHROSCOPES WITH LAMPS

The diagram in Fig. 11 is for a synchroscope of the type on which the needle revolves in plain view around the open face of the meter, when the generators are operating at different frequencies.

The pointer of the meter shown in Fig. 12 does not revolve clear around, but only swings back and forth behind the scale when the machines are out of phase. But as the lamp behind the scale and pointer lights up only when the pointer is passing the lamp and dark spot on the scale, the pointer appears to be rotating either to the right or to the left. In this manner, this type of meter also indicates whether the incoming machine is running slower or faster than the running machine.

Fig. 13 shows the inside of a synchroscope of this type and Fig. 14 shows the connection of its coils and also the transformer which operates the lamp.

The stationary coils, "C" and "C-1", are connected in series with a resistor and then across the busses of the running machine. The movable coil, "M" is connected in series with a resistor, "R", and a condenser, "X", and then across the busses of the incoming machine.

When the two generators are in phase the movable coil holds the pointer in vertical position, but when the machines are out of phase the pointer will swing back and forth with a speed proportional to the amount of difference between the generator frequencies.

If the generators are running at the same frequency, but just a few degrees out of phase, the pointer will stand at a point a little to the left or right of the mark on the scale.

The lamp used with these synchroscopes is caused to light up and go out by being connected to the secondary of a small transformer which has two primary coils, one of which is connected to the running machine and the other to the incoming machine.

These primary coils are so wound that, when the machines are in phase opposition, the flux of the two coils joins around the outer core of the transformer, leaving the center leg idle, and the lamp dark.

When the two machines are in phase or nearly so, the fluxes of the two primary coils oppose each other and set up sufficient flux in the center leg of

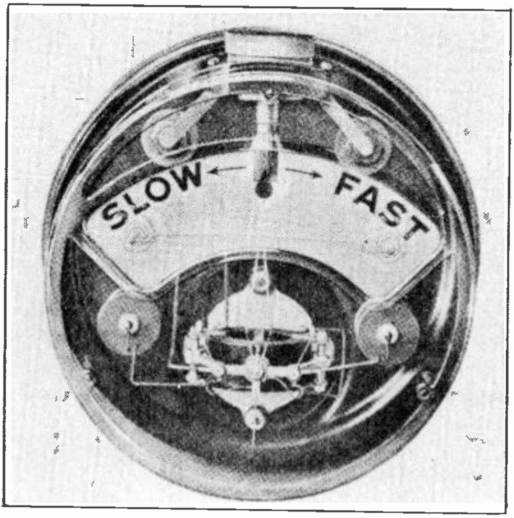


Fig. 13. This view shows the inside of a synchroscope and the arrangement of the various parts, including the lamp and meter coils.

the core to induce a voltage in the secondary coil and light the lamp. Therefore, the lamp will light when the machines are in phase and will go dark when the machines are 180° out of phase.

A. C. generators can also be synchronized with a lamp bank, as will be explained in a later lesson, but the synchroscope is a more convenient and reliable device and it is practically always used for synchronizing alternators in power plants.

As it is not practical to synchronize and parallel more than one incoming generator at a time, one synchroscope can be used for several generators connected to a large switchboard. The synchroscope is frequently mounted on a hinged bracket or arm at the end of the switchboard so it will stand out where it can be seen by the operator from any point along the board.

In larger power plants a synchroscope with a very large face or dial is used in this manner, so it is plainly visible to operators. More complete instructions on paralleling generators by means of synchroscopes will be given in a later lesson.

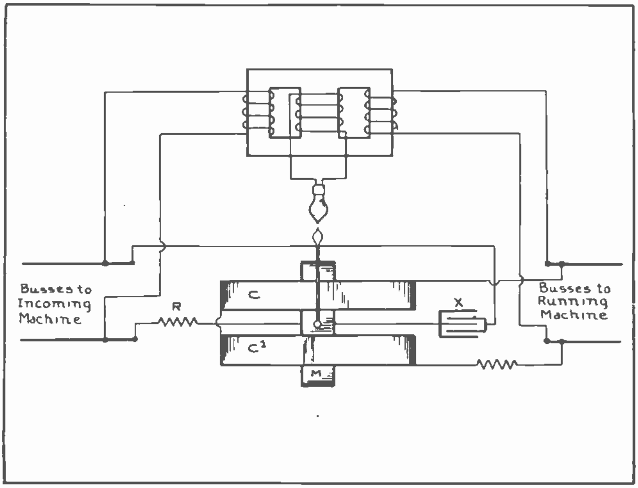


Fig. 14. This diagram shows the important parts and connections of a synchroscope similar to the one shown in Figs. 12 and 13.

Most synchroscopes have their coils wound for operation on 110-volt circuits, but external resistors can be used with them for connecting the instruments to 220 or 440-volt circuits. When they are used with generators of higher voltages, potential transformers are used to reduce the voltage to the instrument.

10. INSTALLATION AND CONNECTIONS OF SYNCHROSCOPES

When installing and connecting a synchroscope, care should be taken to see that the proper terminals of the resistor and reactor are connected to the similarly marked terminals on the instrument. It is very easy to make mistakes in these connections, if they are not very carefully made.

The synchroscope, when shipped from the factory, has usually been tested and is packed in good condition. Therefore, if it doesn't operate correctly after it has been installed and connected, the fault is probably not in the meter, and the external wiring should then be checked over very carefully.

If the meter develops no torque, the trouble may be in the connections from the incoming generator. In this case the circuits through the resistor and reactor should be tested for opens, and the circuits through the meter should also be tested.

If the meter rotates but develops very little torque, the trouble may be in the connections from the running generator and its voltage and connections should be checked. A pair of test lamps can be used to determine whether the synchroscope is operating properly or not. If the lamps are connected to burn brightly, when the two machines are in synchronism, and the synchroscope doesn't indicate synchronism at the same time the lamps do, the cause is probably wrong external connections, or the pointer may be displaced on the shaft.

Disconnect the meter from the generator busses and connect both elements to a single-phase circuit of the proper voltage. If the pointer now stands in vertical position, the meter is correct and the external connections must be checked.

If the instrument indicates synchronism when the two generators are 180° out of phase according to the lamp test, then reverse the two leads from the running generator. If the synchroscope rotates slowly when the generators are operating at widely different speeds and rotates rapidly when the generators are operating at nearly the same speed, the incoming generator may be connected to the running machine terminals.

The foregoing material on various types of A. C. meters, of course, does not cover every meter made, but does cover the more common types and the general principles on which they operate.

A good understanding of these principles and the applications of the various meters explained will be of great value to you in most any branch of electrical work, and will be very helpful in choosing proper meters and installing and testing them on various jobs.

Always remember when handling or working with electric meters of any kind, that they are usually very delicate in construction and should never be bumped or banged around. Even slight jars may damage the jeweled bearings, shaft points, or some part of the moving element.

Connecting instruments to circuits of too high voltage or too heavy current for the range of the meter, will often bend the pointer or damage the moving element, and possibly burn out the coils.

Always try to appreciate the great convenience and value of electric meters for measuring the values of electric circuits, and handle these instruments intelligently and carefully on the job.

Intelligent selection of the proper meters for new electrical installations, or for old ones that do not have proper or sufficient meters, may often result in a promotion for you.

So give this subject proper consideration, and always handle any meters you may have to work with, in a manner that will be a credit to yourself and your training.

EXAMINATION QUESTIONS

1. Name three types of maximum demand indicators.

2. For what purposes are power factor meters used?

3. What instrument is commonly used for testing watthour meters?

4. Name two types of frequency meters.

5. Which type frequency meter is most commonly used?

6. Are frequency meters connected across the line or in series with the line?

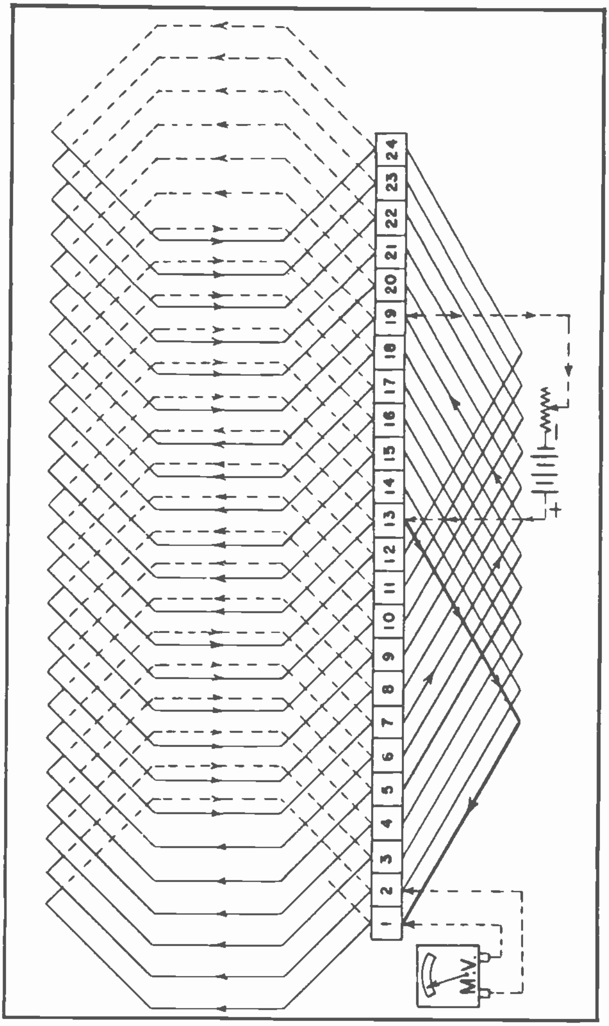
7. For what purpose is the synchroscope used?

8. Draw a sketch showing the proper method of connecting a synchroscope between a running generator and the incoming generator.

9. Is it necessary to have a synchroscope for each of several generators in one plant?

10. Describe two methods for using a 110-volt synchroscope on higher voltage circuits.

ARMATURE EQUALIZER CONNECTIONS.



Although equalizers have been used on large armatures for many years, the application of these connections to small machines is a comparatively recent innovation that has raised questions regarding the advantages of such connections, and the method of testing such windings for faults.

Briefly, equalizer connections provide better commutation, make possible one-half the number of brushes usually used on the lap-wound machine, and provide the manufacturer with a means of avoiding the special slot and commutator bar relationships demanded by wave-type windings. Inasmuch as the equalizers here referred to are permanently connected to the commutator, and inasmuch as they make testing of the armature impossible by the regular procedure, the testing method and other information about these connections should prove of value to maintenance electricians and armature shop men.

The principal purpose of equalizers is to connect together on the armature those points which have the same polarity and which should have equal potential. For a four-pole winding this means commutator bars 180 degrees apart; for a six-pole armature, bars 120 degrees apart; for an eight-pole machine, bars 90 degrees apart. The number of bars spanned by the equalizer will equal bars ÷ pairs of poles. For the armature shown in the diagram, each equalizer will span 24 ÷ 2, or 12 bars, thereby making the connection 1 and 13, 2 and 14, etc. The pitch for any other number of bars or poles would be determined by the same method.

To test such an armature, current must be fed to the armature from an external low voltage D.C. supply, such as a battery, the leads being connected to commutator segments one-half the equalizer pitch apart. Since the equalizer pitch is 12 segments in this case, the leads will be spaced six bars apart or 1 and 7. Any pair of bars so spaced may be used, in a fully equalized armature; bars 13 and 15 being employed in the diagram.

The value of the test current is adjusted to give satisfactory deflection on the millivoltmeter, and volt drop readings are taken between all adjacent pairs of segments. These readings are interpreted in the usual manner, low readings indicating shorts, high readings showing high resistance connections or opens. Tracing the winding and also by actual test, it will be noted that if the readings from bars 13 and 19 are forward, then the readings from 19 to 1 will be backward. This is a normal indication obtained in all windings.

If the factors mentioned are kept in mind, the procedure given will produce consistently accurate results. It is to be noted such an armature will, when tested on a growler, give a shorted indication on all coils, even though the winding is in perfect condition. The reason for this can be seen by tracing from bar 1 through the coil to bar 2, through the equalizer to bar 14, through the coil to bar 13 and back through the equalizer to bar 2. Thus every coil on the armature is apparently short circuited by having another coil placed in series with it through the equalizer connections. This explains the need for a special testing procedure.

ARMATURE TESTING

(growler method)

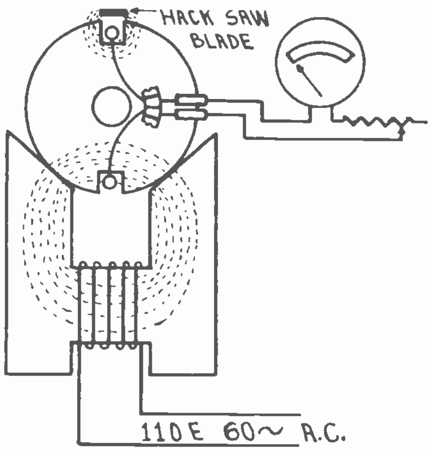
Note: Because of the importance of armature-testing with growlers we are supplementing the material previously given in this subject with this added section.

One of the most widely used methods of testing armature windings for faults is the growler method. This method of testing is simple in application, and the equipment used — a growler and a suitable meter—is relatively inexpensive and dependable. The growler is used to induce A. C. voltage in the armature coils, and the meter is employed to measure these voltages.

When taking meter readings during a growler test, it is essential that the meter prods have the same space position at all times and that the armature be turned when a reading between a different set of commutator bars is required. In other words, if a reading is taken with the test prods directly above the commutator, the next reading must be obtained by leaving the test prods in that position and rotating the armature until the next pair of commutator bars are directly beneath the prods. If the armature is allowed to remain stationary and the test prods are moved from bar to bar, the readings will change as the prods are moved and the meter indications will be meaningless. Only when testing for a grounded bar or a grounded coil does the armature remain stationary in the growler, for in this test one test meter lead is placed on the armature shaft or core and the other is moved around the armature from bar to bar as indicated in diagrams C and G.

The following illustrations indicate the testing method and show the readings obtained with the various faults and the procedure for remedying them.

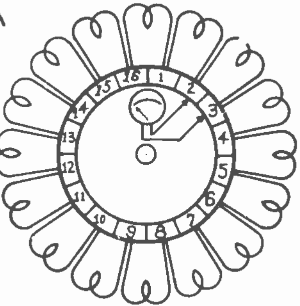
ARMATURE GROWLER TESTS



THE PURPOSE OF A GROWLER IS TO PRODUCE AN ALTERNATING MAGNETIC FIELD WHICH, CUTTING BACK AND FORTH THROUGH THE ARMATURE COILS, INDUCES IN THEM A LOW VOLTAGE MEASURABLE AT THE COMMUTATOR BARS WITH AN A.C. MILLIVOLTMETER. THE RESISTANCE "R" IS USED TO ADJUST THE READING TO APPROXIMATELY MIDSCALE. WHEN A SHORTED COIL IS PLACED BETWEEN THE GROWLER JAWS THE HEAVY CURRENT SET UP IN THE COIL CAUSES PERIODIC MAGNETIZATION OF THE SLOT IN WHICH THE COIL LIES, RESULTING IN THE HACKSAW BLADE HELD NEAR THE SLOT BEING ALTERNATELY ATTRACTED AND RELEASED.

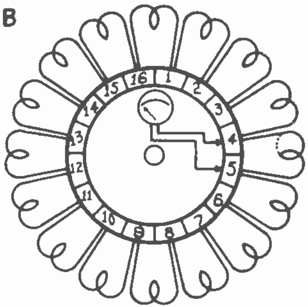
ARMATURE GROWLER TESTS

A



TROUBLE: OPEN COIL
THIS DEFECT SHOWS ITSELF ON THE OPERATING MACHINE BY EXCESSIVE SPARKING AT THE BRUSHES AND BURNING OF THE BARS ATTACHED TO THE COIL. WHEN TESTED ON THE GROWLER, THE METER READING BETWEEN BARS 1 AND 2 WILL BE ZERO. IF THE OPEN IS DUE TO POOR SOLDERING AT THE COMMUTATOR, RESOLDER. IF CAUSED BY AN OPEN IN THE COIL ITSELF, DISCONNECT THE LEADS, INSULATE THE ENDS, AND CONNECT A JUMPER FROM BAR 2 TO 3.

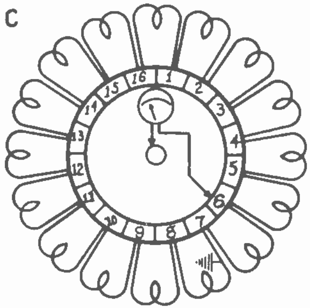
B



TROUBLE: SHORTED COIL
WHEN THE MACHINE IS IN OPERATION, A SHORTED COIL IS INDICATED BY THE EXCESSIVE HEAT IT GENERATES. WHILE OTHER COILS ON THE ARMATURE MAINTAIN A NORMAL TEMPERATURE, THE SHORTED COIL BECOMES SO HOT THAT IT BURNS THE INSULATION FROM THE WINDING. ON THE GROWLER, THE METER READING BETWEEN BARS 4 AND 5 WILL BE LOW OR ZERO. A HACKSAW BLADE WILL VIBRATE OVER THE SLOTS IN WHICH THE SHORTED COIL LIES.

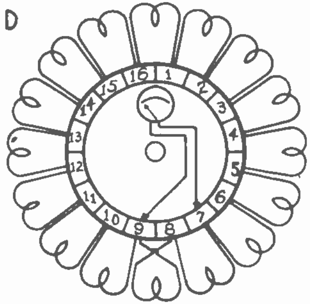
ARMATURE GROWLER TESTS

C



TROUBLE: GROUNDED COIL
A GROUNDED COIL WILL USUALLY GIVE NO INDICATION DURING OPERATION UNLESS THE FRAME OF THE UNIT BE UNGROUNDED: IN THIS CASE, A SHOCK MAY BE FELT WHEN TOUCHING THE FRAME. TWO GROUNDS ON THE ARMATURE PRODUCE A SHORT-CIRCUIT. ON THE GROWLER, A METER READING IS TAKEN BETWEEN THE COMMUTATOR BARS AND THE SHAFT. THE READING BECOMES LESS AS THE BAR CONNECTED TO THE GROUNDED COIL BAR IS APPROACHED AND IS MINIMUM WHEN CONTACTED. IN THE ABOVE SKETCH BAR 7 WOULD GIVE LOWEST READING.

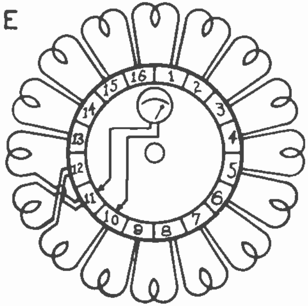
D



TROUBLE: REVERSED COIL LEADS
IN OPERATION, THIS DEFECT WOULD CREATE UNBALANCE IN THE ARMATURE CIRCUIT WITH THE RESULT THAT CIRCULATING CURRENTS WOULD FLOW AND TEND TO CAUSE OVERHEATING. ON THE GROWLER, MAKE A 1 TO 3 BAR TEST. WHEN TESTING BETWEEN BARS 7 AND 9, THE READING WOULD BE ZERO AND THE SAME READING WOULD BE OBTAINED BETWEEN BARS 8 AND 10. THIS WOULD INDICATE THAT THE LEADS OF THE COIL ATTACHED TO BARS 8 AND 9 ARE REVERSED.

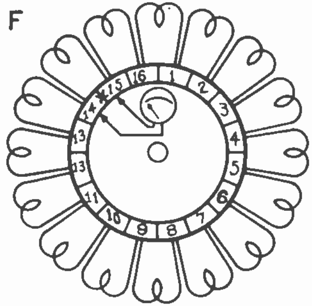
ARMATURE GROWLER TESTS

E



TROUBLE: REVERSED COIL LOOPS
THIS FAULT WHICH USUALLY OCCURS IN A REWOUND MACHINE, MAY PRODUCE SPARKING AT THE BRUSHES DURING OPERATION. WHEN TESTED ON THE GROWLER, THE METER WILL SHOW A DOUBLE READING BETWEEN BARS 10 AND 11, A NORMAL READING ON 11 AND 12, AND A DOUBLE READING ON 12 AND 13. TO REMEDY, UNSOLDER LOOPS ON 11 AND 12 AND REVERSE THEM. HACKSAW WILL GIVE NO INDICATION OF THIS FAULT.

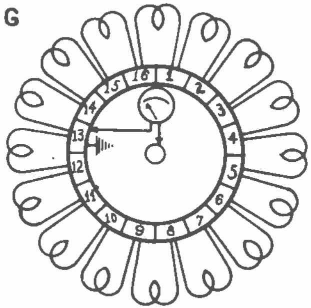
F



TROUBLE: SHORTED BARS
INDICATION DURING OPERATION IS OVERHEATING OF COIL ATTACHED TO BARS 14 AND 15 AND POSSIBLE SPARKING AT THE BRUSHES. ON GROWLER HACKSAW BLADE WILL VIBRATE OVER SLOTS CONTAINING COIL CONNECTED TO SHORTED BARS, AND METER READING BETWEEN 14 AND 15 WILL BE ZERO. REMEDY: REMOVE SHORT FROM BARS OR DISCONNECT COIL AND INSTALL A JUMPER FROM 14 TO 15.

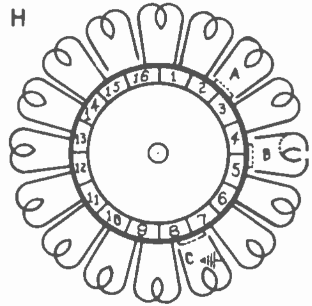
ARMATURE GROWLER TESTS

G



TROUBLE: GROUNDED BARS
IF THERE ARE NO OTHER GROUNDS ON THE MACHINE, THE FAULT WILL NOT AFFECT THE OPERATION OF THE MACHINE AT ALL. IF OTHER GROUNDS ARE PRESENT, SEVERE FLASHING AT THE BRUSHES WILL USUALLY OCCUR. THE TEST PROCEDURE IS THE SAME AS EMPLOYED IN DIAGRAM "C". TO DETERMINE IF GROUND IS COIL OR BAR, DISCONNECT WIRES FROM BAR 13 AND THEN TEST BAR FOR GROUND. REMEDY: RE-INSULATE BAR.

H



THIS SKETCH SHOWS HOW THE DIFFERENT FAULTS ABOVE LISTED ARE REMEDIED. THE LETTERS ON THE SKETCH REFER TO DIAGRAMS ABOVE IN WHICH THE FAULT IS GIVEN DETAILED TREATMENT. "A" SHOWS REMEDY FOR OPEN COIL, "B" FOR SHORTED COIL, "C" FOR GROUNDED COIL. DOTTED LINES BETWEEN BARS REPRESENT JUMPERS. NOTE THAT WITH A SHORTED COIL IT IS ESSENTIAL THAT THE COIL ITSELF BE CUT AS SHOWN IN "B" TO REMOVE THE SHORT CIRCUIT.

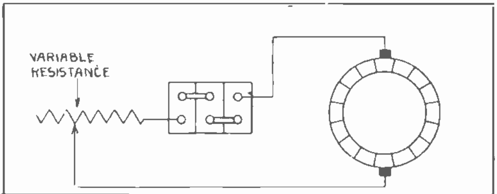
ARMATURE TESTING

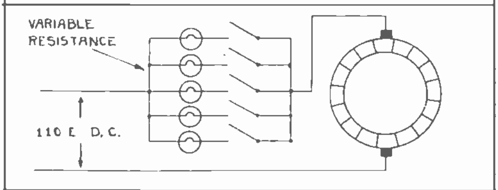
(meter method)

The resistance of all the coils on a normal armature is the same. When a defect develops, such as a short circuit in the coil, a loose connection, or an open, the resistance of the coil changes and this change in resistance will usually indicate the nature of the fault. Due to the very low resistance of armature coils in general, a direct measurement of resistance change due to a fault is difficult to obtain with the instruments available to the average armature tester; however, if current can be caused to flow through the armature, a simple millivoltmeter may be used to test the voltage drop across each armature coil by taking a bar to bar reading around the commutator, and the armature defects may be detected as shown in the sketches below.

It will be noted that the instrument shown is of special type. This meter was developed by the School for maintenance testing of all types on both D. C. and A. C. equipment; however, any meter having the millivolt ranges mentioned could be used for the armature tests indicated. One advantage of the millivoltmeter method of testing is that the procedure does not necessarily require the removal of the armature from the machine; therefore the saving in time and labor on large machines may be considerable.

ARMATURE TESTS USING METER

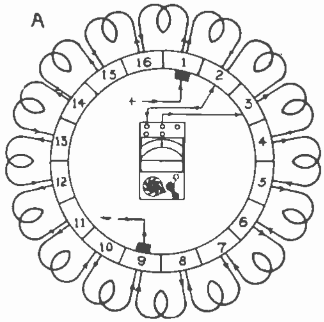




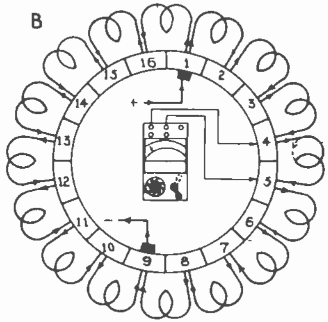
TESTING PROCEDURE

CONNECT THE ARMATURE TO A 6 VOLT, 110 VOLT, OR OTHER D.C. SUPPLY WITH A CONTROLLING RESISTANCE IN SERIES. THIS RESISTANCE MAY CONSIST OF A NUMBER OF PARALLEL-CONNECTED LAMPS ARRANGED TO BE SWITCHED IN OR OUT OF THE CIRCUIT AT WILL. FEED CURRENT INTO ARMATURE THROUGH BARS EXACTLY ONE POLE PITCH APART, AND ADJUST CURRENT UNTIL THE MILLI-VOLTMETER GIVES A MIDSCALE READING ON A NORMAL COIL. THE AMOUNT OF D.C. CURRENT REQUIRED WILL VARY WITH THE SIZE OF THE ARMATURE, FRACTIONAL H.P. UNITS REQUIRING ABOUT 2-4 AMPS, MACHINES UP TO 20 H.P. ABOUT 10 AMPS, AND THE LARGEST ARMATURES CURRENTS AS HIGH AS 20 AMPS. AFTER THE CURRENT HAS BEEN ADJUSTED TO A SUITABLE VALUE, TAKE MILLIVOLT READINGS BETWEEN BARS 1-2, 2-3, 3-4, ETC. IF NO FAULTS ARE PRESENT, THE READINGS WILL BE APPROXIMATELY EQUAL. HIGH READINGS INDICATE HIGH RESISTANCE CONNECTIONS, USUALLY CAUSED BY POOR SOLDERING, WHILE LOW READINGS SHOW SHORTED COILS OR COMMUTATOR SEGMENTS.

ARMATURE TESTS USING METER



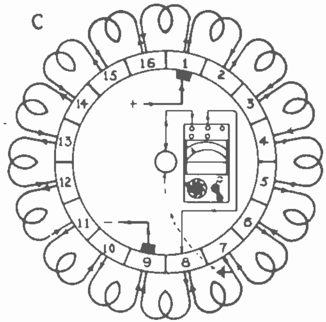
TROUBLE: OPEN COIL
TO PREVENT INJURY TO THE METER, THIS TEST MUST PRECEDE ALL OTHERS WHEN THE MILLIVOLT METHOD OF TESTING IS USED. SET METER ON THE 15 VOLT RANGE AND, WITH CURRENT FLOWING THROUGH THE ARMATURE, TAKE READINGS BETWEEN BARS 1-2, 2-3, 3-4, ETC., UNTIL ALL PAIRS OF SEGMENTS HAVE BEEN COVERED. A HIGH READING BETWEEN ANY PAIR OF BARS INDICATES AN OPEN COIL. NOTE THAT IN THIS METHOD OF TESTING THE METER IS USED TO MEASURE THE VOLTAGE DROP IN EACH ARMATURE COIL, AND THAT THIS IS DONE BY TAKING READINGS BETWEEN COMMUTATOR SEGMENTS.



TROUBLE: SHORTED COIL
FOR THIS TEST SET METER ON THE M.V. RANGE THAT GIVES THE BEST DEFLECTION, STARTING WITH THE 300 SETTING AND WORK DOWN TO THE 50 M.V. RANGE IF NECESSARY. ADJUST CURRENT THROUGH ARMATURE UNTIL APPROXIMATELY MIDSCALE DEFLECTION IS OBTAINED ON A NORMAL COIL AND MAKE A BAR-TO-BAR TEST ON ALL SEGMENTS. THE DEFECTIVE COIL WILL GIVE A LOW OR ZERO READING DEPENDING UPON HOW MANY TURNS ARE SHORTED. IT SHOULD HERE BE UNDERSTOOD THAT THIS METHOD OF TESTING IS MERELY A COMPARATIVE ONE, FOR IT IS HOW THE READINGS COMPARE THAT IS IMPORTANT.

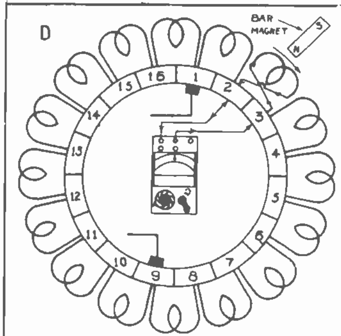
ARMATURE TESTS USING METER

C



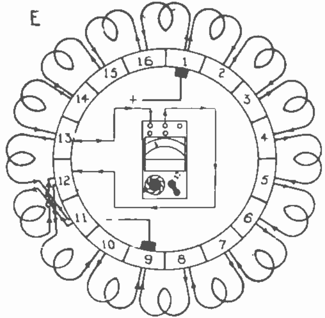
TROUBLE: GROUNDED COIL
TO MAKE THIS TEST, SEND A CURRENT OF SUITABLE VALUE THRU THE ARMATURE AND MEASURE THE VOLTAGE DIFFERENCE BETWEEN EACH SEGMENT AND THE ARMATURE SHAFT. IF THE WINDING IS GROUNDED, A READING WILL BE OBTAINED THAT BECOMES GRADUALLY LESS AS THE BARS TO WHICH THE GROUNDED COIL IS CONNECTED ARE APPROACHED. THE READING WILL BE LOWEST ON THE BARS TO WHICH THE GROUNDED COIL IS CONNECTED. IT SHOULD ALSO BE NOTED THAT AS THE GROUNDED COIL IS PASSED THE METER READING WILL REVERSE. TO DETERMINE IF THE BAR IS GROUNDED, DISCONNECT THE COIL LEADS AND REPEAT.

D

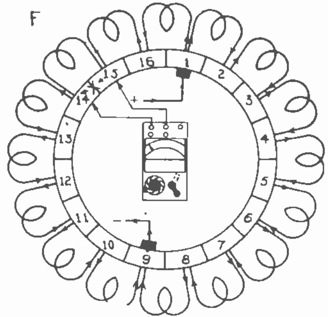


TROUBLE: REVERSED COIL LEADS
USUALLY ENCOUNTERED ON ARMATURES THAT HAVE JUST BEEN REWOUND. THIS FAULT REQUIRES A DIFFERENT TESTING METHOD. SET METER ON 50 M.V. RANGE. SELECT THE FIRST COIL TO BE TESTED, AND FIND THE SEGMENTS TO WHICH THE ENDS OF THIS COIL ARE CONNECTED. WITH THE METER LEADS ON THESE BARS DRAW A MAGNET SWIFTLY ACROSS THE SLOT IN WHICH ONE SIDE OF THE COIL LIES AND NOTE DEFLECTION ON THE METER. REPEAT THIS TEST ON ALL OTHER COILS, ALWAYS MOVING THE MAGNET IN THE SAME DIRECTION. WHEN DRAWN ACROSS A REVERSED COIL, THE METER WILL READ BACKWARDS.

ARMATURE TESTS USING METER

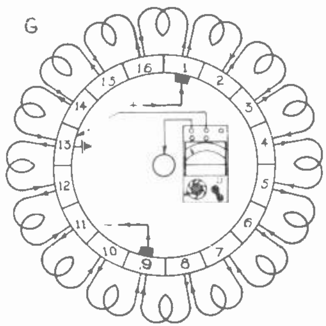


TROUBLE: REVERSED COIL LOOPS
USUALLY FOUND ONLY IN REWOUND MACHINES, THIS FAULT IS CHECKED BY THE REGULAR BAR-TO-BAR TEST. PROCEED IN EXACTLY THE SAME MANNER AS USED FOR LOCATING SHORTED COILS SINCE THE CURRENT IN PASSING FROM SEGMENT 10 TO SEGMENT 11 MUST FLOW THROUGH TWO COILS, IT FOLLOWS THAT THE VOLTAGE DROP BETWEEN BARS 10 AND 11 WILL BE DOUBLE THE VALUE OBTAINED ON A NORMAL COIL: THE SAME IS TRUE FOR BARS 12 AND 13. BARS 11 AND 12 WILL GIVE A NORMAL INDICATION; THUS REVERSED COIL LOOPS ARE INDICATED BY A DOUBLE READING, A NORMAL READING, AND A DOUBLE READING.

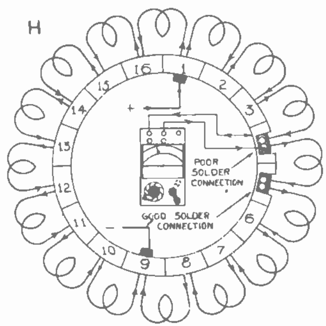


TROUBLE: SHORTED BARS
MAKE SAME TEST AS FOR SHORTED COIL. WITH CURRENT FLOWING THROUGH THE ARMATURE, MEASURE THE VOLTAGE DROP BETWEEN SEGMENTS. WHEN THE SHORTED BARS ARE ENCOUNTERED, THE METER WILL READ ZERO. INASMUCH AS THE SAME INDICATION WOULD BE OBTAINED IF THE COIL LEADS WERE SHORTED, IT WILL BE NECESSARY TO DISCONNECT THE LEADS FROM THE COMMUTATOR SEGMENTS BEFORE IT CAN BE DETERMINED WHETHER THE LOW READING WAS CAUSED BY SHORTED BARS OR SHORTED COIL LEADS. IF AFTER THE COIL IS DISCONNECTED A ZERO READING IS OBTAINED, THE BARS ARE SHORTED.

ARMATURE TESTS USING METER



TROUBLE: GROUNDED BARS
TEST FOR THIS DEFECT IS THE SAME AS FOR A GROUNDED COIL. METER READING FROM BAR TO SHAFT WILL BE ZERO WHEN THE GROUNDED BAR IS CONTACTED. TO DETERMINE WHETHER THE BAR OR THE COIL IS GROUNDED, DISCONNECT THE COIL FROM THE BAR AND TEST AGAIN; IF BAR NOW TESTS CLEAR, COIL IS GROUNDED. WHEN MAKING THIS TEST, THE METER READINGS MAY CHANGE SO RAPIDLY AS THE GROUND IS APPROACHED, THAT A SATISFACTORY DEFLECTION CANNOT BE OBTAINED WITHOUT TURNING TO A DIFFERENT RANGE. THEREFORE, AS THE READING FALLS, THE METER SWITCH SHOULD BE MOVED TO A LOWER RANGE.



TROUBLE: BAD CONNECTIONS
TROUBLE FREQUENTLY DEVELOPS IN ARMATURES AS THE RESULT OF POOR ELECTRICAL CONNECTIONS BETWEEN THE COIL LEADS AND THE COMMUTATOR SEGMENTS DUE EITHER TO POOR SOLDERING OR TO OVERHEATING OF THE ARMATURE WHILE IN SERVICE. HIGH RESISTANCE CONNECTIONS OF THIS TYPE ARE INDICATED BY HIGH READINGS ON THE MILLIVOLTMETER. TO POSITIVELY LOCATE WHICH BAR HAS THE POOR CONNECTION, MAKE THE TEST INDICATED ABOVE. A POORLY SOLDERED JOINT WILL PRODUCE A READABLE DEFLECTION ON THE METER, WHEREAS A GOOD JOINT WILL GIVE NO READING.

ELECTRONIC EQUIPMENT

Demands for speed and accuracy in production call for many electronic applications, others are for guarding the safety of workers, thousands of whom are "green hands." Still others are for the prevention of trespass.

The radio dealer or service man who prepares for this fast growing field will have a part in distribution, installation and maintenance.

No amount of dry-land instruction will teach a man to swim and the same is true of installation and maintenance of electronic equipment. In fact the published information is very scanty and even the engineering forces of large manufacturers must be trained mainly by learning the operating principles of equipment and then analyzing separately each situation calling for installation and maintenance.

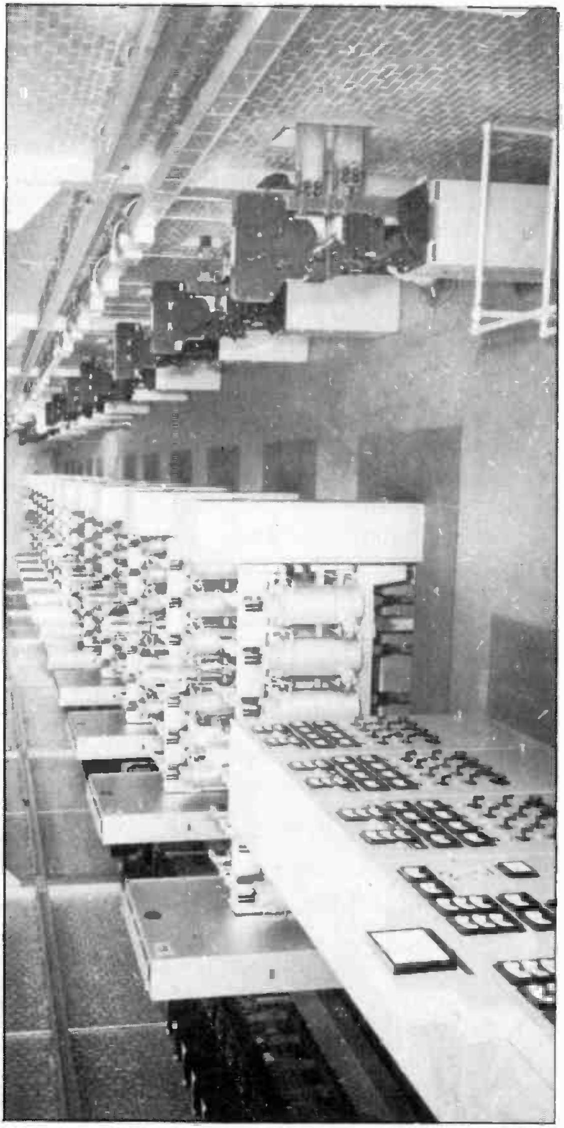
Radio and electronic controls are very similar in many respects, both using vacuum tubes and amplifier circuits. Electronic devices themselves have no moving parts except a relay and require very little attention. Many of their most important uses gain favor because they replace equipment that does require considerable work to keep it in service. However the installation, comprising the electronic device plus the mechanical, electrical, or chemical, equipment which it operates or controls does require some maintenance. The greater the understanding and judgment used in making the installation the less cause there will be for maintenance work.

For the purpose of explanation we are considering mainly electronics for industrial and business uses. These uses fall into four main groups with some overlapping of one on the other.

They are:

I. Rectifiers

II. Time Controls



12-Unit Ignitron Mercury-Arc-Rectifier Installation. Rectifier units are 12-anode, 5,000 amperes, 645 volts. (3,225 KW). View showing master duplex control panel (left foreground), 6-pole high-speed anode breakers (along left wall), rectifier excitation cubicles, ignitron rectifiers, rectifier auxiliary control panels (left center), cathode breakers (along right wall)

III. Heat Measurement and Control

IV. Photoelectric Applications

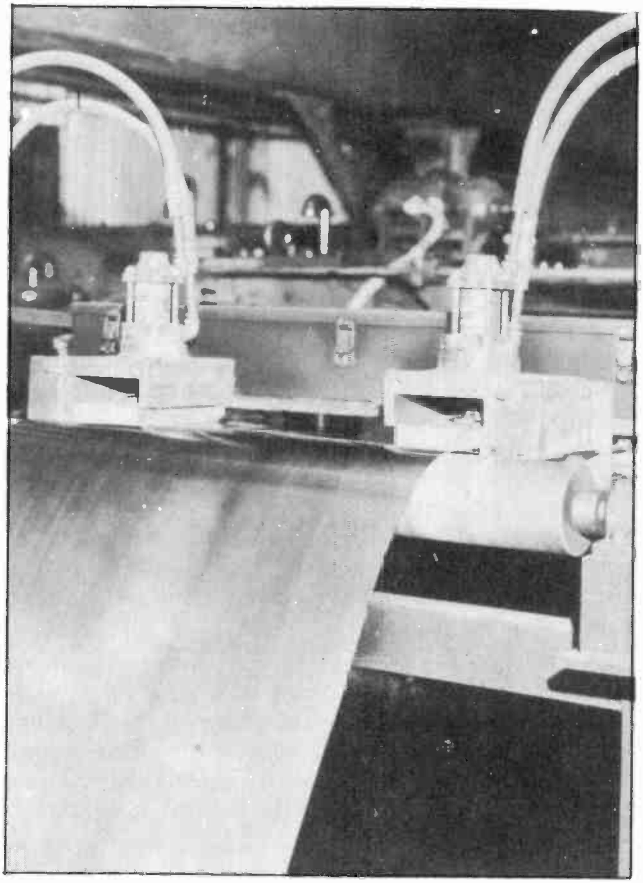
Although Time Controls and Heat Measurement Devices are listed by some manufacturers as Photoelectric Equipment our grouping here is intended to class as Photoelectric applications only those uses which operate by means of a light beam. This group (IV) has, by far, the most varied and the greatest number of uses and will be discussed separately.

Devices in group I operate on the characteristic which causes a stream of electrons to carry current in one direction only, changing A.C. to D.C. For many applications requiring flexible control under load, D.C. motors are superior to A.C. yet the transmission of A.C. power is more economical. Hence power is transmitted as A.C. and converted to D.C. instead of using a motorgenerator it is often less costly to use electronic equipment. Huge rectifiers of that type have long been used for substations of electric railways. They employ large tubes in metal cases. These are gas discharge tubes. The cathode is in the form of a pool, usually mercury, and an ignition electrode is "fired" to start the electron flow in each cycle.

Ignitron tubes, as the manufacturer calls them, when made in the larger sizes are cooled by a water jacket and it is necessary to make sure that they have a constant supply of reasonably clean water. The electronic panel may be equipped with a device which signals any stoppage in the flow of water.

Smaller ignitron tubes are now being used to convert A.C. power to D.C. for the operation of variable speed motors on lathes, drill presses, etc. D.C. motors are needed for such services because their speeds can be regulated by a rheostat and the selected speed will be maintained even though the load varies.

Ignitron tubes are always "hot" and one must be careful working around them because they operate on A.C. voltages of 230 and up When D.C. motors are operating directly on a D.C. source in the usual manner a tendency to gain speed too rapidly is self corrected as follows.



Electrolytic cleaning and shearing line for tin plate. View showing scanning head for pin-hole detector and supporting stand with manually operated side guides which maintain strip at proper pass line by means of air-operated pressure blocks. Scanning head ventilated by compressed air. G-E pin-hole detector and marking device.

When a D.C. motor is running at high speed with a reduced field and it is desirable to lower the speed and increase the field strength rapidly the motor will take on a generator action and pump current back into the line

ELECTRONIC EQUIPMENT

The field of Electronics or that branch of the Electrical and Radio industry dealing with the manufacture, installation and maintenance of Electronic equipment, is rapidly becoming a tremendous industry in itself.

The term electronics deals with the application of electrons and minute electrical charges and currents, as well as with vacuum tubes, photo electric cells, delicate relays and sensitive devices which produce and utilize these minute electrical impulses.

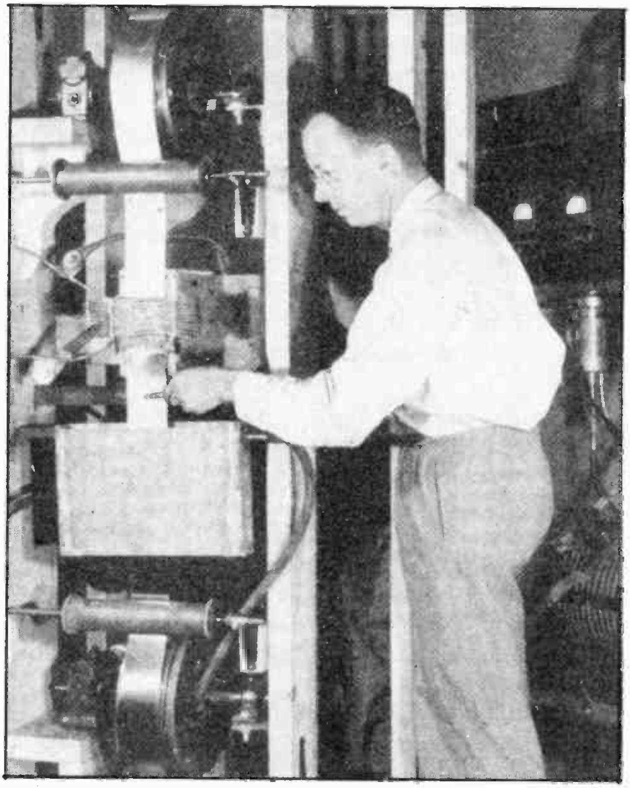
So we can readily see that there is nothing mysterious or unusually difficult about the study of electronics. It is very closely associated with the ordinary principles and applications of electricity and radio equipment, except that it deals with more minute quantities and opens up vast new fields for more sensitive, more accurate operations and controls.

Electronic devices are now being used in ordinary radio equipment, in Television, in industrial controls for production machinery, counting, guaging, timing, inspection, testing color matching, etc. They are also used in hospitals and medical practice for microscopy, Xrays, sterilization and electrotherapy treatments. Electronic equipment controls, electric welding machines, electric induction furnaces, electric heating and baking equipment. It can be used to open garage doors at a flash of a light, to turn electric lights and signs on at dusk and off at daylight, to protect buildings as a burglar alarm, in railway signals and train control and hundreds of other practical time and money saving ways.

The ordinary maintenance electrician, electric wireman, power plant operator, radio mechanic or operator will find an increasing need for a working knowledge of electronic equipment from now on.

In some cases the load which a D.C. motor is driving may get ahead of the motor and drive it as, for example, in the case of an elevator. This is known as an "overhauling load" and when it occurs the D.C. motor acts as a generator and pumps current back into the line.

But with the current coming from a rectifier no such reversal of current is possible and the installation must therefore include a resistor to produce the



Two hundred thousand waves a second have melted tin into evenly-distributed coating on this metal strip.

dynamic braking effect. The resistor is applied by a contact-making voltmeter and a contactor which conects the resistor in the circuit as soon as generator action causes the voltage to rise. If no filter is used in connection with the rectified current an appreciable A.C. ripple will be superimposed on the

D.C. which causes greater overheating than for an equivalent current from a D.C. source. Motors in this service of operating lathes, etc., are often run at low speed and lose the cooling action of high speed operation. These two overheating tendencies require that the motors used must be of a larger size than would otherwise be necessary

Tubes containing mercury and gas-filled industrial tubes may fail to operate because of temperature conditions. At its base the tube should not be colder than 40° C or hotter than 80° C. When the ambient or room temperature is freezing the tubes will not vaporize and when the temperature is too high the pressure becomes so great that they will not conduct continuously. If room temperatures can not be controlled then the air in the vicinity of the tubes must be heated or cooled as required. Ambient temperature of the room should be between 60° F and 100° F.

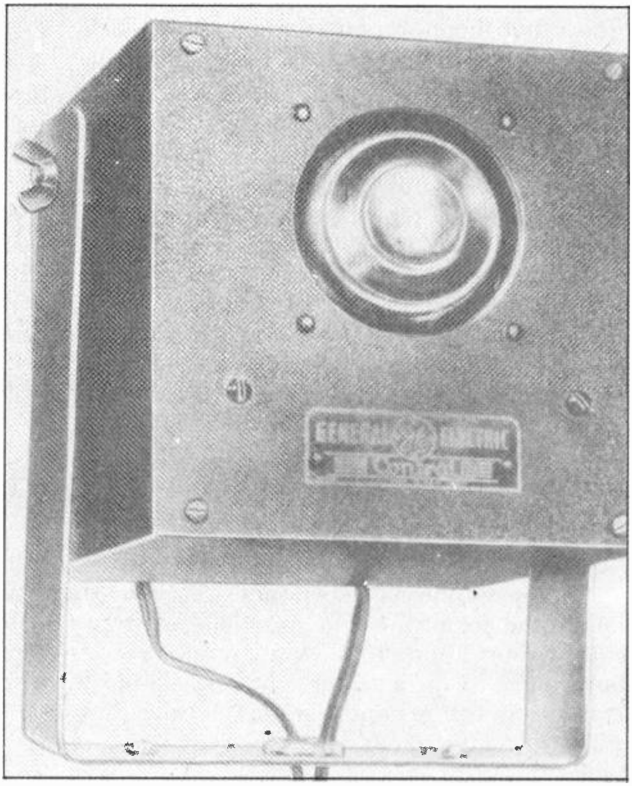
Moisture also interferes with tube operation, especially where high voltages are used. Installations should be planned to avoid excessive humidity.

In looking for trouble where mercury-vapor tubes are employed, one will sometimes discover that the color of the arc in the tube has changed from a brilliant mercury blue to a whitish or greenish discoloration. Such a color change should arouse suspicion as to the condition of the tubes but is not an indication of tube failure.

All tube devices are critical as to voltage but usually are made to operate perfectly within a voltage variation of plus or minus 5%. Some of the larger ones have a series of terminals marked for various voltages.

TIME CONTROLS

The second group of electronic devices is Time Controls. Here we are dealing with a relay operated by the grid bias of an electron tube which is similar to a radio tube. Negative bias on the grid prevents the flow of current. As the negative charge passes off through a resistor in parallel with a condenser, the positive potential is restored and current again flows. A potentiometer in the circuit provides means

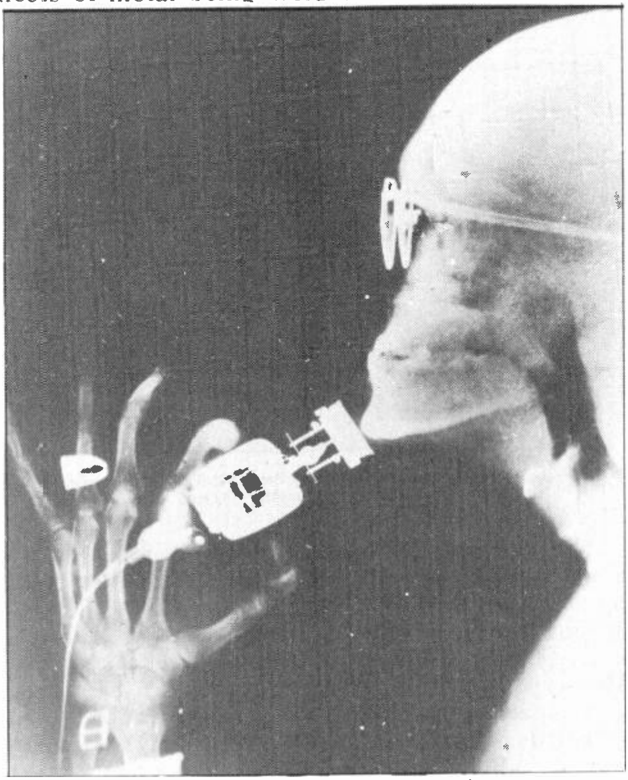


Photoelectric relay. Table mounted for flexibility in setting to light-source.

for setting the time delay action by controlling the degree of initial negative bias.

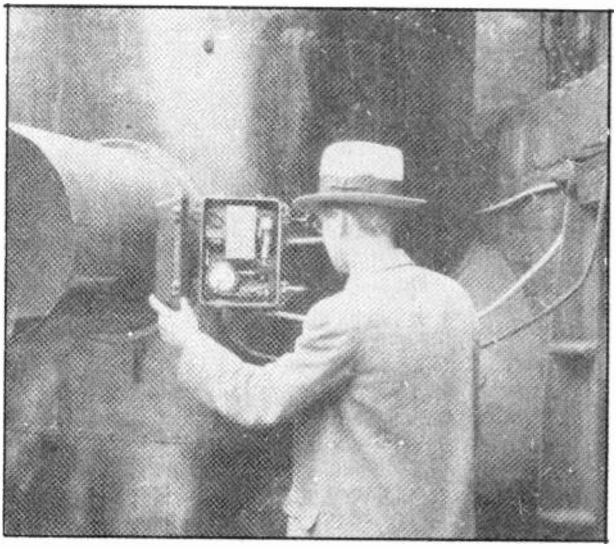
Certain manufacturing procedures require that a series of operations take place in a definite time sequence. Vacuum tube time delays can be arranged so that the whole process stops when any one step is out of time. In plastic moulding the machine may be controlled so that a predetermined time such as 20 seconds is allowed for baking. Some processes require not only timing of each step in the process but also of the intervals between steps. This is true of resistance seam-welding which consists of spot welding in such a manner that each spot overlaps the preceeding one, forming a continuous seam that is tight against liquids and gas.

Resistance welding devices may also have electronic power control so that each spot weld will receive the same amount of current at the same potential. In some cases electronic control is provided to keep a uniform pressure between the sheets of metal being welded.



X-ray taken with Westinghouse tube of average man shaving with electric razor.

Resistance welded control requires, constant pressure, constant surface conditions of the metal, constant current value and constant time duration for each period the current is on. This time duration may be set for 1/20 of a second for thin material up to a full second for heavy material. The periods are in multiples of alternating current cycles. For example if the input source is 60 cycles per second, the periods for which the timer may be set will be 1/60 second, 2/60 second, 3/60 second, etc.

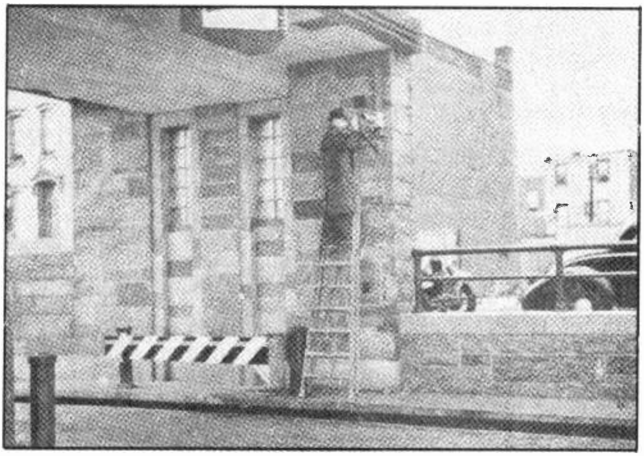


G-E protoelectric smoke-density recorder installed in a power house. It indicates the amount of smoke leaving the chimney.

The welding electrodes are generally cooled with a continuous stream of water and the water supply must be clean.

Time delay devices usually contain only one moving part which is a telephone-type relay. These are very sturdy and efficient even when operated at high speed and seldom cause any trouble. They should be kept dry and free from dust, particularly any metallic dust. Should the relay contacts require any burnishing it may be done with very fine sand paper, lightly applied, **but never with emery paper. In fact emery paper should never be used on any silver or copper contacts as emery dust becomes imbedded in the contacts and causes electric** arcs. An ideal burnishing tool can be simply made from a piece of spring steel by roughening it with emery paper, being sure to remove all traces of emery dust from the tool before using it.

One manufacturer provides his electronic timer with a pair of clips into which may be inserted "timing valves" of various ratings. They are porcelain tubes resembling grid leaks. Each "timing valve" changes the timing range which can be set on the timing dial. The "timing valve" should be wiped occasionally to keep it clean and free from moisture.



Photoelectric height-indicator at entrance to tunnel in New York.

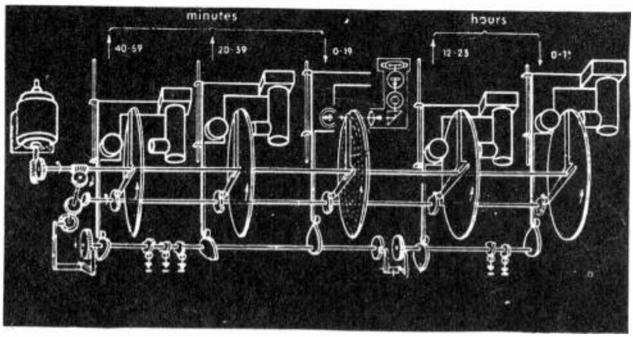
A specialized form of electronic timer is a device for synchronizing A.C. generators. By means of it a generator can be put in parallel with one already running without any danger of injuring the equipment and without causing the lights to dim on the line. When the generator to be put on the line is "hunting" (i.e. changing speed and voltage above and below the required level) it can be caught and cut into the line at just the right instant by the electronic timer. If preferred, the timer can be set so the generator to be added will run in syncronism a prescribed number of cycles before being cut in. An electronic synchronizer operates on a grid-controlled discharge tube and a rectifier tube.

A large number of electronic devices come under the classification of pilots.. Their function is to accomplish, with low voltage and minute current whatever electric control action is to be made. Through amplifiers and relays this current is built up to the required value for operating the equipment that is to be controlled.

When electronic devices operate without receiving the impulse that is intended to cause their operation the fault may lie with some other electrical equipment that is changing the voltage on the line or is sending out a radio-frequency impulse. Such trouble might be caused by a motor starter and in that case may usually be corrected by connecting a condenser across the starter coil. The capacity required is generally between ¼ and 2 microfarads.

ELECTRONIC HEAT MEASUREMENT AND CONTROL

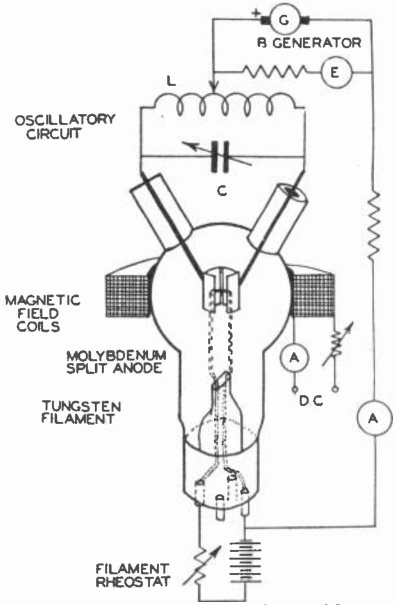
The third group, Heat Measurement and Control is similar to a Photoelectric relay but is not classified in that group because it uses a tube which instead of being sensitive to light is sensitive to radiant energy emanating from hot materials. The tube changes its output according to changes in the



Block diagram of the photoelectric time-telling device.

temperature of the heated body. Amplifiers build up the tube output to sufficient strength to indicate, record or control temperatures. Proper functioning of this equipment requires a reasonable room temperature. It is also important to keep the phototube and amplifier dry and free from any conducting dust or foreign material.

Whatever the type of electronic installation, it is wise to have on hand a complete set of spare tubes. In maintenance work on electronic equipment the first step in "trouble shooting" is to find out if the tubes are O.K. This does not mean that tube failure

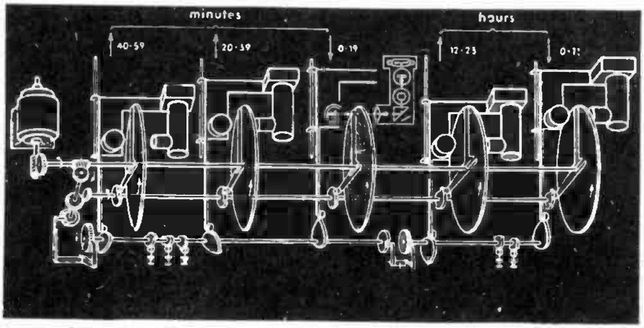


Basic circuit of the magnation oscillator.

is the most frequent cause of trouble but it is the most easily overlooked cause. A sure and simple way of checking tubes is to replace all of them with spares that are known to be perfect and see if that clears up the trouble. If it does, then the tubes known to be good may be replaced, one at a time, by their corresponding used-tubes until failure to operate indicates which one is at fault.

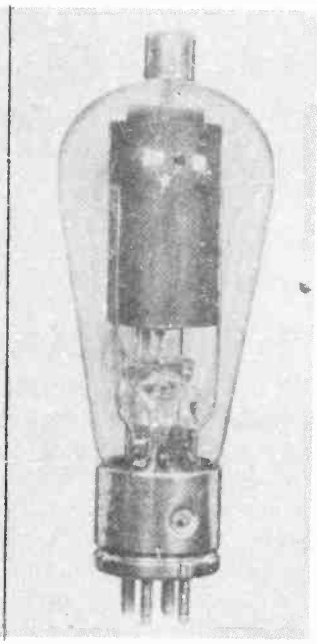
PRACTICAL APPLICATION OF ELECTRONICS

As previously explained, one of the most promsing branches of the electrical and radio fields is "electronics". The turning on and off of a switch automatically, doors opening mysteriously and a thousand and one humdrum tasks turned into novel



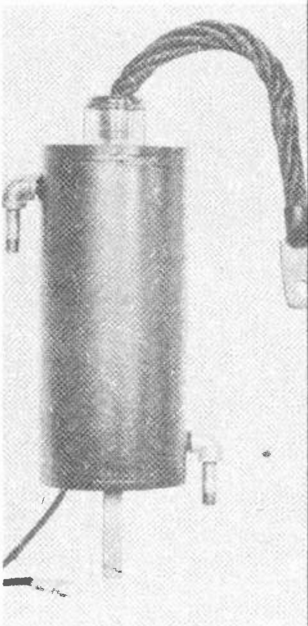
Block diagram of the photoelectric time-telling device.

G-E Kenotron tube, type GL-411

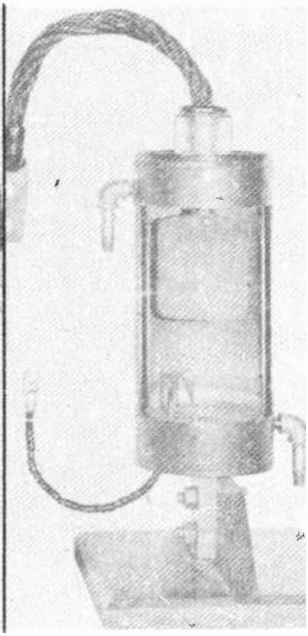


G-E Thyratron tube, type FG-17.

and exciting jobs, is the intriguing field which looms before the well-trained radio man or electrician. We have had the steam age, the great progress in electricity and radio and now the vista that opens up before us with regard to electronic control as the most marvelous of all.



GE-ignitron tube, FG-235-A.



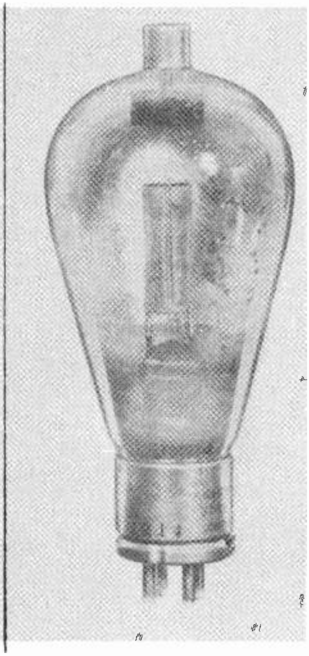
Internal structure of FG-235-A.

Dreams are fine things so far as forecasting the future is concerned, but the man who dreams about electronic control today is simply not awake. **It's here, now,** and you can make money by using it wisely. It is not a crowded field, and men skilled in the work are so scare that they can almost write their own ticket as to wages, if properly qualified

The field is not open to the average radio serviceman but to the man who is a **little above average,** who has studied radio and electricity diligently. If the screwdriver mechanics has no place in radio today, the same man certainly canot aspire to electronic control.

A few reasons why electronic control is valuable are listed so that you will gain an idea of the importance of this new field and how it may be profitably explored.

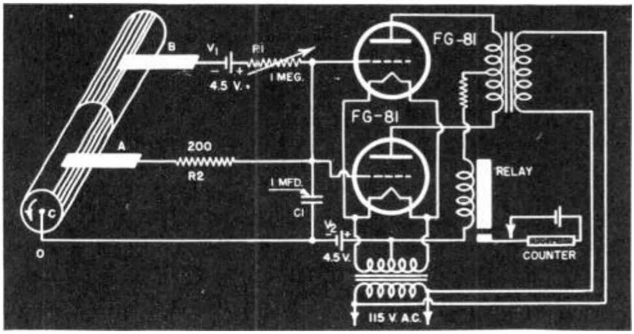
G-E pliotron tube, types PJ-7 or PJ-8.



G-E Phanotron tube, type FG-32.

1. Reducing the cost of a manufactured article.
2. Effecting a saving in maintenance of equipment.
3. Insuring more uniform quality of manufactured products.
4. Safeguarding life and property.

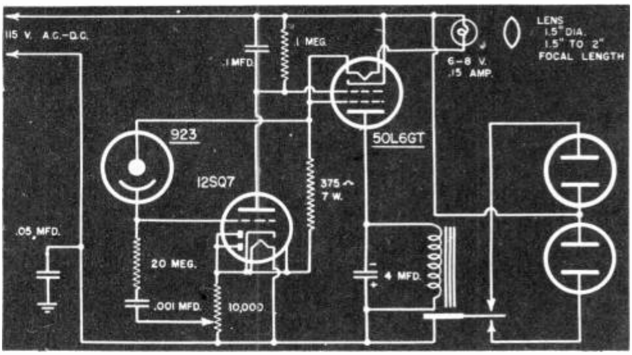
5. Speeding industrial operations.
6. Counting objects accurately.
7. Eliminating the "human error" in production of precision parts.
8. Controlling irregular actions of machinery.
9. As integral parts of advertising display or



A modern hydraulic flow indicator circuit.

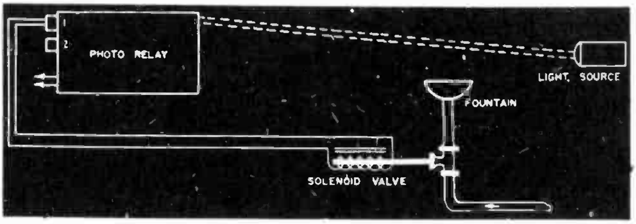
systems.

10. Control of processes not handled by human senses.
11. Controlling delicate operations in mechanical assembly.
12. Improving efficiency of human workers.



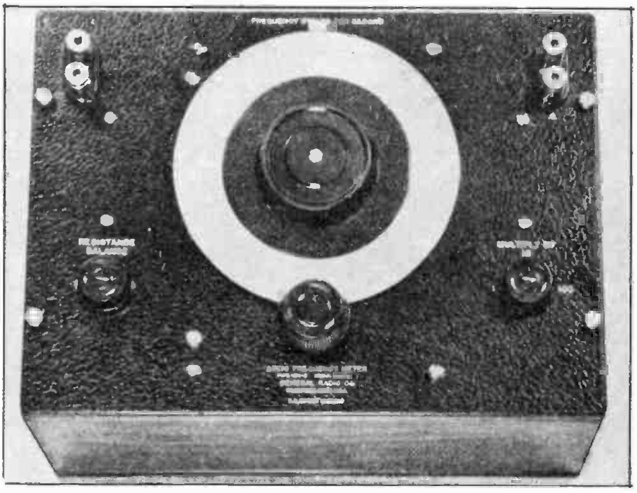
Experimental grid-controlled relay unit.

The first step in an electronic control job should be to make a study of the manufacturing process and just what the client has in mind to accomplish, just what his problem is and how it may most efficiently be solved. It a simple mechanical arrangement will serve the purpose, electronic control should not be used. There would be no economic or practical justification for the electronic system.



A photoelectrically-controlled drinking fountain.

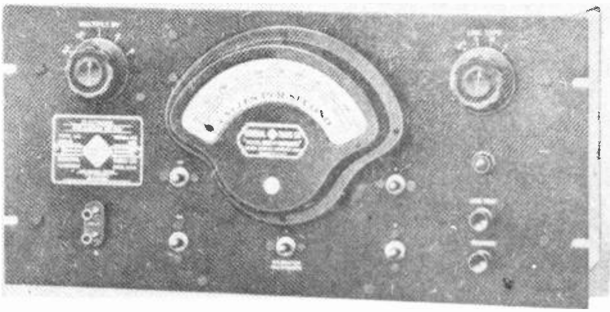
In cases where suitable electronic control would be useful, considerable saving of money and man-hours of labor would be effective. Draw up your plans carefully, and then present them in as clear and understandable a light as possible. If there is something about the machine or process you don't understand, be frank and say so. In this way less time and money will be wasted and satisfaction all around will be assured.



Portable laboratory frequency meter—20 to 20,000 cycles.

When you have estimated the cost, make out a written agreement and have the customer sign that agreement in the presence of a witness, and get the signature of the witness. This eliminates argument later.

The basic structure of an electronic control system may be sub-divided into four main parts. The first is the **detector** which has the job of changing physical movement into electrical movement. Where a photoelectric cell is used, a change in the amount of light hitting the cell results in a change in cell current. Where a temperature device is used such as a mercury thermometer, the temperature changes the level of the mercury solution and a change in pressure or height is used for control of a secondary device or system. In the case of some humidity controlled devices, such as the radiosonde, used for weather observations.



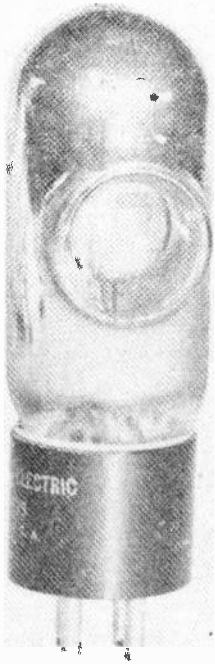
Precision panel-mounted electronic frequency meter.

The greatest use of photoelectric equipment is generally in connection with other electrical apparatus; a motor may be used to raise a platform, an electromagnetic valve may be opened and control the flow of water or oil, a pneumatic pressure may be built up for the purpose of operating a drill, the pressure being controlled by a valve operated by electricity.

A novel unilateral counter is shown in Fig. 1. It numbers the autos going in one direction on a two-way road.

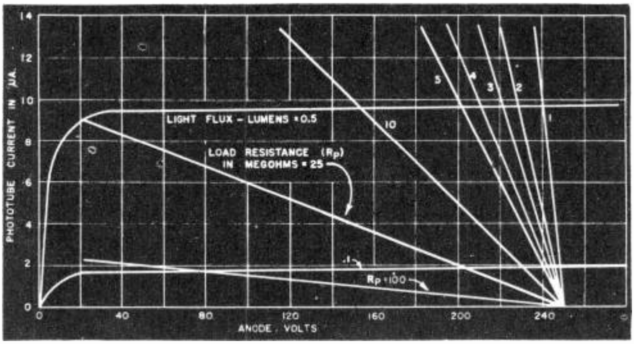
With cells connected as shown, cell illumination corresponds to lower cell resistance and the amplifier tube becomes more negative, lowering the plate current to the tube. When the beam is interrupted, the bias on the tube decreases as the result of increased cell resistance and the plate current increases, this change in current being used to operate a relay which in turn controls a counter.

G-E Type PJ, or FJ photoelectric tube.



Front view of G-E Type FJ-405

Only objects in an upward moving path will be counted, for when light is on both cells the plate currents of the two tubes are at minimum value and all three relays are in drop-out position, as shown, and an object moving upward first interrupts the beam on Pb, causing relay Rb to pull up. The contacts of Ra and Rb are now closed, but Rc cannot pull up for the reason plate current in VTa is still at a minimum value and is not sufficient to operate both Ra and Rc, which are now parallel with each other. The object moves farther up, to a position where it interrupts both beams and then the plate current of VTa increases. However, the coil Rc has so much lower a resistance than the coil of Ra, that only Rc pulls up. In other words, relay Ra cannot get sufficient current for its operation when Rc is in parallel with it. The pulling up of Rc closes the contacts with which the electromagnetic counter is controlled and a single count is registered.

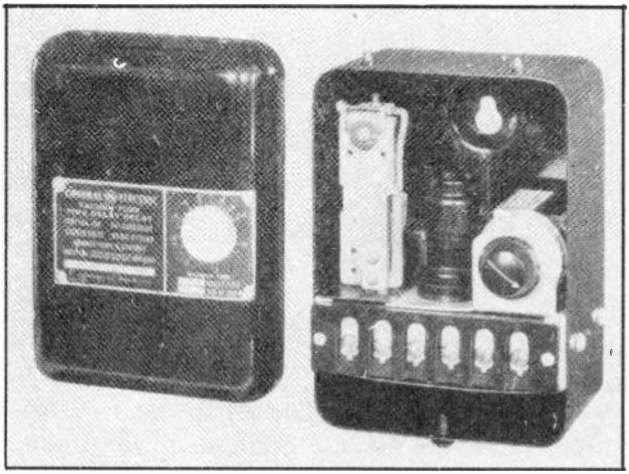


How current varies with light density.

As the object moves on, the beam of Pb is restored causing Rb and Rc to drop out. With Rc no longer taking current away from Ra, the latter relay pulls up and no further action occurs. When the object passes the last beam, restoring light to Pa, Ra drops out, closes its contacts, and the system is ready for another cycle of operation.

The reason no count is made for a downward direction is given by the following explanation. The beam of Pa is interrupted first and Ra pulls up. Nothing happens further until the object moves into the lower beam, cutting off light to Pb and relay Rb now closes. But, since the contacts of Ra are open, Rc is not energized and there is no count. When light is restored to Pa, the contacts of Ra close and Rc cannot pull up now because VTa has a minimum plate current and the electromagnetic counter does not operate. When light finally is restored to Pb, the contacts of Rb open and the system returns to its original condition. Objects shorter than the separation between the two beams are not counted since both beams must be interrupted at the same moment and in correct sequence. Equipment of this kind is generally built to special order, serving a specialized need.

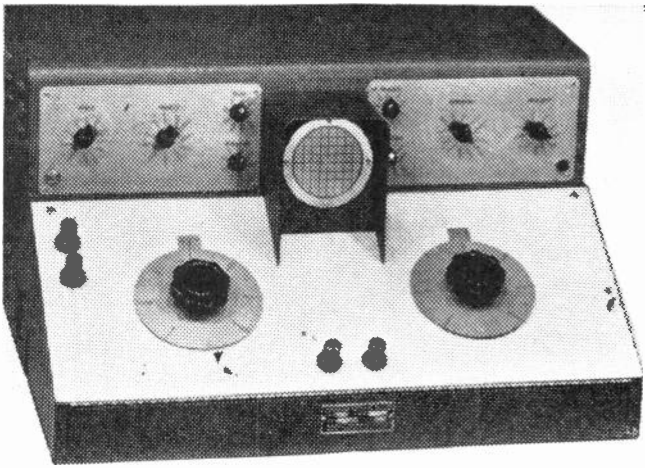
High speed photoelectric circuits have also been levised for counting cigarettes, small screws and



Interior of G-E vacuum tube relay.

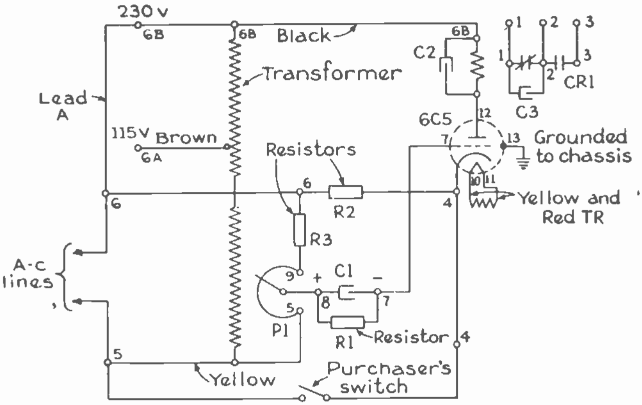
other objects passing in rapid order. Light beam arrangements have been successfully used for production of spark plugs and other fairly close tolerance work, for smoke detector apparatus in cities having ordnances against poorly adjusted furnaces and chimneys. Photoelectric devices measure the amount of foreign matter in a liquid due to the ability of a material to transmit light and also forms the basis for certain forms of egg candling units.

But one of the most interesting of photoelectric applications in the control of products whose final merit is determined by the color of the light



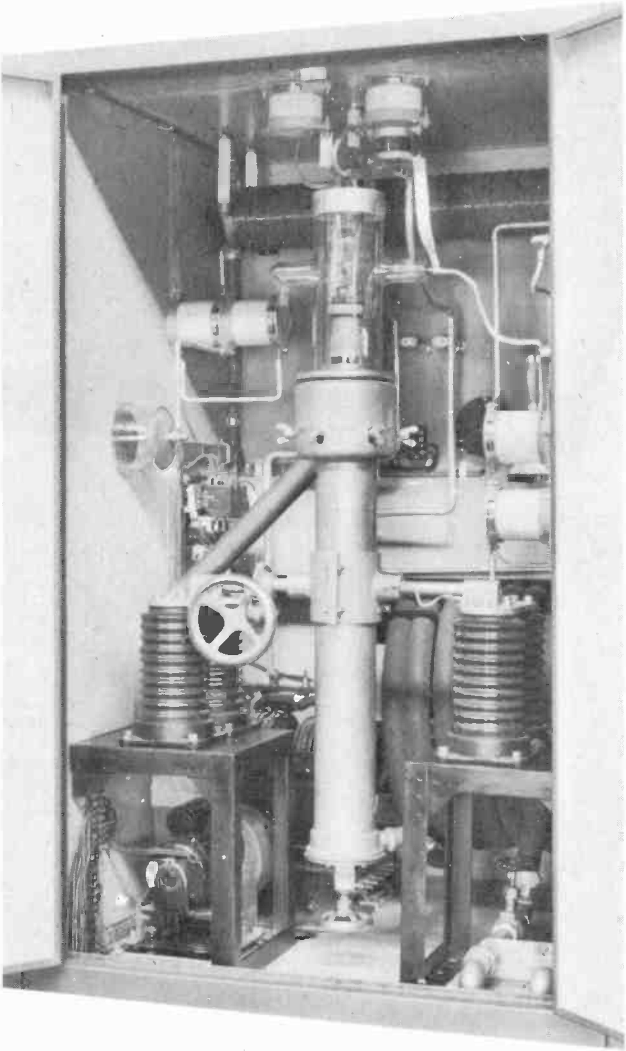
Impedance-matching bridge, used in laboratory work.

that the material reflects or emits. The heating and tempering of steel, the selection of various



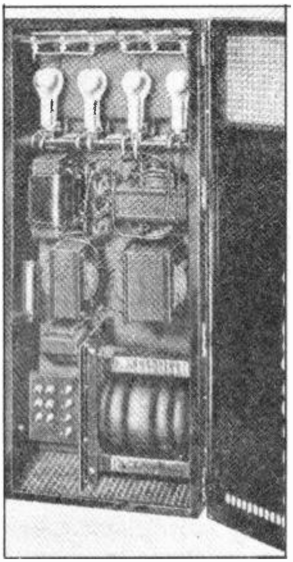
Wiring diagram of relay shown on page 1242.

grades of paper, the roasting of coffee, and yes, even the baking of cake or bread are all processes rendered more complete and more exact.



EXPERIMENTAL ELECTRONICS

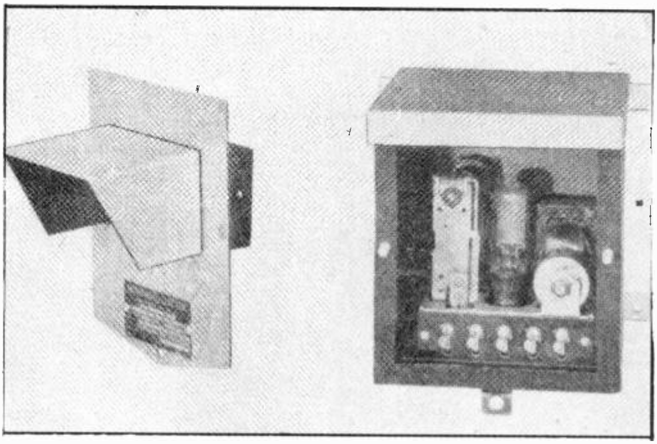
As the name implies, electronics is based upon the electron, its motion and the capabilities of electron emission. However, some of the tubes employed in electronic devices might be more appropriately termed "ionic" devices. Electronic devices are tube devices. It is well known to radio amateurs that the electron stream may be utilized to accomplish a number of operations previously possible only with electromechanical gear. For example, a relay, switch, or signal device may be switched on and off by the passage of tube plate current, controlled in turn by a grid voltage.



High-voltage rectifier panel for industrial applications.

Photocell applications, time-delay devices, capacity-controlled relays and alarms, tube-operated counting devices, and sound-controlled locks and alarms are only a few of the gadgets that are merely combinations of simple electronic circuits.

The reader will, after he has looked over several simple electronic circuits, immediately vizualize embodiments of these hookups in apparatus of his own design. Several of these simple circuits are shown. They are presented as "building blocks" much as were the hundred mechanical movements in the old patent-attorney pamphlets. Some readers will desire to hook up the equipment, just as it is shown, in order to study its operation; others, already familiar with the simple units, will prefer to combine several simple circuits for some more complex application of their own designing.



Midget photoelectric relay designed for outdoor use. It measures only 8 in. high, 8 in. wide, and approximately 10 in. deep.

For weather observations in test balloons, a human hair or combination of hairs change their physical length due to moisture absorption and allow release of a spring controlled electrical contact. All of these systems work with electron tubes and are called electronic controls.

The second part of the basic structure is the **discriminator,** the selector which brings before the detector the object to be examined or analyzed. An example of a selector would be a round hole cut in a soup dish, the size of the hole being just big enough to let a certain size marble or round object pass through and yet exclude slightly larger objects; or it might be a conveyor belt in a factory or a special light filter in the case of an optical system using a photoelectric cell.

The third part of the system, basically, is a **power gain device.** It may be a d.c. amplifier using ordinary tubes and a sensitive relay or some special form of thyratron tube. Its function is to use the small change in energy of the detector so that it can be harnessed to control a relay or switch.

The fourth part of the system consists of the motor or pressure control system used for opening a door, shutting off a valve or doing any other sort of purely mechanical work.

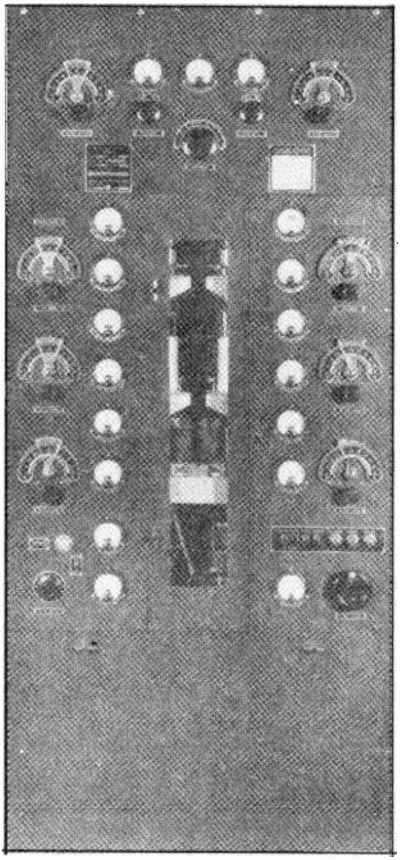
The photoelectric type of electronic control has received the greatest attention in recent years. It consists, essentially, of a light-sensitive cell, light source and associated optical system, amplifier and relay, power relay and the device or operation jig being controlled.

The detector in the photoelectric system is, of course, the photo cell. The three types of cells commonly found in practice are the photoemissive, photoconductive and photovoltaic. When the light beam is invisible to the eye, infra-red is the type of light used. Photovoltaic cells give preference in such infra-red systems to the high red sensitivity photoconductive (selenium) and photoemissive types.

A source of artificial light, using a 6 to 8 volt auto lamp of standard 32 candlepower, in conjunction with a lens system for the efficient focusing and utilization of that light, is included in all photoelectric systems except those using special lamps or depending on natural light for operation. In some units a home movie projection lamp is used, and the bulb in such systems operates directly from the 115 volt line, a.c. or d.c. With low voltage lamps, a.c. only is used, as a transformer is necessary to step down the voltage from 115 to 6 or 8 volts. The bulb is always operated at the lowest voltage which will give adequate light output, thus prolonging the useful life of the lamp.

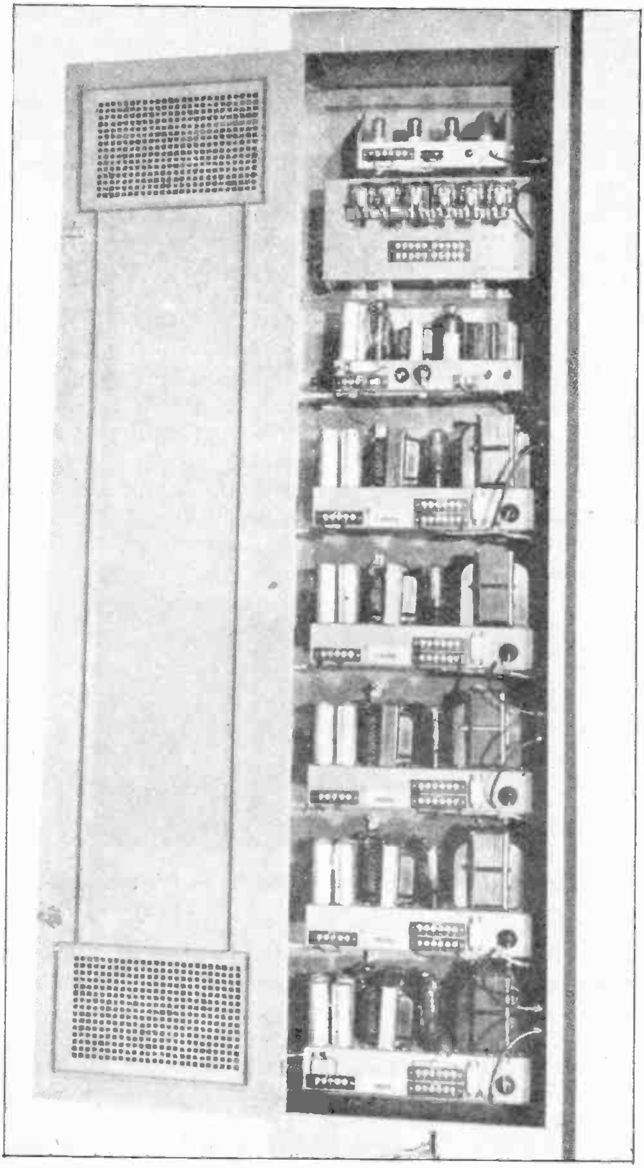
Twin-filament lamps are generally used, so that burn-out of one filament merely means the turning of the lamp in its socket and restoration of service.

These lamps, possessing high infra-red output, can be used with suitable filters for invisible light operation. Parabolic mirrors or lenses can be used, with lenses finding greater favor commercially due to the fact that they are less critical to adjust, are lower in cost and permit easy focusing.



Radio Receptor SMRA Transmitter.

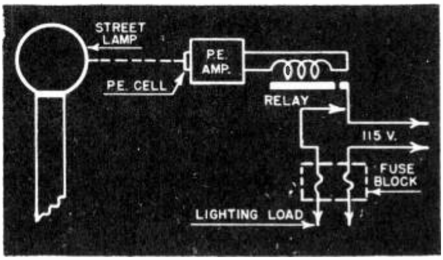
Photoelectric sources must, of necessity, be rugged in construction as they are subject to abuse at the hands of the public or may be damaged by accidental contact with passing object. A rugged steel case is generally used for protection of the fragile lamp and lens.



Electronic tubes in this elaborate PA amplifier make make it possible to cover wide areas.

Commercial light sources generally house the step-down transformer, lens and lamp in one box and the lamp socket or lens may be adjusted for focusing. The lamp is set at the focal point of the lens, if the beam is to be a parallel pattern and back of the focal point if the converging beam is to be focused on the light sensitive cell—but not back farther than twice the focal distance. The beam of light which the unit throws is adjusted until it more than covers the light sensitive cell. In this way, if the position of the light source is moved slightly, or of the cell, the alarm or system controlled by the photoelectric system will not be put in operation falsely.

The average commercial photoelectric installation requires that approximately 5 foot-candles of illumination be the light intensity upon the photo cell. The light intensity will vary inversely as the square of the distance for ordinary lamps. An ordinary lamp will generally be unsuitable for producing powerful beams, since its filament is too large in area.



Photocell and relay operate when street light is turned off.

A practical operation of a beam of light would be the case of a beam being interrupted by a small car on a railroad track in a coal mine, the beam being situated a little distance from the opening or entrance to the mine door. By the time the relay system operates, the car is up to the door and the door swings open.

Where a considerable distance separates the light source and the photo cell, a special pickup lens is used, as in the case of a telescope or camera. Reflection from a mirror can also be used, but losses of about 45 per cent occur.

The amplifier stages and relay following the detector (photocell) are generally placed in a single rugged housing. The power pack may also be included in the same box. Heavy relays are generally placed near the device or machine being controlled. High sensitive relays which in turn control heavy relays.

Fig. 272 shows one of the simplest d.c. control circuits. The tube may be a 6F5, 6SF5, 6Q7 or 6SQ7 when the resistor values shown in the circuit diagram are employed. Any other triode might be used if the resistances are altered to suit the tube characteristics. With this circuit, a relatively small d.c. grid voltage may be employed to control large voltages or currents through the relay which is normally placed in the plate circuit.

The plate circuit relay operates on a few milli-

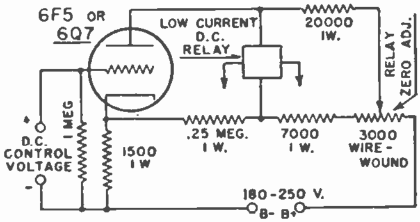


Fig. 272.

amperes or on as little as 1 milliampere. It is a direct-current operated device, such as a Sigma milliampere relay. Such relays may be obtained to close at small current levels ranging through several milliamperes.

It will be observed that the low-current relay is connected into a bridge circuit in the tube plate circuit, in order that the initial steady d.c. plate current may be balanced out to bring the relay contacts to the "full open" position in the absence of a grid-voltage signal.

Before the circuit is placed into operation, the heater and plate supplies are switched on; and, without applying an exciting voltage to the grid input terminals, the zero-set potentiometer is slowly adjusted until the relay contacts swing open. The plate-circuit bridge is then balanced, and the control circuit is ready for operation.

A small voltage applied to the grid-input terminals will then unbalance the plate-circuit bridge, causing current to flow through the relay, closing its contacts. The external contacts of the relay may then be connected to the circuit, machine or device which is to be controlled. If the controlled device requires more power than the low-current relay can safely handle, a second relay may be used after the former to handle the larger values.

The applied grid voltage signal may be a rectified radio signal, amplified voltage from a photocell, small battery voltage or any similar potential sufficiently intense to unbalance the plate-circuit bridge. The actual amount of this voltage will depend upon the characteristics of the tube and the sensitivity of the plate-circuit relay. If the relay used in the circuit of Fig. — has a sensitivity of 0.2 milliampere, approximately 1½ volts will be required to close it. If, on the other hand, the relay sensitivity is 1 mil, the grid signal will need be approximately 6 volts.

Fig. 273 shows a similar circuit adapted for a.c. signal operation. The triode may be any conveni-

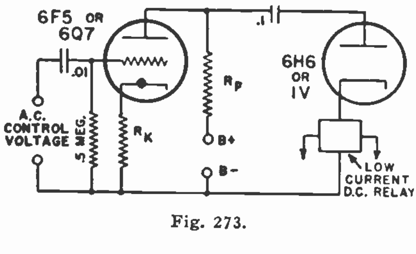


Fig. 273.

ent tube, preferably a power amplifier type, and the cathode resistor, Rk, and the plate resistor, Rp, are the values specified for that tube. The control tube might likewise be a tetrode, pentode or beam power amplifier. The 6H6 diode rectifies the amplified a.f. output signal and delivers d.c. to the low-current relay.

The a.c. signal applied to the grid-input circuit may be the output signal from a radio detector, a line voltage pulse, audio tone signal or similar signal voltage. The actual value of the signal voltage will depend upon the amplification characteristic of the tube. For high-gain tubes, this signal may be quite small. If the normal signal voltage is large enough to cause an overswing of the low-current relay, it may be reduced by increasing the value of the cathode resistor, installing a resistor in the 6H6 cathode lead or altering the value of the plate coupling condenser.

Fig. 274 illustrates an interesting gaseous-tube circuit designed to operate specifically on d.c. signal pulses or a.c. signals superimposed on d.c. In the

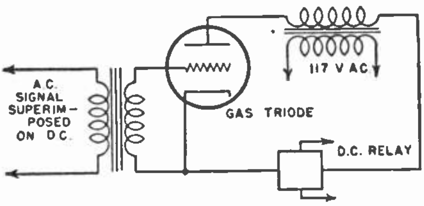


Fig. 274.

former case, the d.c. pulse sets up a pulse in the input transformer secondary; and, if this pulse is of the proper polarity with respect to the grid, the gaseous tube is fired, causing it to pass plate current and close the relay.

The tube may be a triode such as type 884 or 885 or a gaseous tetrode such as type 2051. The plate supply is a.c., this voltage corresponding to rated plate voltage for the tube. If the signal consists of an a.c. superimposed on d.c., a pulse is not delivered to the gas-tube grid until the a.c. component exceeds the d.c.

The gaseous tube is not similar in operation to the better-known vacuum types. It is in reality a high-current-controlled rectifier. The flow of plate current is not controlled over a wide range by the grid voltage, as in the vacuum tube, but merely set off by a certain value of grid voltage, whereupon it continues to flow, maintaining a constant value until interrupted. Some gaseous triodes and tetrodes pass such enormous plate currents that the special plate-circuit relay is not necessary to control external devices.

Fig. 275 shows a quick acting circuit embodying a cold-cathode rectifier tube. The outstanding advantage of this circuit is its ability to remain on the alert without requiring filament and plate power. The circuit shown may be operated by a

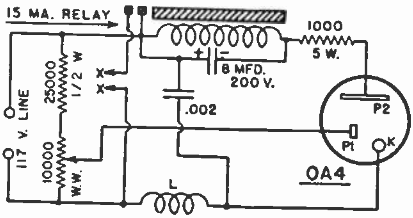


Fig. 275.

"wired-wireless" carrier transmitted over the a.c. power line and will control either an a.c. or d.c. relay.

Low frequencies, generally of the order of 50 to 400 kc., are used for carrier control operations, and the coil, L, and the .002 ufd. mica condenser are arranged to form a series resonant circuit tuned to the carrier frequency. The inductance of L will be governed by the frequency of the carrier.

When the circuit is placed in service, the line voltage is continuously applied to the anode, P1. The carrier voltage drop across the inductor, L, is applied in series with the cathode and P1 in addition to the line voltage. The starter-anode discharge is initiated, in turn initiating the main discharge in the tube and closing the relay.

The adjustment of the 10,000 ohm potentiometer is very important. This resistor is set at the point where the OA4-G tube just "fires"; and then the setting reduced until the discharge is just extinguished. The latter point is correct for operation.

A Practical time-delay circuit is shown in Fig. 276. This device is capable of operating a relay at predetermined time intervals set by the time constant of the resistance-capacitance network, Rt-Ct, in the grid circuit of the tube. A 117N7-GT tube is employed to provide both electrode and rectifier in the same envelope to afford 117-volt heater operation. These features make the device extremely simple, and reduce the number of parts required.

In operation, the double-pole, double-throw switch, S, is first thrown to the left hand position. This removes the d.c. voltage from the plate and screen of the tube and applies it across the grid network, Rt-Ct, charging the condenser, Ct. The switch is then thrown to the right-hand position, applying the plate and screen voltage. The control grid of the tube then receives the drop across the condenser, Rt, due to the discharge of the condenser. Because of the negative polarity of this grid voltage, the tubeplate current will be cut off as long as the grid voltage is present, and the relay in the plate circuit will accordingly remain open. The condenser will eventually discharge completely through the resistor, however; and at this time the grid voltage will be lost, plate current will flow, and the relay will be closed.

The time delay of the circuit depends entirely upon the time the constant of the Rt-Ct combination. The larger the resistor, the longer will be the time required for the condenser completely to discharge. The time interval may be predetermined, therefore, by setting the value of Rt, according to prior calibration.

Fig. 277 shows a circuit capable of intermittent operation at any frequency between one cycle every hour or so to high audio frequencies. Between those limits, any desired rate of repetition may be obtained. The circuit is exceedingly simple in that it employs a neon lamp, rather than a tube, and requires little current for operation. This device is the familiar relaxation oscillator.

Operation of the circuit is explained as follows: The condenser, C, is charged by the 100-watt d.c.

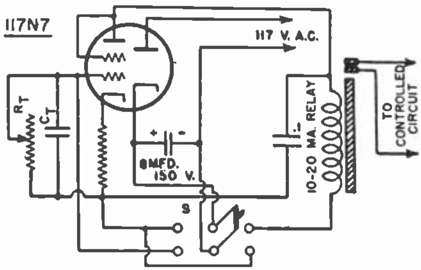


Fig. 276.

source. This condenser charges at a rate determined by its capacitance and the resistance of R. When the voltage across the condenser, due to the charging current, reaches the ignition potential of the neon lamp, the latter is fired and the condenser charge sharply reduced until the extinction potential of the lamp is reached, whereupon the neon discharge is extinguished. The circuit is then ready for a repetition of the cycle.

By properly proportioning the values of C and R, the alternate charge and discharge of the condenser may be set at any desired rate, the relay opening and closing at the same rate. In arranging the circuit, the experimenter must be careful to choose the R value such that the sum of the resistance in the base of the neon lamp and the reactance of the relay be half (or less) of the timing resistance.

A capacity-operated relay circuit is shown in Fig. 278. This simple device may be used in window exhibits where onlookers point at a spot on the glass to acuate a moving object, in counters, invisible burglar alarms, and the like.

This is a "blocked-grid" circuit which actuates a relay whenever a nearby conductive body moves close to the "sensitive" plate—a metal sheet of almost any convenient size.

ELECTRONICS IN MINING

This experimental Electronic device is used to extract valuable ore from otherwise useless soil. This device will soon be used by many modern mining companies.

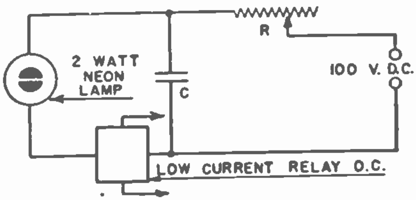
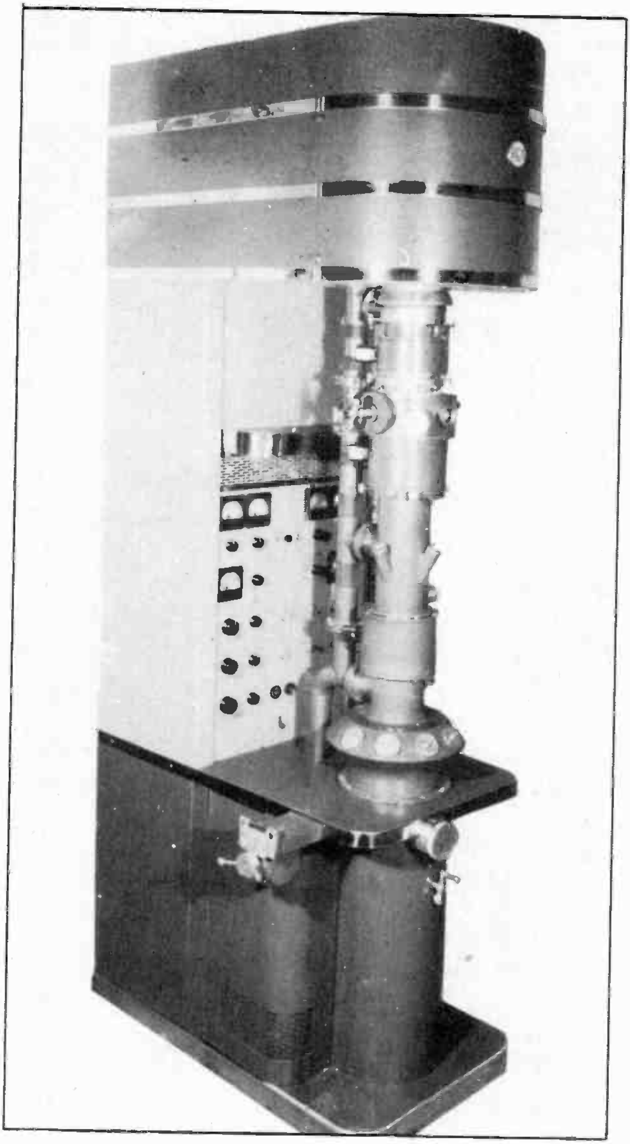


Fig. 277.

A simple triode, such as a 6C5, 6J5, or even a 117-volt type with screen and plate tied together is employed without grid leak. No rectifier tube is



ELECTRON MICROSCOPE

This Electron Microscope is capable of magnifying 20,000 times—requires 30 to 60 KV and stands 84 inches high.

required. The coupled coils, L1 and L2, are ordinary broadcast coils of the tune radio frequency types. The condensers connected in parallel with these r.f. transformers are set so that the circuit is just on the verge of oscillating. Any small additional capacitance, such as that introduced by a body, approaching the sensitive plate, will be sufficient to spill the circuit over into oscillation and close the plate-crcuit relay.

Success of the circuit is due to the absence of

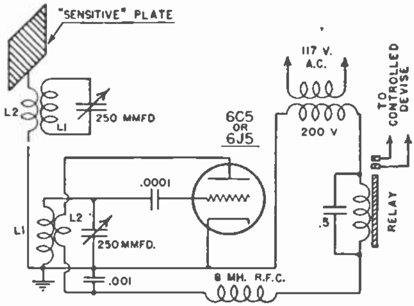
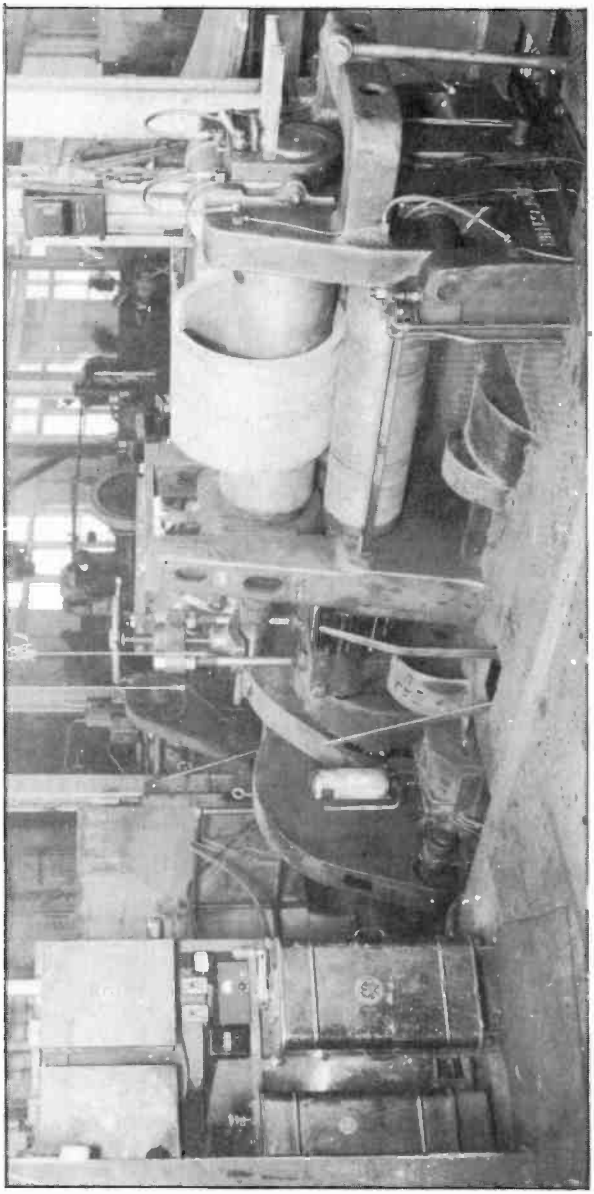


Fig. 278.

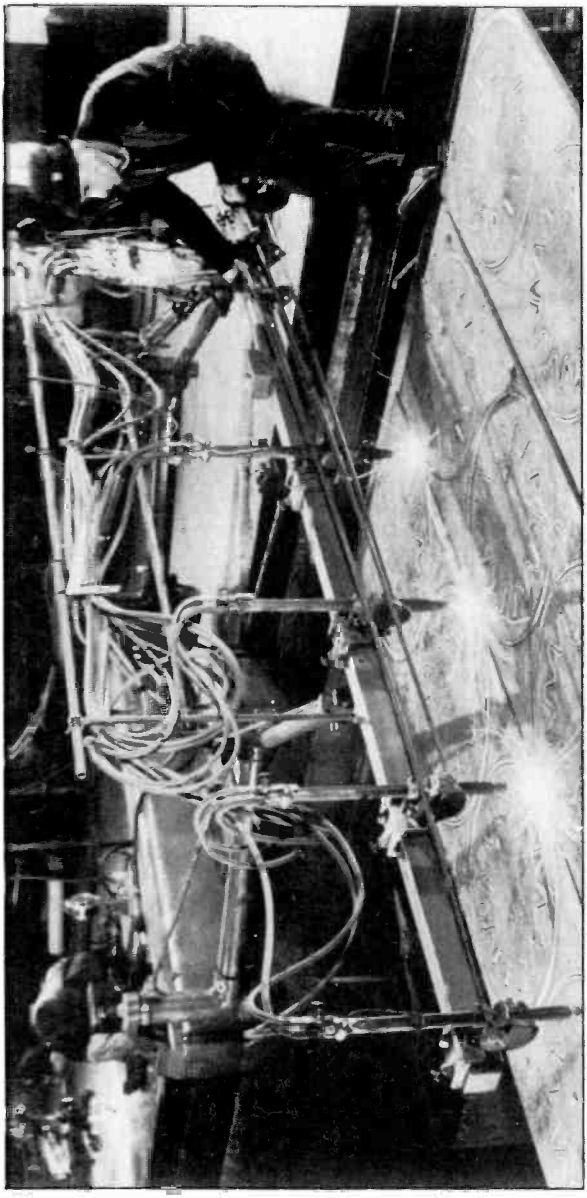
a grid leak. On each positive half-cycle of excitation, the grid collects electrons; and since there is no grid resistor path for these electrons, the resulting negative charge on the grid soon attains a value sufficient for plate-current cut-off.

The circuits shown here are only a few of the representative electronic hookups that may be placed into operation by the student experimenter. Various applications will be apparent to each individual.



No. 5 Bending Roll equipped with G-E electromagnetic strain-gage equipment. Instruments over controller show per cent of rated loading during rolling operations. Alarm given when machine load exceeds rated capacity.

A recording spectrophotometer, a high-precision Electronic instrument widely used in the paper, textile, chemical, and paint industries for analyzing.



Cutting sprocket blanks with Electronically controlled equipment four at a time from steel plate in a large eastern plant.

At work on problems of high voltage electron tubes in G. E. Laboratory, Schnectady, New York.

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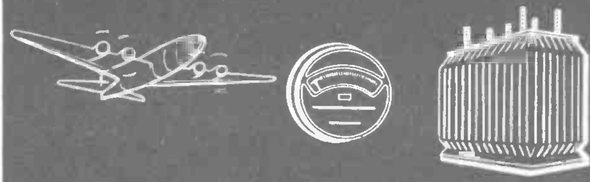

PRACTICAL

Electrical and Radio

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