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Based on the best knowledge and experience of applied electricity.

by **FRANK D. GRAHAM, B.S., M.S., M.E., E.E.**

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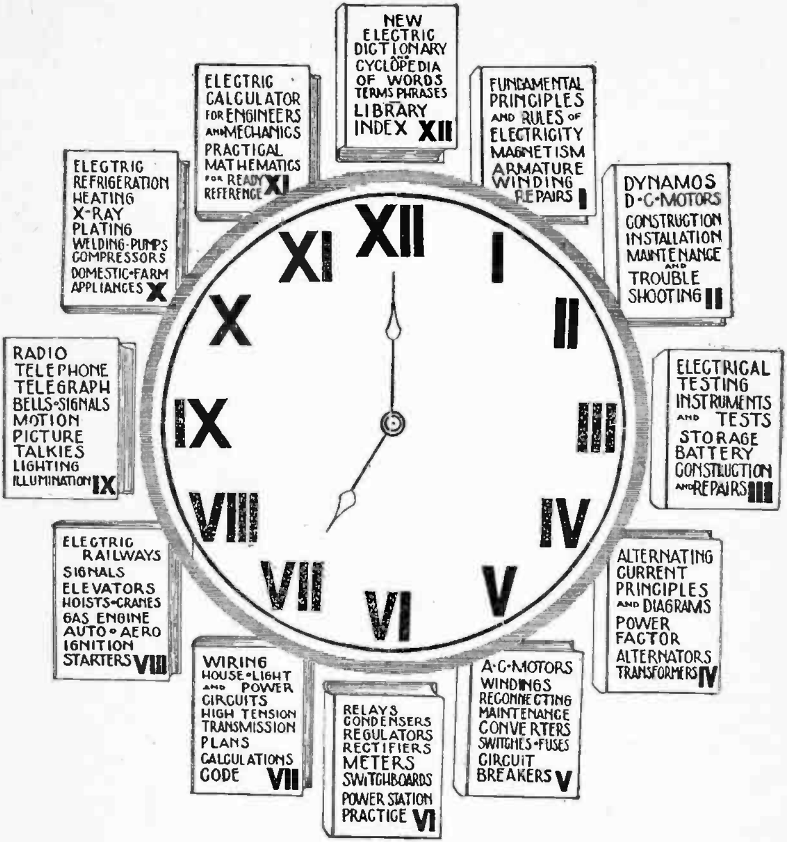

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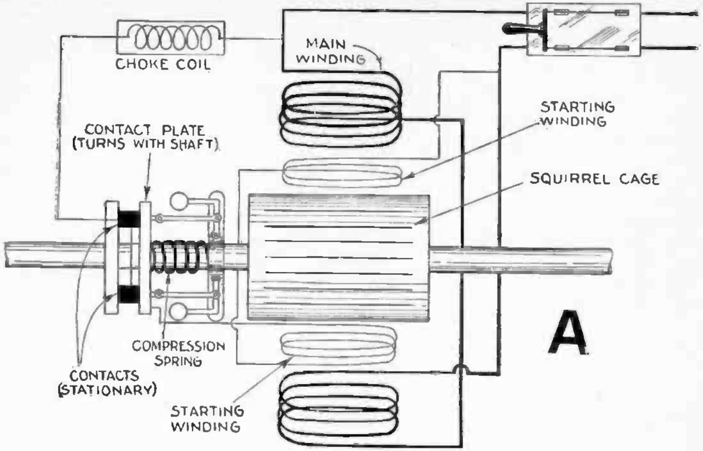

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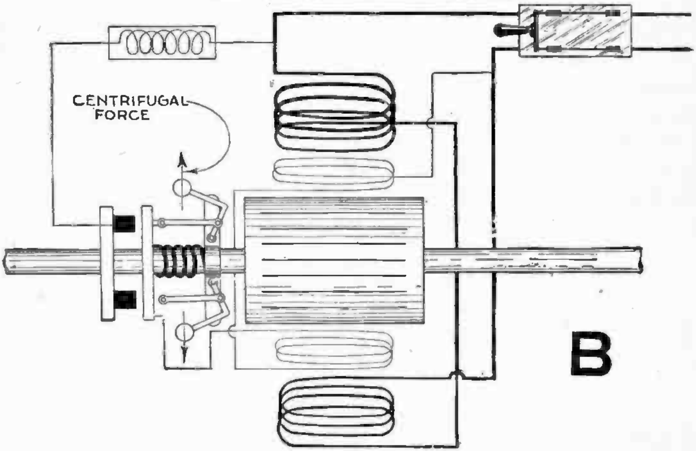

How a Split Phase Induction Motor Cut Out Switch Works

Elementary split phase induction motor with cut out switch. Fig **A,** cut out switch closed at start; starting winding in circuit; fig. **B,** motor speeded up to point where centrifugal force acting on governor weights has overcome the tension of spring and opened switch, cutting out starting winding.

Foreword

This series is dedicated to Electrical Progress—to all who have helped and those who may in the coming years help to bring further under human control and service to humanity this mighty force of the Creator.

The Electrical Age has opened new problems to all connected with modern industry, making a thorough working knowledge of the fundamental principles of applied electricity necessary.

The author, following the popular appeal for practical knowledge, has prepared this progressive series for the electrical worker and student; for all who are seeking electrical knowledge as a life profession; and for those who find that there is a gap in their training and knowledge of Electricity.

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The author and publishers here gratefully acknowledge the hearty and generous help and co-operation of all those who have aided in developing this helpful series of Educators.

The series will speak for itself and "those who run may read."

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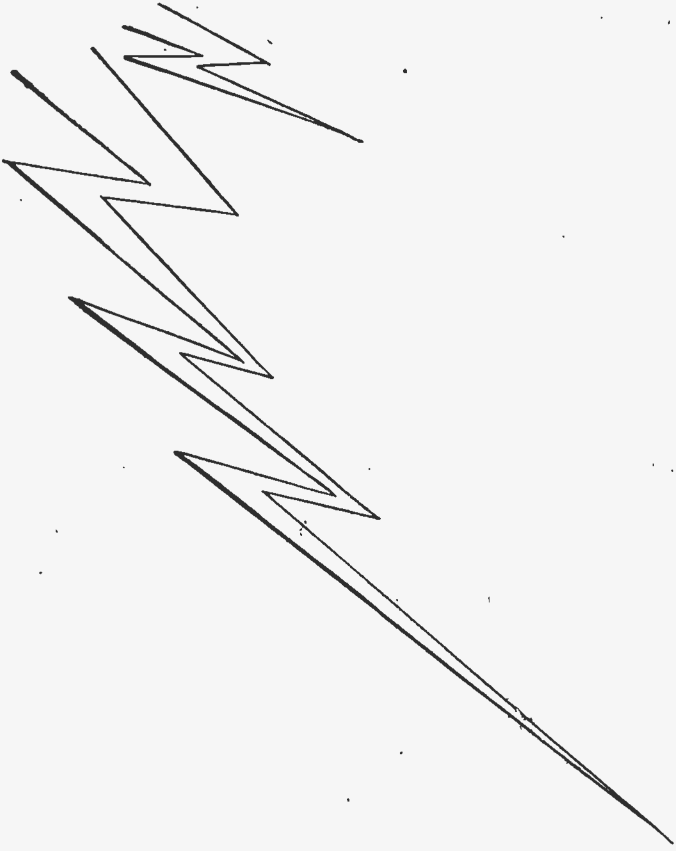

How to Use This Book

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IMPORTANT

To quickly and easily find information on any subject, read over the general chapter headings as shown in the large type—this brings the reader's attention to the general classification of information in this book.

Each chapter is progressive, so that if the reader will use the outline following each general chapter heading, he will readily come to the information desired and the page on which to find it.

Get the habit of using this Index—it will quickly reveal a vast mine of valuable information.

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

FINDER

CHAPTER 57

Internal Resistance Induction Motors

Just as the electrical industry as a whole owes its present day development largely to the invention and perfection of the

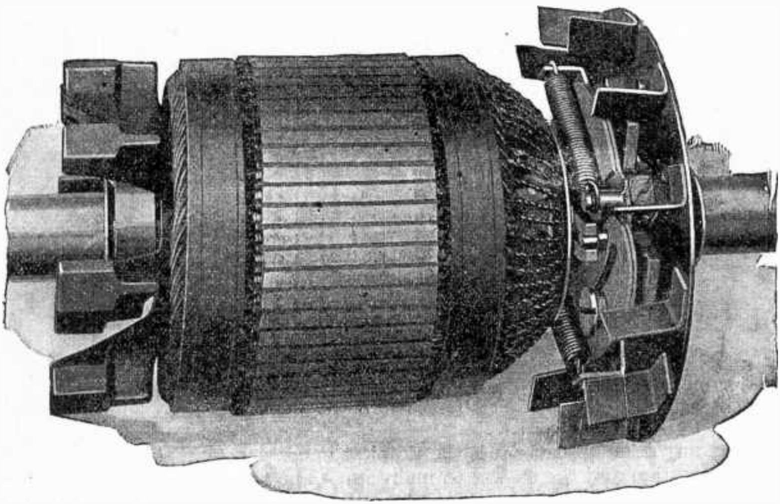


Fig. 2,706.—*Wagner internal resistance motor construction 1.* Armature showing low resistance winding, centrifugal governor and fans. There is a fan on each end of the armature; on the pulley end the blades are designed so that they may be used in balancing the armature, and on the opposite end the blades are spot welded to a steel plate which is rigidly bolted to the core of the armature. The low resistance insulated winding is brought out to a multi-contact short circuiting switch. The squirrel cage which underlies the insulated winding is formed of copper bars and copper rings which are brazed together, forming permanent unbreakable joints.

alternating current system, the electrical power industry owes its development largely to the polyphase induction motor.

The induction motor was simultaneously invented in Italy by Ferraris, in Germany by Dobrowolsky, and in the United States by Tesla.

The original type was the induction motor with a short circuited rotor, known as the squirrel cage motor. Up to the present day, the squirrel cage has been in more general use than any other type. In the beginning, the principal advantage of the induction motor was that it permitted the utilization of polyphase power. Today the induction motor is more generally used

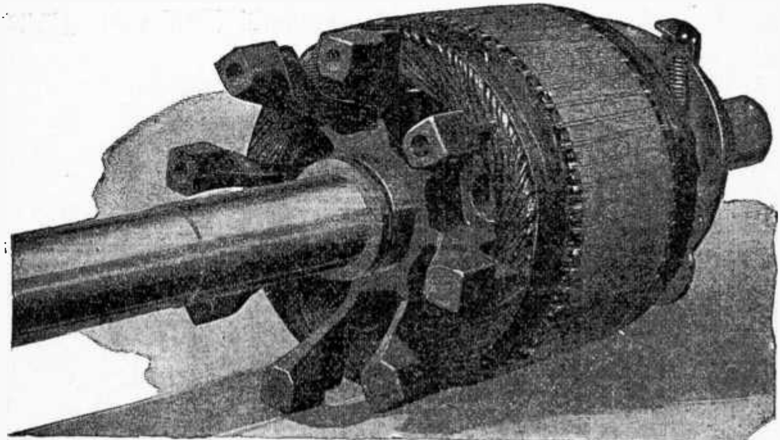


FIG. 2,707.—*Wagner internal resistance motor construction 2.* Another view of the armature.

than any other, because it is the simplest in construction, the most reliable in operation and the easiest to maintain. The squirrel cage motor is well suited to constant speed service where the starting duty is light and infrequent. It does not possess the high starting torque needed for many motor applications.

Starting Squirrel Cage Motors; Difficulties.—If a squirrel cage motor be connected directly across the line voltage with locked armature, it will develop 125 to 150% of full load torque and draw 500 to 600% of full load current. To keep the current down to safe values, it is customary as explained in the preceding chapter to reduce the applied voltage by using a transformer, choke coil or rheostat. This reduction in impressed voltage also reduces the starting torque, the latter varying as the square of the terminal voltage. However, the starting torque developed

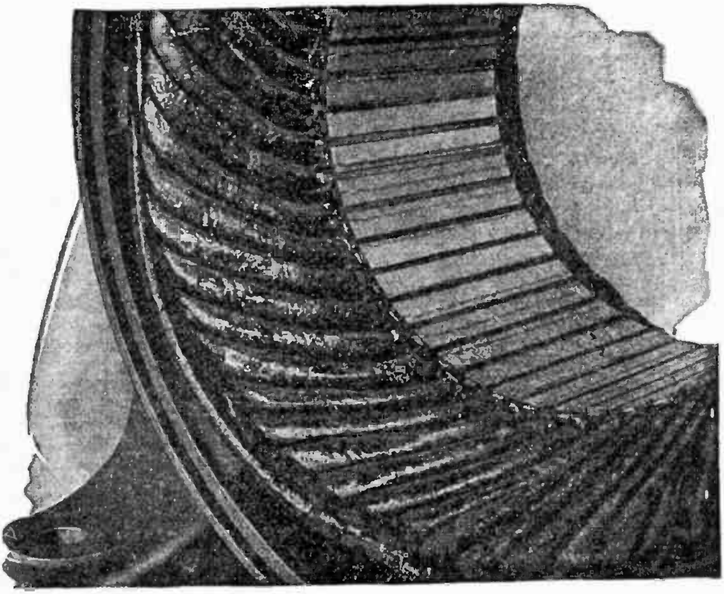


FIG. 2,708.—*Wagner internal resistance motor construction 3.* Detail of field.

by a polyphase motor may be increased by increasing the resistance of the squirrel cage winding, up to the point where the squirrel cage resistance equals its reactance, at which point the maximum starting torque obtainable from this motor is secured.

The disadvantage of using a high resistance armature in a general purpose motor, lies in the large slip and heavy armature losses caused by the high rotor resistance, resulting in a large drop in speed from no load to full load, with increased temperature rise and reduced efficiency.

Development of Internal Starting Devices.—Since speed adjustment is necessary for only a few applications, and the slip

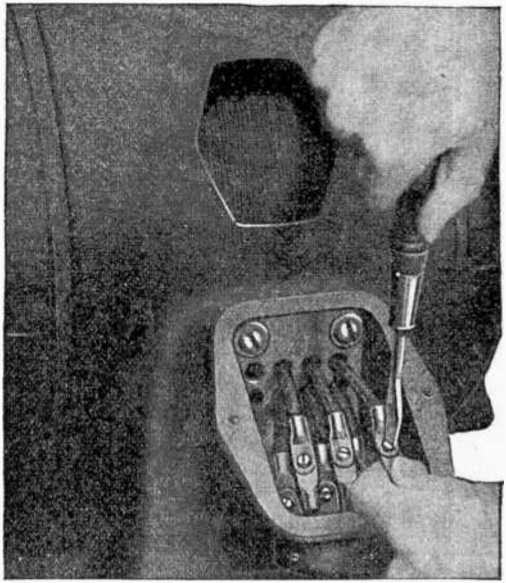
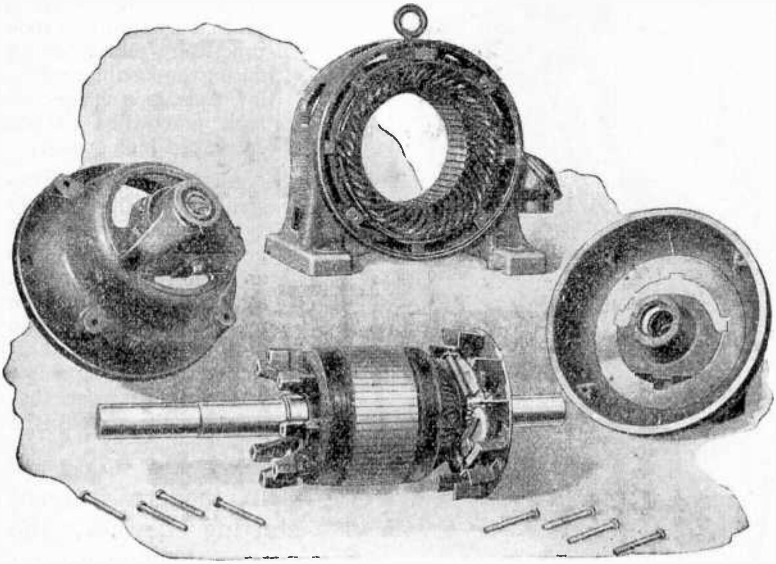


FIG. 2,709.—***Wagner internal resistance motor construction 4.*** Four way terminal box The box is part of the motor frame and can be turned in any one of four directions to suit conditions. The line connections can be brought directly into the box through either solid or flexible conduit. The terminal connections are accessible by removing the two screws that hold the box cover in place. The leads themselves are supported by an insulating block inside the box.

ring motor described later which permits variable speed, involves the drawbacks of extra wiring, friction of the rings, dependence on the skill of the operator in starting and a speed varying with the load when there is resistance in the secondary circuit, efforts were soon made to provide in the motor itself some automatic means of effecting the shift from high to low resistance.

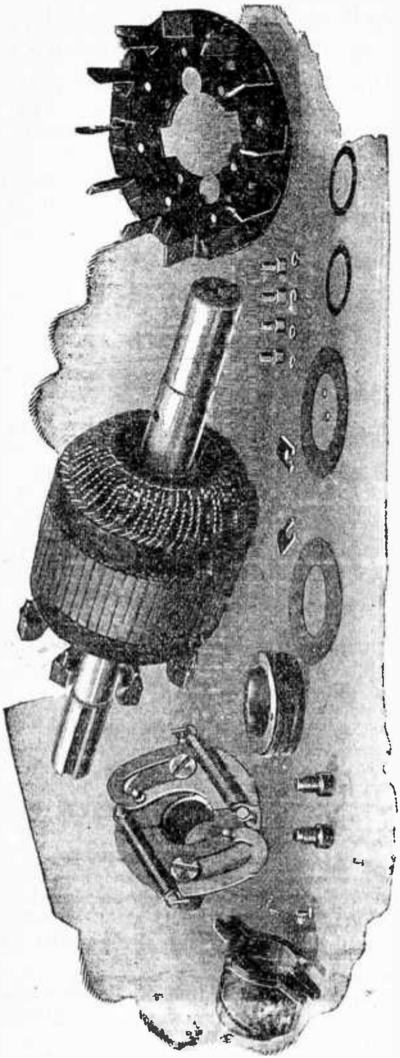
The first attempt was made by Prof. Arnold in Germany shortly after the first invention of the polyphase induction motor. He proposed the use of a rotor winding of many sections, the ends of each section being brought out



FIGS. 2,710 to 2,721.—*Wagner internal resistance motor construction 5.* Disassembly of motor showing assembled armature, field and end plate.

to slip rings and so connected that the voltages in different groups opposed each other at start. This was equivalent to a high starting resistance. When the motor came nearly up to speed, the connections were re-grouped to make the voltages assist each other and give the low equivalent resistance so favorable to efficient running.

In 1894 Prof. Georges patented a motor that operated on the opposing voltage principle, but added an automatic centrifugal governor to shift the connections from starting to running position.



Figs. 2,722 to 2,745.—Disassembly showing armature, fan plates governor and smaller parts.

In 1899 Zani invented a motor in which the rotor resistance was made higher at starting by the use of choke coils and resistors, connected in parallel across the terminals of the armature windings. The centrifugal governor shifted the cores of the choke coils so that the resistors took practically all the current during the starting and the low resistance choke coils took practically all the current at high speed.

All of the devices just described while theoretically correct, were much too complicated and delicate for any motor meant to rotate at 1.800 *r.p.m.* and be reasonably fool proof. The need for a simple and effective self-starting motor was growing at a pace that paralleled the growth of the power industry.

In modern internal starting devices, the automatic change from starting to running connections is obtained by centrifugal force, brought into effect through the means of a centrifugally operated switch which as the speed increases, acts to short circuit one of the windings as shown in the accompanying illustrations.

Although a very large percentage of all alternating current motor applications are at present handled by either squirrel cage or slip ring motors, certain disadvantages inherent in each are generally recognized.

The low starting torque of the squirrel cage motor, and the necessity of a compensator for protecting the line voltage against surges are obviated in the slip ring motor but at a comparatively high cost entailing also costly maintenance of a more intricate motor and control.

Because of its high starting torque and variable speed characteristics, the slip ring motor may be applied to a wider variety of equipment than the squirrel cage motor. Central stations prefer it because of its better power factor at start and provisions against line surges.

Since variable speed is not generally required, a constant speed motor which combines the desirable starting characteristics of a slip ring motor with simple inexpensive control effects an economic saving both for the user and Central Station, which fact accounts for the rapidly increasing installation and popularity of the automatically controlled internal resistance self-starting motor.

By definition an internal resistance induction motor is *one having an armature so constructed as to obtain a high resistance* (ohmic or spurious) *while starting and a low resistance while running without external connections.*

The high resistance may be in the form of

1. Grids.
2. High resistance winding.
3. High reactance winding.

Formerly the high resistance in form of grids was located on the spider inside of the armature itself as shown in fig. 2,746. In this construction the armature is equipped with a winding similar to that of a revolving armature alternator and the ends of the winding are connected to sliding fingers which make contact with the high resistance. The position of these fingers controls the amount of resistance in the armature circuit, and the position of the fingers is regulated by a lever which operates a sliding sleeve mounted on the armature shaft.

Two forms of the second type just classified are given. One employs a combination of

a. High resistance squirrel cage
b. Low resistance lap winding

and the other a combination of

a. High resistance squirrel cage
b. Low resistance phase winding

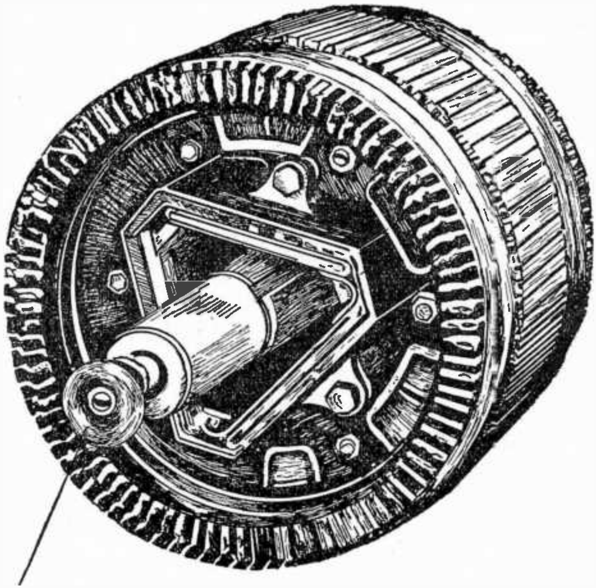


FIG. 2,746.—Phase wound armature for internal resistance induction motor with resistance grids. In starting, the inductors are short circuited through a resistance which is gradually cut out as the motor comes up to speed.

The idea of placing a high resistance winding (for starting torque) and a low resistance winding (for efficient running) on one rotor is not new. The difficulty encountered by builders of "self-start" motors lay in devising a simple fool proof mechanism which would be so rugged as to permit being enclosed in the motor frame without fear of requiring attention of any kind.

The operation of the high resistance squirrel cage, low resistance winding arrangement is shown in the diagram fig. 2,747.

As explained in the preceding chapter, the total opposition to the flow of current in a squirrel cage motor inductor, or *impedance* is made up of the actual or ohmic resistance of the bar and the apparent or *spurious* resistance or *reactance* due to self-induction.

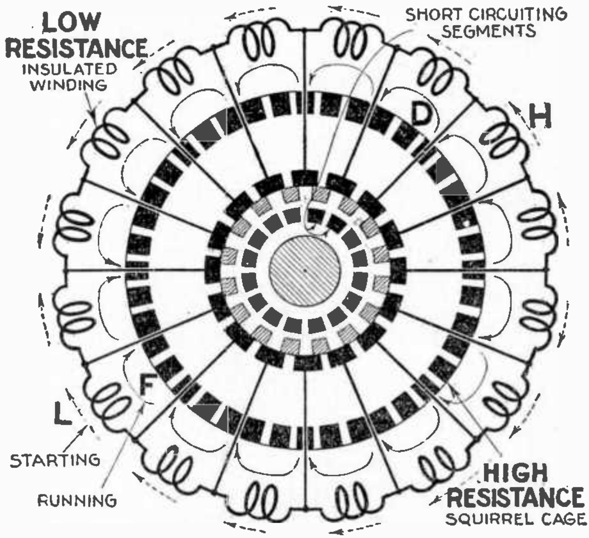


FIG. 2,747.—End view diagram of Wagner *high resistance squirrel cage low resistance winding* type of internal resistance motor showing the shaft, the low resistance squirrel cage, the high resistance insulated winding, and the segments of the multi-contact switch which short circuits the insulated winding when the armature attains 70 per cent of running speed.

Since the reactance depends on the armature frequency (which in turn depends upon the difference between the speed of the rotating magnetic field and the speed of the armature) it is greatest the instant the motor is connected to the line in starting and gradually decreases as the motor speeds up. The effect of this being to cause the current to lag behind the pressure especially at the beginning of the starting period as shown in figs. 2,641 to 2,643. In other words (assuming low ohmic resistance inductors) the effect is that whereas there is a big current flowing at the beginning of the starting period, the maximum flow is reached too late to produce a correspondingly high torque. This initial rush of current causes a fluctuation

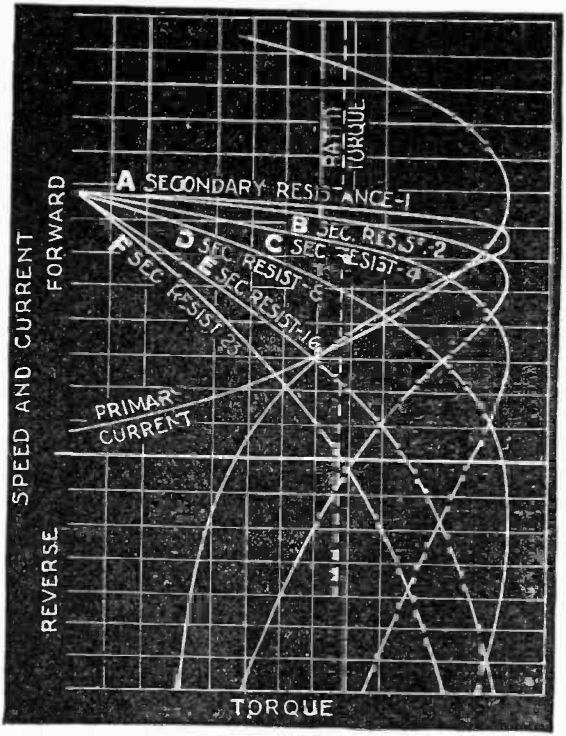


Fig. 2,748.—Speed torque and current curves of a polyphase induction motor with different values of secondary resistance. For constant torque any variation in the armature resistance requires a proportionate variation in the slip. If the slip with a given torque be 10%, for instance, it must be 20% for double the resistance. The armature resistance may be in the windings themselves as in internal resistance motors, or it may be entirely separate from the machine and connected to the windings by suitable means, as shown in external resistance or slip ring motors.

in the line voltage which is objectionable especially if lamps be connected to the circuit. The problem is to so modify the armature of a squirrel cage motor that a higher starting torque will be obtained and with less current.

By increasing the resistance of the armature circuit by some scheme or other, the angle of lag of the current behind the voltage can be lessened; that is, the initial starting condition of an ordinary squirrel cage is changed from the objectionable condition shown in fig. 2,752 to the improved condition shown in fig. 2,753.

Now, *the angle of lag would also be lessened if the reactance of the armature circuit could be lessened;* but after a squirrel cage armature is once built, this cannot be done economically, hence *the necessity of providing* ***an extra*** ***winding*** *to secure the high resistance desired in starting.*

Of course, increasing the resistance of the armature circuit will diminish the current in the circuit, but *this diminution in current will not at first* *decrease the net torque as much as the decrease in angle of lag increases the torque.*

Small increases in armature circuit resistance do not diminish the current very much, but they do materially increase the cosine of the angle of lag, and the greater the cosine (for a given current) the greater the torque.

The operation of the high resistance squirrel cage, low resistance insulated winding arrangement is shown in figs. 2,747, 2,750 and 2,751.

This type motor has a high resistance squirrel cage *to keep down the current and increase the torque while starting*, and a

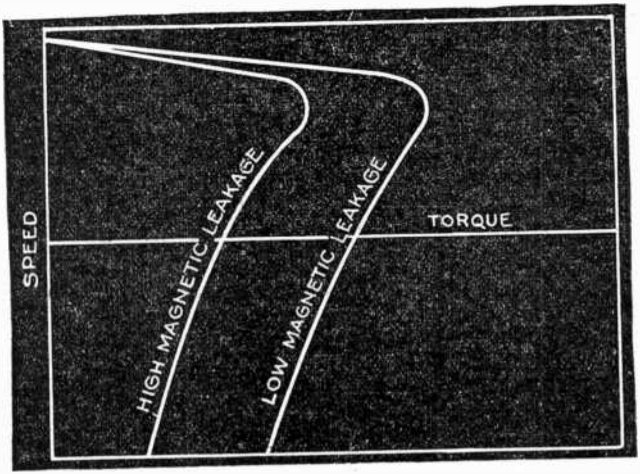
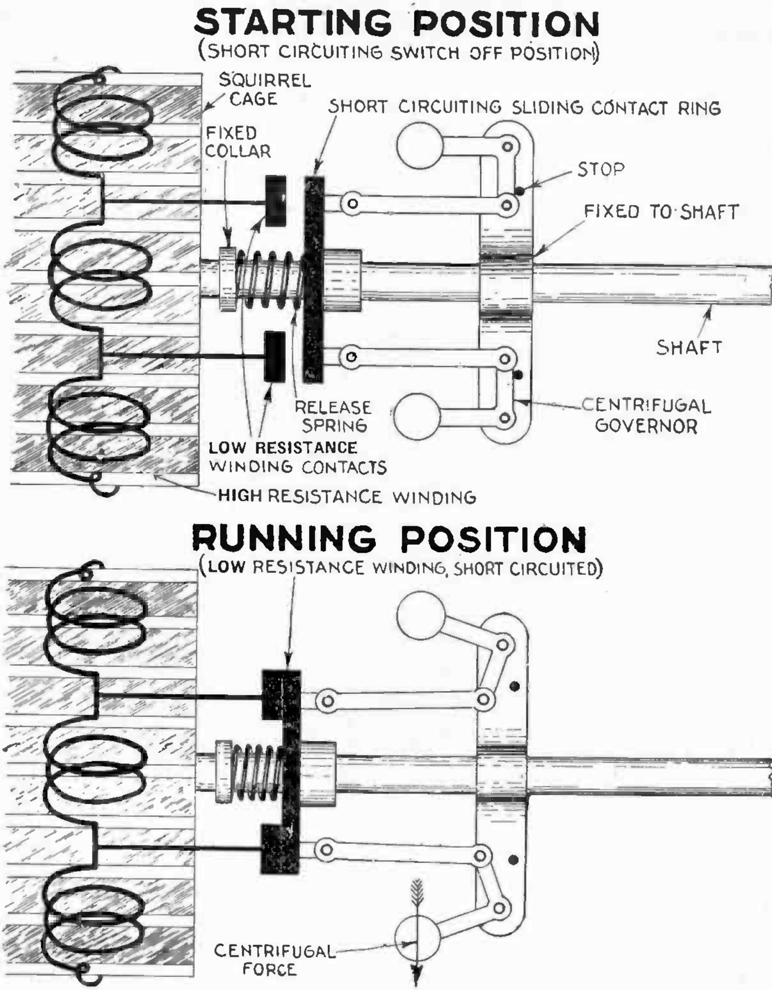


Fig. 2,749.—Speed torque curves of polyphase induction motors showing effect of magnetic leakage. There are relative curves for two similar motors having different values of magnetic leakage.

NOTE.—It may be shown mathematically that maximum torque is exerted when the armature circuit resistance has been increased to equal the rotor circuit reactance.

NOTE.—*The starting torque* is proportional to the square of the impressed voltage. It is directly proportional to the armature resistance and inversely proportional to the square of the total impedance of the motor. A change in armature resistance affects the starting torque both directly and indirectly. So long as the armature resistance is the lesser item in the impedance, an increase of armature resistance results in an increase in starting torque. Beyond this point the inverse relation is greater than the direct relation and increased armature resistance then causes decreased torque at starting. The reactance component of the impedance depends upon the magnetic leakage. If high starting torque is desired, the magnetic leakage should be as small as possible.



FIGS. 2,750 and 2,751.—Diagrams showing operation of multi-contact short circuiting switch of high resistance squirrel cage low resistance lap winding type of internal resistance induction motor. Fig. 2,750, switch open starting position; fig. 2,751, switch closed, running position. The diagrams show a ring instead of a number of segments.

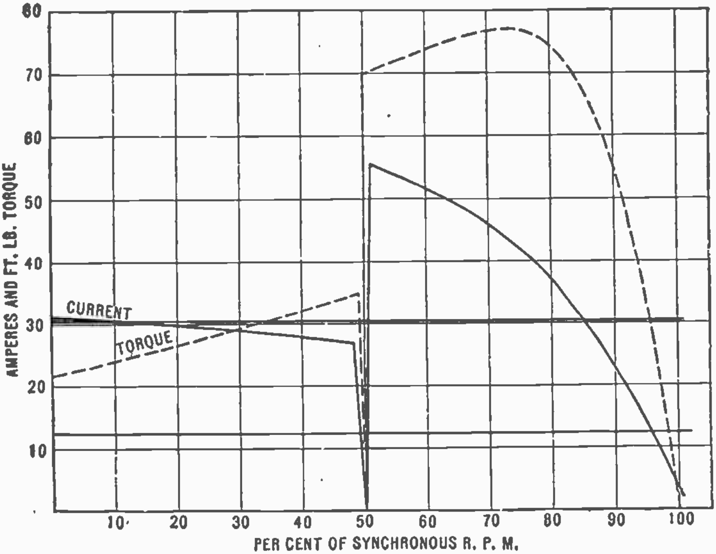


FIG. 2,752.—Starting characteristics of a typical squirrel cage motor.

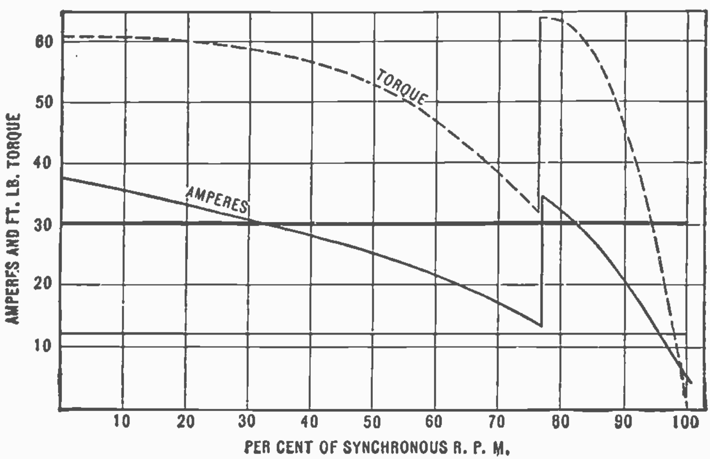


FIG. 2,753.—Starting characteristics of Wagner *internal resistance* motor.

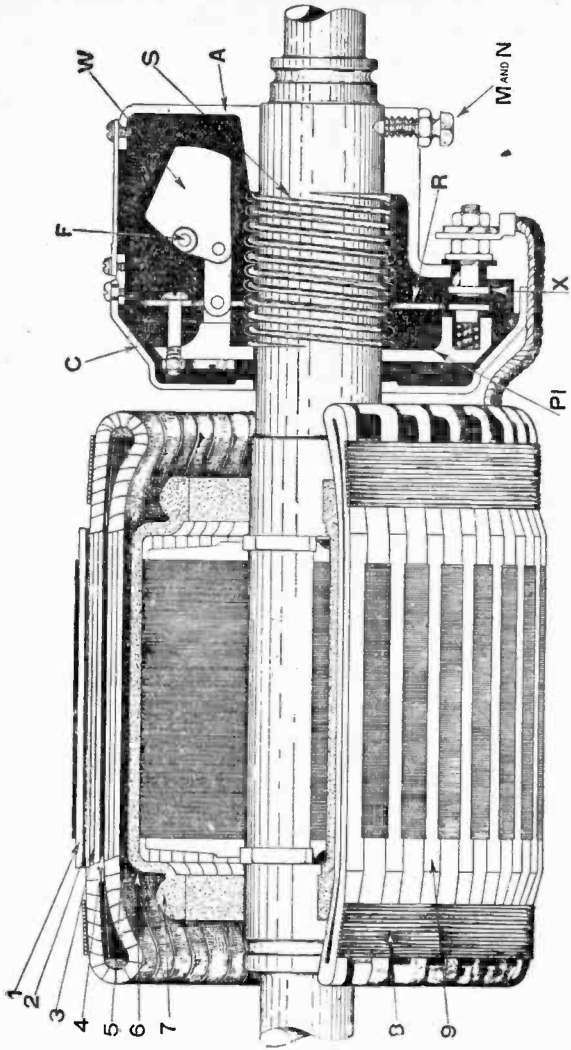
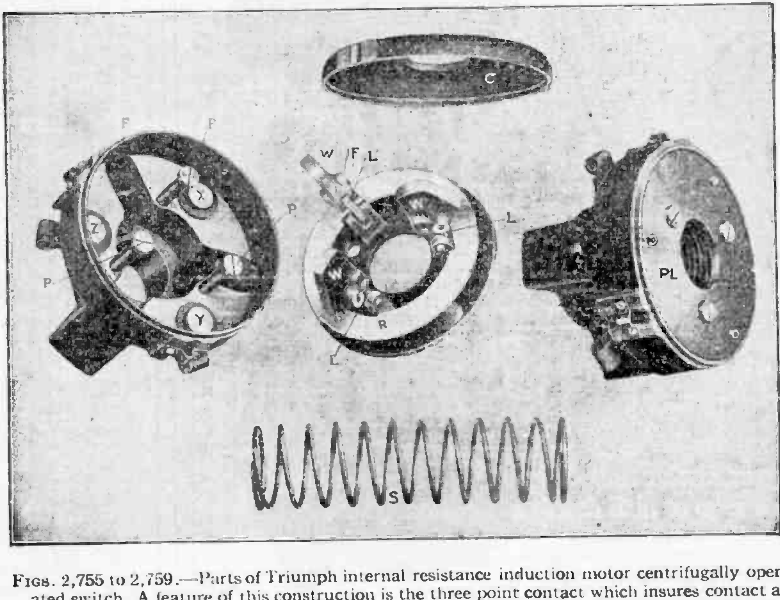


FIG. 2,754.—Sectional view of armature of Triumph high resistance squirrel cage, low resistance phase winding, internal resistance motor. *The parts are:* 1, wedge; 2, laminated core; 3, low resistance, phase winding; 4 and 5, mica insulation; 6, high resistance squirrel cage; 7, squirrel cage end ring; 8, binding wire; 9, wedge; A, governor case; C, inner head of case; F, pivot; W, governor weight; Pl, switch plate; R, contact plate; X, contact; S, spring; M and N, set screws.

low resistance lap winding *for efficient operation after coming up to speed.*

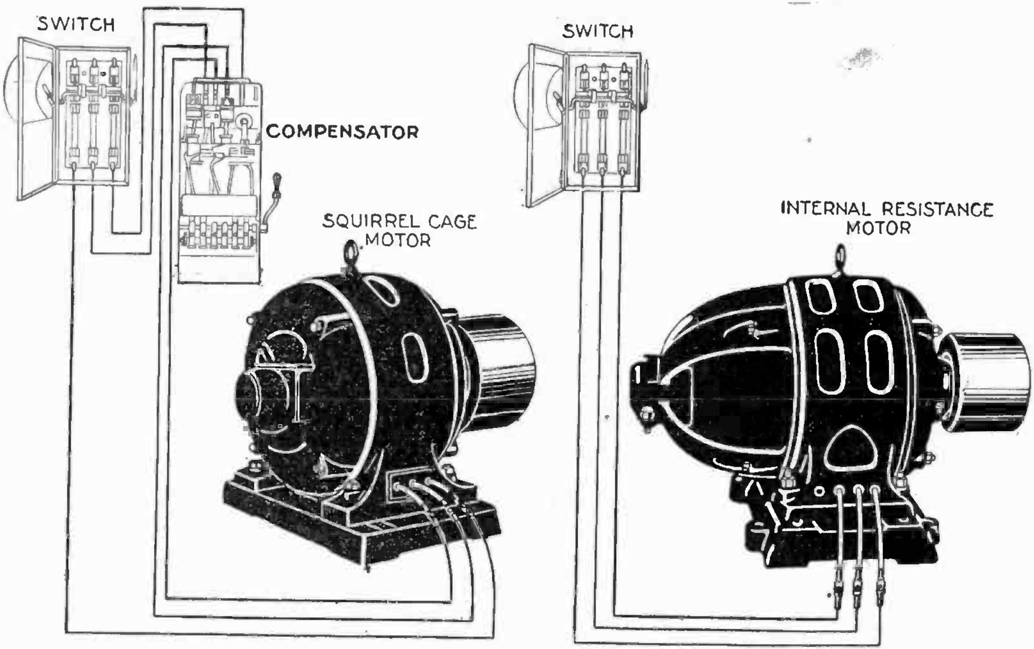
During the starting period before the short circuiting switch acts (fig. 2,747), the voltages induced in one half of the insulated winding oppose those induced in the other half as indicated by the dotted arrows H, these opposing voltages prevent a flow of current. During this time considerable torque is produced due to the high resistance squirrel cage.



FIGS. 2,755 to 2,759.—Parts of Triumph internal resistance induction motor centrifugally operated switch. A feature of this construction is the three point contact which insures contact at all the points even if the alignment be poor. *The parts are:* A, governor case, C; inner head of case; F, pivot; L, link; P, switch plate bolts; R, contact plates; X,Y,Z, contacts.

When, due to increasing speed, centrifugal force operates the short circuiting switch pushing out the segments as indicated by the shaded position, the voltages induced in each of the coils produce currents which circulate in their own respective paths as indicated by the full line arrows D.

The second form of the second type of internal resistance



FIGS. 2,760 and 2,761.—Wiring hook up for internal resistance motor and ordinary squirrel cage motor showing relative simplicity of control for the internal resistance motor. Fig. 2,760 internal resistance motor hook up; fig. 2,761 squirrel cage motor hook up. The squirrel cage except on very small motors, must be started through a compensator, an expensive piece of apparatus and one that must be handled properly by the operator. The squirrel cage motor is restricted in its application because of its low starting torque. On heavy starting machinery the efficiency and power factor of the squirrel cage motor are extremely low. The squirrel cage motor cannot be applied on a basis of full load requirements, because it develops its rated power, only at full speed.

motor has a high resistance squirrel cage and a low resistance phase winding, as illustrated in the accompanying cut.

Fig. 2,754 is a typical example of this form. In operation it starts on a high resistance squirrel cage 6, without a compensator and develops a torque two and one-half times its normal rating. Above this bare winding, and separated from it by mica insulation, is a low resistance phase winding 3, similar to that used on a slip ring motor.

The three wires which normally lead to the slip rings, are instead connected to three contacts on the automatic governor mounted on the shaft. At about two-thirds synchronous speed, the weights W, swing outward, operating like a ball governor on an engine, and compress the spring S, short circuiting the three leads from the phase winding.

At full speed, both windings operate together dividing the load in inverse proportion to the impedance of each. The motor then runs as a constant speed phase wound motor, with characteristics the same as a slip ring motor which has had all of the resistance cut out of the rotor circuit. The short circuiting is done, however, at the motor by direct contact instead of having to pass through the sliding contacts into slip rings and from slip rings to the starter contacts.

The third type of internal resistance motor classified as those having a high reactance winding is commonly known as a double squirrel cage motor and is explained in the section following.

Double Squirrel Cage Motors.—A feature of this type of induction motor is its simplicity since it does not use a centrifugal switch, but ***depends upon the change of frequency in the armature circuits, as the armature changes speed, to change the operating characteristics between starting and running conditions.***

This motor is called the double squirrel cage motor, since the armature has two complete squirrel cage windings.

One squirrel cage is placed within the other as shown in fig. 2,762. The outer squirrel cage has the same proportions as in the ordinary squirrel cage motor, but has a high resistance.

Since there is little iron above the inductors through which the leakage flux may pass, the self-inductance of this outer winding is not very large. The inner squirrel cage is of low resistance and, since it is placed deep in the core iron, with steel fillers or a steel bridge partly closing the path for leakage flux above it, the self-inductance is comparatively great.

The end rings may be attached in a manner convenient for shop facilities, with due regard to mechanical strength and the proper ventilation to dissipate the heat.

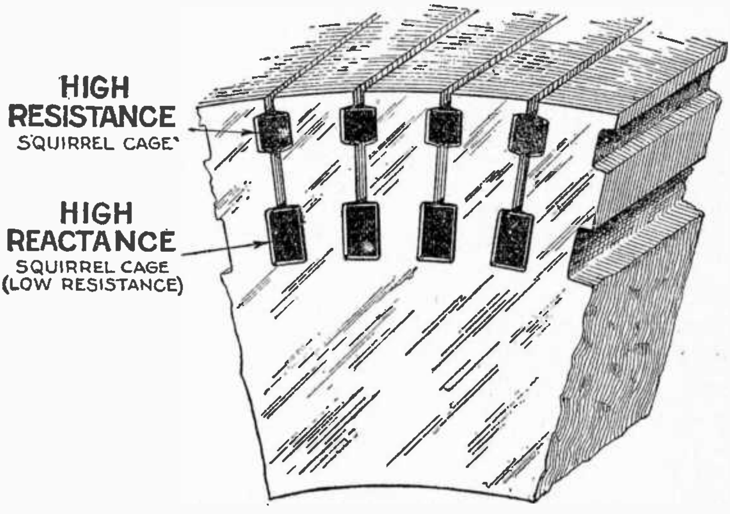


FIG. 2,762.—Detail of double squirrel cage windings showing placement of the high resistance and high reactance (low resistance) squirrel cages.

The rings for the two windings may be combined in one ring, as shown in fig. 2,763, or may be made separate from each other, as shown in fig. 2,764, by suitably changing the bar proportions to give the proper effective resistance relations. The double squirrel cage is not a new type of winding, having been originally developed in 1890, less than a year after the original development of the induction motor. It has, however, only recently come into commercial prominence.

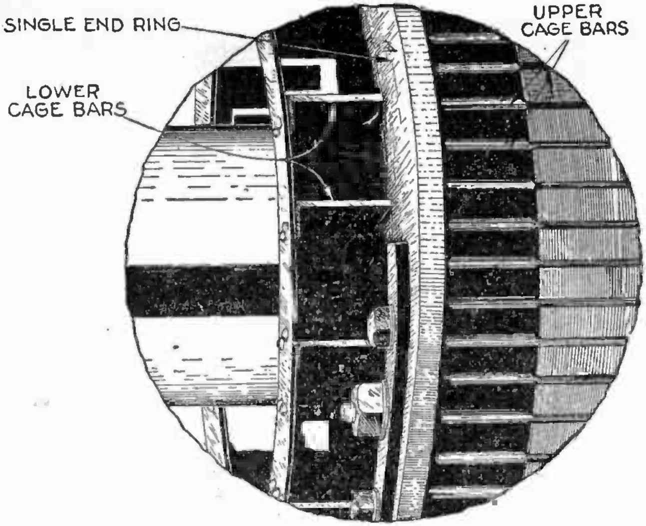


FIG. 2,763.—Westinghouse *single end ring* construction for double squirrel cage armature.

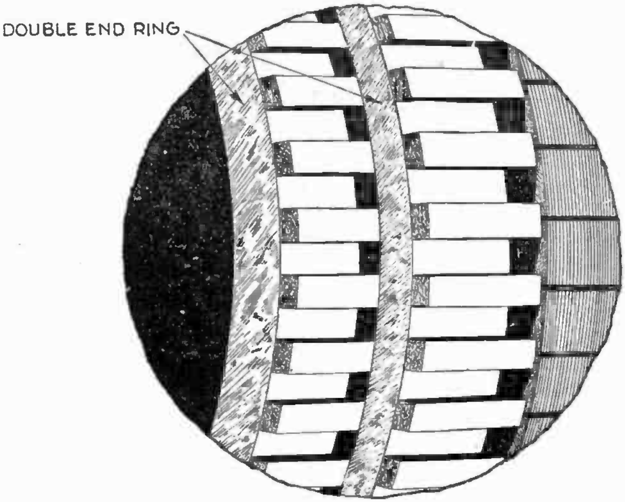


FIG. 2,764.—Westinghouse *double end ring* construction for double squirrel cage armature

The application of this motor is for services requiring high starting torque and continuous running at full load, such as is required for crushers, plunger pumps, belt conveyors, and grain elevator legs. Loads having great fly-wheel effect such as slow speed fans, air compressors, and refrigerating machinery also fall in this class. These duties require starting torques about twice full load value.

The operation of the double squirrel cage to meet the conditions depends upon several things.

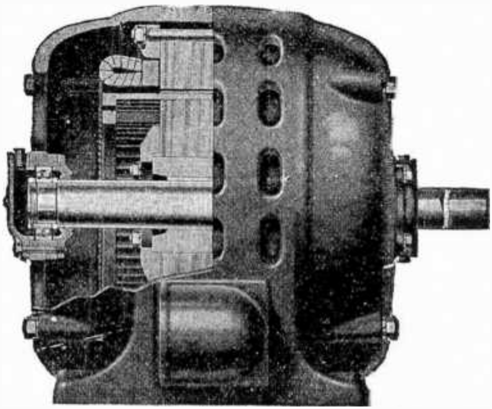
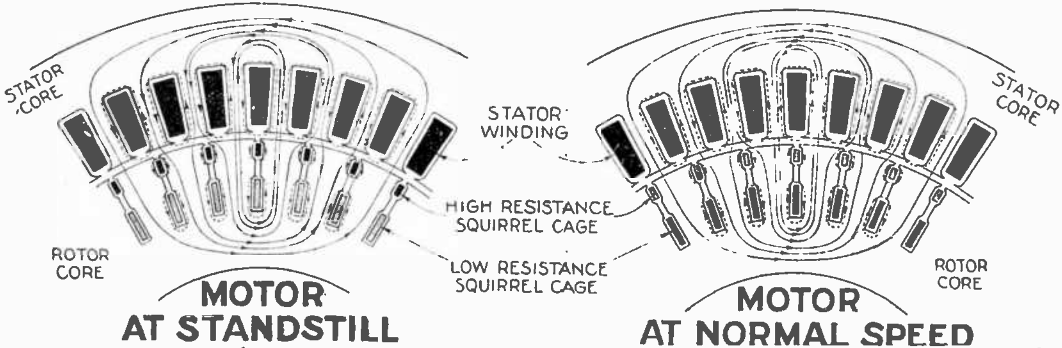


FIG. 2,765.—Fairbanks Morse double squirrel cage induction motor; sectional view showing arrangement of the squirrel cages and other details. *In construction*, the armature laminations are punched for squirrel cage bars, one at the bottom of the slot and the other near the edge of the lamination. When the core is assembled, drawn brass bars of comparatively high resistance are placed in the outer slots and welded to an end ring; in the inner slots are placed heavy pure copper bars of low resistance on which a low resistance end ring is cast. In this way, two separate concentric squirrel cages are formed.

The frequency of the armature flux which produces the voltage in the armature is proportional to the difference between the synchronous speed and the armature speed, being line frequency at standstill and zero frequency at synchronous speed.



FIGS. 2,766 and 2,767.—Double squirrel cage motor diagrams illustrating principle of operation. Fig. 2,766, motor at rest; fig. 2,767, motor at full speed. ***In operation,*** when voltage is applied to the field, currents flow in the windings and set up magnetic fields in the cores. The main magnetic field which links with the field and armature windings rotates at synchronous speed in the manner common to all synchronous and induction motors. This field is indicated by the full lines. In addition to the main field there exist also secondary fields of leakage flux around each inductor or group of inductors carrying current. The paths of leakage flux are shown by the dotted lines. Each links with only one winding, either that on the armature or that on the field. The leakage flux is not useful in producing torque, but does serve to limit the current flowing in the windings. The degree to which the leakage flux limits the current flowing in the inductor depends upon two factors; its volume and the frequency at which the current in the inductor is alternating. A large leakage flux at high frequency greatly impedes the current flowing in the winding. With low frequency and low leakage flux the currents are affected little by the leakage flux. ***At standstill*** the frequency of the currents in the armature winding is equal to line frequency, and the leakage flux is large. These conditions limit the current in the inner squirrel cage winding to a very small amount. The flux around the outer squirrel cage, however, is much less than around the inner; hence the current is not much limited by leakage flux in the high resistance squirrel cage. As a result, the greater part of the armature current will be caused to flow in the outer squirrel cage at the start. Since this outer squirrel cage has a high resistance the result is a high starting torque and low starting current because the resistance of the outer squirrel cage keeps the current at a moderate value and gives a torque approaching that obtained with an induction motor having a single high resistance squirrel cage. ***When the motor has come up to normal speed,*** as in fig. 2,767, that is, when the armature is revolving almost in synchronism with the rotating magnetic field, the frequency in the armature is only a small fraction of line frequency and the leakage flux about the inner squirrel cage is insignificant; consequently, the current in the inner squirrel cage is no longer appreciably limited by leakage flux. Because the inner squirrel cage has a very low resistance and the outer a high resistance, the inner squirrel cage carries the greater part of the armature current at normal speeds. It is evident, then, that at full running speed, the main armature current will be flowing, in the low resistance squirrel cage, thus making the armature copper losses low, and giving the motor a high efficiency at full load speed.

The current in the two squirrel cages is inversely proportional to their respective impedances at any instant.

At start, with full line frequency in the armature, the impedance of the lower winding will be very high, because of its high reactance. The impedance of the upper squirrel cage, however, will be relatively low, since it consists largely of resistance and has low reactance. The result is that the current is large in the upper squirrel cage and small in the lower. Hence, the upper high resistance squirrel cage will have high I^2R losses and will develop a high starting torque, since the torque developed by a squirrel cage is proportional to the I^2R loss in its armature winding; while the lower squirrel cage will be comparatively ineffective at the start, due to the low losses resulting from the small current component and the low resistance.

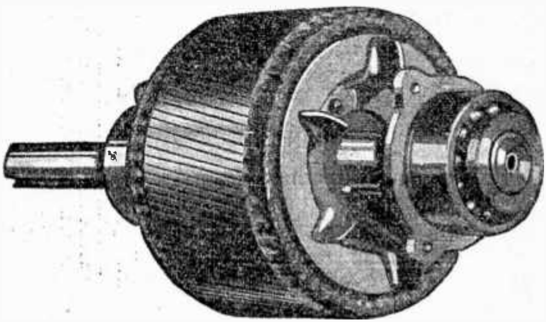
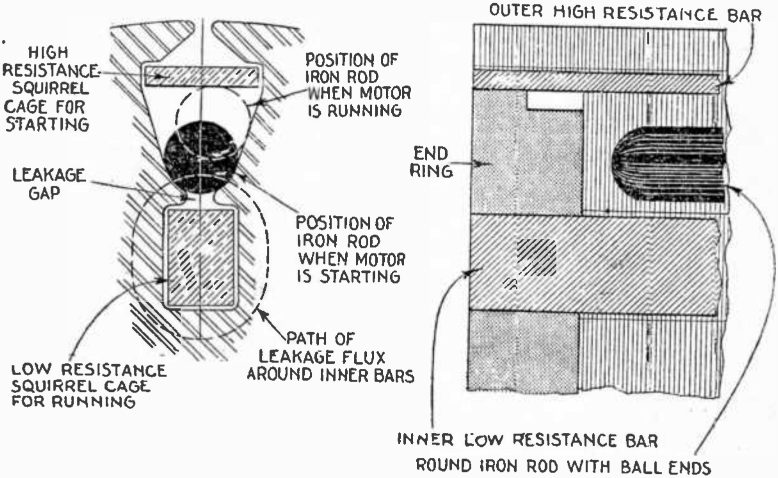


FIG. 2,768.—Fairbanks-Morse double squirrel cage armature with oblique or skewed bars.

As the armature approaches synchronous speed, its frequency becomes low and the impedances of both squirrel cages consist largely of resistance. The current divides between the two armatures almost inversely as their resistances. Hence, the greater part of the current will flow in the lower squirrel cage and produce most of the torque with small slip and small armature loss, while the upper squirrel cage will carry but a small current due to its high resistance. Thus, the change in armature frequency aids in obtaining a motor having high starting torque per ampere taken from the line, and at the same time having good full load regulation and efficiency.

Another way to consider the operation of this motor is to determine the characteristics of each armature winding as though the other armature were not present, and then add the torques developed by each to obtain the total torque.

Double Squirrel Cage Motor with "Choker."—A recent development in double squirrel cage motor design makes use of what is termed the *variable leakage gap principle*. In this motor the current in the inner squirrel cage at starting is choked by means of movable iron rods. These rods as shown in figs. 2,769 and 2,770 are placed in each armature slot between the inner and outer bars.

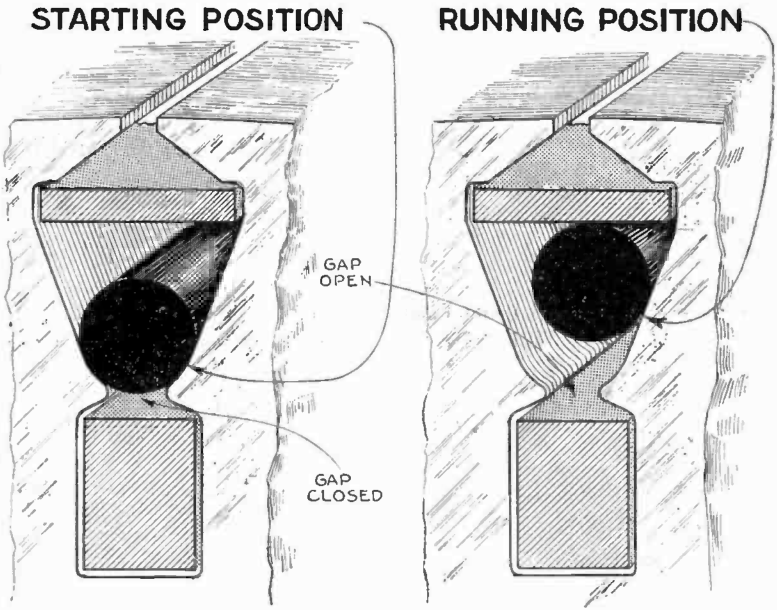


FIGS. 2,769 and 2,770.—Fairbanks Morse "Choker" type, double squirrel cage motor construction. Fig. 2,769, cross section showing high and low resistance bars and choker rod in initial position, air gap closed. Fig. 2,770, longitudinal sectional view. *In operation, in starting*, the iron rods form a path for the leakage flux and short circuit the low resistance squirrel cage, but as the motor speeds up, the iron rods are thrown out by centrifugal force and the low resistance squirrel cage then becomes effective.

The instant the motor is connected to the line the iron rods are pulled down toward the inner bars, closing the small leakage gap in the armature iron, which almost completely chokes the current in the inner low resistance squirrel cage by forming a complete iron circuit around each inner bar. This choking action on the inner armature forces practically all of the current to flow in the outer high resistance winding at starting, thus producing a high starting torque with a low starting current.

As the motor accelerates, the iron rods are thrown out of the leakage gaps, by centrifugal force, thus removing the choking effect from the inner squirrel cage when the motor is running.

At starting there is a slight noise due to the rods changing position, but since this is practically instantaneous the noise is not objectionable.



FIGS. 2,771 and 2,772.—Operation of choker rod of Fairbanks Morse choker type double squirrel cage motor. Fig. 2,771, armature at rest, choker rods held in ***closed position*** by magnetic attraction; fig. 2,772, armature nearly up to running speed, choker rods thrown out by centrifugal force to ***open position***, opening the leakage gaps.

Double Squirrel Cage Characteristics.—The starting torque is approximately 150% of full load torque with full voltage applied, although this value varies between 145 and 180% for the different ratings.

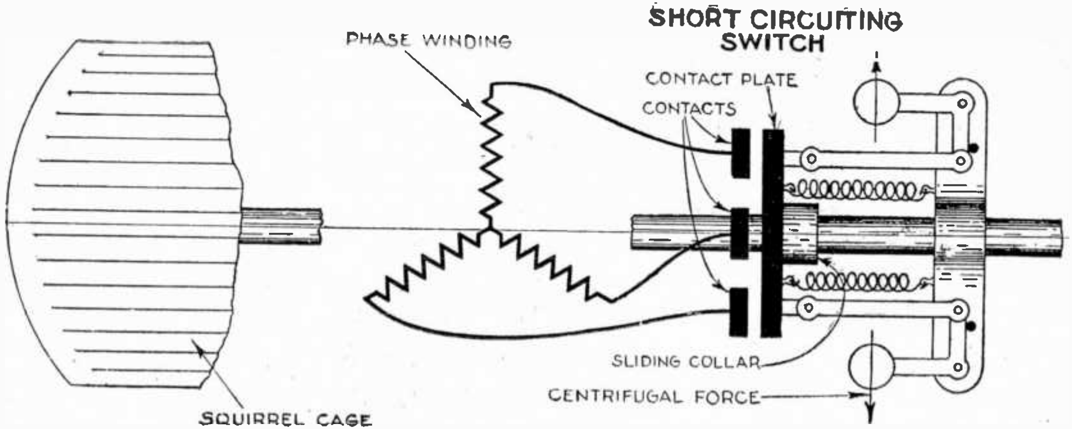


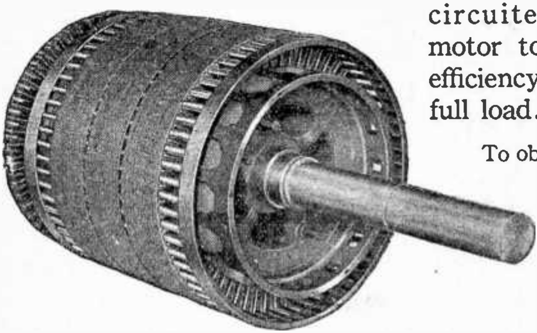
FIG. 2,773.—Elementary internal resistance induction motor having high resistance squirrel cage and low resistance phase winding with automatic centrifugal force short circuiting switch.

The efficiency is practically the same as similar ratings of ordinary squirre cage motors, averaging about 90% at full load.

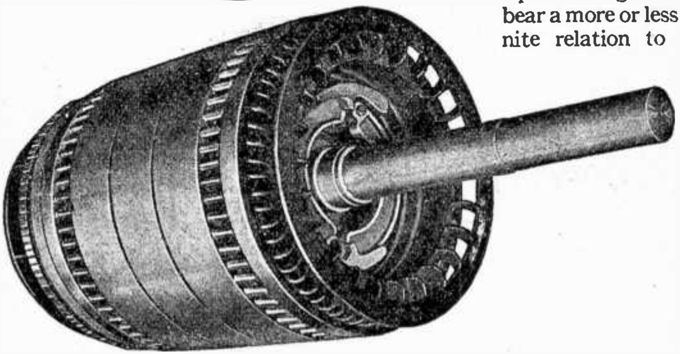
The power factor is slightly lower than that of the ordinary squirrel cage motor but in general averages well above 85%.

The maximum torque or pull-out torque is approximately 200% of full load torque.

High starting torque and continuous running at full load are characteristics frequently demanded, as for instance crushers, plunger pumps, belt conveyors, grain elevator legs, etc. Various types of motors have been used to develop this torque without drawing excessive starting current. The most common type is the external resistance motor, which may develop a high starting torque by the use of a high secondary resistance. This resistance is later short circuited, allowing the motor to operate at high efficiency, and low slip near full load.



To obviate the complications of the external resistance motor, the double squirrel cage motor is used. The maximum torque and the starting current in all squirrel cage motors bear a more or less definite relation to each



FIGS. 2,774 and 2,775.—Century automatic start polyphase induction motor armature. Fig. 2,774, partly assembled; fig. 2,775, complete. There are two separate windings on the armature. ***In operation,*** the motor starts with approximately one third of the armature inductors in service until a predetermined speed (about ¾ of synchronous speed) is reached, when a governor places the additional armature copper in service. The armature inductors which are in active service during the first part of the starting period, as used on the 15 *h.p.* 60 cycle, 4 pole sizes and larger, are in the form of a squirrel cage. This squirrel cage is made up of half round bars and formed U shape end rings brazed together. The starting winding on the smaller sizes consists of bare copper wire coils, each being short circuited upon itself by welding the ends of the coils together. The balance of the armature copper, which is put into service in the latter part of the starting period, is an insulated winding connected to contact segments. The short circuiting of the insulated armature winding is accomplished by the use of short circuiting segments and a centrifugal force governor. When the governor acts (at approximately ¾ full load speed) the copper short circuiting segments slide into a position which connects each insulated coil to a copper short circuiting ring of substantial cross section.

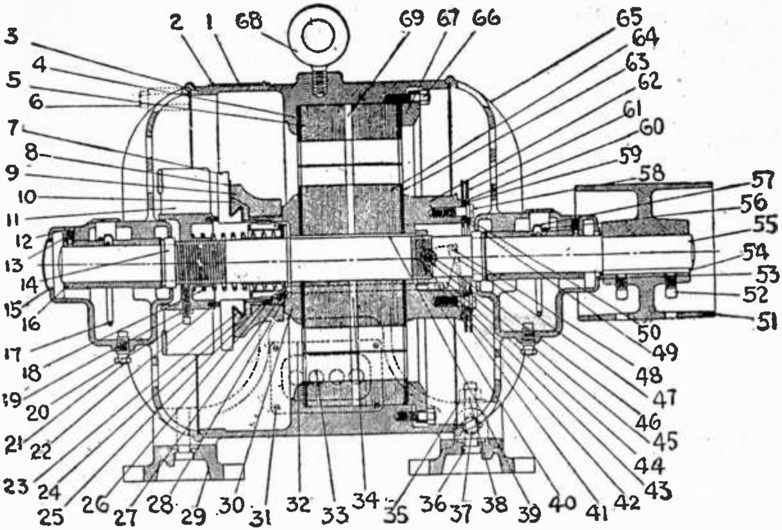


FIG. 2,776.—Century automatic start polyphase induction motor; sectional view showing construction. *The parts are* as given below.

1 Name plate
2 Escutcheon pin
3 Frame
4 Field fibre
5 Field core
6 End bracket screw
7 Contact segments
8 Paper ring
9 Contact head
10 V-ring
11 Ventilating fan
12 Oil well cover
13 Dog point bearing screw
14 Shaft collar
15 Front bearing cap
16 Phosphor bronze bearing
17 Oil ring
18 Governor spring
19 Ventilating fan set screw lock nut
20 Ventilating fan set screw
21 Oil drain plug
22 Fan felt
23 Paper ring, tapered
24 Mica ring
25 Short-circuiting ring
26 Short-circuiting segments
27 Spring barrel
28 Governor pin guide washer
29 Rail
30 Front armature flange
31 Terminal guard screw
32 Terminal guard
33 Porcelain terminal block
34 Armature ventilating grids
35 Sub-base bolt washer
36 Square head machine bolt
37 Sub-base screw
38 Hexagon nut
39 Armature core key
40 Armature nut
41 Governor weight rivet
42 Governor weight pin rivet
43 Governor weight pin
44 Bell crank
45 Bell crank stud
46 Cotter pin
47 Governor weight link
48 Governor weight link rivet
49 Governor weight bushing
50 Governor weight stud bushing
51 Pulley
52 Pulley set screw
53 Back bearing cap
54 Pulley key
55 Shaft
56 Oil ring guard screw
57 Oil ring guard
58 Governor weight stud
59 Governor weight stud washer
60 Governor weight washer
61 Governor weight
62 Back armature flange
63 Armature fibre
64 Armature core
65 End plate
66 Field ring screw
67 Field ring
68 Eye bolt
69 Field ventilating grids

other. This ratio for the average general purpose motor is in the proportion of approximately 175% of full load torque at the maximum point, and 450% of full load current at start. With the double winding, the starting torque is not so closely allied with the starting current. With the above conditions of maximum torque and starting current, the starting torque may have any value between 75 and 250% full load value by varying the resistance and reactance of the upper and lower squirrel cage windings.

If a general purpose motor primary be used with a double squirrel cage secondary, the maximum torque is reduced to approximately two thirds of the original value, when the starting current is brought down to meet the values specified by the N. E. L. A. This means that motors which

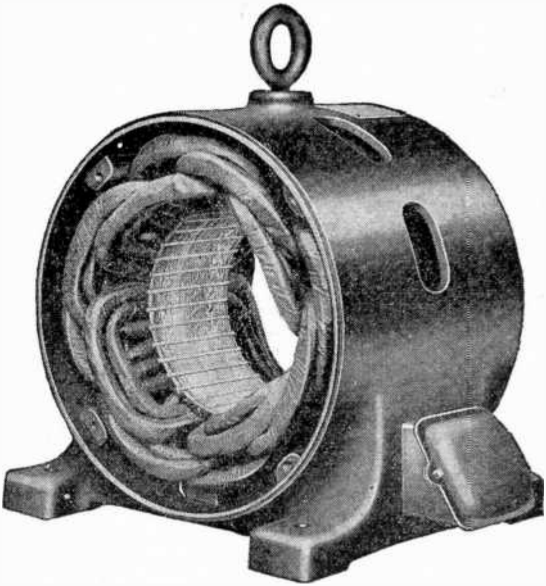


FIG. 2,777.—Century automatic start polyphase induction motor frame and field winding.

have a maximum torque less than about 2.75 times full load torque as a general purpose motor, must have a stronger field when used with a double cage armature. This results in lower power factor, due to the increased magnetizing current. General purpose motors of the higher speeds, that is, 1200-1800 *r.p.m.* and larger motors at 900 *r.p.m.* have maximum torques which are sufficiently high to permit the use of double cage armatures without strengthening the field. Such motors will not have as great a decrease in power factor as the slower speed motors, when used with double cage armatures.

High starting torque, continuous running applications are filled by using external resistance motors or double squirrel cage armatures for full voltage starting. The external resistance motor should be used where the mass to be accelerated is large, as on fly wheels or other high inertia loads, so that the high losses during acceleration can be taken out of the motor to the external resistance.

The double squirrel cage motor is used where the starting torque is high and the inertia is not too large. The double squirrel cage armature is also used where danger of explosion precludes the use of collector rings and brushes, and where simplicity and ruggedness of construction overbalance the other conditions in favor of wound armature motors. Specifications for these motors should include the values of starting current and the maximum torque desired, bearing in mind the ratio between them given above. With greater starting torque the efficiency will be lower. High speed motors with high starting torque will have medium reductions in power factor. Slow speed motors will have a greater reduction in power factor.

High Slip versus High Torque Motors.*—It has long been known that an increase in the armature resistance of an induction motor, without changing other design constants, results in an increase in slip, and up to a certain point, increased starting torque, without change in maximum or pull out torque. Hence there is a widespread idea that the terms "high slip" and "high starting torque" are synonymous. This is not necessarily the case.

Two motors of the same rated horse power and speed may be designed to vary widely in reactance and other characteristics, depending on the purpose for which they are intended. Hence a high slip motor may have a fairly low starting torque; and a motor with high starting and pull out torques may have a low slip.

*NOTE.—The author is indebted to F. J. Johns of Westinghouse Electric & Mfg. Co. for the accompanying discussion of high slip versus high torque motors.

In fig. 2,778:

A, is a high slip motor, designed with a high resistance armature and normal resistance.

B, is a high torque motor, designed with a normal armature resistance and low reactance.

C, is a motor designed with a high resistance, low reactance starting winding and a low resistance, high reactance running winding, such as a motor with a double squirrel cage armature winding, the starting winding being near the armature surface or air gap and the running winding deep

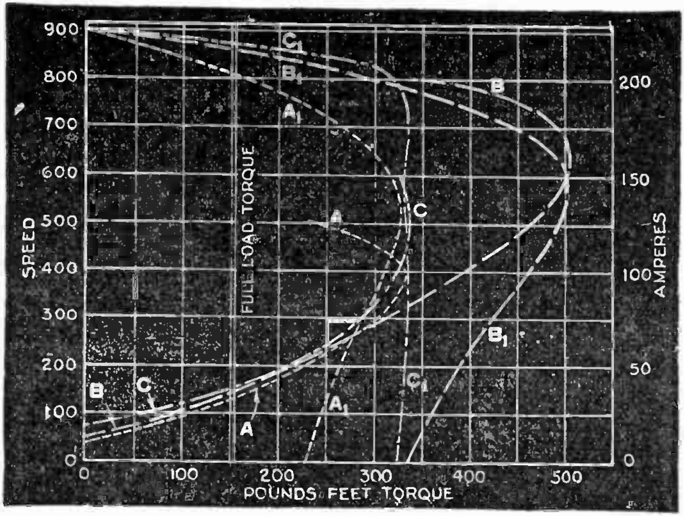


FIG. 2,778.—Speed torque and current curves of 25 *h.p.* 8 pole, 60 cycle induction motors according to F. J. Johns (of Westinghouse Co.) A_1, speed torque of a high slip motor; B_1, speed torque curve of a high torque motor; C_1, speed torque curve of a line start motor; A, current torque curve of a high slip motor; B, current torque curve of a high torque motor; C, current torque curve of a line start motor.

in the armature core below the starting winding. The load current is shifted automatically from the starting winding to the running winding by the change in armature reactance as the armature speed increases.

Because of the confusion of terms, in some cases, high torque motors have been applied where high slip motors should have been used.

A high slip motor should be used on such applications as shears, punch presses and all fly wheel applications where the motor must slow down to allow the fly wheel to give up its kinetic energy, with sufficient time between the operations of the machine to allow the fly wheel to gain speed and store up sufficient energy for the next operation.

Motors for fly wheel application seldom require a high starting torque, the standard torque value being sufficient. For such application, the motor should be referred to as a high slip motor and not as a high starting torque motor.

On the assumption that a high slip, high resistance armature motor is a high starting torque motor, high slip motors have been used for applications such as conveyors, compressors, etc. On these applications a low slip, high starting torque motor should be used, as the motor must start a heavy load from rest and the running speed should be as high as possible.

A difference in speed on a conveyor or similar application of 100 *r.p.m.* may slow up the handling of material, etc., considerably; also the speed variation of the motor from no load to full load should be practically constant.

The torque curves shown in fig. 2,778 are good examples of ideal torque curves.

These three torque curves are free from cusps, and the three motors are capable of bringing up to speed any load they can start. The shape of the torque curve is of importance, as a cusp in the curve which reduces the torque between start and maximum points to a value considerably below the starting value may result in the motor failing to come up to speed. This would require replacement of the motor with one which has a torque curve approaching the curves shown in fig. 2,7.8, or a motor of higher rating.

It is usually recommended that a motor have nearly 200% of full load torque at its maximum or pull out point.

For most applications this is not necessary. Comparing the maximum torque value of the motors shown in fig. 2,778, the line start motor and the high slip motor have approximately the same value of maximum torque, namely 213% of full load torque, whereas the high torque motor has 325% of full load torque at its pull out point.

The horse power of these motors at their maximum or pull out points is 34.6 for the high slip, 48 for the line start and 57.7 for the high torque motor. Obviously the value of maximum torque in terms of full load torque is not always a measure of the maximum horse power that a motor will deliver, momentarily without overheating or pulling out.

The starting currents of the three motors under discussion can be taken from the current curves.

They are the extreme upper ends of the curves. There is not much difference between the starting current for the high slip and the line start motor, but the high torque motor takes considerably more current at start.

From the speed torque and current torque curves in fig. 2,778 the following conclusions can be drawn:

1. A high slip motor is not necessarily a high starting torque motor, *i.e.* a motor with a high armature resistance does not always have a high starting torque.

2. A high starting torque motor can be built without a high resistance armature, in which case it is not a high slip motor.

NOTE —***Effect of changes in voltage and frequency on induction motor operation.*** According to B. G. Lamme, some variations from normal voltage and frequency are generally permissible with any induction motor, but such variations are always accompanied by changes from normal performance. With either the voltage or the frequency differing from normal the following performance changes must be expected:

Conditions	Power Factor	Torque	Slip
Voltage high	Decreased	Increased	Decreased
Voltage low	Increased	Decreased	Increased
Frequency high	Increased	Decreased	Per cent slip unchanged
Frequency low	Decreased	Increased	Per cent slip unchanged

Usually a variation of either voltage or frequency not exceeding 10% is permissible and within this limit the efficiency remains approximately unchanged. The voltage and frequency should not be varied simultaneously in opposite directions, that is, one decreased and the other increased. If an induction motor must operate on frequency other than standard, the performance will be better if the voltage be changed in proportion to the square root of the frequency. Thus a 400 volt, 60 cycle motor operating on 66⅔ cycles will have very nearly its normal operating characteristics if the voltage be raised to $400 \times \sqrt{66\tfrac{2}{3}} \div 60 = 420$ volts. Decreasing the voltage much below normal is seldom permissible on account of resulting increased temperature rises. An increase in the frequency results in a considerable reduction in the maximum load which an induction motor can carry.

3. Two motors of different design can have the same starting torques and different pull out torques; or they can have the same pull out torque values and different starting torque values.

4. Two motors of different design can have widely different values of starting current for the same starting torque; or they can have different values of starting torque for the same starting current.

It is seen, therefore, that in specifying a motor for a given application it is better to do so, not on the basis of design characteristics, but on the basis of operating characteristics desired.

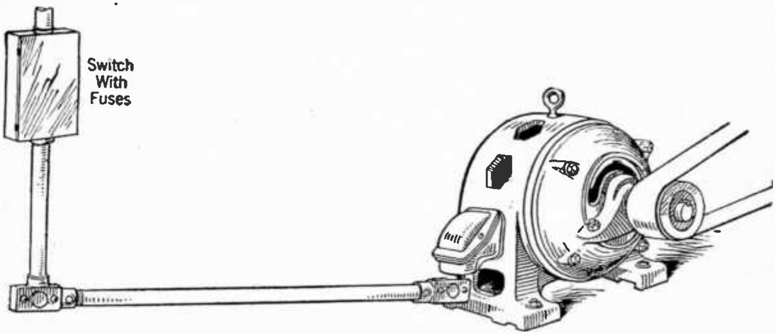


FIG. 2,779.—Installation of Wagner internal resistance motor showing three phase wiring connections.

Ques. For what size motors is the internal resistance method suited?

Ans. Small motors.

Ques. Why is it not desirable for large motors?

Ans. The excessive I^2R loss in the resistances, if confined within the armature spider, would produce considerable heating, and on this account it is best placed external to the motor.

Ques. On what class of circuit are internal resistance motors desirable?

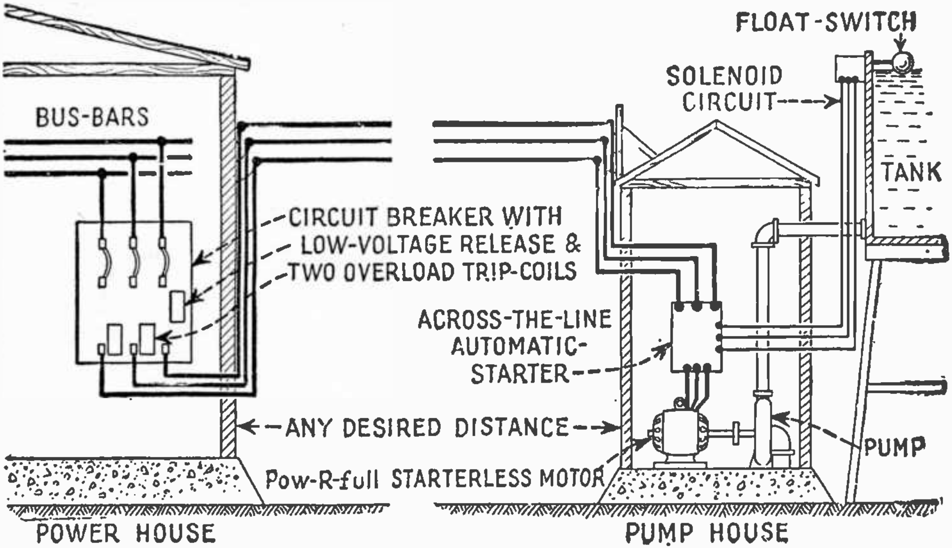
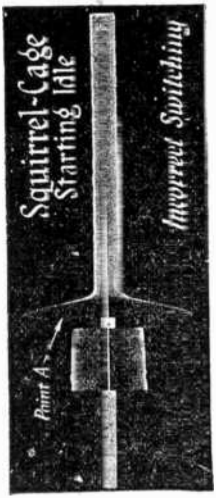


FIG. 2,780.—Remote automatic control of internal resistance motor. *For instance,* in case a pump house be at such a distance that the motor cannot be under the immediate supervision of the operator, it may be desirable to install the circuit breaker with low voltage protection and overload trip coils in the power house from which the motor is supplied, instead of the distant pump house. The float switch and an automatic starter are left in the pump house to control the starting and stopping of the motor. Such an installation makes it unnecessary to visit the pump house every time the protective devices open the circuit. The motor is normally started and stopped by the float switch. In emergencies, the circuit breaker in the power house opens the lines leading to the pump house. When normal conditions are re-established, the operator closes the circuit breaker which causes the float switch to close in the distant pump house thus again resuming the automatic control of the motor.



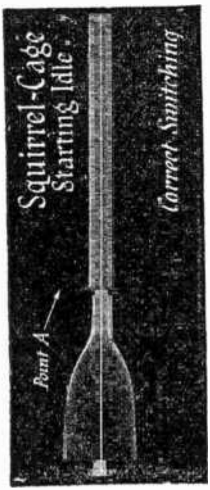


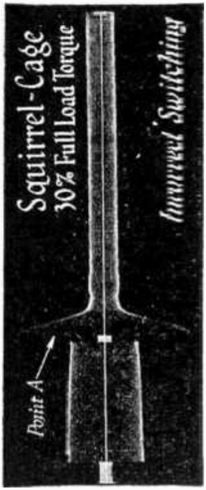
FIG. 2,781.—Starting current with motor idle—switching from "start" to "run" correctly timed.

FIG. 2,782.—Starting current with motor idle—switching from the "start" to "run" incorrectly timed.

Ans. On circuits devoted to lighting service as well as power service, when a high degree of voltage regulation is essential.

The initial rush of current when a squirrel cage motor is thrown on the line is more or less objectionable and there are central stations which allow only resistance type of induction motor to be used on their lines.

Oscillograms of Starting Current for Internal Resistance, and Squirrel Cage Motors.—The current at the instant of starting a squirrel cage motor is 500 to 600% of the full load current if full voltage be applied. Hence compensators or rheostats are almost invariably used to reduce the starting voltage for all squirrel cage motors above 5 *h.p.* Thus the current at starting depends on the compensator taps used or on the amount of resistance inserted in series with the motor. Usually the compensator is tapped at the 70% points so that the current at the instant of starting is limited to 300% of full load value, which is about equal to the maximum current in an internal resistance motor. However, there is a marked difference between the two



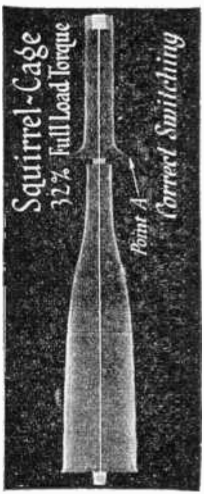


FIG. 2,783.—Starting current with torque equal to 32% full load—switching from "start" to "run" correctly timed.

FIG. 2,784.—Starting current with torque equal to 30% full load—switching from "start" to "run" incorrectly timed.

motors in this respect. The governor inside the starterless motor automatically limits the current so that it never exceeds 300% of full load value.

When a squirrel cage motor is used the plant engineer can set the compensator taps so that the current at start is no more than 300% of full load, but at the moment when the compensator handle is pulled over from starting to running position, there is a sudden drop and jump of current, and considerable voltage fluctuations may result if the handle be pulled over too soon. The oscillograms, figs. 2,781 to 2,786, show clearly the extent to which the squirrel cage current peaks depend on the skill of the operator.

An oscillogram is *the tracing left on a photographic film by an oscillating beam of light, the amplitude of the oscillation being a measure of the line current*. The cylindrical film is rotated at uniform speed. Thus these oscillograms are accurately traced curves showing just how the line current changes with the elapsed time after starting.

The following comments on figs. 2,781 to 2,784 are of major interest.

1. Note the sudden drop of current to zero at the moment of switching. This occurs in all squirrel cage motors, and is followed by a sudden current peak the extent of which depends entirely on the speed of the armature at the time the compensator handle is thrown. With the starterless, no sudden break can occur.

2. Note that the time of correct switching for the 30% full load torque is later than for idling torque, since it takes more time for the loaded rotor to come up to speed. Thus the moment when the operator should make the shift from starting to running conditions varies with the make of the motor, with the compensator taps used, with the load torque and the load inertia. He can only make a guess as to the right moment. The starterless switching automatically occurs at the right rotor speed, hence dangerous current peaks can never occur.

3. At point A, is shown a sudden high current peak, even when the switching is correct. Its cause is as follows: When the compensator handle is shifted from starting to running position, the stator current drops to zero but the rotor is still rapidly rotating and its circuit is not broken, so that a large current still continues in it, and induces a voltage in the field. When now the compensator running contacts are closed, the line voltage may be applied at just the instant of maximum voltage induced by the rotor. If this occur, a very heavy current inrush will take place which will result in flickering of lamps and severe strains in the motor. With the starterless motor this current inrush cannot occur because all the switching is done in the rotor circuit, not the line circuit.

4. Note that all the above oscillograms are for much less than full load torque. It is not unusual to find a frictional starting torque in practice amounting to as much as double full load torque. If such a torque were here used with incorrect switching, the resultant current peak would reach many times the full load current.

The following comments on figs. 2,785 and 2,786 are of major interest:

1. Note that the time of switching occurs later for the high torque—this is because it takes longer for the loaded motor to reach the correct switching speed, which is 70% of synchronous speed. The human tendency with the squirrel cage is to throw the compensator switch after the habit formed time

NOTE.—The oscillograms figs. 2,781 to 2,786 are here shown by courtesy of Wagner Electric Corporation who make *internal resistance* or so-called "Starterless Pow-R-full" motors. In the above text, the claims as to performance of the Wagner motor, are those made by the manufacturer.

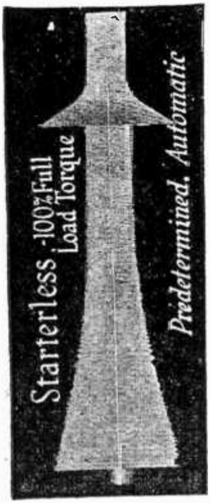


FIG. 2,785.—Starting current with motor idle.

FIG. 2,786.—Starting current with full load torque.

interval has elapsed. This often means that the switch is thrown with the armature at too low speed. The governing mechanism of an internal resistance motor short circuits and thereby throws into action the low resistance running circuit when the armature reaches 70% of synchronous speed. This it does, automatically, independently of human fallibility.

2. No oscillograms of incorrect switching could be taken, since it is impossible to start this motor incorrectly. The switching is done by a governor inside the rotor.

Advantages of Internal Resistance Motors.—There are several advantages gained by the use of this type motor for installation where the motor is adapted to the service requirements as here enumerated.

1. ***Minimum Voltage Fluctuations.*** —During starting, the internal resistance motor has a higher power factor than the squirrel cage, so that it draws a smaller current from the line, for a given starting torque, and therefore causes smaller voltage fluctuations.

2. ***Remote Control*** is very simple as a starter is required it is connected directly across the line.

3. ***High Starting Torque*** of twice the full load torque. This sustained high torque during the starting period brings the motor up to speed so quickly that the starting currents have no time to cause serious heating. The starting torque can

be so high as to cause a sudden kick and belt burning or breakage and in this connection experience has taught that the torque should be limited to twice the full load value. This is the maximum safe torque for most applications.

4. ***Predetermined Starting Characteristics*** which give

   a. Automatic limitation of the current to safe values.
   b. Smooth quick acceleration without appreciable line surges.
   c. Independence of human carelessness in starting.

5. ***Freedom*** from expensive control apparatus.

6. ***High Efficiency*** comparable with the best slip ring and squirrel cage types.

TEST QUESTIONS

1. *What type of induction motor is most generally used?*
2. *What difficulties are experienced in starting squirrel cage motors?*
3. *What is the disadvantage of using a high resistance armature in a general purpose motor?*
4. *Describe the development of internal starting devices.*
5. *Who introduced the automatic centrifugal governor to shift from starting to running connections?*
6. *What is an internal resistance induction motor?*
7. *Name two general classes of internal resistance motors.*
8. *What difficulties were experienced with grids?*
9. *Describe the operation of a motor having a high resistance squirrel cage and a low resistance lap winding.*
10. *What is the object of using a high resistance squirrel cage?*

11. *Describe the mechanism of a multi-contact automatic short circuiting switch.*
12. *Describe the operation of a motor having a high resistance squirrel cage and a low resistance phase winding.*
13. *What name is given to the type motor having a high reactance winding?*
14. *What is the chief feature of the double squirrel cage motor?*
15. *What is the object of a double squirrel cage?*
16. *Upon what does the operation of a double squirrel cage depend?*
17. *Describe a double squirrel cage motor with choker.*
18. *Upon what principle does the operation of a double squirrel cage choker depend?*
19. *State the characteristics of a double squirrel cage.*
20. *Give comparison of high slip and high torque motors.*
21. *State the effect of changes in voltage and frequency for induction motor operation.*
22. *For what size motors is the internal resistance method suited?*
23. *What is the objection to large internal resistance motors?*
24. *On what class of circuit are internal resistance motors desirable?*
25. *State four advantages of internal resistance motors.*

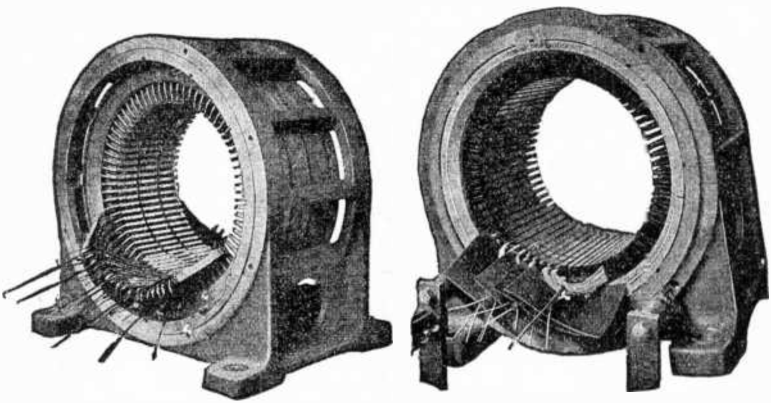
CHAPTER 58

External Resistance or Slip Ring Induction Motors

There are three general types of commercial polyphase induction motors in use today.

1. Squirrel cage.
2. ***Internal*** resistance.
3. ***External*** resistance.

The external resistance induction motor variously called, *slip ring, wound rotor* or *phase wound*, is hereafter spoken of as *slip*



FIGS. 2,787 and 2,788.—***General Electric slip ring motor construction 1.*** ***Partially wound fields*** showing exposed laminations, oiled paper and linen slot insulation, form wound coils wrapped with "assembly" or (sacrifice) tape which affords protection while installing, and a perfect fit in the slots.

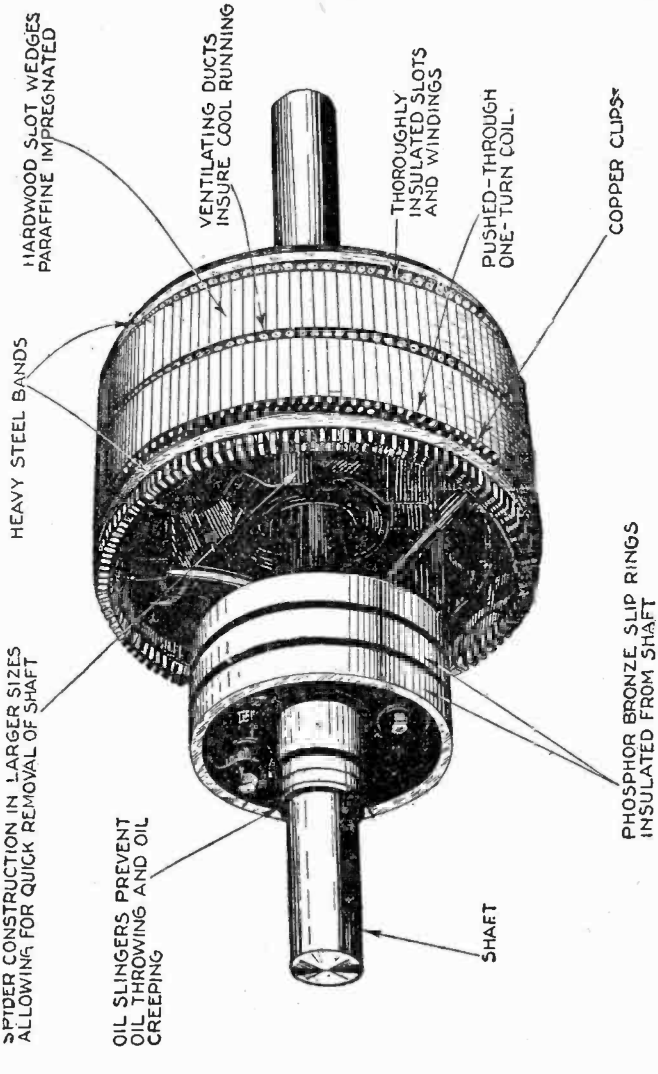


FIG. 2,789.—*Triumph slip ring motor construction.*—1. Armature showing winding and slip rings. The slip ring and brush rigging are shielded to prevent accident to the operator.

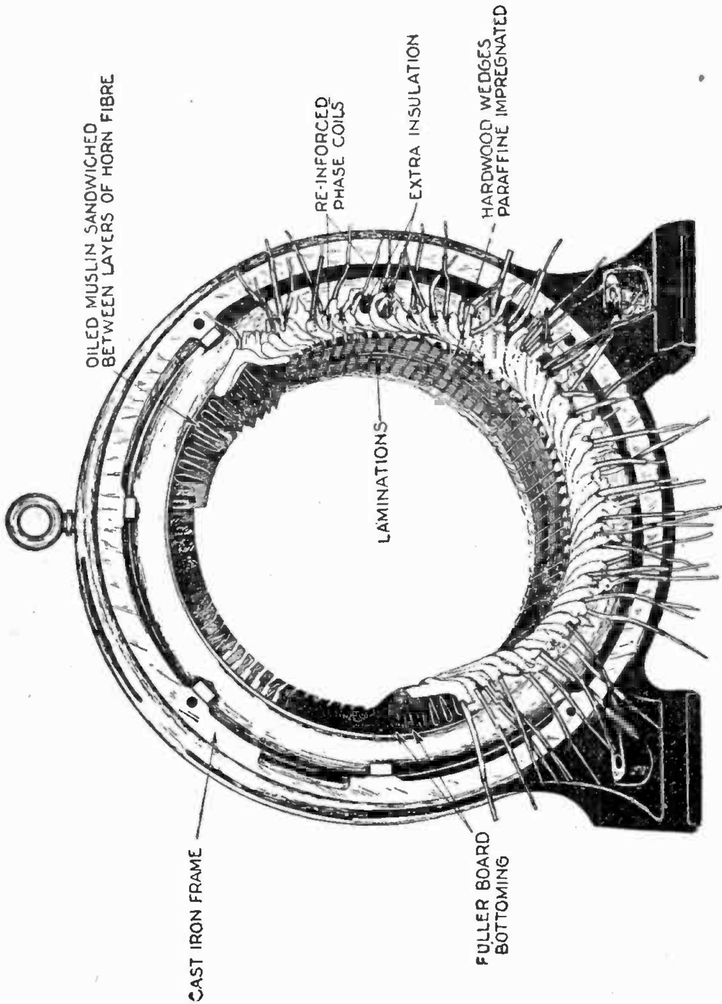


FIG. 2,790.—*Triumph slip ring motor construction.*—2. Frame with field winding partially assembled. Coils are form wound, treated and wrapped.

ring motor to avoid confusion with the internal resistance motor.

By definition, a slip ring motor is *an induction motor which has a polyphase winding similar to that of the stator, the rotor windings being connected at one end and brought out to a variable external resistance through slip rings.*

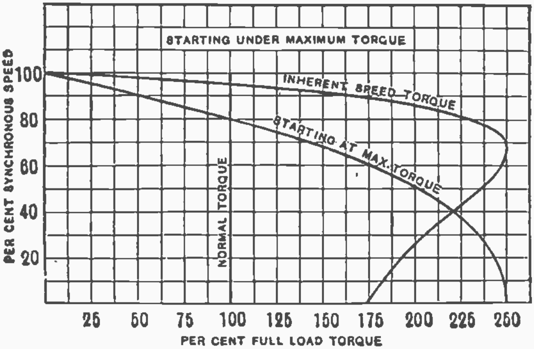


FIG. 2,791.—Speed torque curves for Wagner slip ring motors with armature short circuited (inherent speed torque) and with resistance inserted to give maximum torque at standstill. Wagner slip ring motors for continuous duty are designed for a maximum torque of approximately 250% full load torque. In other words this type of motor, when subjected to an extreme overload, will exert a momentary torque equal to 250% of full load torque before pulling out of step. The upper curve shows the speed torque performance of this motor when operated with the armature short circuited. This curve is called the inherent speed torque curve of the motor in that it shows the performance of the motor with all external resistance short circuited. It will be noticed that the motor develops 175% of full load torque at standstill and that the torque slowly increases in value to 250% at approximately 68% of synchronous speed. The torque then begins to decrease slowly as the motor approaches full speed. At full load the motor develops normal of 100% torque and operates at approximately 95% of synchronous speed. On other than rated load the motor will operate at the speed shown on the curve for the corresponding torque requirement. At 250% of full load torque the motor becomes unstable and will "pull out" as shown by the lower part of the curve which brings the motor to rest. The curve marked "starting at maximum torque" shows the speed torque relations during starting when the resistance inserted and retained in the armature circuit is of such value as to give maximum torque at a standstill. With this same amount of resistance kept in the armature circuit while the motor is operating this curve also shows how the speed of the motor will vary with the torque required by its load.

NOTE.—The commonly used terms *wound rotor* and *phase wound*, for an external resistance motor are ridiculous because they do not fully classify. ***For instance,*** the terms are commonly though questionably applied to *internal* resistance motors such as shown in Chap. 57, and *external* resistance motors such as shown in this chapter. The term *slip ring* fully defines the motor as to type and leaves nothing to the imagination.

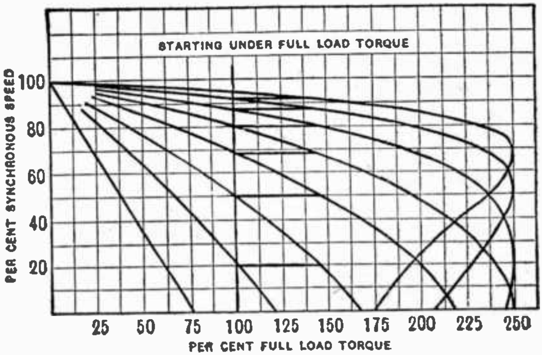


FIG. 2,792.—Speed torque curves of Wagner slip ring motor equipped with starter having eight steps of resistance. The resistance in the armature circuit is contained in a motor controller. Assuming that the motor load requires a little over full load torque to start, it will be noticed that with the controller handle on the first step of resistance, only 75% of full load torque is developed—not sufficient to start the motor. Moving the handle to the second step cuts out a section of resistance and causes the motor to develop 118% of full load torque. The motor will start and the speed increases to 20% of synchronous speed. The speed remains at this value until the controller handle is moved to the third step, which cuts out another section of the starting resistance. The motor speed then increases in accordance with the third curve from the left until 50% of synchronous speed is reached. Moving the controller handle so as to cut out more resistance causes the motor to build up to 68% of synchronous speed, and so on, until full load speed, which in this case is 95% of synchronous speed, is attained.

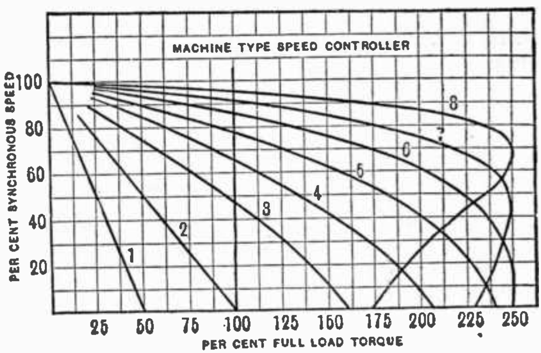
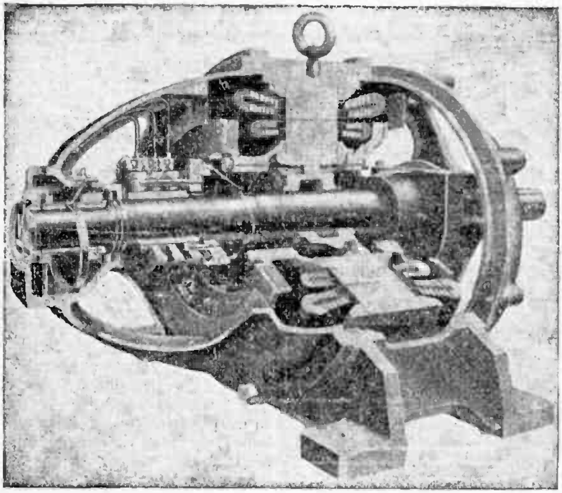


FIG. 2,793.—Speed torque curves of Wagner slip ring motor equipped with machine type speed controller having eight steps of resistance. The diagram shows the speed torque curves of a slip ring motor used with a machine type controller. If the machine driven require full load torque at all speeds, the intersections of the speed torque curves with the 100% torque line, show the motor speeds with the controller handle on the various steps. If the motor load



Ques. How is the armature winding connected?

Ans. It is connected in Y grouping and the free ends connected to the slip rings, leads going from the brushes to the variable external resistances, these being illustrated in fig. 2,795.

FIG. 2,794.—*Westinghouse slip ring motor construction.* Cut away view showing construction.

NOTE.—*Slip ring motor armature winding.*—Usually there are three phase windings, irrespective of the number of phases of the field. The polyphase armature winding creates a uniformly revolving field. It is then possible to use any number of phases desired in the field just as the rotating field alternator may be connected for any number of phases. However, the windings on the armature must be grouped to produce poles corresponding in number and location to the poles of the field. In the squirrel cage winding this effect is obtained automatically although the armature winding is not arranged with definite pole grouping. It has been found that the characteristics of the slip ring motor are improved by increasing the number of phases in the armature winding. The squirrel cage winding is, in effect, a multi-phase winding. Three phase windings are used for slip ring motors because they require but three collector rings. Single phase windings would require two rings only but would afford much poorer performance. An increase above three phases is not justified as the improvement is insufficient to offset the added complexity of motor, control and wiring. ***The star connection*** is used exclusively for armature windings as it yields the highest armature voltage for a given number of armature inductors and adapts itself readily to the insertion of external resistors in the armature circuits.

FIG. 2,793.—*Text Continued.*
vary, the motor speed will follow the speed line corresponding to the setting of the controller handle. ***For example,*** if the torque required be reduced from 100 to 50% of full load torque while the controller handle is on the third step, the speed will increase from 48 to 75% of synchronous speed. If it be desired to retain the same speed at which the motor was operating when delivering full torque, the controller handle should be moved to the second step, causing the motor speed to drop to 50% of synchronous speed.

Comparison of Types.—The squirrel cage motor is the one in most general use. It is simplest in construction, the most reliable in operation and the easiest to maintain. For constant speed service where the starting duty is light and infrequent, this type of motor is eminently well adapted. However, certain classes of service require a higher starting torque than is obtainable with a squirrel cage motor and central stations frequently insist upon a definite limitation of motor starting currents. To

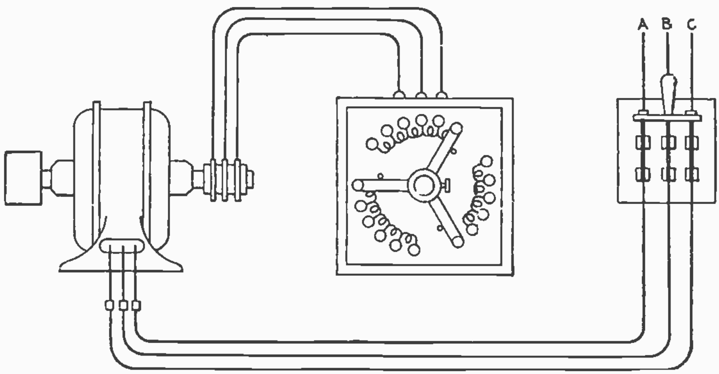
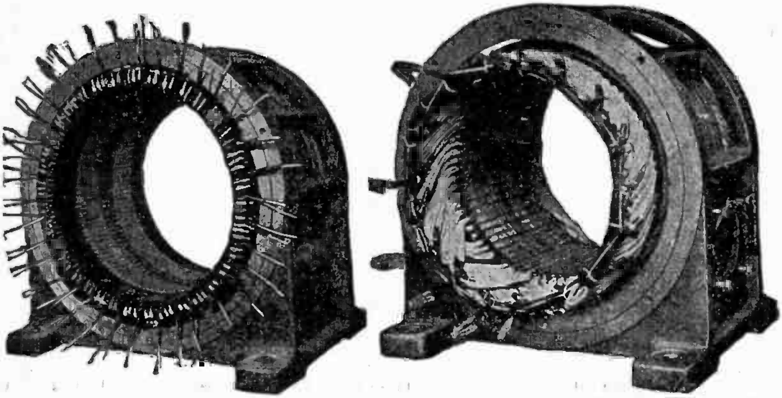


FIG. 2,795.—External resistance or slip ring induction motor connections. The squirrel cage armature winding is not short circuited by copper end rings, but connected in Y grouping and the three free ends connected to three slip rings, leads going from the brushes to three external resistances, arranged as a triplex rheostat having three arms rigidly connected as shown, so that the three resistances may be varied simultaneously and in equal amounts.

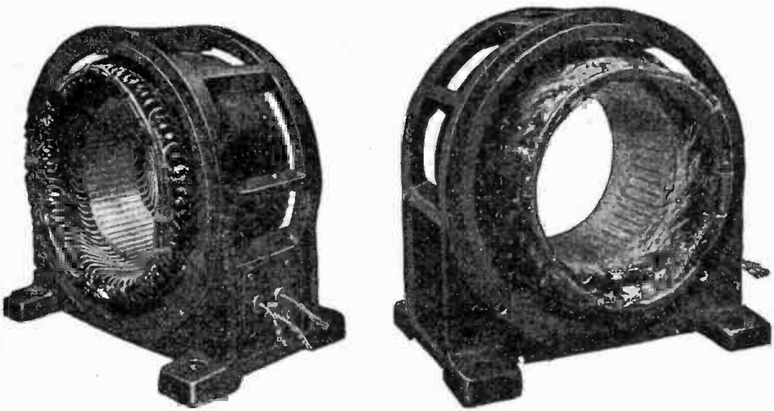
meet these conditions the internal resistance motor described in the preceding chapter was developed.

In addition to meeting conditions just mentioned, the slip ring motor is the only industrial type of polyphase motor *adapted to variable speed service*. Wide variations of speed may be obtained without complicated arrangements.

Starting and speed variation alike are accomplished by means of a controller connected to the slip rings of the motor. This controller consists of an adjustable resistor. With all resistance out of the circuit, that is with the armature short circuited, the motor runs at full speed. Starters and controllers are similar in construction differing only in the rating of the resistors used and in minor details of construction.



Figs. 2,796 and 2,797.—*General Electric slip ring motor construction 2. Field windings being connected.* Views show partially closed slots, heavy fibre and hard wood wedges, end shields, etc.



Figs. 2,798 and 2,799.—*General Electric slip ring motor construction 3. Completed fields* showing systematic arrangement of connections to facilitate reconnecting, compound insulation, outlets for leads, etc.

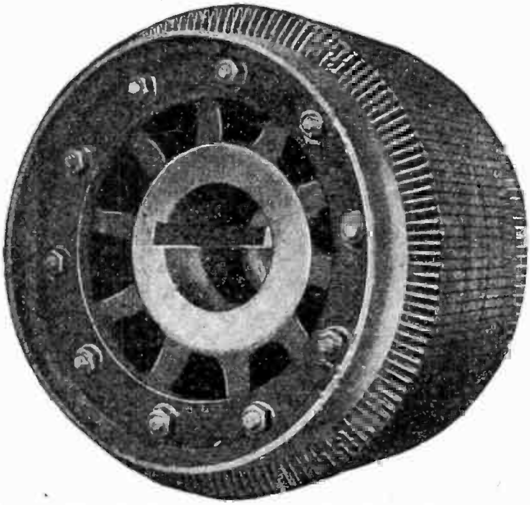


FIG. 2,800.—*General Electric slip ring motor construction 4.* Armature ready for winding showing heavy end flanges secured by through bolts and end fingers.

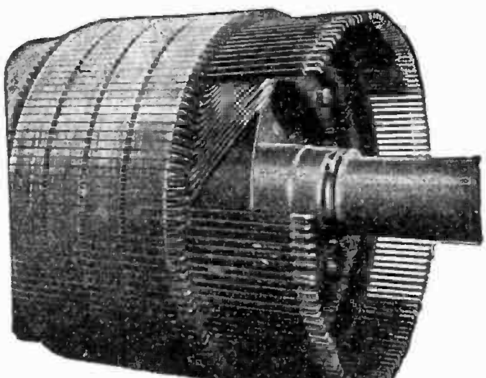


FIG. 2,801.—*General Electric slip ring motor construction 5. Partially wound armature.* Insulated copper bars are inserted in insulated slots and are supported at ends by wide insulated flanges.

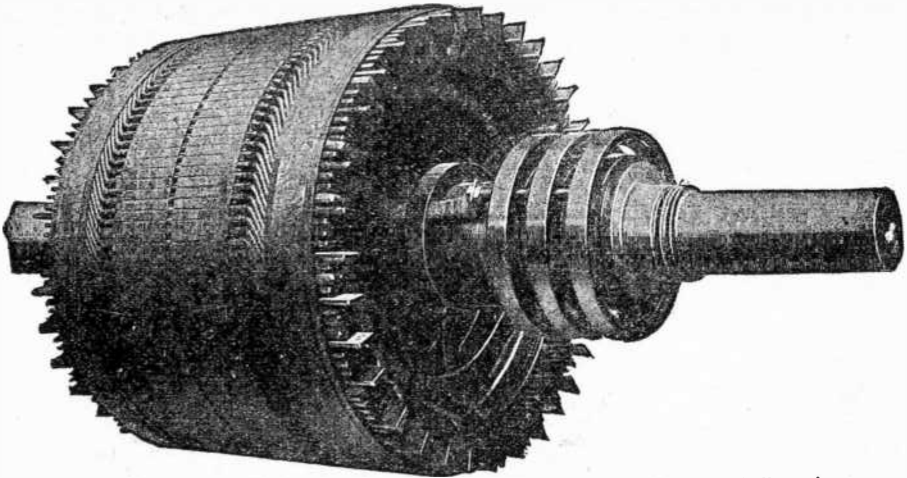


FIG. 2,802.—*General Electric slip ring motor construction 6. Armature complete* showing binding wires, connection clips which act as fans, slip ring.

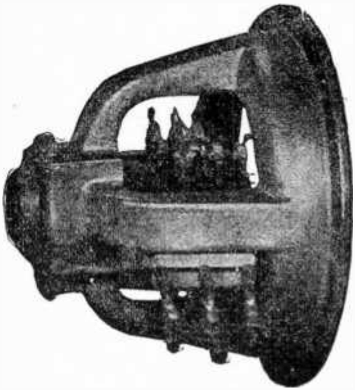
Slip ring motors are used for many of the same purposes as squirrel cage motors. Their applications in industry are in driving pumps, blowers, compressors, forging machines, shears, hammers, punches, bending rolls, straightening rolls and similar apparatus. They are also used for elevators, cranes, hoists and frequently in drives for steel mills, paper mills and other factories. Used with the proper control equipment they give a range of speed from normal down to half of normal.

Considering all three types of motors from the point of view of starting performance, the following comparison can be made.

A *squirrel cage motor* of well balanced design will develop at starting on full voltage 125 to 150% of full load torque and will draw 375 to 450% of full load current.

An *internal resistance motor* of good design will develop from 180 to 225% of full load torque with a starting current of 225% of full load current. These starting currents are 75% of the "locked" currents.

With a *slip ring motor* the starting torque and the starting current are under the control of the operator and may be varied at his will. The slip ring motor accordingly permits the heaviest loads to be started slowly and smoothly with no objectionable line disturbances.



FIGS. 2,803 and 2,804.—*General Electric slip ring motor construction 7.* End shields Shields interchangeable, end for end. Rabbet fits prevent misplacement. Plenty of heavy cap screws hold shields firmly to field frame. Fig. 2,803, collector ring end shield with brush rigging assembly; fig. 2,804, pulley end shield.

Construction of Slip Ring Motors.—The following representing the practice of one manufacturer is typical of approved methods in the construction of motors of this type.

The armature windings are composed of coils having several turns which are grouped into polyphase systems. These coils are connected together at one end. Each phase group of coils is made of one continuous copper bar, reducing the end connections to a minimum and consequently the number of soldered joints, thereby eliminating the human element as much as practicable in the manufacture of the windings. The phase groups are insulated

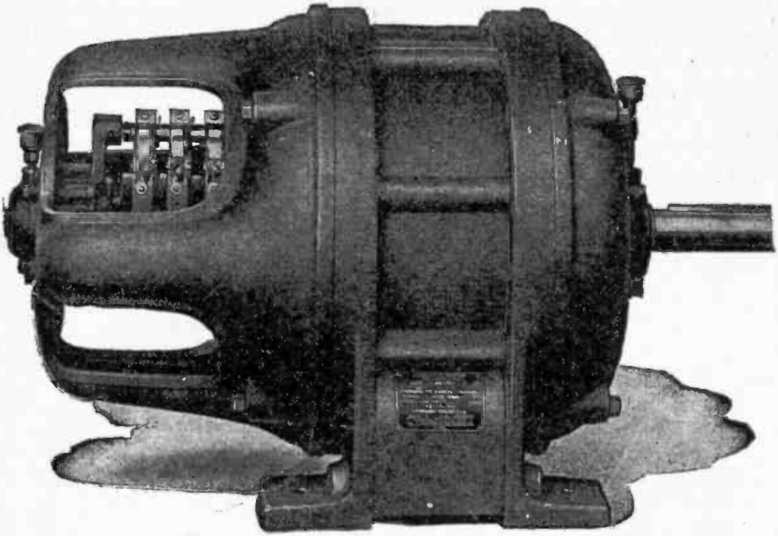


FIG. 2,805.—Allis Chalmers type ARY external resistance or slip ring motor. This type motor is adapted to keep the starting current within limits, or where a large starting torque is required, the slip ring or wound rotor type is used. This type requires a smaller current to develop a given starting torque, and is therefore used where frequent starting is necessary.

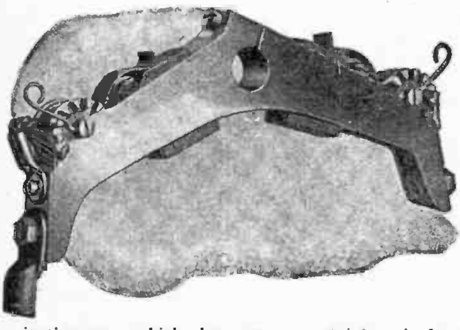


FIG. 2,806.—Brush holder of Allis Chalmers type ARY external resistance or slip ring motor. It is of the double holder type cast in one piece of bronze metal. One holder (with two brushes) per ring is used on small ratings and two holders (four brushes) on larger ratings. The boxes are radial to the slip rings, and adjustment of the angle of contact as the brush wears, is unnecessary. The pressure arms are of heavy, copper plated, clock spring steel, mounted face to face, which equalizes the stresses set up in the brush holder stud. Adjustment of tension is made by means of the tension adjusting arm, which also acts as a retaining pin for the studs on which the pressure arms are mounted. By removing this tension adjusting arm, the entire pressure arm assembly can be readily removed. Current is carried by the brush pig tails from the brush to a lug bolted to the holder. Separate terminal lugs are provided for the secondary leads.

from each other. When the winding is completed, the slots are closed with treated hardwood wedges, which, with the banding wires over the coil extensions, hold the coils securely in position. The armature is baked to expel all moisture, and the winding is completely saturated with hot insulating compound which makes it practically impervious to moisture and other deteriorating elements.

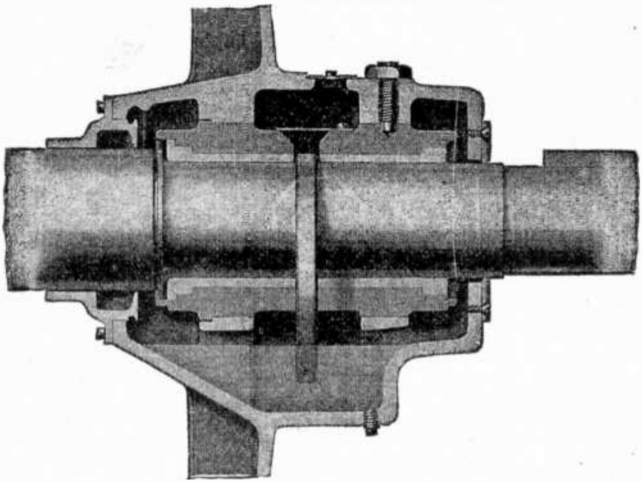
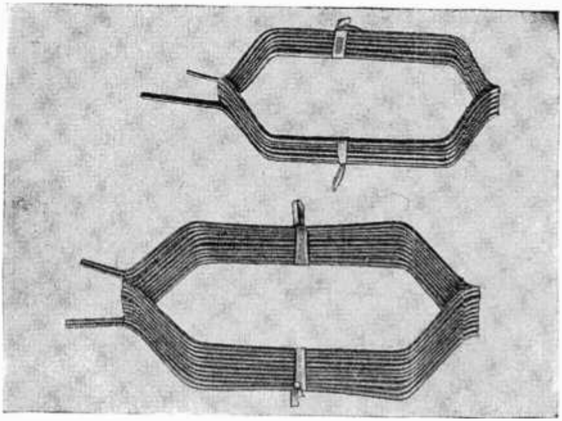


FIG. 2,807.—Sleeve bearing of Allis Chalmers squirrel cage and slip ring motors. ***In construction,*** the bearings are of the ring oiling type and in the small motors have aluminum bronze bushings. The bushings of the larger machines are of cast iron, babbitt lined. Each bearing is protected against the entrance of dust or dirt. Screwed down steel plates for inspection of the oil rings, oil overflows with hinged caps for filling and pipe plugs for draining the oil wells are part of the regular equipment furnished. Suitable slingers are also provided to prevent oil being drawn from the bearings and thrown into the motor. Where motors are intended for gearing or coupling, split bearings and split end brackets or housings are recommended and can be furnished for all motors above 5 *h.p.*

Starting Devices for Slip Ring Induction Motors.—Automatic starters are commonly used for the smaller sizes of slip ring motors. They consist of primary and secondary contactors or magnetic switches mounted on a slate panel with starting resistors, all being enclosed in a steel cabinet. With this type starter, operation is controlled by "start" and "stop" push buttons.

Pushing the "start" button closes the primary contactor and applies full voltage to the field windings with sufficient resistance in the secondary or armature circuit to limit the starting current to 150 or 200% of normal full load current.



Figs. 2,808 and 2,809.—Continuous windings of taped copper ribbon as used on Fairbanks-Morse slip ring motors. The continuous winding has for its object the elimination of a multiplicity of soldered connections.

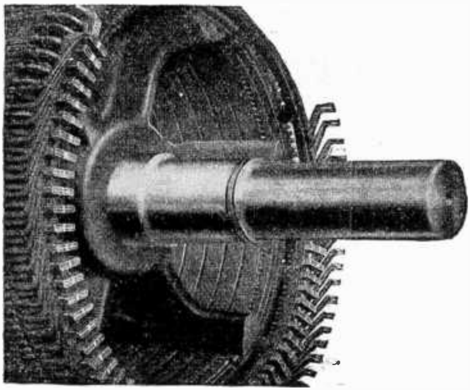


Fig. 2,810.—Armature construction of Wagner 300 *h.p.* slip ring motor.

A time limit relay controls the operation of the secondary contactor, and after a short interval closes it and cuts out the resistance in the armature circuit. Pushing the "stop" button opens both contactors and stops the motor.

The drum type starters have the switching device mounted in a vertical position, and the operating handle has a rotary horizontal motion. A star wheel is mounted on the shaft so that each step can be felt by the operator. The resistance is placed in

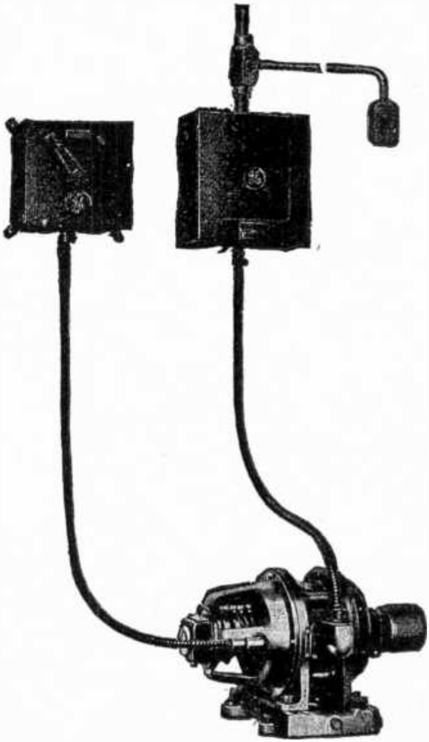


FIG. 2,811.—General Electric slip ring motor with switch and push button in primary and rheostat in the secondary.

a separate frame which may be placed at some distance from the drum convenient to the installation.

Slip ring motors require a primary switch to control the current supply to the field winding in addition to the control for the armature circuit. This may be a magnetic contactor or primary oil switch interlocked with the drum controller.

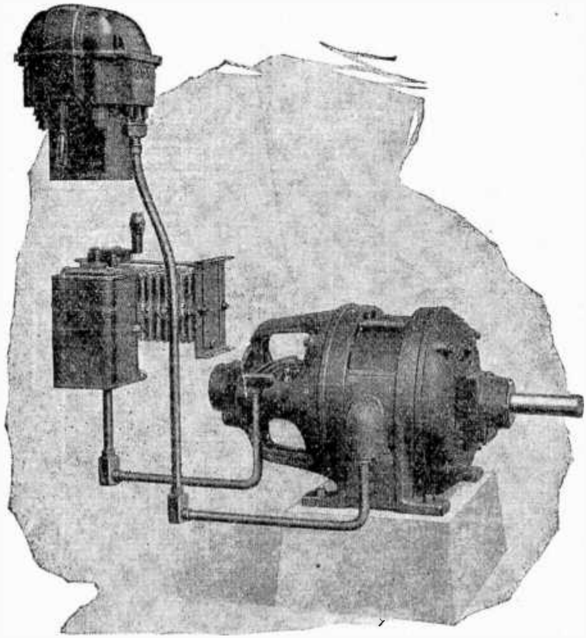


FIG. 2,812.—Allis-Chalmers slip ring motor with drum starter and primary oil switch. A mechanical interlock is sometimes provided between the drum starter and the primary oil switch to prevent closing of the primary oil switch when the secondary resistance is not in the circuit.

Speed Regulating Devices for Slip Ring Induction Motors.—Speed regulators are usually designed to give 50% reduction from normal speed, and consist of a resistance unit designed for continuous service together with a switching device for varying the amount of resistance in the armature circuit.

Speed regulators must be selected with particular reference to the kind of service for which they are to be used. They may be divided into two classes, as,

1. Those for use where the torque varies with the speed at which the machine operates.

2. Those for use where the torque is approximately the same at all speeds. Manually operated speed regulators are classified in two types.

1. Face plate;

2. Drum.

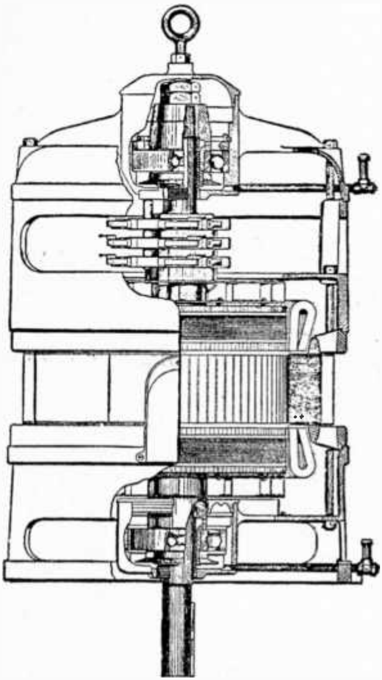


FIG. 2,813.—Allis Chalmers vertical slip ring motor. *It is provided with* ball bearings having a combined radial and thrust bearing at the top and a radial bearing at the bottom. This arrangement is used for motors where the shaft extends downward. If the shaft extension be upward, the thrust is taken at the bottom of the machine. A sleeve is fastened in the bottom of each bearing and extends upward considerably above the level of the oil. The bearing is mounted on another sleeve fastened to the shaft, this fastening being above the stationary sleeve. The construction is such as causes circulation of the oil and a continuous flow thereof to the wearing surface of the bearing at all times. The bearings are supplied with suitable oil level indicators, and means for readily filling the bearings with fresh oil.

Face plate regulators are self-contained and control the secondary circuit only.

Drum type speed regulators consist of a drum switch with a resistance unit mounted separately and are designed for continuous service on any point of the drum switch. These regulators are furnished for either reversing or non-reversing service, the latter controlling the secondary or armature circuit only. The reversing type, in addition to controlling the secondary circuit, is also equipped with a reversing switch for the primary circnit, this switch being mounted on the control shaft and being operated directly by the control handle. This permits a reversal of the same direction of the motor and permits speed control in either direction.

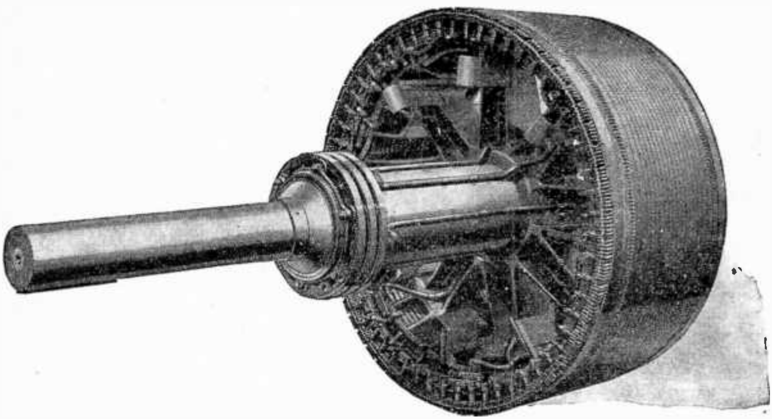


FIG. 2,814.—Allis Chalmers slip ring armature as used on external resistance or slip ring motors. The armature is of the phase wound type having the terminals brought out to three slip rings.

Controllers for intermittent service motors are made either for reversing or non-reversing duty as required; the drum switch and the resistance units are designed only for intermittent service and give 50% speed reduction with one-half full load torque.

Controllers for mine and other service often require special graduations of resistance steps, depending upon the results to be obtained. These controllers are also similar in appearance to the drum type starters. It should be remembered in applying slip ring induction motors and in selecting control equipment for them that they are adjustable varying speed machines. This means that the speed of the motor may be varied, but that when once set will not remain constant if the load change.

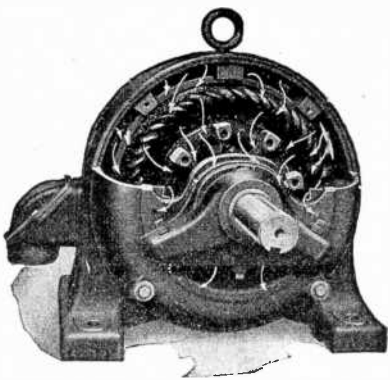


FIG. 2,815.—Sectional view of Wagner internal resistance motor showing directed draught ventilation.

Pole Changing Induction Motor.—The field winding of an induction motor is grouped so as to produce an even number of poles, which number remains fixed in the ordinary type of this motor. The speed depends on this number of poles and on the frequency, the rated no load speed (in revolutions per second), being equal to *the frequency (in cycles per second) divided by the number of pairs of poles.*

From this rule it is evident that if the number of poles could be doubled the speed would be reduced one half. This is done in what is called the "pole changing" or "polar wound" induction motor.

Taps are brought out from the winding to a double throw switch.

Practical difficulties limit the attainable efficient speeds to two, usually in the ratio of one to two. This limitation and the increased cost of building the motor restrict its use. A squirrel cage armature is often used.

In the polyphase motor, shown in fig. 2,816, which is specially designed for oil well pumping and pulling, a slip ring armature with external resistance is used.

A pole changing switch permits two preferred running speeds, one double the other. The armature resistances are used both for starting and for obtaining additional running speeds ranging from each synchronous

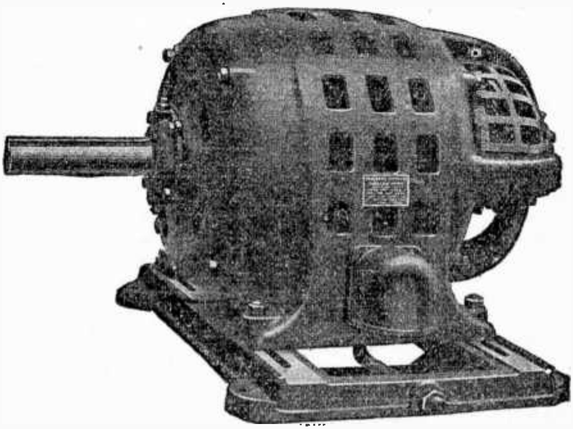


Fig. 2,816.—Fairbanks-Morse type OW ball bearing, three phase, pole changing, slip ring induction, oil well motor arranged to give two synchronous speeds by means of a pole changing switch and speeds below these by inserting resistances in the armature circuit.

speed to one half of this. Thus on one size of these motors a full range of speeds from 300 to 1,200 revolutions per minute can be obtained.

The Heyland Diagram.—By aid of this diagram it is possible to calculate horse power output, *kva* input, amperes per terminal, per cent power factor for different loads, per cent inrush at starting under full voltage, per cent torque at starting, maximum or pull out torque, per cent slip of motor at different loads and actual *r.p.m.* of motor at different loads. All of this data may be obtained from the diagram, after obtaining from test under no load conditions, and with the armature blocked, the volts, amperes and *kw* input to the motor.

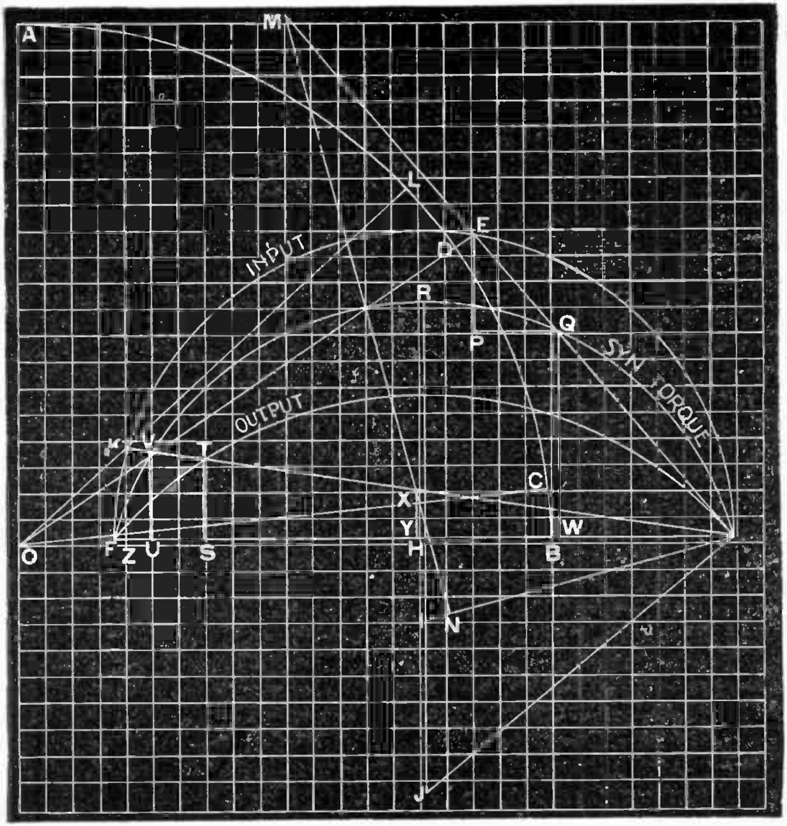


FIG. 2,817.—Heyland diagram for calculating horse power output, *kva* input, amperes per terminal, per cent power factor for different loads, per cent inrush at starting under full voltage, per cent torque at starting, maximum or pull out torque, per cent slip of motor at different loads, and actual *r.p.m.* of motor at different loads.

The following example indicates plainly just how the data is obtained.

Example.—In a test of a 5 *h.p.* 220 volt, 3 phase, 60 cycle, 1,200 *s.r.p.m.* slip ring motor, 17 amperes per terminal, the no load and blocked armature tests gave the following results:

	NO LOAD					BLOCKED ARMATURE				
	Volts	Amperes	Kva	Kw.	P.f.	Volts	Amperes	Kva.	Kw.	P.f.
Test.....	230	12	4.770	.550	11.5	114.3	35.5	7.020	3.980	56.7
Ratioed..	220	11.5	4.370	....	....	220.	68.3	26.000	.....	....

With scale of 250 *va* to one division, 4.370 *kva* = 17.5 div.

$$\frac{\text{Resistance between terminals} \times 3}{2} = .97 = \text{total resistance of armature, hot.}$$

Short circuited full voltage blocked $I^2R = 68.3^2 \times .97 = 4{,}520$ *va* = 18.1 divisions.

Full load of 5 *h.p.* × 746 = 3,730 *va* = 14.9 divisions.

With O, as center, and a radius of 100 divisions, strike arc AB, which is the power factor arc. Draw OC, through 11.5 power factor and lay off OF, equal to 17.5 divisions (no load condition).

Draw OD, through 56.7 power factor and lay off OE, equal to 104 divisions. (Full voltage blocked armature condition.)

Through F and E, draw arc FKEG, with center at H. This is input arc of motor. Connect E and G, draw JG, perpendicular to EG.

With center at J, draw arc through F and G. This is output arc of motor.

Lay off ST, equal to full load, which equals 14.9 divisions. Draw GT, through to K. OK, equals *kva*, input full load, from which full load amperes is calculated to equal 17.8 amperes. (OK, equals 27.2 divisions, multiplied by scale of 250, equals *kva*; this, divided by 220 volts and 1.73 for three phase, equals 17.8 amperes.) OK, extended to L, gives a power factor of 68% for full load.

Draw EP, equal to 18.1 divisions, as per second paragraph above, and PQ, perpendicular to intersection of EG.

With scale of 250 *va*, to one division, 26 *kva* = 104 div. With center I, on HJ, draw arc FQG. This is synchronous torque arc.

Extend GE, to M, the latter being 100 divisions above line FG. Draw MN, perpendicular to IGXY, then in divisions is per cent slip; in this case 9.2%. Then *r.p.m.* is 90.8% of synchronous *r.p.m.* or 1,090 *r.p.m.*

Per cent inrush equals

$$\frac{OE}{OK} \text{ or substituting } = \frac{104}{27.2}$$

which is 383% of full load; with power factor read at D, as 56.7%. Maximum, or pull out torque equals

$$\frac{RH}{TS} \text{ which } = \frac{45}{15} \text{ or } 300\% \text{ of full load}$$

$\frac{QW}{TS} = \frac{39.5}{15}$ or 263%, which is per cent starting torque of full load when armature rings are short circuited, in the case of a slip ring motor FK, is secondary amperes. $\frac{TS}{KZ}$ = per cent efficiency.

$$\frac{\text{synchronous } h.p. \times 33{,}000}{2\pi \times \text{synchronous } r.p.m.} = \text{torque in pounds at 1 foot radius.}$$

TEST QUESTIONS

1. *What are the three general types of commercial polyphase induction motors in use today?*
2. *What other names are given to the external resistance motor?*
3. *Give definition of a slip ring motor.*
4. *How is the armature winding of a slip ring motor connected?*

5. *What type of motor is in most general use?*
6. *Why is the squirrel cage motor generally used?*
7. *What type motor was introduced to overcome the shortcomings of the squirrel cage motor?*
8. *For what service is the internal resistance motor unsuited?*
9. *For what particular service is a slip ring motor especially adapted?*
10. *Compare fully the three types of induction motors.*
11. *Describe the construction of slip ring motors.*
12. *What kind of starting devices are used for slip ring motors?*
13. *Describe the switch and push button type starter.*
14. *Describe the drum type starter.*
15. *What is the construction of speed regulating devices for slip ring motors?*

CHAPTER 59

Single Phase Induction Motors

The general utility of single phase induction motors, particularly the smaller sizes, is constantly being enlarged by the growing practice of central stations generating polyphase current, of supplying their lighting service through single phase distribution, and permitting the use of single phase motors of moderate capacity on the lighting circuit.

The simplicity of single phase systems in comparison with polyphase systems, makes them more desirable for small alternating current plants.

Small single phase motors are manufactured in great numbers, a large percentage of these motors being used to operate household appliances, such as washing machines, ironers, pumps, water systems, refrigerators, oil burners, utility motors, etc. Two fairly new developments which use a large number of motors are domestic electric refrigerators and domestic oil burners.

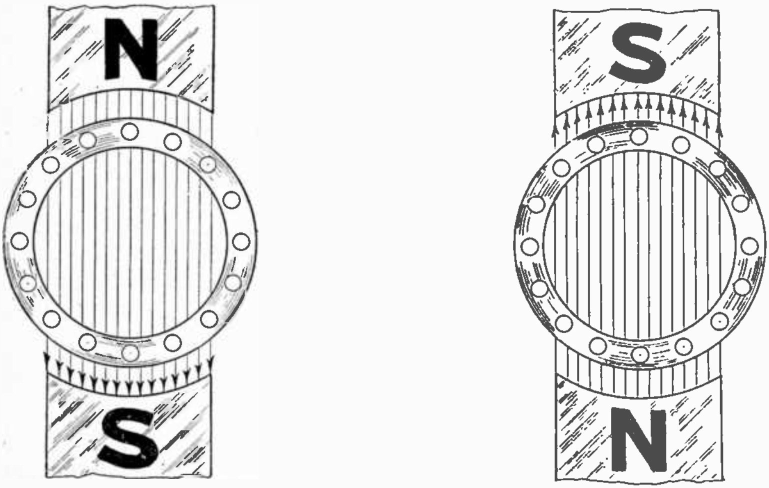
The single phase induction motor has no inherent starting torque.

A polyphase motor connected to a source of polyphase power has a so-called rotating magnetic field, and starting torque is produced due to *the tendency of the armature to follow the magnetic field*.

The starting torque of the polyphase motor may be increased to a certain amount by inserting resistance in its armature circuit, but no amount of resistance inserted in the armature circuit of a single phase induction motor can give it any starting torque.

The single phase motor, with its armature at standstill, has only a *reciprocating field* and there is no tendency for the armature to turn.

For a motor to produce torque, the axis of the magnetic field, due to the armature current, must not be in space phase with the axis of the air

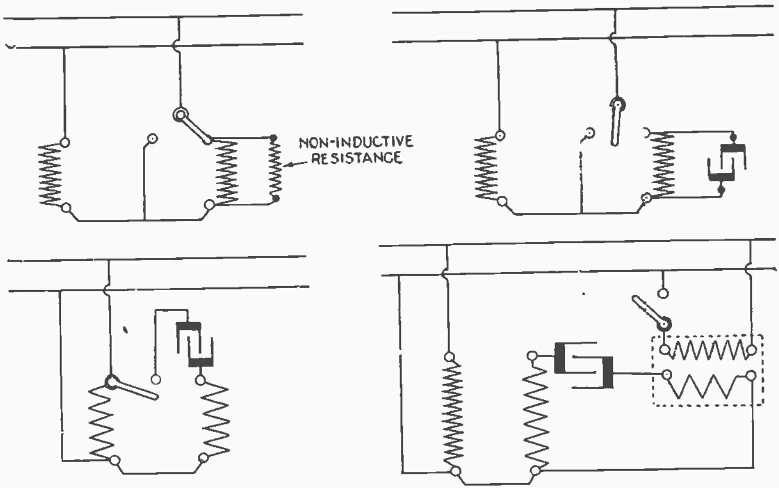


FIGS. 2,818 and 2,819.—Diagrams illustrating a single phase or reciprocating field. A motor is not self starting with a reciprocating field because the magnetization alternates in reversed directions.

gap flux. In the single phase motor the axis of the armature field, with the armature at standstill, is in space phase with the air gap flux and the torque is, therefore, zero. The motor must be started by some auxiliary means.

Various internal means of starting single phase induction motors and bringing this type up to speed have been devised, all of which are based on "*splitting the phase.*" This consists in producing temporarily *a substitute for a two phase current so as to obtain a make shift or bastard rotating field in starting by "doctoring" the single phase.*

When the motor has come to speed, the makeshift second phase is cut out and the motor then runs on the single phase or true phase delivered by the external circuit.

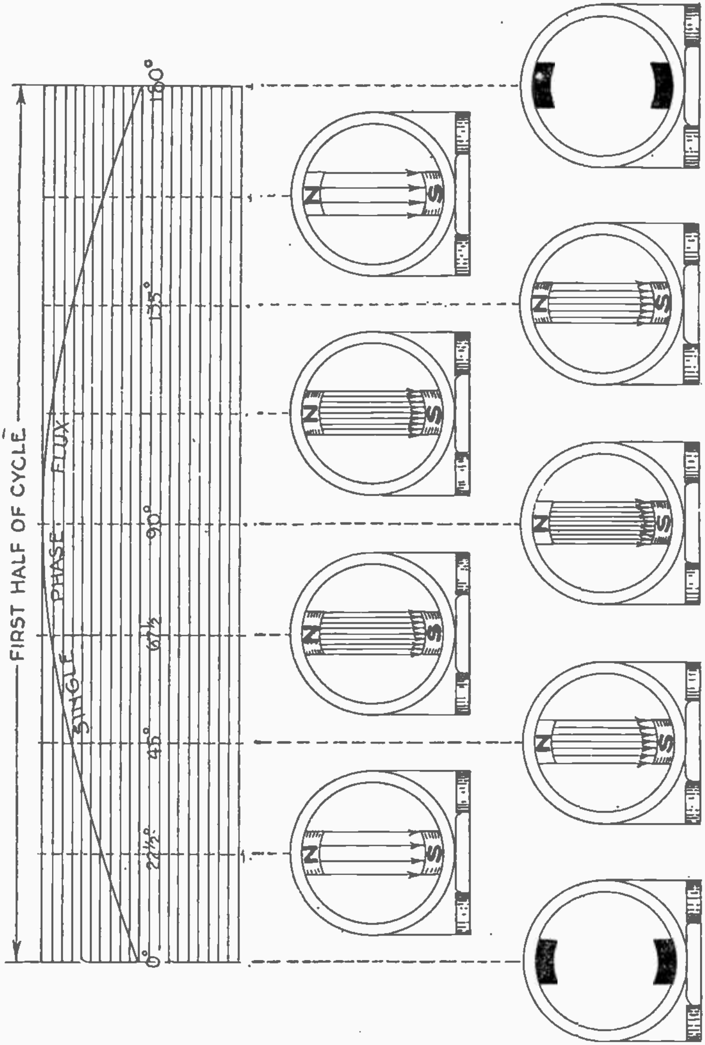


FIGS. 2,820 to 2,823.—Four ways in which the phase can be split for starting split phase motors. Fig. 2,820, non-inductive shunt resistance; fig. 2,821, shunt condenser; fig. 2,822, series condenser; fig. 2,823, series condenser with transformer.

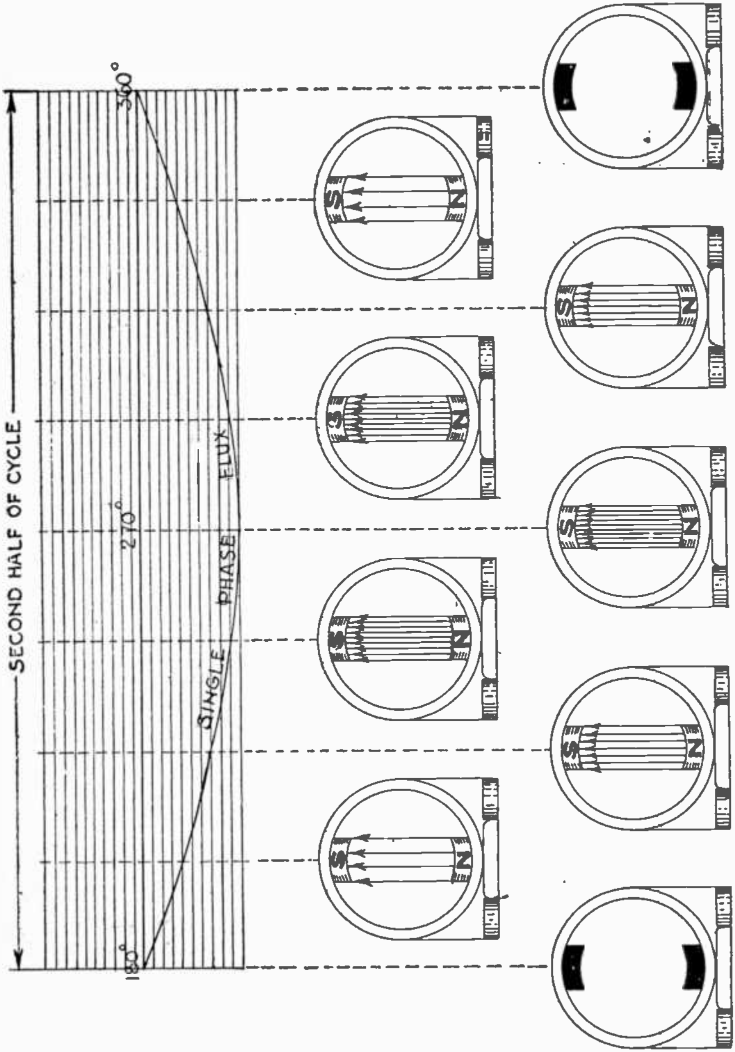
Since the torque for starting motors of this type is obtained by splitting the phase, they are generally known as *split phase* motors.

Phase Splitting.—There are several methods of splitting the

NOTE.—A single phase motor may also be started 1, *manually*, as by giving it a very rapid twist by hand, or 2, *mechanically*, as by aid of an auxiliary motor or other external starter. Accordingly: 1, starting *by hand* is not practical and 2, starting *mechanically* involves unnecessary complications; expense and space.



Figs. 2,824 to 2,833.—Sine curve of single phase current and diagrams showing physical conception of a *reciprocating magnetic field; first half of cycle.* The alternating magnetizing current is assumed to be of such strength that at its maximum strength the field produced may be represented by 10 lines of force as indicated by the parallel lines.



FIGS. 2,834 to 2,843.—Sine curve of single phase current and diagrams showing physical conception of a *reciprocating magnetic field; second half of cycle.*

phase to start single phase motors, as by providing in addition to the main single phase or running winding

1. A starting winding, or
2. Shading coils.

Practically all small single phase induction motors are started by means of a split phase starting winding.

The starting winding is placed in slots at 90 electrical degrees from the main winding. Split phase means that *the main winding and the starting winding are so proportioned that their respective currents are out of phase*, the object being to produce a so called rotating field similar to that in a polyphase motor, as shown in figs. 2.824 to 2,843.

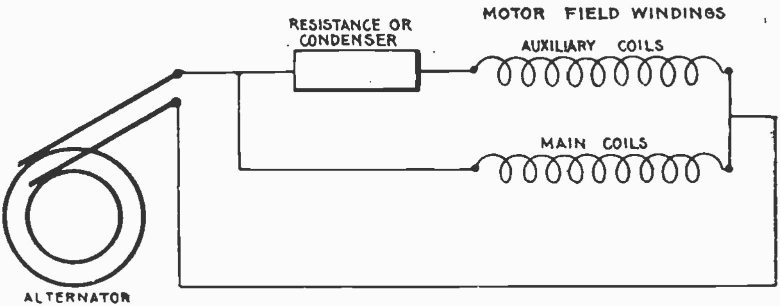
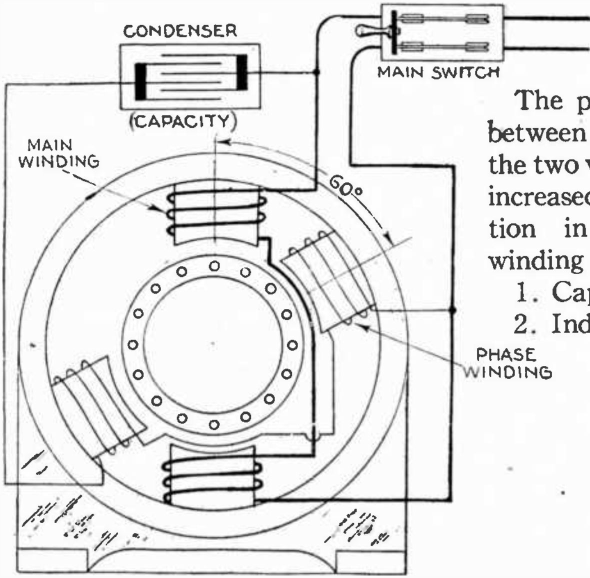


Fig. 2,844.—Simplified diagram showing the principle of phase splitting for starting single phase induction motors. By the use of an auxiliary set of coils connected in parallel with the main coils and having in series a resistance or condenser as shown, the single phase current delivered by the alternator is "split" into two phases, which are employed to produce a rotating field on which the motor is started.

In order to keep the copper loss in the main winding low, the largest possible wire should be used in this winding. The remaining slot space available for the starting winding is, therefore, limited.

The starting winding usually consists of a relatively small number of turns of fine wire. This gives a high resistance and low reactance and the current is nearly in phase with the applied voltage.

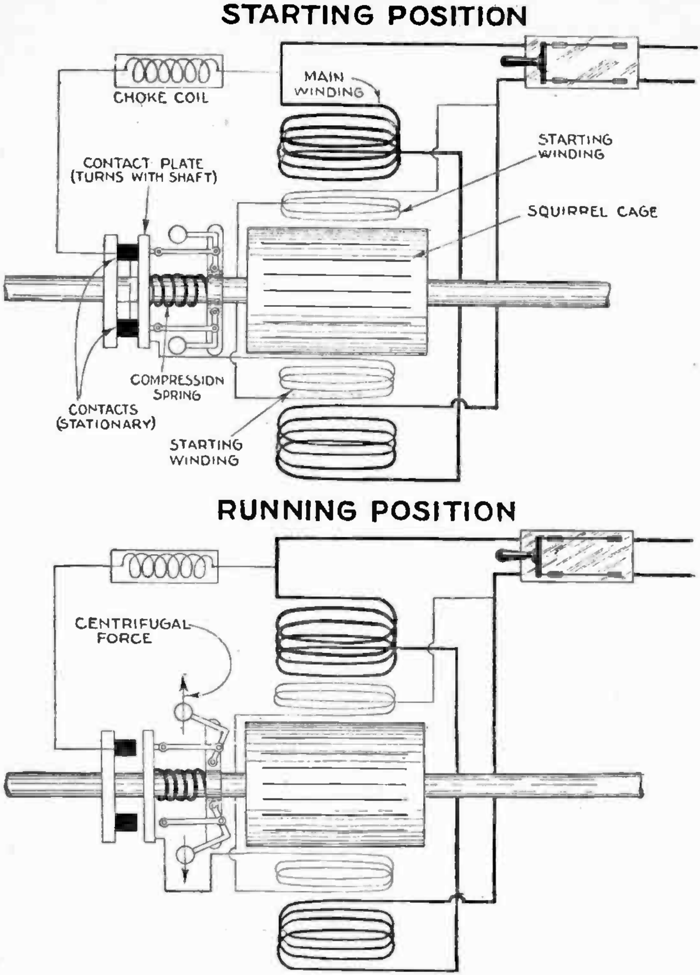
In the ordinary split phase motor, the current in the starting winding is usually 25° to 30° ahead of the current in the main winding. This time phase difference in the currents, combined with the 90° difference in space phase, gives a so called *elliptical magnetic field* which would be a rotating magnetic field if the fields set up by the two windings were 90° apart in time and of the same strength.



The phase difference between the currents in the two windings can be increased by the insertion in the starting winding circuit of

1. Capacity, or
2. Inductance.

Fig. 2,845.—Elementary split phase induction motor *with cut out switch* for application requiring only low starting torque the phase splitting (starting) winding being proportioned to stand the line voltage continuously. Phase difference is here obtained by the use of a condenser. The application of this type is limited. Where the phase coils are to remain in circuit during the *running* period as above, they should be placed physically in phase relation with the current traversing them, *because:* All motors, in operation, generate a *reverse pressure*. This reverse pressure will be in phase with the actual physical phase position of the coils on the motor, that is, if the phase coils be placed say at 90° from the running coils, the reverse pressure will be at 90°. Now, if the phase coils be placed at 90° (as in fig. 2,848) and they be fed with a current that is displaced say 60°, there will be a phase displacement of the remaining 30° between the coils and the actuating voltage. In other words the reverse voltage and the line voltage will be 30° out of phase with each other, resulting in a heavy so called idle current flowing which according to P. E. Chapman, will promptly heat up the phase coils, throw a load on the rotor and slow it down just as a load on its pulley would, and making trouble in general. Hence, the phase coils should be placed to correspond with the phase of the current then traversing them.



FIGS. 2,846 and 2,847.—Elementary split phase induction motor *with cut out switch.* Fig. 2,846, cut out switch closed at start; starting winding in circuit; fig. 2,847, motor speeded up to point where centrifugal force acting on governor weights has overcome the tension of spring and opened switch cutting out starting winding.

If only low starting torque and pull up torque be required, the starting winding can be so designed that it will stand line voltage continuously, and both main and starting windings may be connected to the line during the period of operation of the motor, as shown in fig. 2,845.

To obtain sufficient starting torque and pull up torque requires high current density in the starting winding, and some means must be provided for opening the starting winding circuit when the motor has reached a speed at which the torque, due to the main field, is sufficient to bring the load up to speed.

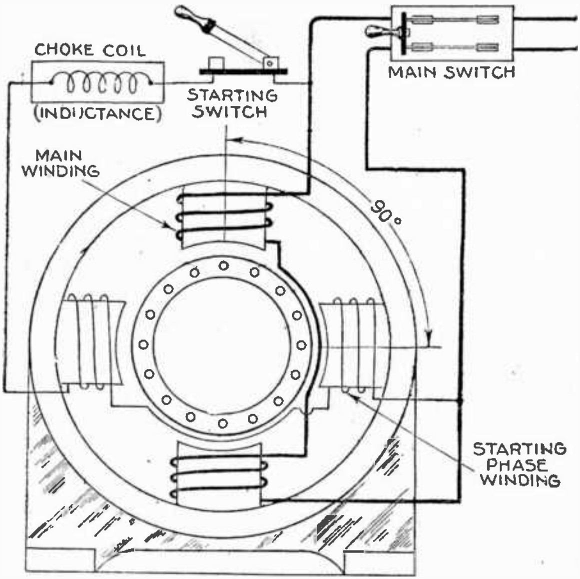


FIG. 2,848.—Elementary split phase induction motor with choke coil method of increasing the phase difference between the current in the starting and running windings. Here a hand operated switch for cutting out the starting winding is shown in place of an automatic cut out switch. *Note:* In motors having phase coils in circuit only during the starting period, they are placed at 90° with the running coils of main winding because with this displacement a better starting torque is secured, and since the phase coils are cut out at about ¾ speed, the reverse pressure (increasing from zero during acceleration) does not result in sufficient "idle current" as to cause undue heating. *In practice* the starting switch is automatically operated as elsewhere explained.

NOTE.—*For simplicity* concentrated coils are shown in the diagrams, however, *in practice* distributed coils are used.

Since the motor must reach a certain speed before its main winding develops sufficient torque, the logical way to open the starting winding is by means of a ***centrifugally operated cut out switch*** as shown in figs. 2,846 and 2,847.

The starting torque of a split phase motor is usually from one and one-half to two times full load torque, while the starting current is considerably greater than the full load current.

Another method of starting small split phase motors which gives low starting torque is by means of a *shading coil*.

The usual construction of a shading coil motor is to surround part of each field pole with a strap of copper which is a closed loop as shown in fig. 2,852. This means that the flux which threads the shading coil lags in time phase behind the flux in the unshaded part of the pole and the

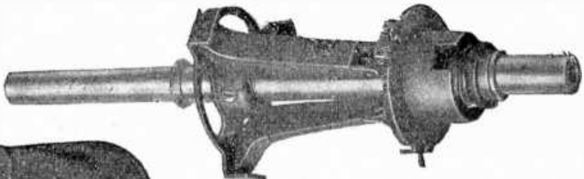


FIG. 2,849.—Century split phase induction motor governor weights which operate cut out switch.

FIG. 2,850.—Century split phase induction motor cut out switch. It is adjusted for a predetermined speed. The governor fig. 2,849 which actuates the cut out is positive in action and opens the starting or phase coil circuit with a rapid break of silver contacts

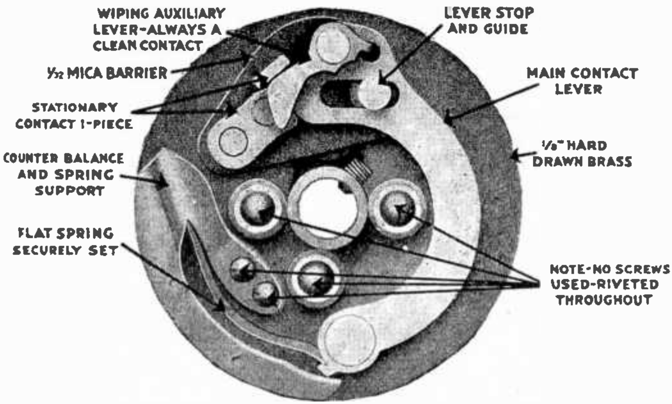


FIG. 2,851.—Janette split phase induction motor cut out switch for making and breaking the starting circuit. There is an auxiliary contact which gives a wiping effect both in opening and closing the switch. Obviously the contact points are always clean.

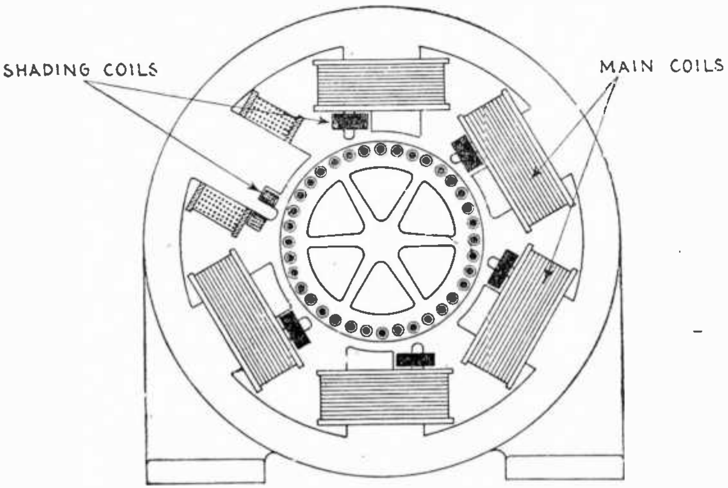


FIG. 2,852.—Single phase fan motor with *shading coils* for starting. In addition to the main field coils, one tip of each pole piece is surrounded by a short circuited coil of wire or frame of copper, as indicated in the figure. This coil, or copper frame, is called a *shading coil* and it causes a phase difference between the pulsating flux that emanates from the main portion of each polar projection and the pulsating flux which emanates from the pole tip, thus introducing an approach to two phase action on the armature.

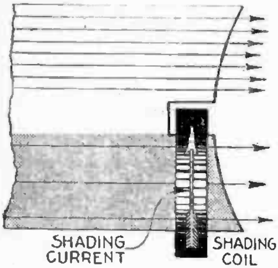
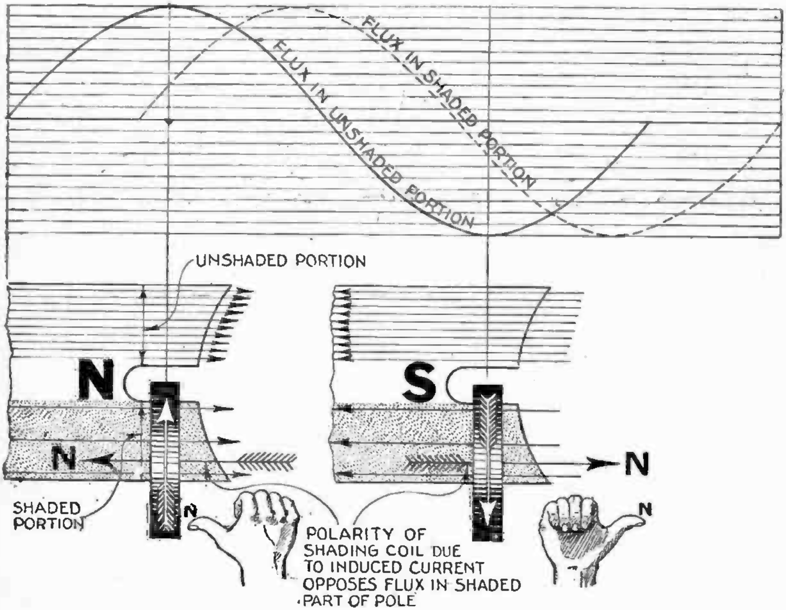


FIG. 2,853.—Diagram showing action of shading coil in alternating current motor. The extremities of these pole pieces are divided into two branches, in one of which a copper ring called a *shading coil* is placed as shown, while the other is left *unshaded*. The action of the shading coil is as follows: Consider the field poles to be energized by single phase current and assume the current to be flowing in a direction to make a north pole at the top. *Assume* the poles to be just at the point of forming. Lines of force will tend to pass through the shading coil and the remainder of the pole. Any change of lines within the shading coil generates a voltage, which causes to flow through the coil a current of a value depending on the voltage, and always in a direction to oppose the change of lines. The field flux is, therefore, partly shifted to the free portion of the pole, while the accumulation of lines through the shading coil is retarded.

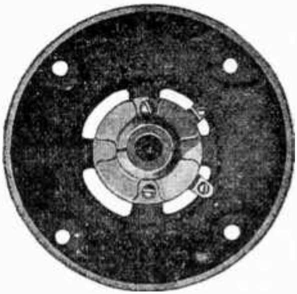


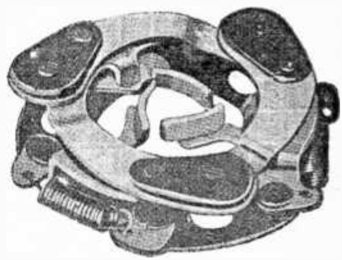
FIGS. 2,854 and 2,855.—Diagrams illustrating why the flux in the shaded portion of the pole lags behind that in the unshaded portion. When the alternating flux passes through the pole it induces a current in the shading coil which, according to Lenz' law, *tends to oppose the flux in the shaded portion which produces it*. The result is that the flux in the "unshaded" portion of the pole, attains its maximum sooner than does the flux in the "shaded" portion.

magnetic field tends to move from the unshaded part of the pole toward the shaded part of the pole.

The direction of rotation of a motor with a shading coil cannot be reversed by any change in the leads, and the motor has the disadvantage that the shading coil is active when the motor is running at full speed and causes additional loss.

The starting torque is inherently low, but is sufficient for most fan motors since the starting torque of a fan motor, under ordinary conditions, need be only great enough to overcome static friction.





FIGS. 2,856 and 2,857.—Domestic split phase induction motor split phase cut out switch. Fig. 2,856, stationary part; fig. 2,857, rotating part. It is of the quick acting type. The stationary part, mounted on one end bracket, is made of a split brass ring assembled on an insulating ring with clips and screws for attaching the leads from the starting winding. The rotating part consists of three contact fingers operated by three auxiliary weights, the entire part interlocking so that the contacts are thrown from the stationary ring simultaneously.

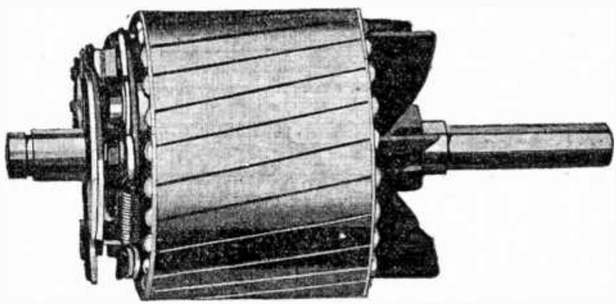
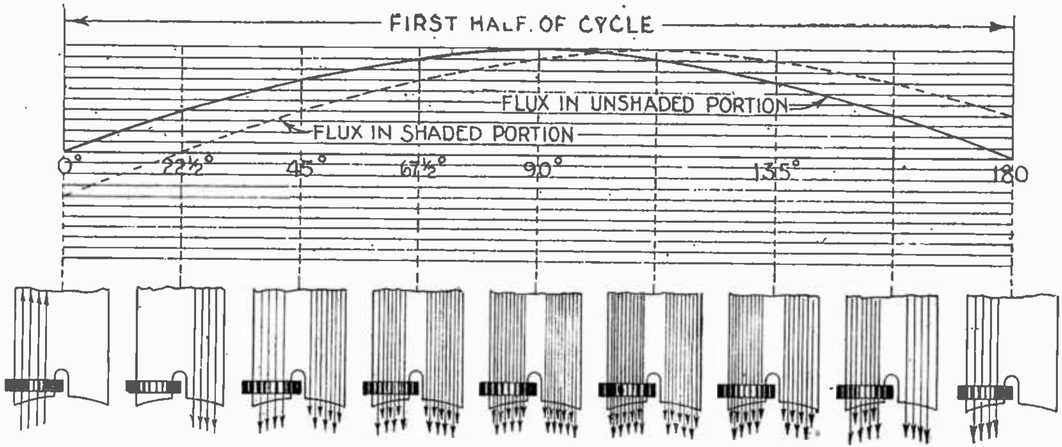


FIG. 2,858.—Domestic split phase induction motor armature complete.



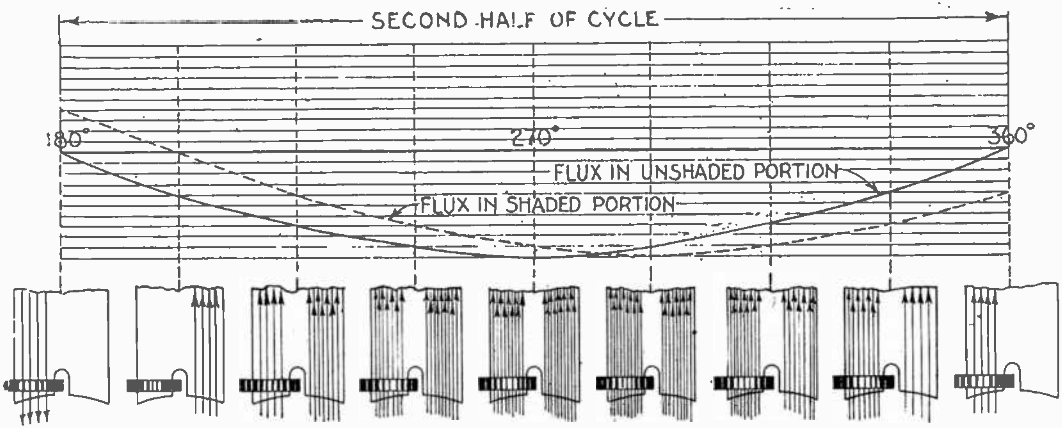
FIGS. 2,859 to 2,868.—Sine curves representing variation of flux in the unshaded and shaded portions of the field of a shading coil type single phase induction motor; first half of cycle. For illustration the lag due to shading coil is assumed to be 22½°.

On account of the disadvantages just mentioned the shading coil method of starting is used only in very small motors and is becoming obsolete.

Ques. How is the plain squirrel cage armature modified to enable the motor to start with a heavier load?

Ans. An automatic clutch is provided which allows the armature to turn free on the shaft until it accelerates almost to running speed.

This type motor is known as the *clutch type* of single phase induction motor. In operation when

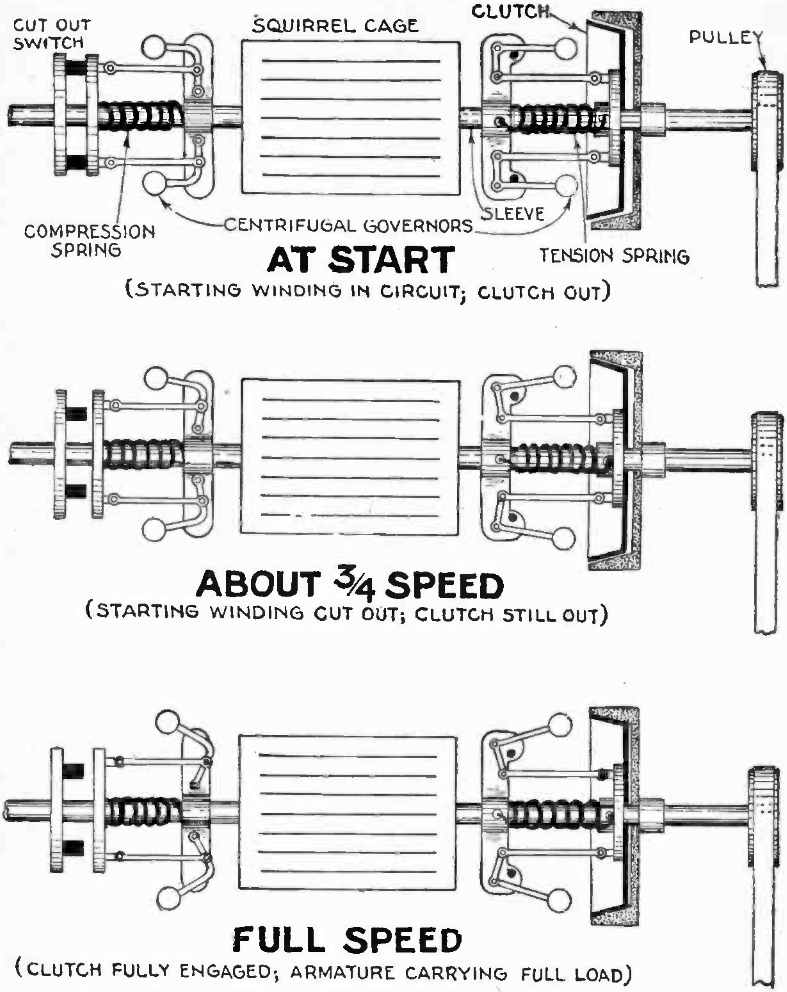


FIGS. 2,869 to 2,878.—Sine curves representing variation of flux in the unshaded and shaded portions of the field of a shading coil type single phase induction motor; second half of cycle.

the circuit is closed, the armature starts to revolve upon the shaft; when it reaches a predetermined speed, a centrifugal clutch expands and engages the clutch disc, which is fastened to the shaft.

Ques. Explain in detail the action of the clutch type of motor in starting.

Ans. It can start a load which requires much more than full load torque at starting, because the motor being nearly up to full speed, has available not only its maximum overload capacity, but also the momentum of the armature to overcome



FIGS. 2,879 to 2,881.—Elementary split phase induction motor *with cut out switch and clutch,* showing working of these automatic devices; the windings are not shown. Fig. 2,879 at start; 2,880, about ¾ speed; fig. 2,881, full speed.

the inertia of the driven apparatus. In this it is assisted by a certain amount of slippage in the clutch, which is the case when the armature speed is pulled down to such a point as to reduce the grip of the centrifugal clutch.

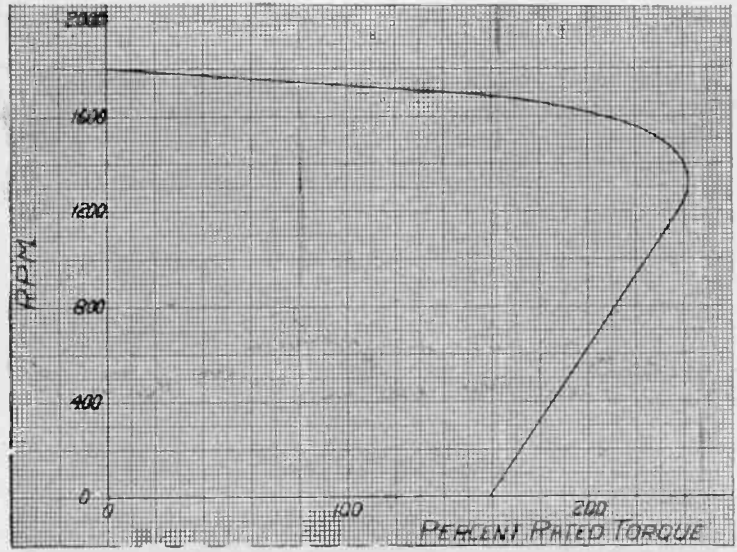


FIG. 2,882.—Domestic split phase induction motor speed torque curve. Operation and characteristics. The speed of an induction motor depends upon the number of poles of the motor and the frequency of the current upon which it is operated. This is why only certain definite speeds are obtainable. The speed changes very slightly from no load to full load, and even at a heavy overload the speed reduction is comparatively slight. Since the speed changes only slightly from no load to full load the induction type is commonly known as a constant speed motor. It is impossible to build a variable speed split phase type motor, without complicating the construction.

Reversing Split Phase Motors.—A single phase motor will operate equally well in either direction, and the direction in which it will start depends upon the direction in which the resultant magnetic field tends to rotate.

If the armature be free to move, it will always rotate in the same direction as the magnetic field.

If the motor be connected for one direction of rotation, it may be made to start in the opposite direction by reversing either winding with respect to the other winding.

Some Characteristics of Split Phase Motors.—With its armature at rest, a single phase induction motor is equivalent

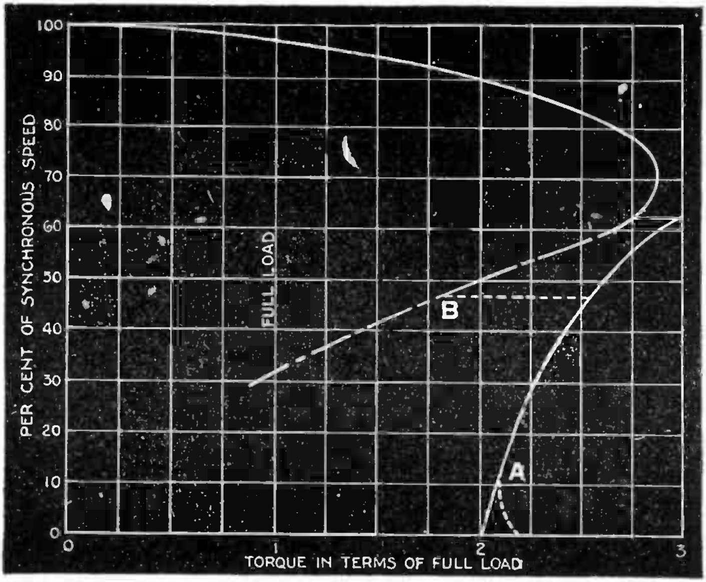


FIG. 2,883.—Speed torque curve of split phase induction motor. The pull up torque is the greatest load torque the motor will pull through and go on up to speed, that is, it is the lowest torque point on the motor curve below pull out. In the above curve it coincides with the starting torque; if the motor had a higher starting torque, as shown dotted, the pull up torque would be at A; or if the centrifugal switch opened below its best operating speed, as shown by the horizontal dotted line, the pull up torque would occur at B.

to a transformer with large air gap with its secondary short circuited. This accounts for the high starting current of this type of motor.

As soon as the secondary begins to turn, a rotational voltage is produced in the secondary. The axis of this voltage is at 90° to the axis of the main field flux. The maximum rotational voltage coincides in time with the maximum of the main field flux. The reactance for the axis of the rotational voltage is high and the current, therefore, lags nearly 90° behind the voltage. The quadrature field produced by this current is in space quadrature and very nearly in time quadrature with the main field. At speeds close to synchronism, the two fields are very nearly of the same strength and approximately a uniform so called rotating field results.

The speed torque characteristics of the main and starting windings combined is shown in fig. 2,883.

As will be seen from the curve, the torque increases with the speed until

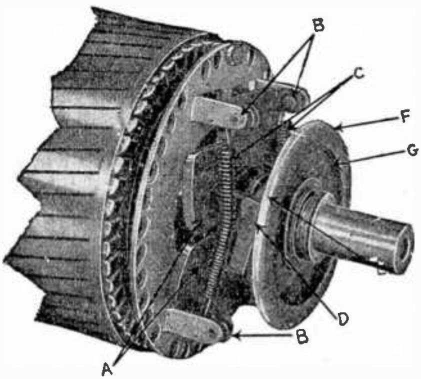


FIG. 2,884.—Wagner split phase induction motor switch mechanism showing construction.

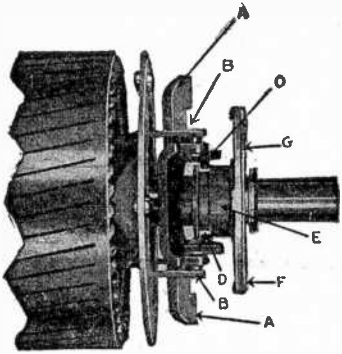
the maximum torque point is reached, thus giving rapid acceleration, and insuring that the motor will bring up to speed any load it will start.

In a polyphase induction motor, changing the armature resistance does not change the value of maximum torque but simply changes the speed at which the maximum torque point occurs.

Adding resistance to the armature of a single phase induction motor not only increases its slip, but also decreases its maximum torque.

For small changes in voltage the speed is practically independent of the voltage.

This means that in cases of low voltage the motor will continue to carry



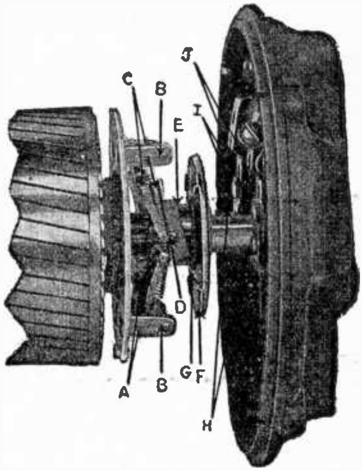
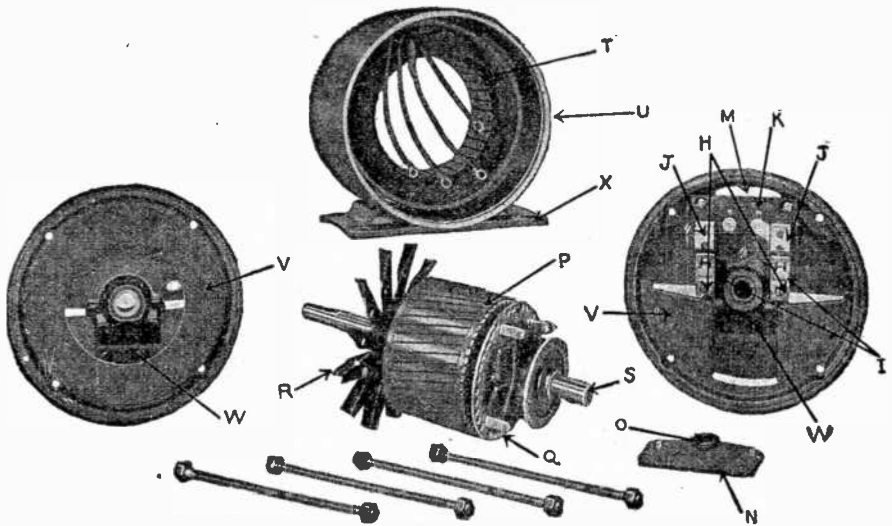


FIG. 2,885.—Wagner split phase induction motor switch mechanism; side view.

FIG. 2,886.—Wagner split phase induction motor switch mechanism with plate in exaggerated position to show construction.

NOTE.—***Parts of Wagner split phase induction motor*** corresponding to the reference letters in the accompanying illustrations. ***The parts are:*** A, governor weights; B, governor weight mounting pins; C, coil springs; D, pivot pins; E, disc collar; F, contact ring; G, bakelite disc; H, contact fingers; I, contact stops; J, contact finger mounting; K, terminal mounting; L, terminal studs; M, terminal opening; N, terminal cover plate; O, terminal bushing; P, dynamically balanced armature; Q, balancing flange; R, fan; S, shaft; T, core; U, frame; V, end plates; W, wool yarn lubrication; X, base.

NOTE.—***Construction and operation*** of Wagner split phase induction motor, in accompanying illustrations. Two stationary contact fingers H, a rotating ring F, and two simple governor weights A, make up the split phase cut out switch. At normal or starting position, the contact ring F, is in contact with the two fingers H. This completes the starting circuit. As the motor gains speed, centrifugal force causes the governor weights A, to swing toward the armature, overcoming the tension strength of the coil spring C. The movement of the governor weights is translated to the ring through pivot pins D.



FIGS. 2,887 to 2,895.—Exploded view of Wagner split phase induction motor showing construction.

its load at approximately full speed, but with increased current and consequently with increased heating.

At rated voltage, the motor will usually deliver about two and one-half times its rated output for a short time. Under this condition of overload the losses are excessive and the temperature rise will be sufficient in a short time to damage the winding.

The normal rating of a single phase motor is usually about one-half that of a polyphase motor of the same dimensions.

For the same output as a polyphase motor, the single phase motor requires more iron and therefore, has more iron loss. In addition the field winding of a single phase induction motor carries the magnetizing current for both the main and quadrature fields and this current is about twice as large as the magnetizing current in one phase of a two phase motor.

The power factor of a single phase motor is less than the power factor of a polyphase motor of the same speed and rating, due to the fact that the single phase motor has more iron to be magnetized, and to the fact that the ratio of the magnetizing current to the power current in the field of a single phase motor is greater than the ratio of the same currents in a polyphase motor.

The efficiency of a single phase motor is lower than that of a polyphase motor of the same rating, since the losses of a single phase motor are inherently greater than those of a polyphase motor.

Since most of the motors which drive household appliances are operated from lighting circuits, the high starting current is objectionable, because any lights being operated from the same circuit will flicker each time a motor is started. This has caused several of the larger power companies to make rules to the effect that single phase motors which require more than 15 amperes starting current may not be operated from their lighting circuits when the motors drive devices which must be frequently started.

Probably the largest application of the small split phase induction motor is on washing machines, which are not classed as frequently starting devices. A one fourth *h.p.* motor is usually used on washing machines. Other applications are wringers, ironing machines, oil burners, player pianos, ventilating fans, refrigerators, coffee grinders, meat choppers, grinders, compressors and general utility motors.

TEST QUESTIONS

1. *For what services are single phase induction motors used?*
2. *What other name is given to single phase induction motors?*
3. *Has a split phase motor any starting torque?*
4. *What is the usual method of starting a split phase motor?*
5. *Define the term "splitting the phase."*
6. *Describe the method generally used for "splitting the phase."*
7. *What is a shading coil?*
8. *What is the objection to the use of shading coils?*
9. *What two methods are generally used to increase the phase difference in splitting the phase?*
10. *Describe the induction method and the capacity method of splitting the phase.*
11. *How is the starting winding cut out of circuit when the motor comes to speed?*
12. *Describe a centrifugal cut out switch.*
13. *What is a centrifugal clutch used for?*
14. *How are split phase motors reversed?*
15. *Give some characteristics of split phase motors.*
16. *How does the torque vary with increase of speed?*
17. *What is the effect of adding resistance to the armature of a split phase motor?*

18. *How does the normal rating of a split phase motor compare with that of a polyphase motor?*

19. *How does a power factor of a single phase motor compare with that of a polyphase motor?*

20. *Why is high starting current objectionable specially in split phase motors?*

CHAPTER 60

Commutator Motors

1. Series and Shunt Motors

By definition a commutator motor is *a motor driven by alternating currents, carrying a commutator upon its armature.* There are numerous types of commutator motors and they may be classed as

1. Series
   a. Single phase
   b. Universal
2. Neutralized series
   a. Conductively
   b. Inductively
3. Shunt
   a. Simple
   b. Compensated.
4. Repulsion
   (sometimes called *inductive series*)
   a. Straight
   b. Compensated
5. Repulsion start-induction
   a. Brush lifting
   b. Short circuiting
6. Repulsion-induction
7. Induction-synchronous

Of these numerous types some are of importance commercially and some only of interest theoretically.

In general, commutator motors are similar in construction to direct current motors in that they have a closed coil winding which is connected to a commutator.

Since, as stated, commutator motors are similar to direct current motors, the question may be asked: Is it possible to run a direct current motor with alternating current? If the mains leading to a direct current motor be reversed, the direction of rotation remains the same, because the currents through both the field magnets and armature are reversed. It must follow then that an alternating current applied to a direct current motor would cause rotation of the armature.

In order to understand the working of commutator motors, first, there should be considered the inductive effects due to operation in an alternating current field as outlined in the explanation following:

Action of Closed Coil Rotating in Alternating Field.—When a closed coil rotates in an alternating field, there are several different pressures set up and in order to carefully distinguish between them, they may be called:

1. The transformer pressure;
2. The generated pressure;
3. The self-induction pressure.

These pressures may be defined as follows:

The transformer pressure *is that pressure induced in the armature by the alternating flux from the field magnets.*

For instance, assuming in fig. 2,896 the armature to be at rest, as the alternating current which energizes the magnets rises and falls in value, the variations of flux which threads through the coils of the ring winding, induce pressure in them in just the same way that pressure is induced in the secondary of a transformer.

A ring winding is used for simplicity; the same conditions obtain in a drum winding.

The generated pressure is that pressure *induced in the armature by the cutting of the flux when the armature rotates.*

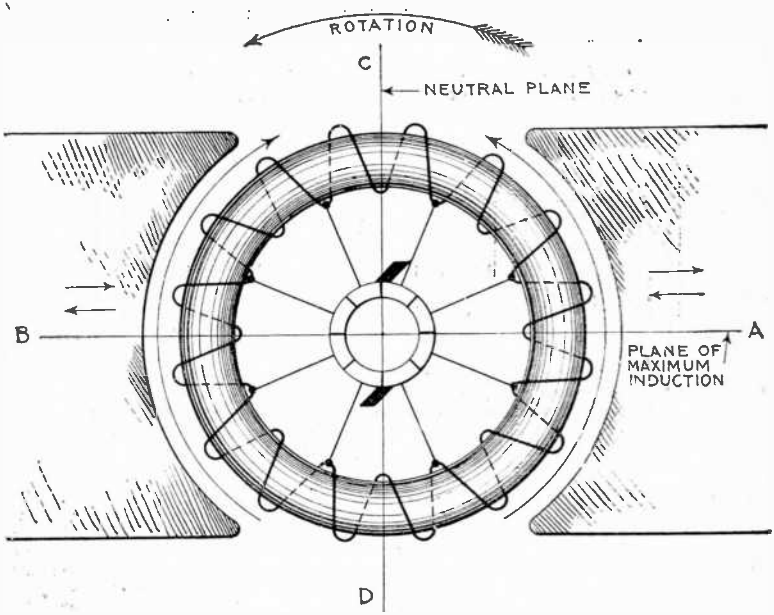


FIG. 2,896.—Diagram of ring armature in alternating field illustrating the principles of commutator motors.

The self-induction pressure *is that pressure induced in both the field and armature by self-induction.*

Nature of the Generated Pressure.—In fig. 2,896, the generated pressure induced by the rotation of the armature is minimum at the neutral plane C D, and maximum at A B. It tends to cause current to flow up each half of the armature from D, to C, producing poles at these points.

Nature of the Transformer Pressure.—This is caused by variations of the flux passing through each coil of the armature winding. Evidently this variation is least at the plane A B, because at this point the coils are inclined very acutely to the flux, and greatest at the plane C D, where the coils are perpendicular to the flux. Accordingly, the transformer pressure induced in the armature winding is least at A B and greatest at C D.

The transformer pressure acts in the same direction as the generated pressure as indicated by the long arrows and gives rise to what may be called *local armature currents*.

Nature of the Self-Induction Pressure.—The self-induction pressure, being opposite in direction to the impressed pressure, it must be

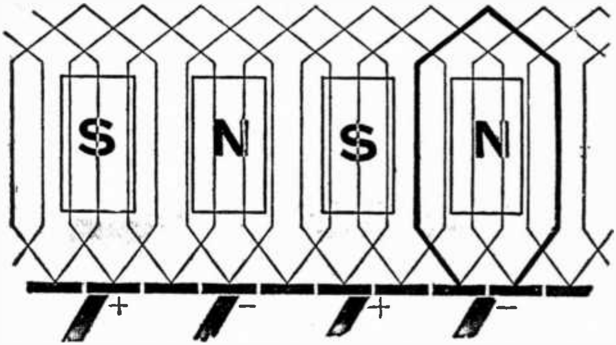


FIG. 2,897.—Detail of winding and commutator illustrating local armature circuits. The serious difficulty encountered in attempting to operate a *d.c.* series motor with *a.c.* is the excessive sparking at the brushes. Whenever a brush touches two commutator bars, an armature coil or section is short circuited; at the moment of this short circuit the armature coil surrounds a field pole as shown by the heavy line, so that the armature coil is related to the field winding as the short circuited secondary coil of a transformer of which the primary coil is the field winding. Therefore an excessive short circuit current is produced through the armature coil and through the tip of the brush. The result is an increased heating of the armature coils, commutator, and brushes, and an excessive sparking at the brush tips as the commutator bars pass from under the brushes.

evident that in the operation of an alternating current commutator motor, the impressed pressure must overcome not only the generated pressure but also the self-induction pressure. Hence, as compared to an equivalent direct current motor, the applied voltage must be greater than in the direct current machine, to produce an equal current.

The Local Armature Currents.—These currents produced by the transformer pressure occur in these coils undergoing commutation. They are large, because the maximum transformer action occurs in them, that is, in the coils short circuited by the brushes.

Ques. Why do the local armature currents cause sparking?

Ans. Because of the sudden interruption of the large volume of current, and also because the flux set up by the local currents being in opposition to the field flux, tends to weaken the field just when and where its greatest strength is required for commutation.

Ques. What is the strength of the local currents?

Ans. They may be from 5 to 15 times the strength of the normal armature current.

Ques. Upon what do the local armature currents depend?

Ans. Upon the number of turns of the short circuited coils, their resistance, and the frequency.

Ques. How can the local currents be reduced to avoid heavy sparking?

Ans. 1, By reducing the number of turns of the short circuited coils, that is, providing a greater number of commutator bars; 2, reducing the frequency; and 3, increasing the resistance of the short circuited coil circuit: *a*, by means of high resistance connectors; or *b*, by using brushes of higher resistance.

Ques. What are high resistance connectors?

Ans. The connectors between the armature winding and the commutator bars, as shown in fig. 2,898.

Ques. Does the added resistance of preventive leads, or high resistance brushes, materially reduce the efficiency of the machine?

Ans. Not to any great extent, because it is very small in comparison with the resistance of the whole armature winding.

Ques. What is the objection to reducing the number of

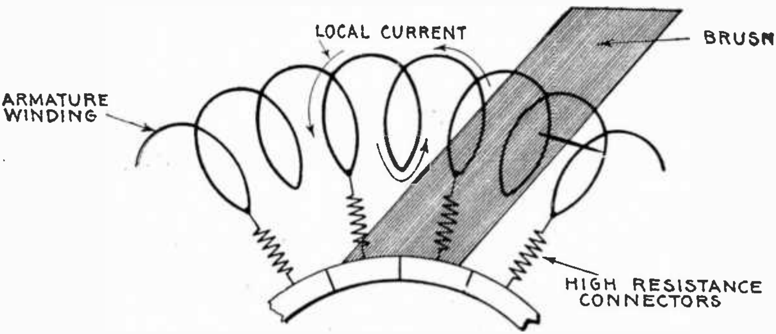


FIG. 2,898.—Section of ring armature of commutator motor showing local current set up by transformer action of the alternating flux, and high resistance connectors to prevent sparking at the brushes.

turns of the short circuited coils to diminish the tendency to sparking?

Ans. The cost of the additional number of commutator bars and connectors as well as the added mechanism.

Ques. What effect has the inductance of the field and armature on the power factor?

Ans. It produces phase difference between the current and impressed pressure resulting in a low power factor.

Ques. What is the effect of this low power factor?

Ans. The regulation and efficiency of the system is impaired.

The frequency, the field flux and the number of turns in the winding have influence on the power factor.

Ques. How does the frequency affect the power factor?

Ans. Lowering the frequency tends to improve the power factor.

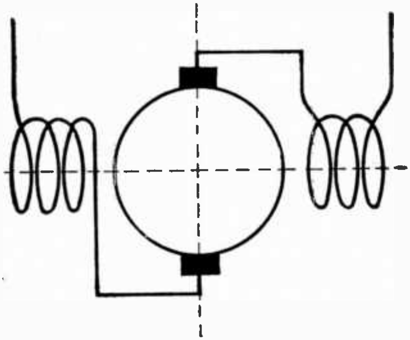
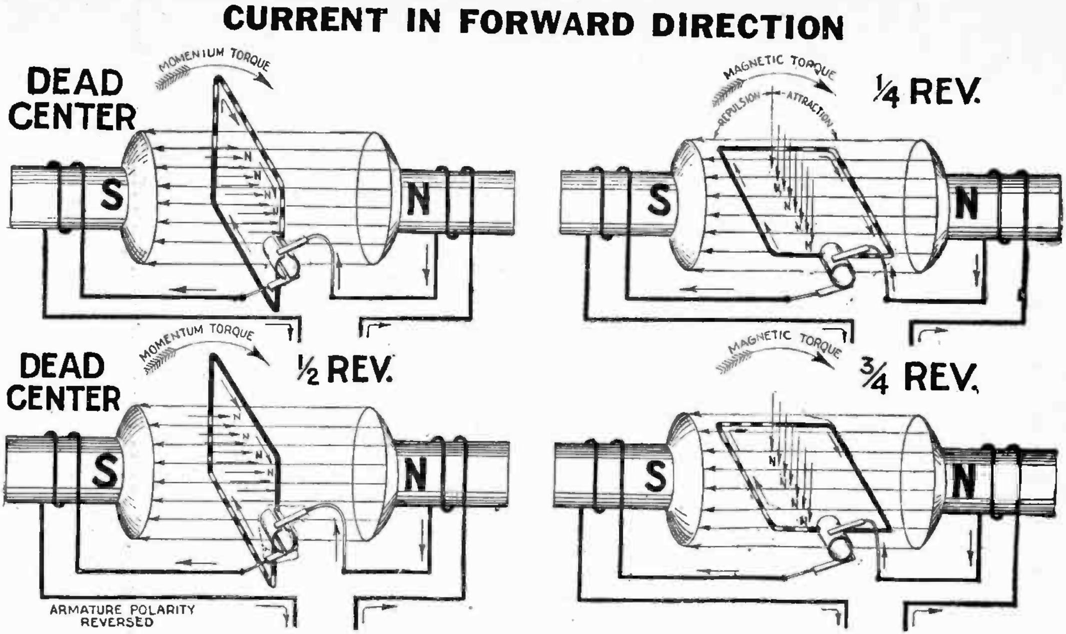


FIG. 2,899.—Diagram of single phase series commutator motor. It is practically the same as the series direct current motor, with the exception that all the metal of the magnetic circuit must be laminated.

The use of very low frequencies has the disadvantage of departing from standard frequencies, and the probability that the greater cost of transformers and alternators would offset the gain.

Series Motors.—This class of commutator motor is about the simplest of the several types belonging to this division. In general design, the series motor is identical with the series direct current motor, but all the iron of the magnetic circuit must be laminated and a *neutralizing winding* is often employed.

It will be readily understood that the torque is produced in the same

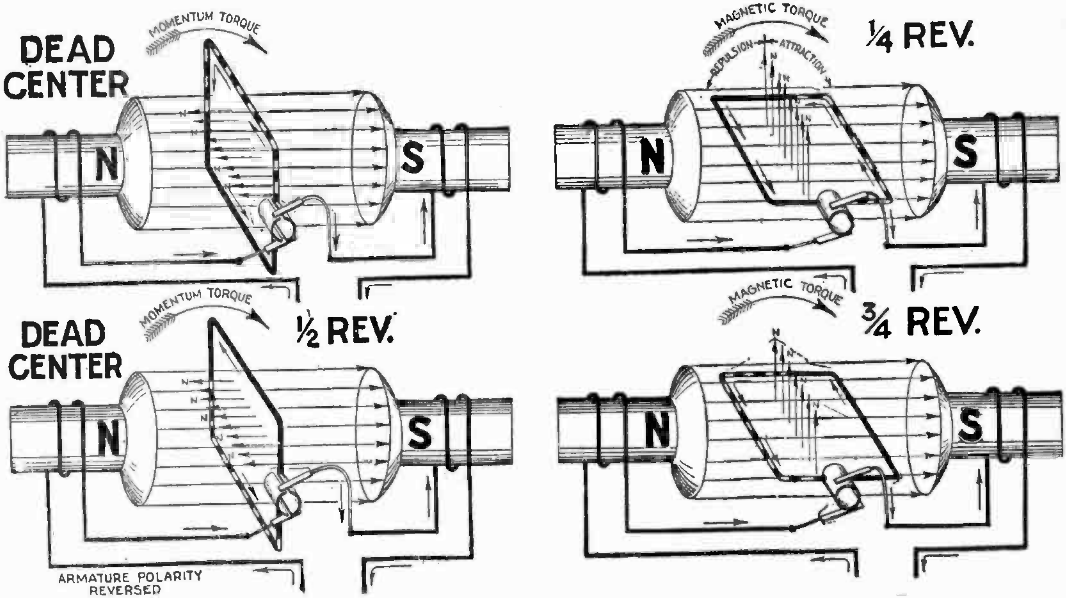


FIGS. 2,900 to 2,907.—*How an a.c. series (commutator) motor works;* diagrams showing that if the current be reversed, the motor will continue rotating in the same direction because the currents through both the field magnets and armature are

way as in the direct current machine, when it is remembered that the direction of rotation of the direct current series motor is independent of the direction of the voltage applied.

At any moment the torque will be proportional to the product of the current and the flux

CURRENT IN REVERSE DIRECTION



FIGS. 2,900 to 2,907.—Text continued. *It must follow* then that *an alternating current applied to a direct current motor would cause rotation of the armature* reversed. Figs. 2,900 to 2,903, cycle with current in *positive* direction; figs. 2,904 to 2,907, cycle with current in *negative* or reverse direction.

which it is at that moment producing in the magnetic system, and the average torque will be the product of the average current and the average flux it produces, so that if the iron parts be unsaturated, as they must be if the iron losses be not too high, *the* *torque will be proportional simply to the square of the current*, there being no question of power factor entering into the consideration.

Ques. What are the characteristics of the series motor?

Ans. They are similar to those of the direct current series motor, the torque being a maximum at starting and decreasing as the speed increases.

Ques. For what service is the series motor especially suited?

Ans. On account of its powerful starting torque it is particularly desirable for traction service.

Neutralized or Compensated Series Motor.—A chief defect of the series motor is the excessive self-induction of the armature, hence in almost every modern single phase series motor a neutralizing coil is employed *to diminish the armature self-induction.*

The neutralizing coil is wound upon the frame 90 magnetic degrees or half a pole pitch from the field winding and arranged to carry a current equal in magnetic pressure and opposite in phase to the current in the armature.

The current through the neutralizing winding may be obtained, either

1. Conductively; or
2. Inductively.

In the conductive method, fig. 2,908, the winding is connected in series as shown and is a better arrangement than the inductive method.

In the inductive method, fig. 2,909, the winding is short circuited upon itself and the current obtained inductively, the neutralizing winding being virtually the secondary of a transformer, of which the armature is the primary. In this method the winding is liable to heat and burn out.

Universal Motors.—The term *universal* as applied to motors means *a motor so designed that it will operate on either direct or alternating current.*

Since the alternating current series motor has the same general characteristics as the direct current series motor, it is possible

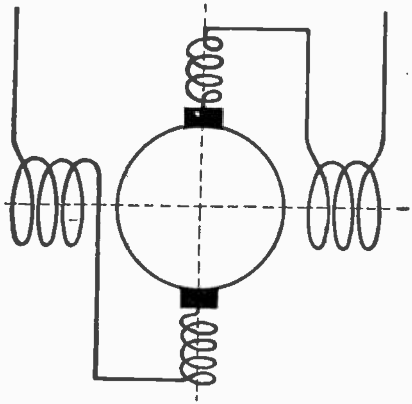


FIG. 2,908.—Diagram of neutralized series motor; ***conductive method.*** In the simple series motor, there will be a distortion of the flux as in the direct current motor. As the distorting magnetic pressure is in phase with that of the magnets, the distortion of the flux will be a fixed effect. If the poles be definite as in direct current machines, this distortion may not seriously affect the running of the motor, but with a magnetizing system like that universally adopted in induction motors the flux will be shifted as a whole in the direction of the distortion, which will produce the same effect as if in the former case the brushes had been shifted forward, whereas for good commutation they should have been shifted backward. As in direct current machines, this distortion is undesirable since it is not conducive to sparkless working, and also reduces to a more or less extent the torque exerted by the motor. The simplest remedy is to provide *neutralizing coils* displaced 90 magnetic degrees to the main field coils as shown. The neutralizing current is obtained by the method of connecting the neutralizing coils in series in the main circuit.

by a careful compromise of design features to build series motors that can operate on either direct current or alternating current circuits of substantially the same voltage.

Motors of this type are used to a small extent for household appliances, such as desk fans, portable vacuum cleaners, hair driers, etc. As a rule, the universal motor has a lower efficiency and is more troublesome in operation than either the direct current series motor or the alternating current series motor. Universal motors are built almost invariably in small sizes only.

In modifying the design of a *d.c.* series motor so that it will operate satisfactorily on either *d.c.* or *a.c.*

1. All the magnetic circuits must be laminated.

To prevent excessive hysteresis and eddy current losses.

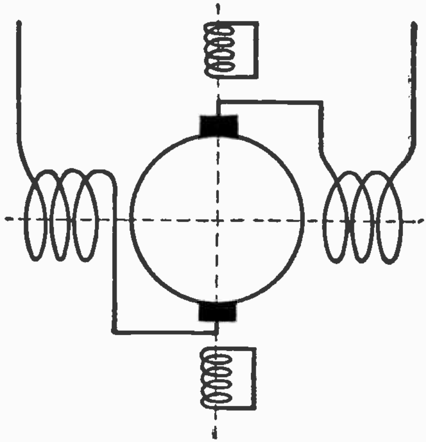


FIG. 2,909.—Diagram of neutralized series motor; ***inductive method.*** Although the conductive method of neutralization is employed in nearly all machines, it is possible merely to short circuit the neutralizing winding upon itself, instead of connecting it in series with the armature circuit. In this case the flux due to the armature circuit cannot be eliminated altogether, as sufficient flux must always remain to produce enough pressure to balance that due to the residual impedance of the neutralizing coil. It would be a mistake to infer, however, that on this account this method of neutralization is less effective than the conductive one, since the residual flux simply serves to transfer to the armature circuit a drop in pressure precisely equivalent to that due to the resistance and local self-induction of the neutralizing coil in the conductive method.

2. Number of commutator bars must be increased.

To reduce the number of turns of the short circuited coils.

3. Resistance of the short circuited coil circuit must be increased.

Reducing the Inductance.—The inductance of the field is reduced by reducing the number of turns per pole. In order that this may be done, and still, without excessive current, produce the total flux needed to develop the required torque, the reluctance of the magnetic circuit is reduced to a minimum.

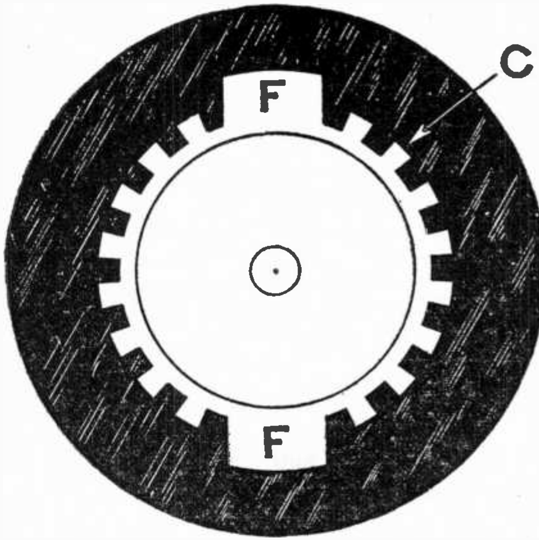


FIG. 2,910.—Core stamping for two pole *a.c.* commutator motor. The field winding in single phase motors is usually a concentrated or massed winding; but instead of being placed on poles which are separated by a considerable distance as in the direct current motor, it is placed in large slots in the laminæ, the large slots F, holding the field winding, and the small slots C, the neutralizing or compensating winding. This latter winding is distributively wound like the stator coils of the induction motor.

This is done by increasing the air gap section per pole by using the arrangement indicated in fig. 2,910. By reducing the air gap length to the minimum mechanically permissible; and by using laminated steel of good magnetic quality for the magnetic circuits. This last change also reduces the core loss and eddy current loss.

To reduce the inductance of the armature winding, a stationary neutralizing or compensating winding is placed in slots in the pole faces (slots C, fig. 2,910) and so connected in series that the main current flows through it in the opposite direction to the current in the armature winding.

By using additional turns in this winding (over compensation) the same effect is produced under running conditions, as is produced in the direct current motor by using inter-poles; that is, due to the rotation of the armature conductors through the flux produced by over compensation, a voltage is produced in the coils undergoing commutation which tends to reverse the load current in these coils and thus improve the commutation.

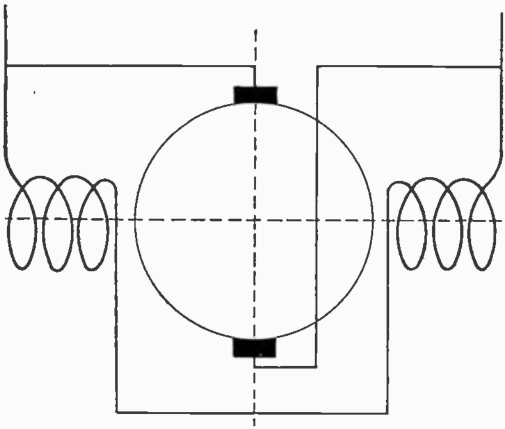


FIG. 2,911.—Diagram of simple shunt commutator motor. Owing to its many inherent defects it is of little importance.

As for the voltage induced in the commutated coils by the alternating main field flux, there is at starting no practical way to prevent this in the single phase series motor.

This voltage is proportional to the frequency of the supply system, to the flux per pole, and to the number of turns between commutator bars under the brushes. It is therefore desirable to have 1, low frequency; 2, many poles; 3, many commutator bars; and 4, thin brushes.

Another feature which has been used to some extent is to make the leads which connect the armature winding to the commutator bars of material of comparatively high resistance

The short circuit current during commutation must then flow through this resistance and is thereby limited to a reasonable amount and the sparking reduced.

Under running conditions, a reverse voltage opposed to the voltage induced in the commutated coils by the alternating main flux, may be generated by supplying a component of flux which lags 90° behind the

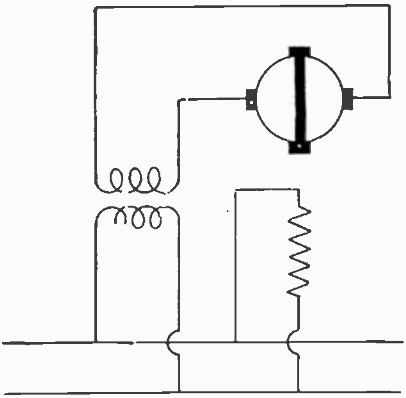


FIG. 2,912.—Compensated shunt induction single phase motor. The transformer shown in the arrangement is capable of being replaced by a coil placed on the frame having the same axis as the field winding, so that the flux produced by the field winding induces in the coil a pressure in phase with the supply pressure. Such a coil will now be at right angles to the circuit to which it is connected. In a similar manner, a coil at right angles to the armature circuit, that is, the circuit parallel to the stator axis, if connected in series with that circuit, will also serve to compensate the motor.

main flux in time and also 90 electrical degrees in space. Such a component may be supplied by connecting a portion of the compensating winding to a voltage in phase with the supply voltage. A transformer is necessary in order to accomplish this, but in most cases one is used anyway.

Shunt Motors.—The simple shunt motor has inherently many properties which render it unsuitable for practical use, and accordingly is of little importance. Owing to the many turns of the field winding there is large inductance in the shunt field circuit.

The inductance of the armature is small as compared with that of the field; accordingly, the two currents differ considerably in phase.

The phase difference between the field and armature currents and the corresponding relation between the respective fluxes results in a weak torque.

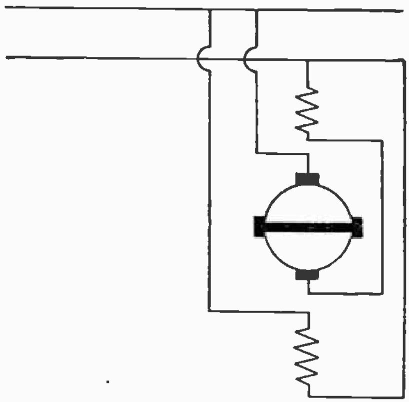


FIG. 2,913.—Fynn's shunt conductive single phase motor. In order to supply along the stator axis a constant field, suitable for producing the cross flux to which the torque is due by its action on the circuit perpendicular to the stator axis, the "armature circuit," as it may be called, has a neutralizing coil in series with it, so that the armature circuit and neutralizing coil together produce no flux. In addition to this, there is a magnetizing coil along the same axis, which is connected across the mains and so produces the same flux as the primary coil in a shunt induction machine. Fynn has proposed a number of methods of varying the speed and compensating this machine. It is, however, complicated in itself, and is only suited for very low voltages, so that on ordinary circuits it would need a separate transformer.

It is necessary to use laminated construction in the field circuit to avoid eddy currents, which otherwise would be excessive. Fig. 2,911 is a diagram of a simple shunt commutator motor.

TEST QUESTIONS

1. *What is understood by the term "commutator motors"?*
2. *Give a classification of commutator motors.*
3. *Explain the action of a closed coil rotating in an alternating field.*

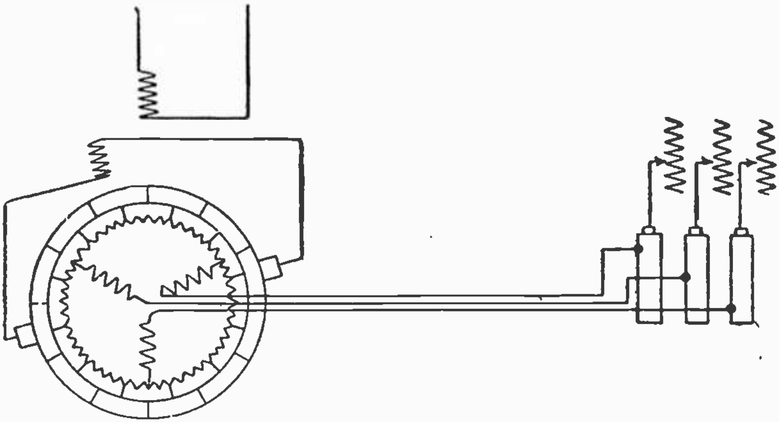


FIG. 2,914.—Fynn's compensated shunt induction motor. This is a combination of the compensated shunt induction motor with the ordinary squirrel cage form. In one form, in addition to the ordinary drum winding on the armature, there is another three phase winding into the "star," of which the drum winding is connected. This second winding is connected to three slip rings which are short circuited when the machine is up to speed. Upon the commutator are placed a pair of brushes connected to an auxiliary winding placed on the frame in such a position that the flux from the primary coil induces in it a pressure of suitable phase to produce compensation. The same pair of brushes is also used for starting.

4. *Distinguish between transformer, generated, and self-induction pressures.*
5. *What is the nature of the three pressures?*
6. *Where do local armature currents occur?*
7. *How can the local armature currents be reduced to avoid heavy sparking?*

8. *What are high resistance connectors?*
9. *What effect has the inductance of the field and armature on the power factor?*
10. *How does the frequency affect the power factor?*
11. *Describe a series a.c. motor.*
12. *What are the characteristics of a series motor?*
13. *What is a neutralized or compensating motor?*
14. *Explain the conductive and inductive methods of obtaining current through the neutralizing winding.*
15. *What is a "universal" motor?*
16. *How is a motor designed so that it will operate on either d.c. or a.c.?*
17. *Explain how the inductance is reduced.*
18. *Describe a simple shunt a.c. motor.*
19. *Draw diagrams of 1, Fynn's shunt conductive single phase motor, and 2, Fynn's compensated shunt induction motor.*

CHAPTER 61

Commutator Motors

2. Repulsion Types

Repulsion Motors.—In the course of his observations on the effects of alternating currents, in 1886-7, Elihu Thomson observed that a copper ring placed in an alternating magnetic field tends either to move out of the field, that is, it is *repelled* by the field (hence the name **repulsion motor**), or to return so as to set itself edgeways to the magnetic lines.

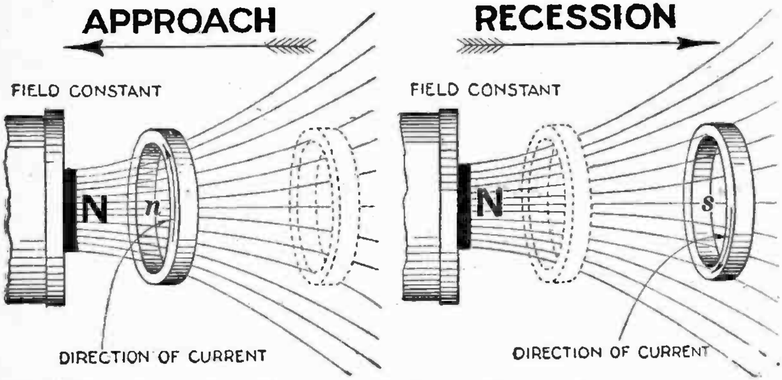
There are several types of motors which operate entirely or partly on the repulsion principle and they may be classified as:

1. Straight repulsion
2. Compensated repulsion
3. Repulsion start induction
4. Repulsion induction.

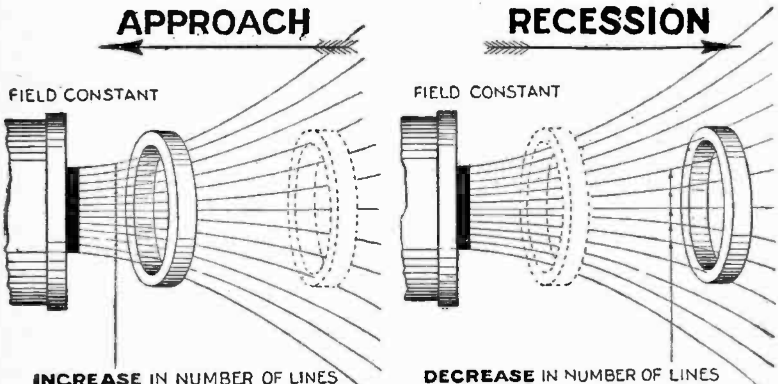
Basic Principles.—In order to understand the operation of repulsion motors the action of a copper ring placed in an alternating field should be noted as shown in the accompanying illustrated repulsion motor principles. The application of Lenz' law is of importance here. It is given as principle 3, figs. 2,919 and 2,920, and by its application the direction of the current induced in the ring is easily determined.

Thus, to determine the direction of the current induced in the ring in fig. 2,921, *the inductive effect of the increasing field is* **the same** *as though the ring were* **pushed** *toward the magnet in a constant field (d.c.) magnet* as in fig. 2,919.

Further, since according to Lenz' law, the inductive effect in the ring *is*

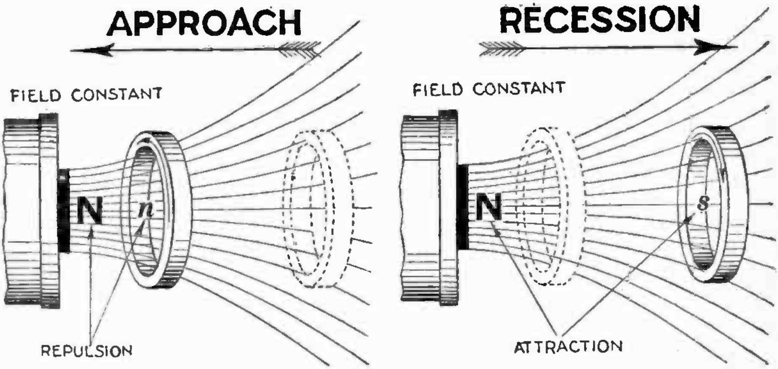


FIGS. 2,915 and 2,916.—*Repulsion motor principles 1. The approach or recession of a copper ring from a magnet pole will induce currents alternating in direction.*



FIGS. 2,917 and 2,918.—*Repulsion motor principles 2. The approach or recession of a copper ring from a magnet pole is respectively equivalent to an increase, or decrease in the number of lines of force which pass through the ring.*

such as ***to oppose*** *the motion which produces it*, the direction of the induced current will be such as to produce a *like* or *opposing* pole (to resist the



Figs. 2,919 and 2,920.—***Repulsion motor principles 3.*** **LENZ LAW:** *The approach or recession of a copper ring from a magnet pole induces a current in the ring in such direction as to set up a magnetic field which opposes the motion which produces it.*

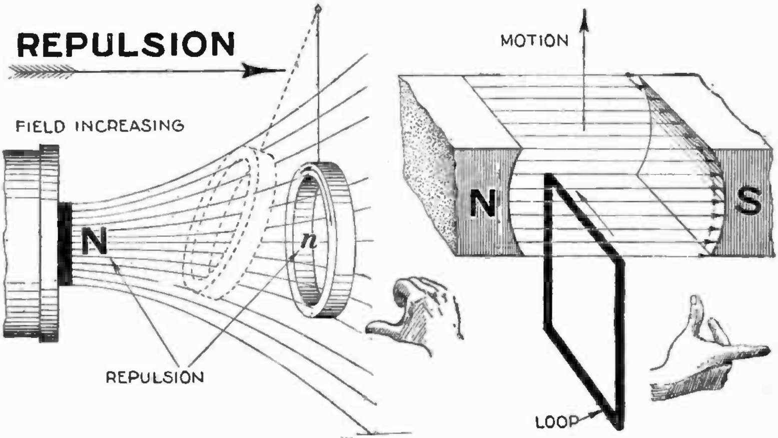


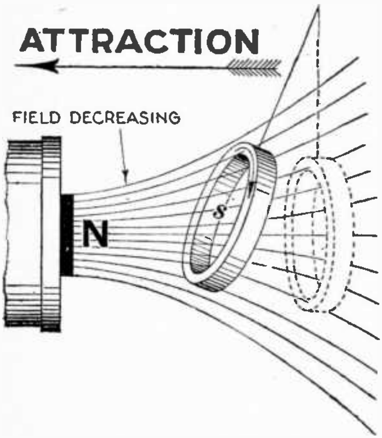
Fig. 2,921.—***Repulsion motor principles 4.*** *A copper ring is repelled from a magnet pole when the number of lines of force passing through the ring is* ***increasing.*** See fig. 2,919.

Fig. 2,922.—Closed loop moving across a magnetic field *so as to increase the number of lines passing through the loop with* application of the right hand rule to verify direction of current in the ring (fig. 2,921).

movement of the ring), as shown in fig. 2,919 the application of the right hand rule being given in fig. 2 922. ***Similarly, when the field is decreasing, as in fig.* 2,923, *the inductive effect is the same as though the ring were pulled away from the magnet in a constant field (d.c.) magnet as in fig.*** 2,920. Here the movement is opposed by *unlike* or attracting poles. Hence, in figs. 2,920 and 2,923, the direction of the induced current is such as to produce a S pole.

If the ring be pivoted, its motion is restricted to rotation. There are, however, positions in which there is no tendency to rotate the ring as:

1. When the plane of the ring is perpendicular to the axis of the magnet, and



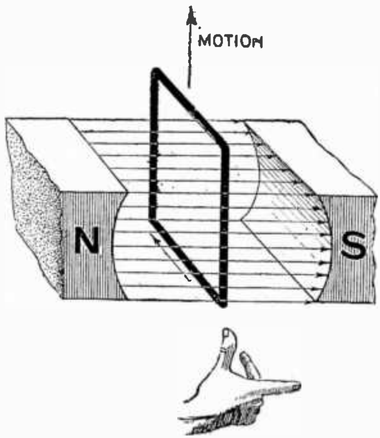


FIG. 2,923.—***Repulsion motor principles 5.*** *A copper ring is attracted to a magnet pole when the number of lines of force passing through the ring is* ***decreasing.*** See fig. 2,920.

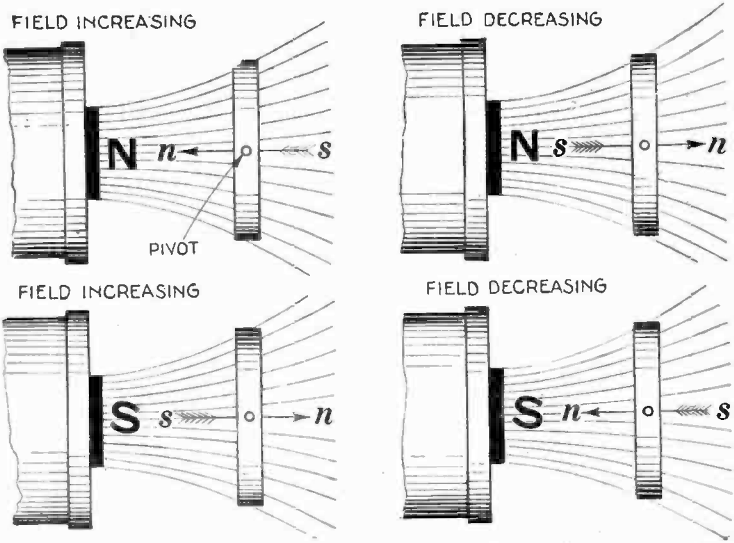
FIG. 2,924.—Closed loop moving across a magnetic field *so as to diminish the number of lines of force passing through the loop* with application of the right hand rule to verify the direction of current in the ring fig. 2,923.

2. When the plane of the ring is parallel with the axis of the magnet.

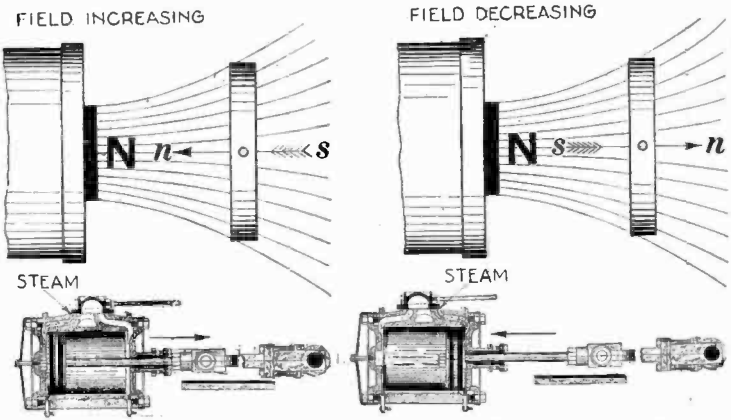
Figs. 2,925 to 2,928 illustrate the first case.

This corresponds in analogy to the so-called "dead centers" of a steam engine as in figs. 2,929 to 2,932. This must be obvious because there is no leverage.

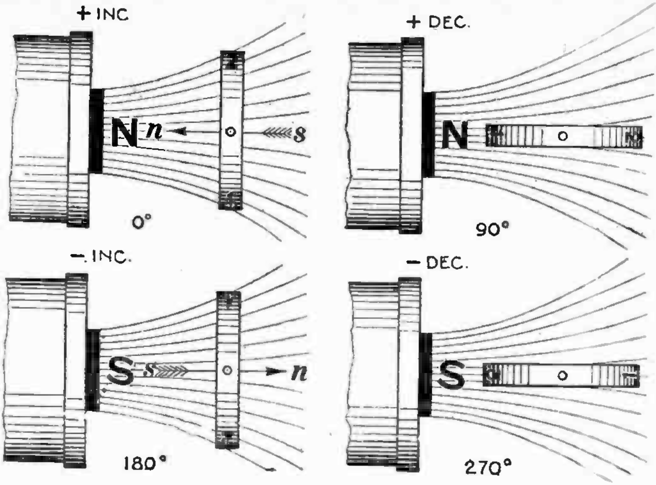
Again, when the coil is placed in the second position in which



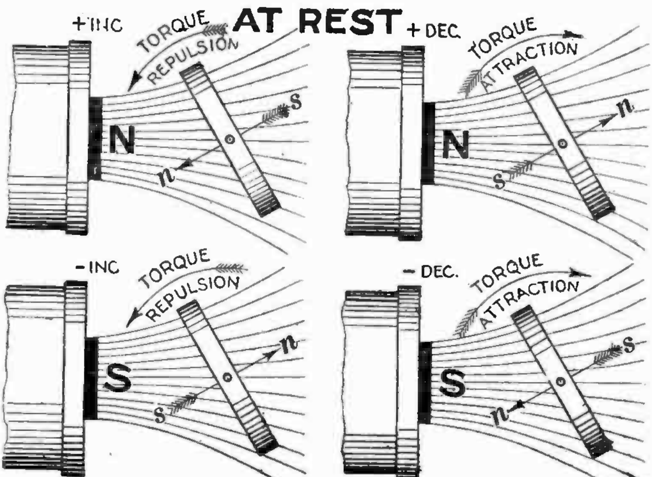
FIGS. 2,925 to 2,928.—*Repulsion motor principles 6. When the plane of a pivoted copper ring is at right angles to the axis of an a.c. magnet there is no tendency for the ring to turn.*



FIGS. 2,929 to 2,932.—Steam engine "dead center" analogy of results obtained with pivoted ring placed in *a.c.* field perpendicular to axis of the magnet—***no torque.***

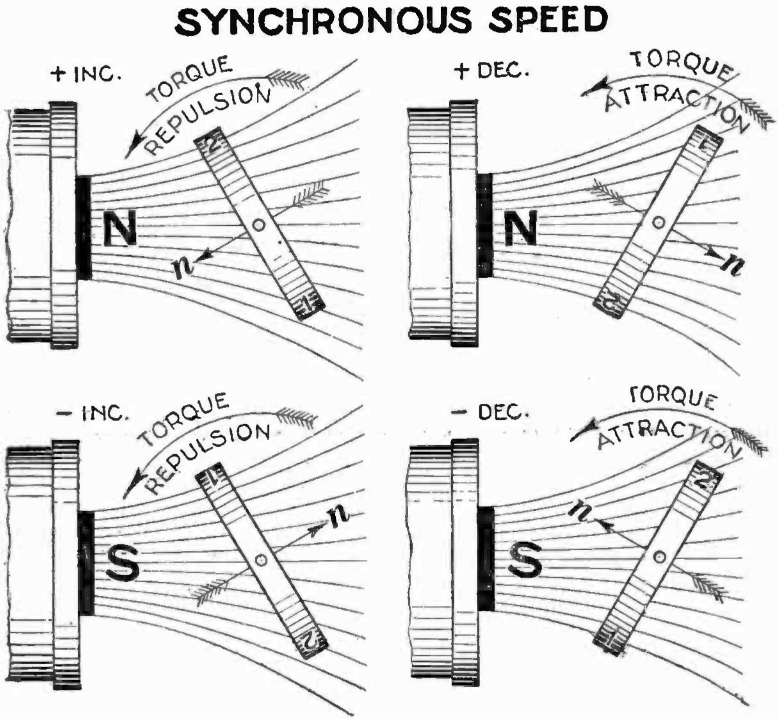


FIGS. 2,933 to 2,936.—*Repulsion motor principles 7.* *When a pivoted copper ring is placed in the field of an a.c. magnet, there are four positions in which no torque is produced.*



FIGS. 2,937 to 2 940.—***Repulsion motor principles 8.*** *When the plane of a pivoted copper ring at rest is oblique to the axis of an a.c. magnet, torque is produced by repulsion and attraction alternately,* ***no useful torque;*** ring vibrates.

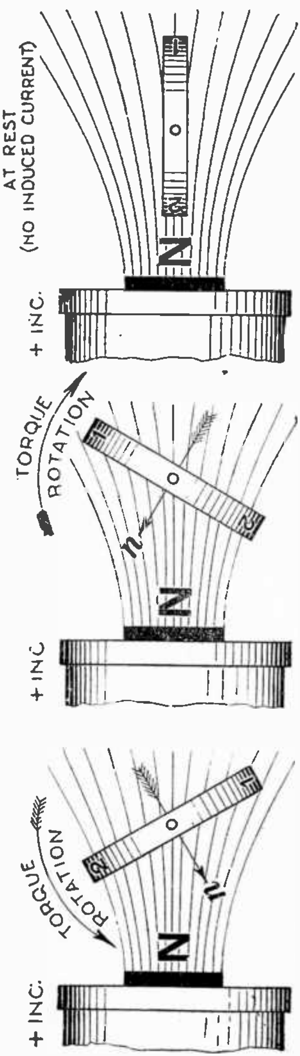
its plane is parallel with the axis of the magnet, no torque will be produced because no current is induced in the magnet, as shown in figs. 2,934 and 2,936; the same holds for increasing field.



Figs. 2,941 to 2,944.—*Repulsion motor principles 9. If a pivoted copper ring be brought up to synchronous speed in an a.c. field, rotation is produced by repulsion and attraction alternately.*

If, the plane of the coil be oblique to the magnet, torque is obtained as shown in figs. 2,937 to 2,940.

Now in fig. 2,937 before the torque there shown has time to overcome the inertia of the ring and cause it to rotate, the field flux, which was increasing, *begins* to decrease, and the torque is



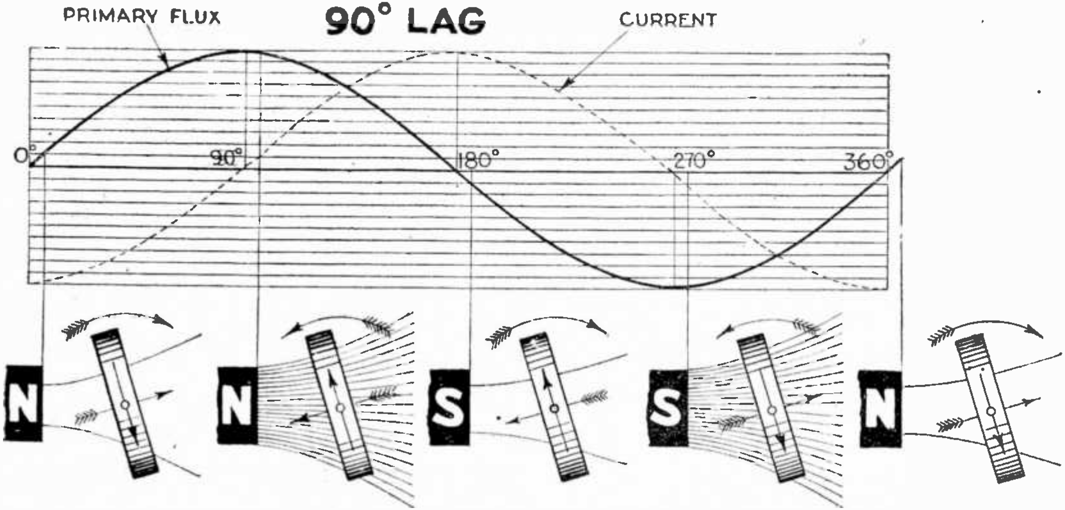
FIGS. 2,945 to 2,947.—**Repulsion motor principles 10.** *When a pivoted copper ring is placed in the field of an a.c. magnet obliquely it tends to set itself edgeways to the magnetic lines, while the flux is increasing (or decreasing).*

reversed as in fig. 2,938, thus causing the ring merely to vibrate instead of rotate. However, if the ring were brought up to synchronous speed, useful torque would be obtained, that is, the ring would rotate in synchronism with the alternation of the flux, figs. 2,941 to 2,944.

For simplicity the foregoing explanations were made assuming the induced current to be ***in phase*** *with the field flux.*

Now since the direction of voltage induced in the ring changes when the field flux changes from *increase* to *decrease* as shown in figs. 2,921 and 2,923 and from decrease to increase, *it will be 90° later in phase than the field flux and if the ring have no inductance the induced current will also be 90° later in phase than the field flux.*

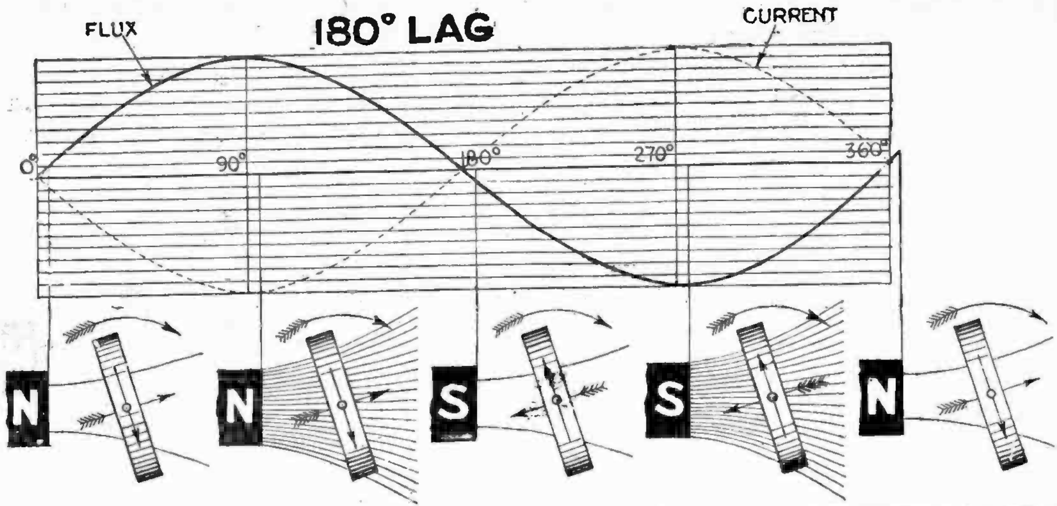
With a non-inductive ring, the torque would be alternating, resulting in no useful turning effect, as shown in figs. 2,948 to 2,953 (unless the ring were turning at synchronous speed).



FIGS. 2,948 to 2,953.—***Repulsion motor principles 11.*** *The current induced in a non-inductive metal ring placed in an a.c. field will be 90° later in phase than the primary flux.* The diagram shows flux and current curves for 90° lag, electrical conditions in the ring being illustrated for each 90° of the cycle.

Considering, in place of the ring, a coil of wire (as in the actual motor) it will contain some inductance so that the current in it will lag more than 90° behind the field flux.

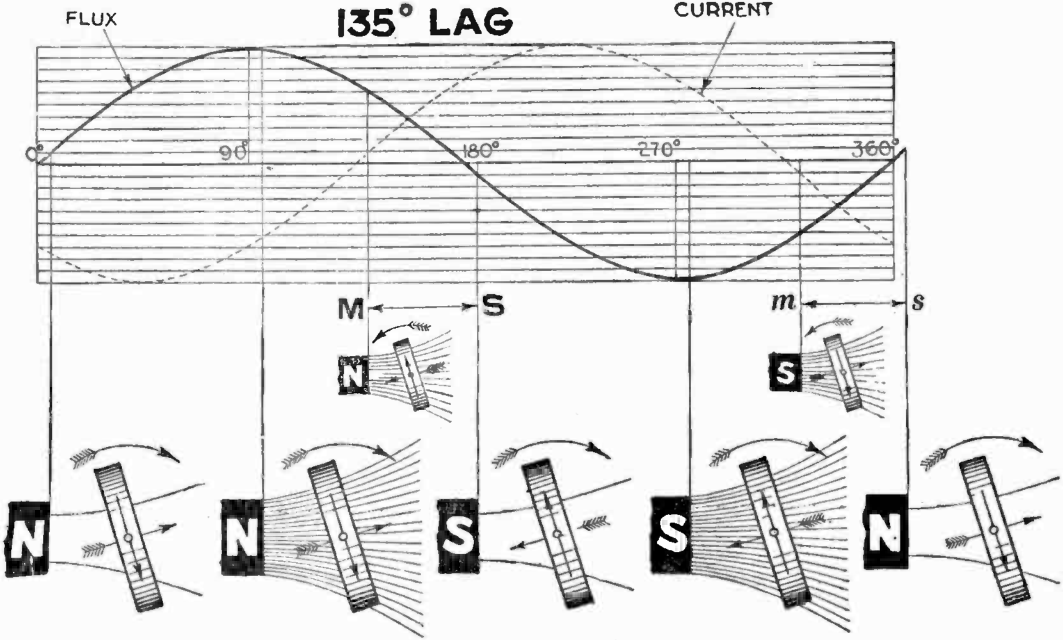
The maximum torque occurs theoretically if the induced current and field flux differs by 180° as in figs. 2,954 to 2,959. However, even to approximate this, requires the coil reactance to be very large with respect to its resistance. This condition implies



FIGS. 2,954 to 2,959.—*Repulsion motor principles 12. Theoretically the maximum torque occurs if the primary flux and current in the ring differ in phase by 180°.*

an extremely small current, so practically the maximum torque occurs when the coil has such impedance that the current induced in it lags somewhere between 90° and 180°, say about 135° with respect to the field flux as shown in figs. 2,960 to 2,967.

In figs. 2,954 to 2,959 for 180° lag, the torque is in the same direction during the entire cycle, but when the lag is less than 180° as in figs. 2,960 to 2,967, the direction of the torque is reversed during



FIGS. 2,960 to 2,967.—**Repulsion motor principles 13.** *Practically maximum torque occurs when the primary flux and current in the ring differ in phase by about 135°.*

certain portions of the cycle as during the intervals MS and *ms*., thus, the net torque while apparently less than for 180° lag, is greater as before stated because a larger current is flowing.

Straight Repulsion Motor.—This motor consists of single phase *a.c.* field and an armature similar to that used on *a.c.* series motors. There is no electrical connection between the field and armature, the brushes of the latter being short circuited.

This motor is a special type of single phase induction motor, because the currents in the armature are set up by the inductive action of the field and are not supplied from an outside source.

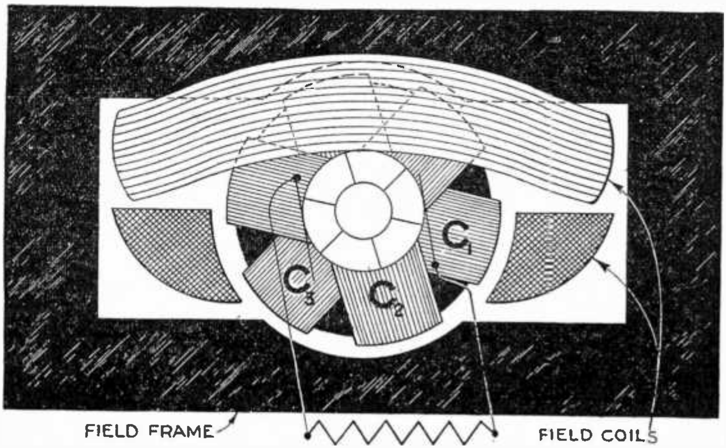


FIG. 2,968.—Early Thompson repulsion motor with open coils.

Elihu Thompson took an ordinary direct current armature, placed it in an alternating field, and having short circuited the brushes, placed them in an oblique position with respect to the direction of the field. The effect was to cause the armature to rotate with a considerable torque.

The inductors of the armature acted just as an obliquely placed ring, but with this difference, that the obliquity was continuously preserved by the brushes and commutator, notwithstanding that the armature turned, and thus the rotation was continuous. This tendency of an inductor to turn from an oblique position was thus utilized by him to get over the difficulty of starting a single phase motor. With this object in view he then constructed motors in which the use of commutator and brushes was restricted to the work of merely starting the armature, which when so started was then entirely short circuited on itself, though disconnected from the rest of the circuit, the operation then being solely on the induction principle.

Ques. What difficulty was experienced with Thomson's motor?

Ans. Since an open coil armature was used, the torque developed was due to only one coil at a time, which involved a necessarily high current in the short circuited coil resulting in heavy sparking.

Profs. Anthony, Ryan and Jackson appreciated the seriousness of this defect, and in 1888 suggested the use of a closed coil armature winding in place of the open coil type (U. S. patent 389,352 Sept. 1888). This resulted in a greatly increased power for a given weight, because the effective turns on the armature were augmented and a given current produced more torque, or a smaller current produced the same torque with less sparking.

On the other hand, sparking with this type of armature is due not only to reversal of current in the coil short circuited by the brush, as in *d.c.* machines, but also to transformer action.

Ques. Did the use of closed coils effectually stop sparking?

Ans. No.

Ques. What other means is employed in modern designs to reduce sparking?

Ans. Compensation and the use of a distributed field winding, high resistance connectors, high resistance brushes, etc.

In explaining the operation of the straight repulsion motor consider the drum armature replaced by a ring armature so that the current flow may be more easily traced.

Fig. 2,969 shows a ring armature without brushes placed in an *a.c.* field. With the armature at rest (assuming current induced in the armature coils to be in phase with the flux, as in figs. 2,954 to 2,959), pressure will be induced in the winding as shown during a half cycle; starting at A, traversing both sides and meeting at C. Since these pressures are equal and opposed to each other there will be no flow of current.

Now if points A and C, be connected by short circuited brushes as in fig. 2,970 current will flow around both sides as indicated.

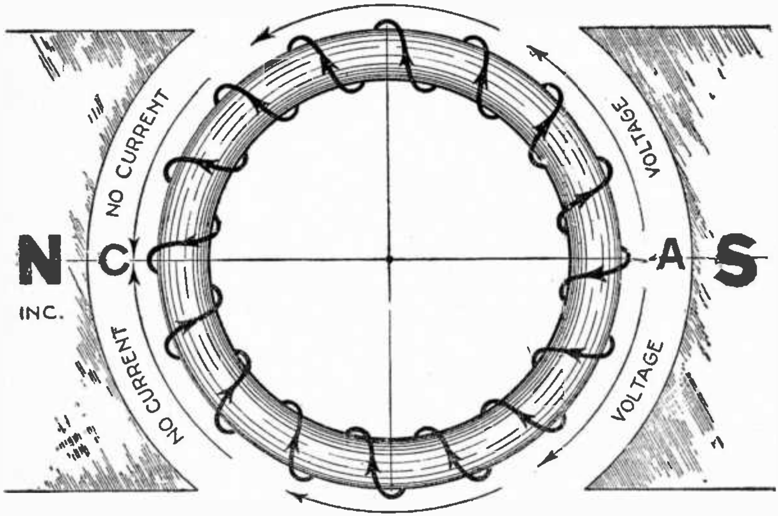


FIG. 2,969.—Wound ring in *a.c.* field showing direction of pressures induced in the inductors by transformer action. *In this and accompanying cuts, induced pressures and currents are assumed to be in phase with the field flux. As shown,* the induced pressures starting from A, traverse both halves of the winding to the point C, indicated by the arrows. Since the pressures induced in one half of the winding are equal and opposite to those induced in the other half, no current will flow.

The inductive effect for quadrants AB and CD, tend to produce counter clockwise rotation, and for quadrants CB and AD, clockwise rotations. These opposing torques balance each other so that the resultant is zero, hence no rotation.

Again if the short circuited brushes be moved to the position

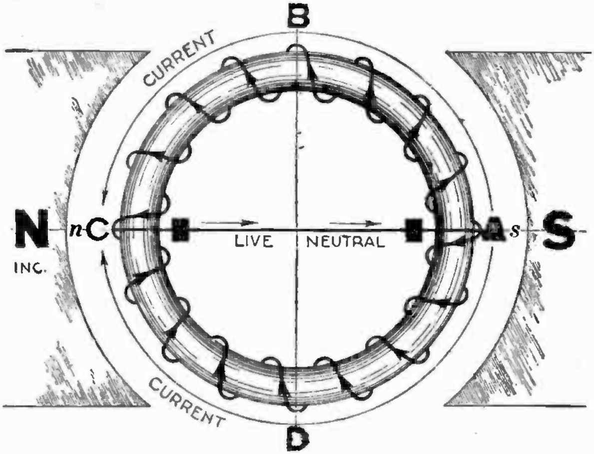


FIG. 2,970.—Ring armature in *a.c.* field with short circuited brushes located on magnet axis. ***For this connection*** there will be a maximum flow of current; *this position of the brushes is called the **live neutral.*** Since the armature is polarized in the direction *ns*, parallel to the field lines of force, there will be no torque tending to produce rotation because there is no leverage.

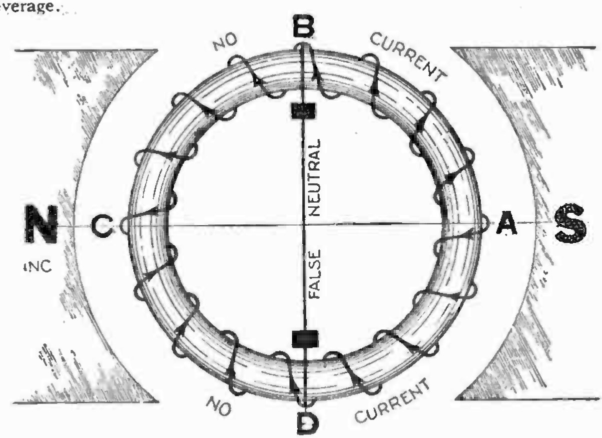


FIG. 2,971.—Ring armature in *a.c.* field with short circuited brushes located at 90° from magnet axis, that is, from *live neutral*. Since the induced pressures in quadrant AB, are balanced by the opposing pressures in quadrant AD, and similar conditions obtain in the other two quadrants BC and CD, there will be no current flow, consequently no torque tending to produce rotation.

shown in fig. 2,971, perpendicular to the magnet axis, connecting points B and D, equal and opposing pressures would be induced in quadrants AB and AD, also in quadrants CB and CD.

These opposing pressures would balance each other so that there would be no current or resultant torque. The two brush positions shown in figs. 2,970 and 2,971 are called the live and false neutrals respectively.

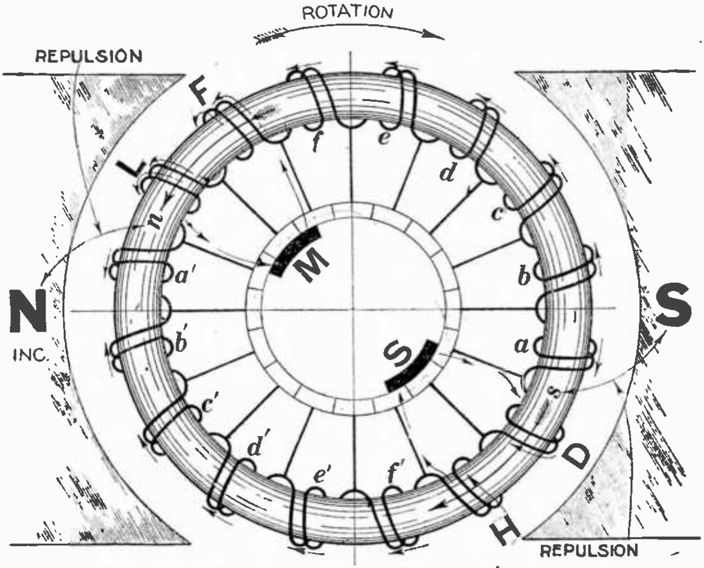


FIG. 2,972.—Ring armature in *a.c.* field with two thick brushes placed to short circuit two pairs of coils L,F, and H,D. ***With this arrangement,*** clockwise rotation will result due to repulsion by the two pairs of short circuited coils. The resultant effect of the other coils is zero as may be seen from the diagram.

Now the strength of current induced in a coil by an *a.c.* magnet depends on the angular position of the coil with respect to the field.

In fig. 2,972, the inductive effect (considering one quadrant) is great in coil L or F, and least in coils *a'* and *f*. It is great in L or F, because a maximum number of lines of force thread through each; least at *a'*, because a minimum number of lines of force can thread through it on account of the acute angle of inclination to the field; also weak at *f*, because the field is weak at that point. Accordingly, the inductive effect may be taken as equal in similarly placed coils as for instance in coils *c* and *c'*.

With the two thick brushes M and S, placed so as to short circuit several coils as L,F, and H,D, current will flow through the two pairs of coils thus short circuited as indicated.

By comparing the diagram with fig. 2,969, or by Lenz law, the current will be found to be in a direction such as to polarize the coils L,F, with a *n* pole near the N pole of the magnet, and to polarize the coils H,D, with a *s* pole near the S pole of the magnet. A clockwise torque is thus produced due to the repulsion of like poles.

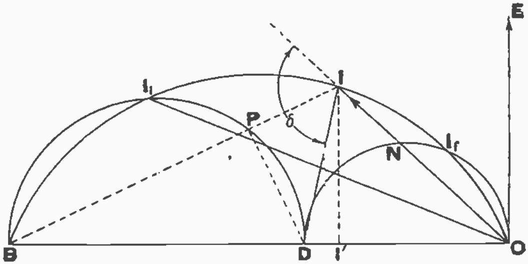


FIG. 2,973—Osnos circle diagram for repulsion motor. ***In construction,*** OE =direction of the impressed voltage, OI_1 the primary current with armature locked, drawn at an angle EOI, corresponding to its phase displacement. OI*f*, is the current with armature revolving without load and EOI*f*, is its corresponding phase angle. Draw an arc of a circle through OI*f*I*l*, the point C, being the center of the circle. This is the circle of current input, and the angle EOI, is the phase of any particular primary current. The ordinate II', is the working or energy component of the current I, and is proportional to the input. Describe the circle BI,D, which has its center on OB, perpendicular to OE. Then on OB, as a diameter describe a second semi-circle OL*f*D. The first of these semi-circles or BI_eD, is the circle of speed and the second circle OI_oD is the torque circle. Thus for a load requiring a current I, the speed is represented by the ratio IPP ÷ D, and the torque by the product OI × IN. The line ID, represents the secondary current in phase and magnitude reduced to primary equivalents. The angle S, is the difference in phase between corresponding primary and secondary currents. This diagram takes into account the copper losses as well as leakage effects, but does not include the windage, friction or iron losses, which must be allowed for, either by addition to the input or subtraction from the output.

It should be noted that with this arrangement only those coils L, F, and H, D, that are short circuited by the brushes have current flowing through them and are accordingly the only coils that produce rotation. The reason for this will be seen by examining the diagram closely. Thus, the pressures induced in coils ***b, c, d, e, f*** and ***a'***, indicated by the small arrows, are balanced by equal and opposite pressures induced in coils ***b',c',d',e',f'***, and ***a***, hence there is no current flowing in these coils; that is, current flows only in coils, L,F. and H,D.

More coils can be utilized and the repulsive effect made stronger **by connecting the brushes** M and S, as shown in fig. 2,974.

The effect of this is to bring all the coils into action, producing a strong clockwise torque, excepting (for the brush position shown), coils *a* and *a'* which are bucking the other coils.

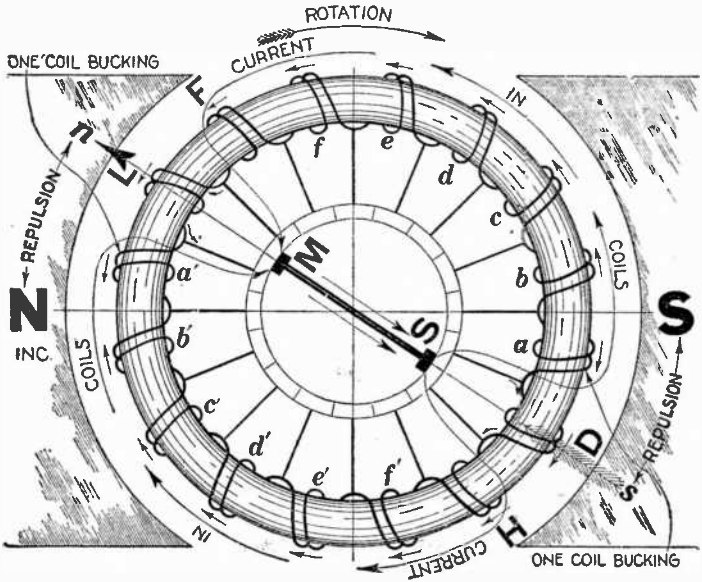


FIG. 2,974.—Ring armature in *a.c.* field with short circuited brushes located at an angle to the magnet axis showing polarization of armature, rotation by repulsion and electrical conditions in the coils.

The current flow due to connecting the brushes, polarizes the armature in the direction *ns,* resulting in repulsion at both poles with the poles of the magnet.

If the brushes be shifted to a less or greater angle than in fig. 2,974, the torque corresponding will be reduced as shown in figs. 2,975 and 2,976, because of reduced leverage in fig. 2,975, and remoteness of poles in fig. 2,976.

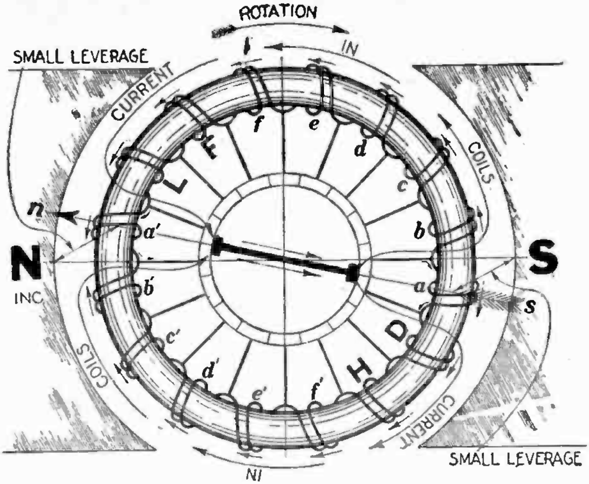


FIG. 2,975.—Ring armature in *a.c.* field with short circuited brushes shifted ***close to the live neutral*** showing weakening of torque (as compared with torque in fig. 2,974) due to decrease of magnetic leverage.

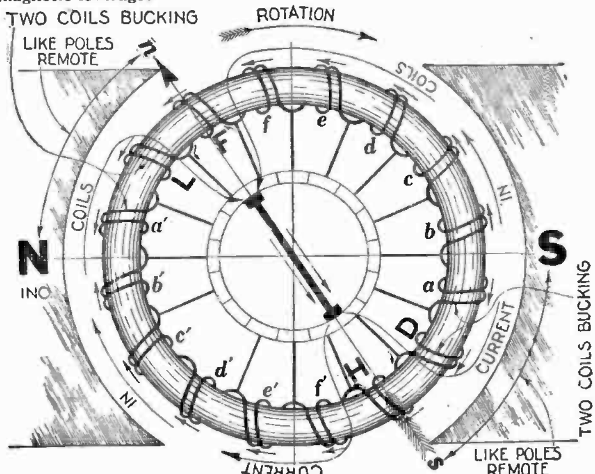


FIG. 2,976.—Ring armature in *a.c.* field with short circuited brushes shifted ***close to false neutral*** showing weakening of torque (as compared with torque in fig. 2,974) due to increase in number of bucking coils.

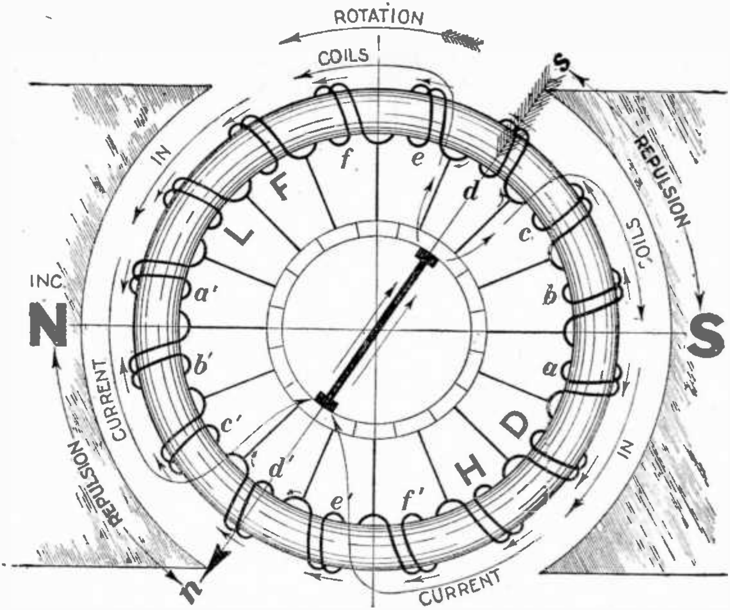


FIG. 2,977.—Ring armature in *a.c.* field with brushes shifted on other side of live neutral showing reversal of rotation. Compare this diagram with fig. 2,976.

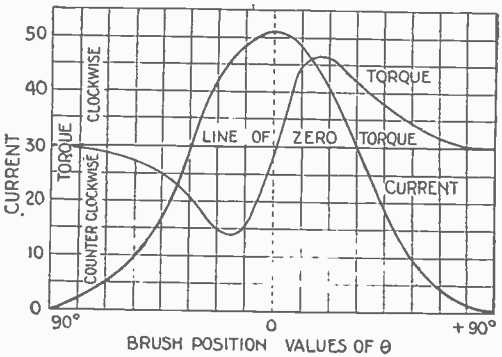


FIG. 2,978—Curves for repulsion motor showing effect on current and torque due to shifting the brushes. Note that the current and torque vary greatly with the position of the brushes.

Again, if the brushes be shifted across the magnet axis, the direction of rotation is reversed, as shown in fig. 2,977.

In other words, *shifting the brushes away from the live neutral magnet axis results in a torque in the direction of the shift.*

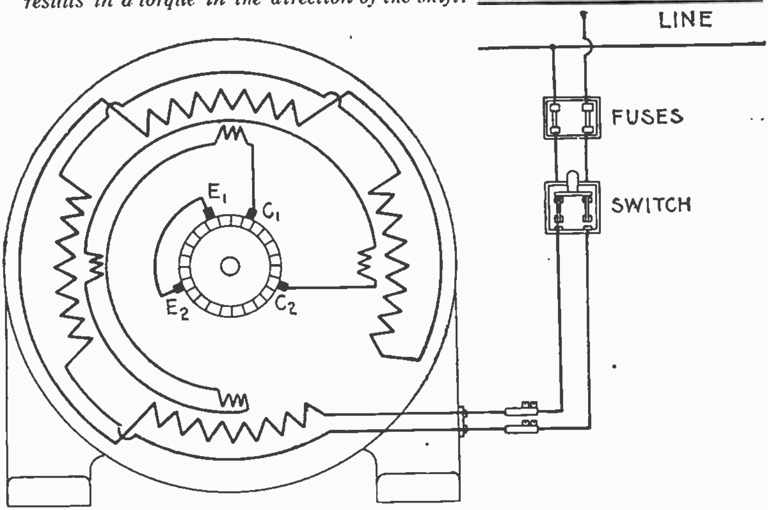


FIG. 2,979—Diagram of connection of Sprague single phase compensated repulsion motor. *To reverse* direction of rotation interchange leads C_1 and C_2 and slightly shift the brush holder yoke. Brushes E_1 and E_2 are permanently short circuited. This diagram of connections applies also to fig. 2,981.

In the accompanying diagrams the electrical conditions were shown for only part of the cycle. In operation the direction of rotation will be the same for the entire cycle because the current in the field and armature reverse together or practically so depending on the amount of lag.

For simplicity the current has been assumed to be ***in phase*** *with the flux, though in practice as already explained* ***it lags*** *about 135° behind the flux.*

Compensated Repulsion Motor.—In its simplest form it consists of a simple or "straight" repulsion motor in which there are two independent sets of brushes, one set being short circuited while the other set is in series with the compensating winding.

Ques. What names are given to the two sets of brushes on a compensated repulsion motor?

Ans. The *energy* or main short circuiting brushes, and the *compensating* brushes.

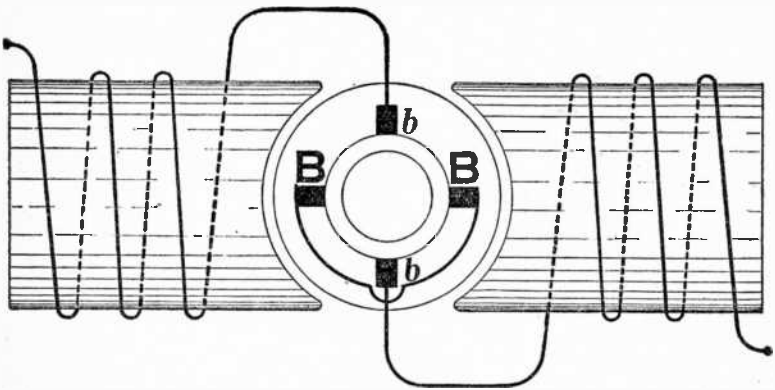


FIG. 2,980.—Compensated repulsion motor. B, and B, main brushes; *b*, and *b*, compensating brushes.

The compensated repulsion motor is a development of the straight repulsion type and was designed with the object of overcoming field distortion so as to increase the power factor of the machine.

The simplest form of compensated repulsion motor is shown in fig. 2,980. The effect of the compensating brushes B and B, considerably modifies the action of the machine.

One effect is largely to neutralize the self-inductance of the field winding, since the current flowing in the armature across these brushes acts as the current of a short circuited secondary, of which the field winding is the primary. The field winding, therefore, acts as a transformer coil; on the other hand, it does not supply the entire magnetic field necessary for the production of the turning effort. This latter field is now mainly supplied by that component of the current which passes through the armature at brushes *b* and *b*.

The current flowing between *b* and *b*, is variously known as the *exciting* or *compensating* current, while that developed between brushes B and B, is called the short circuit current.

This type of motor is characterized by high power factor at speeds

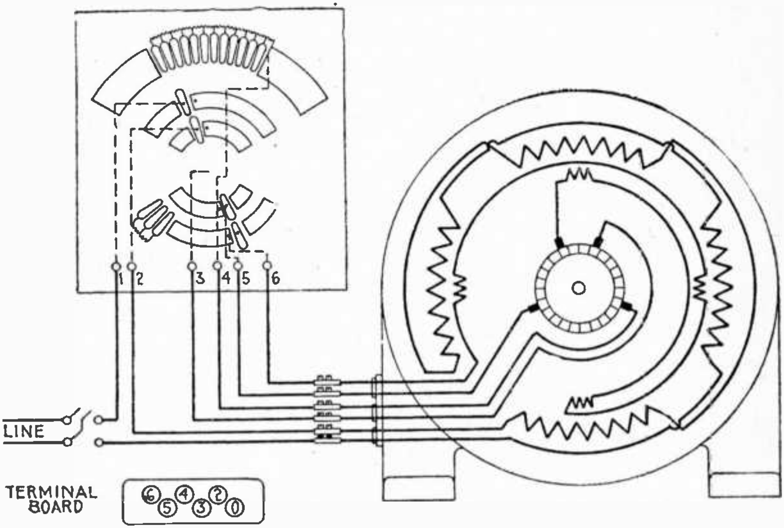


FIG. 2,981—Diagram of connections of Sprague variable speed single phase compensated repulsion motor and controller. The controller is designed to give speed reduction and speed increase as resistance or reactance is inserted in the energy and compensating circuits. Constant speed and variable speed motors are identical with the exception of the leads brought out from these circuits. The standard controller gives approximately 2 : 1 speed variation.

above synchronism, but at low speed its power factor is less than with the *a.c.* series motor, while at all speed points its torque per ampere is not as high.

A further criticism of this construction is, what has been the greatest advantage of the repulsion motor, its connection directly to high tension lines, is no longer practicable, because now the revolving member is also in the main circuit so that the necessary insulation is difficult. This bad feature of the compensated motor is avoided by the Winter-Eichberg modification shown in fig. 2,982. In this design the armature exciting current, flowing between brushes *b* and *b*, instead of being supplied directly to the armature from the high tension lines, is obtained from the secondary of a transformer whose primary is in series with the stator and high tension circuit.

Variable speed is obtained by variation of the voltage supplied by this secondary, which is provided with taps, as shown.

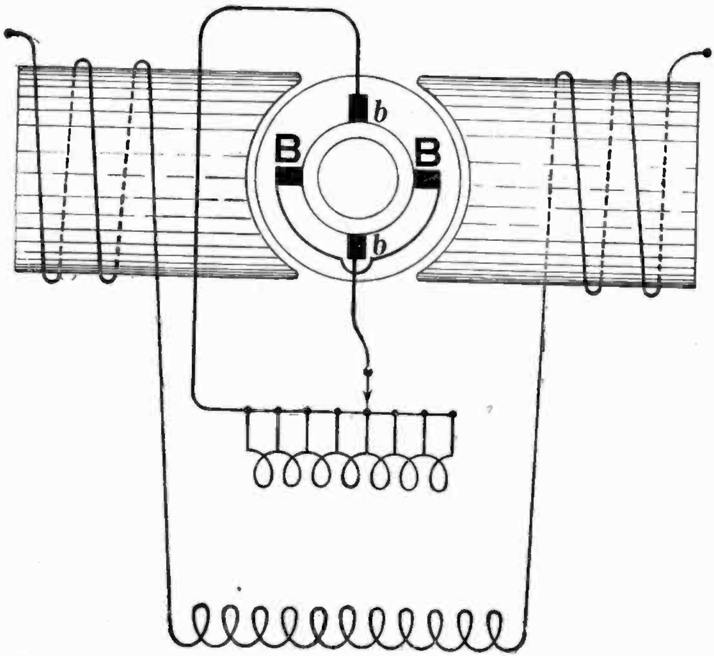


FIG. 2,982.—Modified compensated repulsion motor to permit high tension operation with low tension commutation.

Repulsion Start Induction Motor.—This type of motor is one designed *to start as a repulsion motor and run as an induction motor*. It should be carefully distinguished from the repulsion induction motor later described.

The repulsion start induction motor has a single phase distributed field winding with the axis of the brushes displaced from the axis of the field winding. The armature has an insulated winding. The current induced in the armature or rotor is

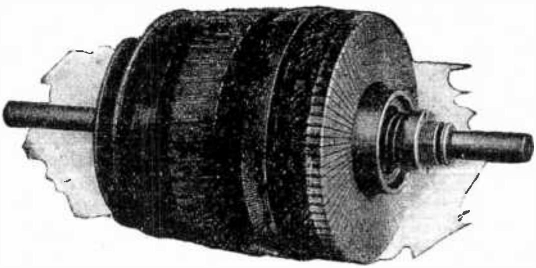
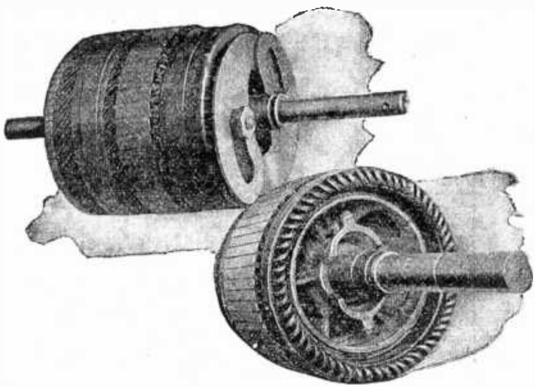
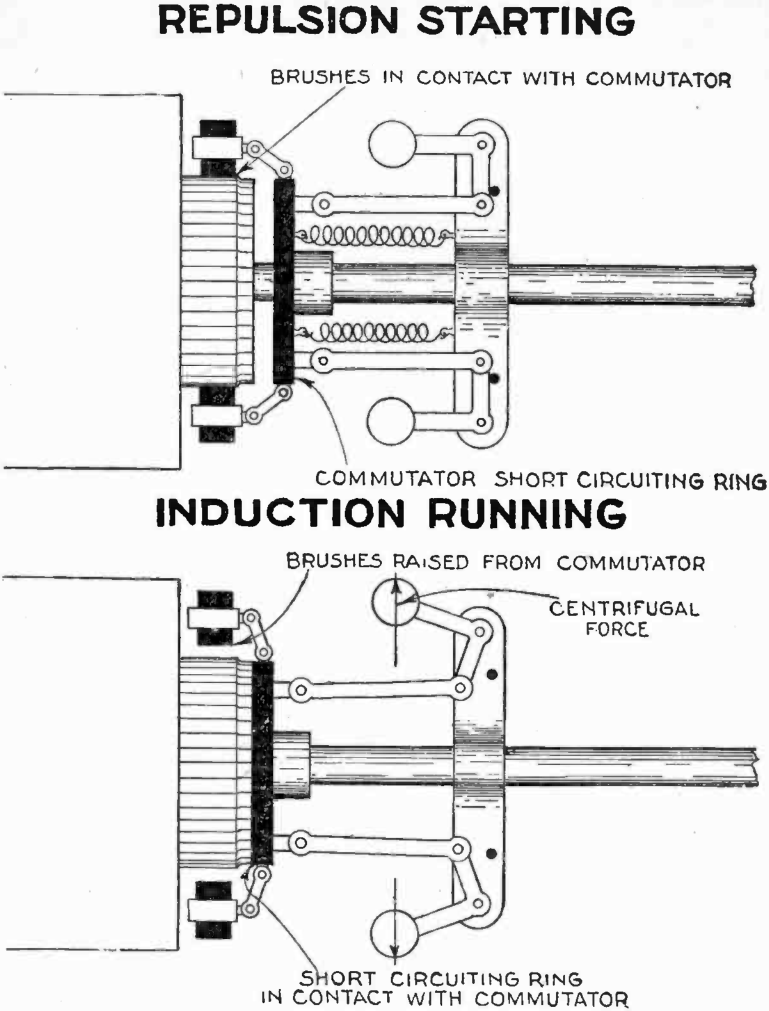


FIG. 2,983.—Wagner single phase repulsion start induction motor armature showing commutator end.



FIGS. 2,984 and 2,985.—Wagner single phase repulsion start induction motor armatures showing type of governor employed on the smaller sizes (fig. 2,984) and on the larger sizes (fig. 2,985).

carried by the brushes and commutator resulting in high starting torque. When nearly synchronous speed is attained the commutator is short circuited so that the armature is then similar in its functions to a squirrel cage armature.



FIGS. 2,986 and 2,987 —Diagrams illustrating operation of brush lifting mechanism of repulsion start induction motor Fig 2,986, brushes in contact with commutator during repulsion starting; fig. 2,987, brushes lifted from commutator and short circuiting ring pressed against commutator, short circuiting the latter, thus causing motor to run as an induction motor.

The elementary diagrams figs. 2,986 and 2,987 show the working principles of the mechanism for simultaneously lifting the brushes and short

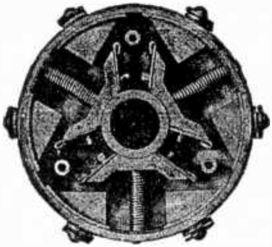


FIG. 2,988.—Baldor single phase repulsion start induction motor centrifugal short circuiting switch. *In construction* there are three centrifugal weights spaced 120° apart and held to the center of a cup shaped housing, when the armature is not rotating. When the armature begins to rotate, the centrifugal force causes these weights to leave center and short circuit six stationary contacts spaced 60° apart on the inside wall of the housing. On 6 pole types four centrifugal weights and eight stationary contacts are used spaced 90° and 45° apart respectively. These contacts are connected to six and eight sections of the commutator by means of leads through the armature slots. It is claimed that this switch serves the same purpose as a switch which has many more parts and short circuits all of the bars of the commutator against a ring, or one which uses a necklace of copper segments to short circuit one commutator bar against the next one. The object of this construction is to secure greater reliability at the expense of a fraction of 1% less of efficiency.

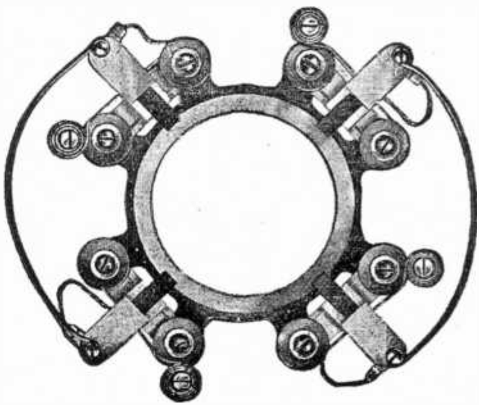


FIG. 2,989.—Baldor single phase repulsion start induction motor brush gear and brushes. *In construction,* each brush is pig tailed to the holder and a copper wire provides the shunt. The holders are insulated so that no current passes the the rocker arm or frame of motor. The commutator being of relatively large proportions and the brushes carefully selected it is not necessary to raise them. The brushes carry current only at starting and when up to speed the centrifugal switch carries all the current.

circuiting the commutator to change the operation from *repulsion* to *induction*. The object of lifting the brushes is to eliminate wear of the commutator during the running periods as it makes no difference electrically whether the brushes be in contact or not after the motor comes up to speed

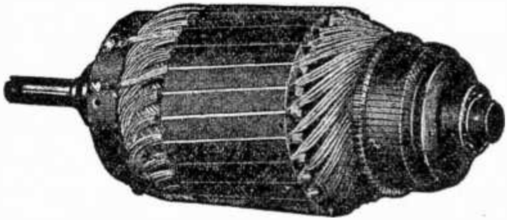


FIG. 2,990.—Baldor single phase repulsion start induction motor armature.

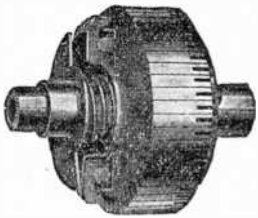


FIG. 2,991.—Baldor fractional horse power single phase repulsion start induction motor commutator showing sectional view of the short circuiting switch. This switch is designed for rolling contact to render it self-cleaning.

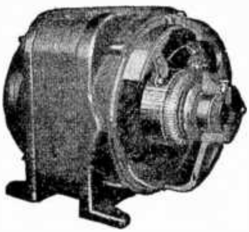


FIG. 2,992.—Baldor fractional horse power single phase repulsion start induction motor.

This motor has gone through many stages of improvement since its first appearance on the market, although its general principle has remained the same. The general reliability of this type of motor is largely governed by the reliability of the short circuiting mechanism. For this reason, it has been the constant aim of engineers to improve on the principle and construction of the short circuiting switch. Centrifugal force, as a means to accomplish the best results, was early resorted to and still remains the most practical method, because the weight being once determined, will always throw out and short circuit the commutator at the same speed.

Since the motor starts on the repulsion principle it has the same starting characteristics as the repulsion motor described above, namely, high starting torque and low starting current.

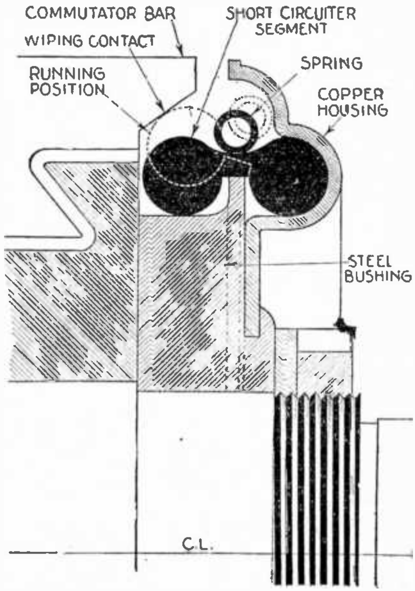


FIG. 2,993.—Master single phase repulsion start induction motor short circuiting centrifugal starting switch; built as a unit.

FIG. 2,994.—Sectional view of Master single phase repulsion start induction motor short circuiting switch showing operation. *It is constructed* so that centrifugal force reacts against the circular coiled spring that rests in a groove upon the outer surface of the short circuiting segments. The ends of the commutator bars are beveled to provide a wiping contact with the segments as they move outward. As the segments reach the end of their travel, they produce a wedging action contact against the commutator bars that gives good mechanical contact.

As the motor speeds up the torque falls off rapidly. At some point on the speed torque curve after the repulsion curve has crossed the induction motor curve, usually at about 80% of synchronism, the commutator is automatically short circuited, producing the effect of a cage winding in the armature, and the motor comes up to speed as an induction motor.

After the commutator has been short circuited, the brushes do not carry current and, therefore, may be lifted from the commutator, but lifting the brushes is not necessary.

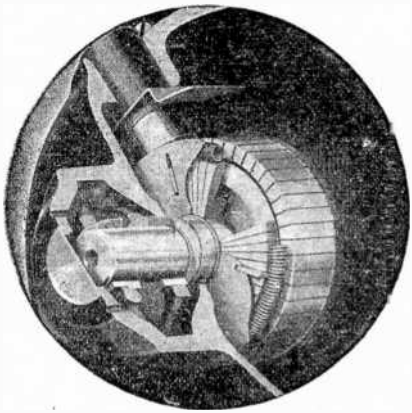
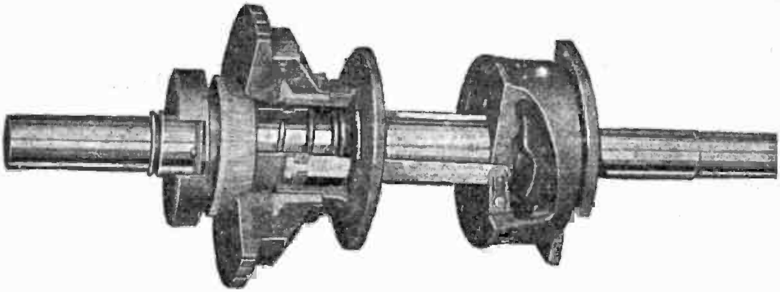
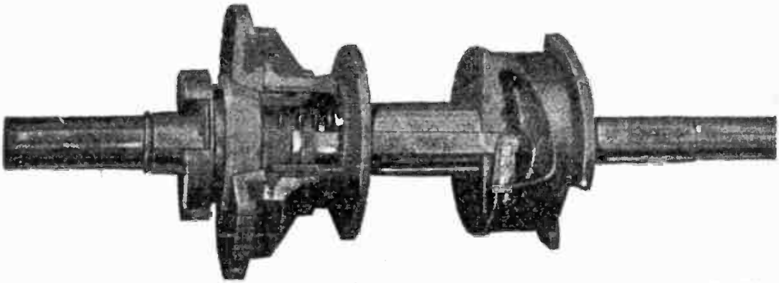


FIG. 2,995.—Leland single phase repulsion start induction motor short circuiting device. The construction is clearly shown in the illustration.

The curve in fig. 2,998 shows the speed torque characteristics of a typical repulsion start induction motor. The short circuiting mechanism operates at point A. At this point the induction motor torque is greater than the repulsion motor torque, which means that if the repulsion winding have sufficient torque to bring the load up to this speed, there will be sufficient torque as an induction motor to bring the load up to full speed. The higher the speed at which the short circuiting mechanism operates, the lower will be the induction motor current at that point and consequently the less disturbance to the line. After the commutator has been short circuited, the motor has the same characteristics as the single phase induction motor described above.





FIGS. 2,996 and 2,997.—Jeannin single phase repulsion start induction motor short circuiting device. Fig. 2,996 starting position switch open; fig. 2,997 running position, commutator short circuited.

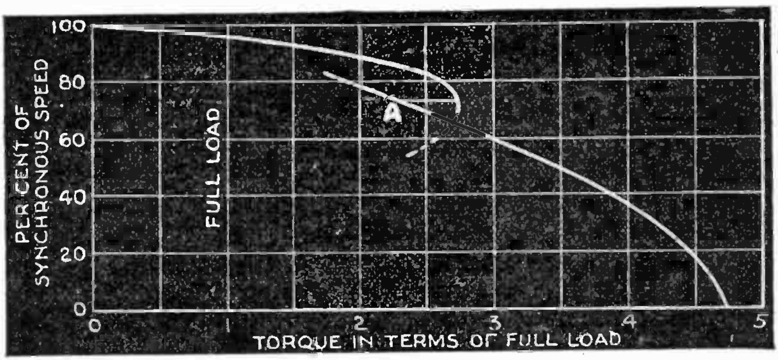


FIG. 2,998.—Speed torque curve of repulsion start induction motor.

If the short circuiting mechanism operate before the repulsion curve crosses the induction motor curve, and the torque of the induction motor is less than that required to accelerate the load, the motor may slow down until the short circuit is removed from the commutator, in which case the motor will again operate repulsion. The armature will then speed up until the commutator is again short circuited after which the armature will slow down until it again becomes repulsion. This cycle will be repeated over and over again until some change takes place.

The efficiency and maximum running torque of the repulsion start induction motor are usually less than those of a cage wound induction motor built of the same parts. In other words, the repulsion start induction motor must be larger than cage wound motor of the same rating to give the same performance.

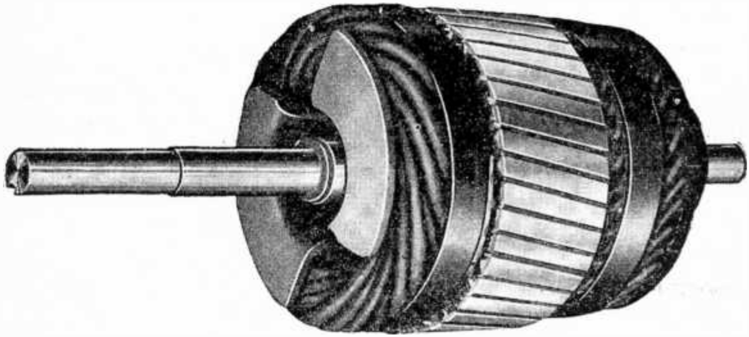


FIG. 2,999.—Jeannin single phase repulsion start induction motor armature showing governor weights which when acted upon by centrifugal force close the short circuiting switch. This operation is shown in figs. 2,996 and 2,997.

Since this motor has low starting current, the fractional horse power sizes may be operated from lighting circuits when used to drive frequently starting devices. Some applications of this motor are air compressors, water systems, gasoline pumps, household refrigerators, meat choppers, etc.

Repulsion Induction Motor.—This is *a combination of the repulsion and induction types and operates by the combined*

NOTE.—*Careful distinction* should be made between *repulsion induction motors* and *repulsion start induction* motors. The questionable practice among manufacturers of calling repulsion start induction motors simply repulsion induction motors should be discontinued as it is erroneous and misleading to the buyer.

principles of repulsion and induction. It is sometimes called a squirrel cage repulsion motor. In this motor is obtained the desirable starting characteristics of the repulsion motor and the constant speed characteristics of the induction motor. It is obviously impossible to combine the two types of motor and obtain only the desirable characteristics of each.

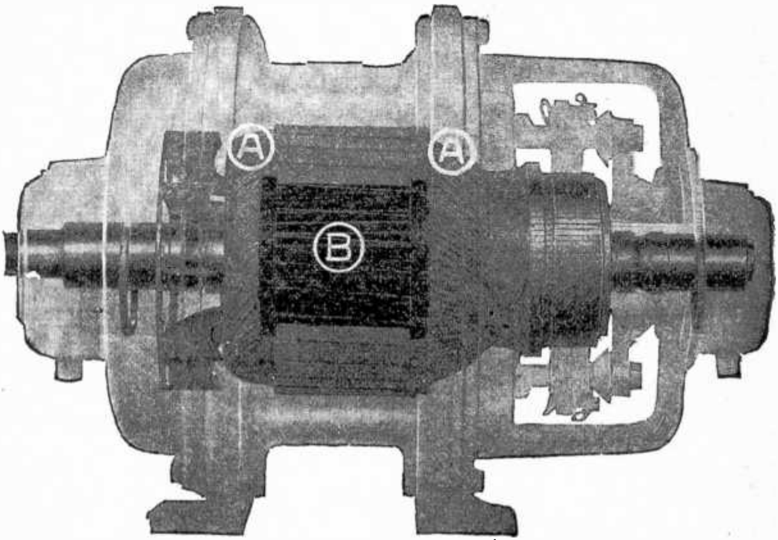
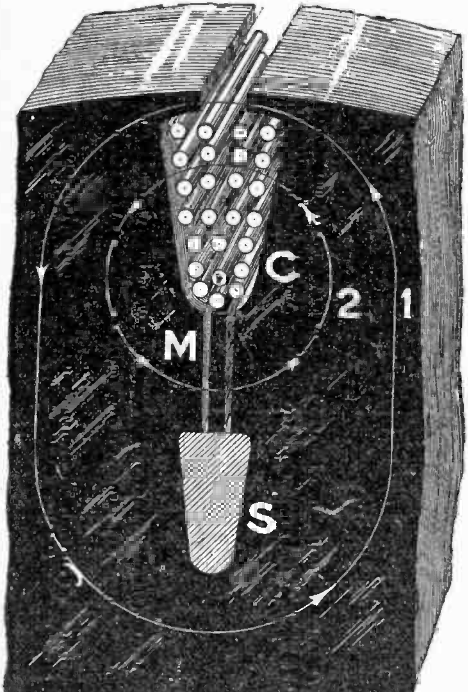


FIG. 3,000.—General Electric constant speed single phase repulsion induction motor; phantom view showing commutated winding A and squirrel cage B. This motor has no centrifugal short circuiting switch and operates on *the combined principles of repulsion and induction:* it is sometimes called the squirrel cage repulsion motor. Winding A, gives the high starting torque of a repulsion motor; winding B, the running characteristics of an induction motor This type motor is adapted to applications requiring frequent starting and stopping, even when the voltage is low, or under severe service conditions.

The field has the same type of winding as is used in the repulsion start induction motor. The armature has two separate and independent windings:

1. Squirrel cage winding.
2. Commutated winding.

Both of these armature windings function during the entire period of operation of the motor. There are no automatic devices such as the starting switch of the split phase motor, or the short circuiting device of the repulsion start induction motor.



The cage winding is located in slots below those which contain the commutated winding. The slots which contain the two windings may or may not be connected by a narrow slot. Usually there are the same number of slots in the two windings. It is not, however. absolutely essential that they be the same, as before stated.

Fig. 3,001 shows the arrangement of the two armature windings.

Due to its construction, the squirrel cage winding has inherently a high inductance. Its reactance with the armature at rest is, therefore, high.

FIG. 3,001.—Repulsion induction motor, or combination squirrel cage repulsion motor. The armature of this machine has a highly reactive squirrel cage in the slots below the commutated winding. The narrow portion between the squirrel cage winding S, and the commutated winding C, is occupied by a metal strip M, of comparatively high resistance. Sparking is minimized by transferring the energy of the short circuited coil to the cage winding through the intervention of the leakage flux which is mutual to the two windings and shown by path 1; and also by similar action to the non-magnetic strips M, as shown by flux path 2. ***In operation*** with voltage impressed upon the motor at standstill, the armature frequency is high and little current will flow in the squirrel cage winding because of its large inductance. As a result, the current will flow mainly in the commutated winding, thus starting the machine as a repulsion motor, and increasing the speed with decreasing torque. When a high speed is reached the cage winding carries its share of the current and the motor will operate at nearly constant speed as an induction motor.

The commutated winding has a low reactance and the current will flow mainly in this winding. The ideal condition at starting would be for all of the flux to pass beneath the commutated winding and none of it to pass beneath the cage winding. If this condition could be obtained; this motor would have the same starting characteristics as the repulsion start induction motor.

At full load speed, which is slightly below synchronism, the reactance of the cage winding is low, and most of the mutual flux passes beneath the cage winding.

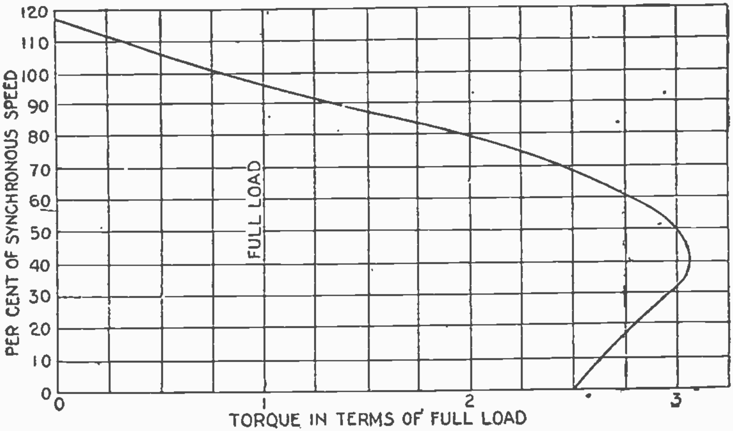


FIG. 3,002.—Speed torque curve of repulsion induction motor. The starting torque is about two and one-half times full load torque and the starting current is about two and one-half to three times full load current. The speed torque curve is very similar to that of a compound wound *d.c.* motor. As the motor speeds up, the torque increases until the maximum torque point is reached, which insures that the motor will bring up to full speed any load that it will start. Due to the somewhat drooping speed torque characteristic, this motor tends to throw off its load as it is overloaded. As the applied voltage is decreased, the motor speed decreases and the power required to drive a constant torque load decreases. The current on overload, therefore, does not increase as rapidly as in the case of the induction motor or the repulsion start induction motor. At light loads, the speed of this motor may be above synchronism. This is a very desirable feature in many cases, for example, driving a pump where the pump starts against low pressure and builds up the pressure. Due to the higher light load speed of this motor, a pump driven by it will build up its pressure in less time than one driven by a constant speed motor.

Both windings produce torque and the output of the motor is the combined output of the cage winding and the commutated winding.

The commutation of this motor is good at all speeds. The no load speed is above synchronism and is limited by the combined effect of the field winding on the commutated winding and the cage winding and the action of the two armature windings on each other. At synchronous speed, a squirrel cage motor has no torque. At synchronous speed and for a short distance above synchronous speed, the torque of a repulsion induction motor is greater than that of the commutated winding alone, which shows that, due to the interaction between the two armature windings, the squirrel cage supplies torque instead of acting as a brake.

At full load speed, and up to about the maximum running torque point, the torque of this motor is greater than the sum of the torques of the cage winding and the commutated winding. The inherent locked torque curve

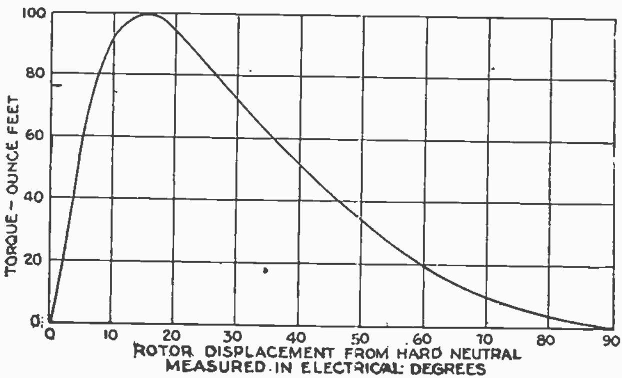


FIG. 3,003.—Locked torque of repulsion motor.

of a repulsion induction motor is similar to that of the repulsion motor shown in fig. 3,003. At soft neutral, the primary winding carries the squirrel cage current in addition to the exciting current of the motor. Since the starting current of the repulsion induction motor is low, it may be operated from lighting circuits when driving frequently starting devices.

The repulsion induction motor is especially suitable for such applications as household refrigerators, water systems, garage air pumps, gasoline pumps, compressors and similar applications. This motor may also be arranged for reversing service by the same method described for the repulsion motor, that is by the use of one transformer field and two main field windings.

TEST QUESTIONS

1. *What did Prof. Thomson observe in experimenting with a copper ring?*
2. *What should be noted in regard to the term "repulsion" as applied to repulsion motors?*
3. *Name four types of repulsion motors.*
4. *Give the basic principles deduced from Prof. Thomson's experiments with a copper ring.*
5. *What is the phase relation between the field flux and the voltage induced in the ring?*
6. *What is the effect of the lag in the current behind the voltage induced in the ring?*
7. *What conditions obtain when the current lags 180° behind the field flux?*
8. *In practice what is the approximate lag to produce maximum torque?*
9. *What is a straight repulsion motor?*
10. *Describe Prof. Thomson's experiments with an ordinary d.c. armature in an a.c. field.*
11. *What difficulty was experienced with Thomson's motor?*
12. *Who suggested the use of closed coils?*
13. *Draw a diagram and explain action of ring armature in an a.c. field.*
14. *What is the position of the short circuited brushes in operating?*
15. *What is the difference between the live and false neutral?*
16. *How is a straight repulsion motor reversed?*

17. *What is a compensated repulsion motor?*
18. *What names are given to the two sets of brushes on a compensated repulsion motor?*
19. *What is a repulsion start induction motor?*
20. *How is a transition from starting to running conditions made?*
21. *What difference does it make whether or not the brushes be in contact with the commutator during the running period of the motor?*
22. *What force is employed to operate the short circuiting switch and brush lifting mechanism?*
23. *What is a repulsion induction motor?*
24. *What mistake is made by manufacturers in using the title "repulsion induction motors"?*
25. *What two kinds of windings are used on repulsion induction motors?*
26. *For what applications is the repulsion induction motor especially suited?*

CHAPTER 62

Commutator Motors

3. Brush Shifting, Adjustable Speed

Brush Shifting Commutator Motor.—This type of *a.c.* commutator motor is designed to obtain adjustable speed by the method of shifting the brushes. The development of satisfactory *a.c.* adjustable speed motors, and combinations for obtaining adjustable speed, has been given much attention both in Europe and in this country because of the quite general use of alternating current and because the usual types of *a.c.* motors give constant speed or approximately constant speed.

The motor selected to illustrate this type is the General Electric BTA motor known as an *a.c.* adjustable speed brush shifting motor.

It operates with three phase current and has shunt characteristics; that is, its change of speed is only moderate as compared with the change in load. It is sometimes known as the Schrage motor; its inventor being K. H. Schrage of Sweden. It is built to supply the demand for an *a.c.* motor having shunt characteristics which will also provide adjustable speed features without unduly complicating the machine.

Such a motor may be used for a wide field of applications where its characteristics are desirable or necessary and where alternating current is the only available power supply.

The motor may in some respects be compared with the slip ring induction motor, although it should be borne in mind that the characteristics of this brush shifting motor are quite different from the characteristics of the slip ring induction motor, as is shown later.

The general construction of the motor is shown in figs. 3,004 and 3,005. The schematic diagram, fig. 3,007 shows how the windings are arranged.

In the description following, the stator is the armature and the rotor, the field. It should be noted in this connection that the rotor with its two windings performs the functions of both field and armature. On account of this complication, the terms rotor and stator are used.

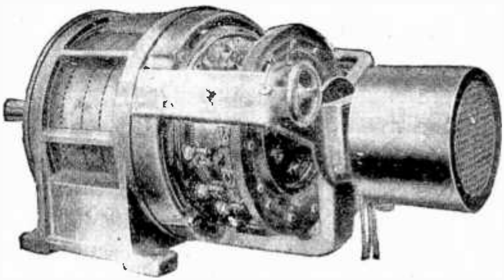


FIG. 3,004.—General Electric 3 phase adjustable speed brush shifting motor. ***The inherent feature of this type motor*** is that its change of speed is only moderate compared with the change of load. It has a full load speed range of three-to-one, the slip reducing the top and bottom speeds and all intermediate speeds as with an induction motor. The change in speed from no load to full load, however, is greater than for an induction motor, but is substantially the same in revolutions per minute over the speed range of the developed ratings, except at and near synchronous speed where it is less. At high speed this amounts to 5 or 10 per cent of the speed in question, and at low speeds to 15 or 20 per cent of the speed in question, depending on the rating of the motor.

The field winding is in the rotor instead of in the stator, as is the case in slip ring induction motors, and is connected to the power supply through slip rings.

The armature winding is in the stator which again differs from its position in the slip ring induction motor. The armature winding has each phase independent. In addition, this shunt characteristic motor has a second winding in the rotor similar to a *d.c.* armature winding which, in this case, also connects to a commutator. This winding, known as the *adjusting* *winding*, is placed nearest the air gap to obtain the benefit of lower reactance and thereby give better commutation.

The motor is provided with two brush yokes, one located at each end of the commutator, so arranged as to shift in opposite directions.

One end of each phase of the armature winding is connected to brushes on one brush yoke and the corresponding other ends of the armature winding are connected to brushes on the other yoke.

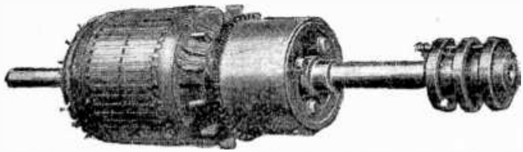


FIG. 3,005.—General Electric 3 phase adjustable speed brush shifting motor rotor or combined field and armature showing slip rings, commutator, etc. ***Torque:*** With the brushes in the low speed position the motor may be thrown directly on the line and will give from 150 to 250 per cent of normal torque at starting with only 125 to 175 per cent of full speed line current. The maximum running torque at low speed is 150 to 250 per cent of normal torque, and increases as the speed is increased. For the high speed position, the maximum running torque is 300 to 400 per cent of normal torque. With the brushes in the high speed position the starting torque is approximately 110 to 150 per cent of normal torque, although the static torque may be materially less than these values due to the position curve and the starting current is approximately 400 to 600 per cent.

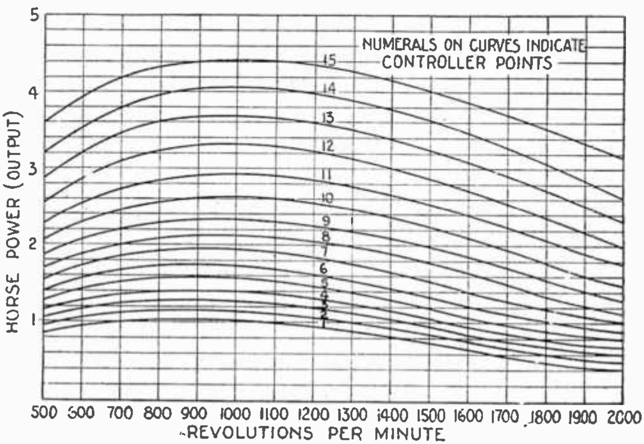


FIG. 3,006.—Horse power output curves for Kimble single phase class A, variable speed motor. The curves show the speeds at various horse powers of a 3 *h.p.* motor at various controller points.

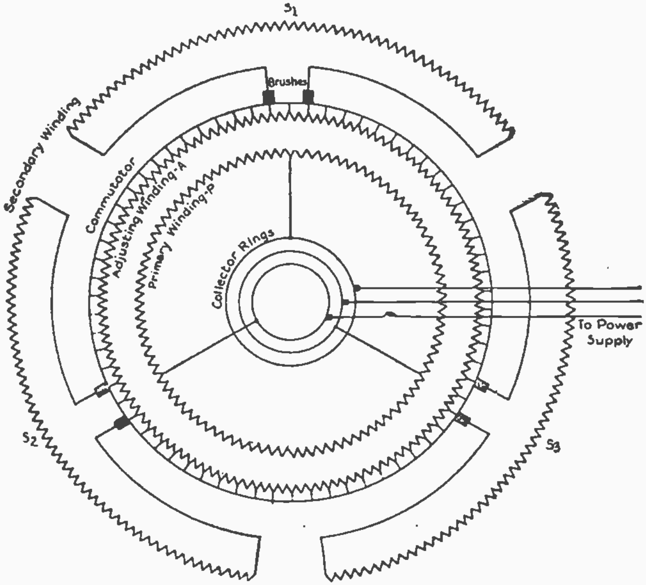


FIG. 3,007.—Diagram of General Electric 3 phase adjustable speed brush shifting motor. The stator contains only the armature winding, each phase of which is connected independently between two commutator brushes. The rotor has two windings: 1, The *field winding* is connected to the collector rings deriving power therefrom. 2, The *adjusting winding* is placed in the same rotor slots and connects to the commutator. ***In construction and operation*** the commutator is provided with two yokes so arranged as to shift in opposite directions. One end of each phase of the armature winding is connected to brushes on one brush yoke and the corresponding other ends are connected to brushes on the other yoke. When the brushes, to which each end of the armature phase is connected, are on the same commutator segment, the adjusting winding is idle, the armature winding is short circuited and the motor runs as an induction motor with speed corresponding to the number of poles and frequency of supply. As the brushes are moved apart, a section of the adjusting winding is included in series with the armature winding, causing the armature winding to generate a voltage to balance the voltage impressed upon it by the adjusting winding, thereby causing the motor to change its speed. Moving the hand wheel in one direction raises the speed and moving it in the other direction reduces the speed. The motor operates both above and below the induction motor synchronous speed.

NOTE.—***The brush shifting adjustable speed motor*** has a low voltage on the commutator which is desirable for certain applications. This voltage is the same when starting or running. Variations of line voltage do not materially affect the speed as with *d.c.* machines, the motor being similar to an induction motor in this respect.

Bus rings on the yokes keep the phases separate and permit the use of several studs per phase. With three phase power supply for the field in the larger sizes of motors, it is frequently desirable to use a different and larger number of phases in the armature winding, and a corresponding spacing of the brushes on the commutator. This is possible since there is no electrical connection between the field and the armature winding. Better commutation and better operating characteristics are thereby obtained.

The field winding in the rotor which connects to the power supply through the slip rings generates the working flux in the machine.

This flux is substantially constant since the line voltage and line frequency are substantially constant. Since the adjusting winding, which connects to the commutator, is placed in the same slots as the field winding, a voltage

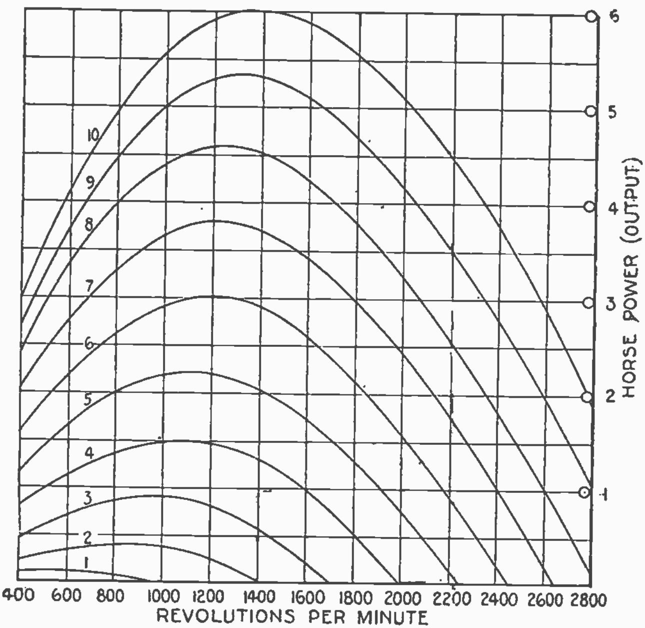


FIG. 3,008.—Horse power output curves for Kimble single phase class L brush shifting variable speed motor.

of constant value and at line frequency is induced in it by the field flux, by transformer action.

The commutator changes the frequency from line frequency to slip frequency, which is the frequency of the armature of the machine. Thus the voltage between two brushes properly located on the commutator will depend upon the number of commutator segments between them or, in other words, upon the number of turns of the adjusting winding included between the two positions on the commutator where the brushes are located. Obviously, the minimum value of this voltage will be zero when the two brushes being considered are together on the same commutator segment, thus

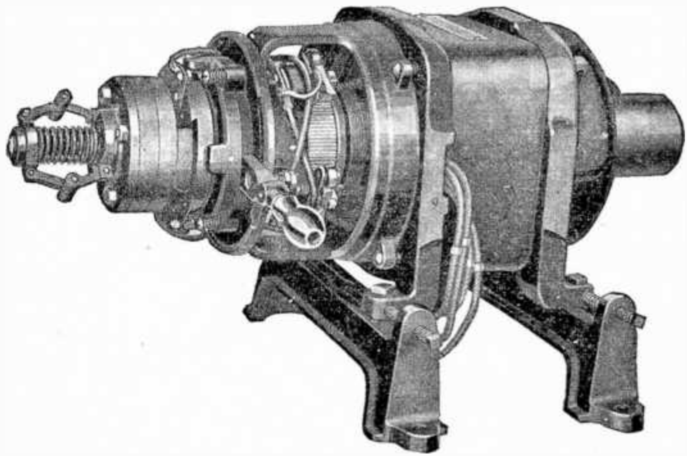


FIG. 3,009.—Kimble single phase adjustable speed brush shifting commutator motor.

including no portion of the adjusting winding. Also, the voltage will have its maximum value when the two brushes are one pole arc or 180 electrical degrees apart on the commutator.

Now assume one of the brushes to be connected to one end of armature phase and the other brush to be connected to the other end of the same phase; and likewise for the other brushes or groups of brushes and armature winding phases. For the condition where the brushes are together on the same commutator segment, it was noted that no portion of the adjusting winding was included and it is apparent that the armature winding is short circuited. Thus is obtained the conditions existing in an ordinary slip ring

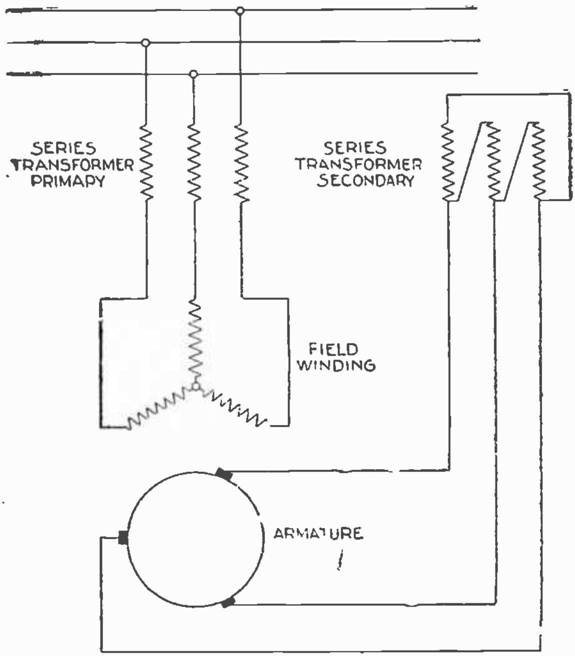


FIG. 3,010.—Connections of a three phase brush shifting series motor. A series transformer is generally used to step down the voltage for the armature as low voltage is necessary to good commutation. The secondary of this transformer is connected for three phases and the armature has three sets of brushes per pole pair. The transformer, by its ability to become saturated, limits the no load speed of the motor to a safe value, which is usually about 150 per cent normal

NOTE.—*The characteristics* of the brush shifting polyphase motor depend to a considerable degree upon design factors, such as ratio of armature to stator ampere turns. In order to gain flexibility in performance these factors may be arranged for adjustment in the field. The armature relations are modified by means of taps in the step down transformer. Light load operation is more stable if the primary turns in this transformer be reduced below the most effective full load ratio. The tap to be selected depends upon the relation of motor rating to load handled.

NOTE.—*The brush shifting polyphase motor* is better suited for use on 25 cycle circuits than on 60 cycle circuits. The commutation is better at the lower frequency and the possible output from a given commutator and frame is greater with low than with high frequency. This is primarily due to the fact that higher voltage per phase and more rotor phases may be used with a given number of brush studs due to the lesser number of poles for a given speed. This results in less current per rotor phase and increases the capacity of the commutator.

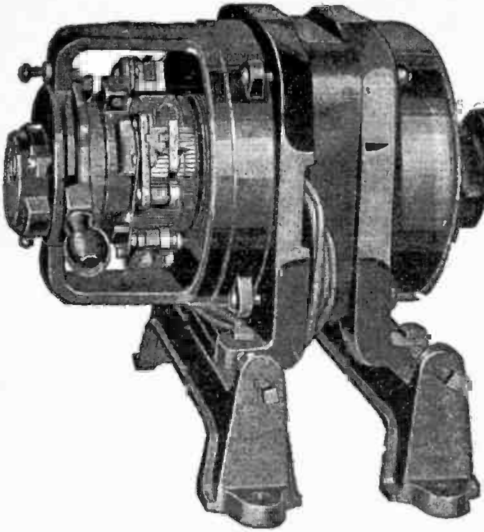
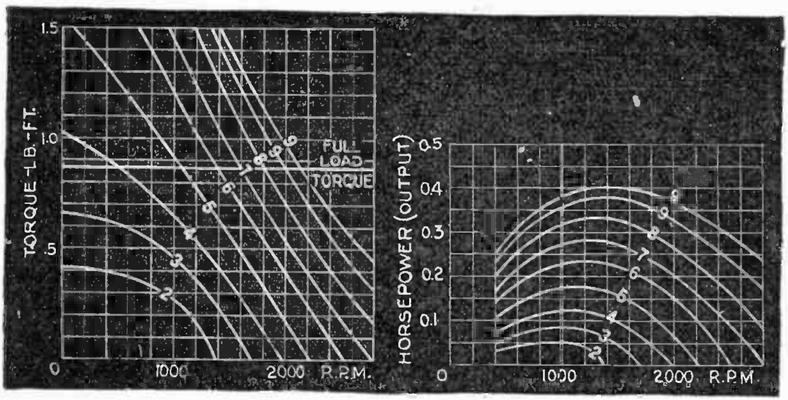


FIG. 3,011—Kimble type LK, variable speed motor.



FIGS. 3,012 and 3,013.—Torque and horse power curves of Kimble type LK variable speed motor. Fig. 3,012 shows speed torque curves of a 1/3-*h.p.* motor with the brushes set a distance corresponding to 2,3,4 etc. bars from neutral, as indicated by the numerals. However, it should be understood that the brush positions are not limited to these settings. Fig 3,013 gives speed output curves at the same brush settings. By the aid of these curves the load on the motor can be found. While these curves are accurate only for one rating, they indicate the general characteristics of all type L.K. motors.

induction motor with short circuited armature and the motor will run as an induction motor with its speed depending upon the frequency of supply and upon the number of poles of the motor.

If the brushes of the motor be now moved apart, some commutator segments and consequently a portion of the adjusting winding will be included in series with the armature winding, thus impressing a voltage at slip or armature frequency across the armature winding. If the brushes be properly located on the commutator, this voltage will cause an increase or decrease in the speed of the motor because the armature winding must generate a reverse voltage with proper phase rotation to balance the voltage impressed upon it by the adjusting winding. The speed of the motor must change until the voltage generated by the armature winding (generated by its cutting the field flux) balances the impressed voltage with just enough difference to permit sufficient current to flow to develop the required torque.

When the gear shaft of the brush shifting mechanism is turned in one direction the speed is raised, and when turned in the opposite direction the speed is lowered. The motor operates both above and below the induction motor synchronous speed. If the brushes of the motor be shifted approximately 90 electrical degrees around the machine, that is, such that the same two brushes are together on a segment 90 electrical degrees from the position referred to, and they then be moved apart as before, the speed would not change but the power factor would. Therefore, by compromising between the two positions speed control is obtained, and also some control over the power factor within the capacity of the windings.

TEST QUESTIONS

1. *What is the object of shifting the brushes?*
2. *Are brush shifting motors in general use?*
3. *What is the nature of the speed of the usual types of a.c. motors?*
4. *What is understood by the term "adjustable speed"?*
5. *What is the field of application of adjustable speed brush shifting motors?*
6. *With what other type motor may the brush shifting motor be compared?*

7. *Describe the construction and operation of General Electric three phase adjustable speed brush shifting motor.*
8. *Where are the field and armature windings located?*
9. *Do variations of line voltage affect the speed?*
10. *Describe the effects obtained by shifting the brushes of General Electric motor to various positions.*

CHAPTER 63

Commutator Motors

4. Fynn-Weichsel Motors

The Fynn-Weichsel Motor.—The disadvantages of low power factor experienced by central generating stations caused the National Electric Light Association in 1921 to address a letter to all motor manufacturers strongly urging them to try to produce a general purpose alternating current motor that would

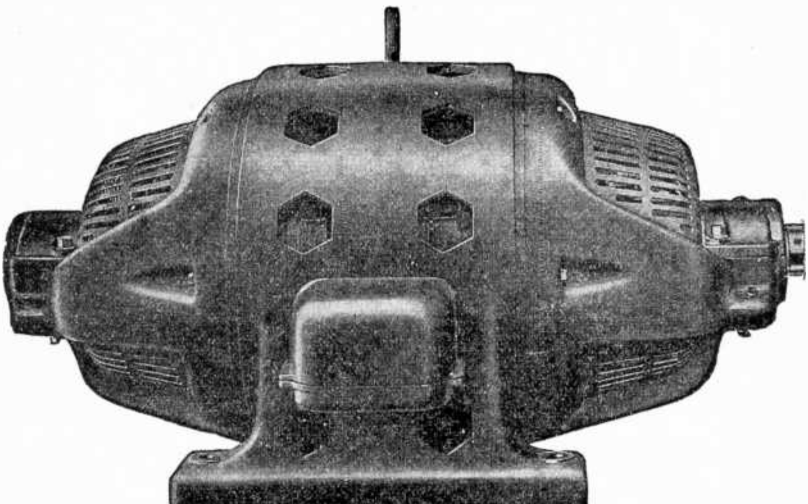


FIG. 3,014.—Fynn-Weichsel external resistance or slip ring induction self-excited synchronous motor; type design for ratings 30 *h.p.* 10 pole up to 200 *h.p.*

operate at unity power factor, or in other words, a motor that would furnish its own magnetizing current. The Fynn-Weichsel motor was produced in response to this request and according to the claims of the manufacturer (Wagner) not only accomplishes this, but in addition corrects low power factor due to other motors on the line, that is, furnishes magnetizing current for induction motors as well as for itself.

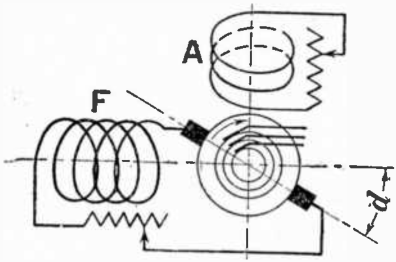


FIG 3,015.—Fynn-Weichsel motor *starting connections*. The starting equipment is similar to that of a slip ring induction motor and as easily manipulated. Pilot circuit automatic starting may be used if desired.

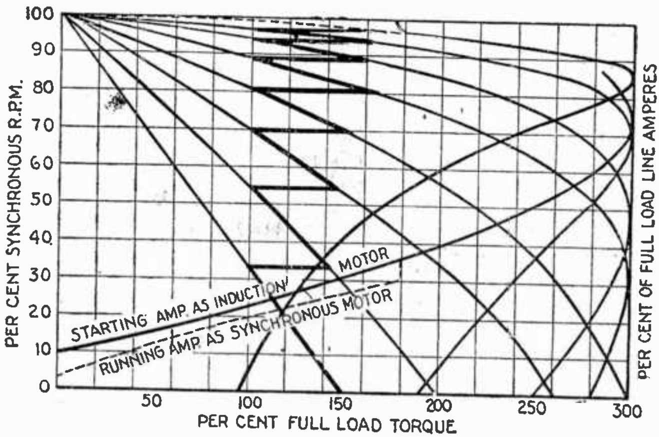


FIG. 3,016.—Fynn-Weichsel motor starting characteristics. ***It will be noted*** that the average current required during the starting period at full load torque is equal to 1 to 1.5 times normal full load running current.

Further, as claimed, for each horse power of medium and high speed Fynn-Weichsel motors installed, its leading magnetizing amperes counteract the lagging magnetizing amperes of induction motors of the same horse power and speed giving substantially unity power factor of the combined load of the two types of motors. It accomplishes this correction irrespective of the load on the two types of motors. However, if the lagging magnetizing amperes of slow speed induction motors are to be counter balanced by the leading magnetizing amperes furnished by Fynn-Weichsel motors of corresponding speed, a greater proportion of Fynn-Weichsel capacity will be

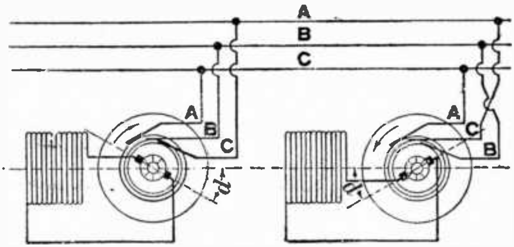


FIG. 3,017.—Fynn-Weichsel motor *running connections. To reverse* the direction of rotation reverse two line wires and shift commutator brushes.

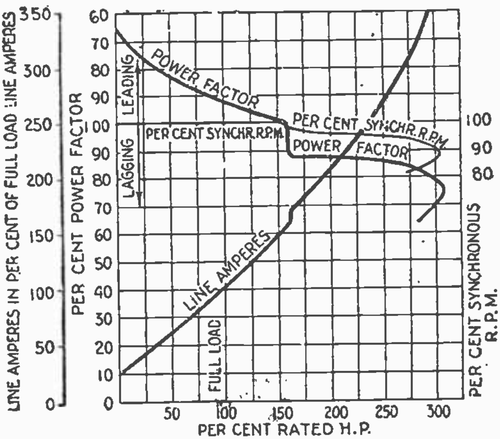


FIG. 3,018.—Fynn-Weichsel motor running characteristics; motor adjusted to operate in parallel with induction motors. *It will be noted* that the motor operates at synchronous speed with a leading power factor to about 160% load. Above this value it drops into induction motor characteristics and continues to run as a slip ring motor, to the breakdown point of approximately 300% load before it stops.

required to obtain unity power factor, due to the large magnetizing current required by slow speed induction motors.

The Fynn-Weischsel motor may be classified as *a slip ring induction synchronous motor;* that is, it starts as a slip ring induction motor and after attaining synchronous speed it becomes a self-excited synchronous motor.

Moreover, if over loaded it drops out of step and operates as an induction motor, resuming synchronous operation if the excess load be removed.

The motor consists of a stator with starting and operating field windings and a rotor field with windings carrying the load and exciting currents.

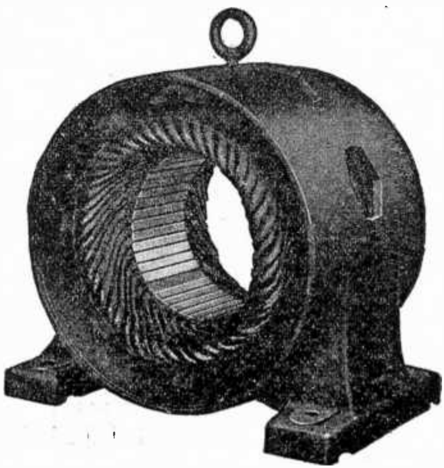


FIG. 3,019—Fynn Weichsel motor frame with starting and running field windings.

The rotor windings are connected to a commutator and slip rings of the usual construction.

Brushes bearing on the commutator suitably interconnect the stator and rotor windings.

Fig. 3,019 shows the stator construction which is quite similar to that of an induction motor. Fig. 3,020, shows the armature with its windings, slip rings and commutator. The complete motor is shown in fig. 3,014. The starting connections illustrated in fig. 3,017 are identical with those of a slip ring induction motor. The running connections are shown in fig. 3,017.

The motor is started in the same manner as a slip ring motor by reducing resistance of the secondary circuit, either manually or with an automatic starter.

The starting characteristics illustrated in fig. 3,018 are identical with those of the induction motor, with the difference, however, that the usual slip ring motor has a running speed with full load of 95 or 96 per cent of the synchronous speed while the Fynn-Weichsel motor operates at synchronous speed.

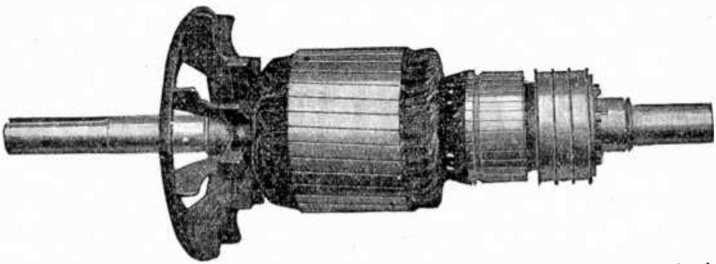


Fig. 3,020—Fynn Weichsel motor armature with windings in which are induced the load and exciting currents.

The motor is so designed that with a load which does not exceed full load by more than 25 to 50 per cent, the rotor will continue its increase in speed, without change in operating connections, until synchronism is reached.

TEST QUESTIONS

1. *What was the object in view in designing the Fynn-Weichsel motor?*
2. *What windings are on the stator?*

3. *What windings are on the rotor?*
4. *How may the Fynn-Weichsel motor be classified?*
5. *How does it start?*
6. *How does it run after starting?*
7. *Describe fully the operation of motor with variable load.*
8. *What are the starting characteristics of the motor?*
9. *What are the running characteristics of the motor?*
10. *Make sketch showing the starting connections.*
11. *Make sketch showing the running connections.*

CHAPTER 64

Converters

The alternating current must change to a direct current in many cases as in railroad work because the induction motor is not so satisfactory as the direct current series motor and the alternating current series motor is slow in coming into general use.

In all kinds of electrolytic work, transformation must be made, and in many cities where the direct current system was started, it is still continued for local distribution, but the large main stations generating alternating currents and frequently located some distance away from the center of distribution have replaced a number of small central stations.

Transformation may be made by any of the following methods:

1. Rotary converters;
2. Motor generator sets;
3. *Mercury vapor rectifiers;
4. *Electrolytic rectifiers.

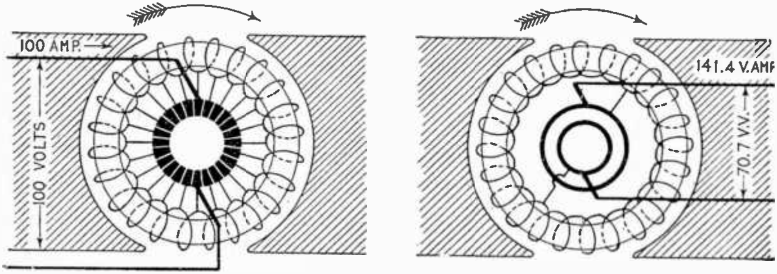
Strictly speaking, *a converter is a revolving apparatus for converting alternating current into direct current or vice versa;* it is usually called a rotary converter and is to be distinguished from the other methods mentioned above.

*NOTE.—Rectifiers are explained in detail in Chapter 71.

Broadly, however, a converter may be considered as *any species of apparatus for changing electrical energy from one form into another.*

According to the standardization rules of the A. I. E. E. converters may be classified as:

1. Direct current converters;
2. Synchronous converters;



FIGS. 3,021 and 3,022.—Gramme ring dynamo and alternator armatures illustrating converter operation. The current generated by the dynamo is assumed to be 100 amperes. Now, suppose, an armature similar to fig. 3,021 to be revolving in a similar field, but let its windings be connected at two diametrically opposite points to two slip rings on the axis, as in fig. 3,022. If driven by power, it will generate an alternating current. As the maximum voltage between the points that are connected to the slip rings will be 100 volts, and the virtual volts (as measured by a volt meter) between the rings will be $70.7 = 100 \div \sqrt{2}$, if the power applied in turning this armature is to be 10 kilowatts, and if the circuit be non-inductive, the output in virtual amperes will be $10{,}000 \div 70.7 = 141.4$. If the resistances of each of the armatures be negligibly small, and if there be no frictional or other losses, the power given out by the armature which serves as motor will just suffice to drive the armature which serves as a dynamo. If both armatures be mounted on the same shaft and placed in equal fields, the combination is a ***motor dynamo.*** In actual machines the various losses are met by an increase of current to the motor. Since the armatures are identical, and as the similarly placed windings are passed through identical magnetic fields, one winding with proper connections to the slip rings and commutator will do for both. In this case only one field is needed; such a machine is called a ***converter.***

3. Motor converters;
4. Frequency converters;
5. Rotary phase converters.

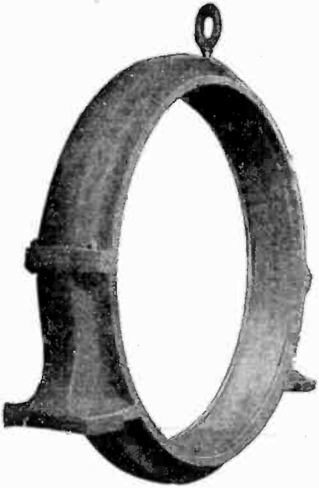


FIG. 3,023.—*Westinghouse synchronous converter construction 1. Field frame.* Material, cast steel. The frames of machines of 500 *k.w.* capacity and above are split horizontally and the upper half is provided with eye bolts so that it can be readily lifted off with its field winding. The supporting feet are cast integral with the frame.

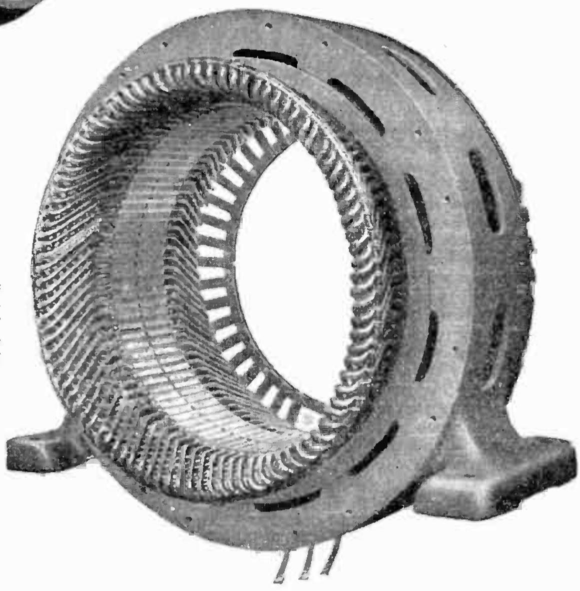


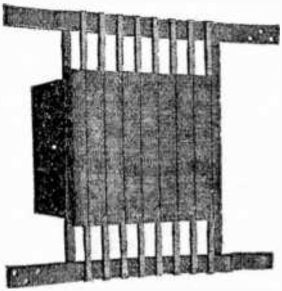
FIG. 3,024.—*Westinghouse synchronous converter construction 2. General field construction* showing assembly of poles with windings.

A direct current converter converts from a direct current to a direct current.

A synchronous converter (commonly called a *rotary converter*) converts from an alternating current to a direct current.

A motor converter is a combination of an induction motor with a synchronous converter, the secondary of the former feeding the armature of the latter with current at some frequency other than the impressed frequency; that is, it is a synchronous converter in combination with an induction motor.

A frequency converter (preferably called a *frequency changer*) converts



FIGS. 3,025 and 3,026.—***Westinghouse synchronous converter construction 3.*** Main pole showing damper winding and view showing shunt and series coils. The main poles are built up of laminated steel punchings to prevent eddy currents in the pole face. The face of the pole is punched with partially closed slots which receive the bars that form a part of the damper winding. Any pole complete with its windings can be removed without disturbing the armature or the remaining pole pieces. The shunt field coils are wound of double cotton covered wire and are made in concentric sections which are rigidly bound together over spacing blocks, leaving an air duct between them. The coils are given a thorough impregnation, which treatment removes all possible moisture and air pockets and hermetically seals the windings. When the coils are mounted on the pole pieces, heavy insulating fullerboard shields protect the sides of the coil from the pole piece. The series field coils consist of bare edge wound strap copper with insulating spacers between adjacent turns, thereby allowing a free circulation of air around each conductor. The impregnating compound, applied to the assembled shunt and series field coils, is the only insulation used on the series windings. The series coil is assembled around the shunt coil and securely bound to it, but separated on all sides from the shunt winding by spacing blocks. This assembly is made before the coils are impregnated and allows them to be handled as a unit. The starting and damping windings are made up of copper bars carried in the slots in the faces of the main poles, all bars being welded to the end ring segments. These segments are bolted together between poles facilitating the removal of an individual pole and at the same time giving a positive contact. A relatively large number of bars well distributed over the pole face is used to obtain the best practical starting and damping action.

alternating current at one frequency into alternating current of another frequency, with or without a change in the number of phases or voltages.

A rotary phase converter changes alternating current of one or more phases into alternating current of a different number of phases, but of the same frequency.

Rotary Converters.—The synchronous or rotary converter consists of a synchronous motor and a dynamo combined in one machine. It resembles a dynamo with an unusually large commutator and an auxiliary set of collector rings.

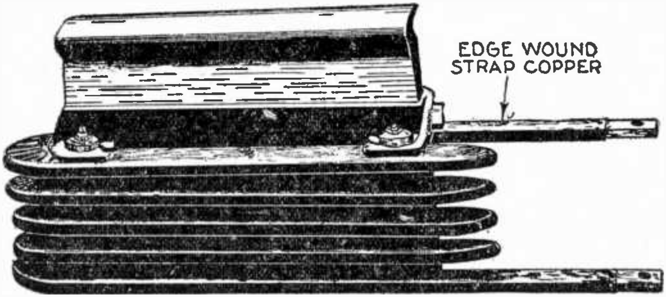


FIG. 3,027.—*Westinghouse synchronous converter construction 4. Commutating pole with winding.* The commutating pole field coils are made from edge wound strap copper. The coil is insulated from the pole piece by a heavy fullerboard shield which completely surrounds the pole piece. Insulating washers are placed between turns, allowing a free circulation of air around each conductor.

Ques. In general, how does a rotary converter operate?

Ans. On the collector ring side it operates as a synchronous motor, while on the commutator side, as a dynamo.

Its design in certain respects is a compromise between alternating current and direct current practice most noticeably with respect to the number of poles and speed.

Ques. Upon what does the speed depend?

Ans. Upon the frequency of the alternating current supplied, and the number of poles.

Fig. 3,028 is a diagram of a ring wound rotary converter. This style winding is shown to simplify the explanation. In practice drum wound armatures are used, the operation, however, is the same.

With this simple machine the following principles can be demonstrated:

1. If the coil be rotated, alternating currents can be taken from the collector rings and it is called an alternator.

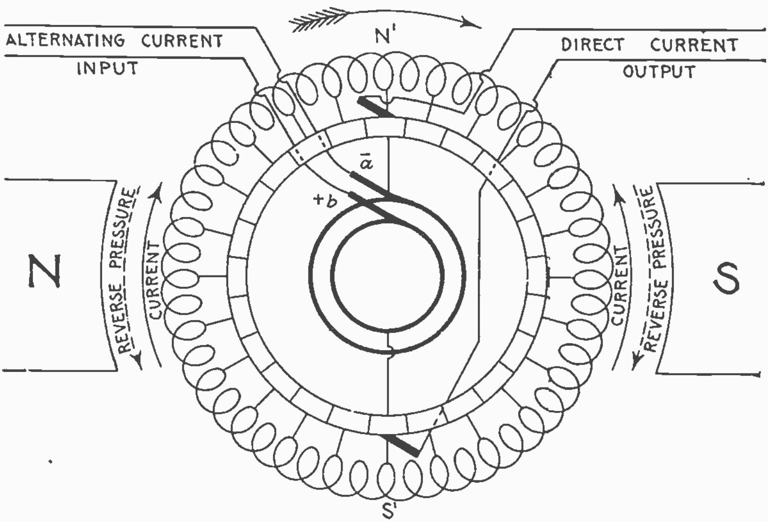


FIG. 3,028.—Diagram of ring wound single phase rotary converter. It is a combination of a synchronous motor and a dynamo. The winding is connected to the commutators in the usual way, and divided into halves by leads connecting segments 180° apart to collector rings. A bipolar field is shown for simplicity; in practice the field is multipolar and energized by direct current.

2. By connecting up the wires from the commutator segments, a direct current will flow in the external circuit making a dynamo.

3. Two separate currents can be taken from the armature

one supplying alternating current and the other direct current; such a machine is called a *double current generator*.

4. If a direct current be sent in the armature coil through the commutator, the coil will begin to rotate as in a motor and an alternating current can be taken out of the collector rings. Such an arrangement is called an *inverted rotary converter*.

5. If the machine be brought up to synchronous speed by external means and then supplied with alternating current at

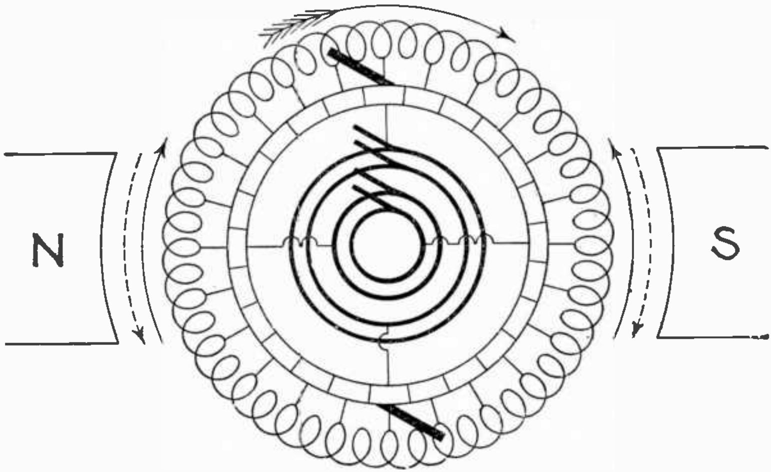


FIG. 3,029.—Diagram of two phase rotary converter. This is identical with the single phase machine with the exception that another pair of collector rings are added, and connected to points on the winding at right angles to the first, giving four brushes on the alternating side for the two phase current. The pressure will be the same for each phase as in the single phase rotary. Neglecting losses, the current for each phase will be equal to the direct current $\times 1 \div \sqrt{2}$ = direct current $\times .707$.

the collector rings, then if the direction of the current through the armature coil and the pole piece have the proper magnetic relation, the coil will continue to rotate in synchronism with the current. A direct current can be taken from the commutator, and when used thus, the machine is called simply a *rotary converter*.

Ques. What is the relation between the impressed alternating pressure and the direct pressure at the commutator?

Ans. The ratio between the impressed alternating pressure

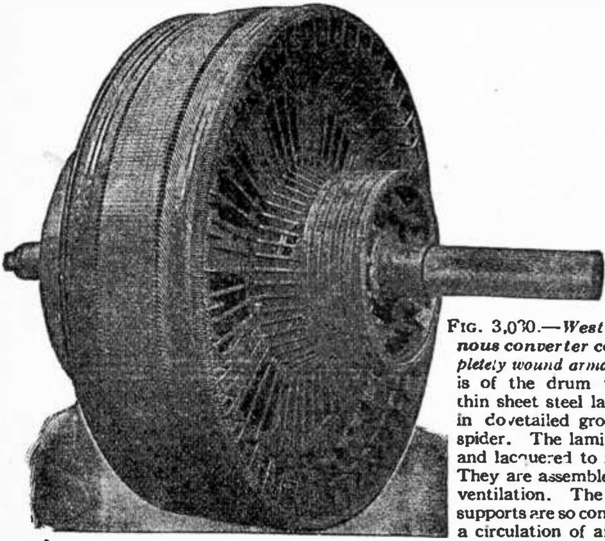


FIG. 3,030.—*Westinghouse synchronous converter construction 5. Completely wound armature.* The armature is of the drum wound type having thin sheet steel laminations supported in dovetailed grooves on a cast steel spider. The laminations are annealed and lacquered to reduce the iron loss. They are assembled with air ducts for ventilation. The front and rear coil supports are so constructed as to set up a circulation of air through the front and rear extensions of the armature coils. The armature coils are form wound, duplicate coils. Mica sheets are tightly wrapped around the portion of the coil lying in the slots and held by cotton tape. After insulation, the coils are dipped in an insulating compound and subjected to baking. The slots are lined with fish paper to protect the coil insulation during assembly. The slot portion of the coils is held in place by hard fibre wedges, and the coil ends are held firmly against the coil supports by steel banding wires. The armature has a number of cross connections to insure electrical balance.

and the direct current pressure given out is theoretically constant, therefore, the direct pressure will always be as 1 to .707 for single phase converters or if the pressure of the machine used above indicate 100 volts at the direct current end, it will indicate 70.7 volts at the alternating current side of the circuit.

Ques. Name two different classes of converter.

Ans. Single phase and polyphase.

Ques. What is the advantage of polyphase converters?

Ans. In the majority of cases two or three phase converters are used on account of economy of copper in the transmission line.

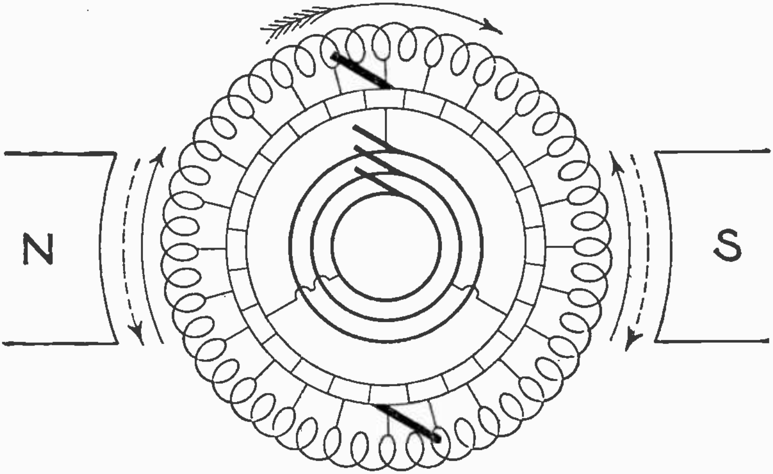
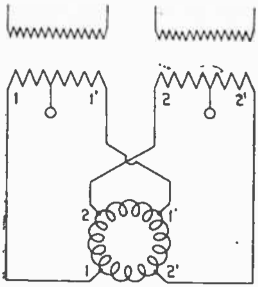


FIG. 3,031.—Diagram of three phase rotary converter. In this type, the winding is tapped at three points 120° distant from each other, and leads connected with the corresponding commutator segments.

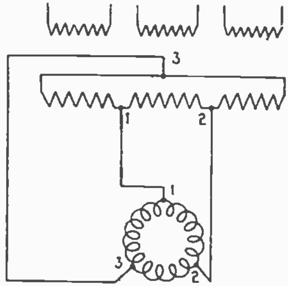
Ques. How is the armature of a polyphase converter connected?

Ans. Similar to that of an alternator with either delta or Y connections.

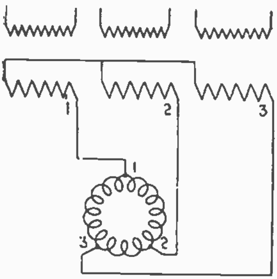
Figs. 3,032 to 3,036 show various converter connections between the collector rings and commutator.



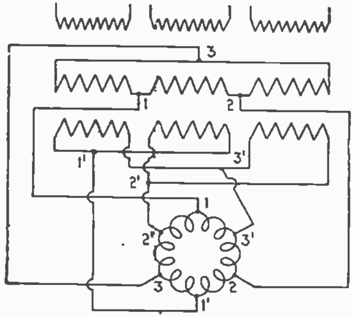
TWO PHASE



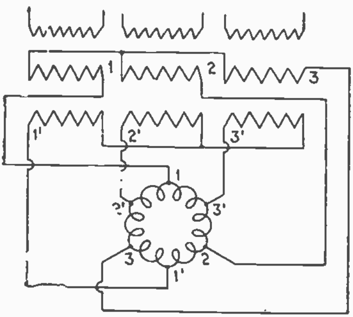
THREE PHASE Δ



THREE PHASE Y



SIX PHASE Δ



SIX PHASE Y

Figs. 3,032 to 3,036.—Various rotary converter and transformer connections. Fig. 3,032 two phase connections; fig. 3,033 three phase delta connections; fig. 3,034 three phase Y or star connections; fig. 3,035 six phase delta connections; fig. 3,036 six phase Y connections.

Fig. 3,032 indicates how the armature is tapped for two phase connections.

Fig. 3,033 shows three phase delta connections, and fig. 3,034 the three phase Y or star connections.

Six phase delta and Y connections are frequently used as shown in fig. 3,035 and fig. 3,036, both of which require two secondary coils in the transformer, one set of which is reversed, so as to supply the current in the proper direction.

Ques. With respect to the wave, what is the relation between the direct and alternating pressures?

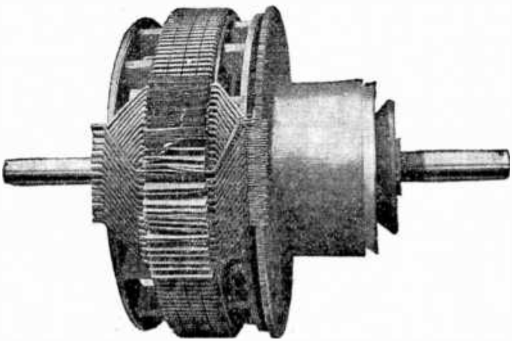
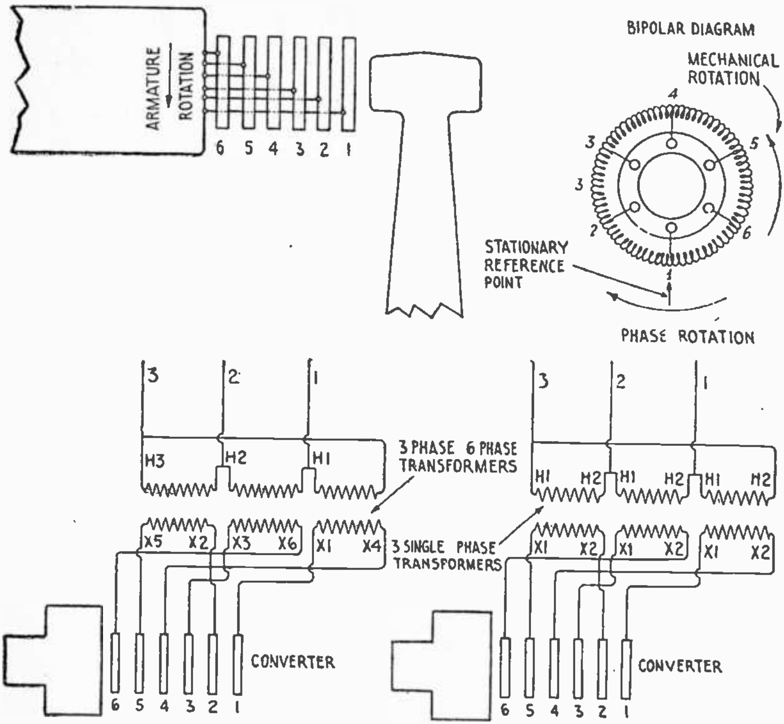


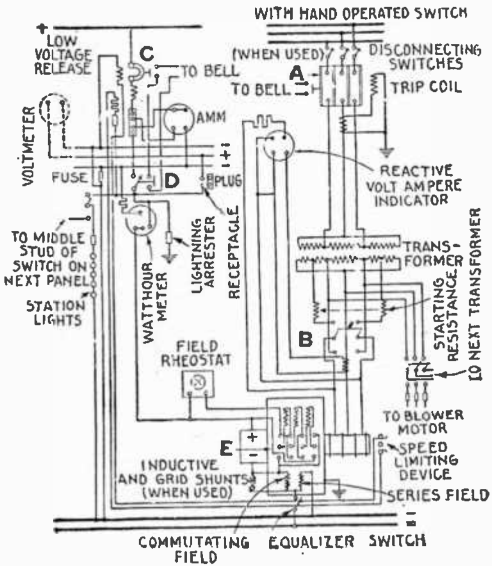
FIG. 3,037.—*Westinghouse synchronous converter construction 6. Partially wound armature showing commutator.* The commutator is made of hard drawn copper bars insulated from each other with moulded mica and held in position by V rings on each end. The cast steel V rings are insulated from the commutator by moulded mica V rings. A moulded mica sleeve also insulates the commutator from its spider. After the commutator is assembled and seasoned, the mica between bars is undercut affording a contact between brushes and commutator and permitting the use of a softer grade of brush.

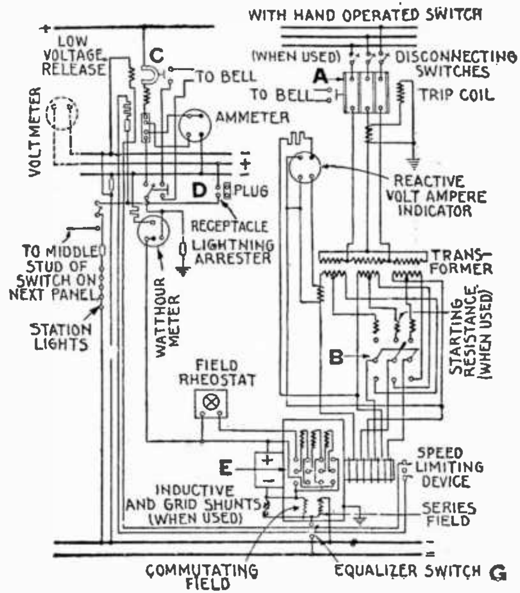
Ans. The direct current voltage will be equal to the crest of the pressure wave while the alternating voltage will depend on the virtual value of the maximum voltage of the wave according to the connections employed.

In a single phase rotary, the value of the direct pressure is 1 to .707, therefore a rotary which must supply 600 volts direct current must be supplied by 600×.707=424 volts alternating current. For three phase



FIGS. 3,038 to 3,041.—Phase rotation in synchronous converters. Figs. 3,038 and 3,039 for 6 phase machine; figs. 3,040 and 3,041 primary and secondary phase rotation in 3 phase diametrical transformers for 6 phase synchronous converter. Synchronous converters are always designed to run clockwise viewed from the commutator end, or counter-clockwise from the collector end and the phase rotation is 1-2-3-4-5-6. The collector rings are numbered from the bearing in toward the armature as in fig. 3.038. The phase rotation on the high voltage side of the transformers is 1-2-3, as shown in fig. 3,039, which shows the corresponding low voltage connections for both 3 phase and 6 phase transformers and for 3 phase and 6 phase transformers and for three single phase transformers. In the case of 3 phase, 6 phase transformers, refer to the numbering of the leads, rather than their mechanical position, as certain forms of 3 phase transformers may have a different mechanical arrangement of low voltage leads from the one shown. When the phase rotation of the high tension supply is known, this diagram may be followed in making the primary connections; if it be not known, make the connections temporarily in the most convenient manner and try them out. In either case, the connections should be tested before any attempt is made to run the converter on full voltage from the *a.c.* end.





Figs. 3,042 and 3,043.—Converter connections. Fig. 3,042, three phase 600 volts; fig. 3,043, six phase 600 volts. It is customary to ground converter bases. The ground connection should be heavy enough to safely carry the short circuit current in case of an armature ground. Do not run single *a.c.* leads through iron pipe—two leads opposite in phase, or three leads 120° apart in phase may be run through a single pipe.

rotaries the ratio is 1 to .612, or in order to produce 600 volts direct current, 600×.612=367 volts on the alternating current side of the rotary is required.

Fig. 3,028 shows a complete diagram of the electrical connections. A single phase rotary is illustrated so as to simplify the wiring.

The table of Steinmetz on page 2,038 gives the values of the alternating volts and amperes in units of direct current.

Ques. How is the voltage of a rotary varied on the direct current side?

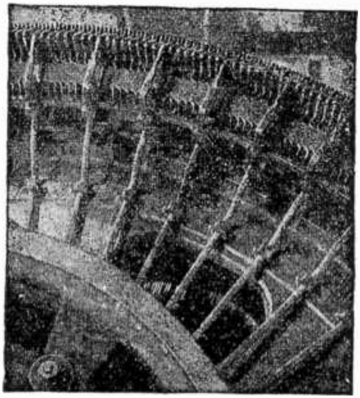


FIG. 3,044.—*Westinghouse synchronous converter construction 7.—Equalizer connections and taps to collector ring.*

Ans. Pressure or potential regulators are put in the high tension alternating current circuit and may be regulated by

NOTE.—***An ideal method*** for controlling the voltage between the *d.c.* terminals of a synchronous converter would be to shift the *d.c.* brushes; by so doing the voltage between the *d.c.* terminals could be varied from its full value to zero independently of any change of the voltage between the *a.c.* terminals of the machine. This method of voltage control is, however, impracticable because of the sparking which is produced at the *d.c.* brushes when they are shifted from the neutral axis. To overcome this difficulty Mr. J. L. Woodbridge proposed the split pole converter (see figs. 3,064 to 3,066, page 2,044), in which each field pole is split into two (or three) parts. One of these parts is permanently excited, and it produces near its edge the fringe of field which is necessary for sparkless reversal. The other portion of each field pole is arranged so that its excitation may be increased or decreased at will, thus shifting the resultant axis of the field with respect to the *d.c.* brushes. The result is exactly equivalent to the shifting of the *d.c.* brushes in so far as the voltage relations of the converter are concerned.

small motors operated from the main switchboard or operated by hand.

Ques. What is the advantage of unity power factor for rotary converters?

Ans. It prevents overheating when the rotary is delivering its full load in watts.

Ques. What greatly influences the power factor of the high tension line?

Ans. The strength of the magnetic field.

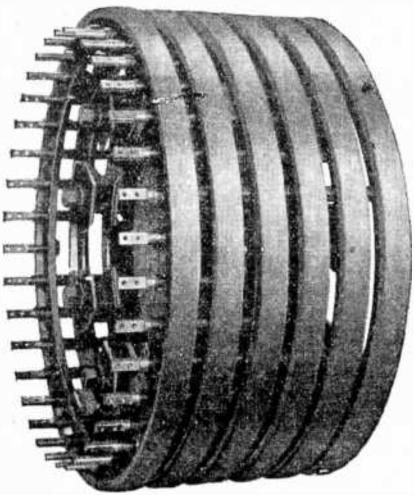
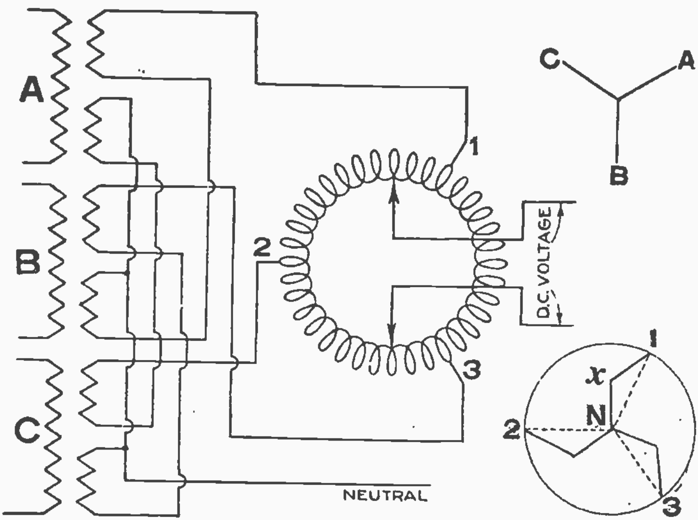


FIG. 3,045.—*Westinghouse synchronous converter construction 8. A. C. collector rings.* The rings are made of a bronze alloy. In the smaller size machines, the rings are shrunk on a cast iron spider insulated by a mica bushing held on by cotton tape and covered with an insulating varnish. In the larger machines, the rings are bolted to a spider by means of insulated bolts and washers. The brass rods to which the collector connections are attached are insulated with micarta tubing and tapped into the individual collector rings.

Ques. Does variation of the field strength materially affect the voltage?

Ans. No.

Since variation of the field strength does not materially affect the voltage, by adjusting the resistance in series with the magnetic circuit, the strength of the field can be changed and the power factor kept 1 or nearly 1 as different loads are thrown on and off the rotary



FIGS. 3,046 to 3,048.—Transformer connections for interconnected Y and voltage vector diagrams A,B,C, for the primary windings and N,1,2,3, for the converter armature. The interconnected Y arrangement utilizes for each phase two half windings which have a 120° phase difference. This arrangement provides a neutral point for use with three wire, *d.c.* service and in addition eliminates the magnetizing effects produced by unbalanced direct currents. ***In the diagrams,*** leg N1, is formed by the upper secondary winding of A, and the lower secondary winding of B, consequently its voltage vector is the sum of 1*x*, along the line A, and *x*N, along the line B. Since the radius of the circle is $2(x\text{N})\cos 30° = 1.732$ (*x*N), and since the voltage ratio for the three phase converter to neutral is .354, it follows that the alternating voltage on each secondary section for unit direct current voltage is $.354 \div 1.732 = .204$.

NOTE—***Allis Chalmers synchronous converters*** are self starting from either the alternating or direct current side. The former, however, is the usual practice, the machine being designed to start as an induction motor. This is accomplished by leading the alternating current to the collector rings at a reduced voltage. The reaction between the armature currents and the current set up in the field structure causes the machine to start up as an induction motor. The field structure is provided with special damping devices, or amortisseur windings, as they are sometimes called, to produce a large starting torque with a relatively small current from the line. On larger sizes, brush lifting devices are furnished to raise the brushes during the starting period. This device is not necessary for the smaller sizes as excessive sparking is eliminated by specially designed commutating poles. All machines are designed for starting without a field breakup switch. The switchboard controlling the converter should contain a double pole single throw field switch with a discharge clip, usually mounted on the starting panel, the machine being started with this switch closed. If the converter be operated inverted, that is, from direct to alternating current, it is started from the direct current side very much as an ordinary direct current motor, and when brought up to the proper speed, as shown by a synchroscope or synchronizing device of some kind, thrown on the line.

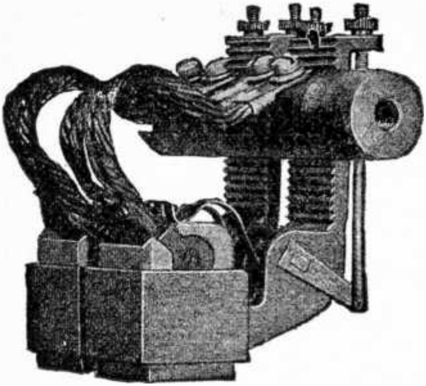


FIG. 3,049.—*Westinghouse synchronous converter construction 9. D.C. brush holder with brush and lifting lug.* The sliding shunt type is used arranged with a corrugated face; they are bolted to the brush holder bracket. These slots in the brush holder make it possible to place the holder at the proper distance from the commutator face. The spring is so arranged as to make it possible to maintain practically uniform tension through the entire wearing length of the brush. The brush holder spring and spring support are so located as to be protected from damage caused by any flashing which might occur at the commutator.

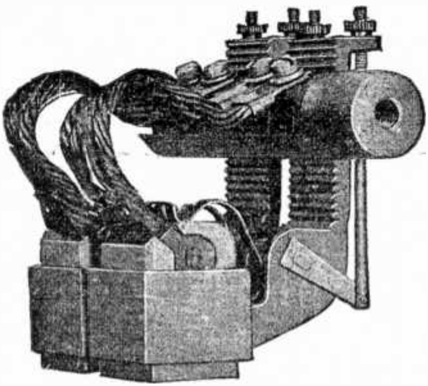


FIG. 3,050.—*Westinghouse synchronous converter construction 10. A. C. brush holder.* They are of the sliding shunt type arranged for mounting on a stud. The spring and tension adjusting mechanism being similar to that on the *d.c.* holder except that a thumb nut micrometer adjustment is employed, which gives an accessible and ready means of adjustment of brush pressure.

NOTE—*Compounding pole synchronous converters* for railway and industrial service are normally compound wound and arranged for automatic compounding which is effected by the proper combination of series excitation and reactance between the generator and converter. This reactance is normally included in the transformer but in special cases may be partly in the transformer and partly in a separate reactance. It is possible to produce by this means approximately constant direct current voltage, provided the voltage drop in the alternating current line be not excessive. Usually it is not practicable to over compound, as an excessive amount of reactance is necessary if the voltage drop in the alternating current be appreciable.

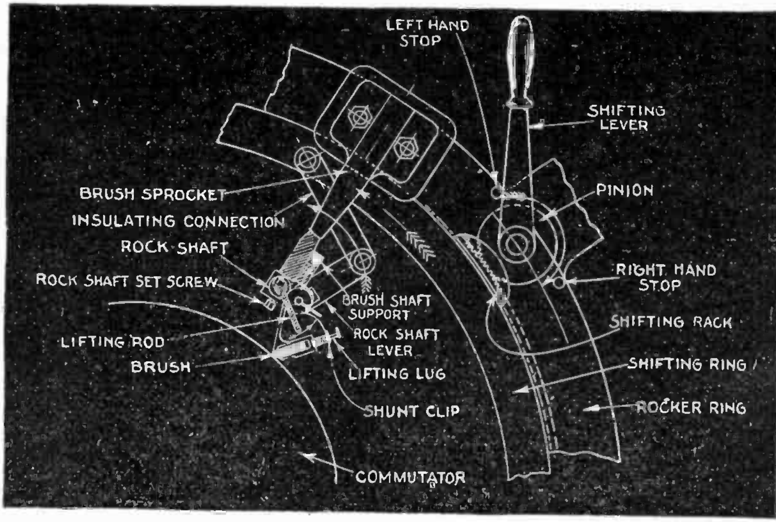


FIG. 3,051 —*Westinghouse synchronous converter construction II. D. C. brush lifting device. It consists of* a cast iron brush shifting ring which fits into a recess in the brush holder rocker ring and is free to turn. Movement of the brush shifting ring is obtained by a shifting lever which provides, by means of the shifting rack and pinion, sufficient movement of the brush shifting ring to raise the brushes from the commutator. A right angle connector for each brush holder bracket is pivoted to the brush shifting ring, the long arm of which is made of hard fibre for means of insulation. The connector head, or short arm, is metal and is pivoted to the rock shaft lever. The rock shaft lever is rigidly fastened to the rock shaft by a set screw. The rock shaft extends the length of the brush holder bracket and is supported by brackets bolted to the brush holder arm. The lifting rod is steel and parallels the rock shaft the entire length of the brush holder bracket, and is rigidly fastened to the rock shaft at each end. Any movement of the shifting lever is imparted to the lifting rod which in turn raises the brushes from the commutator.

NOTE.—*Treatment of commutator and brushes.* Converters are frequently shipped with the commutators freshly ground. This and the initial condition of the brush face do not constitute a fit condition for carrying loads, and heavy loads must not be put upon a converter when first put in service. This point must be insisted upon, for if the converter be misused in this respect, its commutator may reach such a condition as to require turning, and a great deal of trouble may be experienced before proper condition is obtained. If, on the other hand, the following instructions be followed, good results are assured. When the armature is received with the commutator polished from factory testing, the converter may be loaded at once as heavily as the condition of the brush surfaces will permit with good commutation, but if the commutator be not polished, the machine should be run light for at least 24 hours with normal brush pressure, and then an additional 24 hours at approximately half load, in order to establish a polish on the commutator surface. The desired surface will show a very high polish by reflected light and will vary in color from a light straw to a dark brown or even a blue gray the actual color being of no consequence as long as the bars are polished uniformly

Ques. What is the effect of a field too strong or too weak?

Ans. If too strong, a leading current is produced, and if too weak, the current lags, both of which reduce the power factor and are objectionable.

Usually there is a power factor meter connected up in the main generating station and one also in the rotary substation, and it is the duty of the attendant at the substation to maintain the proper power factor.

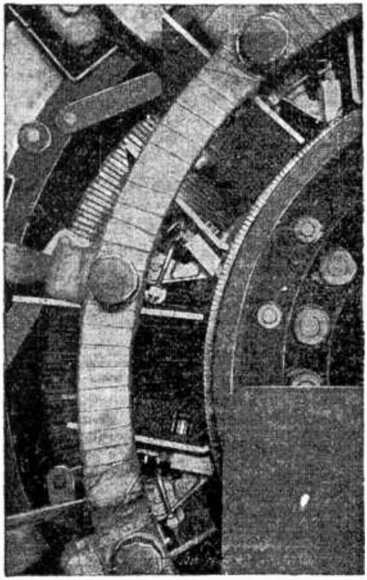


FIG. 3,052.—*Westinghouse synchronous converter construction 12. D.C. flash barriers.* They are standard on all 50 cycle and 60 cycle railway converters. All sizes of *d.c.* brush holders are, however, provided with the lug and tapped hole for mounting flash barriers where special applications or needs demand them on other than railway machines. These barriers do not interfere with the proper maintenance and upkeep of the *d.c.* brushes and commutator which is important from a practical operating standpoint. It is obvious that even the most efficient brush holder will not prevent the generation of gas under short circuit conditions. Therefore, barriers must be able to control as well as dispose of the conducting gases. The space between the barriers forms an arc chute through which generated gases escape, causing minimum damage to brush holders and brushes, which are the parts usually injured by flashing.

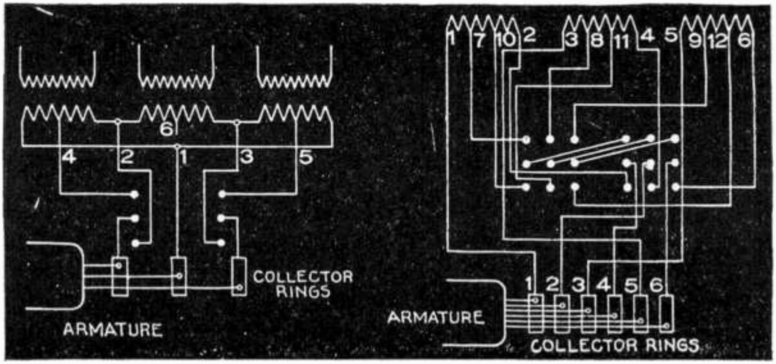
NOTE.—*Continued.*
from edge to edge. Use no lubricant on the commutator either during the polishing period or subsequently. Both the carbon and the graphite brushes now furnished on synchronous converters are self-lubricating, and their characteristics are seriously impaired by the use of any external lubrication. Self-lubricating carbon brushes may in some instances leave a black deposit on the commutator when first put into service. This deposit should be wiped off as rapidly as it appears by means of a piece of dry canvas or other hard, non-linting material, which should be wound around a block and held against the commutator with sufficient pressure to remove the blackening. While the converter is being run to polish the commutator and fit the brushes, the end play device should be in operation so that the commutator and the collector rings will be polished uniformly.

Ques. What is the ordinary range of sizes of rotaries?

Ans. From 3 *kw*. to 3,000 *kw*.

Ques. What is the general construction of a rotary converter?

Ans. It is built similar to a dynamo with the addition of suitable collector rings connected to the armature windings at points having the proper phase relations.



FIGS. 3,053 and 3,054.—***Alternating current starting.*** Synchronous converters are generally started from the *a.c.* side like polyphase synchronous motors. The current in the armature induces a magnetic field in the pole pieces, and as the iron has hysteresis, the induced field lags behind the current producing it, thus creating a torque. It is, however, necessary to reduce the voltage at starting in order to prevent a heavy rush of current and this is done by providing taps on the transformer secondaries. Fig. 3,053 shows the arrangement of taps for starting three phase converters, leads 1, 2 and 3 being the operating terminals, and leads 1, 4 and 5 those for starting at half voltage. Lead 6 is merely for the purpose of making the three transformers duplicates. Large converters are usually connected six phase diametrical, and when started from the *a.c.* side, it is desirable to provide taps on the transformers for one-third and two-thirds voltage as shown in fig. 3,054. Leads 1 to 6, inclusive, are the operating terminals; leads 1, 3, 5, 7, 8, and 9 are for the first step, and leads 1, 3, 5, 10, 11 and 12 are for the second step. Leads 2, 4 and 6 are for the final or full voltage step. Leads 1, 3 and 5 are connected directly to the converter and the starting is done by two triple pole double throw switches as shown. When *a.c.* is used for starting, the armature winding stands in relation to the field winding, as the primary of a stationary transformer to the secondary. A large number of turns in the field spools, compared with the turns in the armature, may produce in the field winding a high induced voltage which should be kept within safe limits. This is done by breaking up the field circuit between the spools by means of a switch provided for that purpose on the frame of the machine.

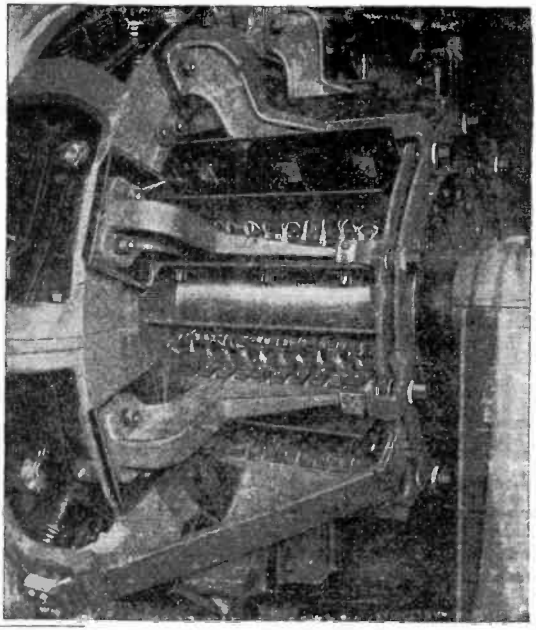


FIG. 3,055.—*Westinghouse synchronous converter construction 14. Insulation showing cup type washers and pedestal flash barrier.*

NOTE.—*The a.c. starting method* does not require any complicated or expensive apparatus, the same switches being used for both starting and running connections. Since it is self-synchronizing, there is little possibility of confusion by the operator, as the difficulty of accurately adjusting the speed is eliminated and less time is required for the starting. After seeing that all the machine switches are open, the high tension oil switch is closed. Then the first starting switch is closed and the converter should start, running on one-half or one-third of the normal voltage as the case may be. As the speed of the machine increases, a volt meter connected across the *d.c.* side will oscillate back and forth and finally come to rest in either a positive or a reverse direction, that is, the machine may come up to synchronism with either positive or negative polarity. For this reason, it is customary to make the field switch double throw and this switch is thrown in the normal position if the volt meter indicate positive polarity. If, however, it show that the polarity of the converter is reversed, the field switch is closed in the other direction, reversing the current through the field coils. The flux set up by this reversed current in the field coils opposes and overcomes the flux induced by the *a.c.* flowing in the armature, causing the armature to drop in speed until it slips a pole, and when the pressure at the brushes is brought to zero, there is no field current and the polarity reverses. If the field switch be now opened, the converter will run in synchronism and the field switch is thrown to its original position, after which the machine is thrown successively on the two-third and the full-voltage taps. When the last switch is closed, the converter is running on full voltage and is ready for service after adjusting the shunt field rheostat to give proper voltage for the station bus bars. Three phase machines starting on one-half voltage taps with the external reactance coils in the circuit will take three-fourths to full load primary current and six phase machines starting on one third voltage taps without the reactance coils in the circuit, approximately three-fourths primary current.

Standard rotary converters have been developed for 25 and 60 cycles. The standard railway machines are compound wound, the series field being designed for a compounding of 600 volts at no load and full load when supplied from a source of constant pressure with not more than 10 per cent. resistance drop and with 20 to 30 per cent. reactance in the circuit. The large size machines are usually wound for six phase operation.

Compounding of Rotary Converters.—Compounding is desirable where the load is variable, such as is the case with inter-

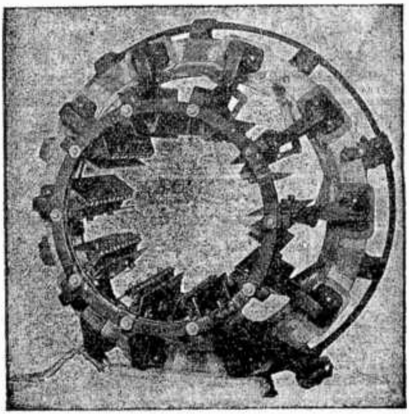
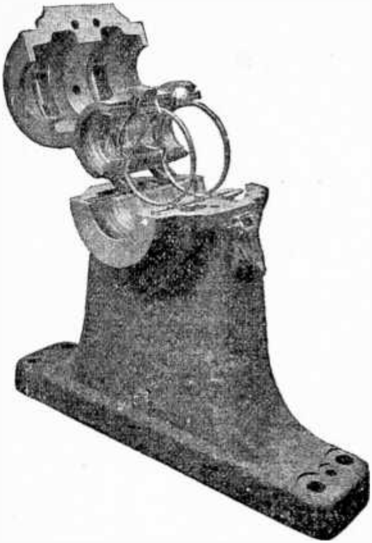


FIG. 3,056.—*Westinghouse synchronous converter construction 13. D. C. brush rigging.* The location of the brush holder cross connecting rings at the outer ends of the brush holder brackets produces a pronounced tendency toward reducing the effect of a flash over to a minimum by flux control over the arc paths. Cup type insulating washers behind the *d.c.* brush holder brackets give the maximum creepage distance and consequently, the maximum protection against arcing to ground. This type washer is used on 60 cycle railway converters of 1,000 *k.w.* and larger. Flat washers are used on the smaller machines.

urban railway systems. The purpose of the compounding is to compensate automatically for the drop due to line, transformer and converter impedance.

On account of the low power factor caused by over compounding, and the fact that substations are customarily connected to the trolley at its nearest point without feeder resistance, over compounding is not recommended. An adjustable shunt to the series field is provided with each machine.



Shunt wound converters are satisfactory for substations in large cities and similar installations where, due to the larger number of car units demanding power, the load is more nearly constant.

Fig. 3,057.—*Westinghouse synchronous converter construction 15. Pedestal bearing.* All converters are equipped with bearings which are horizontally split. The lower half of the bearing housing is cast integral with the pedestal.

NOTE.—*End play device and speed limiting switch.* In order that the brushes may not wear grooves in the commutator and collector rings, the armature should have a slight reciprocating motion parallel with the shaft. To obtain this motion the larger machines are provided with an automatic, *magnetic* end play device. Current for its operation is obtained from the *d.c.* side of the converter. A condenser is connected across the make and break to facilitate the opening and closing of the circuit. Small machines having comparatively light armatures are equipped with a mechanical end play device. All synchronous converters are equipped with a device for automatically opening the direct current circuit in case the speed become too high. This safety device (or speed limiting switch, as it is generally called) consists of a switch which is operated by a centrifugal governor. The centrifugal weight is mounted on the shaft and revolves with it, while the switch is stationary and is mounted on the collector end pillow block. This weight is so designed that it operates at practically the same speed irrespective of the acceleration. The switch can be adjusted to operate at any predetermined speed. Under normal operating conditions, the circuit of the low voltage release coil on the line circuit breaker is closed, but should the speed of the converter increase to the predetermined setting, the switch will open, thus opening the line circuit breaker. The current carrying parts are all stationary and so constructed that failure to operate is practically impossible when properly adjusted. It should be noted that the end play device and speed limiting switch are usually mounted at opposite ends of the shaft so that the operation of one does not in any way interfere with that of the other.

Table of

Alternating Current and Voltage in Terms of Direct Current

(According to Steinmetz)

	DIRECT CURRENT	SINGLE PHASE	TWO PHASE	THREE PHASE	SIX PHASE	TWELVE PHASE	n PHASE
VOLTS BETWEEN COLLECTOR RING AND NEUTRAL POINT	1	$\frac{1}{2\sqrt{2}} = .354$	$\frac{1}{2\sqrt{2}} = .354$	$\frac{1}{2\sqrt{2}} = .354$	$\frac{1}{2\sqrt{2}} = 354$	$\frac{1}{2\sqrt{2}} = .354$	$\frac{1}{2\sqrt{2}} = .354$
VOLTS BETWEEN ADJACENT COLLECTOR RINGS	1	$\frac{1}{\sqrt{2}} = .707$	$\frac{1}{2} = .5$	$\frac{\sqrt{3}}{2\sqrt{2}} = .612$	$\frac{1}{2\sqrt{2}} = .354$	.183	$\frac{\sin\frac{\pi}{n}}{\sqrt{2}}$
AMPERES PER LINE	1	$\sqrt{2} = 1.414$	$\frac{1}{\sqrt{2}} = .707$	$\frac{2\sqrt{2}}{3} = 943$	$\frac{\sqrt{2}}{3} = .472$	.236	$\frac{2\sqrt{2}}{n}$
AMPERES BETWEEN ADJACENT LINES	1	$\sqrt{2} = 1.414$	$\frac{1}{2} = .5$	$\frac{2\sqrt{2}}{3\sqrt{3}} = .545$	$\frac{\sqrt{2}}{3} = .472$	.455	$\frac{\sqrt{2}\sin\frac{\pi}{n}}{n}$

Ratio of Conversion.—The relation between the alternating and direct current voltages varies slightly in different machines, due to differences in design. The best operating conditions exist when the desired direct current voltage is obtained with unity power factor at the converter terminals when loaded.

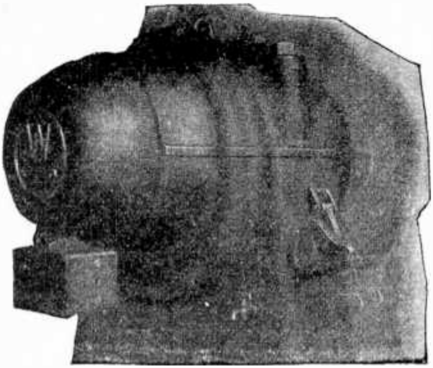


FIG. 3,058.—*Westinghouse synchronous converter construction 16. Speed limit device.*

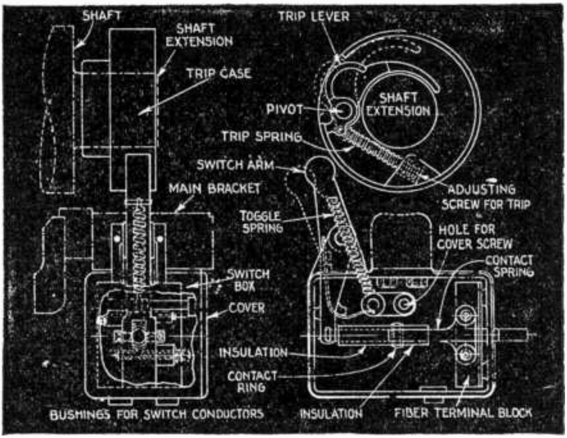
Ques. Upon what does the ratio of conversion depend?

Ans. Upon the number of phases and method of connecting the windings.

NOTE.—*Adjustment of end play device.* After the machine has been brought up to voltage, the end play device should start automatically into operation. If the armature will not come forward or back from the end play device it is due to an endwise pull of the field. Test the machine by running up to full speed on the *a.c.* starting tap and pull off the power without closing the field circuit. If the machine then oscillate freely in either direction and will not oscillate when up to voltage with field closed, trouble is due to pull of field. If this field pull, hold the armature over against, or near to one of the bearings so that the coil detector bumps against it when the armature oscillates, the field should be removed slightly in the opposite direction to correct it. In making this movement, take care not to disturb the air gap by shifting the field to one side or the other. Make reference marks on the feet of the field frame and on the base; move one side of the field exactly the same amount as the other, and take care to give no lateral movement Then dowel the field in the proper position for the best operation of the end play device.

NOTE.—There is always a certain approximate ratio between the alternating and direct current voltage of any given synchronous converter, and the alternating current voltage is the smaller of the two. The ratio varies with the number of phases for which the converter is designed. *For a d.c. voltage of 1,* the *a.c.* voltage will be single phase, .707; two phase, .707; three phase, .615; six phase double delta, .615; six phase diametrical, .707.

For single phase or two phase machines it is 1 to .7; for three phase, 1 to .612, or six phase, 1 to .7 or 1 to .613 depending upon the kind of connection used for the transformer.



FIGS. 3,059 to 3,061.—***Westinghouse synchronous converter construction 17. Detail of speed limit device.*** That end of the shaft upon which the device is mounted is turned to a smaller diameter than the bearing surface of the shaft. Upon this "turned down" portion of the shaft is mounted the centrifugal governor with an adjusting spring which allows it to be adjusted to operate at any predetermined speed. The switch contained in a metal box attached to the bearing housing, completes an auxiliary circuit through the tripping coil of the *d.c.* breaker, and is held closed or open by a pivoted latch so arranged that when the governor operates it trips the latch and releases the spring, insuring a quick and positive opening or closing of the switch. The standard arrangement is for the circuit of the device to be normally closed and to trip open, since this arrangement will immediately detect any trouble in the wiring connections.

NOTE.—***Adjustment of speed limit device.*** This device is adjusted at the factory (General Electric practice) to trip at 15% over speed. Check this adjustment before putting the converter into service in order to detect any change during shipment. For this overspeed test, the machine may be belted and driven by an auxiliary motor, or it may be run inverted as a *d.c.* motor and brought to the required overspeed by weakening the shunt field. In order to control the speed of compound wound converters operating as motors it will probably be found safer to disconnect or reverse the series field, or short circuit it, since the series field opposes the shunt field and tends to make the converter run away. Use an accurate speed indicator or tachometer, and check it first at the synchronous speed of the converter. Open the speed limit switch first by hand to test the circuit breaker trip coil and show that the breaker opens properly. If the speed limit device then fail to open the breaker at the required overspeed, reduce the tension on the spring by turning the nut on the adjusting screw, and conversely, if the speed limit operate at too low a speed, increase the tension on the spring. Check the final adjustment twice.

For example, a two phase rotary receiving alternating current at 426 volts will deliver direct current at 600 volts, while a three phase rotary receiving alternating current at 367 volts will deliver direct current at 600 volts.

Ques. What difficulty would be encountered if other ratios of conversion than those given above were required?

Ans. An armature with a single winding could not be used.

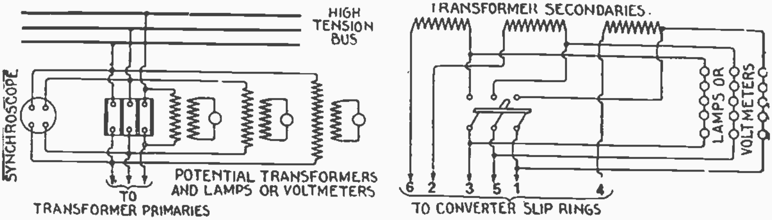
It would be necessary to use a machine with two distinct armature windings or else a motor generator set.

Ques. What change in voltage is necessary between a converter and the alternator which furnishes the current?

Ans. The voltage must be reduced to the proper value by a step down transformer.

Voltage Regulation.—As the ratio of the alternating to the direct current voltage of a converter is practically constant, means must be provided to compensate for voltage variation due to changes of load in order to maintain the direct current pressure constant.

NOTE.—*In the rotary converter* no lead in either sense need be given to the brushes; for the armature reactions of the motor part being, in general, opposed by those in the dynamo part, they cancel one another to a large extent. This property is common to all those motor generators in which there is used, whether with one winding or two, a common core in a common field. The relations between speed and field are peculiar. In the case of those grouped machines, or motor-dynamos in which each armature revolves in its own field, the conditions differ from those of the converter, where there is only one field. If in either case the continuous-current side is the primary (*i.e.* motor) side, the speed of revolution will depend on the field-magnet, the weakening of which will increase the speed. The frequency of the secondary or alternating current will in that case also vary. But the ratio of the primary and secondary voltages will be independent of speed if the fields be alike, or if only one common field be used. The secondary voltage cannot be varied, while the primary voltage is kept constant, unless separate fields and separate windings be employed. If, on the other hand, the alternating-current side be used as primary, then the machine, whether motor dynamo or converter, runs as synchronous motor with a fixed speed.



FIGS. 3,062 and 3,063.—"Phasing out" a synchronous converter. Fig. 3,062 on high tension side of the transformers. Raise the *a.c.* brushes and slip a sheet of varnished cambric or other insulating material between the brush holders and the rings. Close the oil circuit breakers and close the low tension starting switch on the down or running position. Make certain that the full secondary voltage appears at the brushes which bear on the diametrical rings 1-4, 2-5, and 3-6. Then open the starting switch and put the *a.c.* brushes down on the rings. The transformer secondaries will then be connected in Y, the stationary converter armature forming a low resistance neutral, compared with the resistance of the voltmeter, and the following voltage relations should exist at the switch: The voltages between blades and upper, or starting clips, should be the starting voltage, approximately ½ of the secondary voltage. The voltage between blades and lower, or running clips, should be full secondary voltage. Any deviation from these requirements indicates an interchange of starting and running leads. The voltage between each upper clip and the corresponding lower clip should be the difference between the starting voltage and full voltage, or approximately ½ secondary voltage. Any deviation from this requirement indicates an interchange of two starting or two running leads. The voltage between any two upper clips should be about 87 per cent of full secondary voltage and the voltage between any two lower clips should be twice this amount, or about 1¾ times full secondary voltage. Any deviation from this requirement indicates a reversed transformer secondary, or that the switch is connected in consecutive phases instead of alternate phases, as shown. If the voltages at the switch be properly symmetrical according to the above tests, the phase rotation must then be checked. The method of phasing out will depend upon the character of the equipment, and the available auxiliary apparatus. When the converter is arranged to start from the *a.c.* end, and a separate high tension bus fed by a single generator can be used to start the converter, a convenient method is to start the converter first on the starting taps, and then on the running taps by reducing the primary voltage. If a separate bus and generator be not available, start the machine on ½ voltage in the ordinary manner, but before throwing it to full voltage, check the voltages at the starting switch as follows: The voltage between each blade and the corresponding lower clip should be approximately ½ voltage and the voltage between any two lower clips should be about 130 per cent of full secondary voltage. When the converter is designed to start from the *d.c.* side or by an induction motor it must be phased out by means of lamps or volt meters connected around the oil switch as in fig. 3,062 or around the low tension switches as in fig. 3,063. If possible, the synchroscope should be checked at the same time by connecting the lamps at the switch it is connected across. Any apparatus connected across the open switches should be capable of standing double line voltage. While "phasing out" converters designed to be synchronized at the oil switch, make certain that one phase is not reversed on the secondaries, since a reversed secondary phase with delta primary is equivalent to a short circuit. Such a reversal will make itself apparent by excessive current when starting with the transformers connected to the converter, so that the converter will not come to speed from the direct current end, or in the case of induction motor starting preventing the building up of the voltage. When the machine has reached approximately normal speed and voltage, correct phase rotation will be indicated by all the lamps across the oil switch growing bright at the same instant, followed by a period when they will all be dim at once. Reversed phase rotation will be indicated

There are several methods of doing this, as by:

1. Shifting the brushes (objectionable);
2. Split pole method;
3. Regulating pole method;
4. Reactance method;
5. "Multi-tap" transformer method;
6. Synchronous regulator.

Shifting the Brushes.—Were it not for the difficulties encountered, this would be a most convenient method of voltage regulation, since by this procedure the direct current voltage may be varied from maximum to zero. It is, however, not practical because of the excessive sparking produced when the brushes are shifted out of the neutral plane.

Split Pole Method.—In order to overcome the difficulty encountered in shifting the brushes the split pole method was devised by Woodbridge in which each field pole is split into two or three parts.

The effect of this is the same as shifting the brushes except that no sparking results.

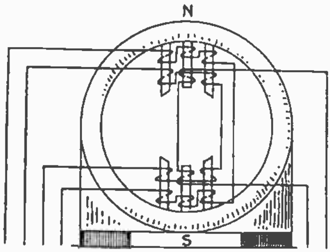
The other part is arranged so that its excitation may be varied, thus shifting the resultant plane of the field with respect to the direct current brushes.

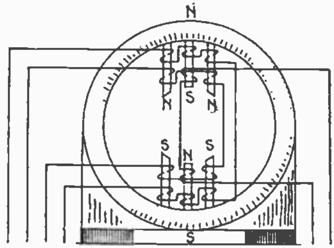
FIGS. 3,062 and 3,063.—*Text continued.*

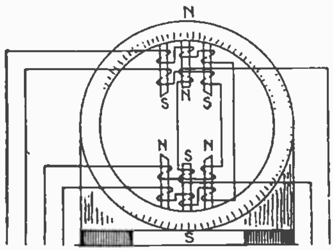
by the lamps growing bright in succession. In "phasing out" at the secondary switches, the indications of correct and reversed phase rotation are the same, respectively, as when "phasing out" on the high side and, in addition, the following indications are possible: If the lamps on two phases fluctuate together, and the third in a different manner, one phase is reversed but the phase rotation of the other two is correct. If the three lamp circuits become bright in a rapid succession and then pass through an interval when all are dim, a combination of reversed phase rotation, and reversed connections on one phase, is indicated. Usually the easiest method of correcting reversed phase rotation is to interchange two lines at the high voltage terminals of the transformers.

One of these parts is permanently excited and it produces near its edge the fringe of field necessary for sparkless commutation.

Regulating Pole Method.—As applied to the rotary converter regulating poles fulfil the same functions as commutating or interpoles (see page 771) on motors and dynamos, that is,



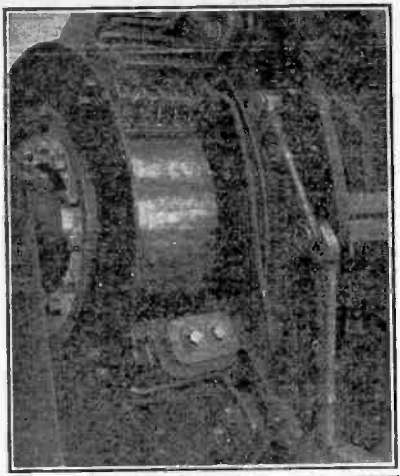




FIGS. 3,064 to 3,066.—Woodbridge split pole rotary converter. Each pole is split into three sections and provided with windings as indicated in fig. 3,064. When excited as in fig. 3,065 the commutator voltage is at its highest value; when excited as in fig. 3,066, the commutator voltage is low. The change in commutator voltage for constant collector ring voltage is in virtue of the property of rotary converters that the ratio of these two voltages is a function of the width of the pole arc.

they insure sparkless commutation from no load to heavy overloads with a fixed brush position.

NOTE.—*In starting six phase converters,* on one-third voltage taps without the external reactance in the circuit, conditions may be found where a starting resistance must be provided to reduce the current rush. With inherent reactance transformers, however, the lower limit of starting voltage is reached and the conditions of starting will be improved. It may be found, however, in some cases of high line reactance and resistance that the voltage will drop too low for starting the machine, and if such be the case, it may be possible to start on the two-thirds voltage tap using a resistance or reactance coil to reduce the starting current. Another arrangement would also be to provide taps at 40 per cent. from one end and 30 per cent. from the other end of the transformers, so that either end could be used for starting.



FIGS. 3,067 and 3,068.—Allis-Chalmers synchronous converter brush raising device. Fig. 3,067, brushes normal; fig. 3,068, brushes raised.

NOTE.—***Another method of a.c. starting*** is by means of a small induction motor supported on one of the pillow blocks and with the rotor mounted on the extended synchronous converter shaft just outside the bearing. By designing the starting motor with less poles than the converter, it will enable the motor to bring the converter up to and above synchronous speed. The field switch of the converter is then closed with all the resistance cut in the field circuit. The resistance is then gradually cut out, thus increasing the iron losses of the converter and the corresponding motor torque necessary for driving it, resulting in a gradual decrease in the speed until the synchroscope indicates that the converter is in synchronism. The *a.c.* main switch is then closed, and the induction motor is cut out and left to run free.

NOTE.—***D.C. starting.*** When starting from the direct current end, the collector rings of the converter are generally connected to the transformers, although this requires considerably heavier starting current than if the connections be interrupted and the *a.c.* end of the converter open circuited during starting. All the switches and breakers are assumed open on starting. Close the main *d.c.* circuit breaker. Cut the field rheostat all out. Throw in the starting switch, cutting out the resistance slowly, so that the machine is running on full voltage in one minute or less. Raise the speed to normal by means of the main field rheostat. Regulate the voltage of the *a.c.* side to the same value as the line voltage by means of the *a.c.* booster or induction regulator. Synchronize around the high tension oil switch by means of field rheostat, holding the voltage of the *a.c.* side steady. Close the high tension oil switch. Raise the *d.c.* load by means of the synchronous booster or the induction regulator, maintaining unity power factor at all loads by means of the field rheostat. The order of operations in shutting down a converter arranged to start from the *d.c.* end is as follows: Drop the load as far as possible by means of the booster or the induction regulator. Open the direct current circuit breaker. Turn the booster rheostat or the induction regulator to the maximum buck position. Open the high tension oil switch. When a converter is designed to operate on a 3-wire distribution system and the neutral for the system is obtained by connecting the middle points of the diametrical transformers, the transformer neutral must be disconnected from the main neutral bus while starting direct current, but the neutral points of the individual transformers may be left connected together. In starting this type of converter from the *a.c.* end, it is necessary not only to disconnect the transformers from the neutral bus, but to disconnect the individual transformer neutrals from each other.

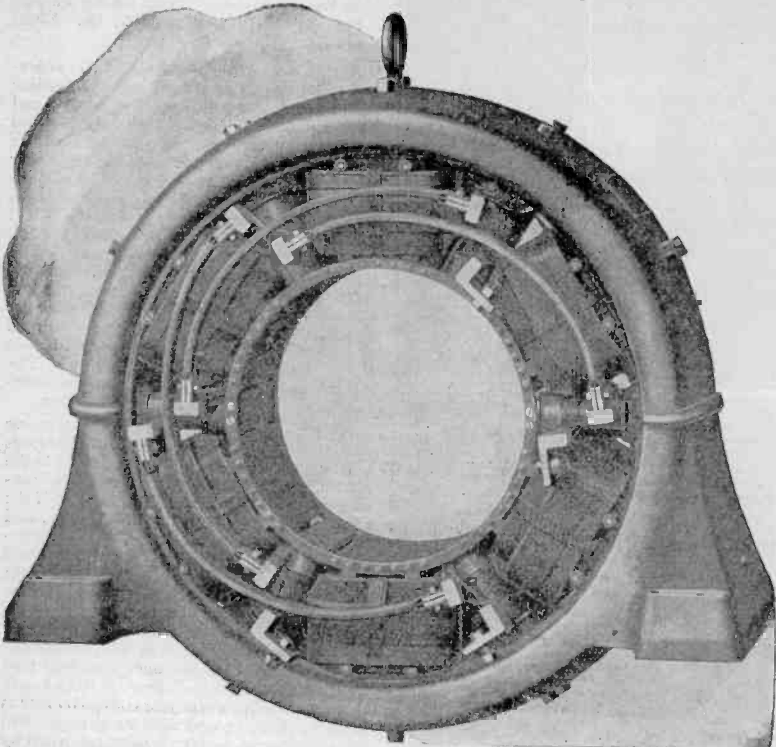


FIG. 3,069.—Allis-Chalmers synchronous converter field yoke with poles and windings.

NOTE.—***Synchronous converters in parallel.*** If several synchronous converters are to supply the same *d.c.* system, they can be connected in parallel in the same manner as shunt or compound wound generators, and they are even frequently operated in parallel with such generators and storage batteries. The different converters will divide the load according to their *d.c.* voltages, and these can be regulated by changing the applied alternating voltage. It is evidently necessary that all of the machines operating in parallel should have the same voltage regulation from no load to full load, and if a battery be also operated in parallel the voltage drop should be sufficiently large so as to cause the battery to take excessive loads. If no battery be used, it will, however, be more economical to have the machines designed for a less voltage drop. Synchronous converters operated in parallel should not be connected to the same transformer secondaries. Such a connection would form a closed local circuit in which heavy cross currents would flow, where any difference in the operating conditions of the machine occurs, as for example if the brushes of one of the machines were slightly displaced relative to the other. Compound wound converters for parallel operation should be provided

The regulating poles are used in order to vary the ratio between the alternating current collector rings and the direct current side without the use of auxiliary apparatus such as induction regulators or dial switches which involve complicated connections and many additional wires. The regulating poles are arranged with suitable connection so that the current through them can be raised, lowered or reversed.

The characteristics of the regulating pole converter being novel, a detailed explanation of the principles involved is given to facilitate a clear understanding of its operation.

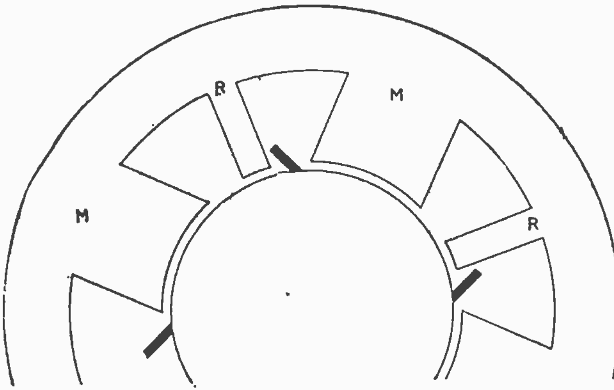


FIG. 3,070.—Diagram of field of regulating pole converter illustrating principles explained in the accompanying text.

NOTE—*Continued.*

with equalizer switches. For connecting a compound wound converter in parallel with one already running, the equalizer switch is closed first, so as to energize the series field from the running machine. Next, the shunt field circuit is closed and the field adjusted so that the voltage will correspond to that of the first machine and finally the main switch is closed. The load can then be transferred from the first to the second converter by weakening the shunt field of the former and strengthening that of the latter. If, for some reason, as for example, a short circuit, the *a.c.* voltage should drop considerably the synchronous converters operating on the system would not drop out of step, as the direct voltage and load would be correspondingly reduced. If other dynamos or storage batteries, however, were operating in parallel on the same system, these would tend to maintain the direct voltage, and in such a case the *d.c.* would reverse and flow toward the converters running them as motors. Care should therefore in such cases be taken that the synchronous converters be provided with proper speed limiting devices and reverse current circuit breakers.

NOTE.—***Two 600 volt converters*** operating in parallel on the *a.c.* and in series on the *d.c.* side, giving 1,200 volts, are generally started one at a time from the *a.c.* side. When both have been brought up to speed and corrected for the right polarity, they are connected in series; then the field is adjusted for the proper voltage and they are ready to be thrown on the direct current system.

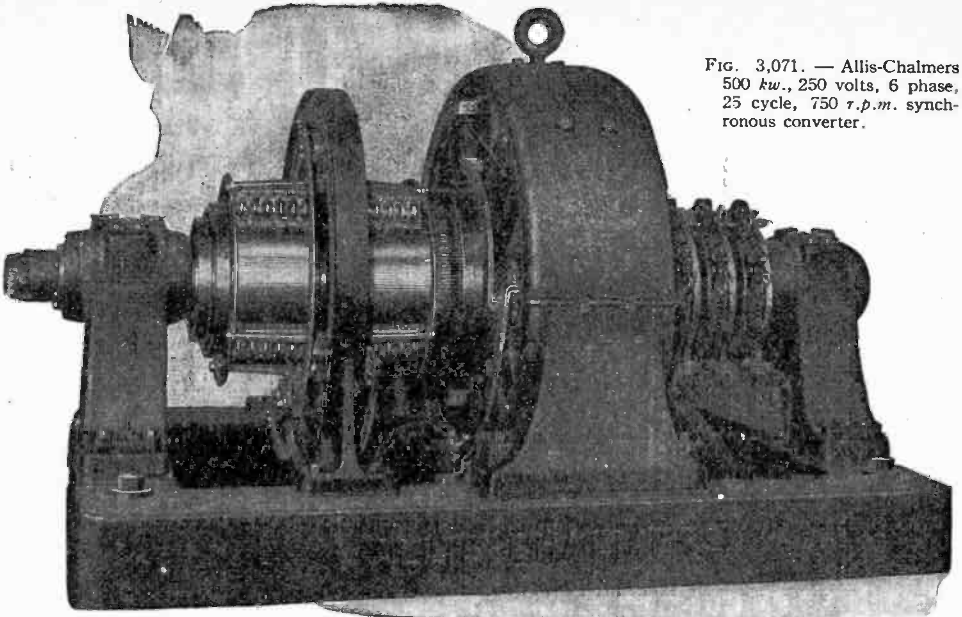


FIG. 3,071. — Allis-Chalmers 500 *kw.*, 250 volts, 6 phase, 25 cycle, 750 *r.p.m.* synchronous converter.

Consider a machine with a field structure as shown in fig. 3,070 resembling in appearance a machine with commutating poles, but with the brushes so set that one of the regulating poles adds its flux to that of one main pole, cutting the inductors between two direct current brushes. The regulating pole is shown with a width equal to 20 per cent of that of the main pole.

To obtain definite figures, it will be assumed that the machine at normal speed, with the main poles excited to normal density, but with no excitation on the regulating poles, gives 250 volts direct current pressure.

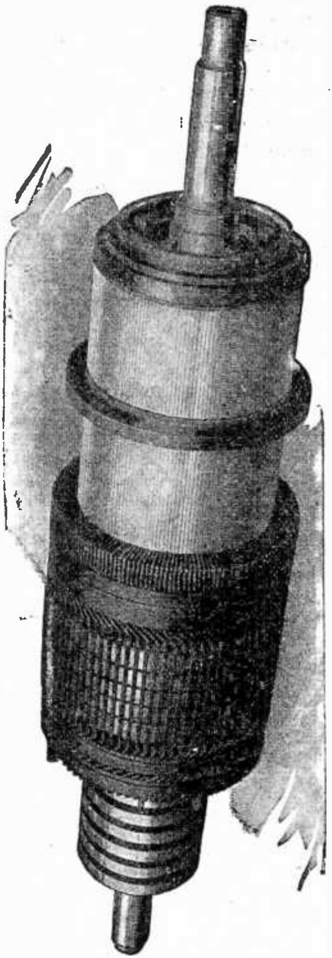


FIG. 3,072.—Armature of Allis-Chalmers 500 *kw.* 275 volt, 750 *r.p.m.*, 6 phase, 25 cycle synchronous converter.

Then with each regulating pole excited to the same density as the main poles, and with polarity corresponding to that of the main pole in the same section between brushes, the direct current pressure will rise to 300 volts at the same speed, since the total flux cutting the inductors in one direction between brushes has been increased 20 per cent.

If, on the other hand, the excitation of the regulating poles be reversed and increased to the same density as that of the main poles, the direct current pressure will fall to 200 volts, since in this case the regulating poles give a reverse pressure, that is, a pressure opposing that generated by the main poles.

Now, if the machine be equipped with collector rings, that is, if it be a converter, this method of varying the direct current voltage from 200 to 300 volts does not give nearly as great a variation of the alternating current voltage; in fact, the latter voltage will be the same when delivering 200 volts as when delivering 300 volts direct current pressure, if the field excitation be the same.

This may be seen by reference to fig. 3,073, which is a diagram of the alternating current voltage developed in the armature windings by the two sets of poles.

The horizontal line OA, represents the alternating current voltage generated by the main poles, alone, with the regulating poles unexcited, that is, when delivering 250 volts direct current pressure.

For a six phase converter OA measures about 180 volts diametrically, that is, between electrically opposite collector rings.

If now the regulating poles be excited to full strength, to bring the direct current pressure up to 300 volts, the alternating current voltage generated by the regulating poles will be 90 degrees out of phase with that generated by the main poles (since they are placed midway between the main poles), and will be about 40 volts as shown by the line AB.

The resultant alternating current volts across the collector rings will be represented by the line OB, with a value equal to 184.

Again, if the regulating poles be reversed at full strength, to cut the direct current pressure down to 200 volts, the alternating current voltage

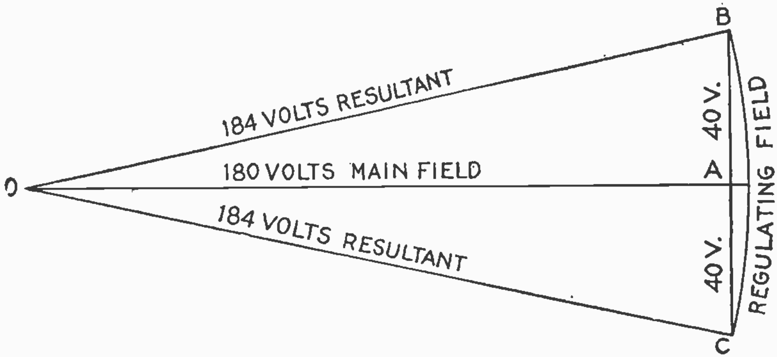


FIG. 3,073.—Voltage diagram for regulating pole converter illustrating principles explained in the accompanying text.

of the main and regulating poles will be OA and AC, respectively, giving the resultant OC, equal to OB, with a value of 184 volts. Accordingly, the direct current pressure may be either 200 or 300 volts with the same alternating current pressure, and if the main field be kept constant, the direct current pressure may range between 200 or 300 volts, while the alternating current pressure varies only between 180 and 184 volts.

The alternating current pressure can be kept constant through the full range of direct current voltage by changing the main field so as always to give an equal and opposite flux change to that of the regulating field. A constant total flux may thus be obtained equal to the radius of the arc BC, fig. 3,073. In this case the line OA, representing the main field strength, will equal OB, when the regulating field is not excited, and 250 volts can only be obtained at this adjustment.

This method of operation gives unity power factor with a constant impressed pressure of 184 volts alternating current with a range of direct current voltage from 200 to 300 volts.

Ques. Where should the regulating poles be located for best results?

Ans. A better construction is obtained by placing them closer to the corresponding main pole, as in fig. 3,074, than when spaced midway between the main poles as in fig. 3,070.

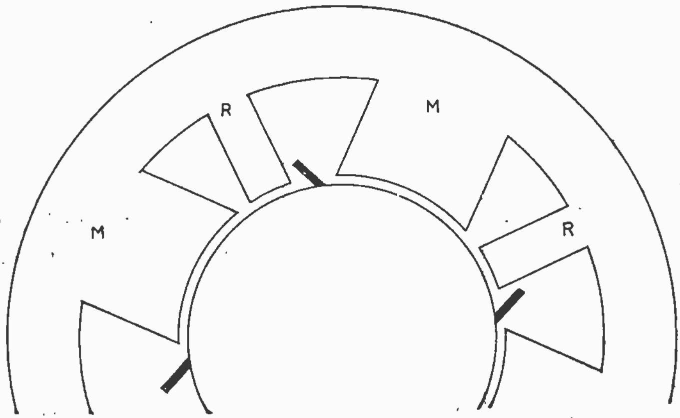
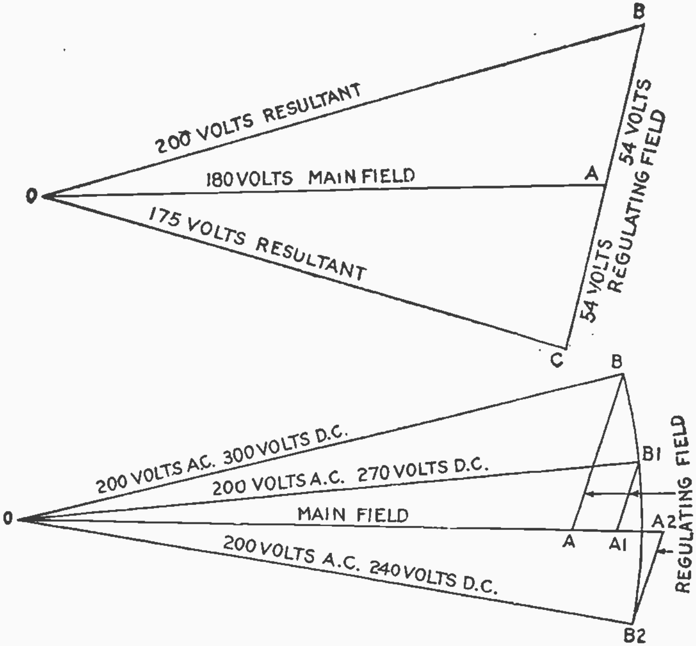


FIG. 3,074.—Diagram illustrating placement of regulating poles. In practice machines are not built as indicated diagrammatically in fig. 3,070, that is, with regulating poles spaced midway between the main poles, because a better construction is obtained by placing the regulating pole closer to the corresponding main pole, as shown above.

Ques. When the regulating poles are spaced as in fig. 3,074, what is the effect on the direct current voltage?

Ans. The effect is the same as for the midway position (fig. 3,070) except for magnetic leakage from the main poles to the regulating poles when the latter is opposed to the former, that is, when the direct current voltage is being depressed.



FIGS. 3,075 and 3,076.—Diagrams illustrating the effect on the alternating current voltage due to varying the regulating field strength (of a machine proportioned according to fig. 3,074), from a density equal to that in the main poles to the same density reversed, the main field strength remaining constant. The D. C. voltage in this case varies from 30 per cent. above that produced by the main field alone to 30 per cent. below, or from 325 to 175 volts, while the A. C. voltage varies only from 200 to 175 volts. To keep the A. C. voltage constant with such a machine the main field must be strengthened as the regulating field is weakened or reversed to reduce the D. C. voltage. This strengthening increases the core loss particularly on low direct current voltages, which however, are rarely required. hence a machine proportioned as in fig. 3,074, would not be operated through so wide a range as 175 to 325 volts. Assume that the range is 240 to 300 volts, and that at the highest voltage, both main and regulating fields have the same density, presenting to the armature practically one continuous pole face of uniform flux intensity. The diagram of A. C. component voltages to give constant A. C. resultant voltage across the rings for the case, is shown in fig. 3,076. At 300 volts D. C., the main field produces an A.C. voltage OA, and the regulating field, a voltage AB, with a resultant OB, equal to about 200 volts A. C. At 270 volts D. C., the main field produces an A. C. voltage OA, and a regulating field voltage AB, giving a resultant A. C. voltage OB, equal to 200 volts. Similarly, at 240 volts D. C., the main field produces an A. C. voltage OA, and the regulating field (now reversed) produces the reverse voltage AB, giving the resultant OB again equal to 200 volts. It will be noted that, theoretically, the main field strength must be increased about 15 % above its value at 300 volts D. C. in order to keep the D. C. voltage at 250 volts,

Ques. What is the effect on the alternating current voltage?

Ans. It is somewhat altered as explained in figs. 3,075 and 3,076.

Reactance Method.—This consists in inserting inductance in the supply circuit and running the load current through a

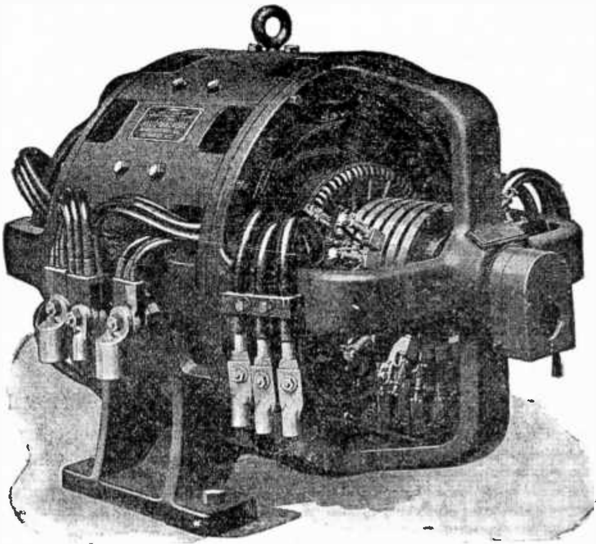


FIG. 3,077.—Collector end of Allis-Chalmers 200 *kw.*, 1,200 *r.p.m.*, synchronous converter.

few turns around the field cores. This method is sometimes called *compounding*, and as it is automatic, it is generally used where there is a rapidly fluctuating load.

If a lagging current be passed through an inductance, the collector ring voltage will be lowered, but will be raised in case of a leading current. The degree of excitation governs the change in the phase of the current to the converter, the excitation, in turn, being regulated by the load current. Accordingly with series inductance, the effect of the series coils on the field

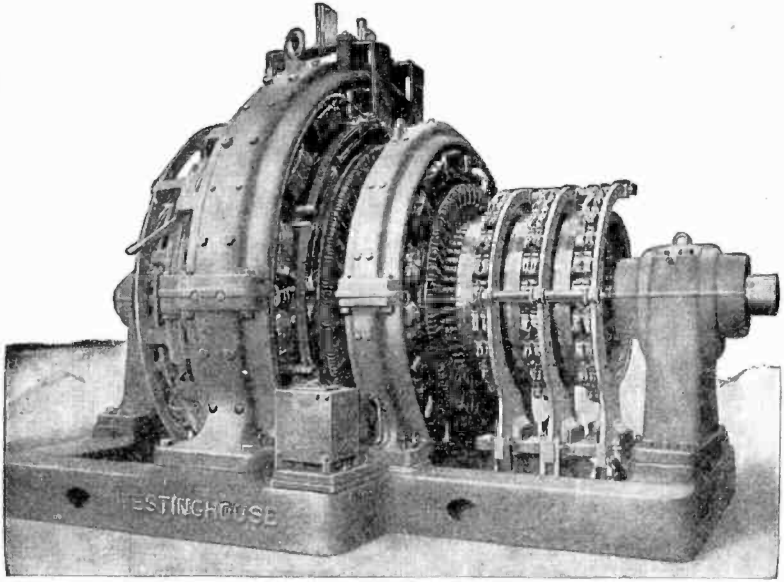


FIG. 3,078.—Westinghouse 8,000 ampere, 60 cycle, booster converter. A booster converter consists of a shunt wound synchronous converter in combination with an alternator mounted on the same shaft with the converter and having the same number of poles. By varying the field excitation of the alternator, the alternating current voltage impressed on the converter armature can be increased or decreased as desired. The direct voltage delivered by the converter is thereby varied accordingly. The synchronous booster converter is simply a combination of two well known and thoroughly tried pieces of electrical apparatus.

NOTE.—*Application of synchronous booster converters.* They are adapted to any application for which a relatively wide variation, either automatic or non-automatic in direct current voltage is necessary. They are particularly desirable for serving lighting systems where considerable voltage variation is required for the compensation of drop in long feeders, or for electrolytic work where extreme variations in voltage are required by changes in the resistance of the electrolytic cells.

NOTE.—*Three wire service.* No extra apparatus is necessary to adapt synchronous booster converters for three wire *d.c.* service. This is taken care of in the converter by a special arrangement of the commutating pole field coils. The neutral wire is taken from the neutral point in the windings of the transformers with which the machine operates.

of the converter is quite similar to that of the compounding of the ordinary railway dynamo.

Multi-tap Transformer Method.—The employment of a variable ratio step down transformer for voltage regulation is a non-automatic method of control and, accordingly, is not desirable except in cases where the load is fairly constant over considerable periods of time. It requires no special explanation.

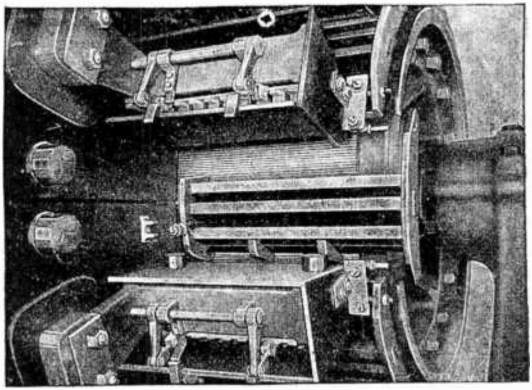


FIG. 3,079.—General Electric commutator of 750/1,500 volt converter showing radial type brush rigging and barrier partially removed for inspection. *In construction,* each group of brushes is enclosed by covers and insulation, thus preventing possibility of burning the springs, shunts or other parts. The attachment for supporting the brushes is at a radial point near the inner end of the commutator where an arc is least likely to form. Each barrier consists of several members or scoops, each of which is made up of a rectangular plane surface of fire proof insulating material set at an acute angle to the commutator surface, parallel with the commutator segments. This device deflects and cools the series of arcs between the segments on the commutator at the time of flashing and thus prevents the arc being carried to the stud of opposite polarity. Each barrier is supported at three points and easily adjusted for proper running clearance. It can also be readily removed for cleaning and inspection.

Synchronous Booster Method.—This consists of combining with the converter a revolving armature alternator having the same number of poles.

Ques. How is the winding of the booster alternator armature connected?

Ans. It is connected in series with the input circuits on the converter.

Ques. How are the field windings connected?

Ans. They are either fed with current regulated by means

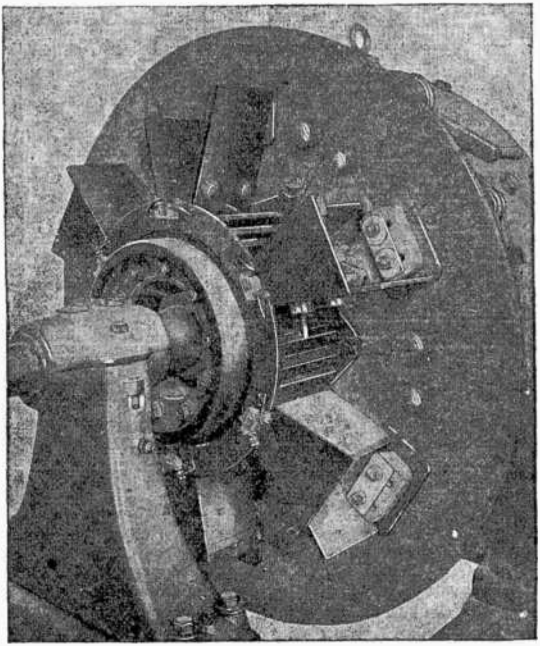


FIG. 3,080.—General Electric radial unit type rigging with flash barriers 300 *k.w.* 750/1,500 volt, 60 cycle synchronous converters.

of a motor operated field circuit rheostat, or joined in series with the commutator leads of the converter.

Ques. For what service is the synchronous booster method desirable?

Ans. For any application where a relatively wide variation in direct current voltage is necessary.

It is particularly desirable for serving incandescent lighting systems where considerable voltage variation is required for the compensation of drop in long feeders, for operation in parallel with storage batteries and for electrolytic work where extreme variations in voltage are required by changes in the resistance of the electrolytic cells.

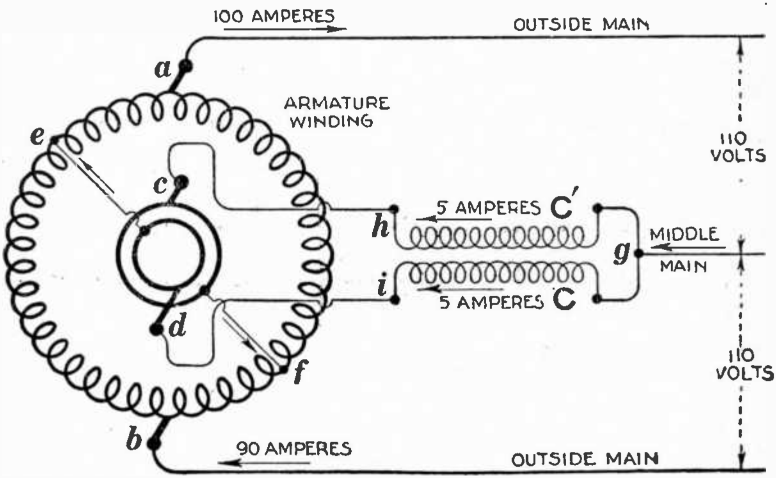


FIG. 3,081.—Double current generator. When the synchronous converter is driven by an engine and used to deliver both *a.c.* and *d.c.*, it is called a *double current generator*. Such a machine can be used to deliver *d.c.* to a 3 wire distributing system. The two coils C and C′, represent the two similar coils of a transformer so wound that the point g, is as it were, the middle of one continuous winding, the terminals *h* and *i*, are connected to the two *a.c.* brushes *c* and *d*, of the machine. The terminals *h* and *i*, are at the same voltage as the points *f* and *e*, of the armature winding respectively. Half of the inflowing current in the middle main flows through coil C′, to the point *f*, and coil C, and it causes the other half of the current in the middle main to flow through coil C, to the point *e*. The current which enters the armature at the point *e*, enters at a "level" such that the voltage induced in the rotating armature between *e* and *a*, is sufficient to carry the current up from *e* to *a*, and the current which enters the armature at the point *f*, enters at a "level" such that the voltage induced in the rotating armature between *f* and *a*, is sufficient to carry this current up from *f* to *a*.

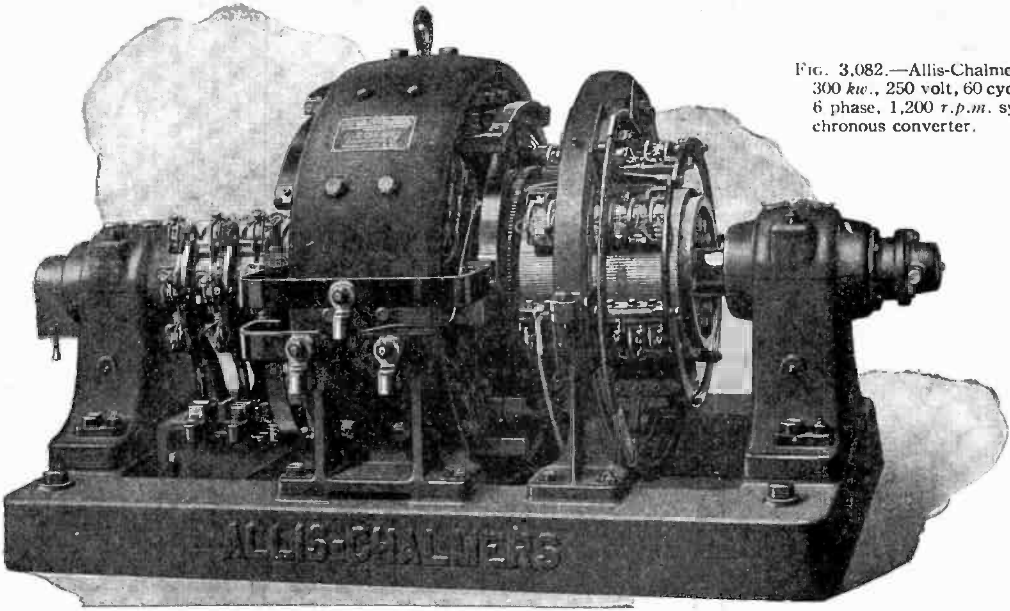


FIG. 3,082.—Allis-Chalmers. 300 *kw.*, 250 volt, 60 cycle, 6 phase, 1,200 *r.p.m.* synchronous converter.

Converter Troubles

Commutator Heating.—Generally due to improper brush pressure, poor commutation, bearing prolonged overload, faulty conditions of commutator surface. Allowable temperature is higher than can be endured by hand.

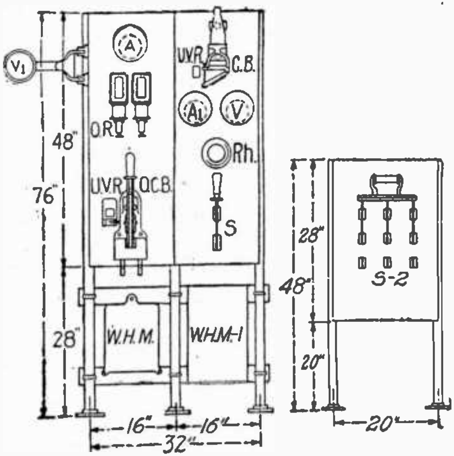
Armature Heating.—Short circuits, or improper connections, of the armature winding cause heating in a particular spot on the armature. Go over the end clips on both ends of the armature and see that they are not bent together and short circuited. Make certain that the collector taps come out at equally spaced points, and that the equalizers are symmetrically connected. In some machines the relation of the equalizers to the collector taps varies, repeating itself at regular intervals around the armature. Continued operation at heavy loads and low power factor produces excessive heating of the tap coils, and will be apparent at equally spaced points on the armature. Change the primary tap connections on the transformer so that better power factor will be obtained at the required voltage, or if possible change the primary voltage at the generating station. General heating of the whole armature is caused by unequal air gap, a grounded shunt field spool, one or more reversed spools, or a break in the field circuit. These troubles cause large circulating currents in the armature winding, and through the equalizers. The air gaps should not vary over 12 per cent. either way from the average value. Check the connections with the connection diagram, and check the polarity by separately exciting the field and holding two iron rods against adjacent pole tips all the way around. The free ends of the rods should attract each other. With a steady current flowing through the field, take the drop on each spool separately with a volt meter. A variation of over 9 per cent. in the drop indicates a faulty spool.

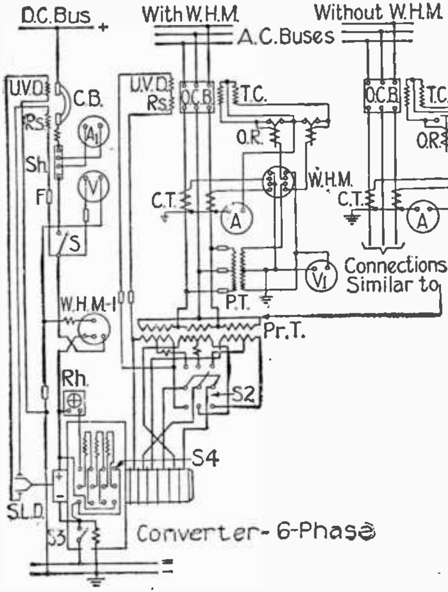
Shunt Field Heating.—Faulty spools or improper connections which cause armature heating may also cause heating of the shunt field. The trouble should be located by the above outlined procedure.

Heating of Contacts.—Bolted contacts may heat if the contact surfaces be not clean, smooth and bolted together with sufficient pressure. Particular care must be taken with the contacts of connecting strips for pole piece bridges on machines which start from the alternating current end in order to prevent excessive heating during starting.

Poor Commutation.—When the *d.c.* brushes spark, the mechanical condition of the converter should first be gone over carefully. If the brushes chatter, the commutator should be stoned or ground, and if they move up and down in the holders perceptibly, it must be turned before grinding. A rough commutator may cause vibration in the entire brush rigging, but vibration may also result from loose assembly of the rigging or poor set up of the machine, with insufficient support under the points where the weight rests on the base.

Flash Overs.—Arcing or "flashing over" at the *d.c.* brushes may be caused by excessive overloads or short circuits on the *d.c.* system, or by





FIGS. 3,083 to 3,085.—General Electric three phase synchronous converter switch board and diagram of connections. *Symbols* A, ammeter (*a.c.*); A_1, ammeter (*d.c.*); C.B., air circuit breaker; C.T., current transformer; F, fuse; O.C.B., oil circuit breaker; O.R., inverse time limit overload release; P.T., pressure transformer; Pr.T., power transformer; Rh., rheostat; Rs., resistance; S., switch; S1, starting switch; S2, equalizing switch; Sh., shunt; S.L.D., speed limit device; U.V.R., under-voltage release; T.C., trip coil; V., volt meter; V_1, volt meter (*d.c.*) (optional); W.H.M., watt hour meter (*a.c.*); W.H.M.-1, watt hour meter (*d.c.*).

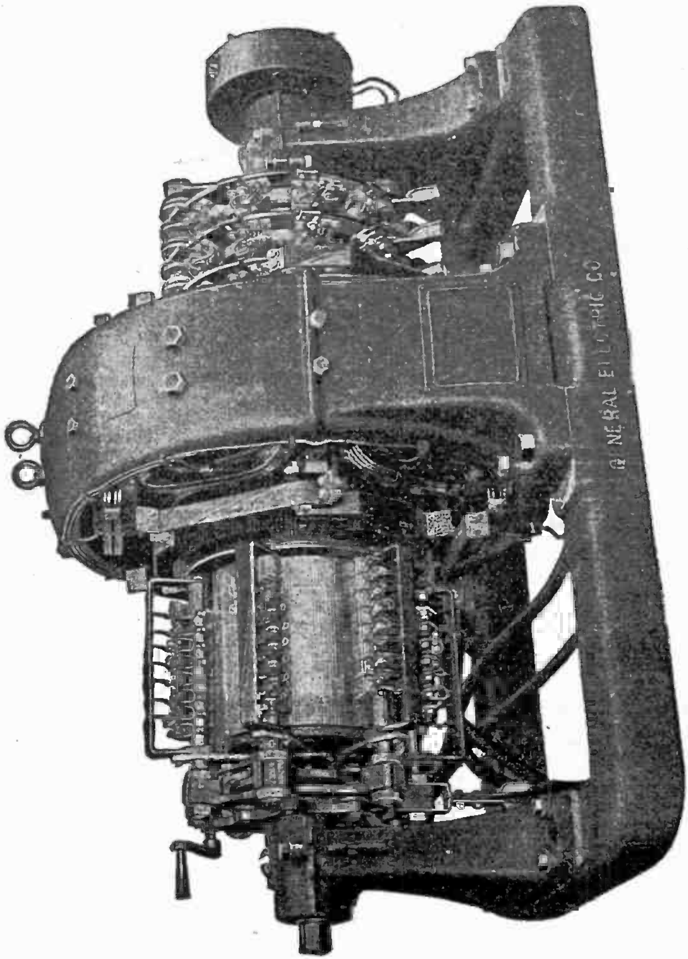


FIG. 3,086.—General Electric 300 *k.w.* synchronous converter for mining service. 275 volts. *d.c.* compound wound; 60 cycles 2,300 volts *a.c.*

disturbances on the *a.c.* supply system due to lighting, switching, or accidents to other apparatus. Protection against short circuits on the *d.c.* system can be obtained by increasing the resistance of the feeder to the distribution point where the trouble is most frequent. Short feeders should be avoided, particularly in railway work. Set the main circuit breakers at about three times full load and the feeder breakers as low as possible for continuous operation. *A.c.* disturbances should be located, and reduced to a minimum. The oil switch should be adjusted to trip instantaneously so that in case of a flash-over the machine will clear itself quickly, and the damage to it will be reduced as much as possible.

Sparking of A.C. Brushes.—The *a.c.* brushes should not be allowed to spark, as they wear away rapidly when sparking. Make certain that the brushes move freely in the holders, and that the pig tails are not caught on the springs or on the sides of the brush holders. See that each brush is running at the proper pressure. If the collector rings be very rough they must be ground or turned.

The synchronous booster method is particularly desirable for serving incandescent lighting systems where considerable voltage variation is required for the compensation of drop in long feeders for operation in parallel with storage batteries and for electrolytic work where extreme variations in voltage are required by changes in the resistance of the electrolytic cells.

TEST QUESTIONS

1. *What is a converter?*
2. *Mention four methods of changing* a.c. *to* d.c.
3. *Give classification of converters.*
4. *Define: 1,* d.c. *converter; 2, synchronous converter; 3, motor converter; 4, frequency changer; 5, rotary phase converter.*
5. *In general how does a rotary converter operate?*
6. *Upon what does the speed of a rotary converter depend?*
7. *State the principles of rotary converters.*

8. *What is the relation between the impressed alternating pressure and the direct pressure at the commutator?*

9. *What is the advantage of polyphase converters?*

10. *How is the armature of a polyphase converter connected?*

11. *With respect to the wave, what is the relation between the direct and alternating pressures?*

12. *In a single phase rotary what is the value of the direct pressure?*

13 *How is the voltage of a rotary varied on the* d.c. *side?*

14. *What is the advantage of unity power factor for rotary converters?*

15. *What greatly influences the power factor of the high tension line?*

16. *Does variation of the field strength materially affect the voltage?*

17. *What is the effect of a field too strong or too weak?*

18. *What is the ordinary range of sizes of rotaries?*

19. *What is the general construction of a rotary converter?*

20. *When is the compounding of rotary converters desirable?*

21. *Upon what does the ratio of converters depend?*

22. *What change in voltage is necessary between a converter and the alternator which furnishes the current?*

23. *Mention several methods of voltage regulation.*

24. *Describe: 1, brush shifting; 2, split pole; 3, regulating pole; 4, reactance; 5, multi-tap transformer; 6, synchronous methods of voltage regulation.*

25. *Where should regulating poles be located for best results?*

26. *How is the winding of a booster alternator connected?*

27. *Describe the methods of starting converters.*

28. *How are synchronous converters run in parallel?*

29. *Describe the "phasing out" of a synchronous converter.*

30. *Mention a number of converter troubles and their remedies.*

CHAPTER 65

Motor Generator Sets

The combination of a motor and a dynamo or alternator is used in preference to rotary converters when it is desirable that the generating element be independent of the *a.c.* line voltage so that any degree of voltage regulation can be obtained. The following combinations of motor generators are made and used to suit local conditions:

Synchronous motor.. ....dynamo
Induction motor............................dynamo
Direct current motor.........................dynamo
Direct current motor.........................alternator
Synchronous motor..........................alternator
Induction motor............................alternator

An advantage of motor generator sets over converters on high frequency circuits, is that the generator can be designed with a few poles and brushes set far apart, which greatly reduces the chance of flashing over in hunting.

Standard practice has adopted high tension alternating current for transmission systems, but direct current distribution is very frequently used. This is particularly true where alternating current apparatus has been introduced in old direct current lighting systems.

The synchronous motor or the induction motor connected to a generator stands next in importance to the rotary converter because it is easy to operate and the pressure may be changed by a rheostat placed in the field circuit of the generator.

The line wires carrying full voltage can usually be connected direct to the motor and thus do away with the necessary step-down transformer required by the rotary.

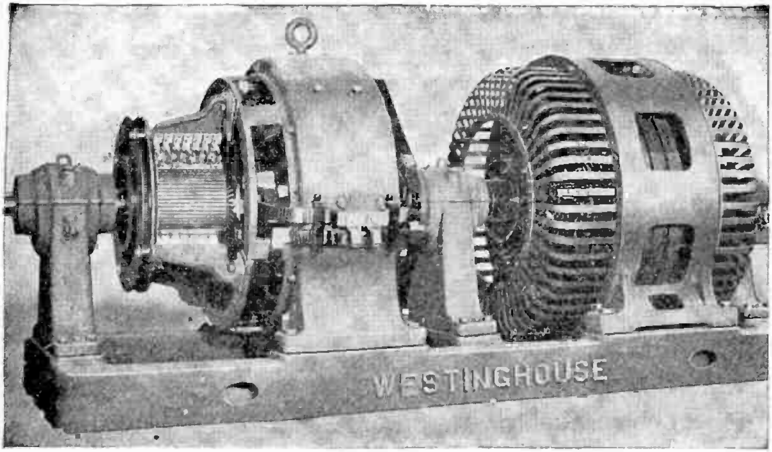


FIG. 3,087.—Westinghouse 500 *kw.*, 1,200 *r.p.m.*. 250 volt *d.c.* 3 phase, 60 cycle, 2,200 volt *a.c.* motor generator. Standard synchronous motor generators consist of a self-starting, rotating field, synchronous motor mounted on a common bed-plate and shaft with a *d.c.* generator. Direct connected exciter for 125 volts is included where required, although the motor fields can be wound for 250 volts, if desired. The motor generators below 100 *kw.* have three bracket bearings, while those of larger capacity are equipped with pedestal bearings.

Ques. What is the behavior of a rotary converter when hunting?

Ans. It is liable to flash over at the direct current brushes, which is common in high frequency converters where there are a great number of poles and the brushes are necessarily spaced close together around the commutator.

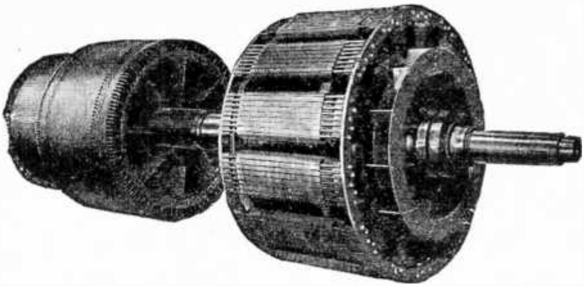


FIG. 3,088.—Westinghouse synchronous motor generator rotating part. *The rotor* consists of the motor rotating field and generator armature mounted on a common shaft, the shaft being arranged for two or three bearings, according to the construction used. The synchronous motor field is equipped with a damper winding which renders the motor stable in operation and readily self starting when a reduced voltage is applied to the stationary armature. While the starting *kva.* required is dependent on the resistance of the cage winding, and all motors start with a very reasonable *kva.*, the resistance of this winding is not increased to a point where the stability will be impaired. A low starting *kva.* is desirable, but the starting conditions are not allowed to affect the design so as to impair good operating stability. The generator armature is of the standard drum type with either a series or multiple winding, depending upon the size. The multiple wound armatures are cross connected by connections in the rear joining points of equal voltage.

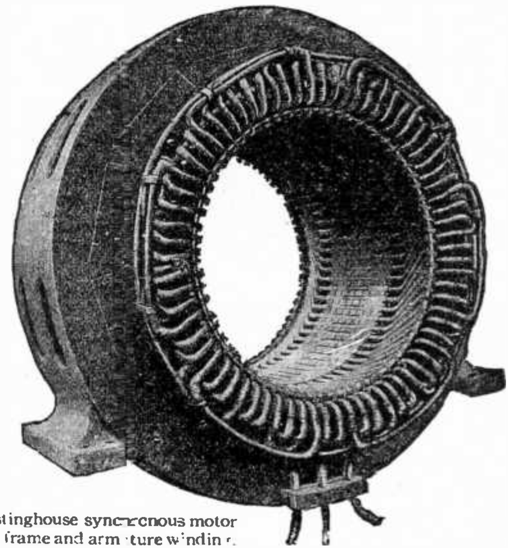


FIG. 3,089.—Westinghouse synchronous motor generator motor frame and armature winding.

Ques. Is this fault so pronounced with motor generator sets?

Ans. The motor generator operating on a high frequency circuit, the generator can be designed with a few poles and the brushes set far apart which will greatly reduce the chance of flashing over.

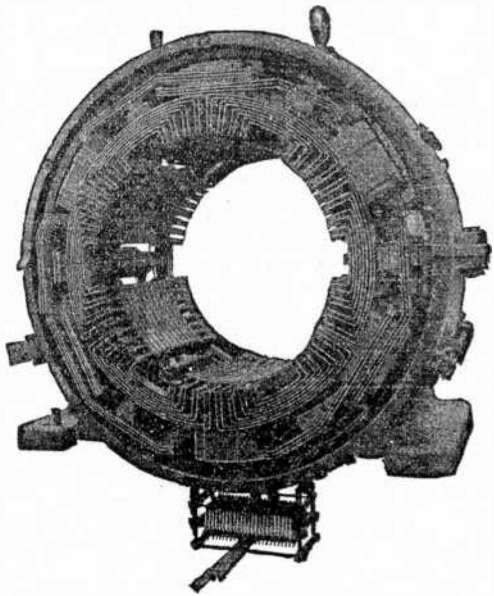


Fig. 3,090.—Westinghouse synchronous motor generator stator, complete, showing compensating winding.

A synchronous motor will drive a generator at a constant speed during changes of load on it, and by having a field regulating resistance it can be used to improve the power factor of the system.

When an induction motor is used its speed drops off slowly as the load comes on the generator, and it is necessary to regulate the voltage of the generator by means of a field rheostat, or compound wound machines may be used.

While an induction motor requires no separate excitation of the field magnets like the synchronous motor, its effect on the power factor of the system is undesirable.

Although it is seldom necessary to convert direct current to alternating, such an arrangement of a direct current motor driving an alternator is often justified in place of an inverted rotary converter, as in this case alternating current voltage can be changed independent of the direct current voltage.

The racing of an inverted rotary under a heavy inductive load or short circuit does not take place in motor generator set mentioned above.

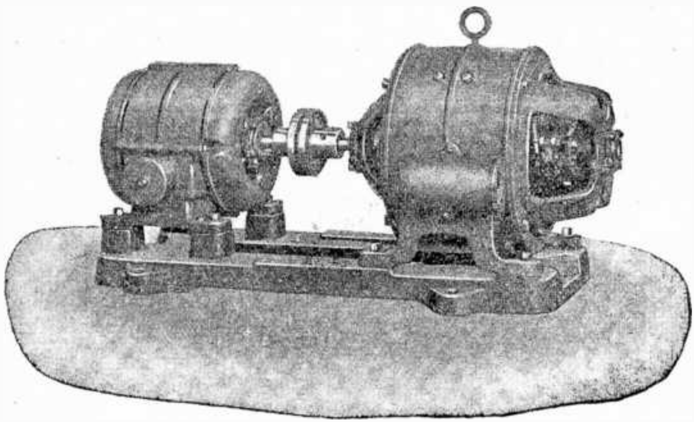


FIG. 3,091.—Crocker Wheeler 3 *kw.* 172 *r.p.m.* induction motor dynamo set.

Frequency Changing Sets.—A frequency of 25 cycles is generally used on railway work and in large cities using the Edison three wire system, and as a 25 cycle current is not desirable for electric lighting it is necessary to change it to 60 cycles by means of a frequency changer for distribution in the outlying districts.

The two machines in this combination are of the same construction, only the synchronous motor would have eight poles and have the 25 cycle current passing through it, while the generator would have 20 poles and produce 62½ cycles per second at 300 revolutions per minute. By supplying the motor with 24 cycles, the generator would produce 60 cycles.

Frequency Calculation.—The frequency obtained at the slip rings will depend on the speed of rotation, the number of poles for which the changer is wound and the frequency of the supply circuit. The old formula holds

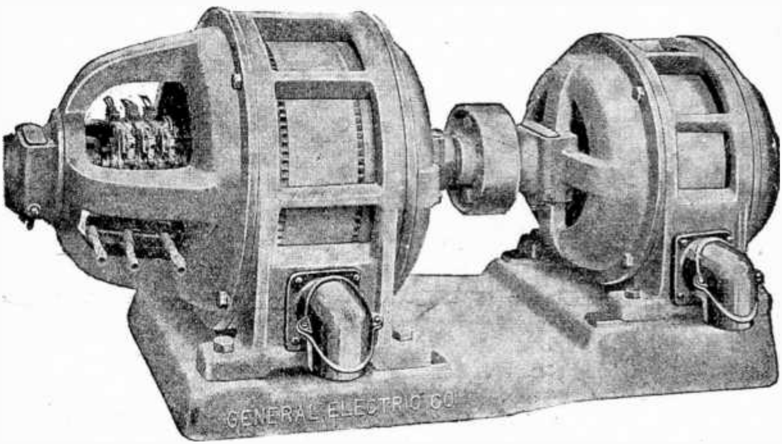


FIG. 3,092.—General Electric induction frequency changer direct connected to induction motor. The induction type frequency changer renders it possible to secure power at various frequencies above those usually provided by commercial circuits. The machine and control are neither expensive nor complicated. The induction type frequency changer consists mechanically of standard slip ring induction motor parts both stator and rotor; the only change necessary is to provide a suitable winding which will insure balanced current and voltage, which is an essential for successful induction motor operation. Standard voltages for given frequencies have been adopted after long and careful consideration. Interchange of frequency changers, motors and control is seriously affected by departure from standards. The frequency changer may be belted or directly driven from a motor, line shaft; in either case the stator must be excited from an *a.c.* source of polyphase energy. Ordinarily the rotor is driven in a direction opposite to that which the machine would tend to run as a motor; in this way frequencies are generated in the rotor equal to that of the excitation circuit plus the frequency due to the reversed rotation of the rotor.

$$N = \frac{r.p.m. \times \frac{P}{2}}{60} + \text{line frequency}$$

or excitation frequency.

N = slip ring frequency

P = number of poles

r.p.m—revolutions per minute of rotor

Example.—Assume 60 cycle excitation and a 6 pole machine at 1,200 *r.p.m.* then

$$\frac{1{,}200 \times \frac{6}{2}}{60} + 60 = 120 \text{ cycles.}$$

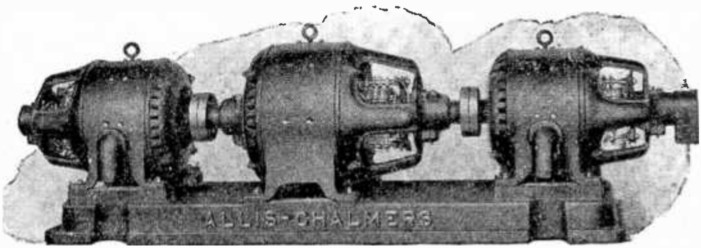


FIG. 3,093.—Allis Chalmers 55 *h.p.* motor driving two 17½ *k.w.*, 250 volt, 1200 *r.p.m.* generators.

Similarly if the speed were 1,800 *r.p.m.* the result would be 90 cycles plus the excitation frequency or 150 cycles at the slip rings.

The maximum speed for standard frequency changers is 2,200 *r.p.m.* When frequencies are required which would demand higher speeds for any particular machine, it will be necessary to select a frequency changer, having a greater number of poles, with a correspondingly lower basic speed.

Frequency changers may be wound for excitation for either 2 or 3 phase circuits. It is necessary to specify the voltage, frequency and number of phases of the circuit from which the frequency changer is to be excited, a winding being suitable for one voltage and frequency only.

The high frequency circuit is always three phase, the voltage depending upon the frequency at which the machine is operating.

Machines are wound in two series, the first series being from 100 to 199 cycles, the second being from 200 and upward. Both are rated from a basis which for the first series is 225 volts at 120 cycles, the second being 114 volts at 200 cycles.

A means of checking connections when first setting up a machine, is to read the slip ring voltage with the machine running at normal speed; if it differ seriously from the tabulated value for the speed, interchange a pair of stator leads and again read the voltage which should now be correct, that is about 15 per cent above rated voltage if the excitation voltage be normal.

Standard machines are designed to give about 15 per cent regulation at 80 per cent power factor.

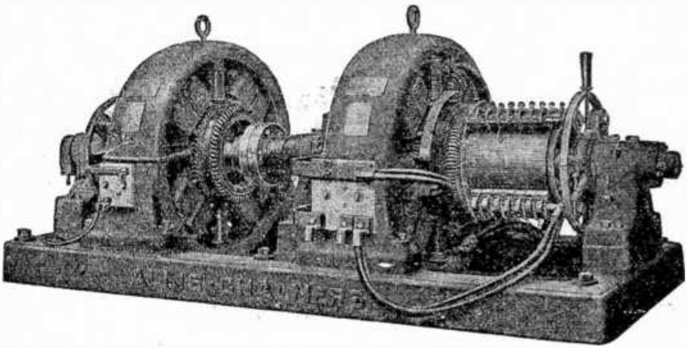


FIG. 3,094.—Allis Chalmers 600 volt motor driving 120 volt, 100 *kw*. series booster. If the voltage of a feeder is to be raised or a higher voltage is wanted to charge a storage battery a booster is useful.

The power input to the stator from the commercial lines for an induction frequency changer at full load is approximately equal to the kilowatt rating of the machine at the frequency of the commercial circuit plus the excitation losses of approximately 10 per cent. ***For example,*** assume a 20 *kw*. machine first series (rated 120 cycle)) delivering power at 120 cycles and excited from a 60 cycle supply. This machine will require 10 *kw*. electrical input, for example:

$$120 \text{ cycles} : 60 \text{ cycles} :: 20\ kw. : X,$$

from which

$$X = 10\ kw.$$

The difference between the electrical input of 10 *kw*. and the total capacity must be provided mechanically to the rotor, therefore 10 *kw*. mechanical energy is required.

Parallel Operation of Frequency Changers.—It is very difficult to construct two or more frequency changers and join them to synchronous motors so that the current wave of one machine will be in phase with the other, since the speed of the motor will depend on the frequency of the line and be independent of the load thrown on it.

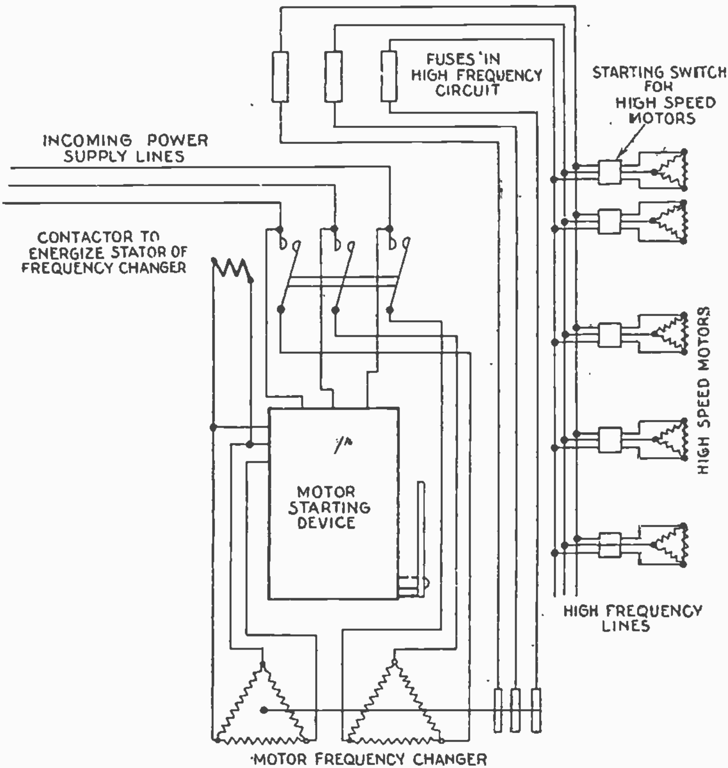


FIG. 3,095.—General Electric typical connections of frequency changer set induction motor driven showing high speed motors on high frequency circuit.

When alternators are run in parallel, if one machine lag behind, the other carries most of the load with the result that the lightly loaded machine will speed up and get in step with the other, or in other words a synchronizing current will flow between the two alternators and tend to keep them in proper relation with respect to phase and load.

Cascade Converter.—This piece of apparatus was introduced by Arnold and La Cour. Briefly, it consists of a combination

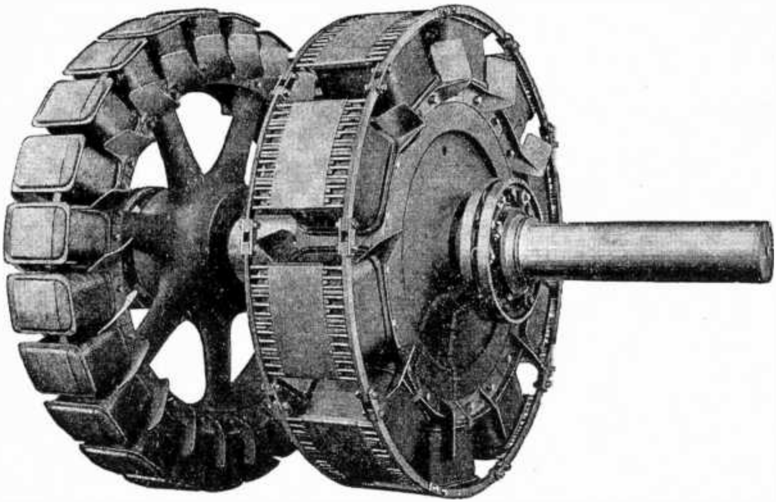


FIG. 3,096.—Allis Chalmers rotor of 1200 *kva.*, 300 *r.p.m.* frequency changing set, showing fans for ventilation and arrangement of dampers used to facilitate starting and to insure parallel operation without hunting.

of an induction motor having a wound armature and a dynamo, the armatures being placed on the same shaft.

The windings are joined in cascade, that is, in series with those of the armature of the induction motor. The line supplies three phase currents at high voltage direct to the field of the induction motor and drives it, generating in it currents at a lower voltage depending on the ratio of the windings.

Part of the current thus generated in the armature passes into the armature of the dynamo and is *converted* by the commutator into direct current as in a rotary converter, but is also increased by the current induced in the winding of the dynamo armature.

Ques. At what speed does the machine run?

Ans. Assuming equal numbers of pole, the armatures rotate at a speed corresponding to one half the circuit frequency.

Thus if the motor have six poles and the frequency be 50, the rotary field revolves at 50×60÷3=1,000 *r.p.m.*, and the motor will revolve at one-half that speed or 1,000÷2=500 *r.p.m.*

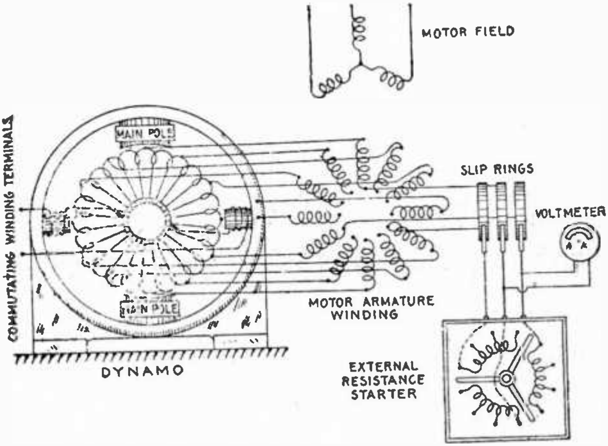


FIG. 3,097.—Diagram of "Cascade" motor generator set or motor converter, as it is called in England where it is used extensively for electric railway work. In the diagram of motor armature winding, some of the connections are omitted for simplicity. The windings are Y connected, and as they are fed by wires joined to the slip rings at the right and center, the rest of the power passes to the converter windings back to rotor winding and out to the slip rings so that part of the power enters the rotor and part through the converter.

Since the connections are so arranged that these currents tend to set up in the armature a revolving field, rotating at half speed in a sense opposite to that in which the shaft is rotating at half speed, it follows that by the superposition of this revolving field upon the revolutions of the machine, the magnetic effect is equivalent to a rotation of the armature at whole speed, so that it operates in synchronism, as does the armature of a rotary converter.

Half the electric input into the motor part is, therefore, turned into mechanical energy to drive the shaft, the other half acts inductively on the armature winding, generating currents therein.

As to the dynamo part it is half generator, receiving mechanical power by transmission along the shaft to furnish half its output, and it is half converter, turning the currents received from the armature into direct current delivered at the brushes.

Ques. What action takes place in the motor armature winding?

Ans. Since it runs at one-half synchronous speed, it generates alternating current of half the supply current frequency, delivering these to the armature of the dynamo.

Ques. What claim is made for this type of apparatus?

Ans. The cost is said to be less than a motor generator set, and it is claimed to be self-synchronizing and to require no special starting gear, also to be 2.5 per cent. more efficient than a motor generator.

Ques. How is the machine started from the high pressure side?

Ans. The field winding is connected directly to the high pressure leads. The three slip ring brushes are connected with external resistances which are used while starting, the external resistances being gradually cut out of the circuit as the machine comes up to speed (the same as with an ordinary slip ring motor).

Ques. How does a cascade converter compare with a synchronous converter?

Ans. It is about equally expensive as the synchronous converter with its necessary bank of transformers, but is about one per cent less efficient. It is claimed to be more desirable for frequencies above 40 on account of the improved commutation at the low frequency used in the dynamo member. For lower frequencies the synchronous converter is preferable.

FIG. 3,098.—Armature of Allis-Chalmers 500 *kw*. synchronous booster converter.

Synchronous Booster Converter. — Where it becomes necessary to adjust the voltage at the *d.c.* end over a considerable range, as for electrolytic work, or for central station service, it is desirable to vary the *a.c.* voltage supplied to the rotary by means of a special *a.c.* booster which adds to or subtracts from the *a.c.* voltage supplied, thus giving double the range of voltage generated by the booster.

The voltage can be varied over the full range in very small steps by adjusting the field strength of the booster. The booster may be of the revolving armature or revolving field type, the former, however, being more simple.

The booster armature is mounted on the shaft between the converter armature and collector rings, with its coils connected in series with the converter armature coils. Thus the voltage generated by the booster is added to or subtracted from the supply voltage.

The variation and reversal of the booster voltage, by means of a field rheostat in the booster field circuit, increases or decreases the *d.c.* voltage delivered by the synchronous converter.

Fly Wheel Motor Generator Sets.—It is always desirable to have as near uniform a load on a station as possible. Such loads as come from the hoisting of coal or ore from docks or mines are quite intermittent in character and have high peaks.

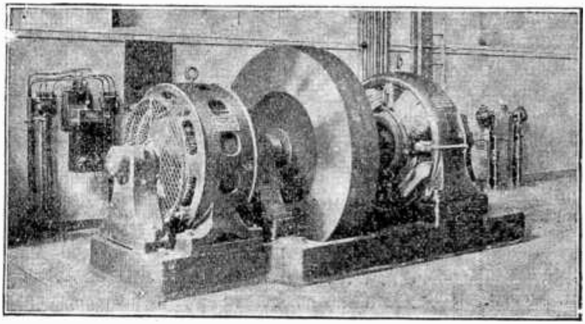


FIG. 3,099.—Allis-Chalmers fly wheel motor generator set designed to smooth out load curve of coal hoists.

Furthermore power is usually transmitted by means of alternating currents to the hoisting centers and it usually is converted to direct current since the direct current motor. has the best characteristics for hoisting work.

By designing the motor generator set with a fly wheel, energy can be stored in and taken out of this fly wheel in such a way that the motor of the set draws practically a uniform load from the line.

Since the energy can be obtained from and put into the wheel by varying its speed, it is necessary to have a motor which can be adjusted in a simple manner within the narrow limits required. An induction motor is therefore required. For small sets this may be of the squirrel cage type requiring no regulating device whatever. For larger sets the phase wound rotor is used

Ques. What systems of electric drives are most common for mine hoist service?

Ans. In order of the frequency of their application, these are:

1. Induction motor with
   a. Master controllers, contactors and grid secondary resistance.
   b. Primary contactors and liquid secondary resistance.
   c. Drum controllers and grid secondary resistance.
2. Ilgner-Ward Leonard System:
   Direct current, shunt wound motor operated from motor generator set with fly wheel by Ward Leonard control.
3. Ward Leonard System:
   Direct current, shunt wound motor operated from motor generator set without fly wheel by Ward Leonard control.

Direct current motors with rheostatic control, using either drum controllers or magnetic control, are used to a comparatively limited extent due to the almost universal use of A. C. power.

Induction Motor-driven Hoists.—The frequent use of this type of motor for mining service is best illustrated by the fact that of 450 General Electric Co.'s mine hoist drives of 250 horse power capacity and above, over 85% are of this class.

The large majority of mine hoists therefore are driven by induction motors with secondary control through reduction gearing, and successful operation has been attained with capacities up to 1800 *h.p.* continuous rating.

The chief reason for their predominance is their low first cost combined with simplicity of installation and operation. The availability of *a.c.* power at reasonable rates, the adaptability of the industrial type motor for this service, its ruggedness and reliability are also contributing causes of its popularity.

In addition to adequate capacity and general rugged construction, the only particulars in which the induction motor intended for mine hoist service demands special attention are, that the slip ring voltage be sufficiently low and the rotor insulation sufficiently good to withstand the double voltage resulting from reversal at full speed, and that the rotor have sufficient binding wire to withstand the possible overspeed to which it may be subjected.

The main factor limiting its application is the comparatively poor control obtainable, although its use may also be precluded on account of conditions of power supply and also on account of a low efficiency on certain frequencies.

In cases where a more precise control is necessary, for example in metal mine hoists where hoisting must be carried on from many levels necessitating frequent shifting of the skips and considerable unbalanced operation; and also with some very high speed coal mine hoists, requiring great accuracy of control at the end of the trip. Usually in the latter case the adoption of one of the Ward Leonard systems also results in higher operating efficiency. The lowering of loads out of balance at reduced speeds can be accomplished with the induction motor only with some difficulty and with the expenditure of considerable energy unless the mechanical brakes are used.

For light duty hoists, using motors up to 100 *h.p.* it is usually satisfactory to use drum controllers for both the primary and secondary circuits or to use contactors for reversing the primary connections and handle the secondary currents directly on the controller segments. In a few cases where the service is exceptionally light and the operation very intermittent this type of control has been used on hoists up to 200 *h.p.* capacity.

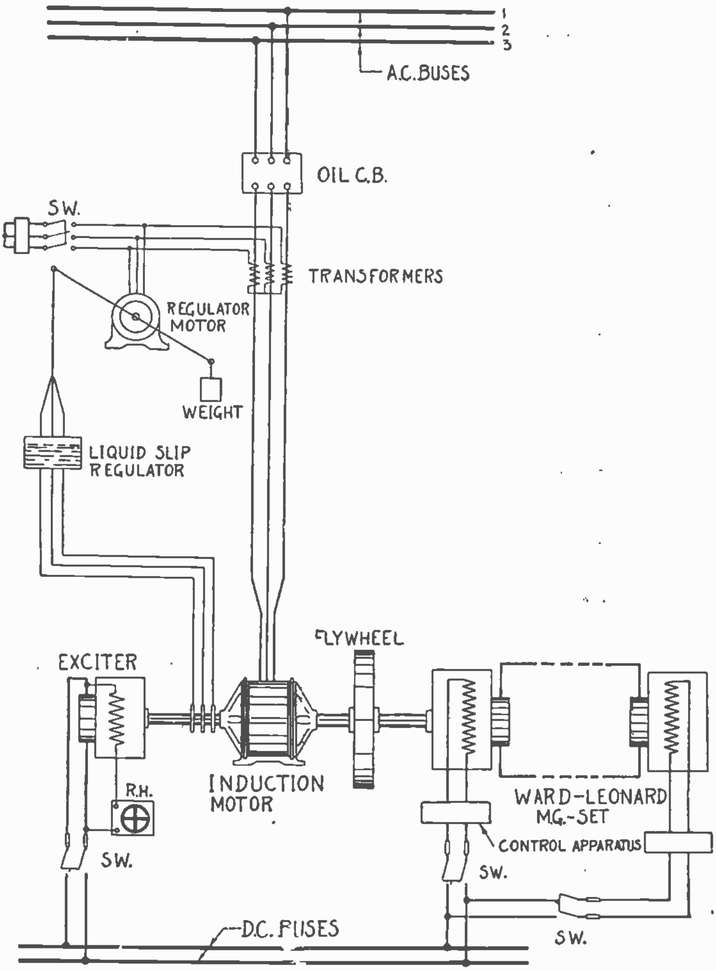


FIG. 3,099-A.—Simplified connection diagram of electric drive for mine hoist service, in which an induction motor with liquid slip regulator provides power to the Ward-Leonard motor generator set.

Usually, however, with hoists driven by motors of 100 *h.p.* and above the conditions require the use of full magnetic type control, that is, contactors are used for both the primary and secondary circuits in connection with grid resistance, or for the larger sizes primary reversing, contactors are used in connection with a liquid rheostat, the resistance being in the form of a liquid and its value being varied by varying its level, in a chamber in which are placed electrodes connected in the secondary circuit. The standard voltages for these equipments are 440 and 2,200 volts, the latter being recommended for motors of 300 *h.p.* and above.

Ques. What are the principles underlying the liquid rheostat type of control?

Ans. Liquid resistances are used on account of their favorable resistance characteristics to an electric current. However, while this principle is a simple one it has required ingenious designing to produce a rheostat that will operate successfully under the conditions encountered in mine hoist service. Besides providing a high resistance to limit the torque at the start and for low speed running, the rheostat must have a low minimum resistance so that the hoist can be operated at full speed without excessive loss in the rotor circuit.

To obtain a low value of minimum resistance, a great multiplicity of plates must be used, spaced closely together. In the earlier designs, and in some still on the market, trouble results from arcing between the plates when the rheostat is hot and steaming during reversal at high speed, since under these conditions double standstill potential is developed between the collector rings and therefore between the plates. A design has been perfected from which a large number of rheostats have been built and put into successful operation, which has overcome all practical difficulties and which embodies all the characteristics essential to successful service. In this design two separate sections of electrodes are used, one of high resistance consisting of widely spaced pipes of graduated lengths and the other of low resistance consisting of a nest of closely spaced plates. At start only the widely spaced pipes are connected in the rotor circuit, but as the level of the liquid rises in the electrode chamber and the motor has reached a considerable speed and the secondary voltage has fallen to a low value, the low resistance section of plates is cut into the circuit in multiple with the pipes by means of a contactor, and the acceleration of the motor is completed, so that at the maximum level of the liquid the resistance in the circuit is very low.

A small continuous running motor driven centrifugal pump forces the liquid which is a weak solution of chemically pure sodium carbonate ($Na_2 CO_3$) into the electrode chamber from a storage tank, which is formed by the lower portion of the rheostat. The speed of the motor is controlled by means of a lever operating a weir, whose position determines the level of the liquid. To this same lever is connected a master controller which operates the primary switches that control the direction of rotation of the motor. As the weir constitutes practically one entire wall of the electrode chamber, it can be emptied practically as quickly as the lever can be brought to the off position.

The rheostat is equipped with an adjustable sill, which in its upper position increases the height of the liquid at the start, thereby decreasing the time required to attain full speed, this being often desirable during the normal operation of the hoist. The liquid in the storage tank is cooled by means of a nest of coils through which cooling water taken from the local water supply is circulated. It is important that this supply of cooling water be free from acid and other corroding chemicals.

Ques. In what type of mine hoist service is liquid rheostat secondary control generally found?

Ans. The liquid rheostat is found chiefly when induction motor driven hoists of large capacities are employed, and also in applications where a considerable amount of partial speed operation is required. For example in metal mine shafts and long slopes, as it supplies a finer degree of control than the grid resistance type.

Ques. What are the principles of the Ward & Leonard System of speed control?

Ans. This method of control depends upon the fact that the speed of a motor armature rotating in a constant magnetic field

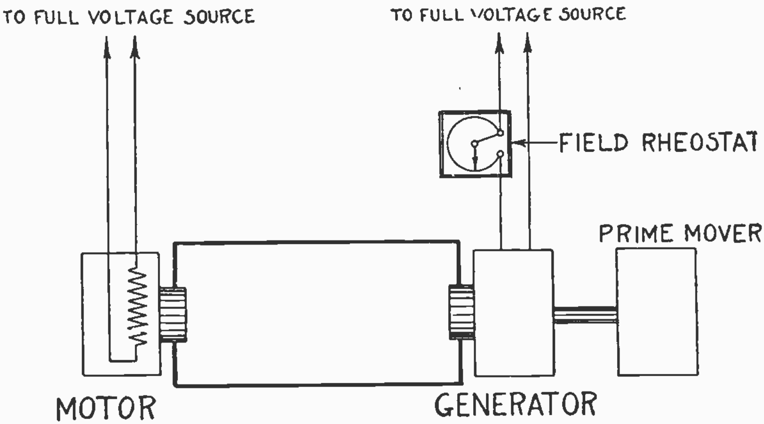


FIG. 3,099-B.—Diagram of connection for variable voltage Ward-Leonard system of speed control.

is proportional to the potential impressed at the brush contacts. Hence, by a variation of this potential the armature speed may be similarly varied.

To accomplish this speed variation, an independent generator for the supply of the motor is required, and the armature terminals of the generator are connected directly to the armature terminals of the motor.

The motor field usually derives its source from the switchboard buses providing for a constant excitation field. The shunt-field of the generator, however, is separately excited and is conveniently controlled by a rheostat operated by a master controller.

As the prime mover drives the armature at constant speed the potential impressed from it to the motor armature is approximately proportional to the shunt-field excitation. In this way the speed of the motor armature is controlled over a rather wide range by the operator.

Ward Leonard Motor-Generator Sets Driven by A.C. Motors. —Ward Leonard motor-generator sets which are not provided with fly wheel equalization are driven by either constant speed induction motors or synchronous motors.

The choice in this matter is influenced by a number of considerations, but chiefly by the relative first cost (which depends on the capacity) and the desirability of power-factor correction. In some cases the high pull-out torque necessary would require a synchronous motor of larger capacity than that necessary to meet the average duty, while an induction motor, which has inherently a high overload capacity, would not be thus handicapped.

The synchronous driven set can be designed to operate at a higher average power-factor, and for this reason is quite commonly used where the station capacity is already operating under a low power factor load.

In the majority of cases, however, the squirrel cage induction motor is employed because of those characteristics to which its general popularity is attributed.

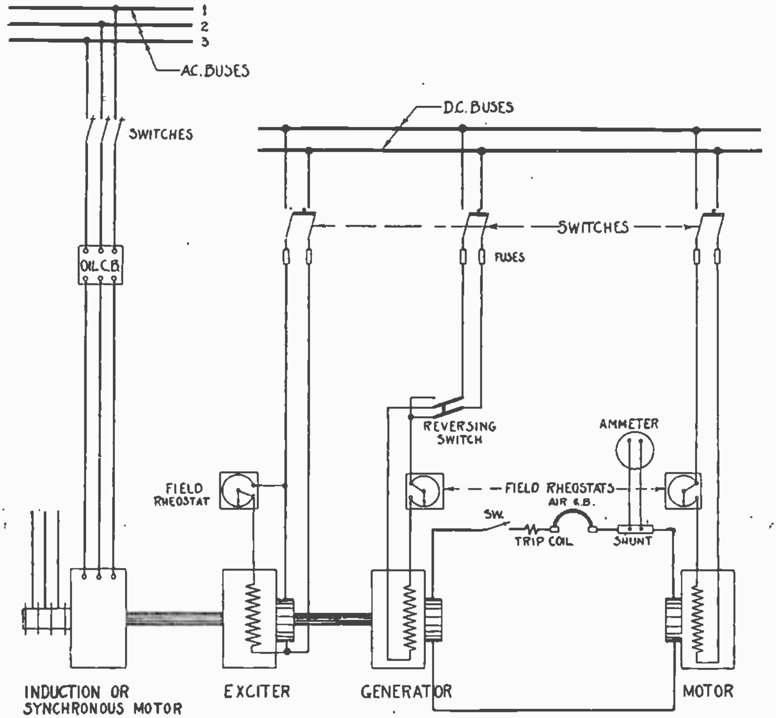


FIG. 3,099-C.—Conventional connection diagram for Ward-Leonard motor generator set without fly-wheel.

The Ilgner-Ward Leonard system of speed control.—In this system of speed control a flywheel is introduced to the motor generator set, its function being to equalize the load in cases where power is generated under such condition as to preclude the possibility of carrying the heavy peak loads without disturbance to other apparatus operating on the system.

This system of control is especially desirable where power is purchased at rates which imposes a heavy reservation charge for peak loads.

As described, the most common use of this system takes the form of a flywheel directly connected to the Ward Leonard motor-generator set in addition to a device for automatically varying the speed through the secondary rheostatic control of the slip ring induction motor that drives the set.

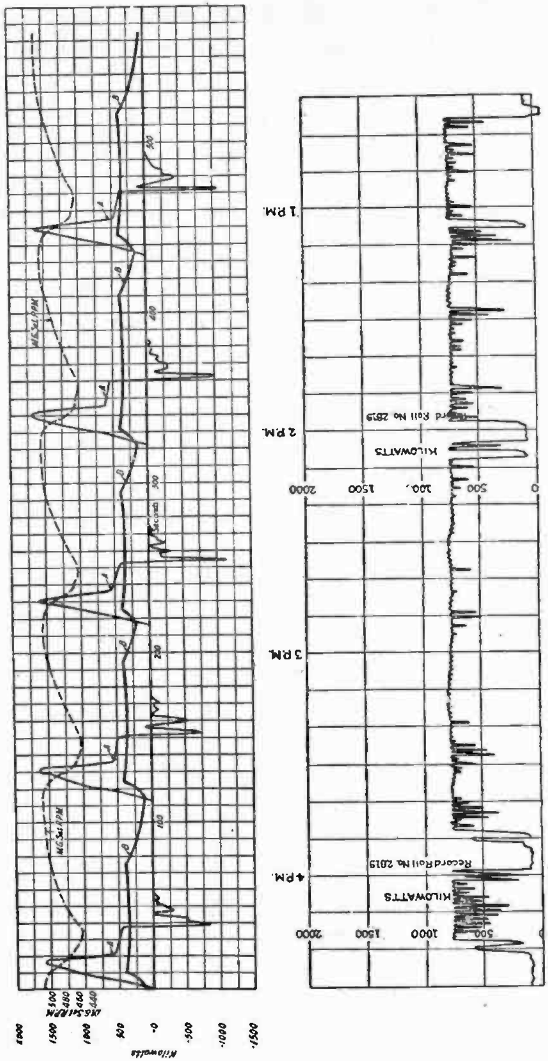
With the utilization of an equipment of this kind, the power taken from the supply circuit is limited to a certain pre-determined value, and whatever power is required by the hoist in excess of this value is given up by the flywheel as the speed of the wheel is reduced. Again, during periods of light demand the speed of the wheel is increased and energy stored up in anticipation of the next load peak period.

This smoothing out action of a flywheel motor generator set used in connection with a *d.c.* hoist motor is shown in fig. 3099D. The extreme fluctuation of load to which the generator is subjected is supplied by the line at a very much lower and more uniform rate, the action of the wheel is illustrated by the speed curve of the motor-generator set.

In fig. 3099E is shown a partial record from the curve drawing watt-meter which measures the input of power to a flywheel set operating a mine hoist. This record gives a good illustration of the effectiveness of a flywheel set in limiting the maximum demand from the line to an adjusted value.

Since in this system the motor generator set must operate at varying speed a slip ring motor is necessary which operates in connection with a liquid type slip regulator.

The regulator is operated by a motor whose primary windings are connected in series (through series transformers) with the windings of the main induction motor, the electrodes which are



FIGS. 3,099-D and 3,099-E.—Illustrating load equalization by use of fly-wheel motor generator set and portion of record from curve drawing wattmeter measuring power input to fly-wheel motor generator set operating mine hoist on Ilgner-Ward-Leonard system of speed control. *Note.*—Letters A and B on curves, fig. 3,099-D indicates *k.w.* input to hoist motor and induction motor of fly-wheel motor generator set respectively.

suspended from one end of a lever arm, the other end of which carries a counterweight for purpose of adjustment.

The torque of the motor varies with the line current and when this current tends to exceed a certain predetermined value, the torque of the motor will overcome the weights of the moving parts of the slip regulator introducing resistance into the rotor circuits of the main induction motor, thereby causing the motor to slow down and thus allow the flywheel to give up its energy.

When the current tends to fall below the predetermined value, the weight of the moving parts of the slip regulator will overcome the torque of the motor and the resistance will be automatically cut out, the wheel absorbing energy as the set speeds up.

When operating on the cycle for which the regulator is adjusted to completely equalize, the regulator will maintain a uniform input to the induction motor within 5% of either side of the average. The regulator is also used for starting of the set, the current during starting being limited to the value for which the regulator is adjusted.

Ques. When is a synchronous converter used in preference to a motor-generator set?

Ans. The matter of comparison of the merits of the synchronous converter with the motor-generator set is one which is influenced by a large number of considerations and the questions as to which should be adopted in a given instance can be answered only by a careful consideration of all the conditions affecting such decision for the particular case involved. Yet, there are certain characteristics of each type which may well be appraised before making a decision.

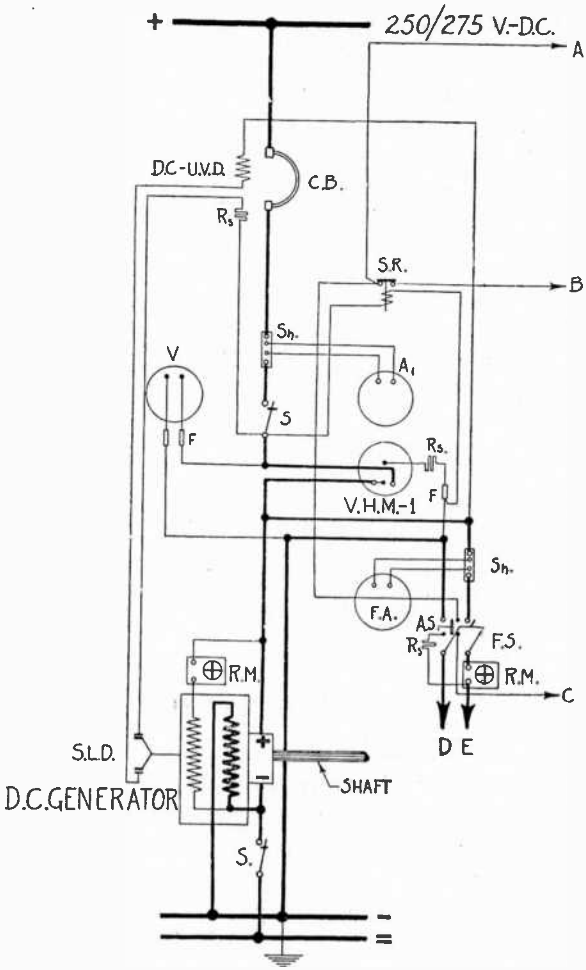


FIG. 3,099-F.—Diagram of connection for D.C. compound wound generator directly connected to a 60 cycle, 3 phase A. C. motor shown on the opposite page.

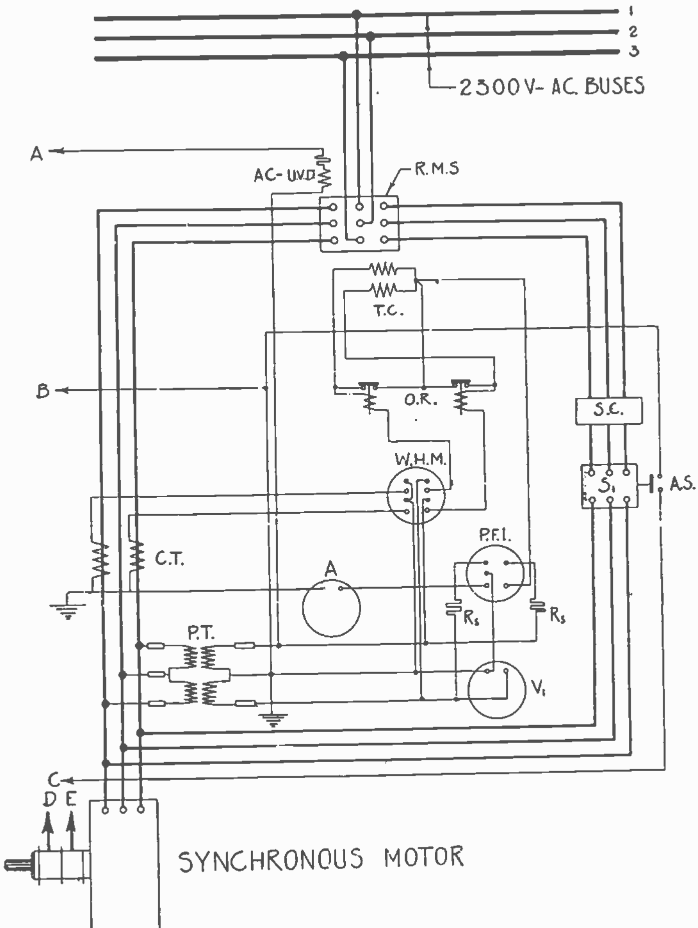


FIG. 3,099-G.—Connection of instrument and control relays for A. C. motor inter-connected to a D. C. compound wound generator. The control scheme includes a starting compensator and starting oil circuit breaker. Under-voltage protection is provided by means of devices inter-connected to the A. C. and D. C. main switches and on the main shaft of the motor generator set. The overload relays will trip the main oil circuit breaker when the over-current exceeds a pre-determined value by means of trip coils, which will become energized when the relays open their contacts due to the over-current. The energy is measured by means of a watt hour meter provided both on the A. C. and D. C. side of the load.

Certain applications for example by their very nature prove themselves suited for synchronous converter usage while others indicate that better economy and better all around service may be expected from a motor-generator application. For example, if an application is to be located at the end of a transmission line where regulation is poor and the voltage is subject to large fluctuations due to switching, the utilization of the motor-generator set is preferred.

However, due to the higher standards of *a.c.* distributors and improvement in interconnection methods, the synchronous converter has found a wider field of application than was previously thought possible. In the case of extreme frequency variations, severe line surges and extreme line voltage drops, the application of the synchronous converter is ill advised.

When making a comparison of the initial cost of both types of equipment, the calculation should be made to include the **step down transformer** for the synchronous converter. In many applications the motor-generator set is designed for direct line operations which tends to lower initial cost. On the basis of such computations, it will be found that the converter with the necessary auxiliary equipment represents about the same initial cost,

Key to symbols shown on diagrams pages 2,080-10 and 2,080-11.

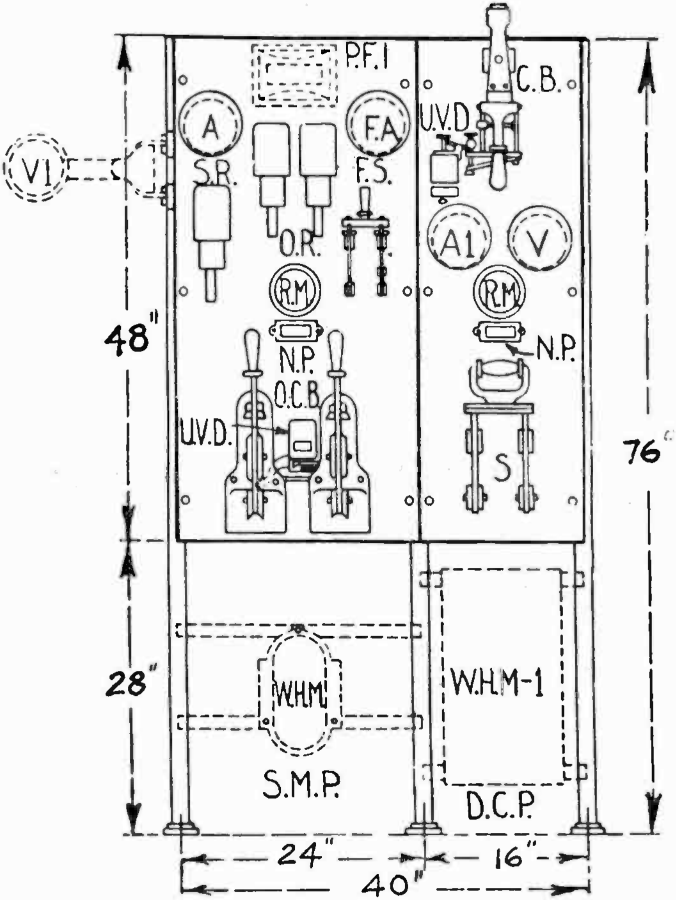
A. = Ammeter (a-c).
A_1 = Ammeter (d-c.).
A.S. = Auxiliary switch.
C.B. = Air circuit breaker.
C.T. = Current transformer.
D.C.P. = D-c. generator panel.
F. = Fuse.
F.A. = Field Ammeter.

Rs. = Resistance.
S. = Main and equalizing switch.
S_1 = Starting switch.
Sh. = Shunt.
S.C. = Starting compensator.
S.L.D. = Speed limiting device.
S.M.P. = Synchronous motor panel.
S.R. = Shunt relay.

F.S. = Field switch.
O.C.B. = Oil circuit breaker.
O.R. = Inverse time limit overload relay.
P.F.I. = Power factor indicator.
P.T. = Potential transformer.
R.M. = Rheostat mechanism.
R.M.S. = Running and magnetizing switch.
T.C. = Trip coil.
U.V.D. = Under-voltage device a-c. or d-c. (optional).
V = Voltmeter (d-c.).
V_1 = Voltmeter (a-c.) (optional).
W.H.M. = Watthour meter (a-c.).
W.H.M.-1 = Watthour meter (d-c.).

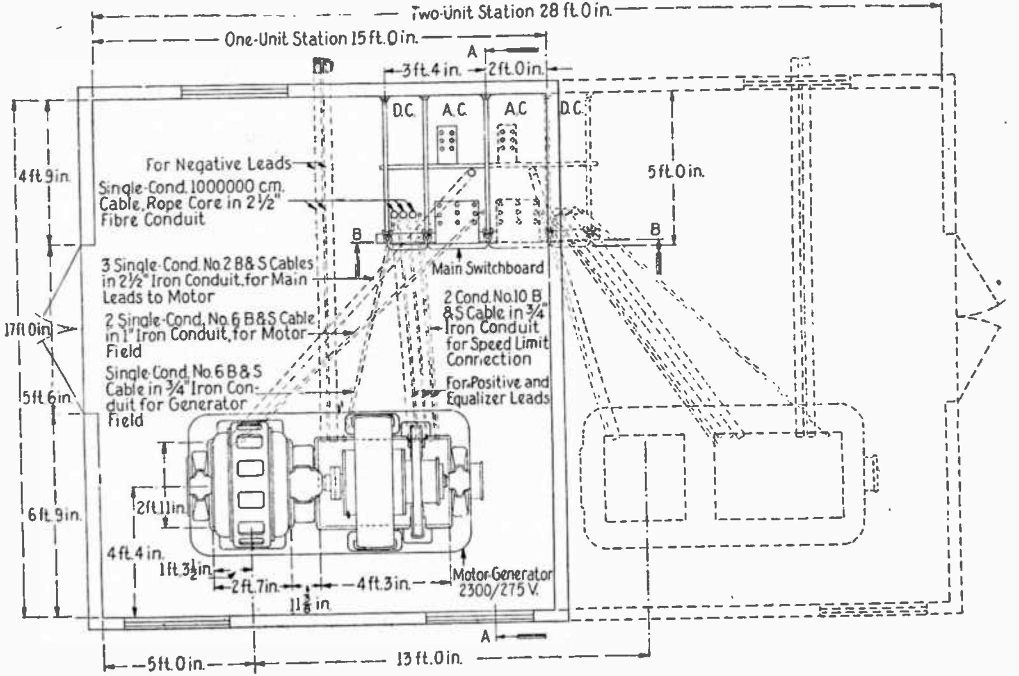
but the added all around efficiency incident to its operation will in time compensate for such added investment. This overall efficiency of the converter exceeds that of the motor-generator set by as much as 3 or 4 per cent at full load and even higher at lighter loads.

The demand for successful commutation at frequently applied heavy overloads is best met by the motor-generator set. Service involving high load peaks at frequent intervals in daily operation is particularly adverse to the best converter performance. In fact such service can be maintained by the converter only at greatly increased maintenance cost of the current collecting parts. Such increased maintenance will be further accentuated in event of a flash-over. Unquestionably the possibilities of flash-over are greater with the synchronous converter than with the motor-generator set.



With or Without A-C. or D-C. Watthour Meter

FIG. 3,099-H.—Front view of switchboard for use with synchronous motor generator set shown in figs. 3,099-F and 3,099-G.



STANDARD 300-KW. SYNCHRONOUS MOTOR-GENERATOR SUB-STATION

FIG. 3,099-I.—Plan view of sub-station, housing 300 *k.w.* motor generator set and control equipment. *Note.*—Provision for future motor generator set is shown in dotted outline.

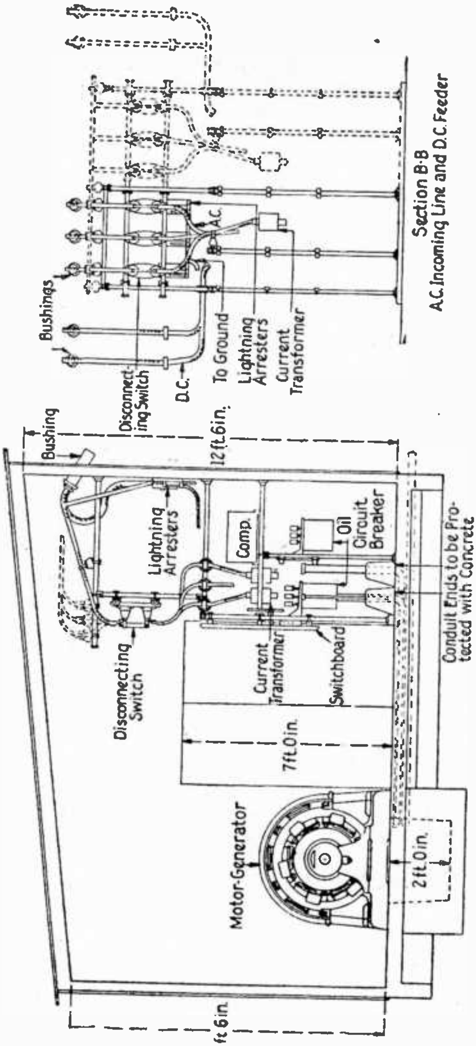


FIG. 3,099-J.—Section of sub-station and arrangement of cables and supports.

TEST QUESTIONS

1. *What is a motor generator set?*
2. *What is a motor generator set used for?*
3. *When is a motor generator set preferable to a rotary converter?*
4. *What combinations of motor generators are in general use?*
5. *What is the advantage of motor generator sets over converters on high frequency circuits?*
6. *What is the standard practice for transmission systems and the exceptions?*
7. *When is direct current distribution used?*
8. *What apparatus is not required with* d.c. *distribution?*
9. *What is the behavior of a rotary converter when hunting?*
10. *Is hunting so pronounced with motor generator sets?*
11. *Does racing under heavy inductive load or short circuit take place with motor generator sets?*
12. *Describe a frequency changing set.*
13. *Is a frequency of 25 desirable for electric lighting?*
14. *How is a low frequency changed to a high frequency?*
15. *What may be said of the parallel operation of frequency changers?*
16. *When alternators are run in parallel, with one machine right behind the other, what happens?*
17. *What is a cascade converter?*
18. *Describe the windings of a cascade converter.*

19. *At what speeds does a cascade converter run?*
20. *How is a cascade converter started?*
21. *How does a cascade converter compare with a synchronous converter?*
22. *What is a synchronous booster converter?*
23. *Describe a fly wheel motor generator set.*
24. *What is the object of a fly wheel on a fly wheel motor generator set?*

CHAPTER 66

A. C. Windings

The windings for alternators and *a.c.* motors are substantially alike. Most alternating current windings are of the open circuit type, that is, there is a continuous path through the wire of the coils of each phase of the winding with the ends of this path forming two free ends. Such a winding does not close upon itself.

For instance, in a revolving armature alternator the terminals of the completed winding are connected to collector rings and the winding is open circuited until closed by the connections between the brushes.

Alternator windings are usually described in terms of the number of slots per phase per pole. For instance, if the armature of a 20 pole three phase machine have 300 slots, it has 15 slots per pole or 5 slots per each phase per pole, and will be described as a five slot winding. Therefore, in order to trace the connections of a winding, it is necessary to consider the number of slots per pole for any one phase.

Classification of Windings.—The fact that *a.c.* machines are built in so many different types, gives rise to numerous kinds

NOTE.—The careless use of the term "armature windings" without regard to whether the winding be an armature, or a field winding should be avoided.

of winding to meet the varied conditions of operation. In dividing these forms of winding into distinctive groups, they may be classified, according to several points of view, as follows:

1. With respect to the form of the armature, as:

a. Revolving;
b. Stationary.

2. With respect to the mode of progression, as:

a. Lap winding;
b. Wave winding.

3. With respect to the relation between number of poles and number of coils, as:

a. Half coil winding;
b. Whole coil winding.

4. With respect to the number of slots, as:

a. Concentrated or uni-coil winding;
b. Distributed or multi-coil winding.

5. With respect to the form of the inductors, as:

a. Wire winding;
b. Strap winding;
c. Bar winding.

6. With respect to the number of coils per phase per pole, as:

a. One slot winding;
b. Two slot winding,
etc.

7. With respect to the kind of current delivered, as:

a. Single phase winding;

b. Two phase winding;

c. Three phase winding.

8. With respect to the shape of the coil ends, as:

a. Single range;

b. Two range;

c. Three range.

In addition to these several classes of winding, there are a number of miscellaneous windings of which the following might be mentioned:

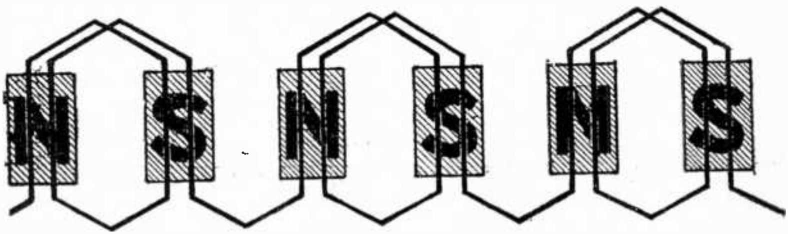


FIG. 3,100.—Single phase *lap* winding suitable for the same conditions as for the wave winding in fig. 3,101.

a. Chain winding;

b. Skew coil winding;

c. Fed-in winding;

d. Impregnated winding;

e. Mummified winding;

f. Spiral winding;

g. Shuttle winding;

h. Creeping winding.

Ques. Define a revolving and a stationary winding.

Ans. The words are self-defining; a winding is said to be revolving or stationary according as the armature, or field forms the rotor or stator of the machine.

Ques. What is the significance of the terms lap and wave as applied to alternator windings?

Ans. They have the same meaning as they do when applied to dynamo windings.

These are described in detail in Chapter 19. Briefly a lap winding is one composed of lap coils; a wave winding is one which roughly resembles in its diagram, a section of waves.

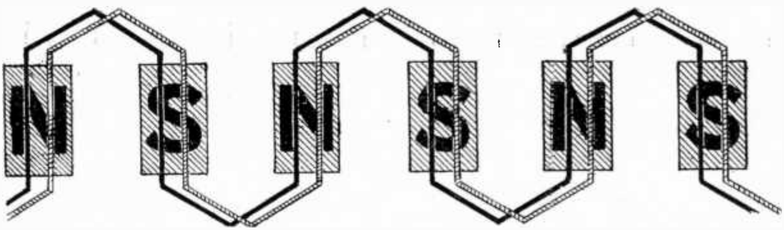


FIG. 3,101—Single phase wave winding having two slots per pole per phase and one coil side per slot.

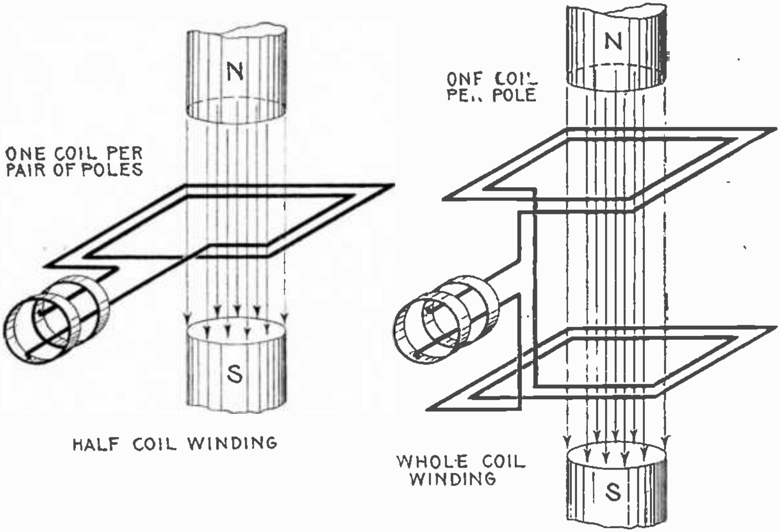
Half Coil and Whole Coil Windings.—The distinction as to whether the adjacent sides of consecutive coils are placed together under one pole or whether they are separated a distance equal to the pole pitch, gives rise to what is known as half coil and whole coil windings.

A half coil or hemitropic winding is *one in which the coils in any phase are situated opposite every other pole*, that is, *a winding in which there is only one coil per phase* **per pair of poles**, as in fig. 3,102.

A whole coil winding is one in which there is one coil per phase

per pole, as in fig. 3,103, the whole (every one) of the poles being subtended by coils.

Concentrated or Uni-Coil Winding.—Fig. 3,104 shows the simplest type of single phase winding. It is a one slot winding and is sometimes called "monotooth" or "uni-coil" winding.



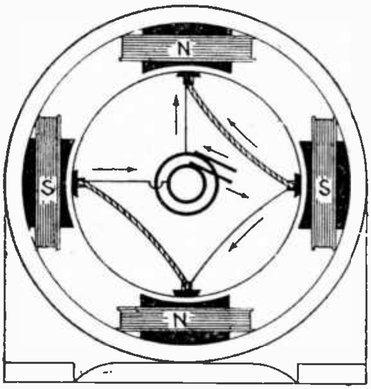
FIGS. 3,102 and 3,103.—Elementary bipolar alternators with *half coil* and *whole coil* windings In a half coil winding there is one coil per phase *per pair of poles;* in a whole coil winding there is one coil per phase *per pole*.

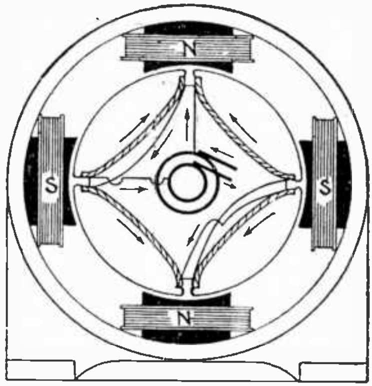
The surface of the armature is considered as divided into a series of large teeth, one tooth to each pole, and each tooth is wound with one coil, of one or more turns per pole. Since all the turns of the coil are placed in single slots, the winding is called "concentrated."

Ques. What are the features of concentrated windings?

Ans. Cheap construction, maximum voltage for a given number of inductors. Concentrated windings have greater armature reaction and inductance than other types, hence the terminal voltage of an alternator with concentrated winding falls off more than with distributed winding when the current output is increased. An alternator, therefore, does not have as good regulation with concentrated winding as with distributed winding nor as great capacity.

Ques. What should be noted with respect to concentrated windings?



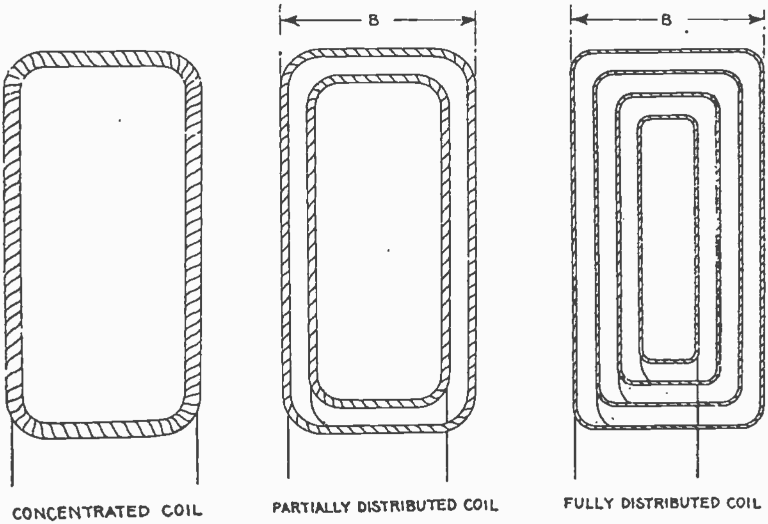


FIGS. 3,104 and 3,105.—Concentrated windings. A concentrated winding is one in which the armature has only *one tooth per phase per pole*, that is, the number of teeth equals the number of poles. A concentrated winding of the half coil type has only one side of a coil in each slot as in fig. 3,104. In the whole coil variety, each slot contains neighboring sides of adjacent coils, as in fig. 3,105.

Ans. A concentrated winding, though giving higher voltage than the distributed type with no load, may give a lower voltage than the latter at full load.

Ques. What is the wave form with a concentrated winding?

Ans. The pressure curve rises suddenly in value as the armature slots pass under the pole pieces, and falls suddenly as the armature slots recede from under the pole pieces.



FIGS. 3,106 to 3,108.—Alternator coils, showing difference between the concentrated, partially distributed, and fully distributed forms. Fig. 3,105 shows a concentrated coil in which all the wire is wound in one large coil; in the partially distributed type fig. 3,107, the wire of fig. 3,106, is wound in two or more coils or "sections" connected as shown, leaving some space inside not taken up by the subdivisions. In fig. 3,108 the wire of fig. 3,106 is *fully distributed*, being wound in a series of coils, so that all the interior space is taken up by the wire, that is to say, the spaces not occupied by the wire (the teeth when placed on the armature) are of equal size.

Distributed or Multi-Coil Winding.—Instead of winding an armature so it will occupy only one slot per phase per pole, it may be spread out so as to fill *several slots per phase per pole*. This arrangement is called a distributed winding.

To illustrate, fig. 3,106 represents a coil of say fifteen turns. This could be placed on an armature just as it is, in which case only one slot would be required for each side, that is, two in all. In place of this thick coil, the wire could be divided into several coils of a lesser number of

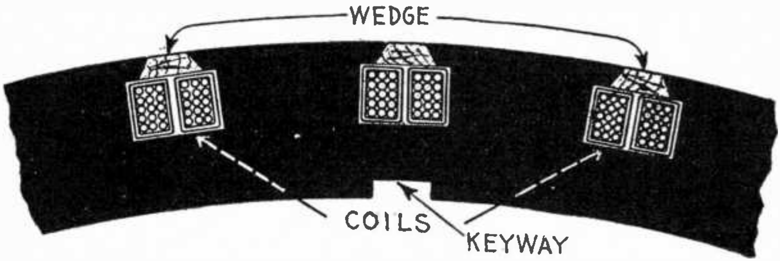


FIG. 3,109.—Laminated core with coils in position; type of punchings used on some machines having concentrated whole coil windings.

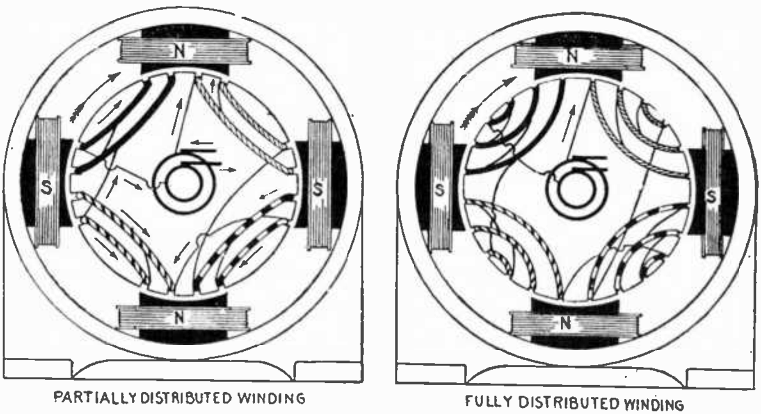


FIG. 3,110.—Partially distributed winding. Each coil unit is here divided into two concentric coils of different dimensions and connected in series, as shown in detail in fig. 3,107. This being a "whole coil" winding the several units are so connected that the winding of adjacent units proceeds in opposite directions, that is, one coil is wound clockwise, and the next counter clockwise, etc., so that the induced currents flow in a common direction as indicated by the arrows for the position shown.

FIG. 3,111.—Fully distributed winding. In this type of winding each coil consists of so many sub-coils that the winding occupies the entire surface of the armature core; that is, there are no extensive spaces unoccupied, the spacing being uniform as shown. This winding is unduly distributed; fig. 3,110 shows a better arrangement.

turns each, arranged as in fig. 3,107; it is then said to be *partially distributed*, or it could be arranged as in fig. 3,108, when it is said to be *fully distributed*.

A partially distributed winding, then, is one, as in fig. 3,107, *in which the coil slots do not occupy all the circumference of the armature;* that is, the core teeth are not continuous.

A fully distributed winding is one *in which the entire surface of the core is taken up with slots*, as in fig. 3,108.

Ques. In a distributed coil what is understood by the breadth of the coil?

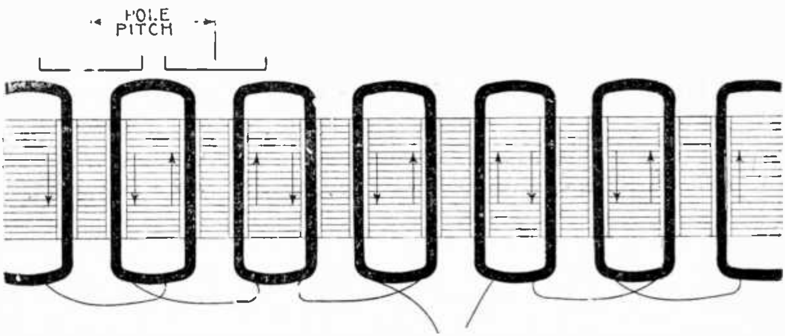


FIG. 3,112.—Developed diagram of single phase concentrated whole coil winding in two slot stamping for six pole alternator. If the sides of adjacent whole coils be slightly separated by placing the winding in a two slot stamping the electrical result will not differ materially from the monotooth whole coil winding.

Ans. The distance between the two outer sides, as B, in figs. 3,107 and 3,108.

Ques. How far is it advisable to spread distributed coils of a single phase alternator?

Ans. There will be little or no advantage in reducing the interior breadth below 25% of the breadth of the pole pitch, nor is there advantage in making the exterior breadth greater than the pole pitch.

Undue spreading of distributed coils lowers the value of the Kapp coefficient (later explained) by reducing the breadth coefficient and makes necessary a larger number of inductors to obtain the same voltage.

The increase in the number of inductors causes more armature self-induction. From this point of view, it would be preferable to concentrate

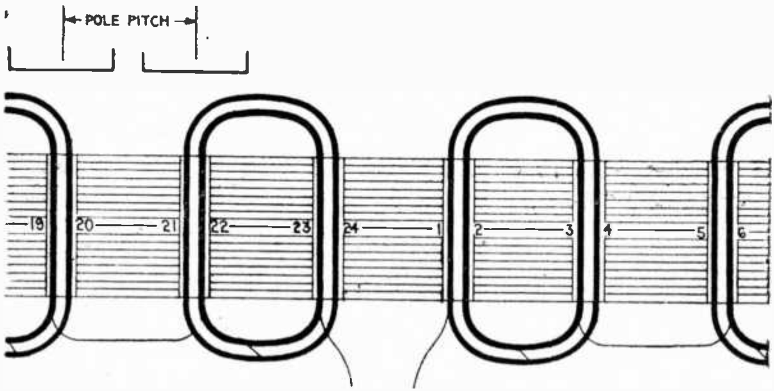


FIG. 3,113.—Developed diagram of single phase partially distributed half coil winding for six pole alternator in one slot stamping, same as in fig. 3,112. In this arrangement the direction of rotation is not reversed.

the winding in fewer slots that were closer together. This, however, would accentuate the distorting and demagnetizing reactions of the armature. Accordingly, between these two disadvantages a compromise is made, as to the extent of distributing the coils and spacing of the teeth, the proportions assigned being those which experience shows best suited to the conditions of operation for which the machine is designed.

Voltage Formula for Alternators.—A volt or unit of electric pressure is *defined as the pressure induced by the cutting of* 100,000,000 *or* 10^8 *lines of force per second*. In the operation of an alternator the maximum pressure generated may be expressed by the following equation:

$$E_{max} = \frac{\pi f Z N}{10^8} \quad \text{.......................(1)}$$

in which

E = volts;
f = frequency;
Z = number of inductors in series in any one magnetic circuit;
N = magnetic flux, or total number of magnetic lines in one pole or in one magnetic circuit.

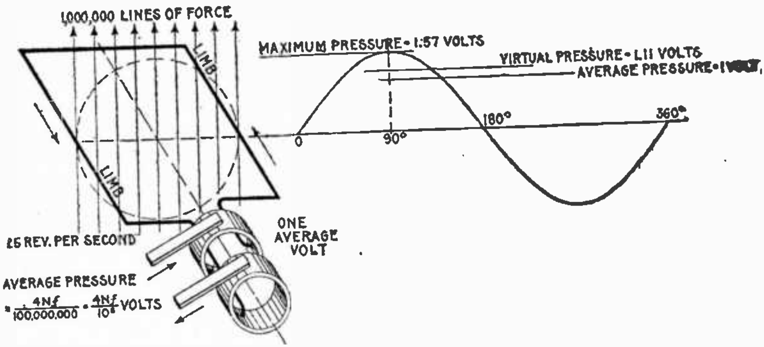


FIG. 3,114.—Elementary alternator developing one average volt. If the loop make one revolution per second, and the maximum number of lines of force embraced by the loop in the position shown (the zero position) be denoted by N, then each limb will cut 2N lines per second, because it cuts every line during the right sweep and again during the left sweep. Hence each limb develops an average pressure of 2N units (C.G.S. units), and as both limbs are connected in series, the total pressure is 4N units *per revolution*. Now, if the loop make f revolutions *per second* instead of only one, then f times as many lines will be cut *per second*, and the average pressure will be 4N f units. Since the C.G.S. unit of pressure is so extremely small, a much greater practical unit called the *volt* is used, which is equal to 100,000,000, or 10^8 C.G.S. units is employed. Hence average voltage $= 4Nf \div 10^8$. The value of N, in actual machines is very high, being several million lines of force. The illustration shows one set of conditions necessary to generate one average volt. The maximum pressure developed is $1 \div .637 = 1.57$ volts; virtual pressure $= 1.57 \times .707 = 1.11$ volts.

The maximum value of the pressure, as expressed in equation (1), occurs when $\theta = 90°$.

NOTE.—Fig. 3,114 is here repeated from the chapter on Alternating Currents to illustrate the unit of pressure or volt as obtained by the cutting magnetic lines of force as in the operation of an alternator.

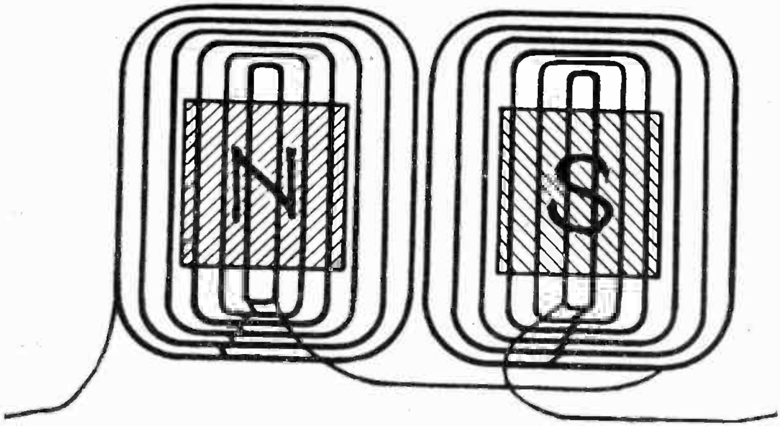


FIG. 3,115.—Developed diagram of single phase winding with excessive distribution of coils. As explained, excessive spreading lowers the value of the Kapp coefficient and consequently voltage; also the use of a larger number of inductors to obtain the same voltage results in an increase of armature self-induction. On the other hand, if the winding were concentrated in fewer slots and these slots were closer together, the result will be an increase in distorting and demagnetizing reactions of the armature. Therefore, a compromise between these two disadvantages must be made.

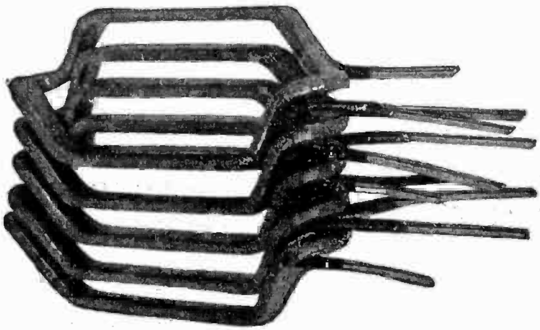


FIG. 3,116.—Allis-Chalmers "diamond" coils forming a five slot distributed coil unit. ***In construction***, the coils are form wound, covered with insulating material and treated with insulating compound. The coils where they pass through the core and for some distance on each side, are further protected by insulating material placed in the slots. Each coil is held in place by means of leatheroid slot wedges. The ends of the coils, where they project beyond the slots, are heavily taped

The virtual value of the volts is equal to the maximum value divided by $\sqrt{2}$, or multiplied by $\frac{1}{2}\sqrt{2}$, hence,

$$E_{virt} = \frac{\frac{1}{2}\sqrt{2} \times \pi f Z N}{10^8} = \frac{2.22 f Z N}{10^8} \quad \ldots\ldots\ldots\ldots (2)$$

This is usually taken as the fundamental equation in designing alternators. It is, however, deduced on the assumptions that the distribution of the magnetic flux follows a sine law, and that the whole of the loops of active inductors in the armature circuit act simultaneously, that is the winding is concentrated.

The Kapp Coefficient.—In practice, the coils are often more or less distributed, that is, they do not always subtend an exact pole pitch; moreover, the flux distribution, which depends on the shaping and breadth of the poles, is often quite different from a sine distribution. Hence, the coefficient 2.22 in equation (2) is often departed from, and in the general case equation (2) may be written

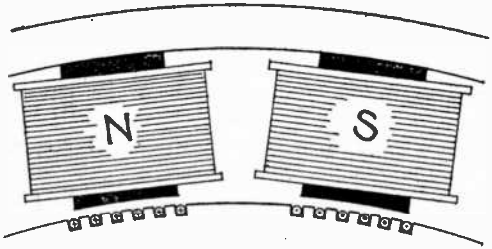
$$E_{virt} = \frac{k f Z N}{10^8} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

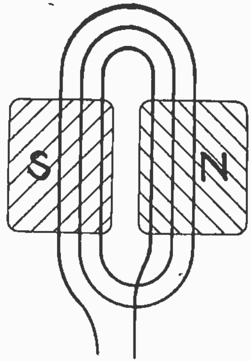
where k, is a number which may have different values, according to the construction of the alternator. This number k, is called the *Kapp coefficient* because its significance was first pointed out by Prof. Gisbert Kapp.

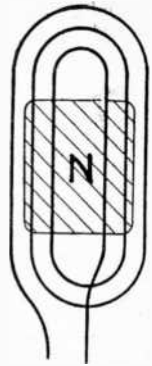
The value of k, is further influenced by a "breadth coefficient" or, spread or span "factor."

The effect of breadth in distributed windings is illustrated in figs. 3,117 to 3,119.

Wire, Strap, and Bar Windings.—In the construction of alternators, the windings may be of either wire, strap, or bar, according to which is best suited for the conditions to be met.







FIGS. 3,117 and 3,118.—Effect of breadth of coils in distributed windings. In the section of the alternator shown in fig. 3,117 the directions of the pressures induced as the armature rotates clockwise are represented by dots for those which act toward the reader, and by crosses for those which act from the reader (the dots and crosses representing respectively the heads and tails of arrows). Since the field is not uniform but maximum at the center and gradually weakening toward the extremities, it is obvious that the maximum pressure is induced in any inductor as it passes the center of the pole, this variation being indicated by the heavier dots and crosses toward the center. Now if a number of these inductors be connected up to form a distributed coil as in fig. 3,118, the pressures induced in each will be added, but as some of the flux goes around the inner coils instead of *through them*, the total pressure induced in the distributed coil is less than it would be if the coil were concentrated as in fig. 3,120.

FIG. 3,119.—Diagram of distributed coil whose inner breadth is less than the breadth of the pole face, showing the disadvantage of such arrangement. The pressure reverses at this point.

NOTE:—***Kapp coefficient.*** This coefficient (symbol k) takes into account: 1, the integration and reduction to a virtual value of the flux wave; 2, the spread factor, and 3, pitch factor of the armature winding. The basis of the coefficient was discussed at an early date by Prof. Kapp, and hence the name.

NOTE.—***Pitch factor.*** It often happens, for various reasons, that an armature coil does not embrace a complete pole pitch, and therefore the two sides of the coil do not lie in similar positions under adjacent poles with respect to the flux. The voltage from instant to instant is not the same in the two sides of the coil, and the resultant voltage will be less than if the coils spanned the complete pole. To allow for this, the pitch factor is introduced into voltage formulæ and is usually taken as the sine of half the angle of span of the coils, the full span being taken as 180°.

Ques. What kind of inductors are used on machines intended for high voltage and moderate current?

Ans. The winding is composed of what is called *magnet wire*, with double or triple cotton insulation.

Ques. What precaution is taken in insulating a wire wound coil containing a large number of turns?

NOTE.—*Spread factor.* In order to minimize the voltage impedance and so improve the regulation, the coils in the various phases of an alternator armature are divided up over a number of slots, instead of being concentrated all in one slot. As a result of this, the voltage in the various coils is not all in the same phase, and the resultant voltage is not the arithmetical sum of the voltage in the several coils. To correct for this, a factor, known as the spread factor, is introduced into voltage calculations. For practical estimation this reduction factor may be taken as .96 in the case of a distributed three phase winding; .90 for a distributed two phase winding; and .84 for a single phase winding distributed over two-thirds of the pole pitch.

NOTE.—*The values of the spread factor* as given in the table below are based upon the same number of inductors being placed in each of the slots and all of the slots being used.

Slots per phase per pole	Spread Factor		
	Single phase	Two phase	Three phase
1	1.000	1.000	1.000
2	.707	.924	.966
3	.663	.911	.960
4	.653	.906	.958
6	.644	.903	.956

NOTE.—*Voltages generated in various single phase windings.* The terms single, double, triple coil, etc., in the table below, indicate whether the inductors are arranged in one, two, three, etc., equally spaced single coils per pole piece, the single coil being determined by the group of inductors lying in one slot. The conditions are equivalent to the component voltages generated in each group being in one, two, three, etc., different phases, irrespective of the number of resultant windings into which they are combined.

Type of Winding	Correction factor for voltage of variously distributed windings
Single coil winding....................	E = 1.000
Double coil winding....................	E = .707 × single coil winding
Triple coil winding....................	E = .667 × " " "
Quadruple coil winding....................	E = .654 × " " "
Multi-coil or thoroughly distributed winding....................	E = .637 × " " "

Ans. On account of the considerable difference of pressure between layers, it is necessary to insulate each layer of turns as well as the outside of the coil, as shown in fig. 3,121.

Ques. Do distributed coils require insulation between the separate layers?

Ans. Since they are sub-divided into several coils insulation between layers is usually not necessary.

Ques. How is a coil covered?

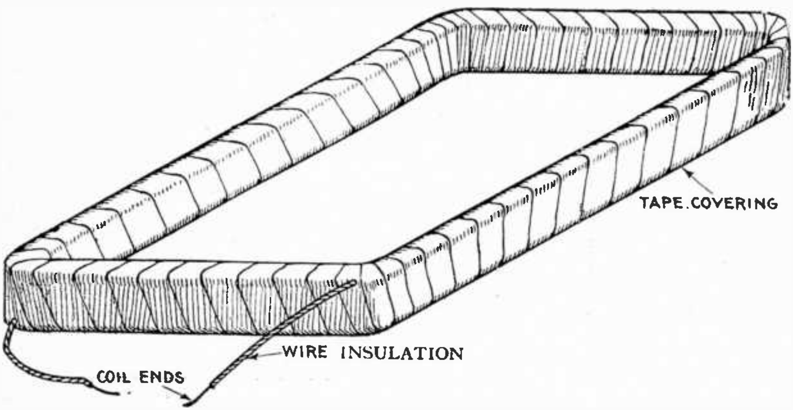


FIG. 3,120.—Simple form of alternator coil, consisting of numerous turns of insulated wire wound around a form, then covered with a tape winding, varnished and baked.

Ans. It is covered with a more or less heavy wrapping of tape depending upon the voltage, which, if high, is reinforced with other insulation.

Unvarnished cotton, sometimes falsely called "linen" (because of its color), is usually used for a coil binder or outer cover. Other insulation is frequently applied under the cotton.

Ques. Is the insulation placed around the coils all that is necessary?

Ans. The slots into which the coils are placed, are also insulated.

Ques. How are bar windings sometimes arranged?

Ans. In two layers, as in fig. 3,131.

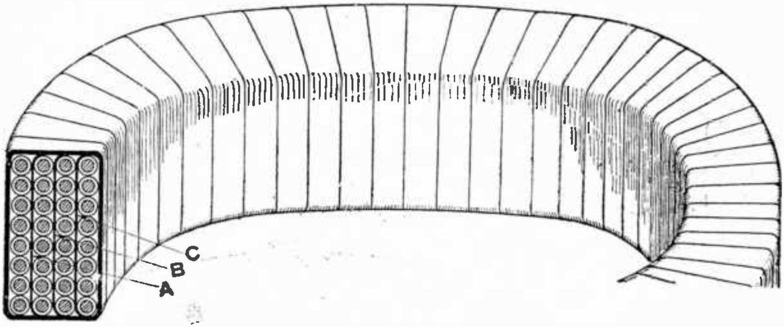
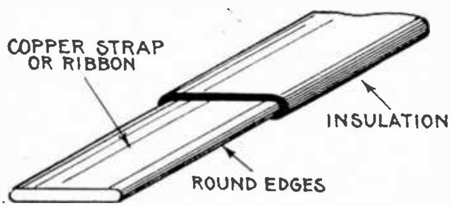


FIG. 3,121.—Method of winding a coil containing a large number of turns, when there is considerable difference of pressure between the layers. In such cases to guard against short circuits or breakdown of the insulation, each layer of turns is insulated from the next layer by the insulating strips A, B, C, in addition to the regular insulation around each wire. After the coil is made up it is wound with insulating tape, varnished and baked.



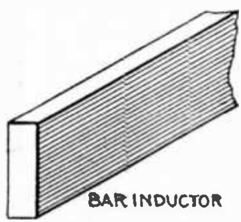
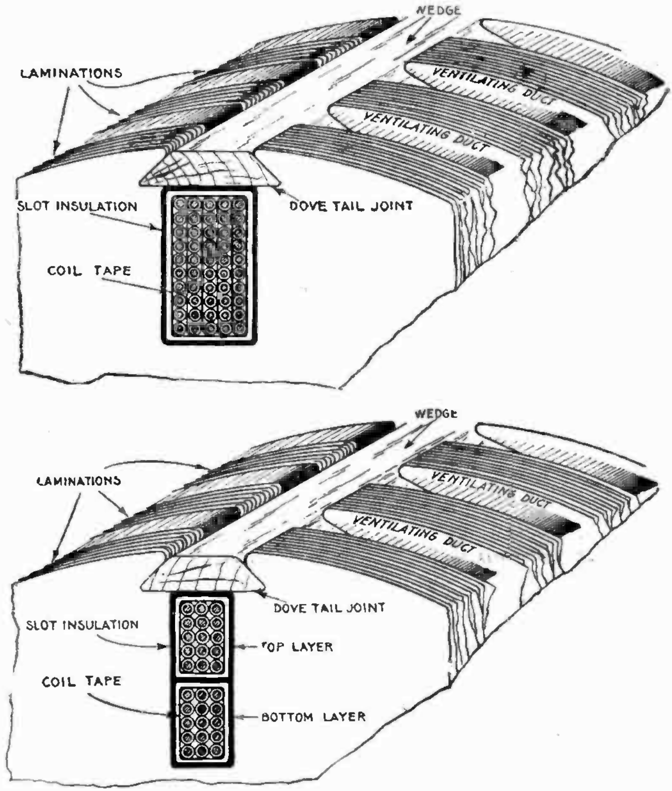


FIG. 3,122.—Copper strap or ribbon with insulation. These are generally from 1/32 to 1/16 inch thick with rounded edges as shown to avoid cutting the insulation.

FIG. 3,123.—Bar inductor. Its shape enables putting the maximum cross section of copper into the slot and is used to advantage on machines which generate large currents.

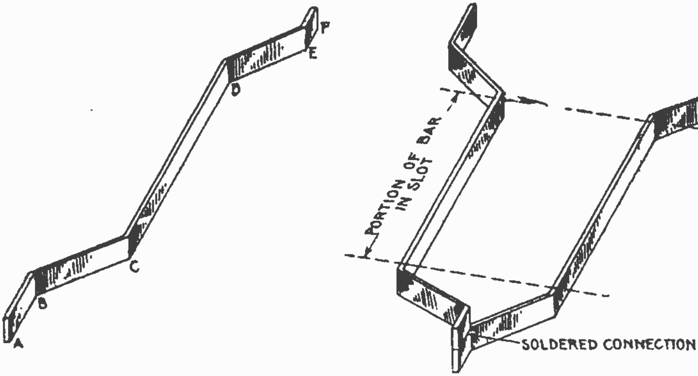
Single and Multi-Slot Windings.—These classifications correspond to *concentrated* and *distributed windings*, previously described. In usual modern practice, only ⅔ to ¾ of the



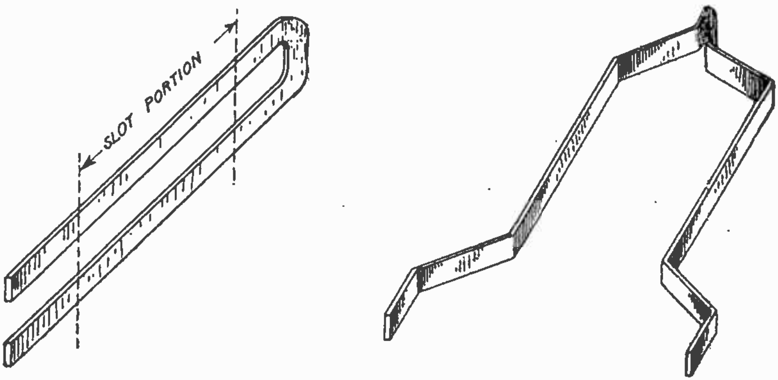
FIGS. 3,124 and 3,125.—Single and double layer multi-wire inductors and methods of placing them on the core. Here the term layer means unit, in fact each unit is made up of several "layers" of wires. In fig. 3,124, where so many wires are bunched together in one unit, each layer of turns is separated from those adjacent by insulating strips on account of the considerable difference of pressure between layers. This insulation may not be necessary in fig. 3,125 where there are two units or so called layers. In both cases the inductors are held in place by wedges driven into dovetail grooves.

total number of slots (assuming the spacing to be uniform) of a single phase armature are wound with coils.

The reason for this may be explained by aid of fig. 3,130, which shows an armature with six slots per pole, four of which are wound.



FIGS. 3,126 and 3,127.—Bent bar inductor and method of connection with soldered joint. Fig. 3,126 shows one bar and shape of bent ends. The portion from C, to D, is placed in the slot; B, to C, and D, to E, bent or connector sections; A, to B, and E, to F, ends bent parallel with slot for soldering. Fig. 3,127 shows two bar inductors connected.



FIGS. 3,128 and 3,129.—Method of avoiding a soldered joint at one end of a bar inductor by using a bar of twice the length shown in fig. 3,126, and bending it into a long U form, as in fig. 3,128, after which it is spread out forming two inductors, as in fig. 3,129.

Owing to the different positions of, say, coils A and B, there will be a difference in phase between the pressure generated in them and consequently the resultant pressure of the two coils joined in series will be less than the sum of the pressure in each coil.

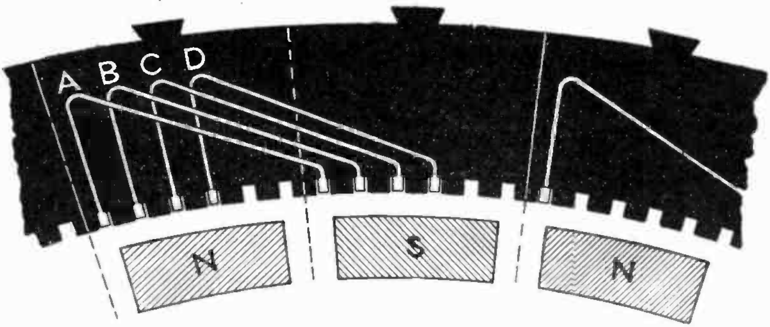


FIG. 3,130.—Diagram of single phase multi-coil or distributed winding to show characteristic differences in construction and action from single coil or concentrated winding.

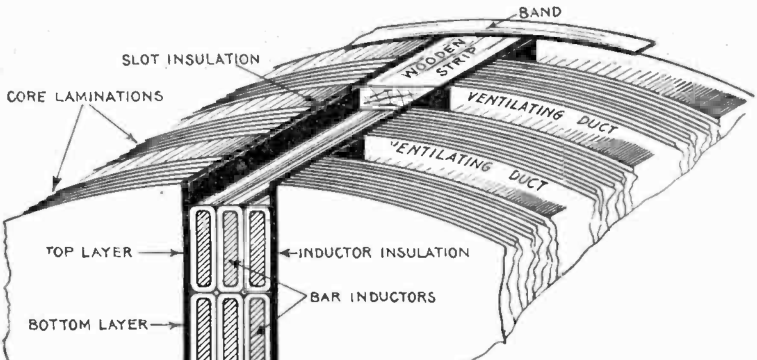


FIG. 3,131.—Arrangement in slot of two layer bar winding. With bar inductors, as must be evident from the illustration, the maximum cross section of copper can be placed in a slot of given dimensions, hence a bar winding is used to advantage for alternators designed to carry a large current.

Ques. What other advantage besides obtaining a sine wave is secured by distributing a coil?

Ans. There is less heating because of the better ventilation.

Single Phase Windings.—There are various kinds of single phase winding, such as, concentrated, distributed, hemitropic,

FIG. 3,132.—Style of armature core stamping used with bar wound machines. This construction, since there are no indentations in the teeth for wedges, makes it necessary to provide bands to hold the bars in place.

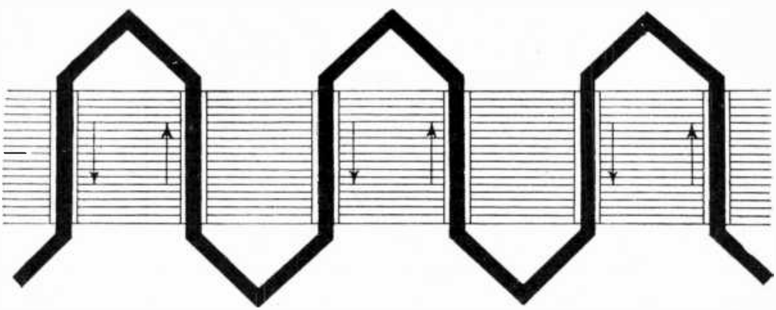


FIG. 3,133.—Developed diagram of a single phase monotooth or one slot bar winding; it is suitable only for operation at low voltage.

etc. Fig. 3,134 shows the simple type of single phase winding It is a "one slot" winding, that is, concentrated coils are used.

The armature has the same number of teeth as there are poles, the concentrated coils being arranged as shown. In designing such a winding, the machine, for example, may be required to generate, say, 2,300 volts, frequency 60, revolutions 1,200 per minute.

These conditions require 720 inductors in series in the armature circuit, and as the armature is divided into six slots corresponding to the six poles, there will be 120 inductors per slot, and the coil surrounding each of the six teeth on the surface of the armature will consist of 60 turns. The connections must be such as to give alternate clockwise and counter-clockwise winding proceeding around the armature.

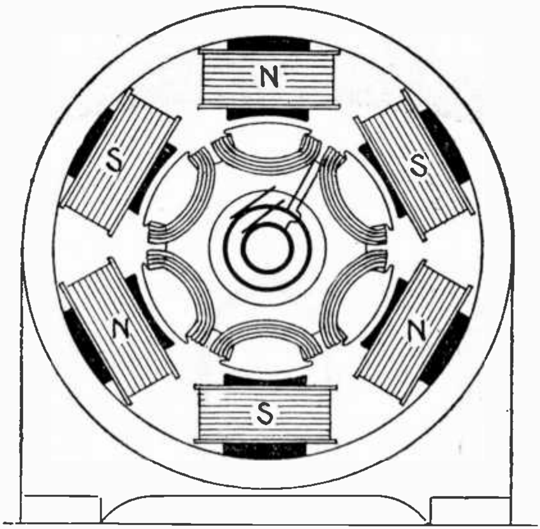


FIG. 3,134.—Diagram of six pole single phase revolving armature alternator, with monotooth or concentrated whole coil winding. For 2,300 volts at 1,200 revolutions per minute, 720 inductors per slot are required. In the case of a concentrated or monotooth winding they may be arranged in "whole coils" as above or in "half coils" (hemitropic) as in fig. 3,135.

Ques. In what other way could the inductors be arranged in concentrated coils?

Ans. They could be grouped in three coils of 120 turns each, as shown in fig. 3,135.

When thus grouped the arrangement is called a ½ coil, hemitropic or club footed winding.

Ques. What are the advantages and disadvantages of a half coil winding?

Ans. In single phase machines, a half coil winding is nearly equivalent electrically to a monotooth winding and therefore

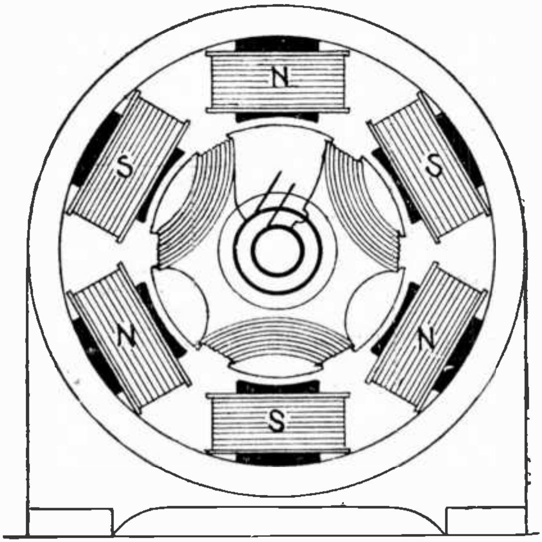


Fig. 3,135.—Diagram of six pole single phase alternator with concentrated half coil or hemitropic winding of same capacity as in fig. 3,134. There are an equal number of inductors but in this case arranged in three instead of six coils. In this winding the direction of winding is not reversed or that the induced pressures would oppose one another.

is not of any particular advantage; the regulation and ventilation are not so good and they require more head room. The wave shape is badly off the sine curves, same as a monotooth.

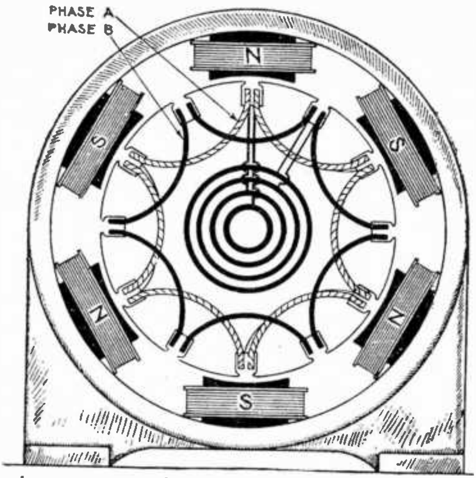


FIG. 3,136.—Two phase concentrated whole coil winding. In this style winding the total number of slots is twice the number of poles, or one slot per pole per phase. It comprises two windings identical with fig. 3,134, being spaced 90 polar degrees as shown. The two circuits are independent, the windings terminating at the four collector rings.

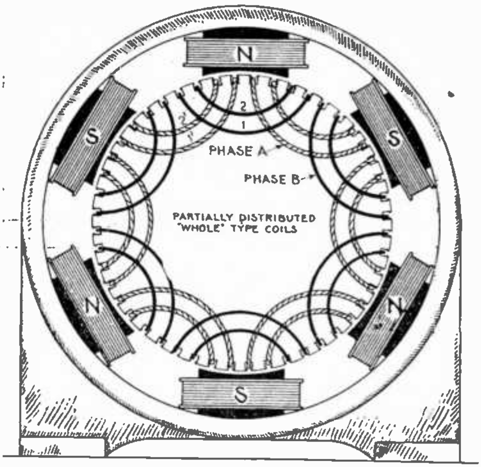


FIG. 3,137.—Two phase winding in two slots per pole per phase. This stamping distributes the coils of each phase into two sections, as A and B. The coils are of the "whole" type and with six poles the total number of slots is 4×6=24, uniformly spaced as shown.

Two Phase Armature Windings.—This type of winding can be made from any single phase winding by providing another set of slots displaced along the surface of the armature to the extent of one-half the pole pitch, placing therein a duplicate winding.

For instance: If the six pole monotooth, single phase winding, shown in fig. 3,134, be thus duplicated, the result will be the one slot two-phase winding shown in fig. 3,136, which will have twelve slots, and will require four slip rings, or two rings for each phase.

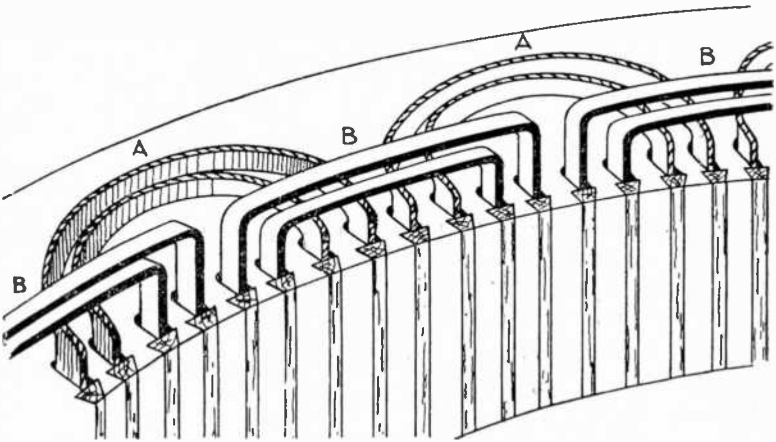


FIG. 3,138.—Treatment of coil ends in two phase, two range concentric chain windings. In this arrangement *straight out* B and *bent up* A coils are used which are placed on the armature as is clearly shown in the illustration.

By connecting up the two windings in series, the machines could be used as a single phase, with an increase of voltage in the ratio of 1.41 to 1.

Ques. How must the coils be constructed for chain type windings?

Ans. They must be made of two different shapes, one bent up out of the way of the other, as in fig. 3,138.

NOTE.—A chain winding which is made up of coils having one, two, or three different shapes is called a one range, two range, or three range winding respectively.

There are numerous kinds of two phase windings; the coils may be concentrated or distributed, half coil or whole coil, etc. Fig. 3,137 shows a two phase winding with four slots per pole, and fig. 3,140 one with six slots per pole.

Three Phase Armature Windings.—On the same general principal applicable to two phase windings, a three phase winding can be made from any single phase winding, by placing

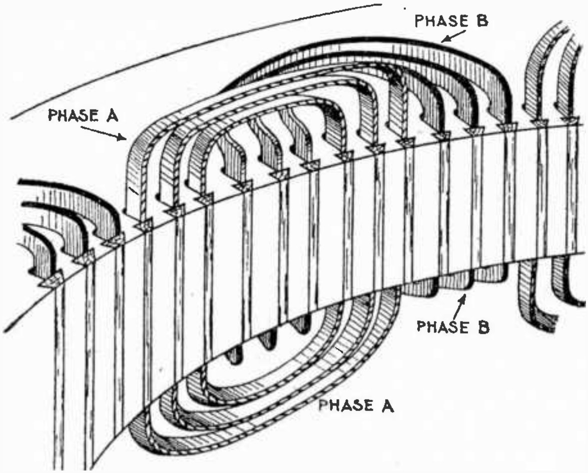


FIG. 3,139.—Two phase winding in three slots per pole per phase showing shaping of the coil ends. The coils are the "whole" type. Every other coil is flat, while the alternates have their ends bent down as shown. With respect to the shaping of the coil ends, it is called a two range winding.

three identical single phase windings spaced out successively along the surface of the armature at intervals *equal to one-third and two-thirds, respectively, of the double pole pitch*, the unit in terms of which the spacing is expressed, being that pitch, which corresponds to one whole cycle.

Each of the three individual windings must be concentrated into narrow belts so as to leave sufficient space for the other windings between them. This limits the breadth or space occupied by the winding of any one phase to one-third of the pole pitch.

Ques. How are three phase coil ends treated?

Ans. They may be arranged in two ranges, as in fig. 3,141, or in three ranges, as in fig. 3,142.

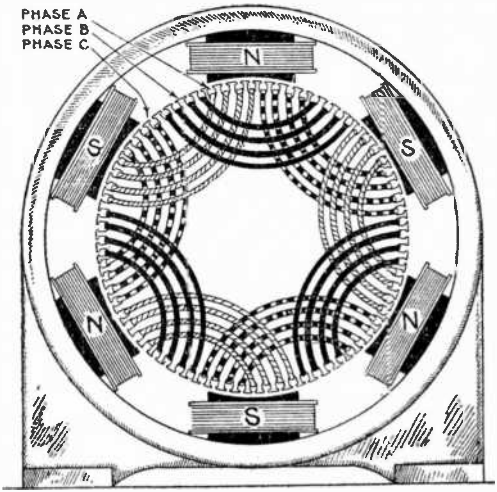


FIG. 3,140.—Three phase winding with distributed coils—wound in four slots per pole per phase; diagram showing placement of the coils.

Ques. What kind of coil must be used for three phase windings in order that the ends may be arranged in only two ranges?

Ans. Hemitropic or half coils; that is, the number of coils per phase must be equal to one-half the number of poles.

Chain or Nested Winding.—One disadvantage in ordinary two range windings is that two or three separate shapes of coil are required. The cost of making, winding, and supplying spares would be less if one shape of coil could be made to do for all phases. One way of accomplishing this is by the method of nested winding. in which *the two sides of each coil are made of*

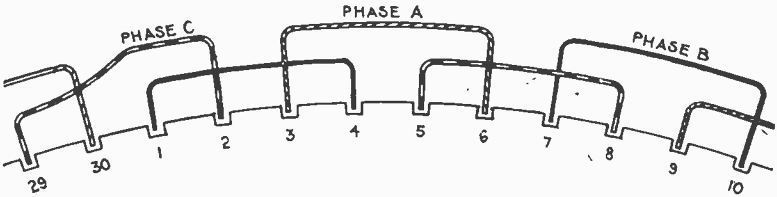


FIG. 3,141.—Three phase, 10 pole, 30 slot winding in two ranges. In this winding perfect symmetry occurs after every four poles. Accordingly in the case of an odd number of pairs of pole, one of the coils must necessarily be askew going from the inner to the outer range as shown at the left.

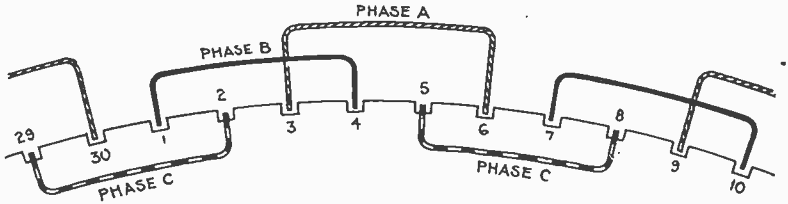


FIG. 3,142.—Three phase 10 pole 30 slot winding in three ranges. The coils of each phase are alike, those of the A phase being all in the straight out range, those in the B phase, in a bent up range, and those in the C phase in a bent down range. This arrangement has the disadvantage, that by reason of the third range, the heads require excessive space. *In practice*, one range is straight and the other two bent back.

different lengths, as shown in fig. 3,143, *and bent so that they can lie behind one another.*

In the case of open slots the coils may be form wound and afterwards wedged into their places.

In chain winding the adjacent coils link one another as in a chain (hence, the name); the winding is similar to a skew coil winding. This plan of winding is supposed to have some advantage in keeping coils of different phases further separated than the two range plan.

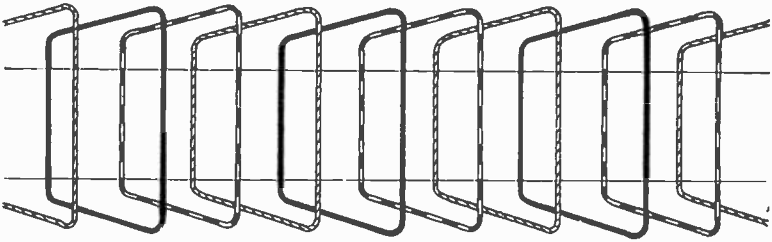
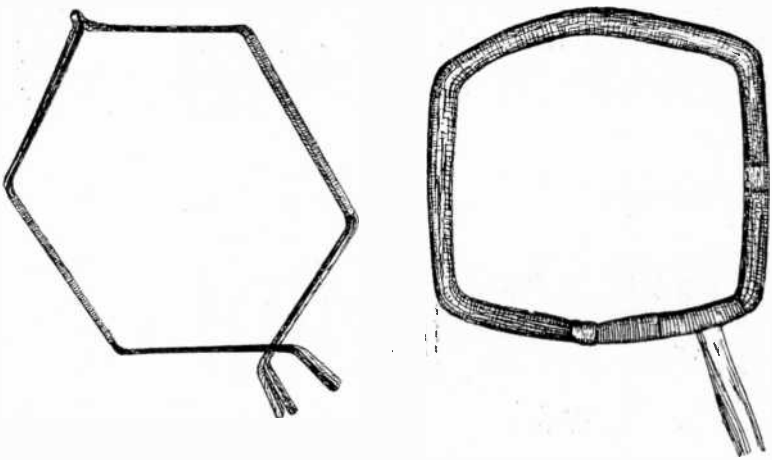


FIG. 3,143.—Diagram showing chain or nested winding. In this method of winding the coils are all similar with long and short sides. It obviates the extra cost of making coils of several different shapes. The diagram represents a winding for one slot per pole per phase.

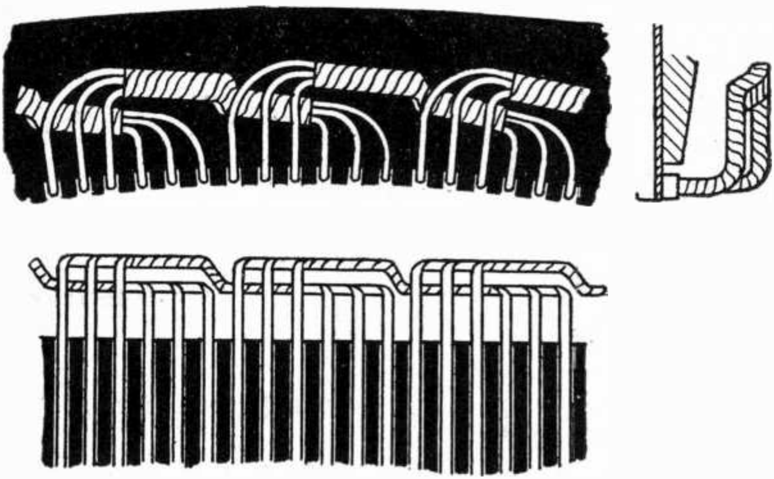


FIGS. 3,144 and 3,145.—Nested, basket, or mush coil and a diamond winding coil showing difference between the two types.

Diamond Winding.—By definition a diamond winding is *one which is made up of similarly shaped overlapping coils which have V-shaped coil ends, so bent that approximately half of each coil end is on one side of the plane of the coil side and the other half of each coil end is on the other side of the plane of the coil* *side. The diamond winding is the real "HE" winding of to-day and is the prevailing type.*

Ques. What are the advantages of the diamond winding?

Ans. A single adjustable form may be used for numerous size coils; it can be connected according to nearly any method; connections may be readily changed; coils easily insulated and assembled; coils and winding all alike; repairs easily made.



FIGS. 3,146 to 3,148.—Views of a section of skew coil winding; so called on account of the skew shape given to the coil ends in order that all the coils may be of one shape

Ques. How are the ends of a diamond coil shaped?

Ans. They are bent so that the plane of the coil side does not bisect the coil end.

Ques. What is a sharp bend at the middle of a diamond coil end called?

Ans. The knuckle.

The coils of practically all two layer overlapping windings are provided with some sort of a knuckle. The function of the knuckle is to permit coil ends to properly cross each other.

Skew Coil Winding.—In this type of winding the object is to shape the coils so that all may be of one pattern. This is

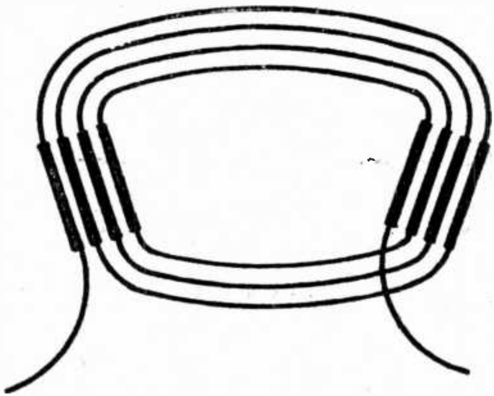
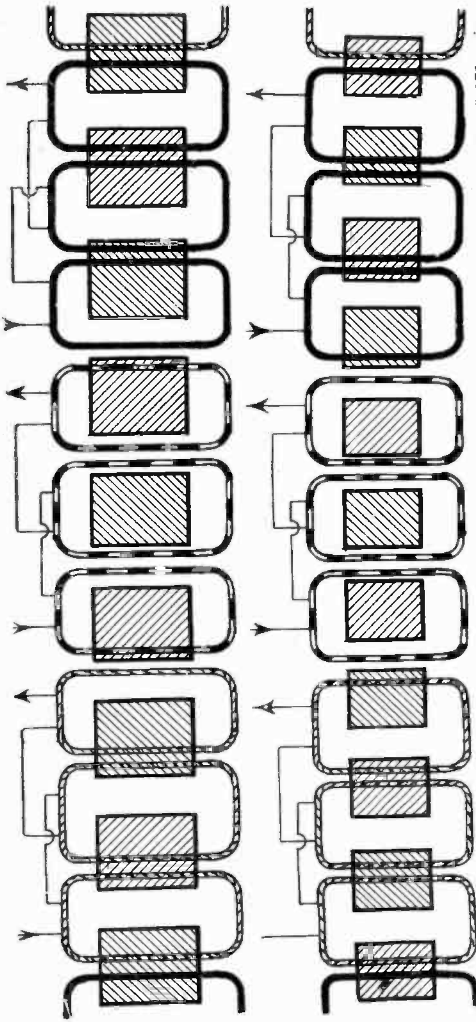


FIG. 3,149.—Diagram showing a spiral coil. This type of coil is one in which each successive turn lies entirely within the previous turn, starting with the outermost turn of the coil. The successive turns of a spiral coil are thus not of the same size, and are not over-lapping as in a "lap" coil.

accomplished by making the ends skew shape as shown in figs. 3,146 to 3,148.

Assembled or Fed-in Winding.—This name is given to a type of winding possible with open or only partially closed slots, in which coils previously formed are introduced, only a few inductors at a time if necessary. They are inserted into the slots from



FIGS. 3,150 and 3,151.—Diagram of creeping windings. Fig. 3,150, nine coils subtending ten poles; fig. 3,151, nine coils subtending eight poles.

the top, the slot being provided with a lining of horn fibre or other suitable material, which is finally closed over and secured in place by means of a wedge, or by some other suitable means. An example of a fed-in winding is shown in fig. 3,145.

Spiral Winding.—This is a winding in which "spiral" coils, as shown in fig. 3,149, are used. The spiral form of coil is very extensively used for armature windings of alternators.

Impregnated or Mummified Winding.—These words applied to a winding are used to express *the treatment the coils of the winding receive* *in the making;* that is, when a winding, after being covered with tape or other absorbent material, is saturated in an insulating compound and baked until the whole is solidified, it is said to be mummified.

Shuttle Winding.—This type of winding consists of *a single coil having a large number of turns, wound in two slots spaced 180° apart.* It was originally used on Siemens' armature and is now used on magnetos, as shown in figs. 2,263 to 2,265.

Turbine Alternator Winding.—For the reason that steam turbines run at so much higher speed than steam engines, the

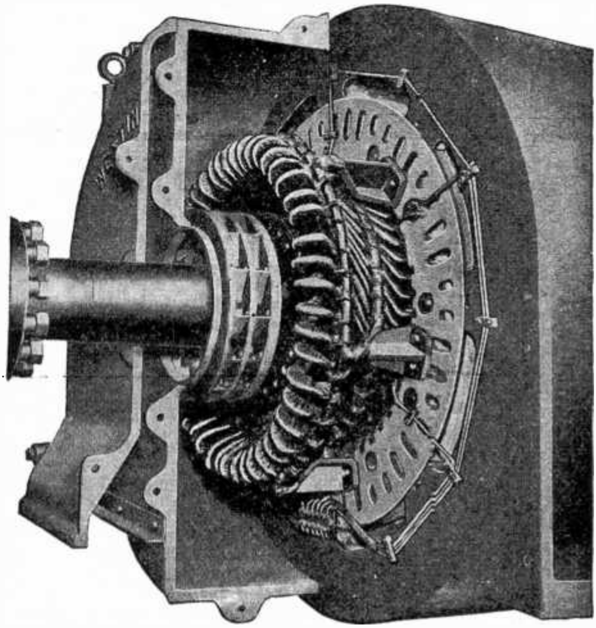


FIG. 3,152.—Westinghouse turbine alternator with end bell removed showing projection of armature winding. Owing to the large current each inductor consists of a large number of insulated small wires to reduce the large eddy currents that would exist if each inductor consisted of solid bars.

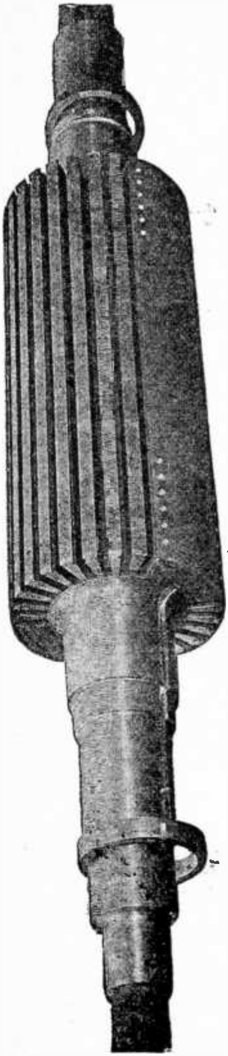


FIG. 3,154.—Westinghouse field core ready for winding. *It is made* from a solid steel forging and has machined radial slots for the field winding. The slots and field winding are distributed so that the flux distribution of the field poles will be such that the generated voltage wave of the armature winding will be practically free from harmonics of an appreciable magnitude.

construction of armatures and windings for alternators intended to be direct connected to turbines must be quite different from those driven by steam engines. Accordingly, in order that the frequency be not too high, turbine driven alternators must have very few poles—usually two or four, but rarely six.

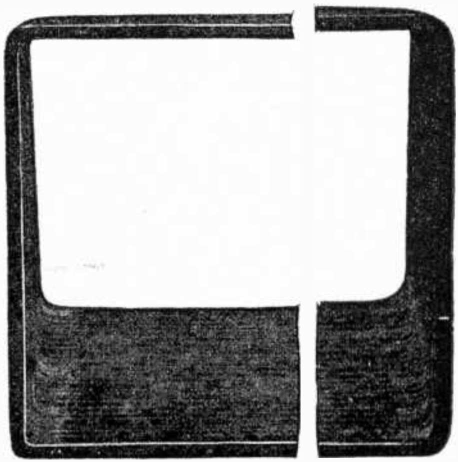


FIG. 3,153.—Westinghouse turbine alternator insulated field coil ready for installing in slots. The individual coils of the field windings are made of continuous copper strap, bent on edge and are held in the slots by means of bronze wedges. The conductors are insulated from each other with highly compressed continuous mica strip and the complete coils are insulated from the core with a moulded pure mica cell. The end turns of the field winding are braced in both circumferential and axial directions by treated asbestos cloth blocks, having clearance to allow axial expansion without distortion from changes in temperature. The end turns are supported in the radial direction by retainer rings made from high grade specially heated-treated continuous steel forgings.

Table of Frequency and Revolutions

FREQUENCY	REVOLUTIONS		
	2 POLE	4 POLE	6 POLE
25	1,500	750	500
60	3,600	1,800	1,200
100	6,000	3,000	2,000

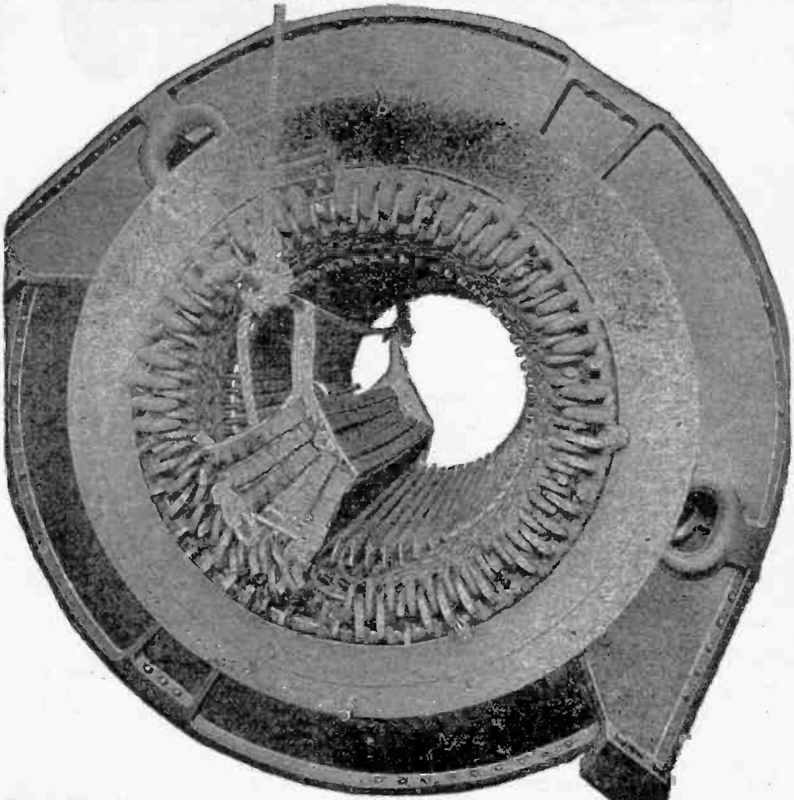


FIG. 3,155.—General Electric turbine alternator. End view showing end of armature winding and method of raising coils for inserting last coil.

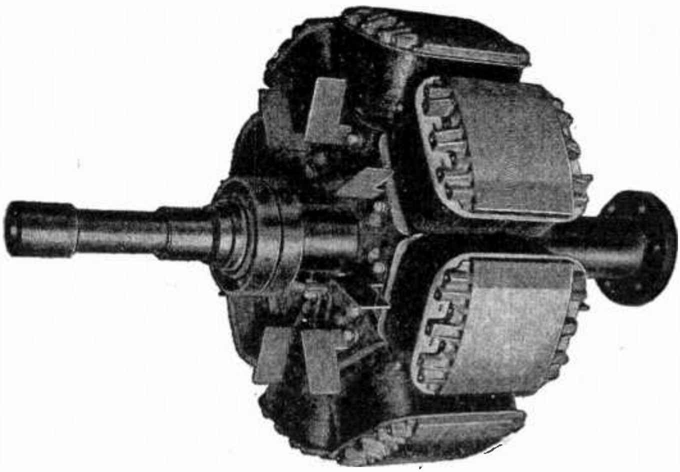


FIG. 3,456.—Westinghouse general turbine alternator field.

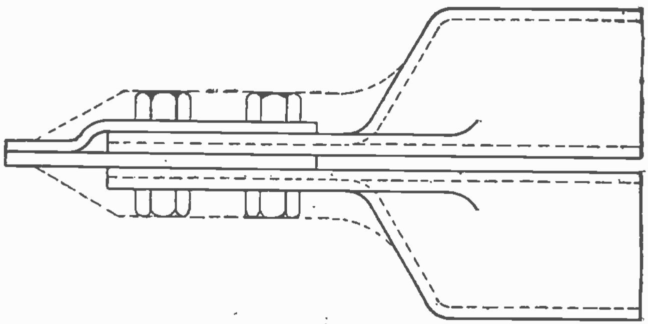


FIG. 3,457.—Diagram of General Electric turbine alternator armature lead showing method of insulation. It is the usual practice for the customer to insulate the connection between the turbine generator armature terminals and the line cables. Insulate joints as follows to guard against trouble: 1, Smooth over the uneven surfaces of the joint and the terminals with a paste in order to form a surface over which the insulating tape can be smoothly drawn; 2, starting each layer of tape at the bottom, insulate the terminals and joints with tapings one half lapped of .012 in. varnished cambric applied with varnish to seal all of the interstices, the number of tapings depending upon the voltage; 3, apply one layer of .012 in. stay binding one half lapped and over this five coats of moisture proof varnish; 4, do not support more than five feet of station cables on these terminals.

From the table, it is evident that a large number of poles is not permissible, considering the high speed at which the turbine must be run.

Ques. How is the high voltage obtained with so few poles?

Ans. There must be either numerous inductors per slot or numerous slots per pole.

Ques. What form of armature is generally used?

Ans. A stationary armature.

Ques. What difficulty is experienced with revolving armatures?

Ans. The centrifugal force being considerable on account of the high speed, requires specially strong construction to resist it, consequently closed or nearly closed slots must be used.

Ques. How is the design of the rotor modified so as to reduce the centrifugal force?

Ans. It is made long and of small diameter.

TEST QUESTIONS

1. *How are a.c. windings usually described?*
2. *Give a classification of a.c. windings.*
3. *What is the meaning of the terms lap and wave as applied to a.c. windings?*
4. *What is the difference between a half coil and a whole coil winding?*
5. *What is a concentrated or unit coil winding?*

6. *What are the features of a concentrated winding?*
7. *Describe a distributed or multi-coil winding.*
8. *In a distributed coil what is understood by the breadth of the coil?*
9. *How far is it advisable to spread distributed coils of a single phase alternator?*
10. *Derive the voltage formula for alternators.*
11. *What is the Kapp coefficient?*
12. *What factors are included in the Kapp coefficient?*
13. *What is the difference between wire, strap and bar windings?*
14. *How is a coil covered?*
15. *How are bar windings sometimes arranged?*
16. *What are the names given to single and multi-slot windings?*
17. *Describe the arrangement of a two layer bar winding.*
18. *What other advantage besides obtaining a sine wave is secured by distributing a coil?*
19. *Name some types of single phase winding.*
20. *What is the advantage, if any, of a half coil winding?*
21. *How must the coils be constructed for two phase windings?*
22. *How are three phase coils made and assembled?*
23. *What is the difference between a one range, two range, and three range winding?*
24. *What is a skew coil winding?*
25. *Describe: 1, fed-in, 2, spiral, 3, impregnated or mummified, and 4, shuttle windings.*

CHAPTER 67

A. C. Windings

2. Grouping of Phases

In the diagrams of the preceding chapter the general arrangements of the coils on the armature are shown for the numerous classes of winding. In polyphase alternators the separate windings of the various phases may be grouped in two ways:

1. Star connection;
2. Delta connection.

Ques. Describe the two phase star connection.

Ans. In this method of grouping, the middle points of each of the two phases are united to a common junction M, and the four ends are brought out to four terminals *a*, *a'*, *b*, *b'*, as shown in fig. 3,158, or in the case of revolving armatures, to four slip rings.

Ques. What does this arrangement give?

Ans. It is practically equivalent to a four phase system.

Ques. How is the two phase delta connection arranged?

Ans. In this style of grouping, the two phases are divided into two parts, and the four parts are connected up in cyclic order, the end of one to the beginning of the next, so as to form a square, the four corners of which are connected to the four terminals; this connection is obsolete.

Ques. Describe a three phase star connection.

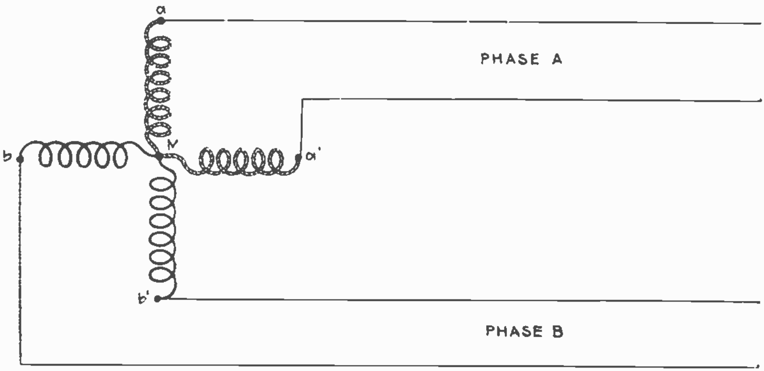


FIG. 3,158.—Diagram of two phase star grouping.

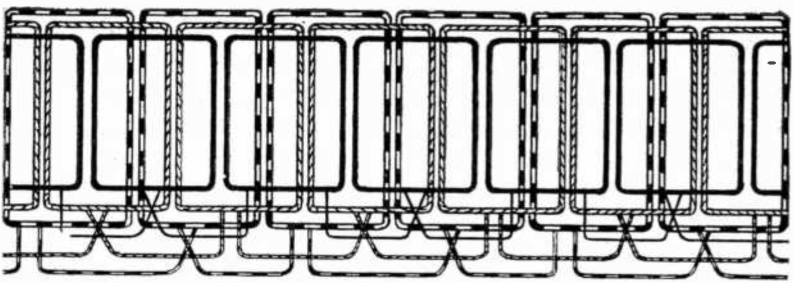


FIG. 3,159.—Three phase winding with whole coils. Two sides of adjacent coils come in one slot. Number of coils per phase = number of poles per phase. Total number of slots = 3 multiplied by number of poles per phase. Whole coils require the ends arranged in three ranges as indicated. The coils are concentrated.

Ans. In three phase star grouping, one end of each of the three circuits is brought to a common junction M, usually insulated, and the three other ends are connected to three terminals *a*, *b*, *c*, as shown in fig. 3,160, or in the case of revolving armatures to three slip rings.

Ques. What other name is given to this connection, and why?

Ans. It is commonly called a Y connection or grouping

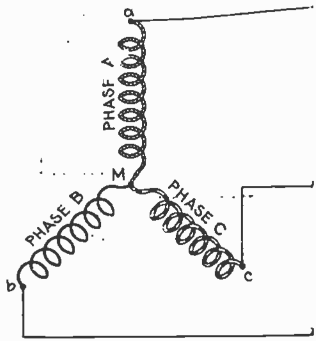


FIG. 3,160.—Diagram of three phase star grouping, commonly called Y grouping owing to its resemblance of the letter Y. The current in each main is obviously equal to the current in each phase winding, but the terminal pressure is the vector sum of the pressures in the component phase windings, that is, $\sqrt{3}$ multiplied by the pressure in one phase.

owing to the resemblance of its diagrammatic representation to the letter Y.

Ques. How is a three phase delta connection arranged?

Ans. The three circuits arc connected up together in the form of a triangle, the three corners are connected to the three terminals, *a*, *b*, *c*, as shown in fig. 3,163, or in the case of revolving armatures to three slip rings.

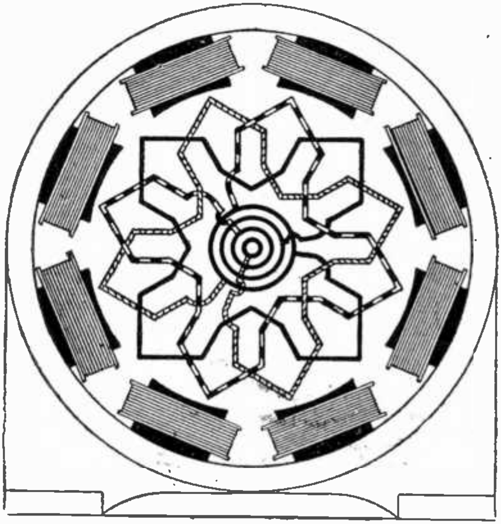


FIG. 3,161.—Radial diagram of a three phase, one slot winding with Y connection.

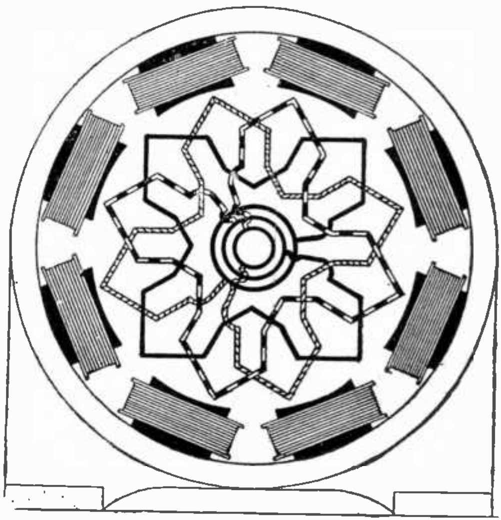


FIG. 3,162.—Radial diagram of three phase one slot winding with delta connection.

Ques. In three phase star grouping, what is the point where the phases join, called?

Ans. The star point.

Ques. In a three phase star connected alternator what is the voltage between any two collector rings?

Ans. *It is equal to the voltage generated per phase multiplied by* $\sqrt{3}$ *or* 1.732.

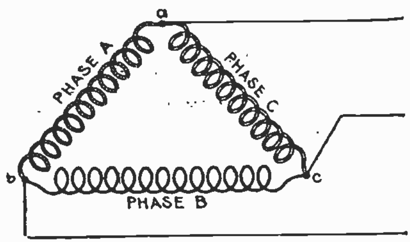


FIG. 3,163.—Diagram of three phase mesh grouping, commonly called delta grouping owing to its resemblance to the Greek letter Δ. The voltage at the terminals is equal to the voltage in one phase, and the current in each line is equal to the vector sum of the currents in two phases, that is, it is equal to $\sqrt{3}$ multiplied by the current in one phase.

Ques. In a three phase star connected alternator what is the value of the current in each line?

Ans. The same as the current in each phase winding.

Ques. What is the value of the total output in watts of a star connected alternator?

Ans. It is equal to the sum of the outputs of each of the three phases. When working on a non-inductive load, the total output of a star connected alternator is equal to $\sqrt{3}$ multiplied by the product of the line current and line voltage.

Ques. What is the value of the line voltage in a three phase delta connected alternator?

Ans. It is equal to the voltage generated in each phase.

Ques. What is the value of the line current in a three phase delta connected alternator?

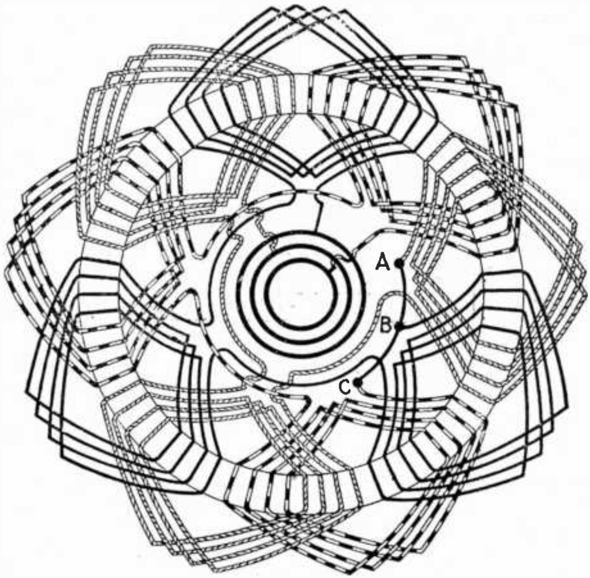


Fig. 3,164.—Radial diagram of three phase *lap* winding with star connection.

Ans. It is equal to the current in each phase multiplied by $\sqrt{3}$.

Ques. What is the total output of a three phase delta connected alternator working on a non-inductive load?

Ans. The total watts is equal to √3 multiplied by the product of the line current and the line voltage.

Ques. What are the features of the star connection?

Ans. It gives a higher line voltage than the delta connection

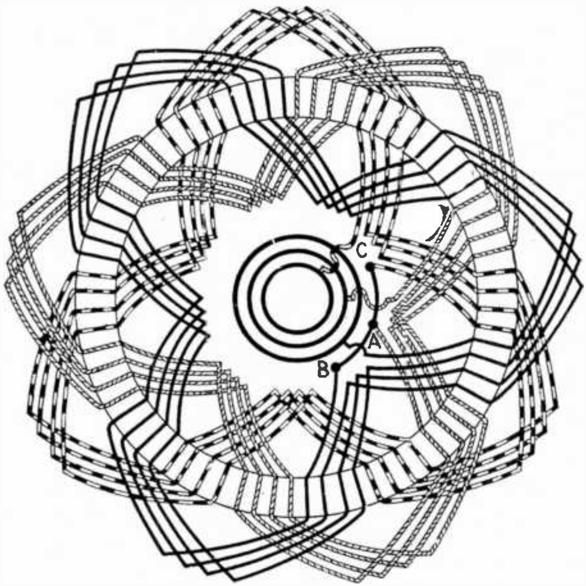


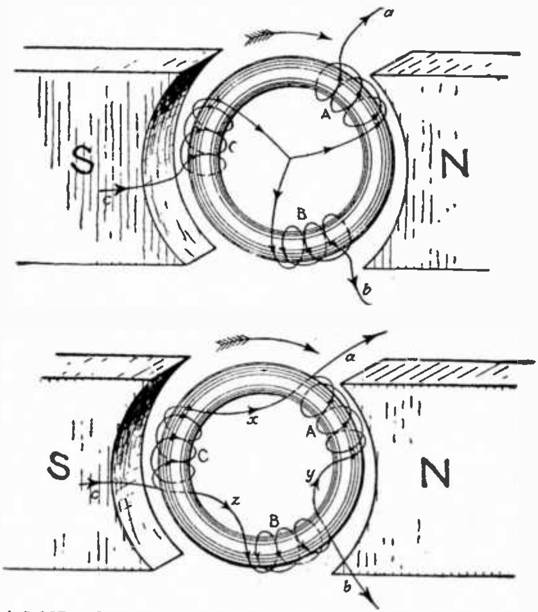
FIG. 3,165.—Radial diagram of three phase *wave* winding with star connection.

for the same pressure generated per phase, hence it is suited for machines of high voltage and moderate current.

The delta connection gives a lower line voltage than the star connection for the pressure generated per phase, and cuts down the current in the inductors; since the inductors, on this account, may be reduced in size, the delta connection is adapted to machines of large current output.

Ques. How is the path and value of currents in a delta connected armature determined?

Ans. Starting with the inductors of one phase opposite the middle of the poles, assume the maximum current to be induced



FIGS. 3,166 and 3,167.—Gramme ring armatures showing three phase star and delta connections, respectively, with direction of currents in the coils. In the figures, the coils A, B, C, are spaced at equidistant positions on the ring core. The arrow heads represent the directions of the induced pressures or currents for the position shown, the rotation being clockwise. In coil A, the pressure is increasing, in coil B, it is diminishing, but is in the same direction as in A, whereas in coil C, it is also diminishing, but is in the opposite direction to what it is in coils A and B. As the rings rotate the three coils have similar alternations of pressure induced in them, but differ in phase. If *a*, *b* and *c*, be joined to collector rings three phase currents can be supplied to the outer circuits. In fig. 3,166 at the instant represented *a* and *b*, are giving their current to their lines, while *c*, is receiving from its line a current equal to the sum of *a* and *b*. In fig. 3,167, at the instant represented, the currents sent out from *a*, will be equal to the sum of the currents in *x* and *y*, and intermediate between them in phase. The current from *b*, will be equal to the difference of the currents in *z* and *y*, and of intermediate phase, while similarly the current received by *c*, will be equal to the sum of the currents in *x* and *z*.

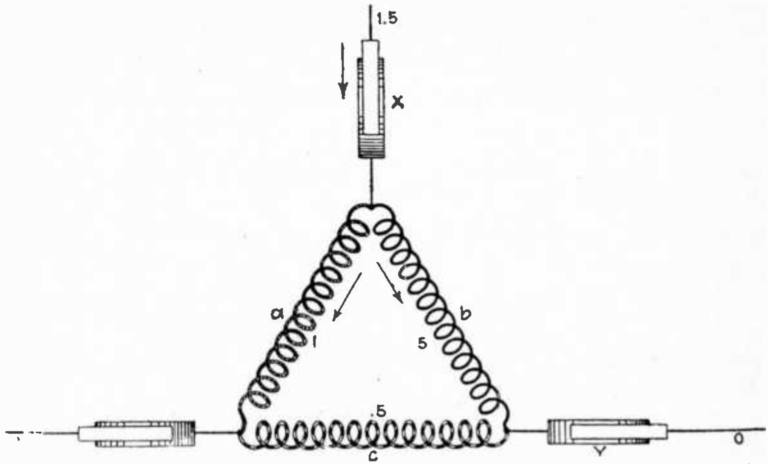


FIG. 3,168.—Diagram showing determination of path and value of current flowing in delta connected armature.

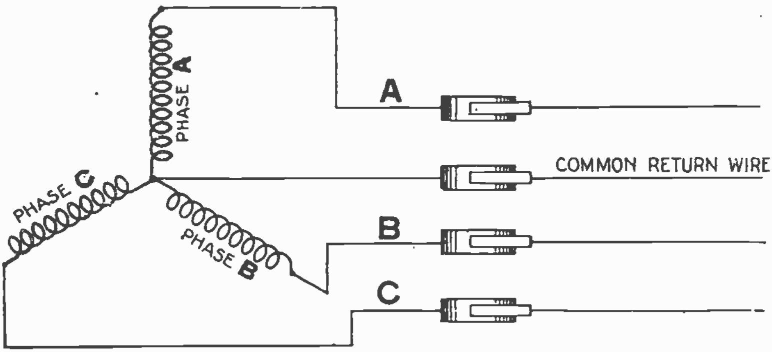


FIG. 3,169.—Diagram of Y connection with a common return wire. When the three lines leading from *a*, *b* and *c*, are equal in resistance and reactance, or in other words when the system is *balanced*, the currents of the three phases are equal and are 120° apart in phase (each current lagging behind its pressure by the same amount as the others) and their sum is at each instant equal to zero. In this case the resultant current being equal to zero there is no need of a common return wire. However, in some cases, where power is distributed from transformers or three wire systems, the different branches are liable to become unbalanced. Under such circumstances the common return wire is sometimes used, being made large enough to take care of the maximum unbalancing that may occur in operation. The return wire is used sometimes on alternators that furnish current mostly for lighting work.

at this moment; then but one-half of the same value of current will be induced at the same moment in the other two phases, and its path and value will best be shown by aid of fig. 3,168,

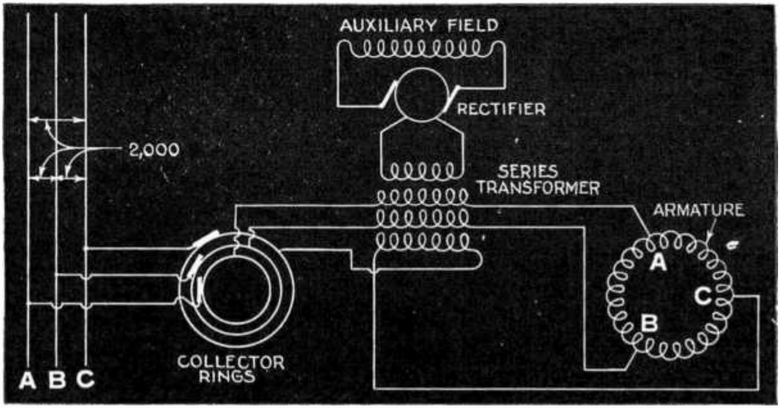


FIG. 3,170.—Diagram of Westinghouse three phase composite wound alternator. The armature inductors are of the closed coil or delta connected type, but are tapped at three points per pair of poles to the three collector rings. All three connections between the armature coils and the collector rings run through primary circuits of the series transformer within the armature, these three primaries each giving their own effect upon the secondary. Since the resultant of three equal alternating electric pressures 120° apart is zero, so that some special arrangement must be adopted to make these pressures act with, instead of against each other. The arrangement is a reversal of the connection of one of the primaries of the series transformer. This is shown in the case of the lowest primary indicated in the diagram.

in which X, may be taken as the middle collector ring, and the maximum current to be flowing from X, toward Z. It will be seen that no current is coming in through the line Y, but part of the current at Z, will have been induced in the branches *b* and *c*.

Ques. Since most three phase windings can be connected either Y or delta, what should be noted as to the effects produced?

Ans. With the same winding, the delta connection will stand 1.732 as much current as the Y connection, but will give only 1 ÷ 1.732 or .577 as much voltage.

TEST QUESTIONS

1. *What are the two ways of grouping a.c. windings?*
2. *Describe the two phase star connection.*
3. *Describe the two phase delta connection.*
4. *Describe the three phase star connection.*
5. *Describe the three phase delta connection.*
6. *In three phase star grouping, what is the point where the phases join, called?*
7. *In a three phase star connected alternator what is the value of the current in each line?*
8. *What is the value of the total output in watts of a star connected alternator?*
9. *Give voltage, current, and power values of the delta connection three phase.*
10. *What are the features of the star connection?*
11. *How is the path and value of current in a delta connected armature determined?*
12. *Draw diagram showing determination of path and value of current flowing in delta connected armature.*

13. *Draw diagram of Y connection with a common return wire.*

14. *Draw diagram of a three phase composite wound alternator.*

15. *Since most three phase windings can be connected either Y or delta what should be noted as to the effects produced?*

CHAPTER 68

Winding A. C. Motors

The winding instructions given in this chapter relate to the familiar types of *a.c.* motor most frequently met with in repair shops.

There are several methods of winding the field coils of small single or split phase motors, which are in common use:

1. Skein winding
2. Mould winding
3. Hand winding

Operations Preliminary to Winding.—The following operations should be carefully performed before starting to wind.

1. The coil and insulating materials comprising the windings that go into a slot are usually so proportioned that they completely fill the slots. Hence if any foreign substance were to remain lodged in the slot at the time of winding, it would not leave room for the coil, and an attempt to drive the coil home would probably result disastrously. Therefore. the first step in winding should be a detailed inspection of each slot for foreign substances and irregularities of punchings.

2. Blow all dirt out of the slots with compressed air.

3. Examine the core on both faces for flared out punchings or retaining fingers. If any be found, drive them back until the core is even and straight on both sides.

4. By the location of the terminal block, determine on which side of the core the coil leads should be wound.

5. Mark the slots (top and bottom) indicating the proper throw for the first coil.

6. If the grouping be irregular, mark all the slots into which the bottoms of the phase coils are to be placed.

7. The windings should always make a tight fit in the slots. In cases where the coil with the customary slot insulation does not make a tight fit, side fillers, bottom fillers or spacing pieces of insulating materials must

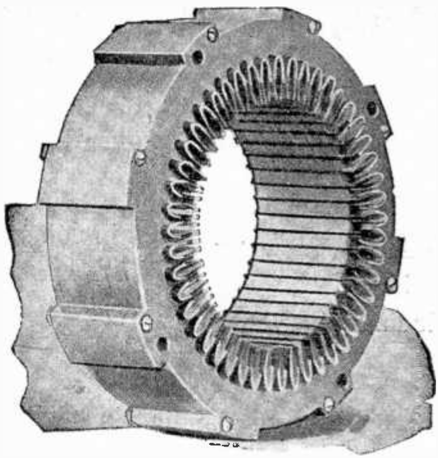


FIG. 3,171.—Master polyphase squirrel cage motor laminated field core with slot insulation in place.

be used. In order to determine the exact amount of filler needed, try the winding out in one slot. All filler needed in depth should be placed in the bottom of the slot, or between the top and bottom parts of the coils, in order to bring the winding as near to the bore as possible.

From this point on, the procedure will vary, depending on whether the stator has open slots or partially closed slots.

Slot Insulation.—Several methods of insulating the slots of small motors are in use at the present time, the principal ones being:

1. Fish paper cell only.
2. Fish paper and treated cloth cells.
3. Combination cells only.

When a fish paper cell only is used it should be about 15 mils thick and should be cut to extend about one eighth inch beyond the fibre punchings.

It should be of such width as to come just to the edge of the tooth tip, that is, it should not obstruct the slot opening passage for wires into the cell. The cell should, of course, be formed to fit the slot if possible. After the slot is wound a 1/32 or 1/16 in. thick fibre strip of suitable width should

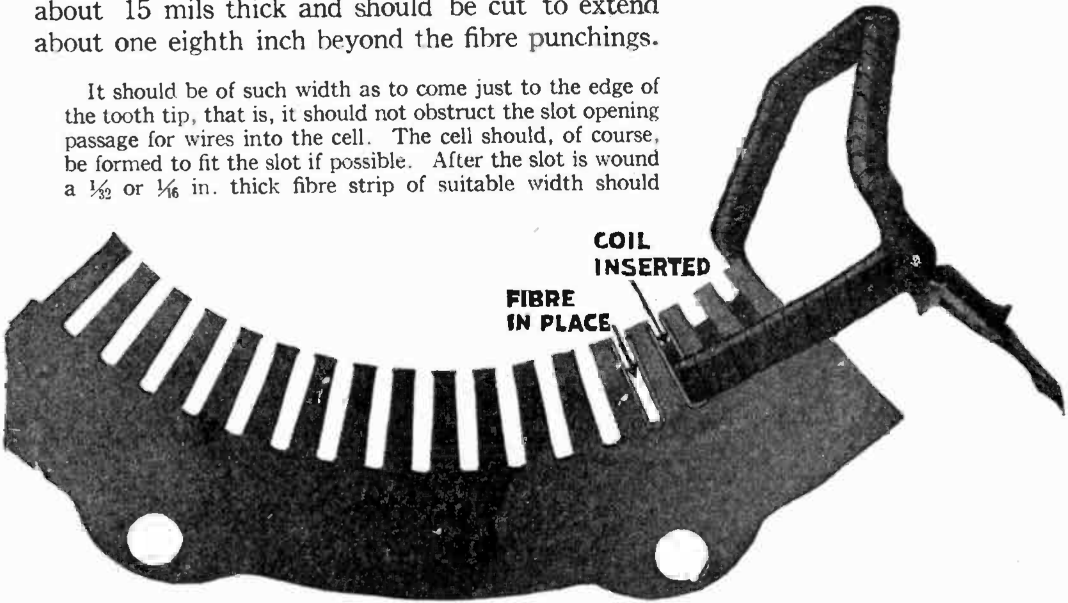


FIG. 3.172.—Section of Lincoln field lamination with one coil in place showing insulation.

be inserted in the top of the slot under the teeth and between the teeth and the fish paper cell. This fibre wedge should extend about one-eighth inch beyond the punchings.

The starting winding of split phase motors should be insulated in the slots from the main winding by a fibre strip, as wide as the slot, or by an additional fish paper cell. Where an additional cell is used, the first fish paper cell into which the main winding is wound should be folded over and the second fish paper cell placed on top.

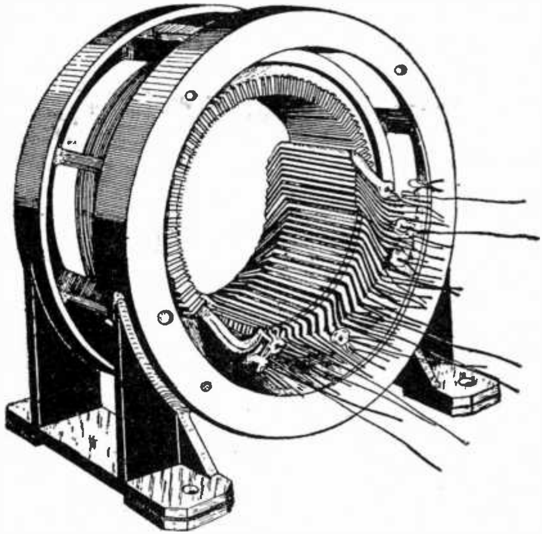


FIG. 3,173.—Lincoln polyphase induction motor construction illustrating phase insulation. In every polyphase induction motor there are sets of windings or coils, each carrying a different phase of current. A large percentage of the failures or "burn outs" in field windings come at the points where these different phase windings cross each other. Accordingly at the points where the different phases approach each other, insulation is provided to withstand considerably higher voltage.

The starting winding should be insulated from the main winding on the ends with drilling or light canvas in case considerable shaping be necessary to form the windings. Where shaping of the end windings is not necessary, no insulation is required between the main and starting windings except that provided on the individual wires and by the insulating varnish which is applied to the completely wound stator.

When a fish paper cell and a treated cloth cell are used, the fish paper cell is usually not more than 10 mils thick and is required merely to prevent the iron puncturing the treated cloth.

This fish paper cell is the same size and shape as the one described above. The treated cloth cell, however, extends through the slot opening toward the center about three-fourths inch to one inch. After the wires are inserted the treated cloth cell should be cut off flush with the slot and folded over, and the fibre wedge inserted as described.

The starting winding should be insulated from the main winding where it is wound in the same slot with the main winding the same as described above except use a treated cloth cell in addition to the fish paper cell. The starting winding is insulated from the main winding on the ends as described.

When a combination cell is used the procedure is the same as for the fish paper cell.

A combination cell generally consists of a piece of fish paper to which varnished cambric has been attached by means of varnish. The combination cell should be inserted so that the fish paper side is next to the iron.

When necessary all end windings should be laced and in some cases where the end windings are bulky they should be taped from iron to iron with linen tape.

All small motors should be dipped in varnish and baked, after they are completely wound and insulated.

Any good grade of insulating varnish which does not bake too hard will be satisfactory. Some insulating varnishes require a longer time to bake than others, and some require higher temperatures than others, but in no case should the temperature exceed 125° C., and the length of the baking time should never be less than four hours.

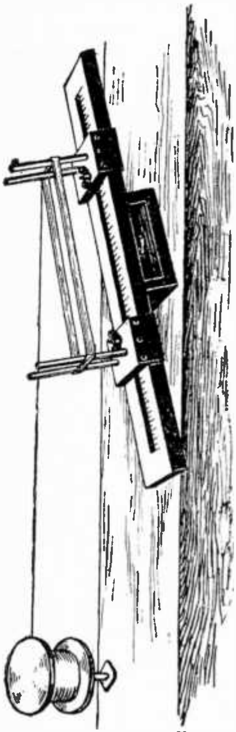
Before immersing the wound primary into the insulating varnish it should be kept heated for several hours at 50° C. to permit it to dry out thoroughly. It should then be immersed immediately into the insulating varnish and allowed to remain there until bubbles cease to rise.

Skein Winding.—In this method of winding, *a skein of wires is looped a number of times through the slots to form one pole.* Thus, the total number of turns per pole is a multiple of the number of turns in the skein.

The multiple depends upon the number of times the skein is looped through the slots and the number of slots used per pole.

When rewinding a skein wound motor the number of times the skein is looped through each slot should be noted, the length of the skein measured and the turns counted.

In case the skein length be not cbtainable directly from the old winding, it may be calculated from the dimensions of the primary core by considering the mean diameter D, of the



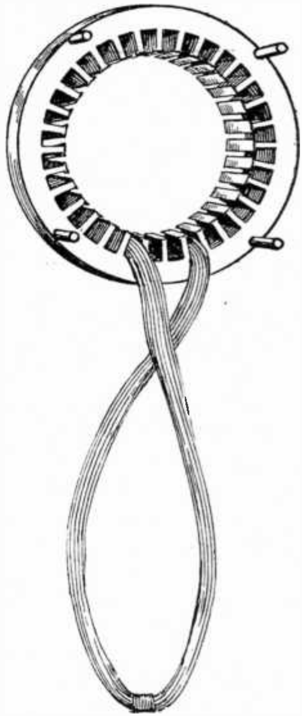


FIG. 3,174.—Adjustable shuttle or skein winder showing operation of winding a skein corresponding to fig. 3,175.

FIG. 3,175.—Skein placed in slots and half twist taken ready for the second operation.

winding to be the distance from center to center of diametrically opposite slots, as indicated in fig. 3,177.

Using this value of D, the pole pitch at the slot centers is calculated from the formula:

$$\text{pole pitch} = \frac{\pi D}{\text{poles}}$$

This distance is then laid out as a developmen‡; the slot centers are indicated by dots on this line and the probable mean line of each loop is

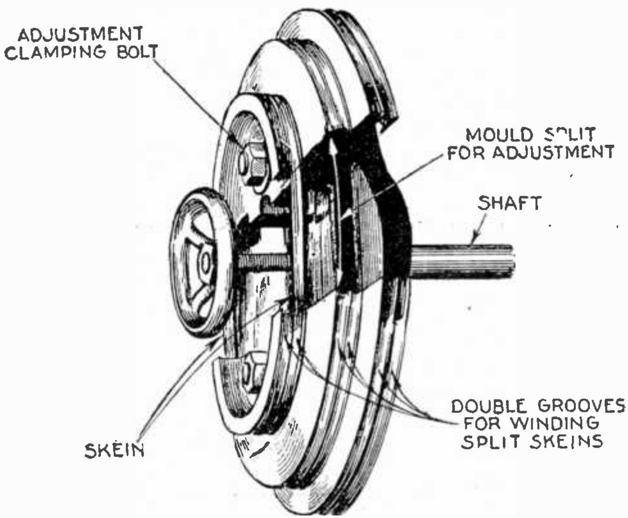


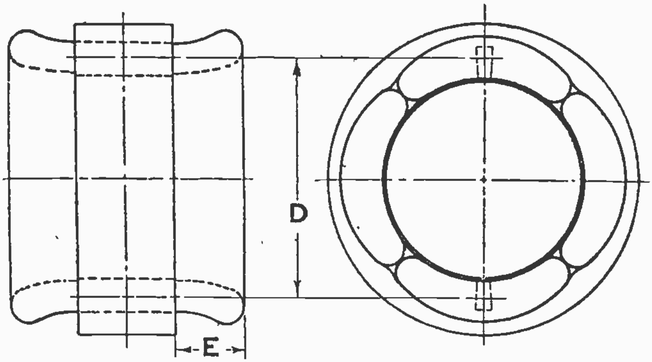
FIG. 3,178.—Winding head for winding skeins. The double grooving permits winding two skeins of the same size or one split skein. When the skein is over ½ in. square and of wire larger than No. 19, it should be wound in two sections. Note that the winding mould is split through the center so as to be adjustable for different sizes of skeins.

drawn, as in fig. 3,179, assuming the probable coil extension E, fig. 3,177. The lengths L_1, L_2, L_3, L_4, are measured, and each length is multiplied by the number of times the skein is looped through the slots for that length. Then these products are added together, and the sum is multiplied by two to include the extensions on the other side of the core. To this total is added the product of core width by the number of times the skein bundle crosses the core. This gives the total skein perimeter.

A trial skein with the required number of turns should first be made and wound, and the length corrected, if necessary, for the remaining skeins. After a little experience, corrections will usually be unnecessary.

Another method of determining the skein length or perimeter is by trial with a single wire.

This wire should be laid in the slots just as the skein of wire would be



Figs. 3,177 and 3,178.—Shape of connecting coils for single phase motors.

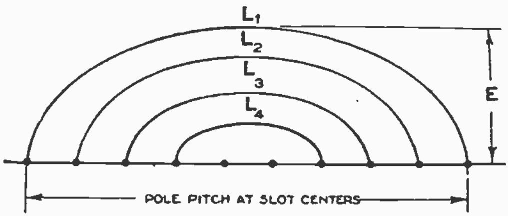


Fig. 3,179.—Diagram illustrating method of determining length of loops.

inserted, making proper allowance for the bundle of wires the single wire represents. Then this wire is removed and measured; one skein is wound for trial and correction is made, if necessary, for the succeeding skeins.

The distribution of the windings in the slots varies with the design of the motor and depends upon the number of slots and the number of poles.

Winding Table for a 36 Slot Motor

SLOT Nº	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
MAIN WINDING	1 1	2	2	1			1	2	2	1 1	2	2	1			1	2	2	1 1	2	2	1			1	2	2	1 1	2	2	1			1	2	2
STARTING WINDING				1	1	1	1						1	1	1	1						1	1	1	1						1	1	1	1		

Winding Table for a 36 Slot Motor

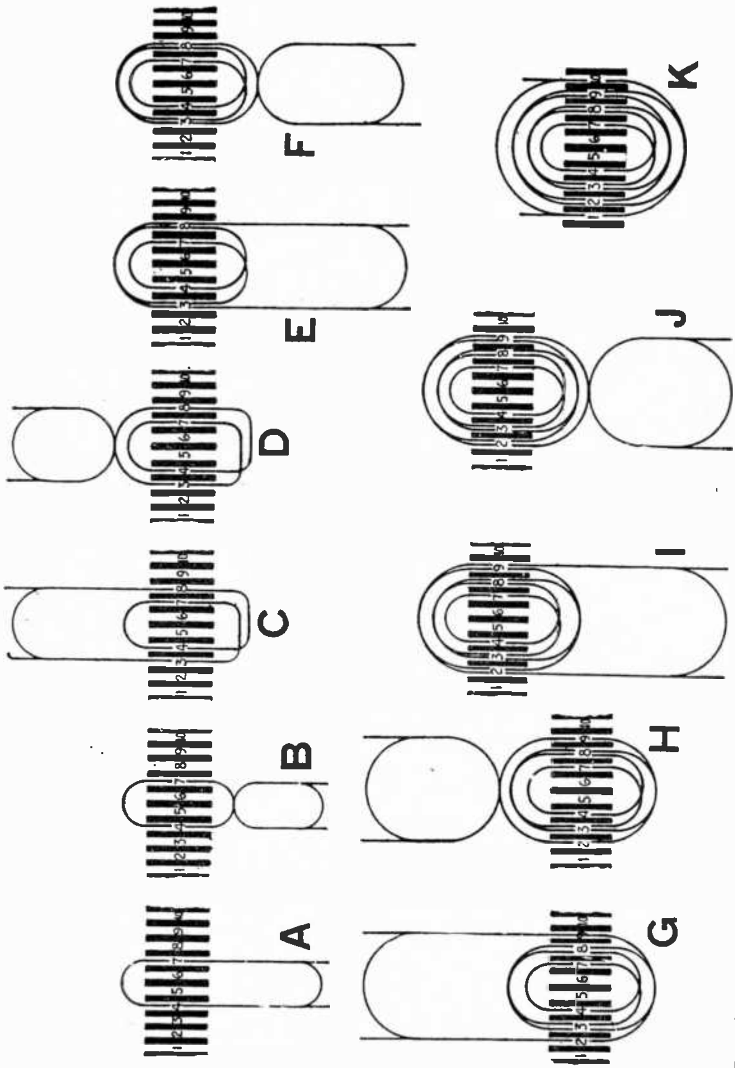
(with less common distribution)

SLOT Nº	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
MAIN WINDING	1	1	1				1	1	1	1	1	1				1	1	1	1	1	1				1	1	1	1	1	1				1	1	1
STARTING WINDING				2	1 1	2							2	1 1	2							2	1 1	2							2	1 1	2			

The distribution most commonly used in a 36 slot, four pole motor is shown in the accompanying table. The numbers in the slots indicate the number of times the loop passes through each slot. The second table shows another distribution for the same number of slots and poles, which is less common because the starting winding is too concentrated with this distribution.

Skein Winding Procedure.—After the skein length and distribution have been determined and the slots insulated, the procedure in winding a single pole of a four pole, 36 slot primary is as shown in figs. 3,180 to 3,190, for the main winding distribution given in the upper table on this page.

A developed view of a small portion of the primary core, looking at the teeth, with the first operation of putting the skein in slots 4 and 7 completed is shown in fig. 3,180. The short end of the skein should be firmly pressed against the core. The leads of the coil should be on the long end of the skein.



FIGS. 3,180 to 3,190.—Detail of slots and skein showing progressively the method of winding a skein with distribution as specified in the upper table on page 2,139.

A half twist is next made in the skein, as shown in fig. 3,181, and the long end of the loop is then passed through the core and the sides are threaded into slots 3 and 8, as shown in fig. 3,182. The winding should be pressed firmly against the side of the core

The half twist is repeated, as shown in fig. 3,183, but the twist should be made in the opposite direction to the first twist.

Throughout the winding, the half twists should be alternated in direction so as not to snarl the winding on the last loop. The loop is then laid

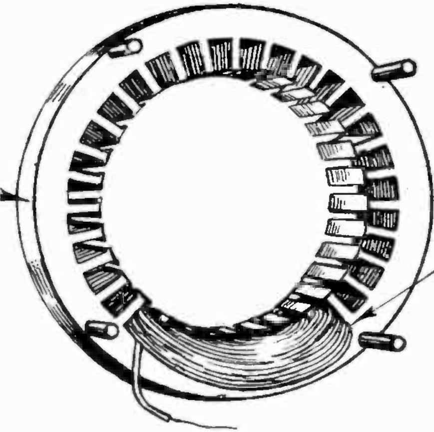


FIG. 3,191.—Field core showing one pole completely wound corresponding to fig. 3,190.

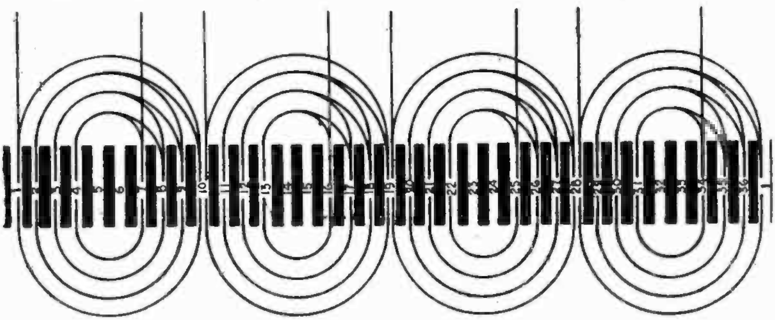
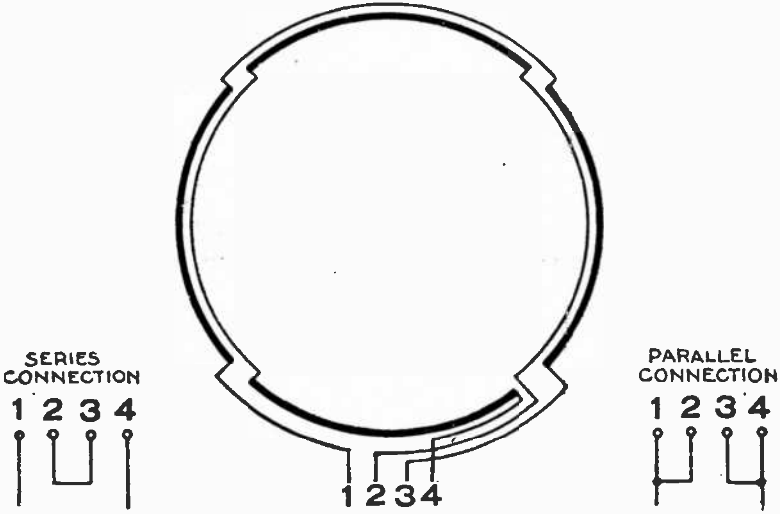


FIG. 3,192.—Diagram showing completed main field skein winding with each pole wound as shown progressively in figs. 3,180 to 3,190.

back in slots 3 and 8 for the second time, as in fig. 3,184. The half twist shown in fig. 3,185 is then made and the loop laid in slots 2 and 9, as in fig. 3,186. Again a half twist is given, fig. 3,187, and the skein is laid back in slots 2 and 9 for the second time, as shown in fig. 3,188. Another half twist, shown in fig. 3,189, is made and the skein is threaded into slots 1 and 10, fig. 3,190, thus completing the winding of one pole. It is important that the direction of the half twists be alternated to obtain a smooth winding and to avoid difficulty on the last part of the loop.

The winding of the second and remaining poles is performed exactly the same as that of the first.

The completed winding for a four pole, 36 slot motor is shown in fig. 3,202.



FIGS. 3,193 to 3,195.—Diagrams showing connections for winding in fig. 3,202.

For repulsion induction and repulsion starting, induction running motors, the primary winding is complete as shown in fig. 3,202, and the coils are connected together as shown in fig. 3,197.

Four leads are usually brought out so that these motors may be connected externally for either 330 or 110 volts.

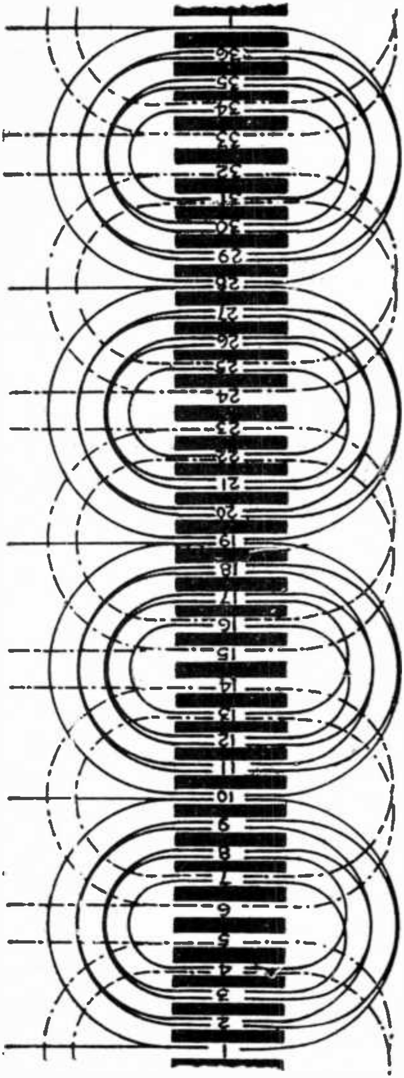


Fig. 3,196.—Diagram showing completed main and starting windings.

For single phase squirrel cage motors the starting winding is displaced 90 electrical degrees from the main winding, or in other words, the pole centers of the starting winding are located midway between the pole centers of the main winding. Its distribution and the length of the skein must be determined as explained for the main winding.

The starting winding is essentially a resistance winding. As it is important that its resistance in the re-wound motor be the same as it was originally, the length of the skein should be carefully determined. The distribution of both the main and starting winding and the number of times the skein bundle passes through each slot are shown in fig. 3,196.

The main and starting winding coils should be connected together as shown in fig. 3,197 or fig. 3,198. The particular diagram to be used depends upon whether the winding is to be connected in series or in series-parallel for the circuit on which the motor is to operate.

It will be noted in fig. 3,196 that the poles lap in slots 1, 10, 19, and 28 for the main winding. This is not essential but depends upon circumstances. The winding in the particular motor selected, for the example could have been distributed as indicated in 2nd table page 2,139, but in that case the starting winding would not have as advantageous a distribution as in the first table, and a smaller size of wire would probably be required for the main winding because the number of wires per slot would be higher for the same effective number of turns and, consequently, the copper loss would be higher. Under some conditions, however, and with other pole and slot combinations, it is often advantageous to distribute the winding so that adjacent main poles do not lap.

Mould and Hand Winding.—The mould winding method is

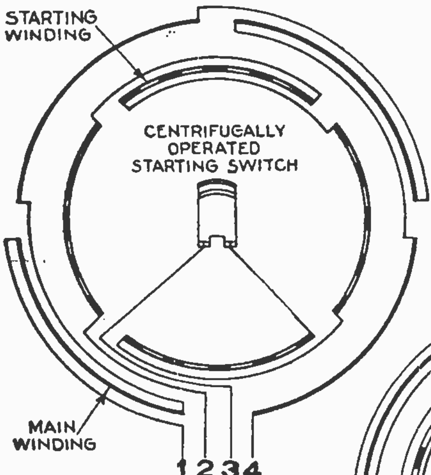


FIG. 3,197.—Diagram showing series connections of four pole motor. ***Clockwise rotation:*** Connect 1 and 2 to one line; connect 3 and 4 to other line. ***Counter clockwise rotation:*** Connect 1 and 3 to one line; connect 2 and 4 to other line.

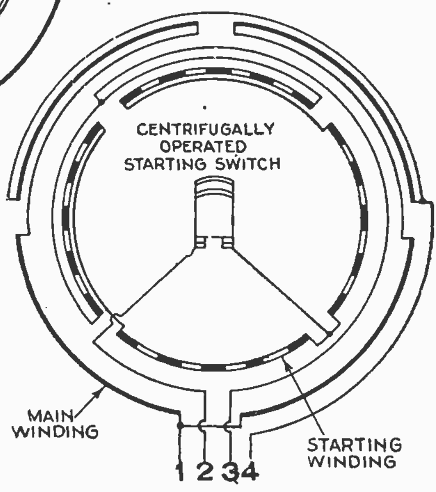


FIG. 3,198.—Diagram showing connections of a four pole, two path motor. ***Clockwise rotation:*** Connect 1 and 2 to one line; connect 3 and 4 to other line. ***Counter clockwise rotation:*** Connect 1 and 3 to one line; connect 2 and 4 to other line.

sometimes employed in winding small motors of the induction type. It takes its name from the fact that the pole coils are first wound on a mould, and then placed in the slots.

In most cases one pole set of coils is wound together so that individual coils do not have to be connected together after being placed in the slots. As far as the final results are concerned, the mould type of winding has the same general appearance as the hand type. Any mould wound small motor can be hand wound, that is, one wire at a time wound in by hand, when it is repaired. The winding diagram of both the mould wound and the hand wound motors is the same, and is shown in fig. 3,202 for the main winding.

The starting windings of motors with either mould wound or hand

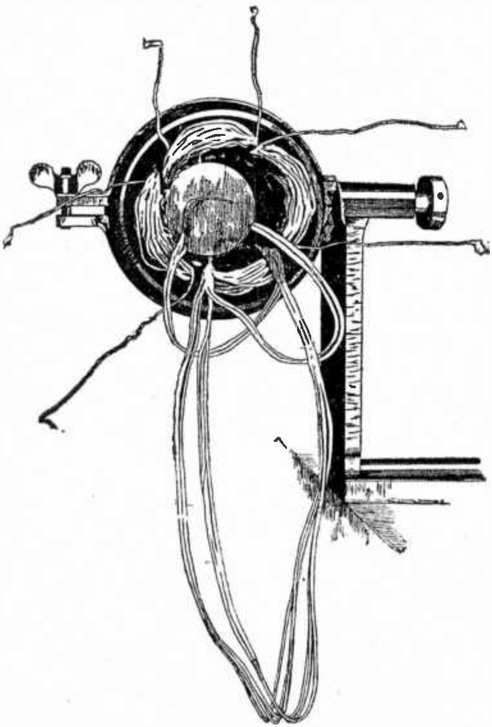


FIG. 3,199.—Method of winding split skein in the slots. First or bottom section is shown twisted and being wound into the slots first to reduce the piling up of the ends.

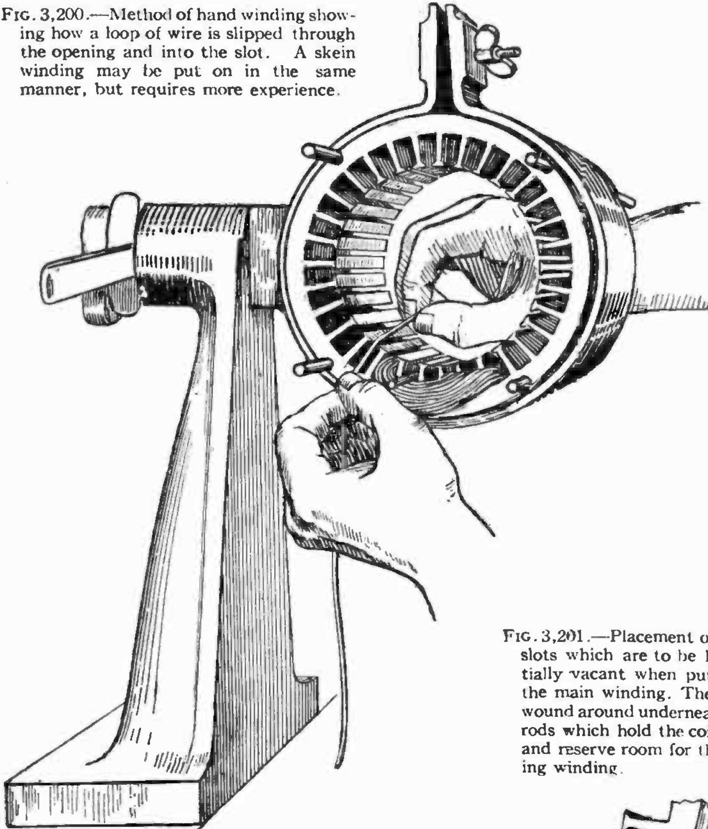


FIG. 3,200.—Method of hand winding showing how a loop of wire is slipped through the opening and into the slot. A skein winding may be put on in the same manner, but requires more experience.

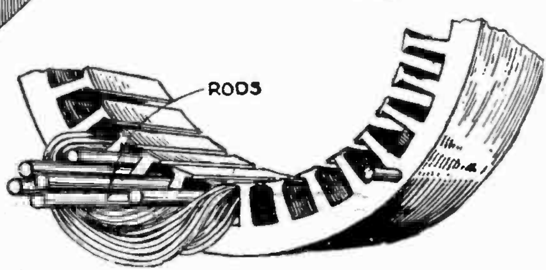


FIG. 3,201.—Placement of rods in slots which are to be left partially vacant when putting on the main winding. The wire is wound around underneath these rods which hold the coils down and reserve room for the starting winding.

wound main windings are generally skein wound, although they too may be mould wound, but they should not be hand wound because the resistance of the starting winding is very important, and in the case of a hand winding, would vary too much.

In case the starting winding is skein wound, the procedure is the same as described above.

When the starting winding is mould wound, and no mould is available for rewinding, it is necessary to measure the entire length of the starting winding coil of one pole of the motor to be rewound and to wind that same amount of wire into the slots.

The split phase, cage wound and single phase internal resistance motors most commonly encountered have two, four or six poles. The four pole, 36 slot winding and connecting diagrams have been given in connection

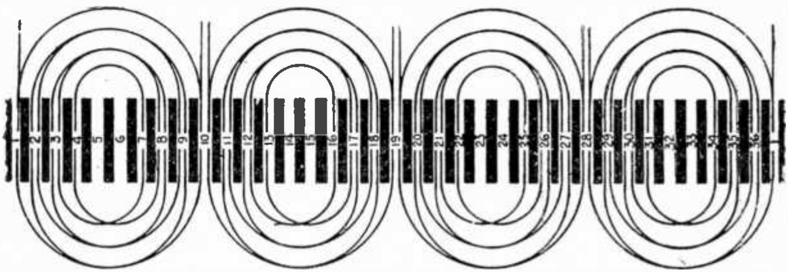


Fig. 3,202.—Diagram of main winding for mould or hand winding.

with the description of the method of winding. Two and six pole winding distributions and connections are shown on pages 2,148 and 2,149.

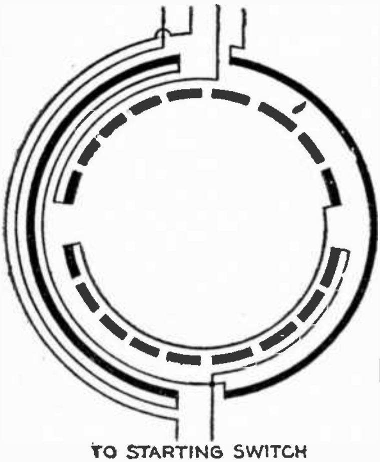
Open Slot Winding.—Coils for an open slot winding usually are fully insulated and treated with varnish before winding. They are of two kinds:

1. Phase coils
2. Plain coils

The phase coils differ from the plain ones only in that they are more heavily insulated on the ends to withstand the voltage

Winding Table for 2 Pole 24 Slot Motor

SLOT No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
MAIN WINDING	1 1	2	2	2	1				1	2	2	2	1 1	2	2	2	1				1	2	2	2
STARTING WINDING			1	2	2	2	1 1	2	2	2	1				1	2	2	2	1 1	2	2	2	1	



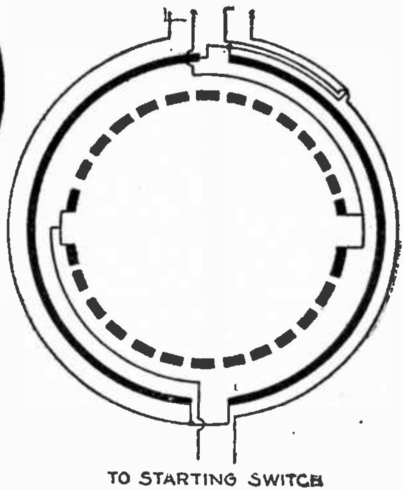
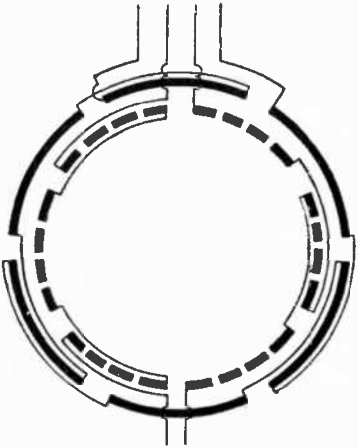


Fig. 3,203.—Diagram showing series connections for a two pole motor.
Fig. 3,204.—Diagram showing connections for a 2 pole 2 path motor.

Winding Table for 6 Pole 36 Slot Motor

SLOT No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
MAIN WINDING	1 1	2	1		1	2	1 1	2	1		1	2	1 1	2	1		1	2	1 1	2	1		1	2	1 1	2	1		1	2	1 1	2	1		1	2
STARTING WINDING			2	1 1	2				2	1 1	2				2	1 1	2				2	1 1	2				2	1 1	2				2	1 1	2	



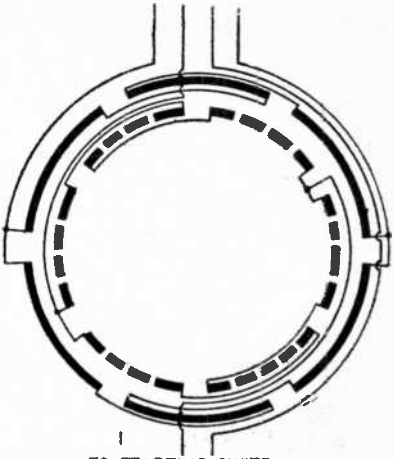
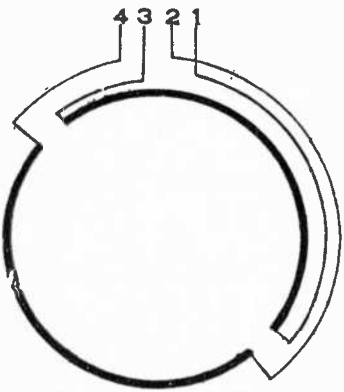


FIG. 3,205.—Diagram showing series connections for a 6 pole motor.

FIG. 3,206.—Diagram showing connections for a 6 pole two path motor.



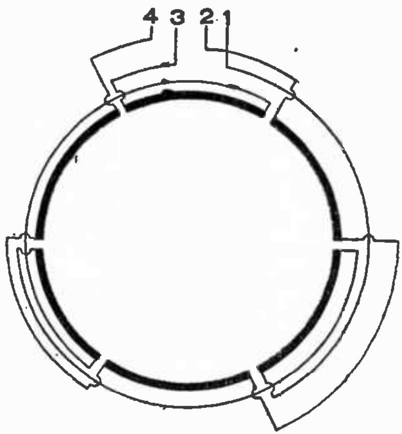


FIG. 3,207.—Diagram showing connections for a 2 pole repulsion-induction motor.

FIG. 3,208.—Diagram showing connections for a 6 pole repulsion-induction motor.

between groups, which is much higher than the voltage between coils.

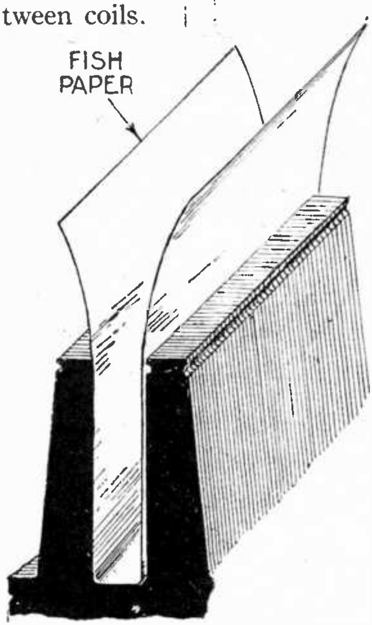


Fig. 3,209.—Open slot with fish paper cell in place.

They are usually taped with colored tape or otherwise marked to distinguish them from the plain coils. Coils which have been fully insulated and treated before winding are rather delicate and are liable to have their insulating qualities impaired or broken down completely by careless or rough handling, or by unskilled workmanship. Such coils are heavily insulated on their straight parts, that is, on those parts of the coil that are put into the slot. This insulation furthermore is of such nature that it will not stand being disturbed either by bending, pounding or abrasion.

The insulation on the coil ends is more pliable and will stand a reasonable amount of bending.

For best results, therefore, the coils must be assembled into the slots without excessive pounding; without scraping the coils against the slots; and without bending their straight parts. To avoid the first, regulate the tightness of the coils in the slot to a nice driving fit by means of fillers—a coil which is too loose is almost as undesirable as one which is too tight, as any movement of the coil in the slot during operation will inevitably weaken the insulation.

To prevent scraping the coil against the rough sides of the slot, use a thin fish paper winding cell, as shown in fig. 3,209.

Rub paraffine on the inside of this winding cell, and also on the coil. This will act as a lubricant and enable the coil to slide into the slot without damage. Such winding cells must be sufficiently thick to take up irregularities in the slot and of rather stiff material. They must be placed in the slot directly against the iron and not inside of the filler, so that the friction between the cell and the wall of the slot will be greater than the friction between the cell and the coil. Otherwise, the cell would not stand up, but would go down with the coil as shown in fig. 3,210, and crumple up in the bottom of the slot, taking up room that has not been allowed for.

To guard against bending of the straight part of the coil, avoid driving the coil into the slot with the face of the mallet directly.

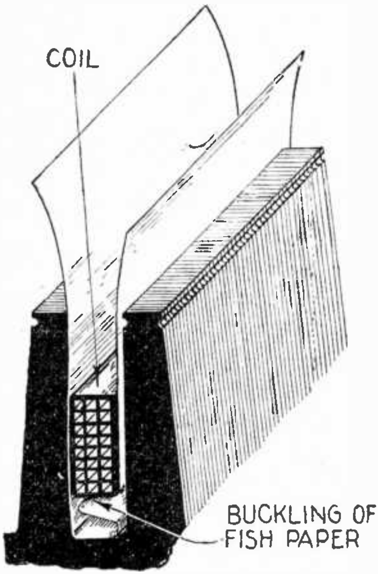


FIG. 3,210.—Wrong method of inserting coil showing buckling of fish paper cell.

Always use a fibre winding drift of the proper length and width over the coil to distribute the blow. Start the coil into the slot with the straight part equally spaced on each side of the core.

If the coil fit properly, it cannot be moved lengthwise in the slot after it has been driven to the bottom. Equal spacing on both ends of the core is essential because the heavy insulation ends at the first bend; and if the extensions of the straight part of the coil at the ends of the slot be not equal, the insulation may break down to ground on the short side.

After the slots, into which the phase coils and the first coil are to be wound, have been marked off and after proper fillers have been determined to give the correct winding fit, proceed by inserting the winding cell and fillers into the slot into which the bottom or shorter straight part of the first coil is to go.

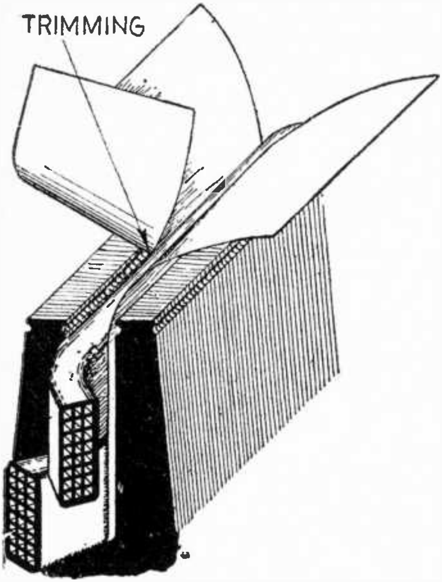


FIG. 3,211.—Slot with coils inserted showing trimming of slot cell.

Get the first coil started into the top of the slot with the lead toward the proper side of the frame, then drive it down to the bottom part of the slot by means of the fibre slot drift and mallet. Enter the top part of the first coil into its proper slot, but do not drive it down, because it will have to be raised up later in order to put in the last coils.

All the first coils whose top parts go into slots temporarily, as in fig. 3,212, are called "throw coils," and their number equals the throw of the winding minus one.

For instance, if the throw of the winding be 1 to 10, there will be 9 coils in the throw.

Having completed the throw, proceed with winding plain and phase coils in the order indicated by the layout, until the first throw coil from the other way is reached. Then raise the upper parts of all the throw coils out of the slot just high enough to enable the last coils to be inserted as shown in fig. 3,213.

Raising them too high is liable to injure the coils.

After all coils are wound, drive them down tightly in the slots with a fibre slot drift and mallet and trim off the projecting parts of the winding cell, as shown in fig. 3,211.

Care must be taken that the coils are not injured in this operation. If there be room in the slot the cells may be trimmed high enough to permit folding them over the coil; otherwise they should be trimmed even with the bottom of the wedge grooves.

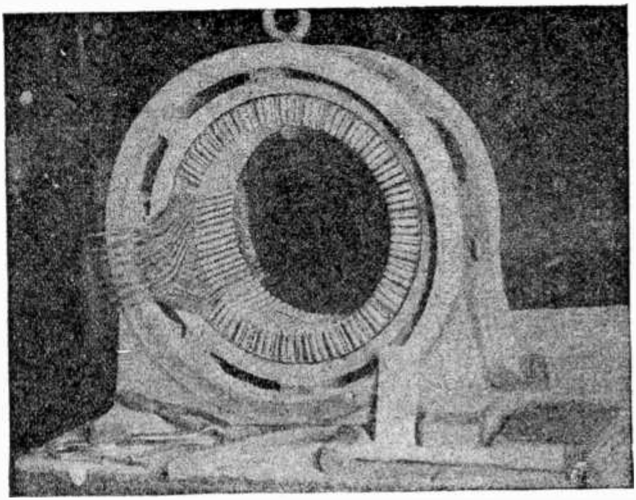


FIG. 3,212.—Detail of core showing throw coils in temporary position. The slots which are to receive the phase coils should be marked with chalk.

The winding is now ready for wedging.

This is best done with a wedge driver. If the iron section be wider than six inches, two or more wedges are used per slot. For best results the wedges should be chamfered at the lower entering end to prevent

NOTE.—*A phase coil* is the first coil and the last coil of coil groups in an overlapping polyphase winding. The intervening coils are called *throw coils.*

damaging the coils. They should not project more than ⅝ in. out of the slot, as a longer projection is apt to curl up and rap on the rotor.

The winding must now be tested for soundness of insulation between phases and to ground.

This is done by scraping the insulation from the ends of all the coil leads and connecting all the coils in each phase together with bare copper wire. Care should be exercised that no lead touches the frame or bridges

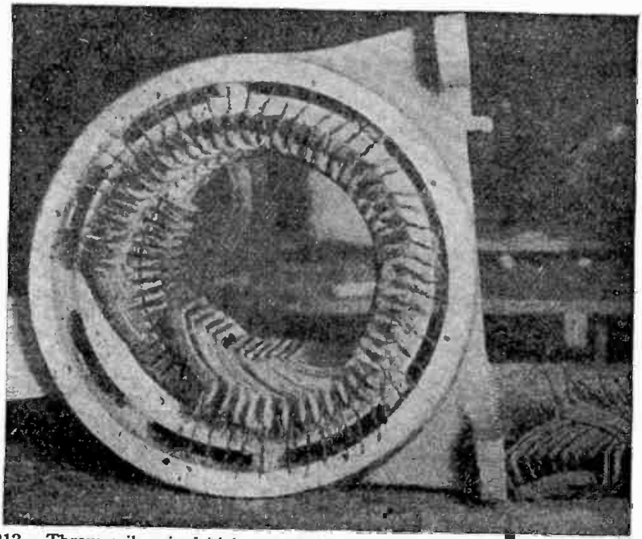


Fig. 3,213.—Throw coils raised high enough to permit inserting the last coils.

across between phases. Then touch the terminals of the testing transformer to any two phases simultaneously, repeating these tests until all phases have been tested to one another. Then touch the testing terminals to each phase and ground simultaneously.

In case of a breakdown to ground do not patch the winding by driving insulating materials past the coil into the slot, but remove the grounded coil and properly repair it or replace with another. The removing of a coil is the reverse proceeding—step by step, of placing the last coil in the original operation.

Metal Wedges.—In case magnetic wedges be used, certain precautions are necessary. These wedges consist of two strips of steel held in place at the top of the slot by a strip of brass. The steel parts lie in the wedge grooves and the brass part in a recess formed by the two steel pieces as shown in fig. 3,214. The whole is insulated from the punchings by a thickness of fish paper. The grooves which are to receive the metal wedges must be straightened, not filed, until smooth and even, and

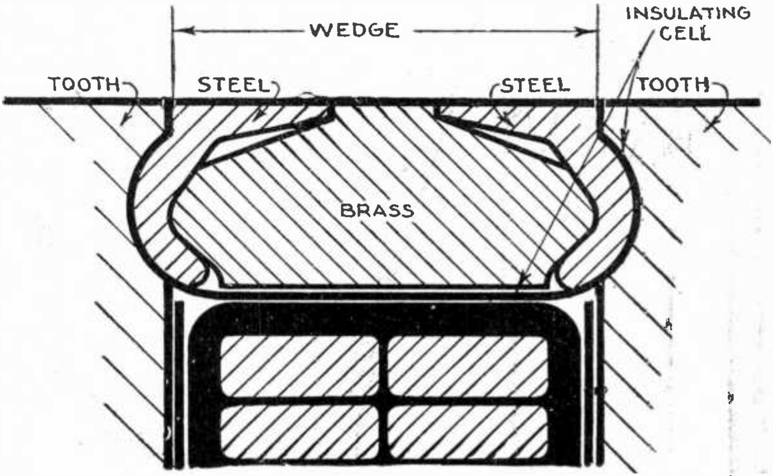


FIG. 3,214.—Cross section through a magnetic wedge.

the winding must lie in the slots solidly and low enough to permit the insertion of the wedges.

Up to seven inches width of iron, the steel part of the wedge is of one piece, bent into the shape of a hair pin, and spread with a single piece of brass. For wider iron, two separate steel wedge pieces are used, one for each side.

The steel parts should extend about ¼ inch beyond the side of the slot on each end. Two brass spreaders are used whose combined length equals the width of the core, and these are driven in from opposite sides.

Before inserting the wedges, apply a coating of heavy shellac to the grooves and insert a piece of fish paper so folded that it will cover the top of the winding, extend into each groove and project above the too of the slot about one-half inch.

Insert the steel wedge into the fish paper cell and with a knife or screw driver spread it open enough on one end to start the brass piece. The latter is then driven with a wedge driver until its end is even with the ends of the steel; a commutator punch or special tool is then used to drive the brass even with the edge of the core.

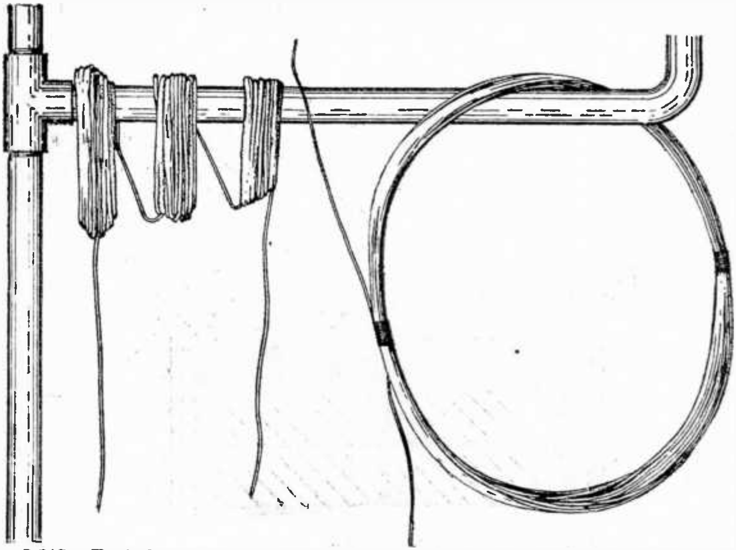


FIG. 3,215.—Typical mould wound and skein wound coils.

Wedge every other slot, keeping the eyes off the hair pin, if the steel be in one piece, on the same side of the yoke.

After half the slots are filled as just described, begin wedging the remaining slots by placing the steel wedges with the eyelets on the opposite side of the core.

When the first wedge in the second round has been driven, it can be tested for tightness, as the wedges on either side will prevent the teeth from bending. This is done by placing a finger across the slot, so that it covers not only the wedge in that slot, but also the tooth on either side. Then strike a gentle blow on the wedge with the peen of a riveting hammer or similar tool. A jar indicates looseness, which is remedied by removing the wedge and using heavier fish paper or a double thickness of fish paper for insulation in all slots yet to be wedged.

The proper thickness of paper having been determined, proceed to fill the remaining slots until the wedging is completed. The brass parts of the wedges are then even with the edge of

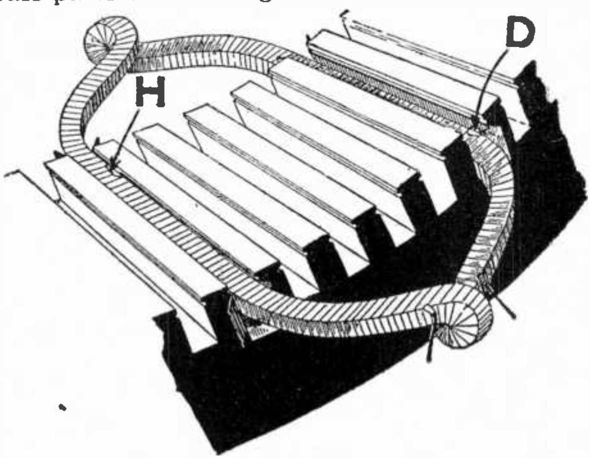


FIG. 3,216.—Coil grounded on core. Should two grounds occur simultaneously, as for example at H, and D, a short circuit would be formed in the loop, and if the normal voltage remained on the motor, this short-circuited turn would immediately become hot enough to destroy the insulation on the complete coil.

the core, while the steel parts extend beyond both the core and the brass. This extension should be nicked or clinched to prevent the brass pieces backing out.

If the brass be in two pieces they should be soldered together in the middle, thus completing the operation. The fish paper that extends out of the slot into the bore is now trimmed even with the wedge with the rounded end of a knife. The wedges are then ready for testing for their insulation from the iron. This is done by means of a 110 volt test circuit with a lamp in series, holding the terminals of one line on the iron and the other on the wedge.

Partially Closed Slot Winding.—The coils for this class of winding are usually uninsulated, except for the cotton covering on the individual wires. They are all of one kind when they come to the winder, that is, there is no difference between plain and phase coils, as in the case of the open slot windings;

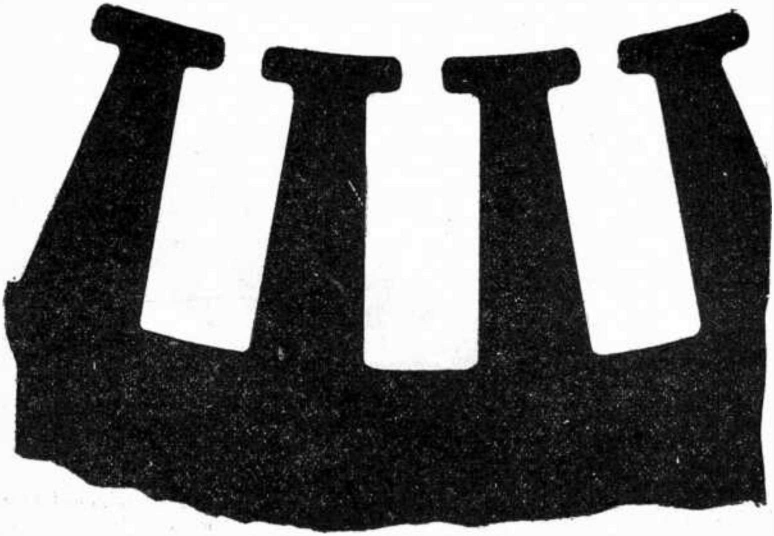


FIG. 3,217.—Lincoln field core showing partially enclosed slot used in the smaller motors. The object is to give a more even distribution of the magnetic flux or field and thus obtain better operation. The coils are wound on pins and stretched to shape. The ends, or exposed parts, are fully taped, and this tape is extended so that when coils are placed in the core, the tape extended clear into the iron leaving no wire exposed. The insulating varnish seals the wire at points where it enters the slot. The coils are insulated and protected from the core laminæ by a cell of horn fibre placed in the slot. After the coils are put inside the fibre cells in the lamination slot, the sides of the cells are bent over and a "U" shaped piece of insulating fibre is inserted over the whole assembly. On top of this are driven fibre wedges which hold all securely in place.

NOTE.—The discriminating buyer of motors can always avoid future trouble if he will inspect the motor to see if ends be fully taped and tape extends clear into the iron so that no wire is exposed.

but, according to the service requirements, the design may call for the winder to differentiate between the plain and phase coils by one of the following methods:

1. Tape those coils that start and end a group.

2. Tape all coils, with extra taping on the phase coils.

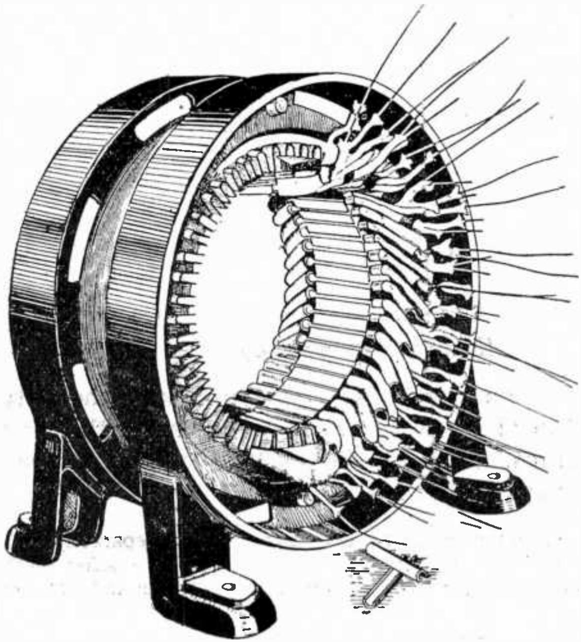


FIG. 3,218.—Lincoln partly wound field on core having partially enclosed slots. Begin at the top coil and follow the process of inserting the coils.

3. Tape no coils, but place insulating material (usually treated cloth), between the ends of the phase coils.

4. Place insulating material between the ends of all coils and a double thickness between phase coils.

In a two coil per slot winding with partially closed slots, the coils are wound or pulled to finished shape, their individual turns being held together by bands of light but strong twine.

These bands are placed at the points where the leads leave the coil, and thus serve the additional purpose of anchoring the leads to the coil. As the coils in a winding of this type are uninsulated at the start, the insulation to ground is applied to the slot in the form of a winding cell, which lines the slot completely with the exception of a narrow opening corresponding to the opening in the slot.

For best results this cell must meet the following requirements:

1. Possess the proper insulating qualities.
2. Have sufficient mechanical strength.
3. Fit the slot perfectly.
4. Have a proper seal at the top of the slot.
5. Have a sufficient extension beyond the iron on both ends.

Requirements 1 and 2 are met by making the cells from a combination of treated cloth and fish paper, the former supplying the insulating qualities, while the latter furnish the desired mechanical strength.

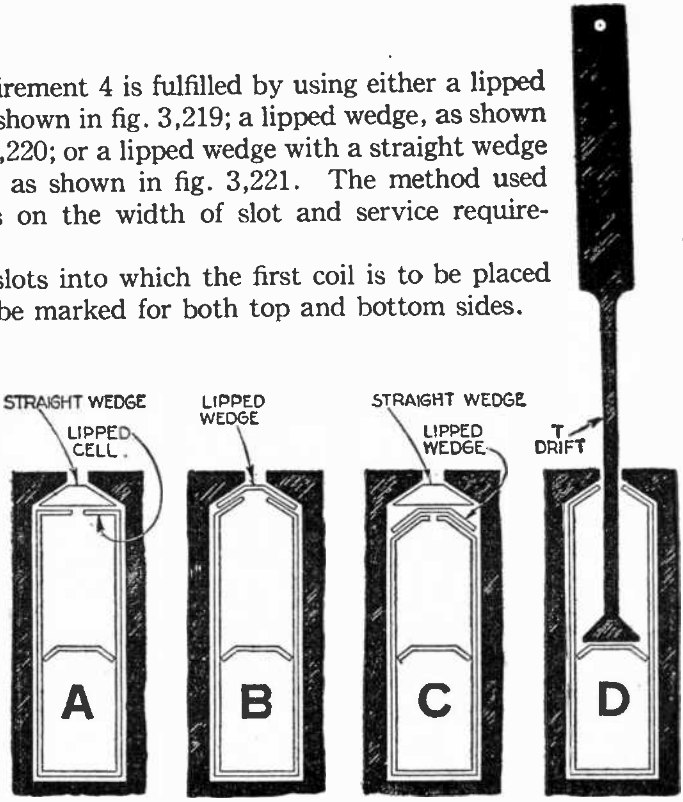
The two materials can be assembled in a slot separately, or cemented together and formed into the cell as a unit. The latter method is the latest practice, being more economical of materials and slot room.

Requirement 3 is met by forming the cells with dies designed to take care of each size of slot.

The fit must be particularly good with respect to its width at the bottom of the slot—a poor fit here is sure to result in a break in the cell and consequent grounding of the winding. Leave the cells long enough to extend at least three-eighths inch beyond the iron at the bottom of the slot, but short of the bend in the coil. If the cell extend beyond the bend of the coil, it will be torn during the winding.

Requirement 4 is fulfilled by using either a lipped cell, as shown in fig. 3,219; a lipped wedge, as shown in fig. 3,220; or a lipped wedge with a straight wedge over it, as shown in fig. 3,221. The method used depends on the width of slot and service requirements.

The slots into which the first coil is to be placed should be marked for both top and bottom sides.



FIGS. 3,219 to 3,222.—Slot details showing: **A,** lipped cell and straight wedge; **B,** lipped wedge; **C,** both lipped and straight wedges; **D,** use of T drift.

Also all slots that are to take the bottom parts of coils that are to be the beginnings and endings of groups should be marked. Cells should then be placed in all slots.

Next take the throw coils (in number one less than the throw of the winding) and apply a temporary taping on the whole upper half, from the leads to the opposite extremity of the coil.

With the leads toward the proper side of the frame, proceed to thread the lower parts of the throw coils into the slots, the upper parts remaining in the bore to the last, being protected against damage by the temporary taping.

The threading of coils into the slot is done one wire at a time, the first one being threaded through completely before starting on the second.

This tends to keep the wires from crossing one another. Avoid bends and nicks as they take up slot room, while crossed wires may result in short circuits.

To make the wires slide past one another readily, rub the coils with paraffine.

When the lower half of the coil is in the slot and the coil properly located with respect to the extension on both ends, insert the center strip, which should be slightly longer than the cell.

It is important that this strip shall properly separate the two coils in the slot. It should be as good an insulator as the insulation used between phases—usually being of the same material as the slot cell. This center strip is tapped home with a T-drift.

To keep the winding and center strip from getting out of place during further manipulations, insert a temporary wooden filling piece large enough to fill the rest of the slot.

Depending upon the design, the portion of the coil outside of the slot is now taped before proceeding with the next one; or else left untaped and triangular pieces of treated cloth inserted between adjacent coils and groups as they are wound. The first coil after the throw coils is threaded into both the top and bottom of the respective slots.

The top is inserted by taking out the temporary filling piece and threading the wires into the slot as before, except that the spring in the wires already in the slot may necessitate an occasional tapping down with the T-drift, or packing the last wires with the fibre cell drift.

When all the wires are in place, close the slot by one of the methods shown in figs. 3,219 to 3,221 according to the design, making sure that a seal has been established between the cell and the wedge.

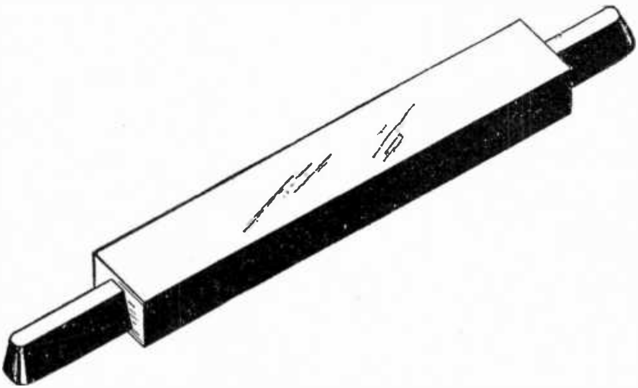


Fig. 3,223.—Wedge driver for lipped wedges.

Flat wedges are driven with the ordinary wedge driver as shown in fig. 3,237.

Lipped wedges are best driven with a specially shaped wedge driver, shown in fig. 3,223. The rest of the coils are then inserted, wedging and insulating them until the throw coils are reached. These are raised to clear the slots underneath them sufficiently to permit inserting the lower parts of the remaining coils. The temporary tape is then removed from the throw coils and they are threaded one by one into the tops of their respective slots.

If the coils or groups be separated by insulating pieces, after the winding is completed, these should be trimmed off even with the winding. as shown in fig. 3,211.

Connecting.—The connecting operation may be considered as consisting of three steps.

1. Stubbing the groups
2. The connecting proper
3. The placing and securing of terminal leads.

Each group starts and terminates with a phase coil, The stubbing operation consists of connecting all the coils of a

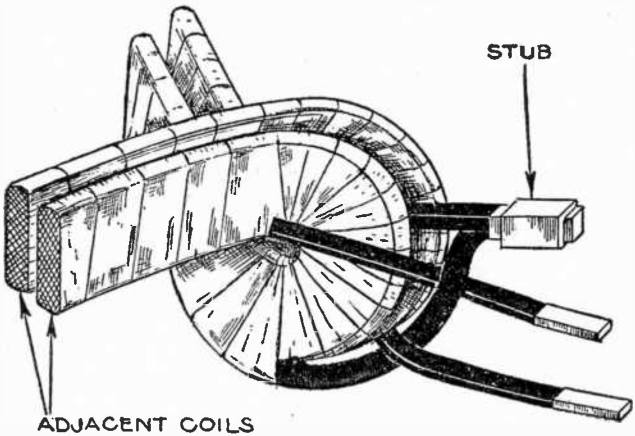


FIG. 3,224.—Stub or connection between adjacent coils.

group in series, the outer lead of each coil connecting to the inner lead of the adjacent coil.

Then tap down with the drift or mallet any wires that may not lie in place. Make sure that the winding clears the bore and the bracket. Test for grounds and short circuits between phases in the same manner as described for open slot windings.

After connecting, the stator is ready for treatment with varnish and baking.

The length of the stub, that is, the distance it is permitted to extend away from the coil, is determined by the clearance to the bracket. The stub is made by scraping the wires clean with the scraper shown in fig. 3,238 (**J**) and fastening the inside lead of one coil to the outside lead of the adjacent coil by means of a copper sleeve connector, as shown in fig. 3,224. A suitable flux is then applied and the stub soldered, preferably by pouring molten solder over it. A group thus connected will form a continuous circuit, beginning with the outer lead of one phase coil and terminating with the inner lead of the other.

The cross connections and terminal leads are connected to the group ends in accordance with the connection diagram, using lap joints which are held together either by sleeve connectors or by the wrapping of turns of small bare copper wire around the joints, which are soldered the same as the stubs.

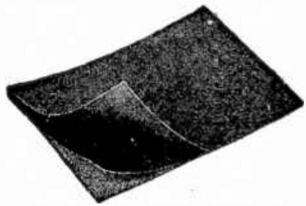


FIG. 3,225.—Century form wound pyramidal type coils. The pyramidal style of field winding is used in all Century polyphase motors, except two pole motors which for constructional reasons are made with the diamond coil or lap style of winding. The coils are placed in partially closed slots and held in place by retaining wedges.

FIG. 3,226.—Century 3 ply insulating sheet. The slot insulation consists of several layers of such insulating material as fish paper and varnished cambric. At all points where the coils extend from the core slots, they are protected and insulated from each other by insulation composed of layers of varnished cambric and tape. All individual coil leads are insulated with varnished cambric tubes. The completed field winding is saturated with insulating compound and baked.

The stubs and connection joints should be freed from burrs, and then thoroughly insulated according to the voltage with treated cloth tape held in place with cotton or friction tape.

The connecting wires and lead cables should then be laid down as nearly parallel to one another, as possible on the outside of the end winding, being careful that ample clearance to the end bracket is provided. They should be tied in place by strong, light string. The terminal leads are then brought out of the frame and cleated in place. They should be protected with insulating tubes where they are fastened into the cleat.

On testing the winding for rigidity on its front and rear extensions, it will be found that the connections between adjacent coils and groups have a bracing effect on the front end which the rear end lacks.

To secure this part of the winding against vibration it is braced, in ordinary industrial motors, by tying each coil securely to a heavily insulated steel ring. All exposed parts of the winding can now be painted or sprayed with an air drying finishing varnish.

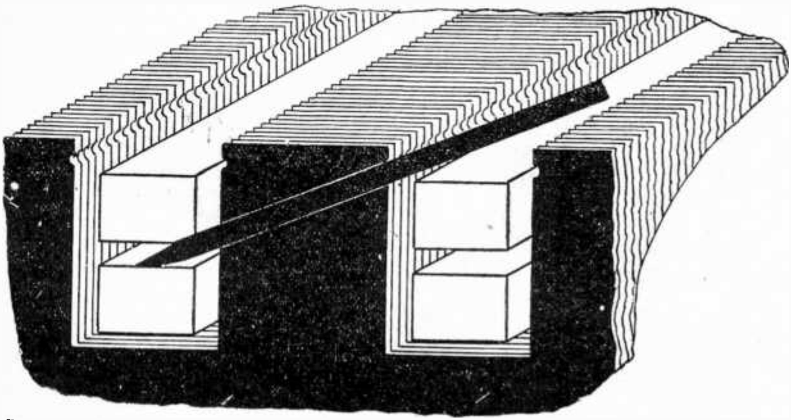


FIG. 3,227.—Wrong way to remove a coil. Don't use the lower coil as a fulcrum.

Removing Coils.—In case it become necessary to remove a coil before the winding has been treated, and baked, proceed in the reverse order, step by step, from the original winding operation, considering the coil to be removed as the last one inserted, under the throw.

Should a coil have to be removed from a winding that has been treated and baked, it will be necessary to heat the winding in order to soften the varnish. Saturating the part to be opened with paraffine helps to soften the varnish. The coils should be removed while the winding is hot.

For raising the wires out of the slot use a piece of thin fibre sharpened to the general shape of a screw driver. Metal tools will injure the cotton covering on the wires, and will necessitate tapping the wires, which usually overcrowds the slot.

Winding Tools.—There are certain tools which are essential to the successful winding of any type of machine. In addition to these, certain types of winding require tools which have been

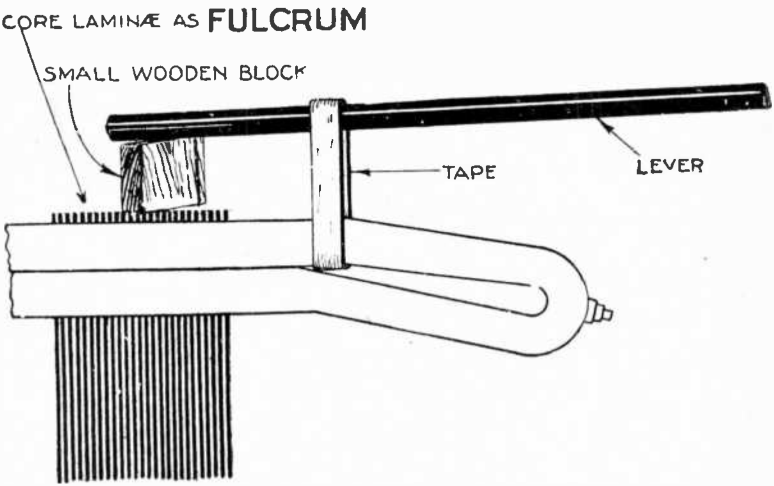


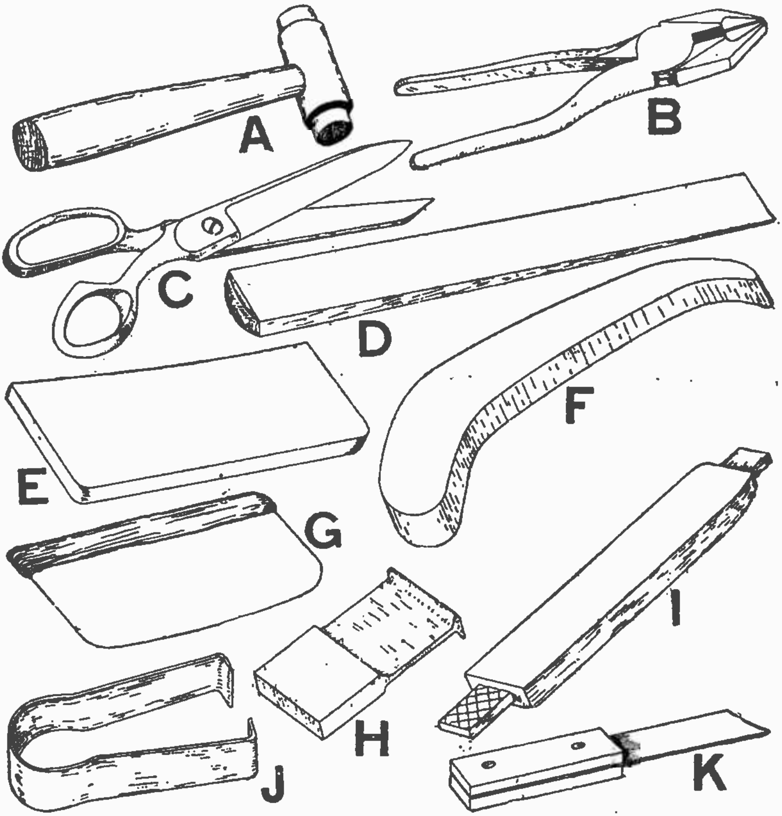
FIG. 3,228.—Right way to remove a coil. Use the core laminæ as a fulcrum.

especially developed to meet the specific needs. An experienced winder will in some cases develop his own tools, or at least modify them to meet his personal requirements. The tools illustrated in figs. 3,229 to ,3239 are, however, sufficient for most windings of *a.c.* stators.

The following instructions for the proper use of tools should be carefully noted·

1. When striking hard blows on tools other than fibre, be careful not to roughen the surface of the rawhide face.

Avoid striking the coils a hard blow directly with the mallet—use a drift or shaper. A blow from a mallet is concentrated on a small spot. A drift distributes the effect of the blow and avoids damage.



FIGS. 3,229 to 3,239.—Hand tools ordinarily used in winding induction motors. *These are*: A, rawhide mallet; B, pliers; C, scissors; D, steel winding drift; E, assorted thicknesses of fibre slot drifts; F, fibre shaping drift; G, fibre cell drift; H, steel T-shaped cell drift; I, wedge driver; J, lead scraper; K, knife.

2. Pad the jaws of the pliers with tape, when using them to grasp insulation.

Do not use pliers in place of a cold chisel.

3. Use scissors solely to cut insulating cloth, and thin insulating materials.

Avoid using scissors in place of pliers or scraper. Do not bend the points by prying with them, as they will cut poorly after being bent, no matter how sharp their edges.

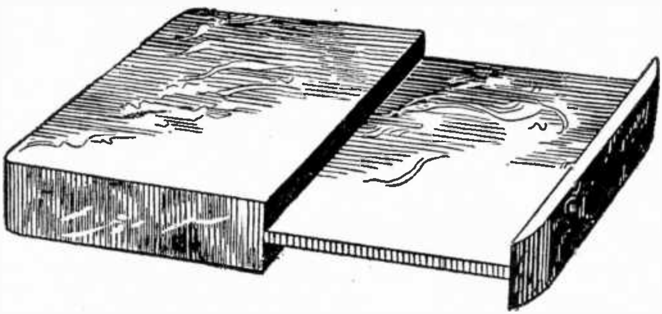


FIG. 3,240.—Martindale coil tamping tool.

4. Keep smooth all surfaces that come in contact with the coil; nicks in a drift leave corresponding scars on the insulation when used in shaping the coil.

Never use a steel hammer on that part of the drift that comes in contact with insulation in shaping the coil—use nothing but a rawhide mallet.

5. Slot drifts should have flat square faces with their corners slightly rounded. Always use the same edge of the drift to pound on. This will leave the other edge smooth for contact with the coil. As the coil edge of the slot drift becomes rounded from use have it filed or ground flat, as a flat edge offers the largest surface and distributes the blow over the coil better.

Always use the thickest possible drift, as a thick drift is easier on the coil than a thin one. Never use a piece of metal instead of fibre for a slot drift with which to drive the coil down into the slot.

6. Keep the shaping drift smooth and free from nicks. Pound it only with a rawhide mallet.

Do not use the fibre shaping drift on anything but coils, and insulating materials.

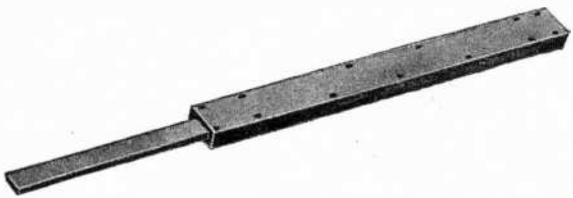


FIG. 3,241.—Martindale wedge driver.

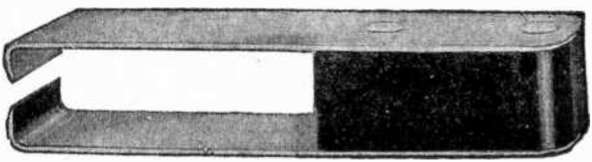


FIG. 3,242.—Martindale insulation scraper.

7. Use a fibre cell drift, and that only, for threading wires into a partially closed slot.

Do not use a piece of metal for a cell drift. Do not pound on the fibre drift.

8. The T-drift is used in packing the insulating spacer between the top and bottom coils in partially closed slots. It should be used only on windings or insulating materials, as any other use might nick it, causing damage to the windings.

Do not strike a hard blow on the T-drift as this will bend the shank and render the drift useless.

9. Be sure the tongue of the wedge driver is square on the end which drives the wedge. An irregularly shaped tongue will drive improperly or damage the wedge. Wedge drivers with slot depths of $\frac{3}{32}$, $\frac{1}{8}$ and $\frac{3}{16}$ in. should be available, and the size which most nearly fits the wedge should be used.

Do not use the tongue of the wedge driver for a chisel or drift.

TEST QUESTIONS

1. *Name three kinds of windings used on a.c. motors.*
2. *Describe some operations which should be done before winding.*
3. *Name several methods of slot insulation.*
4. *How should the starting winding be insulated from the main winding?*
5. *What thicknesses of fish paper should be used for the various methods of slot insulation?*
6. *What is skein winding?*
7. *How is the length of skein determined for a given winding?*
8. *Describe fully the operations performed in the skein winding.*
9. *How are the leads brought out?*
10. *Describe the method of mould and hand winding.*
11. *How are coils insulated for open slot winding?*
12. *What is the difference between phase coils and throw coils?*

13. *How does the insulation differ in phase and throw coils?*
14. *How is a coil prevented scraping against the rough sides of the slot?*
15. *What precaution should be taken in raising coils to insert the last coil?*
16. *How is a winding tested for soundness of insulation between phases and ground?*
17. *If test show a ground, what should be done?*
18. *What are metal wedges?*
19. *What should be done before inserting wedges?*
20. *When should the operation of putting in the wedges be started?*
21. *How is a wedge tested for tightness?*
22. *Describe fully the method of winding for partially closed slots.*
23. *How is a coil threaded into a partially closed slot?*
24. *How are partially closed slots closed?*
25. *Give three operations in connecting.*
26. *What should be done after connecting?*
27. *How should a coil be removed?*
28. *Why should the core be used as a fulcrum in removing a coil?*
29. *What are the essential winding tools?*
30. *Describe each tool and its proper use.*

CHAPTER 69

A. C. Winding Diagrams

Key to Connections

On account of the undue multiplicity of drawings that would be required in showing developed views of windings for the various numbers of poles, phases, slots, coils per slot, etc., various modes of representation have been devised to indicate the arrangement of windings without showing them in full detail.

One method often used is the *group diagram*. In this the coils are "stubbed" or grouped into pole phase groups and then cross connected to form magnetic poles.

To attempt to show "developed" windings, that is a picture of the actual coils rolled out flat for all possible numbers of poles, phases, slots, coils per slot, etc., would require a very large number of diagrams even for full pitch windings.

The diagrams which follow have been selected and prepared for this work by the General Electric Co.

NOTE.—*A. C. Windings.* The windings for *a.c.* motors and alternators are substantially alike and often may be used for either machine. The winding of a single phase motor or alternator has only one group of inductors per pole, placed in one slot or several slots depending upon whether or not the winding is concentrated or distributed. Two phase and three phase windings may be considered as made up of single phase windings properly placed on the same armature. For the two phase windings two separate single phase windings are used, spaced 90 electrical degrees apart. For the three phase winding, three single phase windings are used, spaced 120 degrees apart. Although the single phase windings are independent of each other, their terminals are connected in star or delta. The spread or space occupied by each single phase winding is known as the phase spread of the winding. For a two phase winding the phase spread is (180÷2) or 90 degrees. For a three phase winding it is (180÷3) or 60 degrees. In a single phase winding, the phase spread is theoretically 180 degrees. Nothing is gained however by winding all the slots of a single phase machine. *In practice* only about 75 per cent of the available slot space is utilized making the phase spread for a single phase winding about 135 electrical degrees.

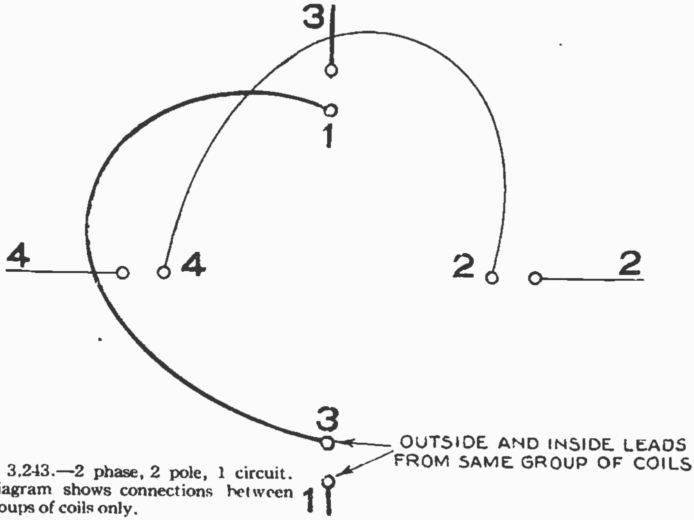


FIG. 3,243.—2 phase, 2 pole, 1 circuit. Diagram shows connections between groups of coils only.

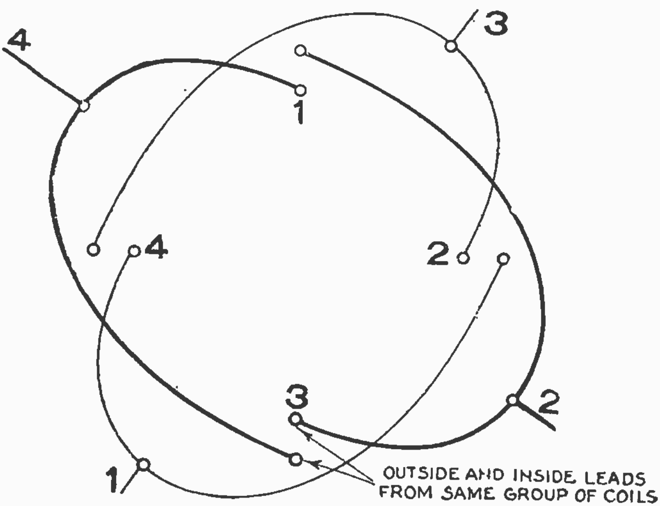


FIG. 3,244.—2 phase, 2 pole, 2 circuit. Connections between coil groups only.

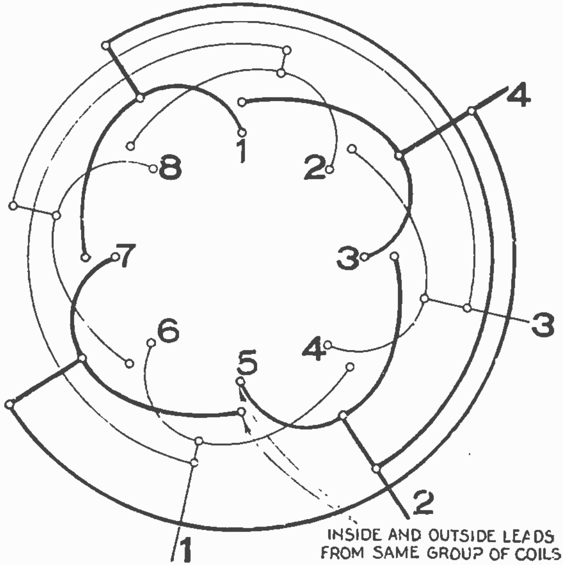


FIG. 3,245.—2 phase, 4 pole, 4 circuit. Connections between coil groups only.

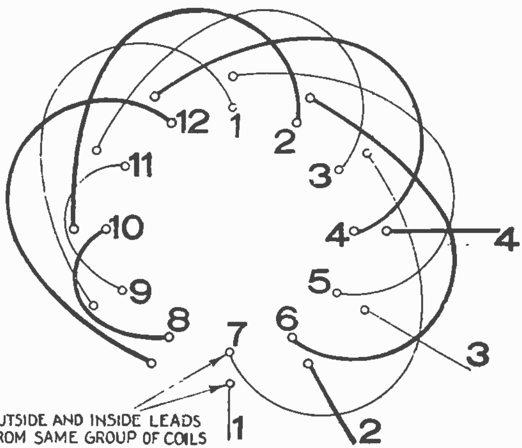


FIG. 3,246.—2 phase, 6 pole, 1 circuit. Connections between coil groups only.

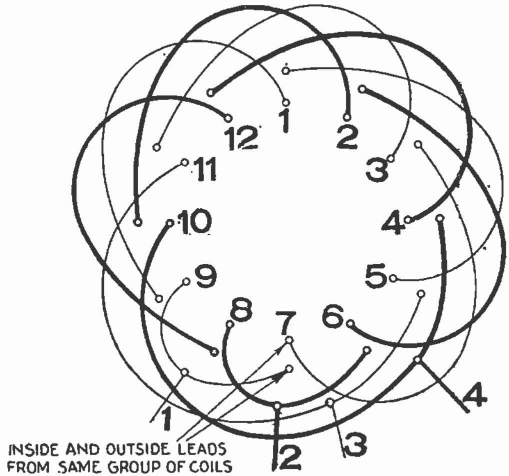


FIG. 3,247.—2 phase, 6 pole, 2 circuit. Connections between coil groups only.

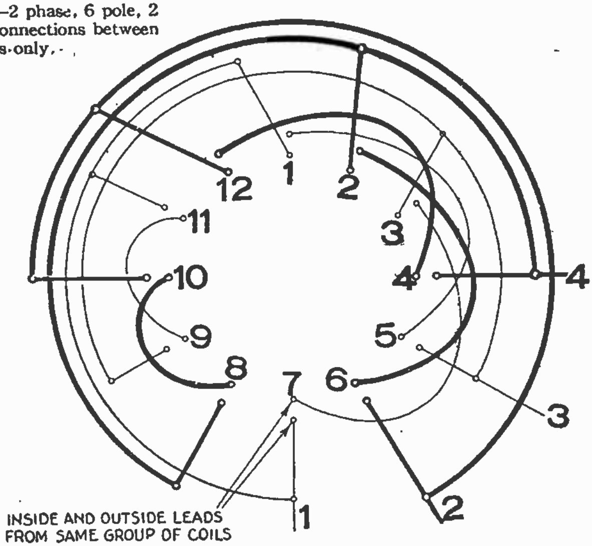


FIG. 3,248.—2 phase, 6 pole, 3 circuit. Connections between coil groups only.

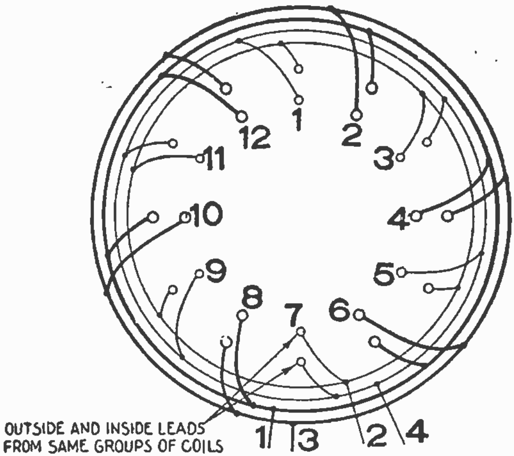


FIG. 3,249.—2 phase, 6 pole, 6 circuit. Connections between coil groups only.

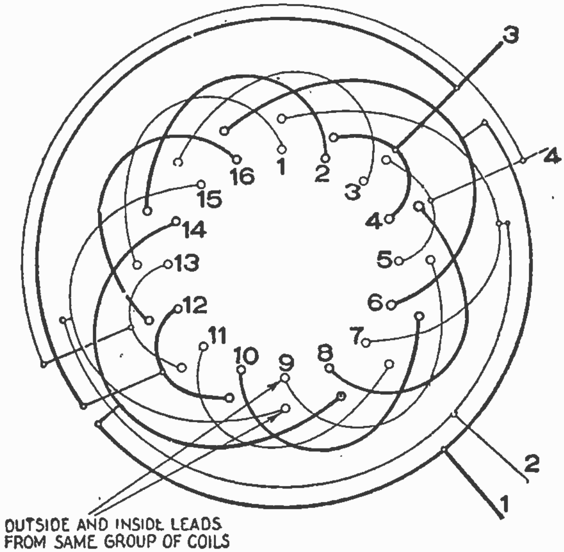


FIG. 3,250.—2 phase, 8 pole, 4 circuit. Connections between coil groups only.

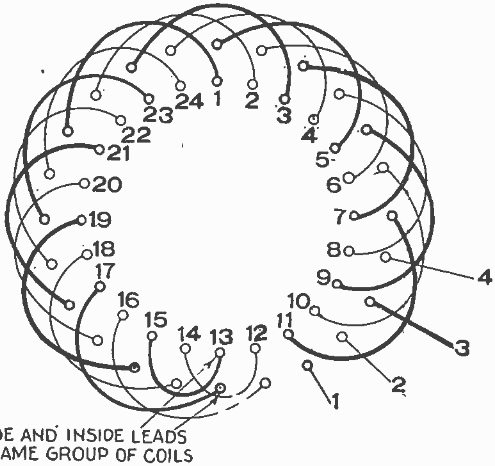


FIG. 3,251.—2 phase, 12 pole, 1 circuit. Connections between coil groups only.

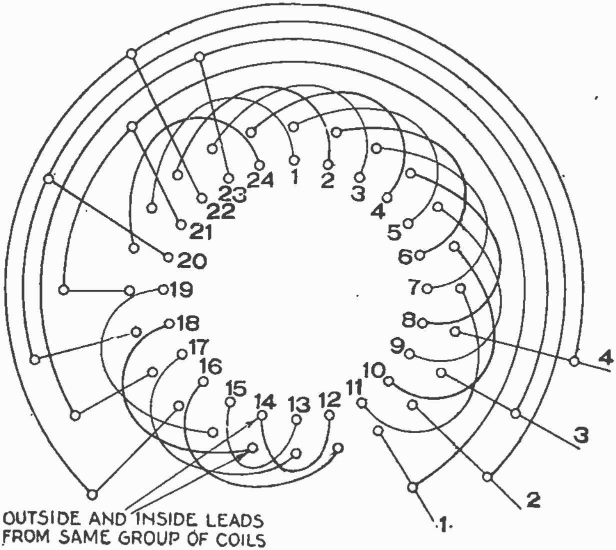


FIG. 3,252.—2 phase, 12 pole, 3 circuit. Connections between coil groups only.

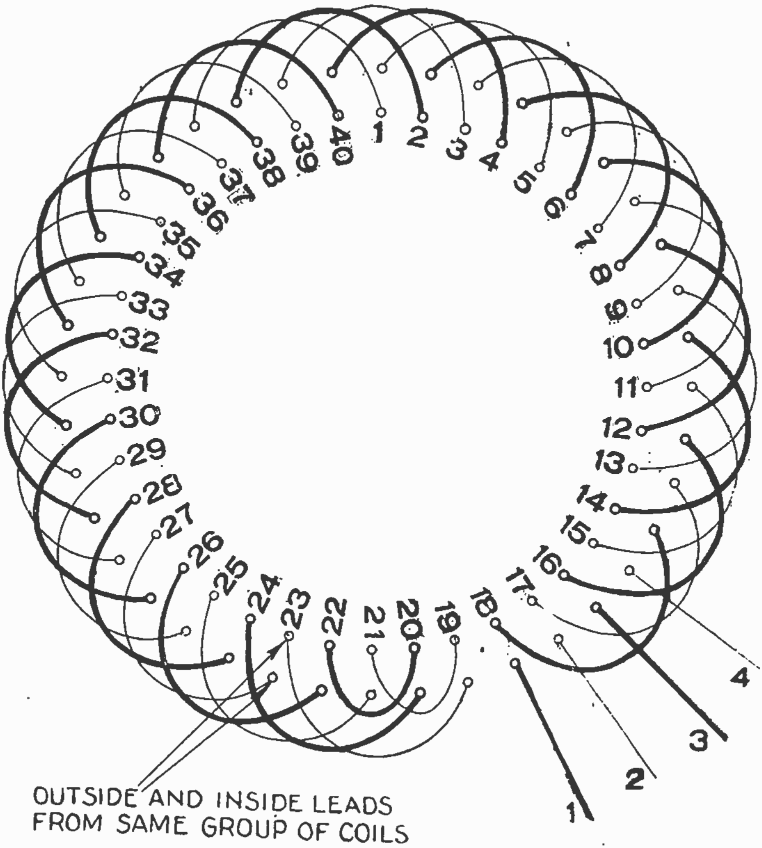


FIG. 3,253.—2 phase, 20 pole, 1 circuit Connections between coil groups only.

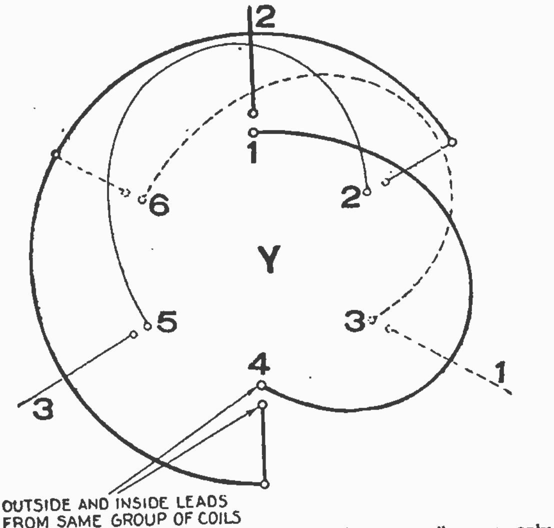


FIG. 3,254.—3 phase, 2 pole, 1 circuit Y. Connections between coil groups only.

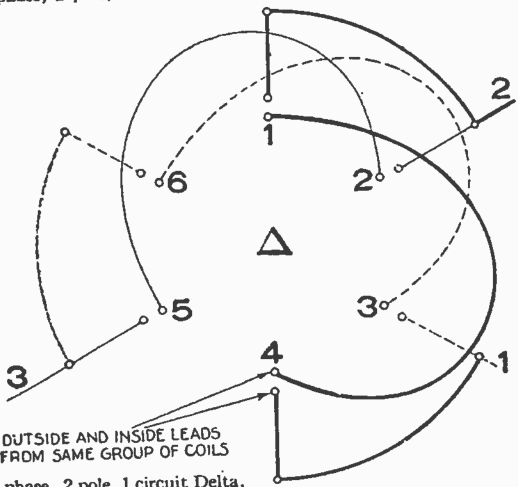


FIG. 3,255.—3 phase, 2 pole, 1 circuit Delta.
Connections between coil groups only

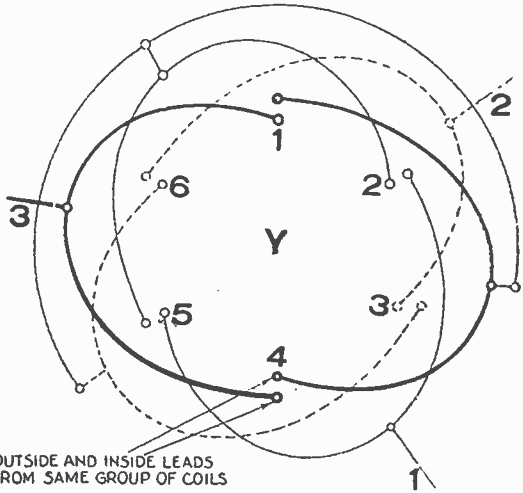


FIG. 3,256.—3 phase, 2 pole, 2 circuit Y. Connections between coil groups only.

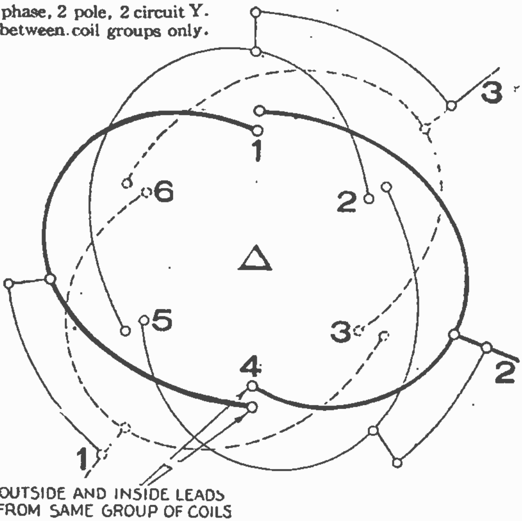


FIG. 3,257.—3 phase, 2 pole, 2 circuit Delta. Connections between coil groups only.

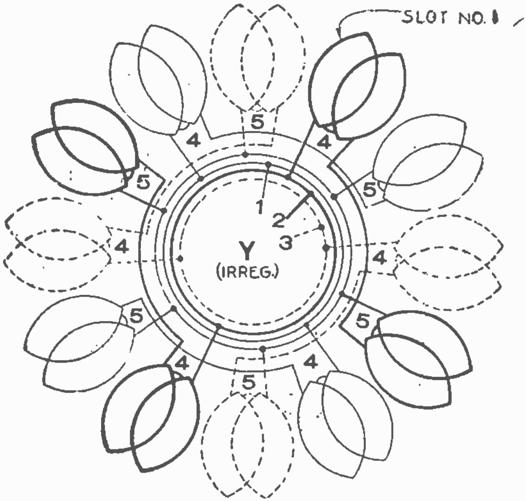


FIG. 3,258.—3 phase, 4 pole, 2 circuit Y (irregular).

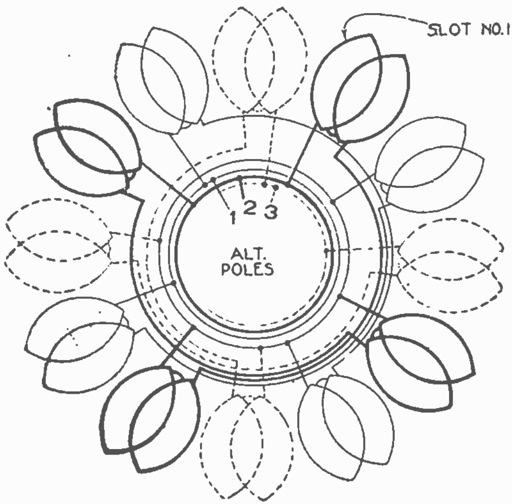


FIG. 3,259.—3 phase, 4 pole, 2 circuit alternate poles.

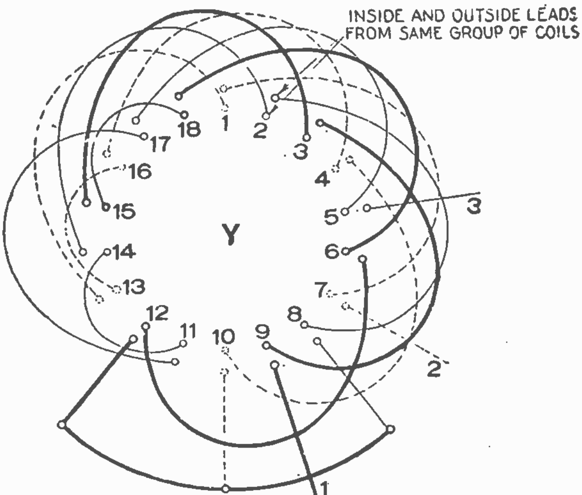


FIG. 3,260.—3 phase, 6 pole, 1 circuit Y. Connections between coil groups only.

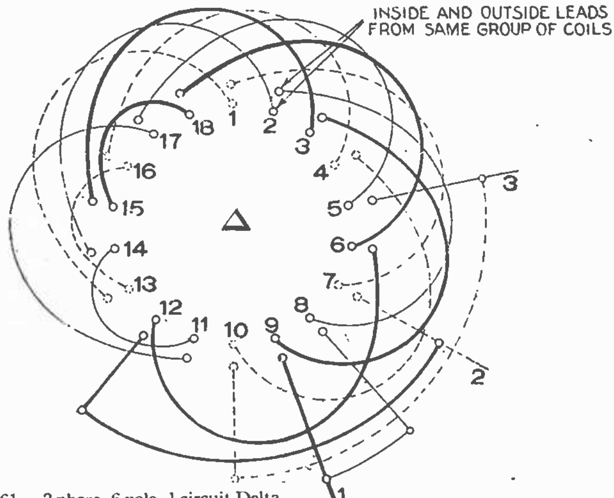


FIG. 3,261.—3 phase, 6 pole, 1 circuit Delta. Connections between coil groups only.

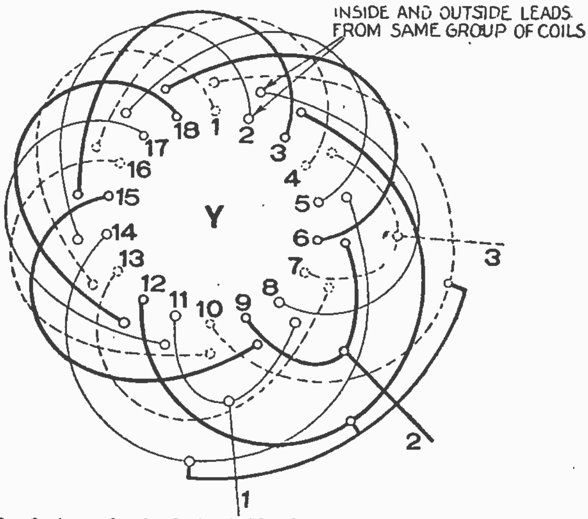


FIG. 3,262.—3 phase, 6 pole, 2 circuit Y. Connections between coil groups only.

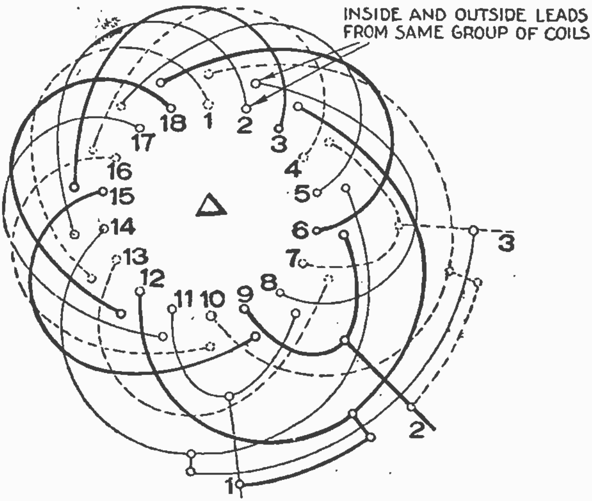


FIG. 3,263.—3 phase, 6 pole, 2 circuit Delta. Connections between coil groups only.

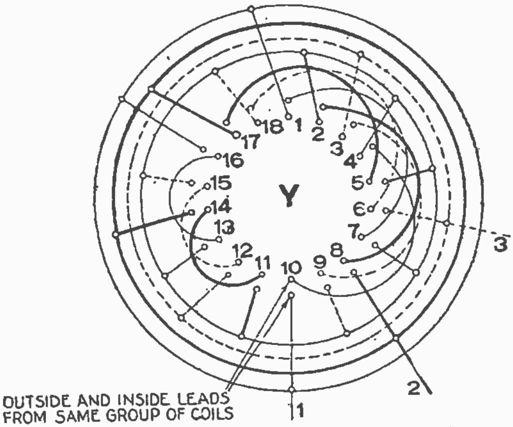


FIG. 3,264.—3 phase, 6 pole, 3 circuit Y. Connections between coil groups only.

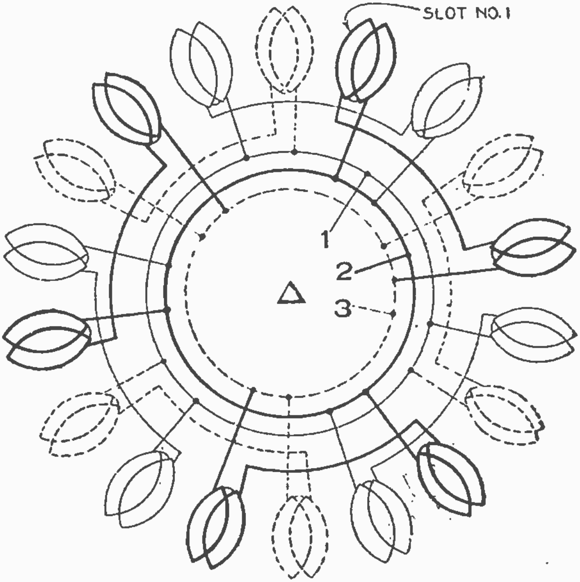


FIG. 3,265.—3 phase, 6 pole, 3 circuit Delta.

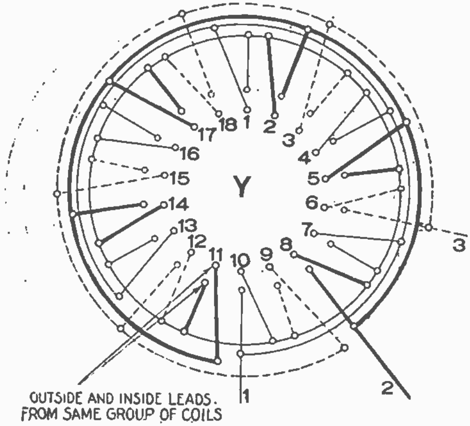


FIG. 3,266.—3 phase, 6 pole, 6 circuit Y. Connections between coil groups only.

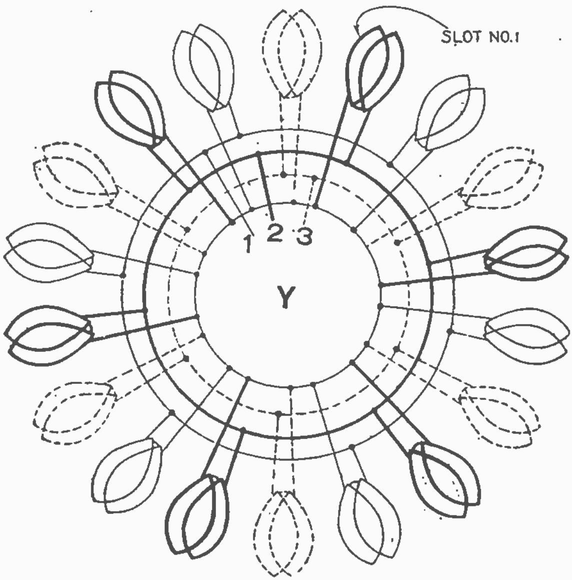


FIG. 3,267.—3 phase, 6 pole, 6 circuit Y.

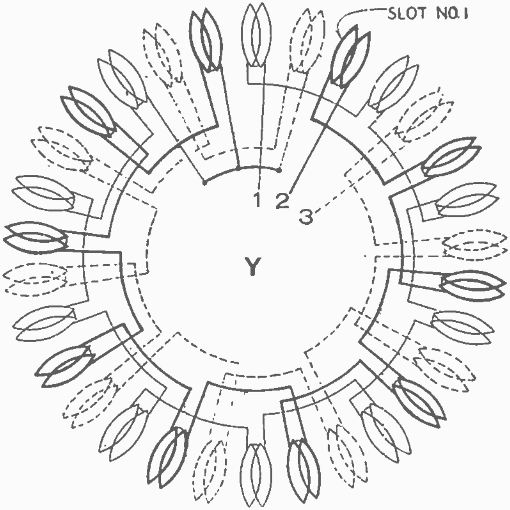


FIG. 3,268.—3 phase, 10 pole, 1 circuit Y

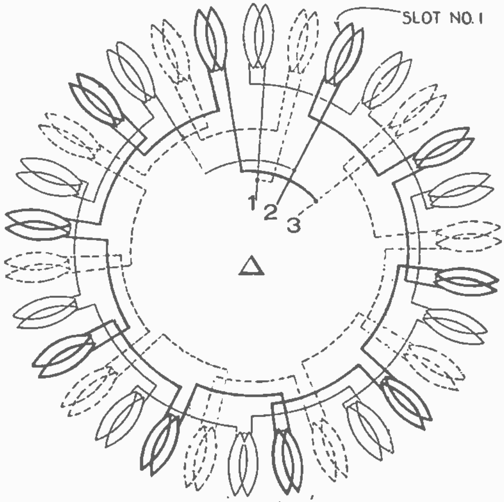


FIG. 3,269.—3 phase, 10 pole, 1 circuit Delta.

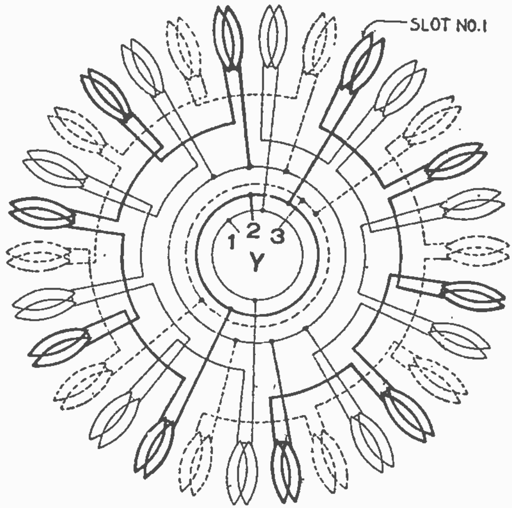


FIG. 3,270.—3 phase, 10 pole, 2 circuit Y, regular.

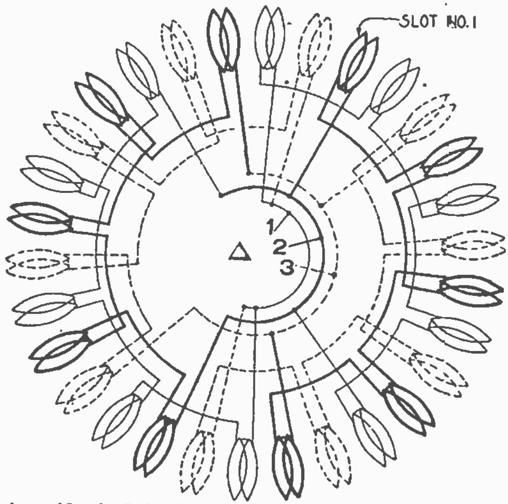


FIG. 3,271.—3 phase, 10 pole, 2 circuit Delta.

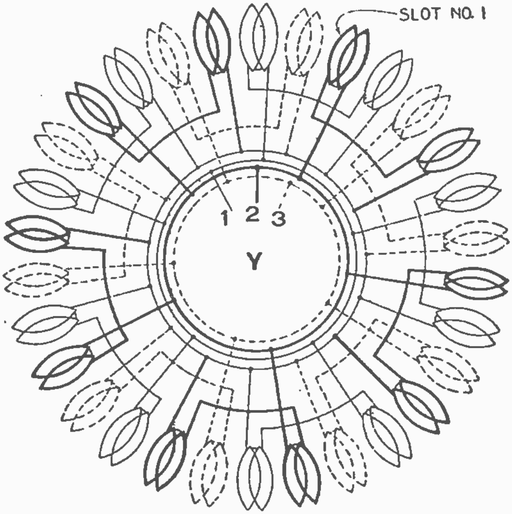


FIG. 3,272.—3 phase, 10 pole, 5 circuit, Y.

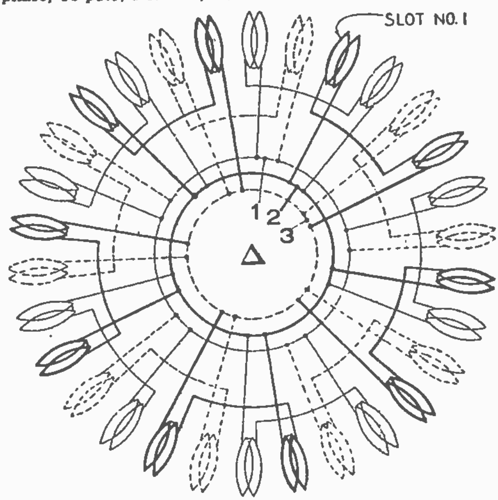


FIG. 3,273.—3 phase, 10 pole, 5 circuit Delta.

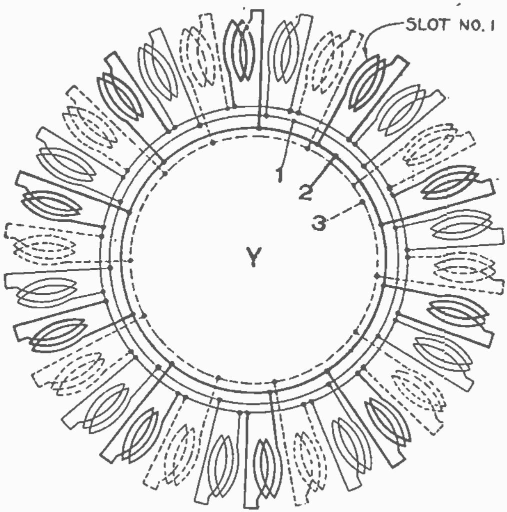


FIG. 3,274.—3 phase, 10 pole, 10 circuit Y.

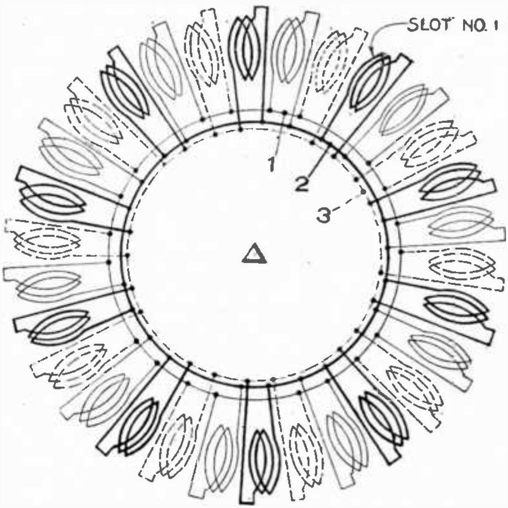


FIG. 3,275.—3 phase, 10 pole, 10 circuit Delta.

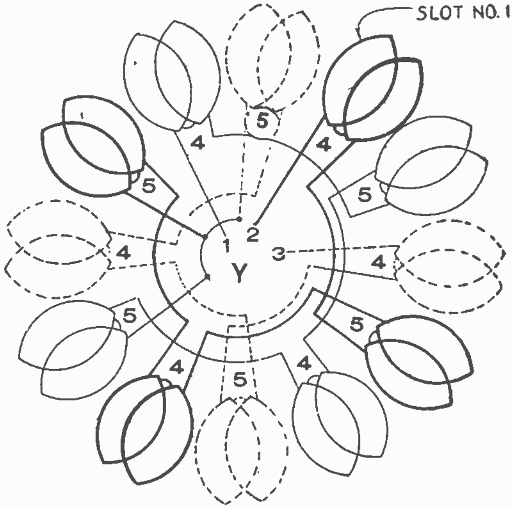


FIG. 3,276.—3 phase, 4 pole, 1 circuit Y, irregular.

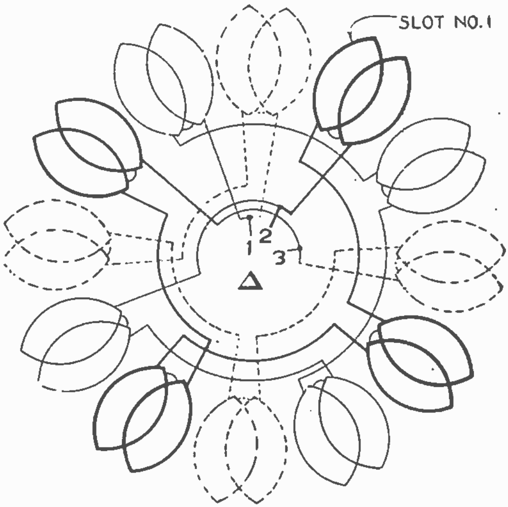


FIG 3,277.—3 phase, 4 pole, 1 circuit Delta

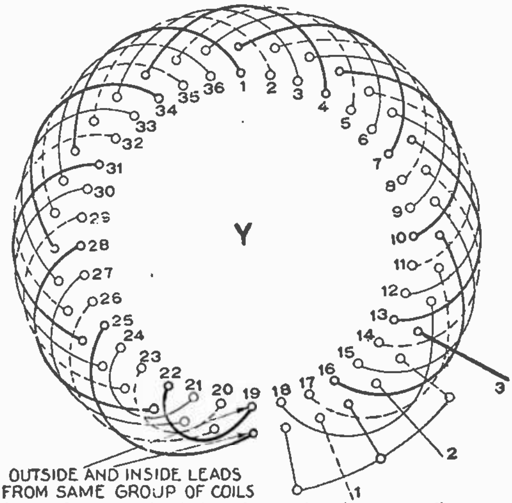


FIG. 3,278.—3 phase, 12 pole, 1 circuit Y. Connections between coil groups only.

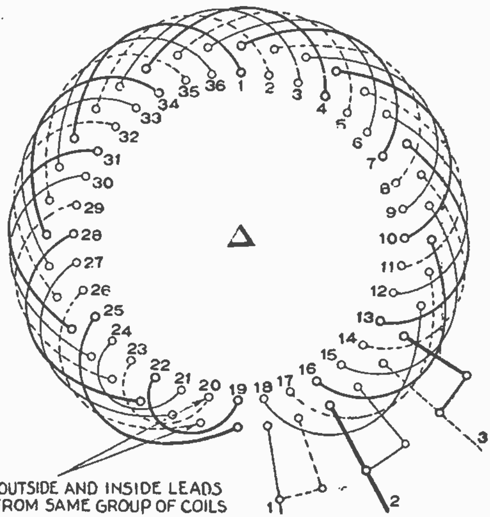


FIG. 3,279.—3 phase, 12 pole, 1 circuit Delta. Connections between coil groups only.

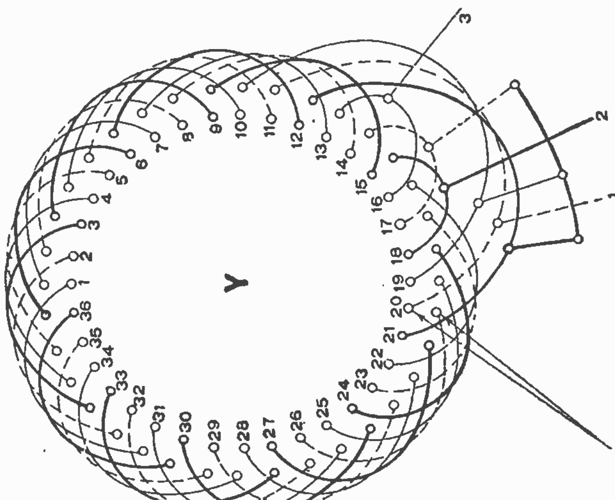


FIG. 3,280.—3 phase, 12 pole, 2 circuit Y. Connections between coil groups only.

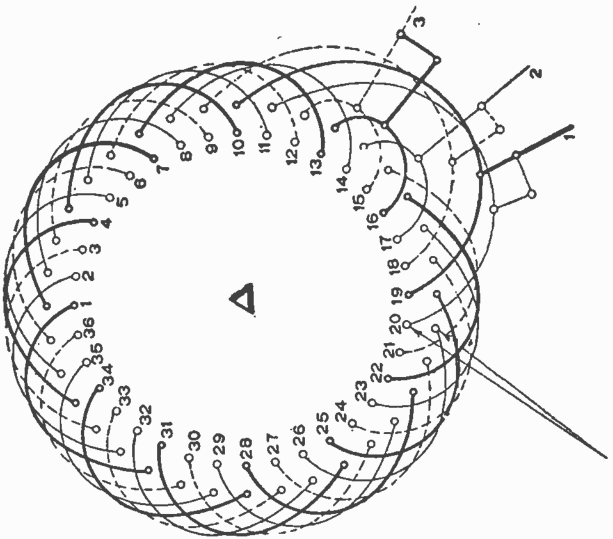


FIG. 3,281.—3 phase, 12 pole, 2 circuit Delta. Connections between coil groups only.

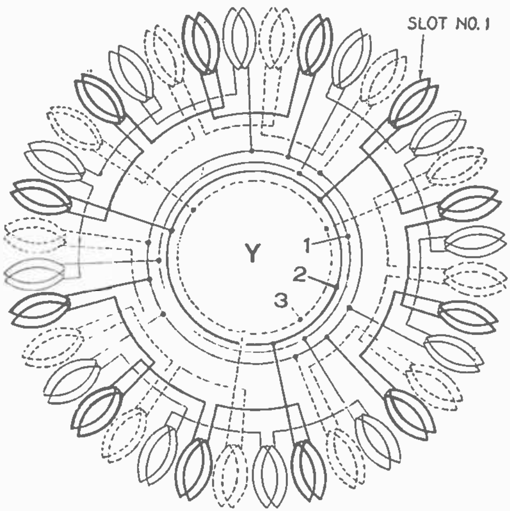


FIG. 3,282.—? phase, 12 pole, 3 circuit Y.

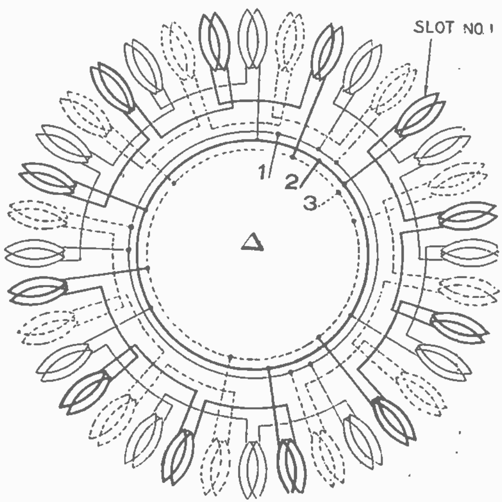


FIG. 3,283.—3 phase, 12 pole, 3 circuit Delta.

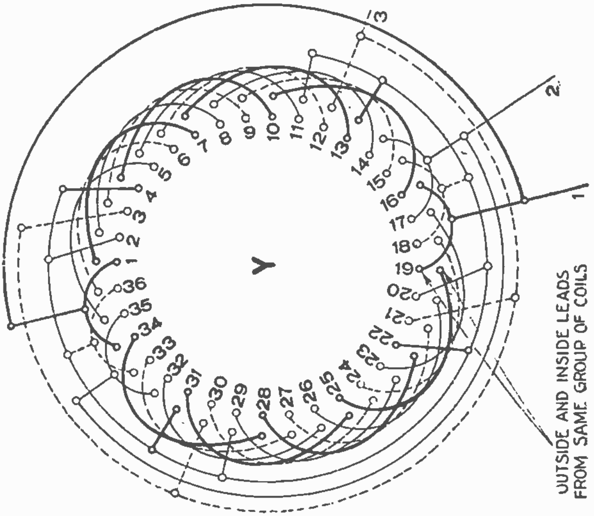


FIG. 3,284.—3 phase, 12 pole, 4 circuit Y. Connections between coil groups only.

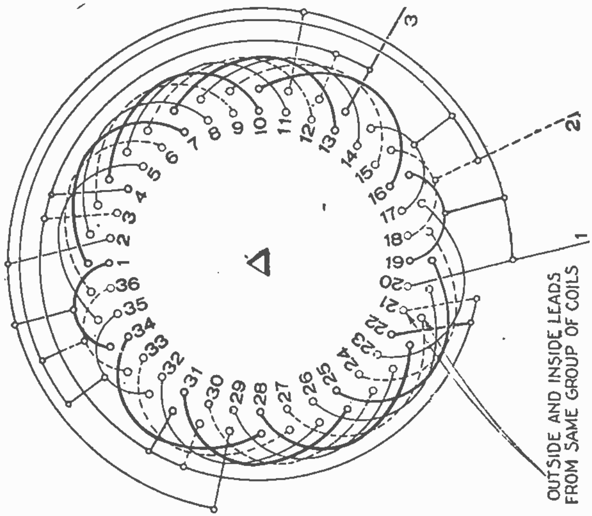


FIG. 3,285.—3 phase, 12 pole, 4 circuit Delta. Connections between coil groups only.

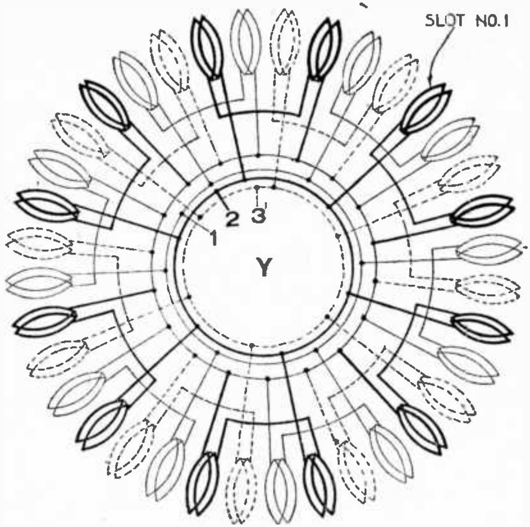


FIG. 3,286 —3 phase, 12 pole, 6 circuit Y.

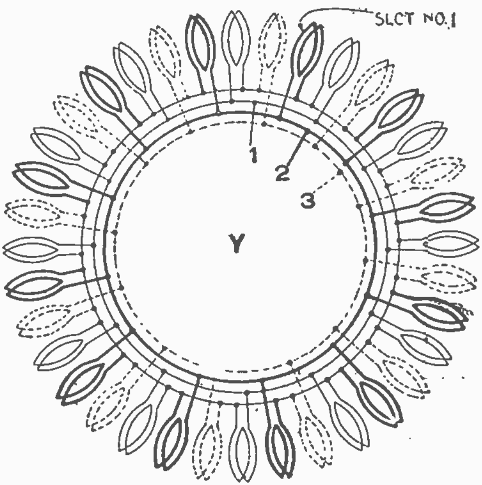


FIG 3.287.—3 phase, 12 pole, 12 circuit Y.

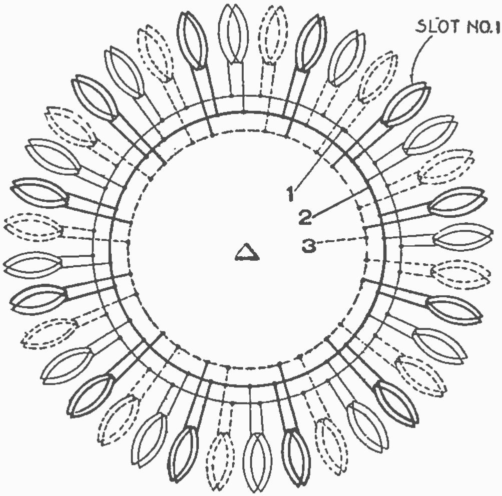


FIG. 3,288.—3 phase, 12 pole, 12 circuit Delta.

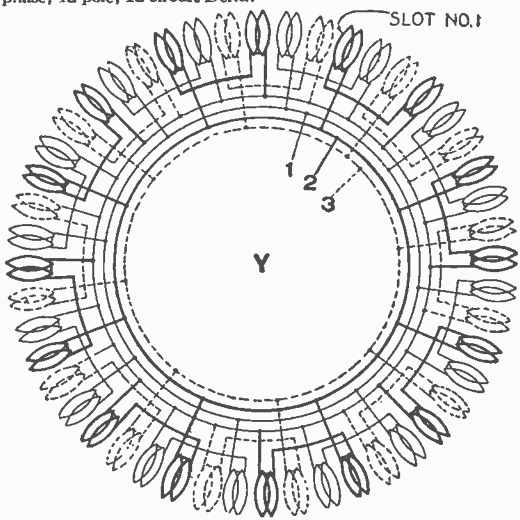


FIG. 3,289.—3 phase, 16 pole, 8 circuit Y.

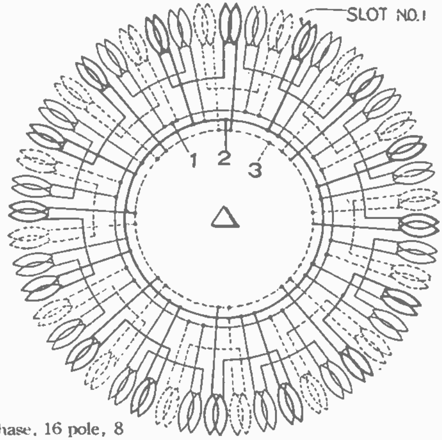


FIG. 3,290.—3 phase, 16 pole, 8 circuit Delta.

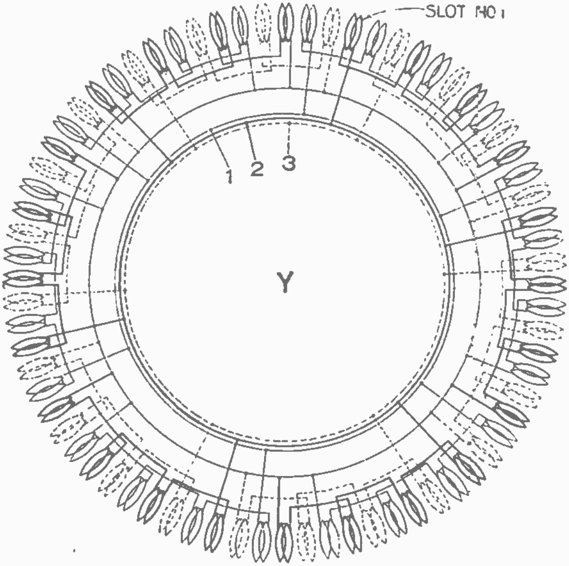


FIG. 3,291.—3 phase, 24 pole, 6 circuit Y.

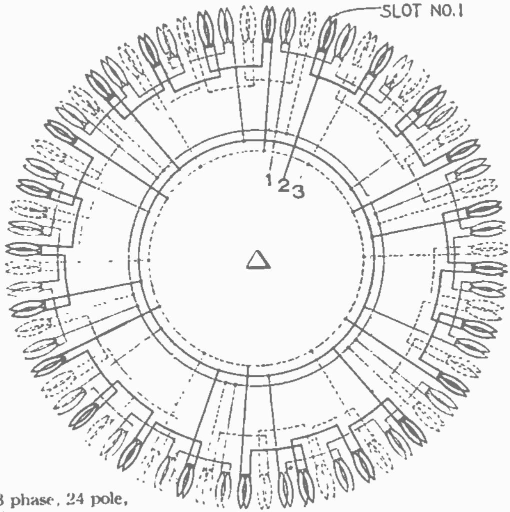


FIG. 3,292.—3 phase, 24 pole, 6 circuit Delta.

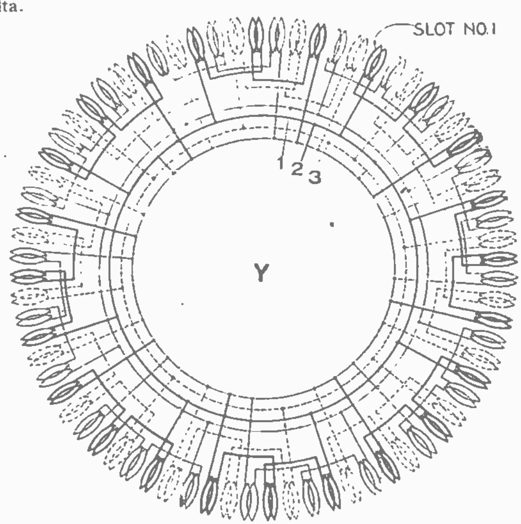


FIG. 3,293.—3 phase, 24 pole, 8 circuit Y.

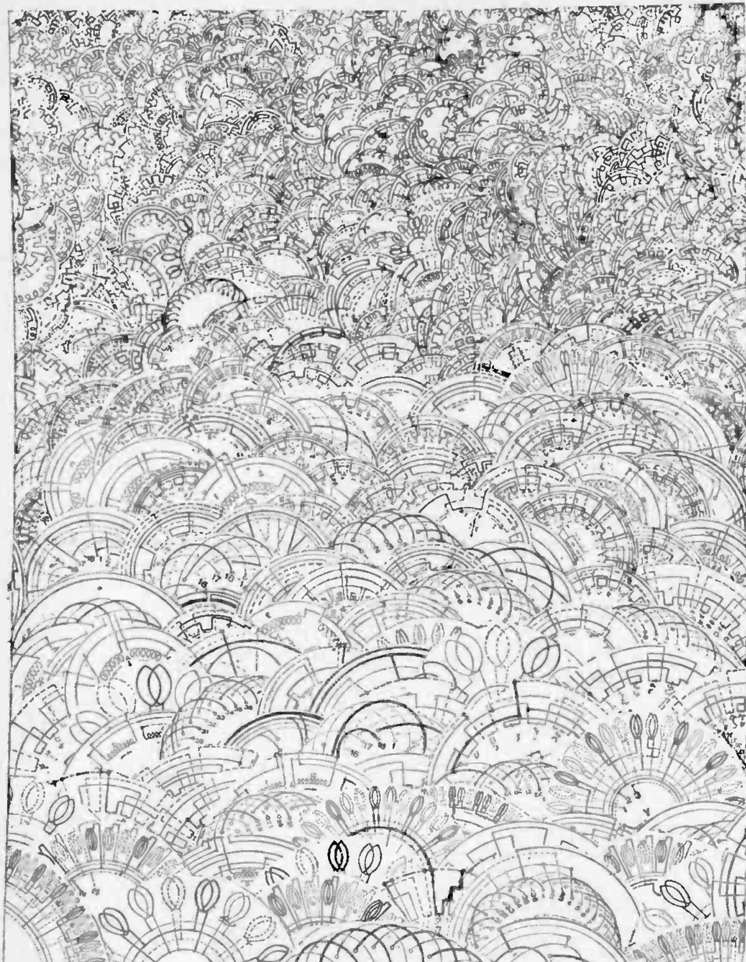


FIG. 3,294 to 3,924.—Collection of winding diagrams showing the great multiplicity of types; the combinations possible are almost infinite. Accordingly the student should seek to master principles rather than look for a diagram of any particular winding.

CHAPTER 70

Reconnecting A. C. Windings

It frequently happens that machines are not suited to the conditions of the plant for which they are intended. This may be due to changes in the conditions, or to the purchase of a second hand machine designed for different conditions than those required. For instance, the voltage, speed, horse power, etc. may be wrong and the machine must be changed if possible to meet the requirements.

There are some changes in the windings of an *a.c.* motor that can easily be made by a repairman, and also some which should not be attempted. Complicated changes should not be attempted except by men of experience. The operation of making such changes is known as *reconnecting*.

By reconnecting the windings, a machine may be adapted to changes in

1. Voltage;
2. Frequency;
3. Phase;
4. Speed;
5. Rotation.

All changes in operating conditions may be reduced to terms of change in voltage and so considered.

Preliminary Consideration. — Before any reconnection change is made, the adaptation of the motor to the proposed change, as limited by its design, should be carefully considered these limitations of design to be considered are:

1. Strength of the insulation.

If the change be for higher voltage, is the insulation adequate?

2. Cross section of copper available to carry the current.

There should be a sufficient number of coils in series to prevent the current rising above the safe carrying capacity of the winding.

3. Cross section of iron available to carry the magnetic flux.

4. Speed (*r.p.m.*) as limited by safe tangential velocity of rotor.

The speed should be such that the tangential velocity at the surface of the rotor will not exceed 7,000 ft. per minute, that is

$$3.1416 \times \text{rotor diameter} \times r.p.m.$$

should not exceed 7,000. If so, the manufacturer of the motor should be consulted before making the proposed change.

In reconnecting a winding, the current strength in the copper and flux density in the iron should remain the same. Assuming the machine to be correctly designed, it will operate at best efficiency when the above conditions obtain. An increase of current or magnetic flux will cause the machine to overheat, and if decreased, the efficiency will be lowered.

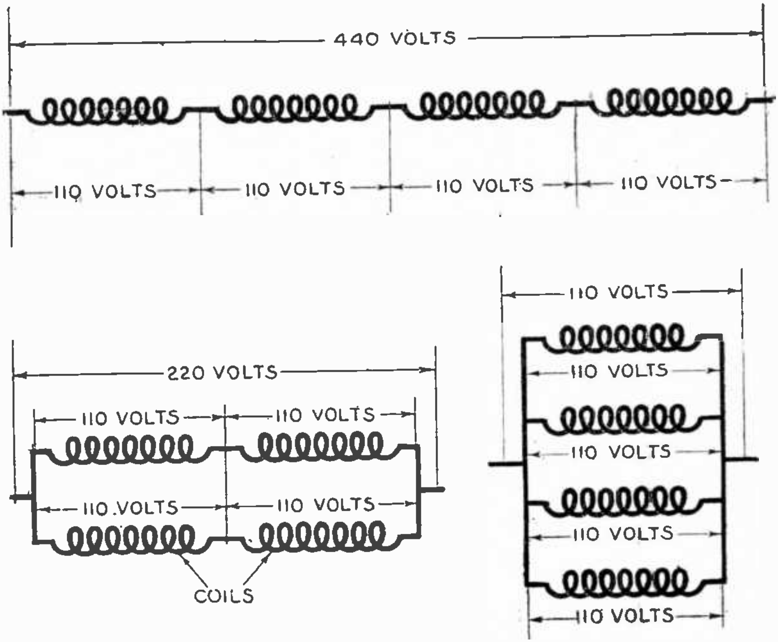
Voltage Changes.—Nearly all commercial motors are arranged so that they can be reconnected for two voltages.

To make these changes, the polar groups are connected in series for the higher voltage and in parallel for the lower voltage.

In changing to higher voltages it should be noted that motors as manufactured are provided with insulation good for 550 volts or for 2,500 volts.

The capacity of the insulation should accordingly be considered and no change be made beyond the capacity of the insulation.

In making a voltage change, *the voltage per coil or per turn must be approximately the same after reconnection as before.*



FIGS. 3,925 to 3,927.—Various connections of windings such that the voltage per coil remains the same.

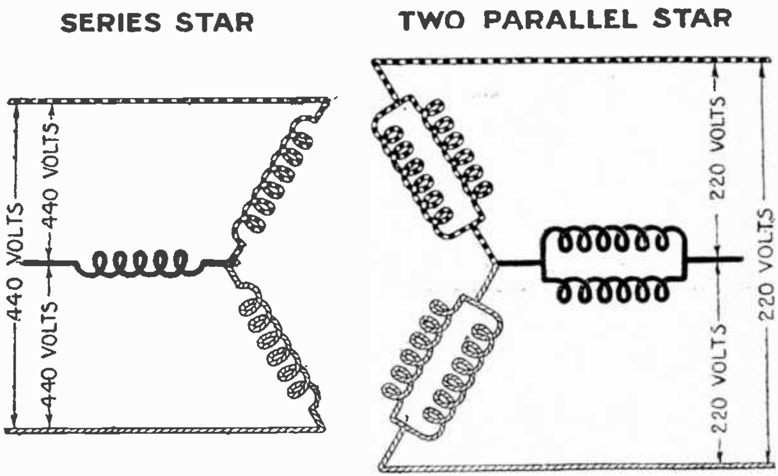
Thus, if a winding for a single phase 4 pole stator be designed to operate at 440 volts when the 4 coils which form the poles are connected in series, as in fig. 3,925, it will operate at 220 volts if the coils be connected as in fig. 3,926, so that there are 2 paths in parallel, with each

Motor Voltages with Various Connections and Phases

Form of connection	Three phase series star	Three phase 2 parallel star	Three phase 3 parallel star	Three phase 4 parallel star	Three phase 5 parallel star	Three phase 6 parallel star	Three phase series delta	Three phase 2 parallel delta	Three phase 3 parallel delta	Three phase 4 parallel delta	Three phase 5 parallel delta	Three phase 6 parallel delta	Two phase series	Two phase 2 parallels	Two phase 3 parallels	Two phase 4 parallels	Two phase 5 parallels	Two phase 6 parallels
Three phase series star........	100	50	33	25	20	17	58	29	19	15	12	10	81	41	27	20	16	14
Three phase 2 parallel star.....	200	100	67	50	40	33	116	58	39	29	23	19	162	81	54	40	32	27
Three phase 3 parallel star	300	150	100	75	60	50	173	87	58	43	35	29	243	122	81	60	48	41
Three phase 4 parallel star.....	400	200	133	100	80	67	232	116	77	58	46	39	324	163	108	80	64	54
Three phase 5 parallel star.....	500	250	167	125	100	83	289	144	96	72	58	48	405	203	135	100	80	68
Three phase 6 parallel star.....	600	300	200	150	120	100	346	173	115	87	69	58	486	243	162	120	96	81
Three phase series delta........	173	86	58	43	35	29	100	50	33	25	20	17	140	70	47	35	28	23
Three phase 2 parallel delta.....	346	173	115	87	69	58	200	100	67	50	40	33	280	140	94	70	56	47
Three phase 3 parallel delta....	519	259	173	130	104	87	300	150	100	75	60	50	420	210	141	105	84	70
Three phase 4 parallel delta...	692	346	231	173	138	115	400	200	133	100	80	67	560	280	188	140	1 1	93
Three phase 5 parallel delta....	865	433	288	216	173	144	500	250	167	125	100	83	700	350	233	175	140	117
Three phase 6 parallel delta...	1,038	519	346	260	208	173	600	300	200	150	120	100	840	420	280	210	168	140
Two phase series.............	125	63	42	31	25	21	72	37	24	18	15	12	100	50	33	25	20	17
Two phase 2 parallels.........	250	125	84	63	50	42	144	73	49	37	29	24	200	100	67	50	40	33
Two phase 3 parallels.........	375	188	125	94	75	63	216	111	73	55	44	37	300	150	100	75	60	50
Two phase 4 parallels.........	500	250	167	125	100	84	288	148	97	73	58	49	400	200	133	100	80	67
Two phase 5 parallels........	625	313	208	156	125	105	360	165	122	91	73	61	500	250	167	125	100	84
Two phase 6 parallels........	750	375	250	188	150	125	433	217	144	108	87	72	600	300	200	150	120	100

path containing 2 coils in series. Also by connecting the 4 coils in parallel as in fig. 3,927, the machine will operate at 110 volts. In each of these cases the voltage per coil is the same. Since in each case the voltage per coil, 110 volts is the same, the current density in the copper will be the same. Consequently, the same operating characteristics will obtain in the 4 path connection as in fig. 3,927 at 110 volts as in the 1 path connection, as in fig. 3,925 at 440 volts.

Numerous voltage changes may be made with two and three



FIGS. 3,928 and 3,929.—Winding diagrams illustrating a 440 volt series star connected motor and reconnection for operation at 220 volts as described in the accompanying text.

phase motors as is evident from the accompanying table prepared by A. M. Dudley.

Example.—A motor is connected series-star for three phase 440 volts. How should it be connected for 220 volts?

In the table (page 2,204) look along the horizontal line corresponding to *three phase series star* and under the intersecting vertical column headed *three phase series star* is found the number 100. This means that the motor as it stands on 440 volts is considered 100 per cent. The new voltage is to be 220, which is 50 per cent of 440. Hence, the same horizontal line in the table, namely *three phase series star* is followed along until the desired figure of 50 is found, which is under the vertical heading "*three phase 2 parallel star.*" This is the correct answer: that is, if a motor be connected three phase series star for operation on 440 volts, it must be connected three phase 2 parallel star, as in fig. 3,929, to operate correctly on 220 volts.

Frequency Changes.—For the same number of poles a change in frequency will cause the speed to vary directly as the frequency.

In order to maintain the speed constant in making a frequency change, the voltage on the motor should be varied in the same proportion as the frequency is changed.

A change in frequency may be regarded the same as *a voltage change because the voltage changes with the frequency.*

Increase in frequency *usually causes the machine to run a little cooler, and decrease, a little warmer.*

A change in frequency should be offset by a change in voltage in the same direction and amount; thus, if a motor be operated at 110 volts on 60 cycles, it should be operated at $\frac{5}{6}$ of 110 = 92 volts on 50 cycles.

In making a frequency change if the speed is to remain the same, *the number of poles must be changed in the same ratio as the frequency, or approximately so.*

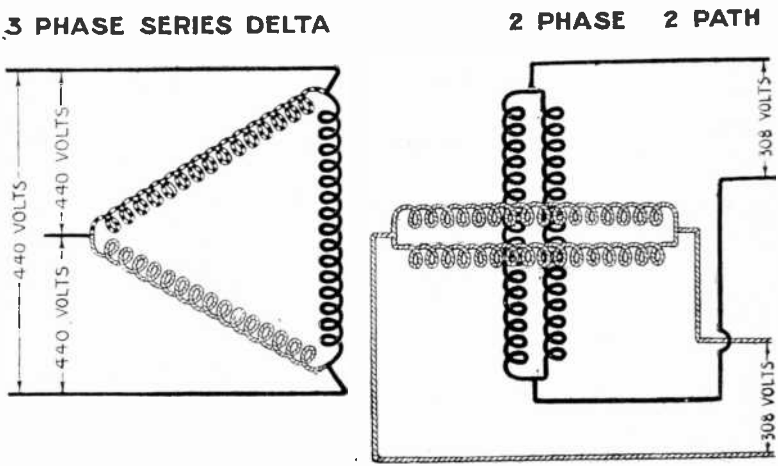
Example.—If a motor have four poles and be operated on 25 cycles, it will have a synchronous speed of 3,000 ÷ 4 = 750 *r.p.m.* If the motor is to have the same speed on 60 cycles, the nearest possible pole number is 10 and the synchronous speed will be 7,200 ÷ 10 = 720 *r.p.m.* It is apparent that in very few cases of this kind is it possible to re-connect the same winding.

Sixty cycle motors are often run on 50 cycles without change, but the practice results in increased iron losses, hotter running and slower speed. Under such conditions, the output of the motor in horse power should be reduced to keep down the copper losses.

Phase Changes.—The change most fequently desired is from two to three phases, or from three to two phases.

Example.—A three phase 440 volt motor is to be reconnected for two phase 440 volts. What changes must be made?

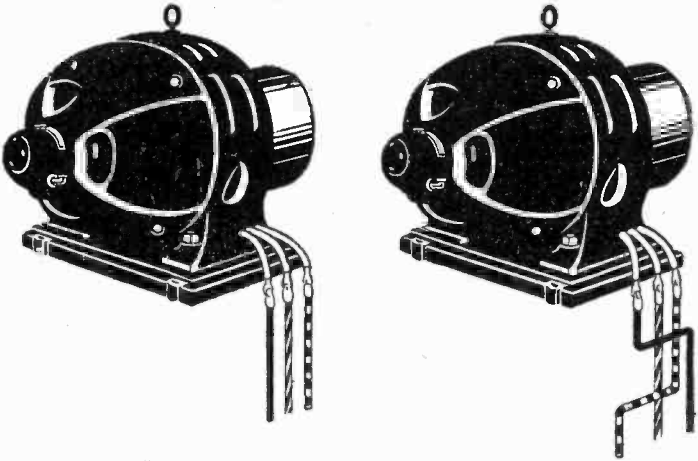
In the table on page 2,204 it is seen that the winding as it stands on 440 volts is four pole three phase series delta. Select the horizontal column



FIGS. 3,930 and 3,931.—Winding diagrams illustrating a 440 volt series star connected motor and reconnection for two phase operation. As explained in the text, the voltageris reduced to 308 volts.

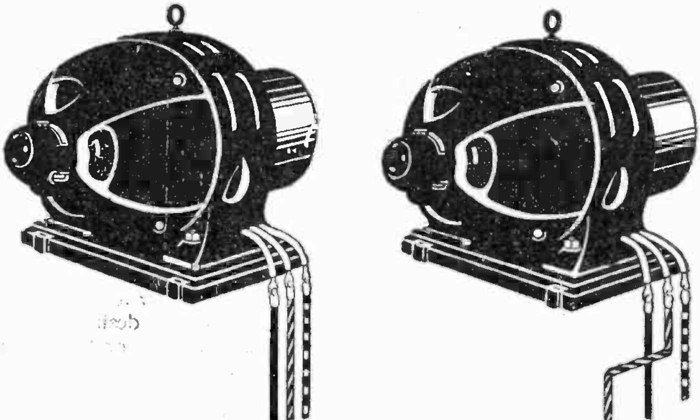
in the table marked three phase series delta and follow it across, looking for a vertical column showing the value 100, since the desired two phase voltage is the same as the present three phase voltage or 100 per cent. Inspection shows that there is no 100 under any two phase connection. This indicates at once that a three phase series delta connected motor which is normally operated on 440 volts cannot be changed and operated on two phase 440 yolts, without rewinding. The nearest value to 100 under a two phase column is 70, shown under *two phase 2 parallel.* This

2 PHASE 3 WIRE MOTOR



FIGS. 3,932 and 3,933.—Reversing two phase three wire motor; *Interchange the two outside leads.*

3 PHASE MOTOR



FIGS. 3,934 and 3,935.—Reversing three phase motor. *Interchange the connection of any two leads.*

means that if a three phase 440 volt motor which is connected series delta, be reconnected for 2 parallel two phase, it should be operated on 70 per cent of 440, or 308 volts.

Speed Changes.—The speed of an induction motor may be changed by regrouping the field coils for a different number of coil groups. In this connection it should be noted that *an increase in the number of poles will decrease the speed, whereas, a decrease in the number of poles will increase the speed.*

There are numerous cases where a change of two poles is permissible, as for example, changing from four poles to six, or from ten to eight and the like. The changes would consist in rearranging the phase coils to agree with the new grouping and checking the chord factor, to note its effect on the voltage. It is often possible to get a fair operating half speed by connecting for twice the number of poles.

Practically all reconnections involving pole changes give only a fair operating performance.

Reversing Polyphase Induction Motors.—For a two phase four wire machine, interchange the connections of the two leads on either phase.

For a two phase three wire motor, interchange the two outside leads.

For a three phase machine, interchange the connections of any two leads.

TEST QUESTIONS

1. *What is understood by the term reconnecting?*
2. *What changes can be made by reconnecting?*
3. *How should reconnecting changes be considered?*
4. *What is the preliminary consideration before making a change?*
5. *In reconnecting, what two things should remain the same?*
6. *How are voltage changes made?*
7. *What should be especially considered in changing to a higher voltage?*
8. *How are frequency changes made?*
9. *How does an increase in frequency affect the operation?*
10. *How are phase changes made?*
11. *What are the most frequently made phase changes?*
12. *How are speed changes made?*
13. *Does the motor operate efficiently after a speed change is made?*
14. *How are polyphase induction motors reversed?*

CHAPTER 71

A. C. Motor Management

Installation, Operation, Care

There are certain precautions that should be taken with *a.c.* motors in starting, running and stopping in order that the efficiency of the supply current and indirectly the working of other motors and lamps connected to the mains in the immediate neighborhood, may not be affected by abnormal variations of the voltage. These precautions should be observed also to prevent any danger of the motor itself being subjected to detrimental mechanical shocks and excessive temperature in the working parts.

1. Installation

Foundation.—A solid substantial foundation should be provided for the installation of any motor. This provides a firm support for the machine and the mass of the foundation will serve also to absorb any vibration that may occur in operation.

Concrete is a good material for foundations. A good mixture for this purpose consists of, one part Portland cement, two parts clean sharp sand, and three parts broken stone. Only the best grade of cement should be used.

When the anchor bolts which hold down the machine are cast in the concrete their location must be determined with great accuracy, otherwise they will not be in line with the holes in the base or bed plate of the machine. Moreover in case of a broken bolt it would be a difficult matter to put in a new one.

A much better method is to "cast" iron pipes in the concrete.

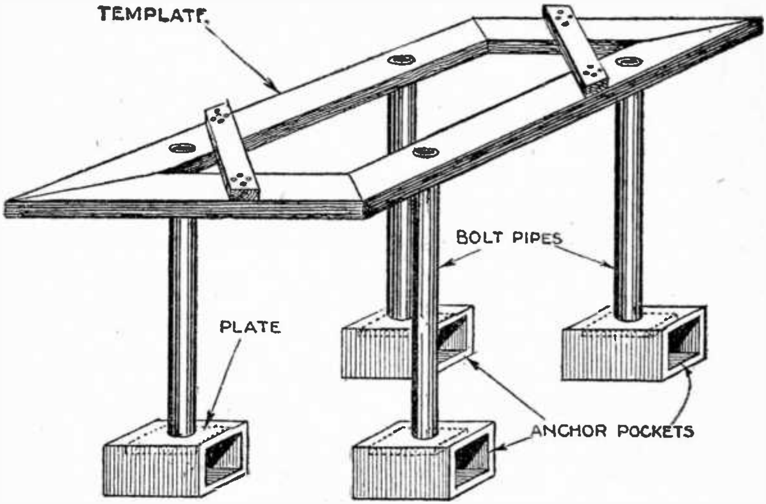


FIG. 3,936.—View showing template for locating anchor bolt centers, pipes through which the bolts pass, and bolt boxes at lower end of bolts. The completed foundation is shown in fig. 3,937, with template removed. The template is made of plain boards upon which the center lines are drawn, and bolt center located. Holes are bored at the bolt centers to permit insertion of the pipes as shown.

These iron pipes should be a little larger than the bolts, pockets being provided at the lower end.

The bolts are inserted in the pipes and being accessible through the pockets are easily anchored. Since the pipes are larger than the bolts, a slight variation in location is permitted so that there will be no difficulty in aligning them with the holes in the machine. A wooden template should be made with holes corresponding to those in the motor base as shown in fig. 3,936.

Floor or Wall Mounting.—All motors are shipped from the factory assembled for floor installation unless otherwise ordered. For wall or ceiling mounting, turn both end brackets

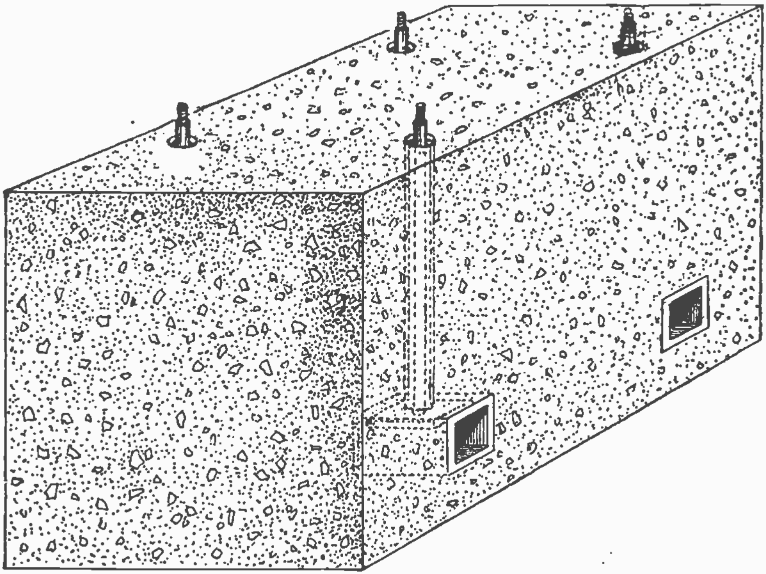


FIG. 3,937.—Concrete foundation, showing method of installing the anchor bolts.

so that the oil well covers will be directly above the shaft when the motor is in the desired position.

Care should be taken, when loosening or tightening the nuts on the through bolts holding brackets to frame, that the motor core is not shifted. Since the motor core is mounted on these through bolts it is essential that the tightening of these nuts be done uniformly, that is, by an equal amount on each bracket.

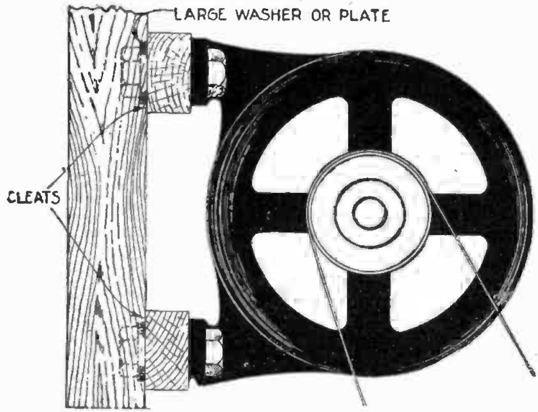


FIG. 3,938.—Method of mounting motor on wooden wall.

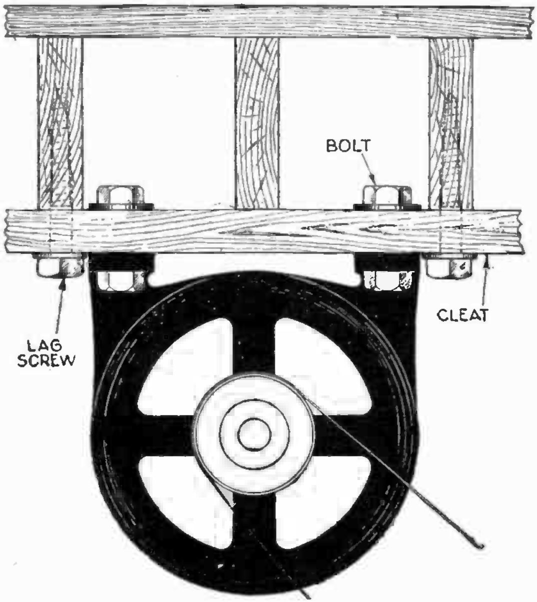


FIG. 3,939.—Method of mounting motor on wooden ceiling.

Whenever the end brackets are removed or rotated make sure that the joints are clean before they are replaced and tightened. Check the air gap and see that the rotor revolves freely.

Lining up an Engine Type Synchronous Motor.—When on the foundation, the sole plates supporting the stator should be leveled, and temporarily set for grouting, using metal wedges closely spaced and evenly driven. Inch over holes are provided in the sole plates for moving the stator horizontally. Square the motor frame to the shaft by spanning a steel wire across the outside, touching the finished bosses on the guards

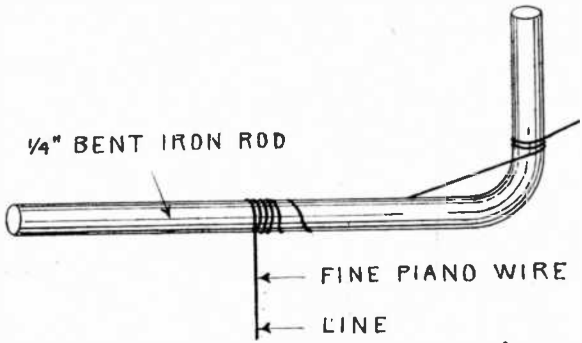


FIG. 3,940.—Small bent lever of 3/8 round iron to secure wire center line taut in position.

and gauge from this wire to machined surface of spider rim, and be sure that stator laminations are exactly opposite the field pole laminations on both sides of the machine.

Before shimming and grouting, see that the air gap on top is considerably smaller than on the bottom. A practical air gap gauge is shipped with every motor. See also that air gap is even on both sides of the core horizontally and vertically.

After the sole plates have been grouted and set, raise the stator slightly, using the jack screws provided for in the feet and now insert shims in both sides in sufficient numbers to even up the air gap vertically.

It is good practice to leave the air gap on top slightly smaller (10 or 15 mils) in order to relieve the bearings from the dead weight of the rotor.

Adjusting screws inserted in the frame on both sides and pushing against the sides of the sole plates are used to move the stator sidewise and make uniform air gap adjustment on both sides.

When motor has been set for correct air gap, dowel stator feet to sole plates.

Erecting Motors of Split Construction.—When assembling the unit, the lower part of the stator is first put in position

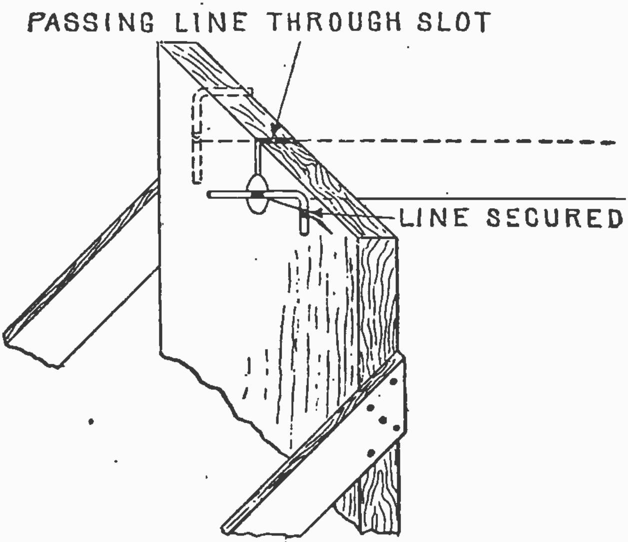


Fig. 3,941.—Method of securing wire center line.

and moved over as far as the movement on the sole plates will allow. The machined joints are then carefully inspected and cleaned and the winding near the joints examined.

Before the upper part is put in position see that the dowel holes are free from dirt or any foreign matter.

When in position the bolts with reamed seats holding the two frame halves together should be carefully installed and tightened up. The disconnected coils should then be carefully assembled in the slots and connected up. The shaft is now turned with the key seat up and the rotor rests on the shaft with the key in place.

A wooden cradle made for the other half of the shaft and bolted to this half of the rotor, holds it securely in place so it may be given half a revolution. After this half of the rotor has been blocked up from the bottom of the pit, taking precaution to block only against pole face proper, not the end rings, the wooden cradle may be removed to allow the second half of the rotor to be put in place. It is understood that before starting to assemble the rotor, the shaft diameter and key should be checked with

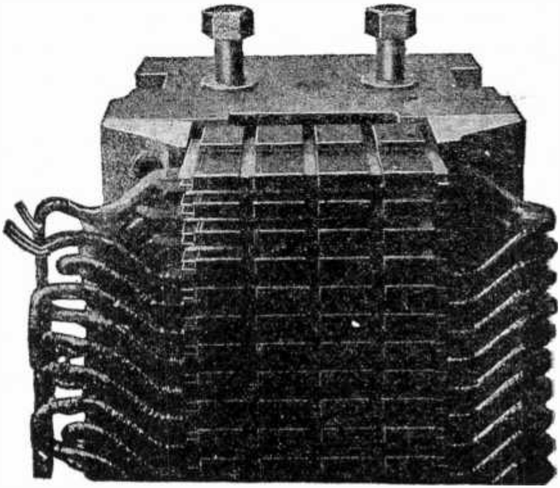
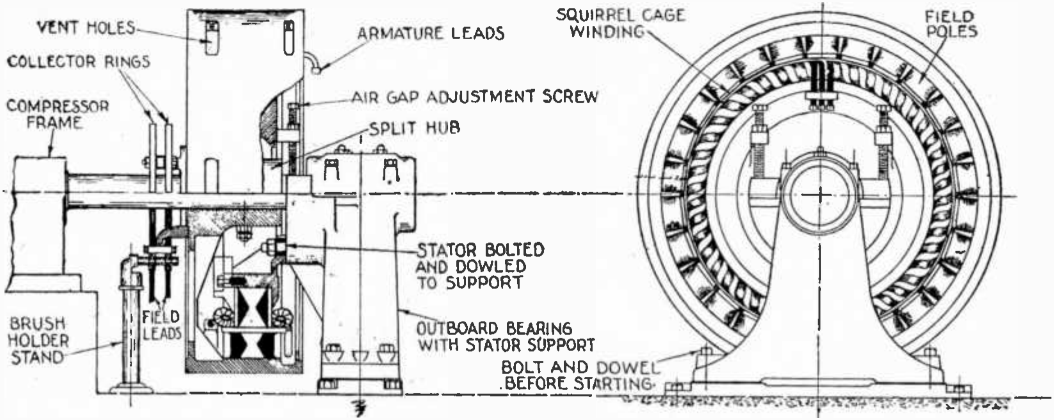


FIG. 3,942.—Detail of joint showing split stator construction of Ideal 600 *h.p.*, 2,200 volt, 3 phase, 25 cycle, synchronous motor.

the bore and keyway in the rotor, that all surfaces be thoroughly cleaned and dowel pins put in place at the rim.

After the hub bolts have been installed and the two rotor halves securely fastened to the shaft, the rim bolts should be put in place and the collector rings assembled. These rings should afterwards be smoothed off with a fine emery cloth to remove any projections which would cut into the brushes. Finally, the field coils and squirrel cage windings are connected up and the motor set for air gap as outlined above.



FIGS. 3,943 and 3,944.—Ideal fly wheel type synchronous machine with stator mounted on out board pedestal.

Installation Notes for Fly Wheel Type Synchronous Machine.—The following directions will be found helpful when erecting a machine such as shown in figs. 3,943 and 3,944, having the stator mounted on outboard pedestal.

1. Do not mount brush holder rigging before stator and rotor are in place with permanent air gap setting.

2. With hub bolt loose and split wedged in rotor hub, slip rotor in position on the shaft and tighten hub bolt. Care must be taken when opening up hub bore for sliding fit on shaft that suitable steel wedges are used with a taper of not less than ⅛ in. to the foot and expanding first undertaken at the spoke end of hub. Block up under flywheel to support shaft and rotor.

3. Mount stator on stator support pad leaving bolts slightly loose; adjust concentricity of stator diameter in respect to bearing with stator adjusting screws using machined surfaces on inside diameter of stator support pad and machined surface of shaft.

4. With sole plate temporarily in place on foundation, slide pedestal onto the shaft with stator intact. Wedge up sole plate on four sides with metal wedges until shaft turns free in bearings. Grout sole plate.

5. Adjust air gap up and down and sidewise, leaving air gap at the bottom 10 to 15 mils smaller than at the top, according to instructions given on certified outline drawing furnished with the machine.

6. Carefully remove pedestal with stator intact from shaft, then drill and ream holes for proper dowel pins and dowel stator in place, then tighten all stator holding bolts.

7. Reassemble on shaft, bolt and dowel pedestal to sole plate and mount brush holder rigging on its foundation plate. Adjust brushes to collector rings.

8. See that no tools are left in the machine. Rotate rotor by hand a couple of revolutions to see if it run free and true, and machine is ready for the initial start.

9. In case the machine be built with solid rotor hub and collector rings mounted inside the rotor on the hub, disregard (Note No. 1) and reference made in other notes to split rotor hub, outside collector rings and brush holder mounting. Make use of threaded stud or studs to be inserted in hole or holes drilled and tapped in the shaft extension and face of rotor hub to pull rotor on or off the shaft, but be sure to remove brushes from the holders before this is done.

Drive Gear.—Power may be transmitted from the motor to the machine to be driven by either:

1. Belt
2. Toothed Gearing
3. Chain
4. Direct connected.

Belt drive is largely used where room is available for adequate length of belt.

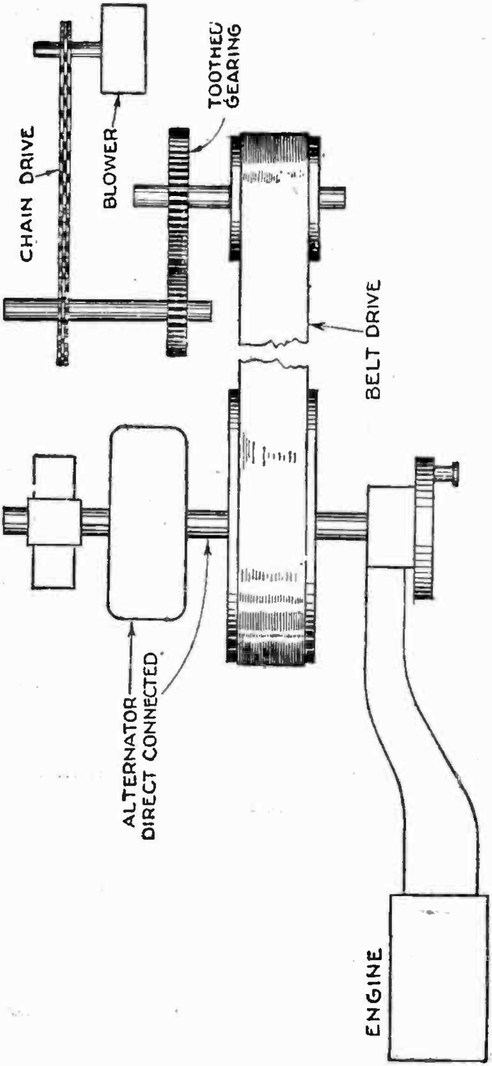


FIG. 3,945.—Installation with various kinds of drive gear showing that the power may be transmitted from the engine to the machine or machines to be driven by: 1, belt; 2, toothed gearing; 3, chain; 4, direct connected.

Align the pulleys and see that the belt is just tight enough to carry the load without slipping. If possible make the lower side of the belt the driving side. *Do not tighten belt any more than necessary to prevent slipping.*

Vertical belt drive should be avoided. Best results are obtained by locating the base so that adjusting screws come on the side of the motor opposite the belt.

There should be a reasonable distance between the center of the rotor shaft and the center of the shaft being driven, so as to eliminate the necessity of having to run the belt very tight, which would produce unnecessary friction loads.

A pulley of the size regularly listed with the motor should be used. as the size has been selected to secure continued satisfaction from the belt and the bearings.

Belt drive is fully treated in the chapter on Installation of Dynamos and Motors, pages 880 to 894.

If the motor be geared to the apparatus to be driven, the gear and pinion should not mesh so tight as to prevent a thin piece of paper being pulled from between the teeth without tearing.

In the case of chain drive mount the motor so that the chain may be tightened.

Secure accurate alignment. Driven and driving shafts must be parallel. Avoid vertical chain drives if possible. Chain belt should never be drawn up tight.

Fuses and Overload Protective Devices.—When a motor is started automatically, or installed in an out of the way place or controlled from a distance, or installed where the operator seldom inspects the motor, the use of a fuse having a rated capacity of 125% of the rated ampere capacity of the motor as shown by the name plate is recommended. The same should apply to the setting of overload devices such as time limit overload relays.

For motors of the automatic start, across the line type use

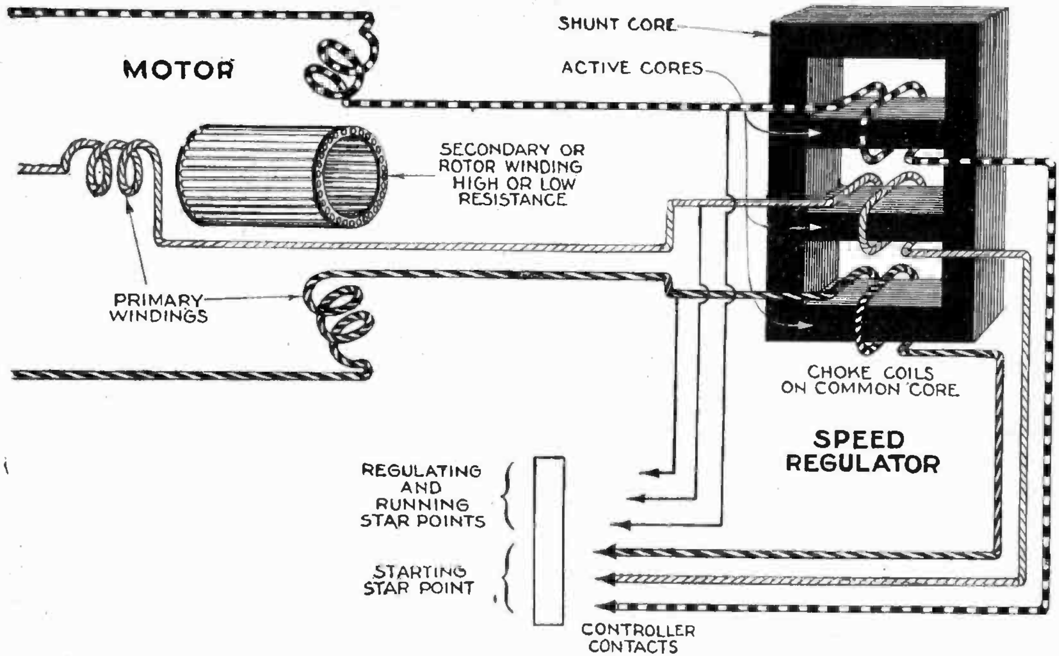


FIG. 3,946.—P. E. Chapman choke coil induction motor regulating system, designed to take the place of the "slip ring" type of induction motor starting or speed control, that is, resistance in the secondary (usually the rotor) circuit, because of the large losses which occur with external resistance coils, whereas choke coils are highly effective. This system was applied originally to the Chapman armature winding machine. ***In this application*** the star point of the primary of a polyphase motor is opened and a choke coil inserted in each one of the three legs, the other end of these choke coils are brought to three

FIG. 3,946.—*Text continued.*

contacts of the controller placed so that in the first position of the controller they will be short circuited to form a starting star point. As the controller lever is further advanced it successively short circuits one after another of the choke coils until they are all cut out. This arrangement gives four steps of regulation with but three coils. The choke coils are put in the star point because the controller can then be made single pole, if they were put in the line, the controller would have to be triple pole (for three phase) increasing its complication. In order to save space, material, and energy losses these choke coils are wound on a common core such as is used for polyphase transformers. As the choke coils are themselves short circuited, it is necessary to provide a by pass or shunt core so that the magnetism linked with the active coils will not be compelled to pass through the short circuited coils as this would ruin the choking effect of the active coils. Should the operator cut the starting resistance out of the secondary of an induction motor too soon, that is, before the motor attains a proportionate speed it will start a much smaller load, do it much slower and waste more energy than it will when the resistance is carefully cut out as the speed of the motor increases. For applications where the duty is nearly "all starting" as is the Chapman winding machine; giving the rotor itself a high resistance will cause the motor to start at maximum torque no matter what the position of the controller.

inverse time limit overload relays, thermal overloads or fuses set for 150% of the full load motor current.

In case the starting duty be severe and these fuse and relay settings do not permit starting, use a double throw starting switch which will cut out or shunt out the fuse or relays during starting.

2. Operation

Before Starting.—In general certain precautions are necessary before starting a motor especially the first time.

1. Make sure that all bolts, nuts and screws are tight, that the oil wells are filled with a good grade of mineral oil, and that the commutator and other parts are clean.

2. Remove all external load if possible and turn the armature by hand to see if it run freely.

3. Make sure that the oil plugs are tight and that the oil wells are filled to the top of the overflows at the side of bearings with a good grade of light mineral oil.

4. See that the voltage on the name plate corresponds with the line voltage.

5. Check all electrical connections with diagrams to avoid possibility of injury to machine by errors in wiring.

6. Before putting the motor in service it is desirable to run it without load for a short time to determine if there be unusual heating in bearings or windings.

Operating Squirrel Cage Motors.—When the motor is started without a compensator, simply close the line switch. When starting with hand operated compensator, move the compensator switch lever to the starting position, and when the motor comes up to speed (in about 5 to 20 seconds) throw the lever quickly to the running position.

Operating Slip Ring Motors.—In starting (combined operation, primary and secondary control):

1. See that the control handle is in the OFF position.

2. See that the disconnecting or separate overload protective switch, if used. is closed.

Constant Speed Motors.

Move the handle of the starting device slowly to the full speed position Starting resistors have a time limit of acceleration from zero to full speed in 15 seconds, 30 seconds and 60 seconds, depending upon the type of resistor used.

Adjustable Speed Motors.

Move the handle of the starting device slowly to any desired speed point. The resistors for this type of control must be rated for continuous duty on any speed point.

In stopping return the handle of the starting device to the OFF position. For other types of apparatus, such as automatic, see further instructions furnished with the apparatus.

Repulsion Motor Operation.—To start the motor:

1. If without starter, close the main switch.

2. If a starting box be used, see that the arm is in the OFF position. Then close the main switch (the line switch should always be either fully closed or fully open) and move the lever of the starting device firmly on to the first contact; hold it there for two or three seconds to allow the motor armature to accelerate slowly; then move the rheostat lever from one contact to the next until it is in running position.

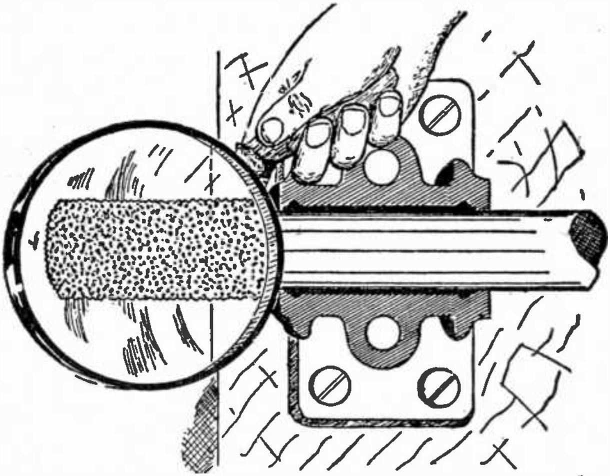


FIG. 2,947.—Magnified view of a shaft showing its rough granular structure. ***In operation,*** these minute irregularities interlock and act as a retarding force, or ***frictional resistance***. Hence, the necessity for lubrication which prevents actual contact by presenting a thin intervening film against which the surfaces rub. The magnifying glass shown above is simply suggestive of magnification, in fact, to see the rough granular structure the shaft would have to be viewed under a microscope.

To stop the motor:

1. Open the main switch.

2. If a starter be used, be sure that the starting lever is returned to the OFF position by the time the motor stops.

3. *Care*

To insure the best operation, make a systematic inspection

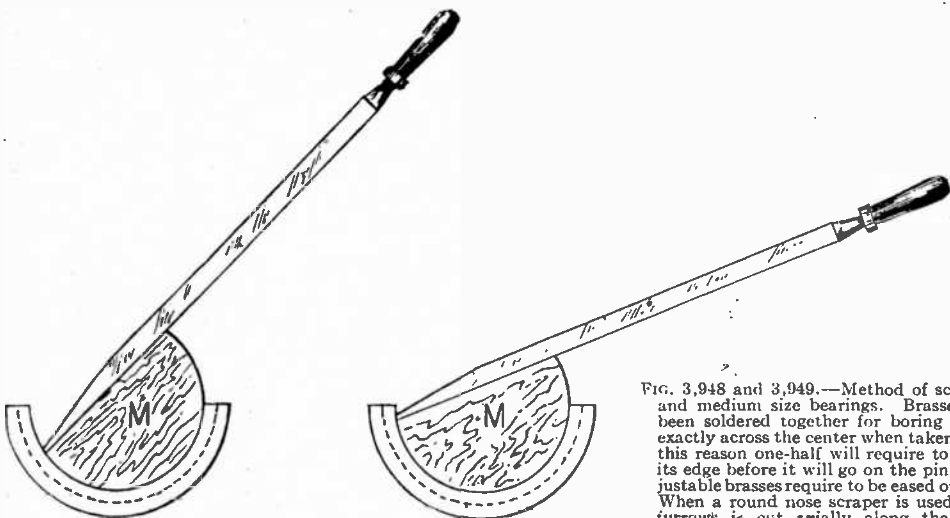


Fig. 3,948 and 3,949.—Method of scraping small and medium size bearings. Brasses that have been soldered together for boring seldom split exactly across the center when taken apart. For this reason one-half will require to be eased at its edge before it will go on the pin. Many adjustable brasses require to be eased on their sides. When a round nose scraper is used, a series of furrows is cut axially along the brass: and further, these furrows cannot be commenced at the edge of the brass, nor can they be carried with uniformity to the other end of the brass. When a half-round scraper is used the results are far from perfect. In the first place, a half-round scraper is not a tool on which a great deal of pressure can be easily applied, owing to the manner in which it has to be handled. A further disadvantage lies in the fact that it is practically impossible to apply the operating force at a constant angle to the surface being scraped. Exactly the same remarks apply to the cutting angle, which cannot be maintained at a constant angle, to the cylindrical bore of the brass. The illustration shows a very useful method of scraping out small and medium sized brasses. In the figure, M, is an approximately semi-cylindrical piece of wood which is placed in the brass, the latter being securely held in the vise or elsewhere. The flat scraper as shown, rests with its flat side upon this wooden guide, and its cutting edge against the surface of the brass. Now, as the scraper handle is lowered, the wooden rest revolves in the brass, and as the scraper rests with its flat side upon M, the flat side always remains constant. It will be obvious to any practical engineer that a great deal of pressure can in this way be applied to the cutting edge, and long, wide uniform cuts can be taken with ease.

at least once a week. Give the following points special attention:

Cleaning.—Treat a motor as you would any other high grade apparatus. Dirt, dust and oil should not be allowed to accumulate in the motor.

Any oil which may overflow from the bearings should be wiped from

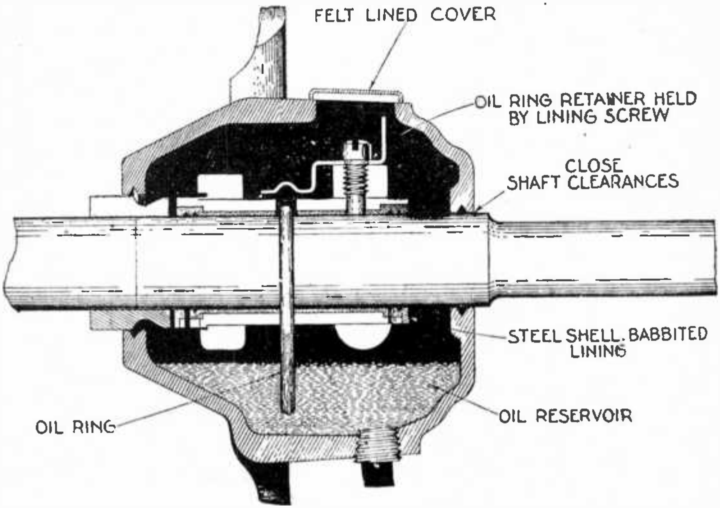


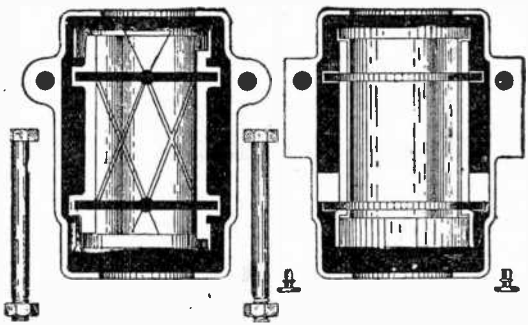
FIG. 3,950.—Sectional view showing a ring oiler or self oiling bearing. As shown the pedestal or bearing standard is cored out to form a reservoir for the oil. The rings are in rolling contact with the shaft, and dip at their lower part into the oil. *In operation,* oil is brought up by the rings which revolve because of the frictional contacts with the shaft. The oil is in this way brought up to the top of the bearing and distributed along the shaft gradually descending by gravity to the reservoir, being thus used over and over. A drain cock is provided in the base so that the oil may be periodically removed from the reservoir and strained to remove the accumulation of foreign matter. This should be frequently done to minimize the wear of the bearing.

the motor. A little attention in this regard will result in continued satisfactory operating results and enable the motor to give the best service for many years.

Bearings.—Prevent excessive heating and wear of all bearings by proper lubrication, belt tension and alignment.

Where the air gap has become closed on one side replace the bearings. Wear of the bearings will cause a closing up of the air gap on one side and may allow the rotor iron to strike the stator iron resulting in trouble.

Oil Wells.—Before starting the motor, wash out the bearings with kerosene or gasoline to remove any dirt or cinders which may have accumulated after motor has left the factory; then replace the drainage plugs, after dipping them in a mixture of red lead and shellac to prevent leakage. Tighten plugs securely. Fill the oil wells through the oil holes at the top with a good grade of light mineral oil (not heavy cylinder oil, animal fat or vegetable oil).



FIGS. 3,951 to 3,956.—Self oiling, self aligning bearing open. Views showing oil grooves, rings, bolts, etc.

Fill bearings with enough oil to cause oil to appear at the overflow at the side of the bearing.

To avoid incorrect oil level, never oil the motor when running.

Do not use oil so thick that it splatters or is thrown off the oil ring. Refill the oil wells at regular intervals, the frequency depending upon local conditions, such as severity or continuity of service, cleanliness, etc.

If the oil rings rattle, it is a sure indication that there is not sufficient oil in the wells.

Brushes and Collector Rings.—In the care of motors having brushes and collector rings see that the brushes move freely in the holders and that they make firm and even contact with the collector rings.

Keep an extra set of brushes on hand. New brushes should be sanded in to fit the curvature of the rings.

Brush pressure on the rings should be from 2 to 3 pounds per sq. in. of brush section area. Collector rings should run true and have a clean polished contact surface.

When replacing worn down brushes, they should be fitted by means of the fine sand paper folded around the commutator and rotor revolved by hand in the desired rotation until a proper fit is obtained. Never use emery cloth.

It should be noted that commutation cannot be improved by shifting the position of the brushes.

Commutator.—The commutator surface of commutator motors should be kept clean and polished. Under normal operating conditions the commutator will require only occasional cleaning with a piece of non-linting material. Vaseline or oil of any description should not be used.

Roughness may be removed by polishing the commutator with a piece of sandstone or sand paper. Run the commutator at a high rate of speed during the polishing and move the sandstone or sand paper back and forth along the surface, parallel with the shaft. After this has been done, clean the commutator and brush faces carefully. Emery cloth as stated before should not be used on a commutator or brush.

When, due to roughness or wear of the commutator, it is necessary to turn down the commutator in a lathe, or to re-slot the mica strips, it is recommended that this work be done by an experienced workman or sent to a service shop.

TEST QUESTIONS

1. *Why should certain precautions be taken in operating a.c. motors?*
2. *What kind of foundation should be provided?*
3. *Name a good concrete mixture for a foundation.*
4. *What provision should be made for the anchor bolts?*
5. *How is the foundation template made?*
6. *How are motors mounted on the wall and ceiling?*
7. *Give method of erecting motors of split construction.*
8. *Name four kinds of drive gear.*
9. *Enumerate the features of the different kinds of drive gear.*
10. *What size fuses should be used with a.c. motors?*
11. *How should a squirrel cage motor be operated?*
12. *Describe the method of operating slip ring motors.*
13. *What does a shaft look like under a microscope?*
14. *Give a method of scraping small and medium size bearings.*
15. *What treatment should the oil wells receive before starting?*
16. *What attention should be given to brushes and collector rings?*
17. *How is a commutator kept in proper condition?*

CHAPTER 72

A. C. Motor Troubles

If trouble be experienced in the operation of a machine, tighten all nuts, bolts, etc. and make sure that the armature is free to revolve; that is, that the bearings are in good condition and that there is no mechanical obstruction to prevent rotation.

In hunting for electrical troubles first make sure:

1. That the voltage is actually available at the motor switch.

2. That it corresponds to the voltage stamped on the name plate of the machine.

3. That the circuit is of proper frequency.

4. That the fuses are intact.

5. That the motor terminals are properly connected for the voltage to be impressed on the motor.

6. That all connections and contacts are properly made in the circuit between the motor switch and the motor.

7. That the starting device (if any) is operating properly.

8. That the brush yoke is firmly clamped up against the shoulder on the bearing housing.

9. That the yoke is properly set on the running position for the rotation desired.

10. That the correct neutral is being used.

11. That the correct compensation is being used.

SYNCHRONOUS MOTOR TROUBLES

Faulty Starting.—This may be due to the following causes:

1. Voltage too low, at least half voltage is required to start.

2. Open circuit in one phase. Motor heats up.

3. Too much static friction due to too great belt tension and too tight bearings.

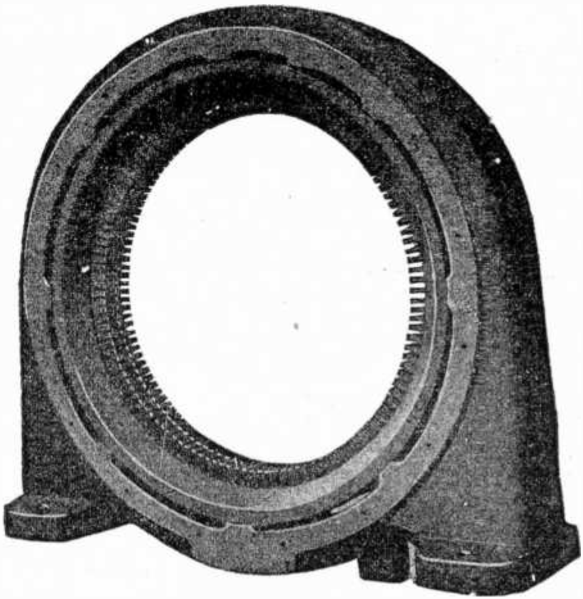


FIG. 3,957.—Engine type stator with guard segments and brush holder support removed, 200 *h.p.*, 440 volt, 3 phase, 60 cycle, 80 *r.p.m.* synchronous motor (small motor frame is shown for comparison).

4. Too much field excitation.

5. Armature windings incorrectly connected.

6. Reversed phase in compensation

Motor Fails to Start.—When a synchronous motor will not start it is usually due to:

1. Too low voltage.
2. Faulty connection in the auxiliary apparatus.
3. Too great starting load.
4. Open circuit in one phase, or short circuit.
5. Either condition results in a buzzing noise.
6. Too great field excitation.

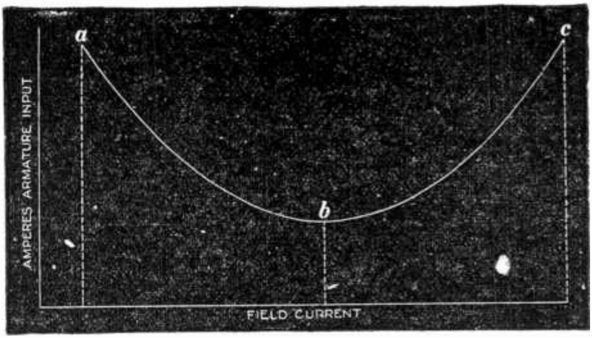


FIG. 3,958.—Curve for synchronous motor showing effect of varying the field current on the armature current required for a given output.

Field Faults.—These may be due to:

1. Field circuit broken.
2. Excessive induced voltage at start.
3. Punctured insulation due to excessive voltage.

Armature Faults.—Abnormal conditions usually met with are:

1. Short circuit in armature coil, with resulting burn out of the coil.

2. Wrongly connected coil resulting in reversed polarity and requiring extra field current to make up for the bucking pole.

Hunting.—This unsteady operation has been fully explained in another section. Synchronous motors under certain conditions tend to hunt, as in the case of

1. Long lines.

2. Unsteady speed of alternator as when driven by a gas engine. The application of "bridges" to the pole pieces tends to stop hunting.

3. Field too strong.

Weak Torque.—Sometimes a synchronous motor will start without difficulty but fail to develop its full torque. This may be due to:

1. Exciter voltage too low.

2. Reversed field spool.

3. Short circuit in field.

4. Open circuit in field.

Heating.—This may be due to

1. Overloading.

2. Excessive armature current.

INDUCTION MOTOR TROUBLES

Motor Fails to Start.—When difficulty is experienced in starting induction motors, such difficulties may be due to a number of causes, such as:

1. One or more fuses blown.

2. Voltage too low.

3. Too great starting load.

4. Worn bearings, permitting armature to touch field laminæ, introducing excessive friction.

Failure to Carry Load.—When the motor stops after starting, the causes may be:

1. Hot bearings, increasing the load by excess friction.

2. Excessive tension on belt causing bearings to heat.

3. Failure of short cut out switch in internal resistance motors.

4. Single phasing on the running position of starter.

Winding Faults.—Sometimes mistakes are made at the factory in the windings of a motor. Symptoms of winding faults are:

1. Excessive and unbalanced starting currents.

2. Peculiar noise.

3. Overheating.

In a three phase motor the faults may be:

1. One armature coil short circuited.

2. One phase or one leg of armature open circuited.

3. One phase of field open circuited.

4. Short circuit in field.

5. Field coil reversed.

Squirrel Cage Faults.—A squirrel cage winding is subject to unsatisfactory operation due to such causes as:

1. Poor soldering of the bar joints, increasing the armature resistance and causing local heating at the joints.

2. Unbalanced currents due to some good bar joints and some poor ones.

REPULSION INDUCTION MOTOR TROUBLES

Motor Fails to Start.—Checking the above points as listed will frequently locate the cause outside of the motor, where otherwise considerable time might be spent searching for it

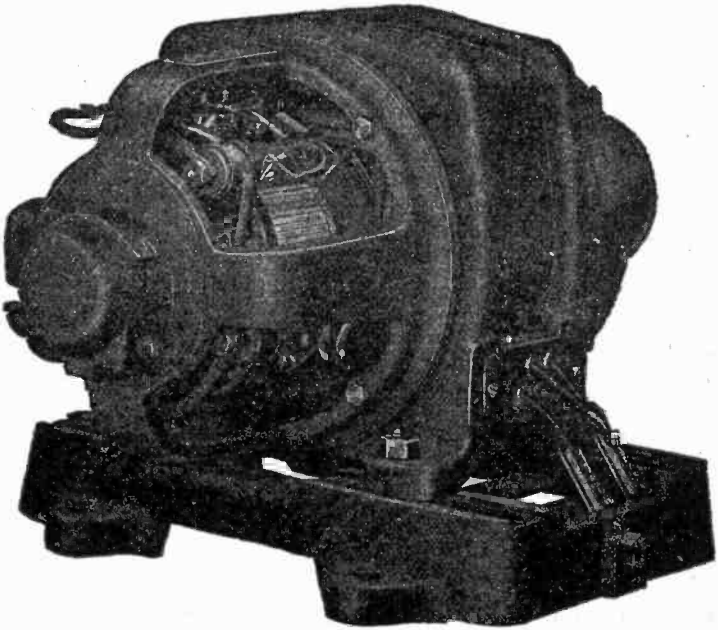


FIG. 3,959.—General Electric type R1, 4 pole, 2 *h.p.*, 1,800 *r.p.m.*, 60 cycle single phase repulsion induction motor.

inside of the motor. Obviously, the actual voltage of the motor terminals should also be checked.

If, after following these suggestions, the trouble be not located, the brief outline following will assist in locating the difficulty:

1. No voltage. Inspect fuses, switches, and all connections. Test line with volt meter or lamp. Notify power plant if no voltage.

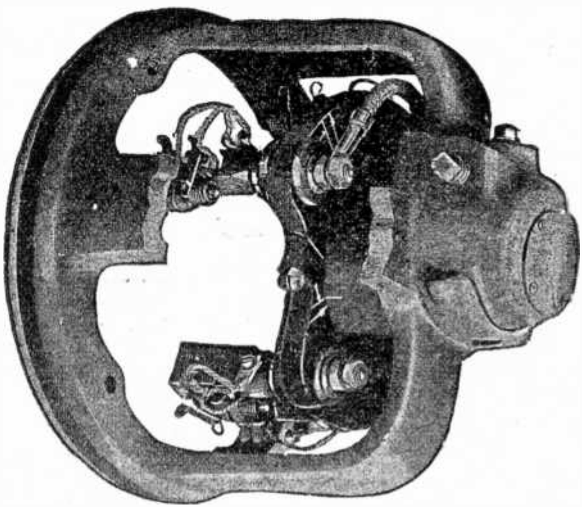


FIG. 3,960.—Sectional view of General Electric type R1, single phase repulsion induction motor end shield showing method of reversing. *To locate* the brush rigging in the proper position, a reference mark is chiseled in the bearing housing and two sets of marks are stamped on the yoke; each of these sets has one light mark with an N, stamped at right angles to it, while the other has an arrow at right angles indicating the direction of rotation. In a motor of unidirectional rotation, one or the other of these marks (depending upon direction of rotation) should always be opposite the reference mark on the housing as shown.

2. Low voltage. Determine with volt meter whether due to power plant, or too small service lines.

3. Excessive overload. Decrease the load or install a larger motor. The load should always be measured by an ammeter and compared with the

full load amperes on the name plate, as this constitutes the full normal electrical input.

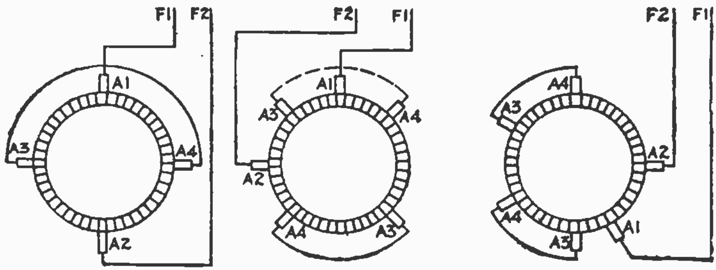
4. The bearing linings stuck or "frozen" to shaft. Put in new linings, clean the shaft with crocus cloth.

5. The armature rubs. Put in new bearings, remove dirt or particles that may fill the air gap. Make sure that the iron has not been displaced so as to cut into the slots and short or ground the windings.

6. Incorrect location of the brush yoke.

7. Energy circuit, open. Inspect the brush rigging.

8. Wrong brush spacing. Figs. 3,961 to 3,963 show the correct relative brush spacing on R1 motors. The total number of commutator bars di-



FIGS. 3,961 to 3,963.—Brush spacing on General Electric type R1, single phase repulsion induction motors. Fig. 3,961, two pole; fig. 3,962, four pole; fig. 3,963, six pole. Short circuited brushes, A3 and A4 are the energy brushes. Small motors have compensating brushes at A1 and A2. The compensating brushes are connected on unidirectional motors to the compensating field winding by leads which are tagged F1 and F2. The yoke at points beside the holder to which these leads are attached is plainly stamped A1 and A2. The compensating field winding may consist either of a set of coils, independent of the main and lying in the central slots of each pole, or may be a tapped off portion of the main winding.

vided by the number of poles gives the number of bars between energy brushes and between compensating brushes. Between adjacent energy and compensating brushes are one-half this number of bars. It should be noted that figs. 3,961 to 3,963 do not show the position relative to field winding.

Abnormal Heating.—When the motor seems to be overheating, take the temperature with a thermometer. The overheating may be due to:

1. Overload. Reduce the load or install a larger motor.

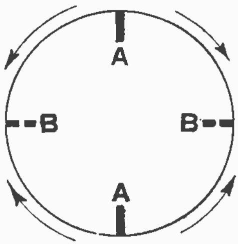
2. Excessively high or low voltage. Take up with the power plant.

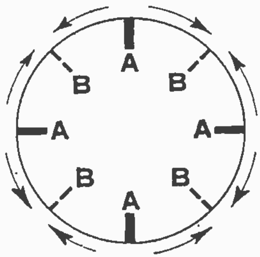
3. Low frequency. Take up with power plant.

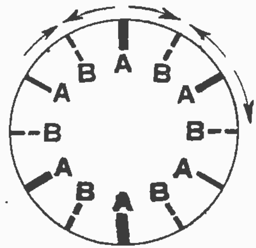
4. Incorrect brush pressure.

5. High or projecting mica.

6. Short circuit in the field winding. Remove all the brushes from the commutator and close the main switch. A short in the field winding will be indicated by excessive line current and by abnormal heating of the shorted part of the winding. This may be repaired in the usual way.



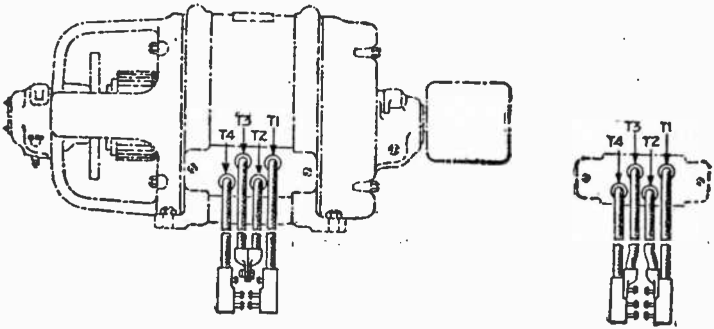




FIGS. 3,964 to 3,966.—Number and relative positions of neutrals, General Electric type RI single phase repulsion induction motor. Fig. 3,964, two pole; fig. 3,965, four pole; fig. 3,966, six pole. A, A, etc. are true neutral positions. B, B, etc. are false neutral positions. The arrows indicate direction of rotation when brush yoke is shifted with compensating brushes removed. *To locate neutral:* 1, disconnect motor from any mechanical load; 2, see that all brushes fit commutator perfectly; 3, raise all compensating brushes so that they will not make contact on the commutator; also bend pigtails so that they will not touch the end shield arms in rotating yoke; 4, after loosening the cap screw move the yoke so that one of the "N" marks on the yoke comes opposite the supposedly correct reference mark on the housing, or if new reference mark is being found the yoke may be left in any convenient position as permitted by the length of leads "F1" and "F2" (see figs. 3,961 to 3,963); 5, throw in the main line switch momentarily. (If any starting device be used this should be on the first point.) If the armature rotate, gradually shift the yoke in the direction opposite to rotation. (Allow the motor to come to rest and repeat the operation until a point is reached where the armature definitely "locks" when current is thrown on momentarily Temporarily mark this point on the housing opposite either line marked letter "N" on yoke.); 6, while holding the yoke in this new found position, close the line switch for a few seconds and quickly shift the yoke slightly from this point. If the armature start with a very strong torque in the direction of shift, the correct neutral has been found, but if the armature slowly start to revolve in the opposite direction from shift, false neutral has been found. The true neutral will be found 90 degrees from this point in a two pole machine, 45 degrees in a four pole machine and 30 degrees in a six pole machine as here shown. From the figures it will also be noted that each motor has several true neutral points. The one where the reference mark may be most readily stamped on the housing and which will not interfere with the connection of leads "F1" and "F2" will naturally be selected; 7, remove previous reference marks and chisel the new mark that it may serve as a permanent reference point.

7. Short circuit in armature. When the above test with the brushes removed from the commutator is made for a short in the field winding, it may be found that the armature is shorted, with all brushes out, throw in the line switch and slowly turn armature. If the armature have a tendency to lock under each pole and the bearing linings be known to be in good condition, it shows a short circuit in the armature. This is easily verified if an ammeter be available. The line current will be high and will show a decided deflection as the short circuited coil comes under each pole.

8. Using brushes other than those recommended for use with the R1 motors.



FIGS. 3,967 and 3,968.—Interchangeable voltage connections General Electric type R1 single phase repulsion induction motor. Fig. 3,967, 220 volts; fig. 3,968, 110 volts.

9. Reversed compensation.

10. Incorrect position of the yoke.

NOTE.—*Checking Compensation* (General Electric repulsion induction motors)—1. With the brush yoke on neutral, that is, the line marked "N" opposite the correct reference chiseled on the bearing housing, see that all energy and compensating brushes (being replaced) are making firm, even contact with commutator. Close the line switch and note the direction of rotation of the armature. Compensation will be correct if the armature rotate in the direction indicated by the arrow line on the yoke nearest the neutral. If rotation be in the opposite direction, interchange leads "F1" and "F2" running to the compensating brushes, or chisel a new reference mark on the housing opposite the other "N" line on the yoke, and shift the yoke so that the first "N" line will now come opposite the second reference mark on the housing. *Incorrect compensation* is indicated by a very high no load current. 2. Shift brush rigging so that the mark on the yoke at right angles to the arrow indicating the desired direction of rotation is opposite the correct reference mark on the bearing housing, and securely clamp the yoke in place against the shoulder on the bearing housing.

High No Load Speed.—This abnormal operation may be due to:

1. Open circuit in the compensating circuit if the motor show a no load speed of about 1½ times rated speed. Poor contact in this circuit may result in a high no load speed.

2. Incorrect position of yoke.

3. Incorrect brush spacing.

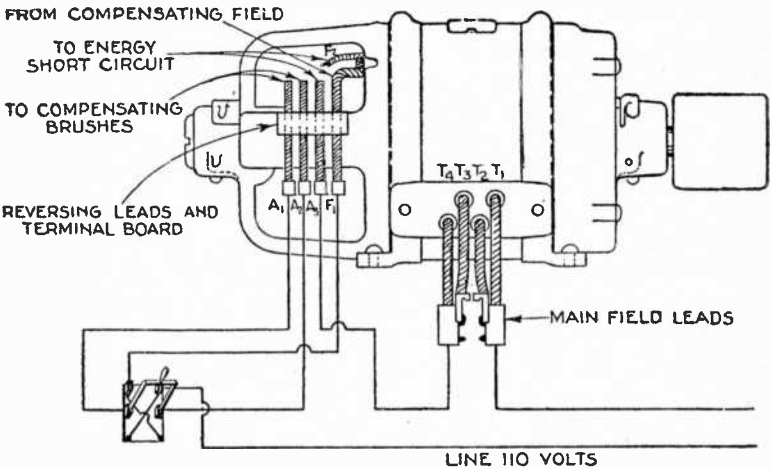


Fig. 3,969.—General Electric type R1 motor connected for 110-volt reversing operation, with double pole, double throw switch.

Low Running Speed.—This defect in operation may be due to:

1. Overload. Reduce the load or install a larger motor.

A poor contact in the energy circuit. This cause also reduces output of the motor.

3. Incorrect brush spacing.

4. Incorrect position of the yoke.

Sparking at the Commutator.—Causes contributing to this fault are:

1. The brushes bind in the holder. Clean the brushes; see that the correct brushes are used.

2. The brushes reversed, that is, riding on the toe only.

3. The brushes worn so that the springs no longer hold the brushes in firm contact with the commutator.

4. Incorrect brush tension. Readjust to about 2½ lb. per sq. in.

5. Loose brush holder. Tighten all parts; adjust and refit brushes.

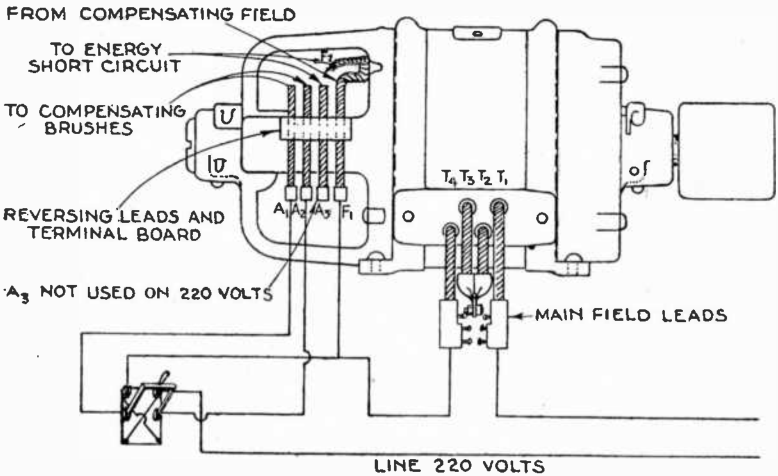


Fig. 3,970.—General Electric type R1 motor connected for 220 reversing operation, with double pole, double throw switch.

6. Rough commutator, grooved commutator, eccentric commutator; high bars, high mica.

7. Loose bars in the commutator. Heat in an oven or by running, tighten shell nut, turn and polish.

8. Open circuit in armature. Remove one set of compensating brushes, being careful to see that yoke is properly set in the running position, and throw in the line switch. If the sparking under the energy brushes assume

short, light green sparks that do not tend to lengthen out into flashes that will follow the curvature of the commutator, the armature is apparently in good condition, but, if the sparking assume long, tongue-like flashes which are rather vivid and noisy and which tend to follow the curvature of the commutator, the armature has an open coil. Allow the motor to run for approximately one minute and this open may be verified by checking for burnt and pitted adjacent commutator bars. Care should be taken to make sure that slivers of high or projecting mica do not cause the above sparking and lead one to believe that the armature is open.

9. Incorrect compensation.

10. Incorrect position of yoke.

Low Starting Torque.—This defective operation may be due to:

1. Reversed compensation. poor contact or open in energy circuit; short in the field or armature, or open in the field or armature or wrong brush position.

2. In case of a re-turned commutator, do not allow the mica to project beyond the face of the commutator.

Split Phase Motor Troubles

Speed Too Low.—This may be due to any of the following causes, which may be corrected by the remedies given.

1. Wrong voltage and frequency.

2. Overload; reduce load on motor, replace with a larger motor if necessary.

3. Grounded starting and running windings. Test out with magneto lamp bell or volt meter.

4. Short circuited or open winding in field current. Test out as above.

5. Too small connection wires. Increase size of wires.

Faulty Starting.—Motor starts, runs slowly, will not pick up to normal full load speed, and blows fuses, due to:

1. Failure of cut out to work properly. Test cut out for grounds or short circuit. Oil pivots and springs, sand paper rough spots.

2. Grounded plate, test with lamp or magneto, one wire to each slip ring or contact plate.

3. Open circuit in starting or running winding.

Test out with magneto or lamp.

4. Grounded or short circuited starting or running winding.

Test out with magneto, bell and battery or volt meter.

Motor Fails to Start.—This fault is sometimes encountered. In such cases

1. Test line voltage with lamp.

2. Test fuses with lamp.

3. Trace out all connections for grounds, open or short circuit.

4. See if brushes be making proper contact with collector rings or contact plates.

5. See that rotor is free to rotate in bearings.

Motor Fails to Start and Hums Loudly.—This may be due to the starting winding being burnt out, open, or grounded.

If motor hum, this indicates that the main or running winding is not open; the motor may be started by rotating the armature by hand until it reaches its normal rated speed.

Sparking at the Brushes.—As the brushes of split phase motors are only used in starting, sparking may be due only to worn and loose brushes, or dirty slip rings.

Clean slip rings with a benzine soaked rag. Apply a little vaseline with the finger to each slip ring to prevent cutting by the brushes.

Heating of the Windings.—This may be due to any of the following causes:

1. Moisture in windings. Dry out in an oven.

2. Short circuit or ground. Test out with magneto, lamp, bell or volt-meter.

3. Overload. Reduce load or install a larger motor.

4. Too low line voltage. Check up with volt meter.

5. Too high line voltage. Any voltage in excess of 5% on 220 volts, 10% on 110 volts should be reduced as this will cause the windings to burn out.

6. Wrong frequency. A 40 cycle motor cannot be used on 60 cycle current as the rotor will not revolve in synchronism with the alternator.

7. Wrong voltage connections to motor.

8. Connection wires too small. This will cause a voltage drop.

Heating of the Rotor.—This is usually caused by overloading the motor or by broken soldered connections of end bars. Reduce load or solder broken connections.

Fractional Horse Power Motor Troubles

Motor Fails to Start.—Be sure that the wires connected to the motor terminals make good contact; that each of the brushes of the motor makes perfect contact with the commutator; that the connected load is not too great for the size of motor used.

Motor Hums Loudly and Refuses to Start.—The fault may be due to

1. Short circuited field windings.

2. Grounded connections, or cut out switch.

Test out individual windings with volt meter, holding one wire to frame the other to each lead of field windings.

Test cut out switch with magneto, one wire to shaft, the other to each half of cut out plates.

Motor Runs Too Slow.—This fault may be due to

1. Burnt out, short circuited, or grounded winding.

2. Grounded cut out switch.

3. Cut out switch refuses to short circuit itself.

This may be due to corroded springs, dirty parts, dirt in springs and pivots.

Care of Compensators.—These should be inspected once a year and the oil changed. Use only oil as furnished with the compensator by the manufacturer, as this has been found to give the best results; any other grades of oil will cause a lot of unnecessary trouble.

If the contact fingers on the switch of the compensator be scorched or burnt they should be smoothed with a piece of sand paper, if they be too far burnt or worn, they should be replaced with new ones.

Tighten all springs on switch and no voltage release, so that contact fingers press firmly on all contacts.

Oil all exterior moving parts of switch handle, also the no voltage release.

Grounding of Compensators.—The cases of all compensators should be grounded especially when installed on high voltage circuits, to insure safety to the operator if for any reason the current carrying parts should accidentally come in contact with the case.

A good contact is obtained by securing the ground wire under a screw or bolt on the compensator.

The ground wire should be run to a water pipe as required by the *Code*.

Compensator Troubles

Motor Fails to Start.—If the fuses and motor be in good condition, examine all contacts and see if contact fingers make contact.

Press with a screw driver all contacts and see if motor start. Trace out all leads from terminal block to contacts. Examine all transformer taps. In case of a burn out on one coil of a three phase compensator the coil may be cut out by a slight change in connections and the compensator used temporarily until a new set of coils can be obtained.

Compensator Hums.—This is due to an improper sealing surface of the no voltage release or loose laminations of the solenoid or transformer.

Tighten all screws on the no voltage release solenoid plunger and no voltage coil, also tighten screws on transformer.

No Voltage Release Fails.—If the voltage release fails to hold switch in running position, the fault may be due to:

1. Burnt out; no voltage coil.

Test with a magneto.

2. Wrong connections.

3. Latch of no voltage release stuck.

This may be due to dirt or foreign object. Remove same.

4. Overload relay plunger stuck.

This causes an open circuit in the no voltage release circuit. Inspect all relays, and try moving by hand, and note if they make contact.

Fuses, Single Phasing and Burn Outs.—The author is indebted to Mr. P. E. Chapman of St. Louis, Mo., manufacturer of armature winding machines and authority on motors, for the following polyphase motor troubles, due to improper fusing:

The commonest cause of burn outs in polyphase motors is "**single phasing**". By definition, single phasing is *the opening of one leg or wire of a two or three phase circuit, whereupon the remaining leg at once goes or becomes* **single phase.**

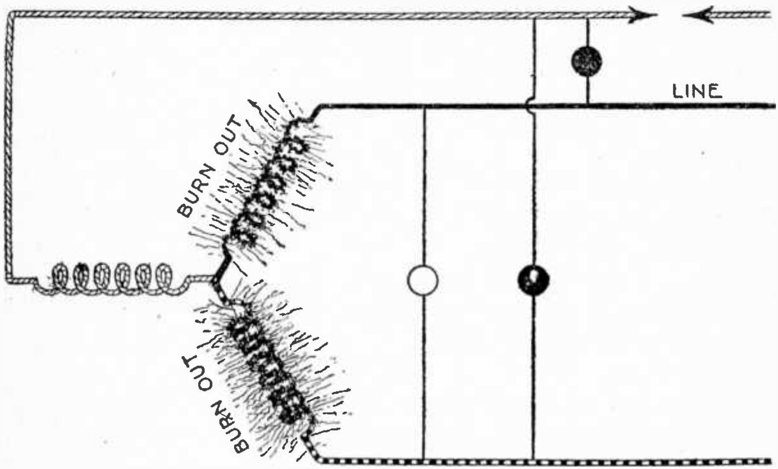


FIG. 3,971.—Single phasing of star connected motor. Test lamps are shown to indicate the condition of the supply phases beyond the break. The dark one shows the dead phases. Owing to reverse voltage generated by all motors when running, the two dark lamps will actually be only a little dimmer than the normal or bright one. If the motor be stationary and is therefore generating no reverse voltage, the two lamps will show half voltage for they are in series with each other. If one lamp only be used for testing, it will be totally extinguished only when the dead leg is not connected in some way with the line as through a load.

NOTE.—*Single phasing of three phase circuit.* When a three phase circuit is functioning normally, there are three separate and distinct currents flowing in the circuit. It should be noted that any *two of these three currents jointly use the same wire.* Accordingly, an open circuit in one leg or wire kills two of the phases and there will be only one phase or current working although two wires remain intact. This remaining phase in a motor will then attempt to carry all the load.

The usual cause of single phasing is the so-called ***running fuse,*** which is a fuse whose capacity is near the full load current of the motor in circuit with it.

Therefore the worst enemy or menace a polyphase motor has is the so-called "running fuse" or for that matter any other single pole disconnecting device. The nearer its capacity is to the motor rating, the greater menace it is to the motor, as one of them will blow more frequently. The usual cause of blowing a close or running fuse is a load, either momentary or sustained. A short circuit may blow two fuses at the same instant, but this hardly ever occurs with a load. Therefore, part of the motor windings are still in circuit—***single phase.***

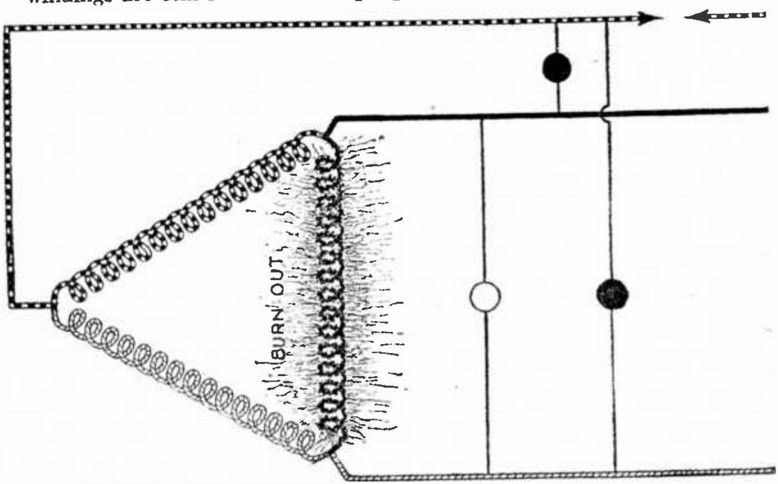


FIG. 3,972.—Single phasing of delta connected motor.

When single phasing occurs, the *h.p.* capacity of a polyphase motor drops to about half its rating, the running or load carrying current increases in the one phase. However, the maximum current it would safely carry per leg (three phase) drops and its locked current (that is, the maximum current standing still) drops. It is seldom that the single phase load or locked current will blow the remaining running fuse or fuses.

If the motor be standing still it will not start, and unless disconnected, will burn out promptly. If it be running, when single phasing occurs, and carrying half load or less, it will continue to run without damage because half loads do not blow normal fuses. If it be running on a full or over load, when single phasing occurs, it will try to keep on running, throwing all the work on part of the windings, which sooner or later burns out. If the load be too heavy, it stops the motor, and as it cannot then re-start nor blow the remaining fuse, the burn out is prompt.

A polyphase motor, if given plenty of current (large fuses) will take care of *itself* under ordinary mishaps, such as interrupted power, or severe temporary overload, but if it be closely (running) fused, it may single phase and burn out. It is particularly true on polyphase motors that a fuse (or circuit breaker) cannot protect it against internal mishaps; therefore, on polyphase motors, the fuses should be used to protect the *line*, or wiring to the motor against catastrophies, such as burnt out motors, or other causes of dead shorts; hence the fuse size should be as large as the wiring to the motor will permit.

The running fuse sizes given in contemporary tables are too small, and therefore a menace to polyphase motors. They should be eliminated, or if an over zealous inspection department insist that running fuses must be used, they should be at least 2½ times the rating of the motor or more. The most satisfactory running fuses, or, those that will do the motor the least damage, are the so called "starting" fuses of these same tables, although they are possibly a little large.

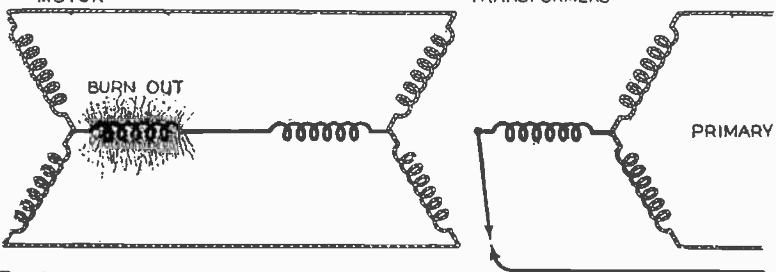


FIG. 3,973.—Single phasing of star connected motor fed from transformer.

A three phase motor fused with two fuses only (third leg solid copper) is much safer than one with three fuses. This is rapidly becoming standard practice.

Delayed-action, multipolar circuit breakers with at least two actuating members are the best protection for polyphase motors. They do not cause single phasing. They will permit momentarily heavy currents such as occur at starting the motor or its load and still open on a sustained or damaging overload.

Notes on Single Phasing in Three Phase Motors.—Single phasing of the immediate motor circuit causes two legs of a Y connected motor to burn out, as in fig. 3,971. If the motor be delta connected, one leg is burned, as in fig. 3,972. If the motor be Y connected and fed from transformers, having primaries connected to a three wire, three phase circuit, and one of the primaries be opened, it will quickly burn out one leg of the motor, as in fig. 3,973. In practice, the "good" leg or legs are usually so badly damaged by heat from the burnt out ones, as to be useless

TEST QUESTIONS

1. *When hunting for troubles what preliminary items should be attended to?*
2. *What are the causes of faulty starting of synchronous motors?*
3. *If a synchronous motor fail to start, what is usually the trouble?*
4. *What may field faults be due to?*
5. *Name some abnormal conditions met with in the armature.*
6. *What are the causes of hunting?*
7. *What are the causes of weak torque of synchronous motors?*
8. *What causes heating?*
9. *Name some causes why an induction motor will not start.*
10. *When an induction motor stops after starting, what are the causes?*
11. *Mention some winding faults in a three phase induction motor.*
12. *What are the causes that produce unsatisfactory operation of a squirrel cage?*
13. *When hunting for repulsion induction motor troubles, mention some items that should be checked?*
14. *What are the causes of abnormal heating in a repulsion induction motor?*
15. *What causes high, no load speed?*
16. *Mention some causes of low running speed of repulsion induction motors.*

17. *What are the causes which contribute to sparking at the commutator?*
18. *How should a faulty commutator be treated?*
19. *What causes low starting torque?*
20. *Mention causes of too low speed of a split phase motor.*
21. *Give four causes with remedies for faulty starting of a split phase motor.*
22. *What are the causes of failure to start a split phase motor?*
23. *If a split phase motor fail to start and hum loudly, what may this be due to?*
24. *What causes sparking at the brushes of a split phase motor?*
25. *Give causes of heating of the winding.*
26. *What causes a rotor to heat?*
27. *What should be done if a fractional horse power motor fail to start?*
28. *If the motor hum loudly and refuse to start, what are the causes?*
29. *Give three causes why a fractional horse power motor runs too slow.*
30. *How should compensators be grounded?*
31. *Mention some compensator troubles.*

CHAPTER 73

Control Apparatus

For the proper control of the alternating current in any of the numerous systems described in the previous chapter, various devices, which might be classed as "control apparatus," are required. These may be grouped into several divisions, according to the nature of the duty which they perform, as

1. Switching devices;
   - *a*. Ordinary switches;
   - *b*. Oil break switches;
   - *c*. Remote control switches.
2. Current or pressure limiting devices;
   - *a*. Fuses;
   - *b*. Reactances;
   - *c*. Circuit breakers;
   - *d*. Relays
3. Power factor regulating devices;
   - *a*. Synchronous condensers.
   - *b*. Static condensers;
4. Regulating devices;
   - *a*. Induction voltage regulators:

b. Variable ratio transformer regulators
c. Compensation shunts;
d. Outdoor induction regulators;
e. Automatic voltage regulators;
f. Line drop compensators;

5. Indicating devices;

a. Moving iron instruments { plunger type; inclined coil type; magnetic vane type;

b. Hot wire instruments;

c. Induction instruments { shielded pole type; repulsion type;

d. Dynamometers;

e. Instrument transformers;

f. Watthour meters { induction type; Faraday disc type;

g. Frequency indicators { synchronous motor type; resonance type; induction type;

h. Synchronism indicators { lamp or volt meter; resonance type; rotating field type;

i. Power factor indicators { watt meter type; rotating field type;

j. Ground detectors;

k. Oscillographs.

6. Lightning protection devices;

a. Air gap arresters;
b. Multi-gap arresters;
c. Horn gap arresters;
d. Electrolytic arresters;
e. Vacuum tube arresters;
f. Choke coils;

CHAPTER 74

Switches

A switch is *a piece of apparatus for making, breaking, or changing the connections in an electric circuit.*

The particular form and construction of any switch is governed by the electrical conditions under which it must operate, and this gives rise to a multiplicity of types which may be classified

1. With respect to the number of blades per circuit leg, as

    a. Single
    b. Double
    c. Triple, etc.

2. With respect to the movement of the blade, as

    a. Swinging
    b. Revolving
    c. Radial (combined swinging and revolving)
    d. Oscillating
    e. Reciprocating.

3. With respect to the kind of blade, as

    a. Lever
    b. Knife.

4. With respect to the number of legs, as

    a. Single pole
    b. Double pole, etc.

5. With respect to the number of contacts or sets of contact controlled, as

a. Single throw
b. Double throw.

6. With respect to the number of circuits controlled, as

a. One point
b. Two point
c. Three point, etc.

7. With respect to the number of leads, as

a. Two way
b. Three way, etc.

8. With respect to circuit protection, as

a. Plain
b. Fused
c. Barrier.

9. With respect to the break, as

a. Single
b. Double
c. Quick
d. Snap
e. Horn

10. With respect to the medium in which the break takes place, as

a. Air {open; enclosed;
b. Oil

11. With respect to the method of mounting, as

  a. Front connection
  b. Back connection
  c. Surface
  d. Flush
  e. Pendant
  f. Straight through.

12. With respect to the method of operating, as

  a. Pull
  b. Push
  c. Rotary
  d. Remote control
  e. Automatic, etc. { clock control; hydraulic control; pneumatic control;

13. With respect to service, as

  a. Disconnecting
  b. Lighting
  c. Electrolier
  d. Heating
  e. Master
  f. Motor starting
  g. Field discharge
  h. Antenna
  i. End cell.

etc.

It will be seen from the foregoing classification that there is a large multiplicity of switch types to meet the great variety of service conditions encountered.

Switch Terms

Barrier.—A non-combustible insulating block placed between parts of opposite polarity to prevent flash overs.

Blade.—The movable contact member.

Contact block.—The base or jaw projection to which is attached a lug.

Cross bar.—The insulating connecting piece which is attached to the blades, and to which is attached a handle.

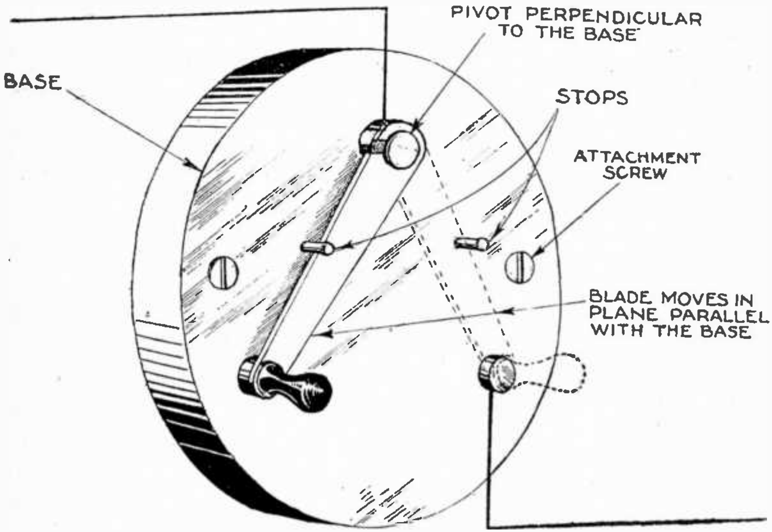


FIG. 3,974.—View of lever switch illustrating its distinguishing feature, *the movement of the blade parallel with the base*

Hinge jaw.—The jaw to which the blade is pivoted.

Jaw.—The stationary contact member.

Leg.—One side of a switch circuit.

Lug.—A fitting which connects a conductor to the contact block.

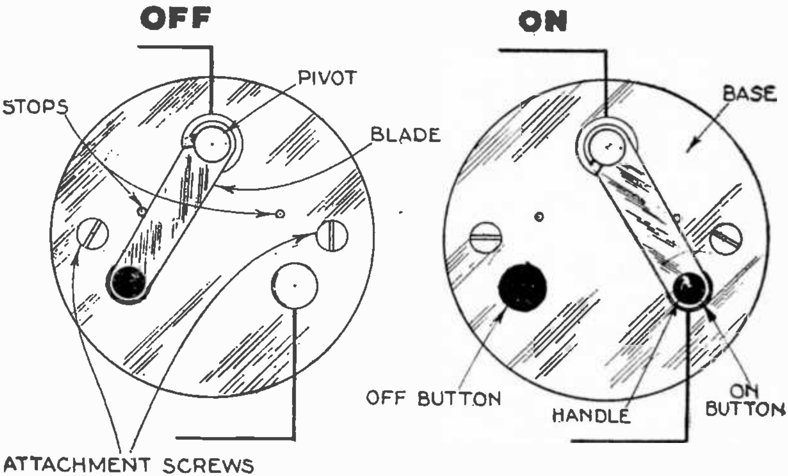
Point.—A name given to a stationary contact button on a switch to designate the number of paths. Carefully distinguish from "*way*."

Pole.—A conductor or lead of a circuit acted upon by a switch.

Push button.—An acorn or cylindrically shaped part which is pressed by the finger to move the moving contact of a switch.

Throw.—A term which relates to the extent of the blade movement, with respect to the contact range.

Way.—A name given to the stationary contact buttons of a switch to which external circuit wires are connected. Carefully distinguish from "*point*."

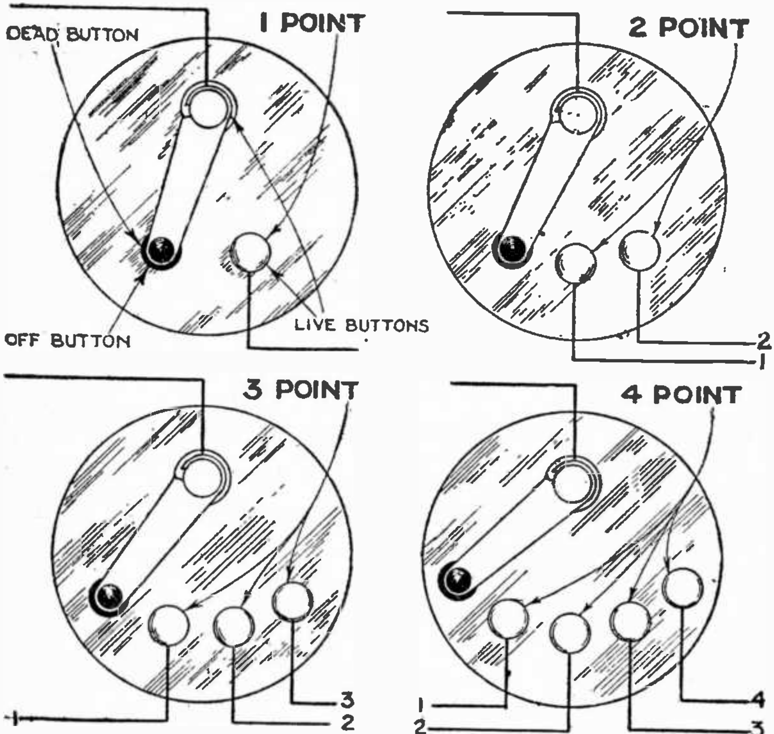


FIGS. 3,975 and 3,976.—Lever switch illustrating construction and operation.

Lever Switches.—This type of switch is for light duty. Its distinguishing feature is that the blade, pivoted at one end and operated by a handle at the other end, *swings in a plane parallel with the base.* To obtain the movement, the pivot is perpendicular to the base, as shown in fig. 3,974. The working of the switch is further illustrated in figs. 3,975 and 3,976.

The meaning of the term *point*, which must be carefully distinguished from *way*, is illustrated in figs. 3,977 to 3,980. Here it will be seen that the number of points is equal to the number of "live" buttons (not including the pivot button) or one less than the number of external wires.

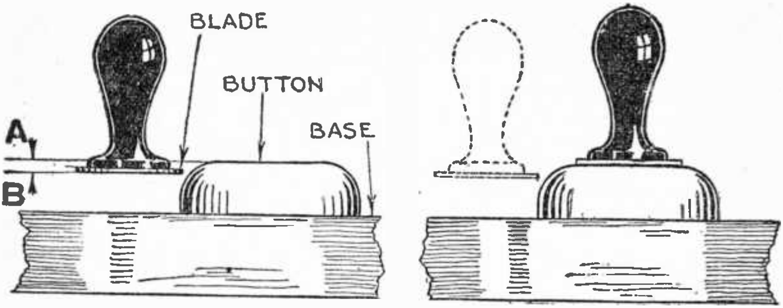
The satisfactory working of a lever switch depends on good contact at



FIGS. 3,977 to 3,980.—Lever switches illustrating the term "*point*." Here are shown 1, 2, 3 and 4, point switches controlling 1, 2, 3 and 4 circuits respectively. The use of these switches is explained at the end of this chapter.

the two ends of the blades. To obtain this, the pivot end must be properly adjusted. Proper contact with the other buttons is due to spring action of the blade, as shown in figs. 3,981 and 3,982.

The dead button serves the purpose of holding the blade in the off position.



FIGS. 3,981 and 3,982.—Detail of blade and button of lever switch illustrating spring action of blade in securing firm contact with the button. When the blade is not in contact with a button it swings some distance as AB fig. 3,981 below the plane of the button contact surface. In engaging a button it rides over the rounded outer part of the button, thus slightly bending the blade and causing its spring action to hold it in firm contact with the button.

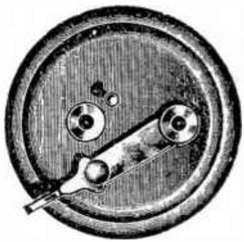


FIG. 3,983.—Front view of Fahnestock *one point, lever, wooden base battery switch*. The wires are connected by spring clips to which the buttons are attached.

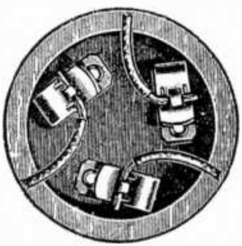


FIG. 3,984.—Back view of Fahnestock *two point, lever, wooden base battery switch.*

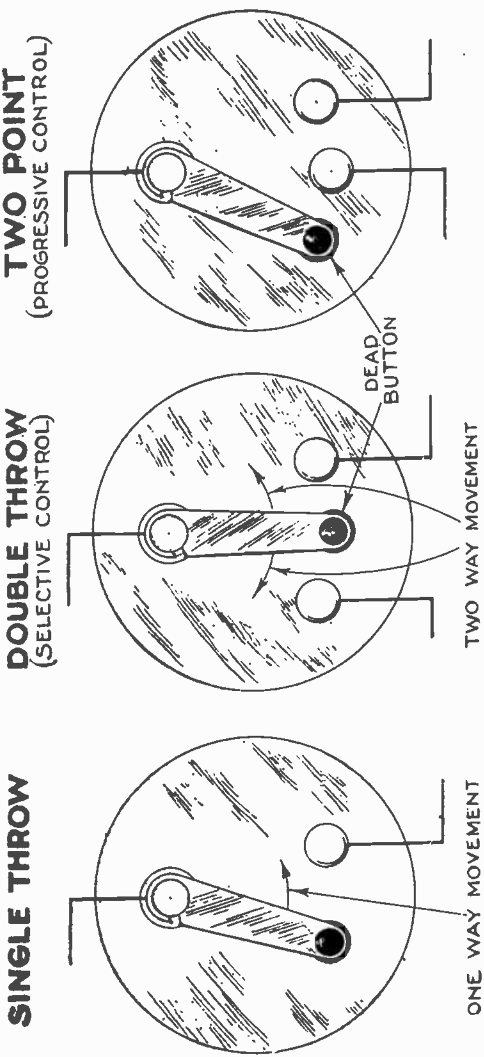
Figs. 3,983 and 3,984 show one and two point switch construction. It will be noted from the back view (fig. 3,984) that the number of points is *one less than the number of external wire connections*.

Switch contact in the case of lever switches is due to spring action of the blade pressing against a button; this is single contact. A more efficient method is that of double contact called knife contact because it is used in knife switches. Fig. 3,985 shows a lever switch with this kind of contact. Here it will be noted that the blade is held on both sides in firm contact by the spring action of the stationary contacts.

Single and Double Throw Switches.—The term throw relates to the movement of the blade in closing the circuit. If the movement of the blade from the off position be limited to one direction, the switch is single throw. If the blade can move on either side of the off position to a live contact, the switch is double throw. The distinction between the two types is shown in figs. 3,986 and 3,987.

FIG. 3,985.—Fahnestock *double or knife contact*, lever switch.

Here also should be noted the difference between a double throw and a two point switch as shown in figs. 3,987 and 3,988. It will be seen that the difference is both mechanical and electrical. Each switch controls the same number of circuits, but the double throw gives ***selective control***, whereas the two point switch gives ***progressive control***. Accordingly,



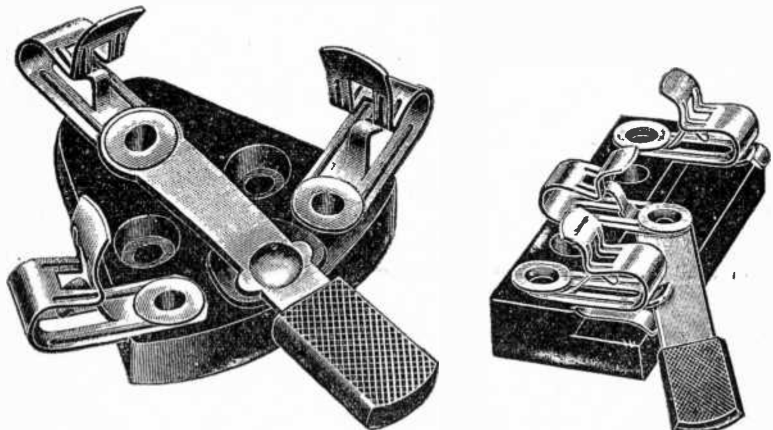
FIGS. 3,986 to 3,988.—Single throw, double throw and two point lever switches illustrating the differences between these types.

if the wrong switch be selected, it may be totally unsuited to the service.

Single and Multi-Pole Switches.—In an electric circuit there must be one wire to furnish a path for the current to its point of application, and another or "return" wire, unless the ground be used instead of the latter wire. If a switch open and close one wire only of the circuit, it is a single pole switch; if it simultaneously open and close both wires of the circuit, it is a double pole switch. Similarly for three pole and four pole switches. The term *leg* is sometimes used in place of pole.

Since the electric current cannot be **stopped instantly** *when the circuit in which it is flowing, is broken,* **an arc is formed** *as the switch contacts separate*; this tends to burn the contacts, and to short circuit, the severity of such action depending on the voltage the length of the break line, etc. Accordingly, if the circuit be broken on both wires, the arcing will be reduced.

The operation of a two pole lever switch is shown in figs. 3,991 and 3,992.

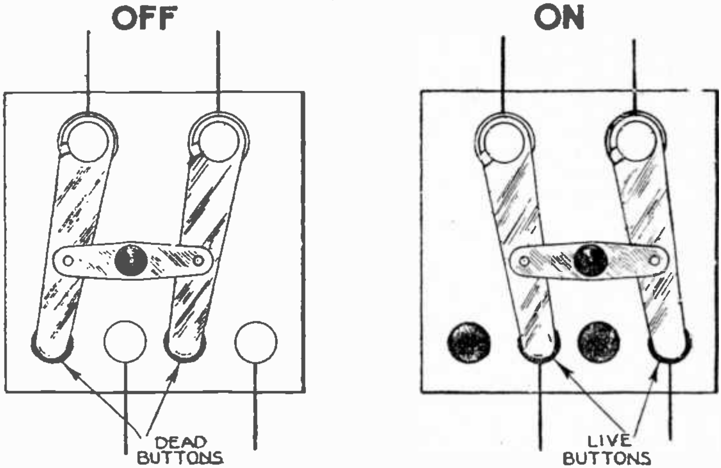


FIGS. 3,989 and 3,990.—Fahnestock *double throw, lever switches*. Fig. 3,989 short arc swing; fig. 3,990. long or 180° arc swing. The latter amplitude of swing is that used on knife switches.

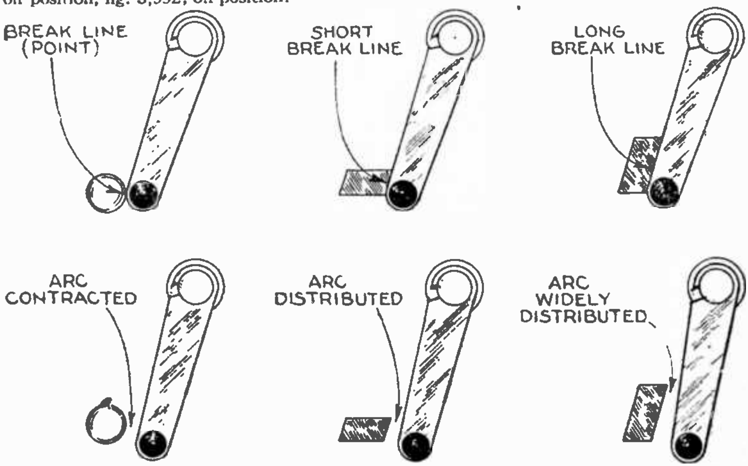
Here a lever type switch is used to illustrate the working principle, but the knife type is inherently better suited.

The burning action of the arc as stated, depends upon the length of the break line, that is, when the blade and contact are in "line and line" position.

The term *line and line* means the position when the edge of the blade is on the point of leaving the edge of the contact. Evidently this "edge" in the case of the round button contacts as in fig. 3,993, would be only a point. Accordingly as the blade leaves the contact the arc would be concentrated and severe burning of the metal would occur as compared



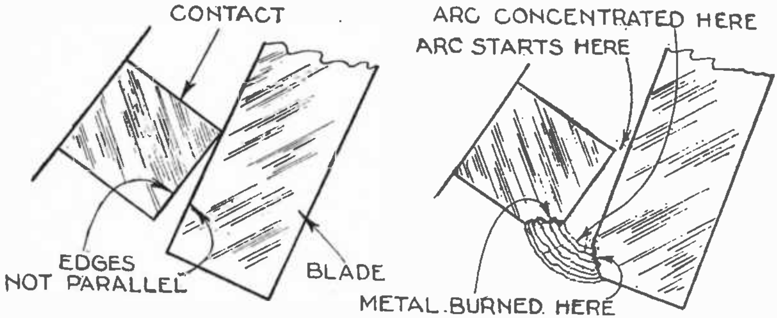
FIGS. 3,991 and 3,992.—*Double pole lever switch* showing essentials and operation. Fig. 3,991, off position; fig. 3,992, on position.



FIGS. 3,993 to 3,998.—Various break forms and results obtained as explained in the text. The illustrations show blade and different shaped contacts of lever switches.

with the forms shown in figs. 3,994 and 3,995. The results obtained by thus extending the break line are shown in figs. 3,997 and 3,998.

Sometimes the blade and contact of a switch having a long break line are not in alignment, with the result shown in figs. 3,999 and 4,000. Accordingly the parallelism of the blade and contact edges for line and line position should be maintained.



FIGS. 3,999 and 4,000.—Detail of blade and contact out of alignment showing arc concentrated and at one end resulting in undue burning of the metal.

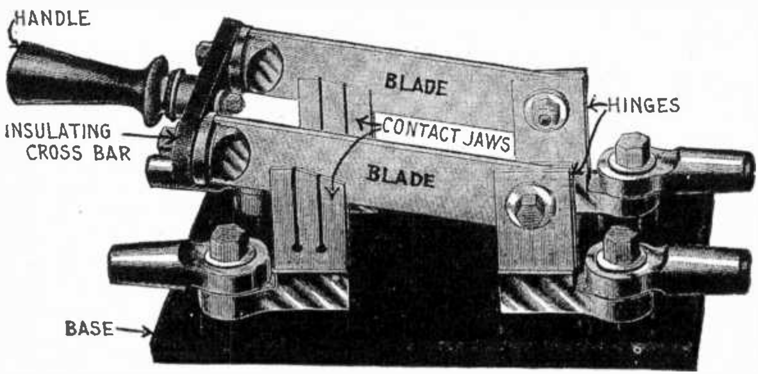


FIG. 4,001.—A single throw, two pole knife switch. As usually constructed it is made of hard drawn copper with cast terminal lugs and fibre cross bar.

Knife Switches.—This is a type of switch made in considerable variety and largely used. Its distinguishing feature is that the blade, pivoted at one end and operated by a handle at the other end, *swings in a plane perpendicular to the base.* To obtain this movement the pivot is parallel with the base. The subject of knife switches is presented extensively in Chapter 35 on D.C. Auxiliary Apparatus, which should be read in connection with this matter.

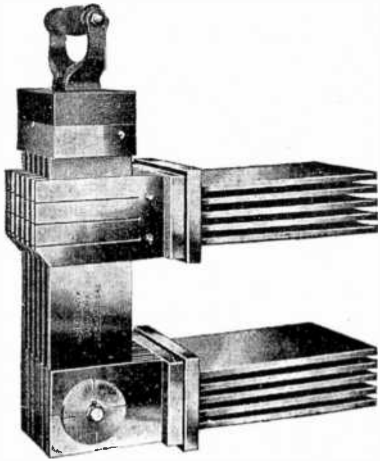


FIG. 4,002.—Barkelew *back connection, single pole multi-blade knife switch with laminated studs.*

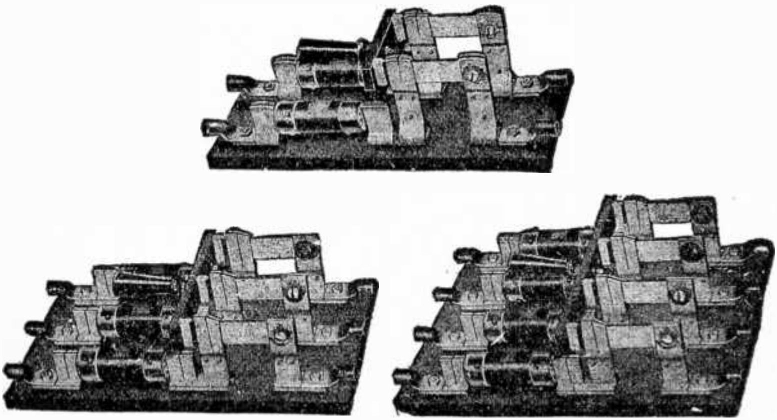
The general construction of a single throw double pole knife switch is shown in fig. 4,001:

Note the angle of the top edge of the contacts. It is made thus so that the sloping edges will touch the blades their full length when the contacts and blades are in line and line position thus giving maximum break line. This form of knife switch is for front connection mounting. Where desired for switchboard mounting the back connection form such as shown in figs. 4,002 or 4,033 is used. When circuit protection at the switch is desired, the latter is provided with fuse terminals for the insertion of cartridge fuses, as shown in figs. 4,003 to 4,005.

There are various forms of fuse terminals, examples being shown in figs. 4,006 to 4,008.

According to the Electrical Code:

Switches rated above 600 amperes at 600 volts and 600 amperes at 250 volts, and therefore exceeding the capacities of standard sizes of cartridge enclosed fuses, may be arranged for fuses in multiple, provided as few fuses as possible be used, and the fuses are of equal capacity, and the multiple terminals for each pole are mounted in common.



FIGS. 4,003 to 4,005.—Mendell 250 volt *d.c.* or *a.c.* *single throw knife switches* with *fuses* inverted in clips. The figures show switches with 2 to 4 poles.

Switches marked with the combined rating, 250 volts, *d.c.* or 500 volts, *a.c.* shall not be provided with fuse terminals.

Switches having fuse terminals and intended for use in ungrounded branch circuits shall have fuse terminals in each pole.

Barriers.—By definition a barrier is *an insulating block placed between switch contacts of opposite polarity so that they may be placed closer together without danger of a flash over.* Its object then is to reduce the width of the switch base, thus making the switch more compact.

Fig. 4,009 shows the placement and proportion of a barrier.

According to the Code:

Barriers designed to be placed between poles of switches at hinge jaws shall be of such size and so located as to provide a separation between

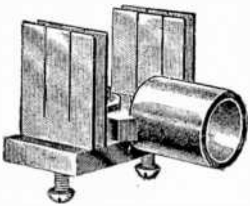


FIG. 4,006.—Lyons *enclosed fuse holder* for front connection, 601 to 1,200 amperes.

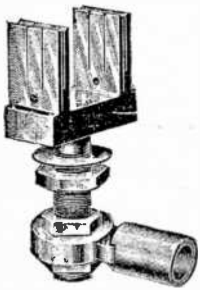


FIG. 4,007.—Lyons *enclosed fuse holder* for back connection, 601 to 1,200 amperes.

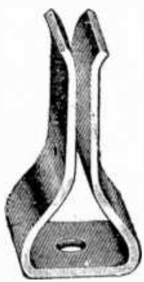


FIG. 4,008.—Lyons *fuse clips* for N.E.C. *standard fuses*, 61 to 200 amperes.

contact parts measured in the shortest insulating surface path over the barrier equal to that required for switches without barriers, and to provide a separation between other current carrying parts.

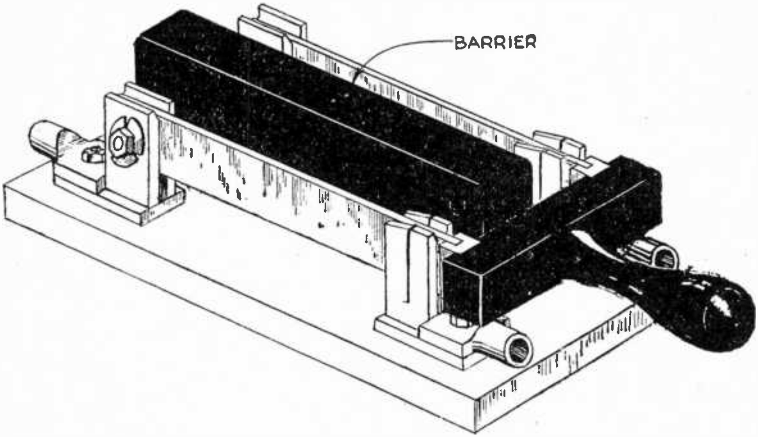


FIG. 4,009.—Barrier as applied to a double pole single throw knife switch.

Notes from the Code

NOTE.—Switches marked with the combined rating, 250 volts, *d.c.* or 500 volts, *a.c.* shall not be provided with fuse terminals.

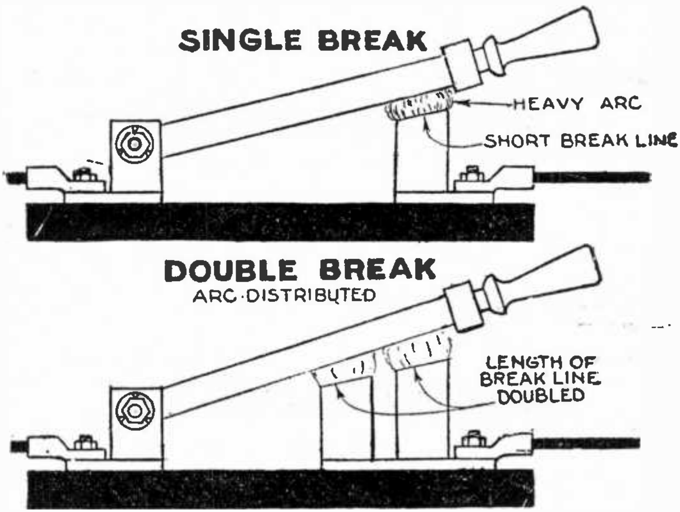
NOTE.—Switches having fuse terminals and intended for use in ungrounded branch circuits shall have fuse terminals in each pole.

NOTE.—Auxiliary contacts of a renewable or quick break type or the equivalent shall be provided on all 600 volt switches designed for use in breaking currents from 200 to 1000 amperes, inclusive.

NOTE.—Single throw knife switches shall be so placed that gravity *will not* tend to close them. Double throw knife switches may be mounted so that the throw will be either vertical or horizontal as preferred, but if the throw be vertical a locking device shall be provided, so constructed as to insure the blades remaining in the open position when so set. When practicable, exposed knife switches shall be so wired that blades will be dead when the switch is open.

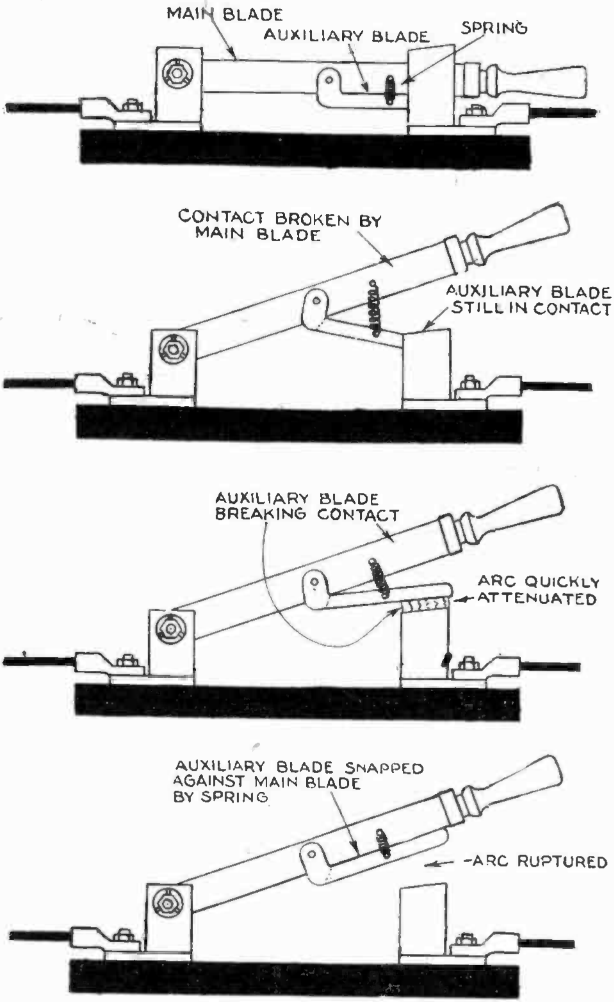
Single and Double Break Switches.—According to the severity of the duty, switches may be made single break or double break. That is, when the current is too heavy to be controlled by a single contact, an additional contact connected in parallel is provided, thus doubling the length of the break line.

The distinction between single and double break is shown in figs. 4,010 and 4,011.



FIGS. 4,010 and 4,011.—*Single* and *double break single pole single throw knife switches* illustrating single and double break.

Quick Break Switches.—In the operation of a switch when the circuit is broken, the arc tends to burn the metal of the switch along the break line, in amount depending upon the intensity and duration of the arc. Evidently the quicker the arc is ruptured (put out) the less will be the injury to the contact and blade by burning.



FIGS. 4,012 to 4,015.—Construction of ***quick break switch*** and its operation progressively shown. Fig. 4,012, switch in ***ON*** position; fig. 4,013, main blade out of contact; fig. 4,014, auxiliary blade breaking the circuit; fig. 4,015, ***OFF*** position, auxiliary blade held against main blade by spring.

In a quick break switch, the arc is ruptured much quicker than can be done in a plain switch.

There is an auxiliary blade pivoted to the main blade and so arranged that the auxiliary blade will remain in the contact clip until the main blade has been opened to a certain predetermined amount. Then the auxiliary blade under spring tension is quickly pulled out of contact.

Horn Break Switch.—A switch of this type is *one provided*

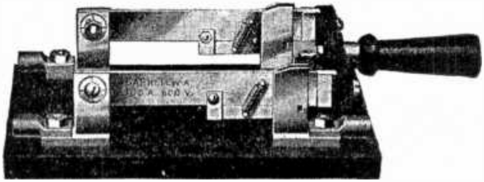


FIG. 4,016.—Barkelew *two pole single throw quick break knife switch.*

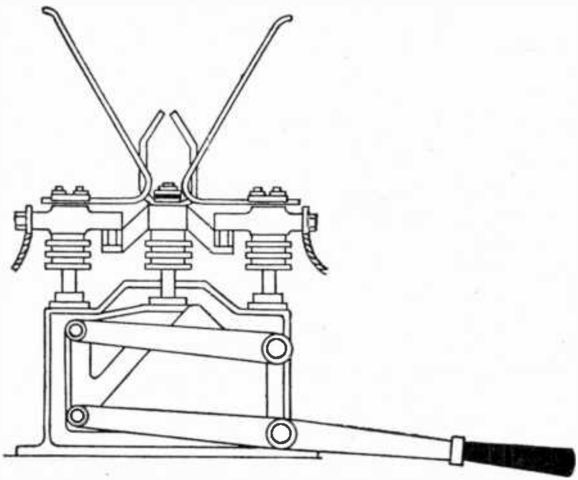


FIG. 4,017.—Horn break switch. ***In operation,*** the arc formed at break will travel toward the extremities of the horns because of the fact that a circuit will tend to move so as to embrace the largest possible number of lines of force set up by it. Hence, the arc that starts between the horns where they are near together rises between them until it becomes so attenuated that it is extinguished.

with horn shaped extensions to the contacts, as shown in fig. 4,017.

The arc formed on breaking the circuit, as it travels toward the extremities of the horn, becomes attenuated and is finally ruptured.

An objection to horn break switches is the considerable space required for the horns and arcs, and the line surges caused by the arc. Horn switches were used extensively for high pressure

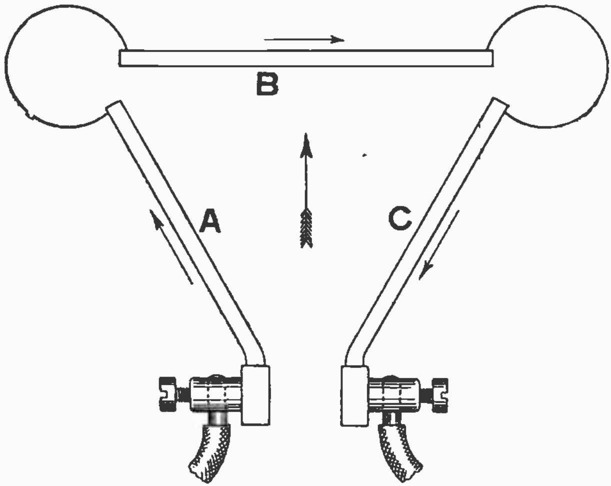


FIG. 4,018.—Experimental circuit, illustrating the action of horn break switches.

a.c. circuits before the introduction of oil switches. The horn break, however, is of theoretical interest.

It is often thought that the action of the horn break is due to the arc being carried up high by the upward draught of air resulting from the rise of temperature due to the arc. Although the upward draught of air probably does assist the action of the arc, this type laid over on its side will repel the arc to the further extremities of the horns almost as well as with the horns in the vertical position. The effect appears to be chiefly due to magnetic repulsion.

It is well known that if a heavy current be caused to flow in opposite directions through two adjacent conductors, the conductors tend to repel each other, as shown in fig. 4,018.

If three conductors A, B, and C, fig. 4,018, be arranged in the form of a triangle, and the conductor B, be left free to move in the direction indicated by the arrow, on sending a heavy current through the circuit, B, will be repelled by both A, and C, as the direction in B, is nearly opposite to that in A and C. It is evident that the shape of the conducting circuit, when the arc is, say half way up the horns will be simiiar to that formed by the three conductors A, B, and C; the arc, being the conductor, B, will be repelled by A and C, further toward the extremities of A and C.

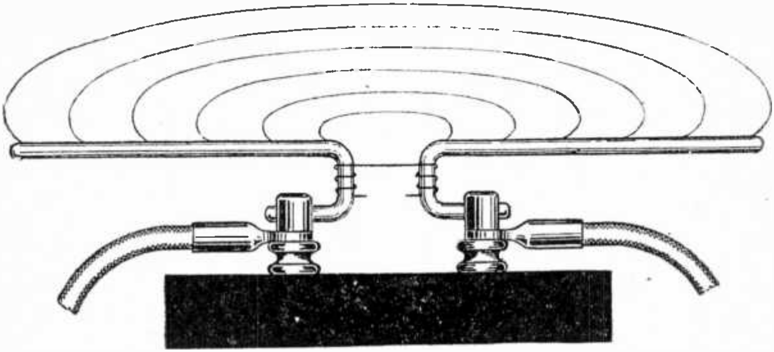


FIG. 4,019.—Flat horizontal horn break fuse.

To ascertain to what extent the action of the horn break could be attributed to magnetic repulsion, Leonard Andrews made a number of experiments with different shapes of projecting horns.

In these experiments, the length of the fuse wire was in all cases 3 inches, and in all experiments a single strand of 16 copper wire was short circuited across the terminals of a 2,000 volt, *kw*. alternator. It was found that a pair of horns projecting horizontally as shown in fig. 4,019, interrupted the arc formed on blowing a fuse bridging the two horns with equal certainty and much greater rapidity than in the case of the horns arranged in the usual manner. The arc was repelled to the further extremities of the horns, the path of the arc being as indicated by the curved lines. It is evident that the upward draught of air has in this case nothing

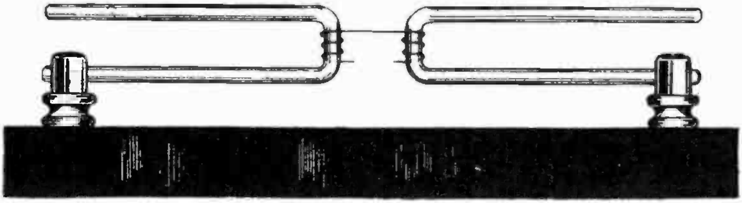
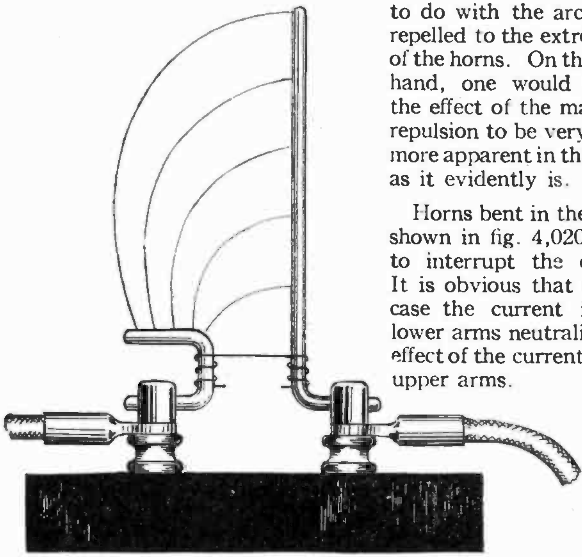


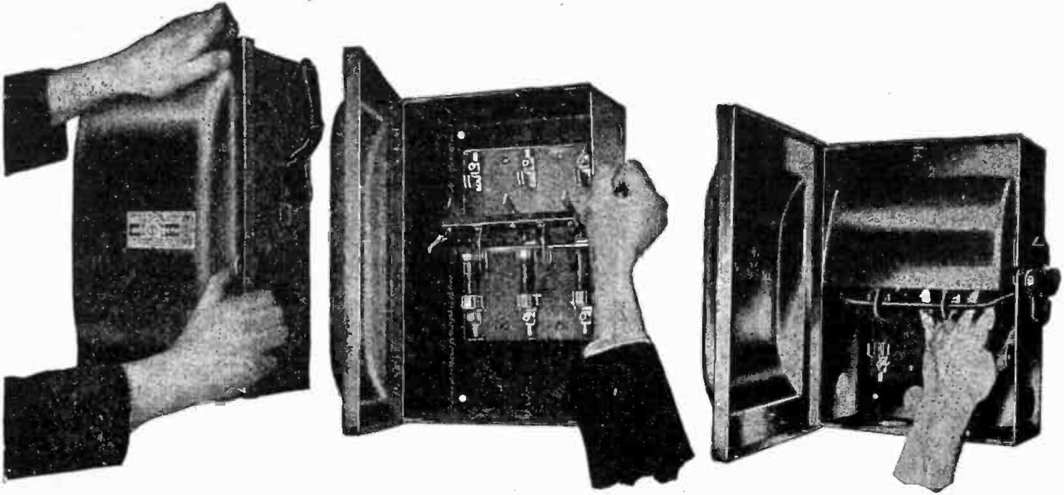
FIG. 4,020.—Action of flat horns neutralized.



to do with the arc being repelled to the extremities of the horns. On the other hand, one would expect the effect of the magnetic repulsion to be very much more apparent in this case, as it evidently is.

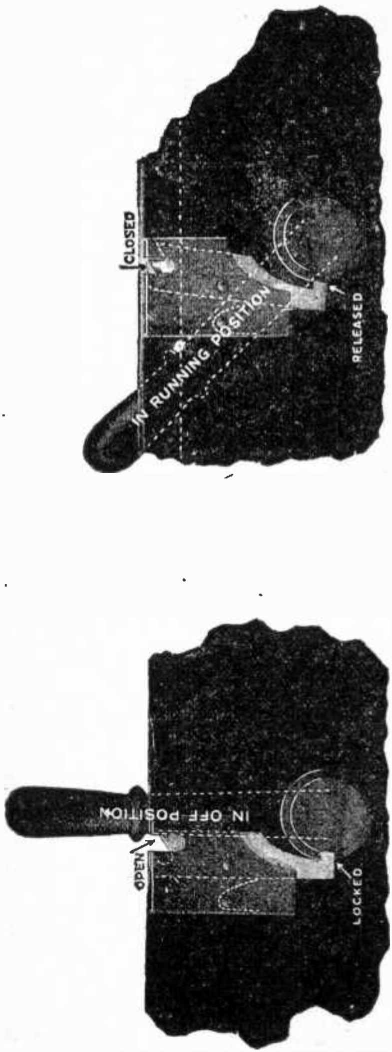
Horns bent in the shape shown in fig. 4,020 failed to interrupt the circuit. It is obvious that in this case the current in the lower arms neutralizes the effect of the current in the upper arms.

FIG. 4,021.—Long and short horn break fuse. Photographs taken of the arc produced with these horns indicate that the arc is repelled with considerable force from the extremity of the short horn. There appeared, in fact, to be quite a blow pipe action from this horn. To ascertain to what extent this was so, the experiment was repeated with the horns thoroughly enclosed in a chimney built of fire bricks, about 3 inches clearance being allowed between the horns and the interior of the chimney. It was found on removing the bricks after the fuse had blown that the arc repelled from the extremity of the short horn had burned a hole about a quarter of an inch deep in the brick upon which it had impinged. The bricks directly above the burnt brick were slightly blackened, but those on the opposite side of the vertical horn were barely marked The arc was not at once extinguished as in the open type horn fuse, but was repeatedly re-established for several seconds, each time with a very loud report. Apparently it was repelled to the extremity of the short horn, and was then reflected back by the brickwork, and thus re-established.



FIGS. 4,022 to 4,024—Trumbull safety switch showing operation. In fig. 4,022 operator cannot open box because switch is closed. He must throw switch into "off" position first; fig. 4,023, operator cannot close switch because cover is open, and he must close the box first—the interlocking catch can be manipulated by an expert when necessary to examine switch under load; fig. 4,024, operator cannot touch a live part as the shield covers the upper contacts, which are alive, as well as the entire switch, which is dead. Dead fuses only are exposed and can be renewed with absolute safety. Shield can easily be removed when necessary to examine switch.

Air and Oil Break.—The choice between air and oil as a medium in which to break the arc depends upon the service conditions. The large amount of space required in order to be certain that the arc will be broken in open air, limits the use of air break switches to comparatively low voltage. The air break switch, however, may be enclosed



FIGS. 4,025 and 4,026—Trumbull interlocking device for safety switches. Fig. 4,025, when switch is in "off" position the catch is thrown back enabling the cover to be raised, thus locking handle hub so switch cannot be closed until cover is down; fig. 4,026, catch in box locks over pin on cover and holds box closed until switch is thrown into "off" position.

by some form of cover for the purpose of protecting the operator or to prevent unauthorized operation.

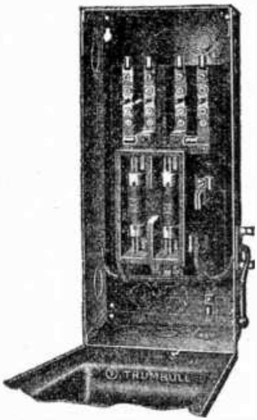
The enclosed air break requires less space than the open air break, but its effect on circuits containing inductance and capacity is very little diffe ent, so that there will be the same oscillatory rises of voltage on opening the circuit. In addition, the explosion on opening heavy currents with this switch is at times so heavy as to endanger not only the switch itself, but all delicate instruments in the immediate neighborhood.

For high tension circuits the oil break is used almost exclusively and also in low tension work they are extensively used on account of the compactness of the construction and the reliability of the operation.

The arc being completely enclosed, this

switch can be used in mines and mills where the air is charged with explosive gas or dust.

The oil break is used almost invariably on *a.c.* systems. Oil break switches are used on low voltage circuits when air break switches are objectionable, for reasons of head room, limited space for connections, or where the open arc is a source of danger; and on high voltage circuits, where air break devices are not practicable, owing to the space required for breaking a high voltage arc in air. The oil break is particularly effective on *a.c.* circuits, because as the switch contacts part, the oil surrounding the contacts immediately rushes to fill the spaces in the break between the contacts, and induces a high resistance which is in proportion to the speed at which the contacts part. Also, the pressure of the oil confines the arc to a limited area and tends to quench it. When the voltage passes through zero, the resistance of the oil tends to prevent the arc re-establishing. As the distance between the contacts increases, the arc holds for a shorter portion of each succeeding half cycle, until the arc finally fails to be re-established. The circuit is then open. The number of half cycles that the arc holds depends upon the voltage of the circuit, and the amount of current to be ruptured.



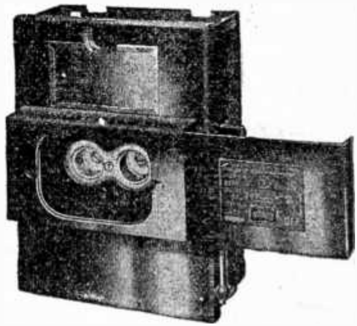
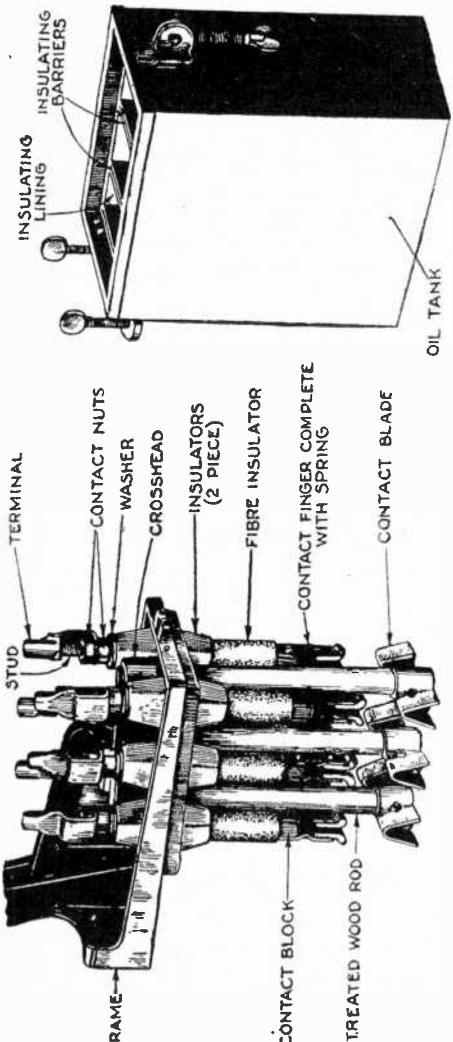


FIG. 4,027.—Trumbull meter service switch 30,400 amperes with cover open showing switch and fuses.
FIG. 4,028.—Trumbull meter service 125 and 250 volts switch showing switch and blades dead service side, fuses exposed.

The insulating value of the oil and its burning and carbonizing characteristics also make a difference in the length of time that the arc will hold.

As the gases formed by the burning of the metal of the contacts and the oil adjacent to the contacts must pass through the oil, in order to escape, these gases are cooled and rendered less dangerous than if they were



FIGS. 4,029 and 4,030.—General Electric oil break switch for switchboard service. Fig. 4,029 switch mechanism; fig. 4,030, oil tank.

generated in the open air. These characteristics of the oil switch make possible the breaking of an electric circuit with a minimum disturbance.

The oil switch is not nearly so effective on *d.c.* As there is no zero pressure point in this case, the breaking of a *d.c.*, circuit under oil results in severe burning of the metal and oil, and the generation of much gas; consequently, there is considerable tendency of the arc to hold between the opening contacts. However, oil switches are sometimes used on *d.c.* circuits where conditions are such that, to break an arc in the open air, is prohibitive.

Oil Break Switches.—The extensive use of high pressure currents and alternating current motors and other devices introducing inductance make it necessary to use switches radically different from the ordinary air break types.

By definition an oil break switch is *one in which the circuit is broken under oil.*

The oil switch is most used especially on high pressure alternating current circuits, because of the fact that the oil tends to cause the current to break when at its zero value, thus preventing the heavy arcing which would occur with an air break switch, and the consequent surges in the line which are so often the cause of breakdown of the insulation of the system.

The oil break is not a quick break.

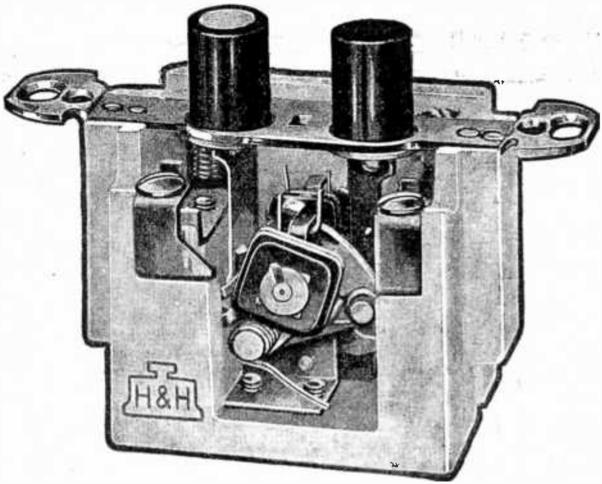
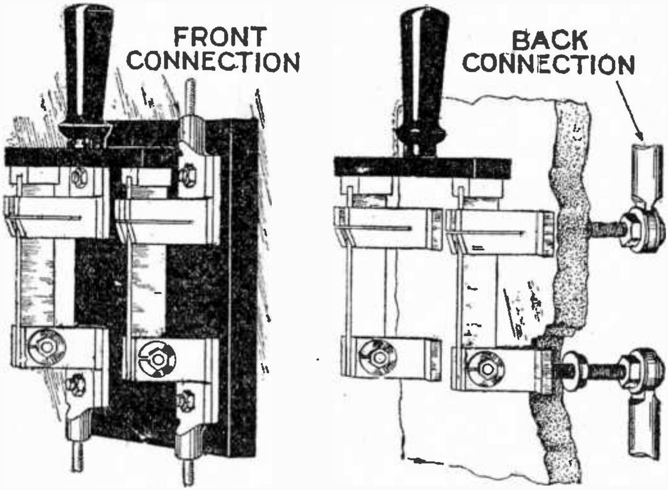


FIG. 4,031.—Hart and Hegeman momentary contact switch. Pressure on the button closes the circuit as long as the button is held in. Releasing the button opens the circuit. Quick make and break. The two circuit type has two separate single pole switches, each controlling a separate circuit. Both buttons cannot be operated at the same time.

Oscillograph records show that the effect of the oil is to allow the arc to continue during several cycles and then to break the current, usually at the zero point of the wave.

Rupturing Capacity of Oil Switches.—While an oil switch may be designed for a given pressure and to carry a definite amount of current, it should not be understood that the switch will necessarily rupture the amount of normal energy equivalent to its volt ampere rating.

Oil switches are often used on systems with generator capacity of many thousand kilowatts. It is, therefore, essential that the switches shall be able to break not only their normal current, but also greatly increased current that would flow if a short circuit or partial short circuit occur.

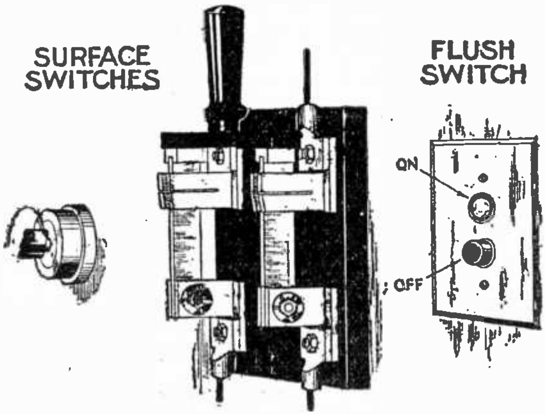


FIGS. 4,032 and 4,033.—Front and back connection knife switches. With the back connection the wires and the terminals are out of sight, thus improving the appearance.

Methods of Mounting Switches.—To meet the varied conditions of service, switches are designed with numerous ways of attaching them to the supporting member.

Figs. 4,032 and 4,033 show what is called front and back connection respectively. The appearance is improved by the back connection as the connecting wires are not visible.

The term *surface* as applied to a switch indicates that the switch is mounted on the surface of the supporting member as in figs. 4,034 and 4,035 instead of being mounted as in fig. 4,036. A switch designed for this method of mounting is called a flush switch.



Figs. 4,034 to 4,036.—Views showing difference in appearance of the surface and flush type switches. In the latter type there is practically nothing projecting beyond the surface of the wall except the push buttons.

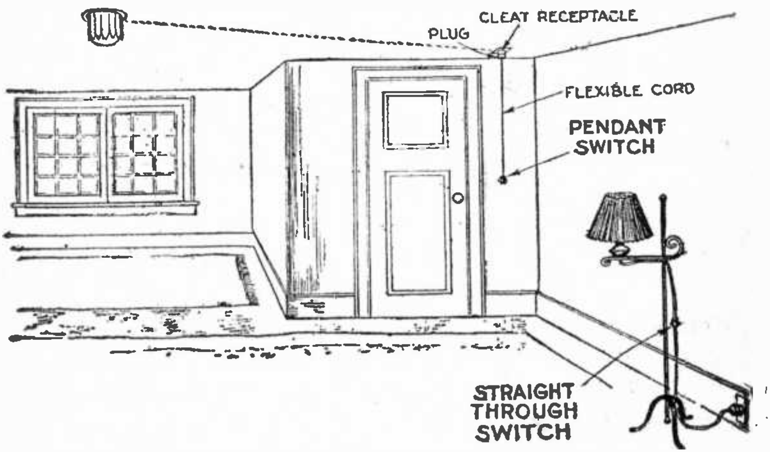


Fig. 4,037.—Interior of room illustrating the installation and use of pendant switch and straight through switch.

The word *pendant* means *hanging loosely by one end*, hence a pendant switch is one attached to the circuit wires at one end leading to a receptacle or other connection as shown in fig. 4,037. Pendant switches may sometimes be used to advantage instead of pull chain switches in locations where the pull cord of a pull chain switch would not hang vertically in a straight line from the switch.

A straight through switch, as its name implies, is one designed to be mounted at any point in a (flexible) circuit so that the conductors enter and leave the switch in a straight line, as shown in fig. 4,037. This type switch is used for such applications as for controlling small heating devices, vacuum cleaners, irons, etc. It is also called a feed through switch.

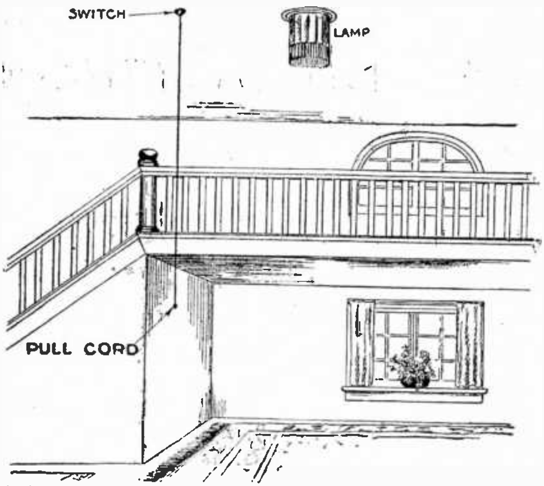


FIG. 4,038.—Typical application of pull cord method of operating the switch. Evidently the switch may be quite remote from the end of the pull cord, thus avoiding the expense of extra wiring as would be in the case of a pendant switch.

Methods of Operating Switches.—Owing to the great variety of service conditions, various mechanisms for opening and closing switches have been devised for the convenience and safety of the operator.

Where the switch is in an inaccessible location as on the ceiling, the pull method is used as in fig. 4,038.

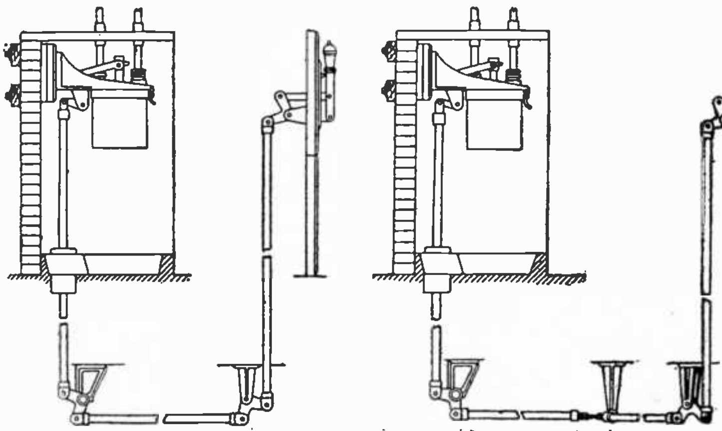
Wall switches of the flush type are operated by the push method, there being two buttons connecting with an oscillating mechanism for *on* and *off* positions of the switch as shown in fig. 4,036.

The snap type switch operates by the rotary method; fig. 4,034.

Remote Control Oil Switches.—It is desirable in the case of switches on high pressure circuits to locate the parts which carry the high pressure current at some distance from the switchboard in order that they may be operated with safety.

With respect to the manner in which the switches are operated they may be classed, as

1. Hand operated. 2. Power operated.



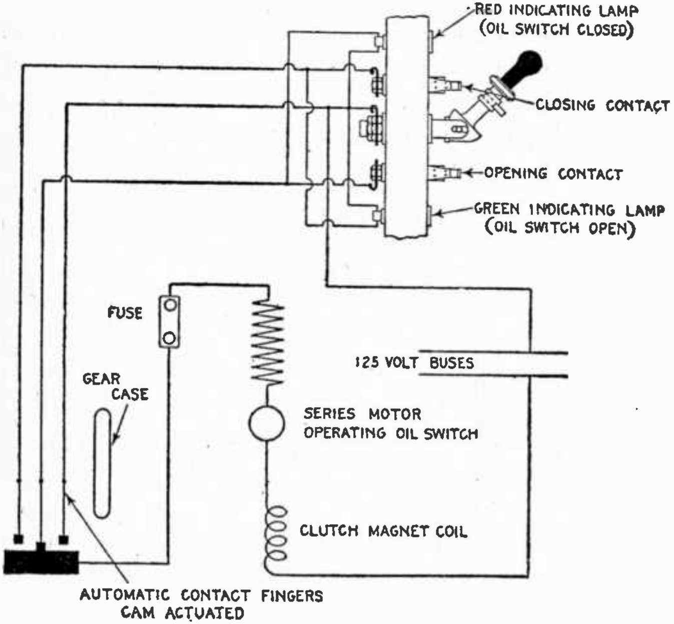
Figs. 4,039 and 4,040.—Views showing mechanism of hand operated remote control switches. Fig. 4,039, straight mechanism; fig. 4,040, angular mechanism.

For hand operation, the mechanism between the operating lever and switch proper, consists simply of a system of links and bell cranks. Various shapes of bell crank are used, to permit change in direction or position of the force applied to operate the switch.

In the case of power operation, electricity is used in most cases; in some installations, switches are operated by compressed air.

Remote control should be employed for pressure above 1,100 volts.

Red and green lamps are used as indicating devices with electrically operated switches; *red* for *closed* and *green* for *open* as shown in fig. 4,041.



OIL SWITCH IN CLOSED POSITION

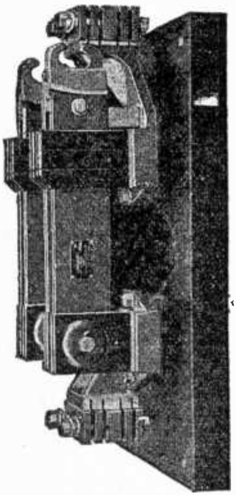
FIG. 4,041.—Diagram of connections of motor operated remote control switch. The motor which operates the switch is controlled by a small lever generally mounted on the panel with the instruments which are in the circuit controlled by the switch. The standard pressure for operating the motors is 125 volts.

Motor operated switches are used for exceptionally heavy work where the kilowatt rupturing capacity is greater than that for which the other types are suitable.

Disconnecting Switches.—By definition a disconnecting switch is *a knife switch placed in series with the service switch so that the apparatus controlled by the latter may be repaired in safety by disconnecting it from the bus bars or live circuit.*

Disconnecting switches are not intended to rupture the load current.

Since disconnecting switches are not designed for opening under load, no attempt should be made to open them with current in the circuit.



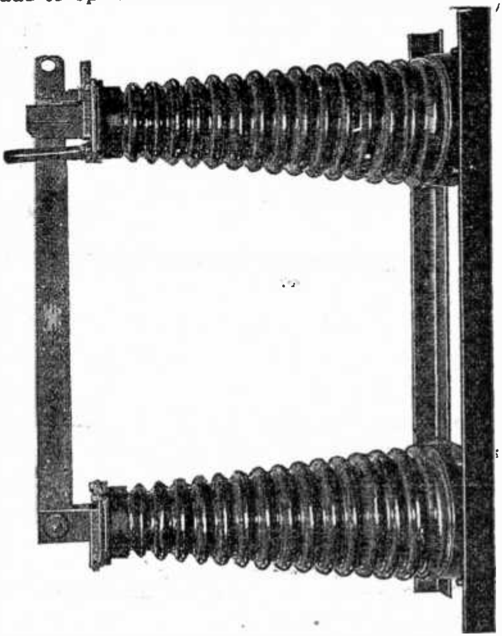


FIG. 4,042.—Westinghouse single throw front connected disconnecting switch for indoor mounting. The blades are single bars for the lower voltages and are clipped, braced and reinforced for the higher voltages to give rigidity. Two single blades are used on all 2,000 ampere switches and two pairs of single blades in all 3,000 ampere switches. A single blade is used on all other sizes up to and including the 15,000 volt switches and on the 600 to 1,200 ampere, 25,000 volt switches. The 200 and 400 ampere, 25,000 volt and the 50,000 and 73,000 volt switches have a truss blade that is very rigid because of its broad base.

FIG. 4,043.—Westinghouse double throw rear connected disconnecting switch.

Disconnecting switches are opened and closed with a hook on the end of a wooden pole.

Care and Adjustment of Lever Switches.—To obtain the best results from lever switches, they should be given a reasonable amount of attention.

When switches are sent out mounted by the manufacturers, they are carefully adjusted and will usually maintain this adjustment for a considerable period. The object in the adjustment of lever switch clips is to give the clips the initial deflection, so that when the blade is forced into them, they will exert a proper pressure and make good contact with the blade.

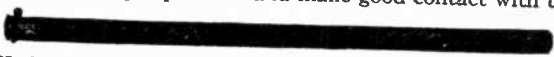
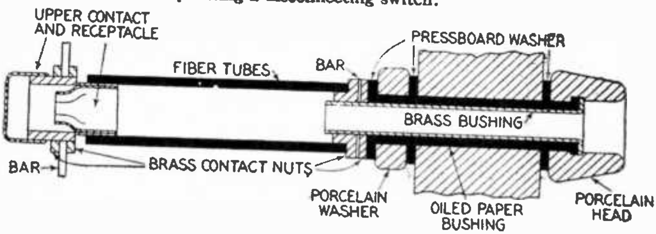
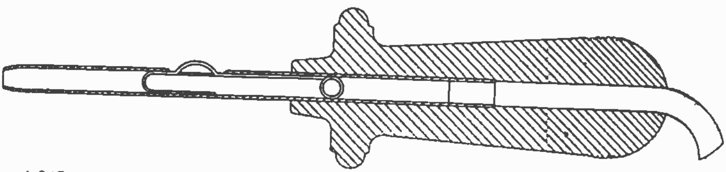


FIG. 4,044.—Hook for operating a disconnecting switch.

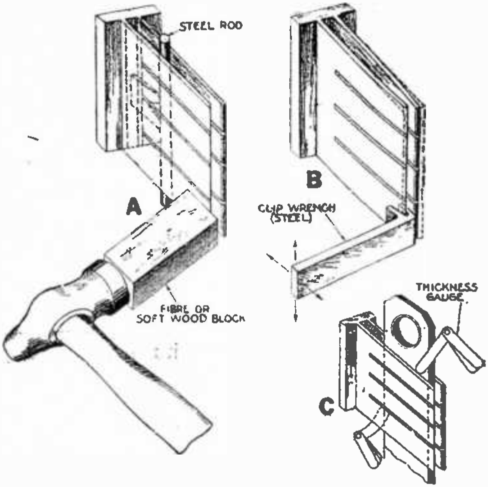




FIGS. 4,045 and 4,046.—***Bus transfer plug switch.*** The method of supporting the contact farthest from the panel consists of a porcelain pillar of the same height as the receptacle, clamped to a brass connecting or bus bar which in turn is fastened to the receptacle.

When it is necessary to disturb the adjustment of the switch either for remounting or some other cause, proceed as follows:

The setting of the clip is accomplished by means of a hammer blow applied to a clip finger through a block of fibre or soft wood held against it as shown at A, in fig. 4,047, where the clips are illustrated as parallel, or in the condition before adjustment. After they have set, they should appear somewhat as at B, where the full lines show the deflection of the clips away from their original position indicated by the dotted lines.



FIGS. 4,047 to 4,049.—Methods of adjusting knife switch jaws.

FIG. 4,050.—Westinghouse rear connected motor starting switch. for pressures up to 600 volts. It is used for starting rotary converters and direct current motors of large capacity having starting torque small enough to permit cutting out the starting resistance in few steps. The clips can be connected to any type of resistor, the steps of which are successively short circuited as the switch closes; the amount of resistance in the armature circuit is thus gradually reduced. A pause should be made after each step of resistance is thrown in to allow the motor speed to accelerate. If the starting switch do not have to carry the full load current and can be short circuited by another switch, a starting switch of smaller capacity equivalent to 50 per cent of running current of the machine can be used. The switch is of the single pole, single throw, rear connected, four point, knife blade type.

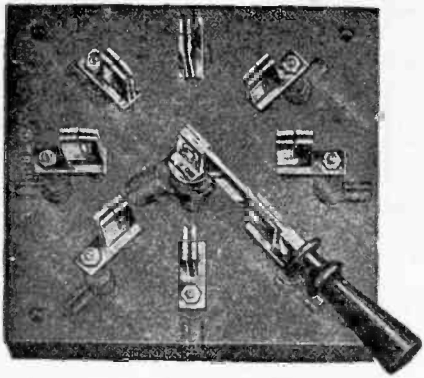


FIG. 4,051.—Metropolitan ratio switch, back connections. This type of switch is used for selected control, transformer ratios and for testing.

The setting at the ends of the clips in good practice is not any greater than will allow the blade to easily enter between the beveled ends of the clips. The form of the deflection curve given to the clip fingers must be such as will cause the clips to bear evenly across the entire width of the blade when the switch is closed, and the setting of the clips for this result can only be secured by repeated trial. In the first place, the contact clip block should be located firmly in its permanent position on the panel or on the switch insulator to which it is attached, and the contact surface of the blade should be well coated with vaseline to prevent undue wear during adjustment.

The operations shown on page 2,289 are not necessarily consecutive; for instance, the secondary adjustment with the clip wrench shown at B, may precede the operation of setting shown at A, although usually this is not the case.

The first operation gives the clips some initial setting by a few hammer blows; then the switch blade is closed into contact and the clearances examined by means of a gauge 0.002 inch thick. This test is shown at C, which indicates how all portions of the contact surface of the blade may be reached by means of a thickness gauge and the condition of the contact ascertained.

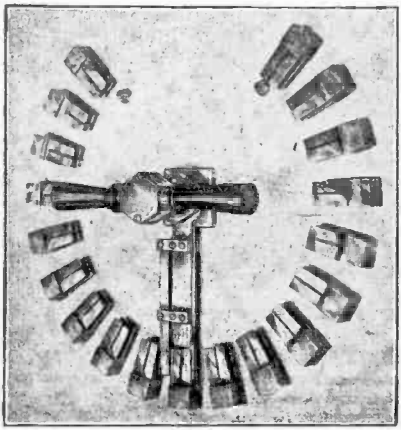
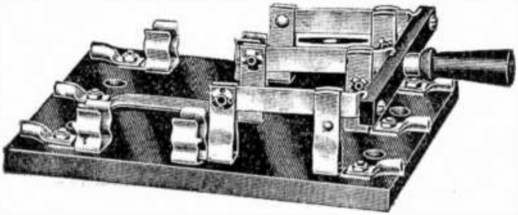
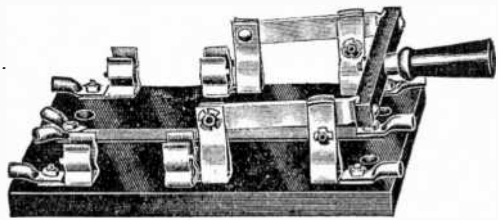


FIG. 4,052.—Metropolitan end cell switch, back connections. End cell switches are used to cut in the end cells of storage batteries as the voltage of the line drops due to discharge.

If it be found that any contact finger does not bear evenly upon the blade, the next operation is to withdraw the blade and change the setting of that contact clip finger. For instance, if the clip fingers do not bear at the front side of the blade, but are making contact at the back, a round steel rod which is of the same diameter as the thickness of the blade is slipped in between the clips as shown at A, up against the blade stop, and, by means of a hammer and block, additional setting is given to the contact finger until the outer end of the contact finger bears against the blade the same as it does at the inner side.

It may be found, however, after adjusting for one side of the contact finger, that the other side does not bear upon the blade, in which case





FIGS. 4,053 and 4,054.—Lyons solid neutral type switches. In fig. 4,053 a removable solid neutral bar is used in place of the usual fuse connections. This construction permits removal of the solid neutral bar and replacing in its stead the regular fuse clips, if desired. In the construction shown in fig. 4,054, a solid strap is used terminating at both ends in a line parallel with back and front connections. This permits somewhat easier handling because of the omission of one working pole.

it may have to be given a slight twist, as shown at B, by the clip wrench. The arrows illustrate the different directions in which the clip wrench may be pulled for various kinds of secondary adjustment.

Other clip fingers must be adjusted by combination of the methods described, and tested carefully with a thickness gauge at all points, the object being to secure practically a uniform pressure at all points on the blade without any loose places that the thickness gauge will enter.

The blades and clips of lever switches should have properly finished surfaces when they leave the manufacturer.

Snap Switches.—By definition a snap switch is *one having an automatic spring actuated mechanism within the switch which causes the contacts to open or close with a snap.*

The construction is such that this rapid action takes place no matter how slowly the button or handle is moved by the operator. Hence, any fool can operate a snap switch without danger of burning the contacts by undue arcing and that is the reason they are made that way.

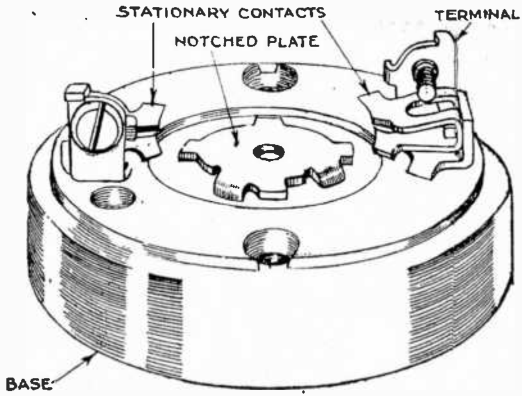


FIG. 4,055.—H & H snap switch porcelain base showing stationary contacts (jaws) terminals and notched plate.

A snap switch consists essentially of:

1. Stationary contacts with terminal connection;
2. Movable contacts;
3. "Snap" mechanism;

all mounted on a porcelain base and protected by a cover so that only the operating handle projects. The accompanying illustrations show typical construction.

In fig. 4,055 is seen a snap switch base having mounted on it the terminals or binding posts, stationary contacts and a notched plate held stationary by lugs which fit into slots in the porcelain base. The duty of this notched plate is to prevent rotation of the movable contacts until the full force of the spring is brought into action by turning the operating handle.

The movable contacts are shown in fig. 4,056. In this particular switch an indicator dial is provided as seen in the illustration, though many switches do not have this attachment.

Part of the operating mechanism is

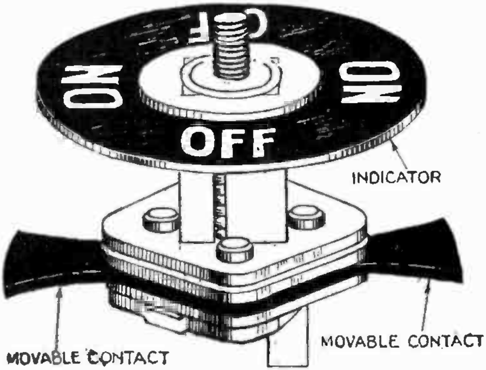


FIG. 4,056.—H & H snap switch movable contacts (blades) with indicator dial.

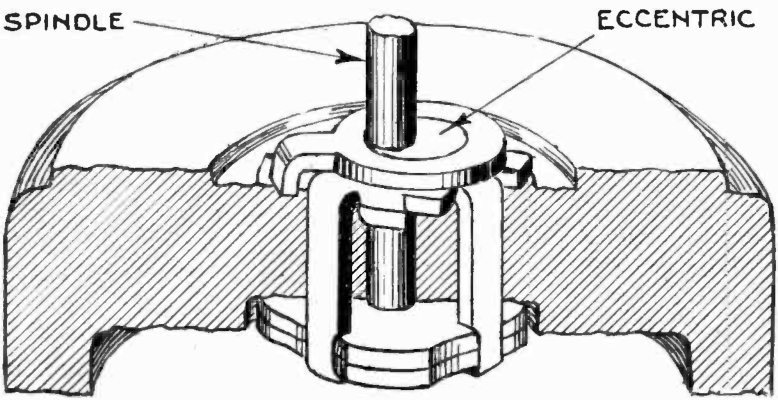


FIG. 4,057.—H & H snap switch shock resisting release parts mounted on porcelain base.

shown in fig. 4,057. The illustration shows the shock resisting release parts consisting of the eccentric with projecting lug. shaft, and notched plate mounted on the porcelain base.

In operation as the handle is turned and the spring tightens, the eccentric on the spindle forces the stop out to the cam point where it is released just when the spring is at proper tension. This stop and cam receive the shock of the snap. To resist the wear and at the same time retain their toughness, these parts are carefully case hardened. They are, furthermore. formed with

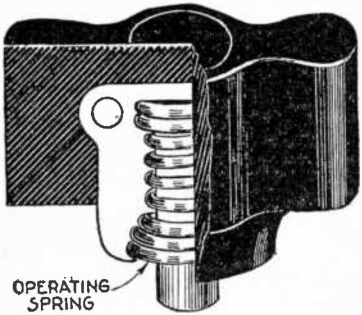


FIG. 4,058.—H & H switch self adjusting handle.

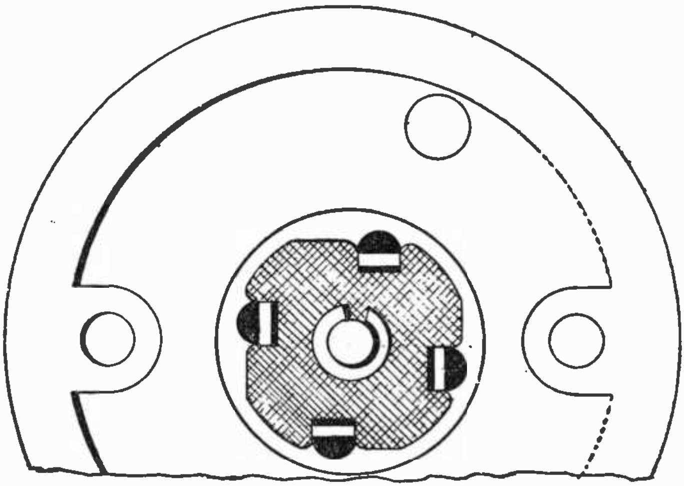


FIG. 4,059.—H & H snap switch method of attaching mechanism to base. *In construction,* metal plates on top and bottom of the porcelain base, riveted together, form the supports for the spindle and act as bearings for it. No matter how the spindle is yanked or wrenched in service these plates hold the spindle and mechanism in alignment.

accuracy and smoothly finished, to reduce friction and wear to a minimum.

Fig. 4,058 shows the operating handle. In this design there is a steel plate running lengthwise through the handle, so that if the rubber were to soften under extreme heat, the handle could still be turned. A strong spring in the handle holds the cover of the switch tight to the porcelain, preventing dust getting into the mechanism.

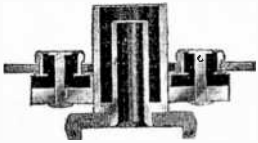
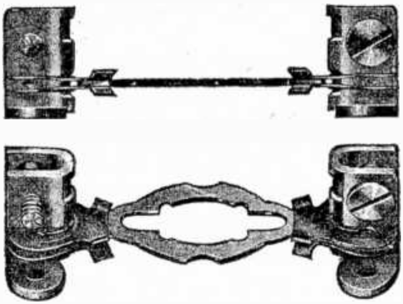


FIG. 4,060.—Diamond snap switch showing formed sheet mica used to insulate the mechanism from the current carrying parts. The black portions of the cut show the mica, which is contained in the brass sleeve which carries the switch plate. It is put together under high pressure and the central pin holds it securely in position.



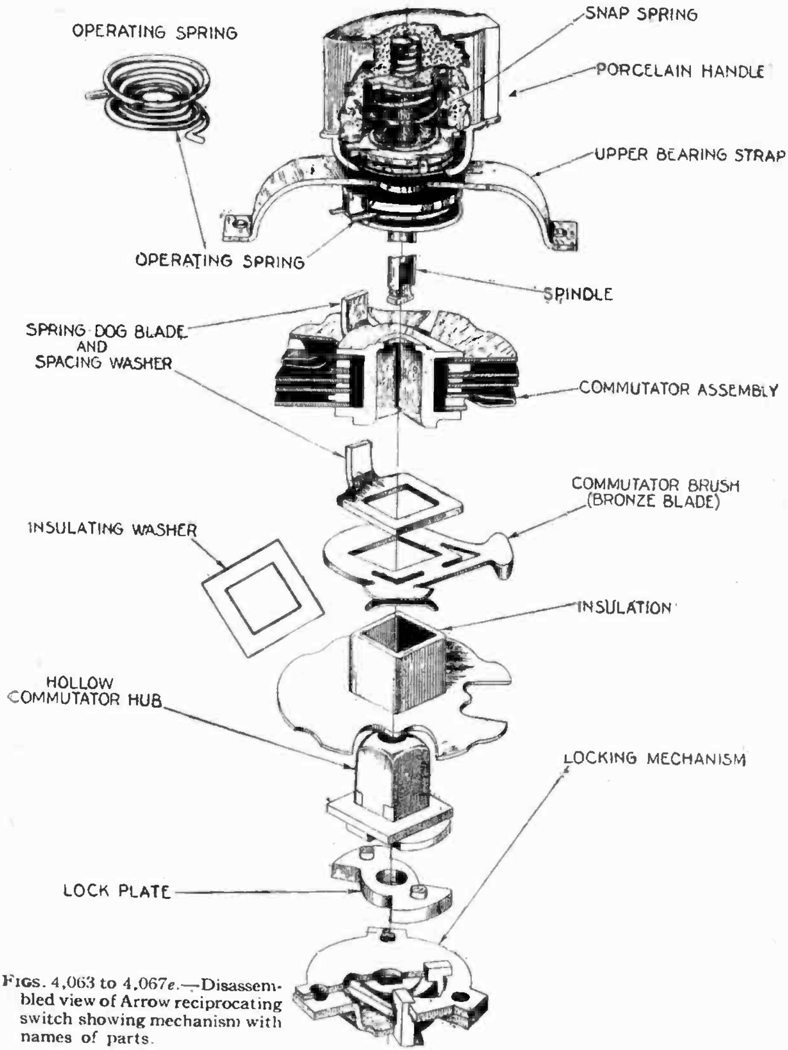
FIGS. 4,061 and 4,062.—Diamond snap switch contacts. They are of the knife form.

The cycle of operation of a snap switch is here given which should be helpful to an understanding of the rather complicated mechanism.

Snap Switch Cycle

1. Handle is turned increasing tension of spring.

2. When the predetermined tension is reached the movable contacts are released.



FIGS. 4,063 to 4,067*e*.—Disassembled view of Arrow reciprocating switch showing mechanism with names of parts.

3. The force of the spring acting on the released movable contacts causes them to make a quick break.

4. Another turn of the handle actuates the spring to quickly close the switch.

Fig. 4,068 shows a typical snap switch which will serve to illustrate further the construction and operation of snap switches. The switch here shown

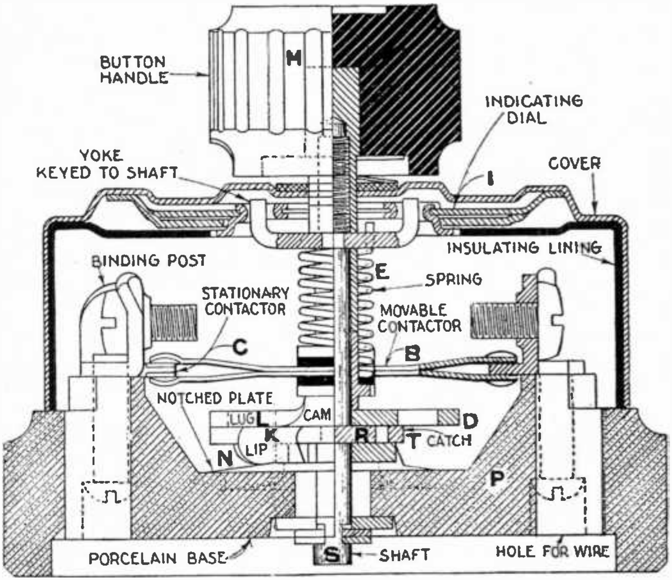


FIG. 4,068.—Arrow rotating button snap switch; sectional view showing mechanism.

is known as a rotary surface type snap switch. It consists of a porcelain base on which are mounted the stationary contacts C, and the switching mechanism which is enclosed by a cover and operated by the handle.

The operation of the standard rotary snap switch is clockwise and non-reciprocating.

The switch base is made of a mixture of clays commonly known as electrical porcelain and fired at a high degree to obtain the vitreous composition.

Mounted on this switch base are two contact posts which serve a double purpose of holding the incoming circuit wires, and provide suitable contact area for carrying the current.

Binding screws are provided and are so arranged that they cannot be backed out, eliminating the possible loss of screws in wiring operation.

The center mechanism is of the lock and release type, consisting of a

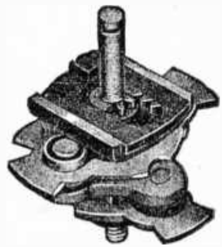
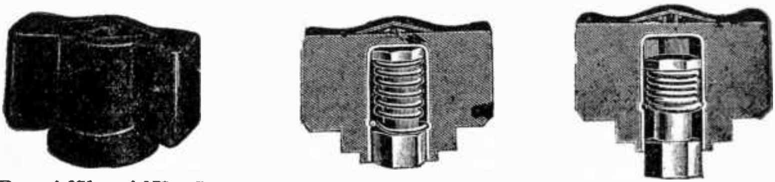


Fig. 4,069.—Diamond snap switch base showing terminals and steel detent which locks the mechanism. The detent is supported by a steel plate which is prevented turning by lugs set into the porcelain at its outside edge.

Fig. 4,070.—Diamond snap switch operating mechanism. It is the same as used on the rotary flush switches. *In operation,* the movement is accomplished by a rack and pinion and the action is quick and positive.



Figs. 4,071 to 4,073.—Diamond snap switch handle. Fig. 4,071 external view of handle; fig. 4,072, spring in normal position; fig. 4,073, spring compressed.

rack mounted in the bottom of the switch base, a cam, and switch plate mounting support.

The two switch plates are made of spring temper phosphor bronze insulated from the member carrying parts by means of electrical fibre. These parts are mounted and held in position in the switch base by means of a spindle protruding through the switch base and fastened by means of a lock ring.

This mechanism is actuated by means of a helical compression spring of music wire held in place by means of a spindle lock washer which also provides for locating studs for turning the indicating dial.

The cover is drawn from brass sufficiently heavy to prevent denting and provides, by means of a removable dial, indication showing whether the switch is in the "On" or "Off" position. The switch handle of com-

Figs. 4,074 to 4,076 —*Various Diamond snap switches. 1.* Fig. 4,074 single pole; 4,075 double pole; 4,076, three way.

position has a moulded interior and is furnished with a spring washer providing a means for holding the cover tightly to the switch base.

This type of switch is largely used in the residential and industrial wiring fields and for the control of lighting and low wattage heating circuits.

In the operation of a snap switch the operation of coiling the spring by turning the handle is shown in figs. 4,072 and 4,073.

There is a very large variety of snap switches, and they may be classed as

1. Single pole

FIGS. 4,077 and 4,078.—*Various Diamond snap switches. 2.* Fig. 4,077, two circuit; fig. 4,078, three circuit.

FIG. 4,079.—Diamond two or three point electrolier snap switch.

FIG. 4,080.—Diamond series parallel heater type snap switch.

2. Double pole
3. Three way
4. Four way

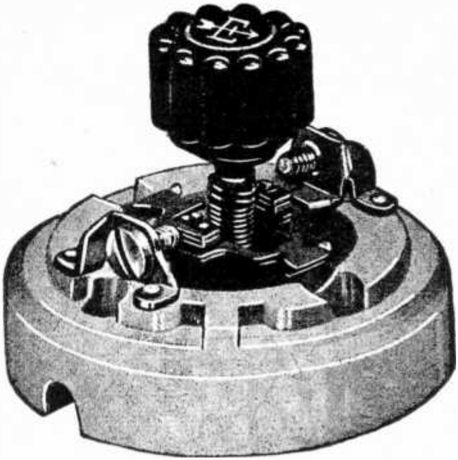


FIG. 4,081.—Bryant heater switch; view without cover showing mechanism.

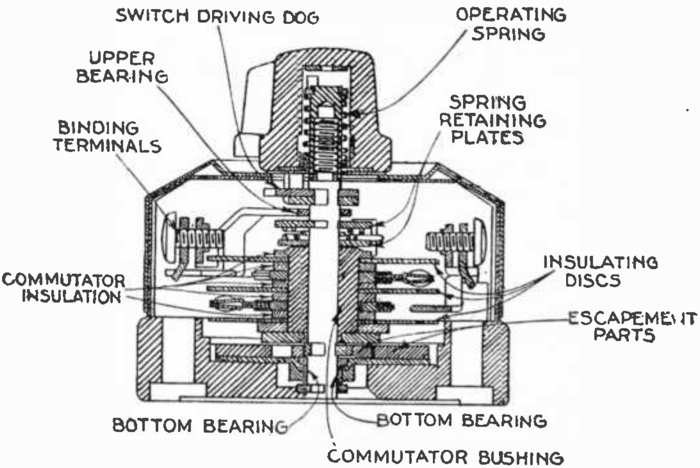
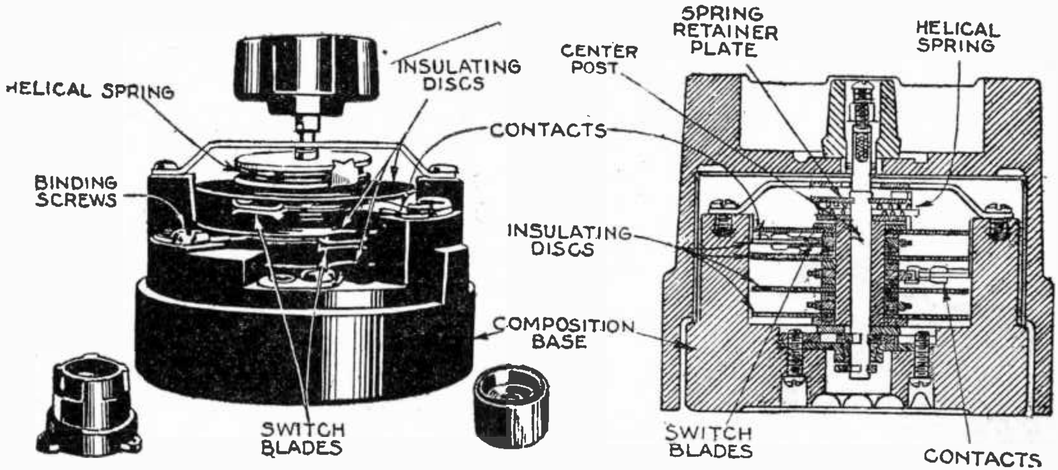


FIG. 4,082.—Sectional view of Bryant heater switch.



FIGS. 4,083 to 4,085.—Bryant motor control switch. Fig. 4,083, cast iron cover; fig. 4,084, mechanism; fig. 4,085, stamped steel cover.

FIG. 4,086.—Sectional view of Bryant motor control switch. *The parts are* indicated in the view.

5. Two point
6. Three point
7. Two circuit
8. Three circuit
9. Electrolier
10. Heating, etc.

Construction details of the various types of snap switch in general use are shown in the accompanying illustrations.

TEST QUESTIONS

1. *What is a switch?*
2. *What governs the form and construction of a switch?*
3. *Give classification of switches.*
4. *Why is there such a great multiplicity of switch types?*
5. *Explain terms relating to switches.*
6. *What is a lever switch?*
7. *What is the meaning of the term "point" and "way"? Carefully distinguish.*
8. *What purpose does the dead button serve on a lever switch?*
9. *What is the difference between a two and a three point switch?*
10. *What is the difference between a single and a double throw switch?*
11. *What happens in the operation of a switch when the contacts separate?*
12. *Upon what does the burning action of the arc depend?*
13. *What is a knife switch?*
14. *What is the difference between a single pole and a two pole switch?*
15. *What is the object of barriers?*
16. *Give the Code requirements for barriers.*
17. *What is the difference between a single and a double break switch?*
18. *What is a quick break switch?*
19. *Describe the construction and operation of a horn break switch.*
20. *Give an objection to horn break switches.*

21. *How does the arc travel in a horn break switch?*
22. *Describe Andrews' experiments with horn break switches.*
23. *What is the object of an enclosed break?*
24. *Describe an oil break switch.*
25. *On what kind of circuits are oil break switches used?*
26. *What is the action of the oil in rupturing the arc?*
27. *What may be said in regard to the rupturing capacity of oil switches?*
28. *What are the various methods of mounting switches?*
29. *What is a surface switch?*
30. *What is the difference between a pendant and a straight through switch?*
31. *What are the uses of surface, pendant and straight through switches?*
32. *What are the various methods of operating switches?*
33. *Describe a remote control oil switch.*
34. *Give two methods of operating a remote control oil switch.*
35. *What kind of indicating devices are used with electrically operated switches?*
36. *What is a disconnecting switch?*
37. *For what service should disconnecting switches be not used?*
38. *Explain in detail the repair and adjustment of lever switches.*
39. *What is a plug switch?*
40. *Describe the construction of a motor starting knife switch.*

CHAPTER 75

Fuses

By definition a fuse is *a conducting element of such dimensions as will melt or dissipate at a predetermined current value, and thus rupture the circuit and protect it against abnormal conditions of current.*

All branch lines should be fused at the junction with the main line, and all electrical apparatus, if not protected by some other automatic device, should be protected individually by fuses.

An element with low melting point connected between terminals, constitutes a fuse. An excess current flowing through the fuse raises its temperature until the element volatilizes and breaks the circuit. The breaking of the circuit forms an arc that develops heavy gases and scatters molten metal.

The ideal fuse is one that is reliable and safe in operation, with an element which can be renewed readily and at a minimum cost.

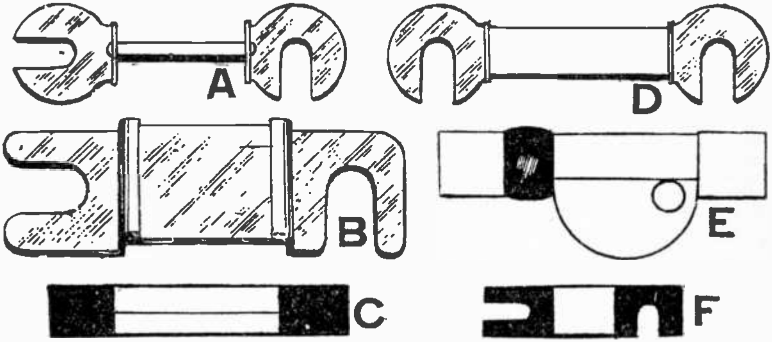
Fuses may be divided into two general classes:

1. Those designed to protect the circuit and apparatus against both short circuits and definite amounts of overloads.
2. Those designed to protect the system only against short circuits.

To the first class belong link and enclosed fuses of the National Electrical Code that opens on 25% overload. To the second belong the expulsion fuses, which blow at several times the current they are designed to carry continuously.

Fuses are especially suitable for protecting motor circuits, because they will carry an overload for a short time, but open if the overload continue.

Open Link Fuses.—During the first years of the electrical industry several forms of open type fuse were used. These were not safe in operation because the arc formed on blowing was not smothered and because the molten metal thrown out would ignite material, and also would cause severe burns to



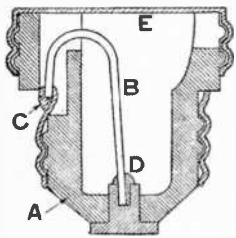
FIGS. 4,087 to 4,092.—Various open fuses. **A,** fuse for main and branch blocks; **B,** standard railway fuse; **C,** Edison main style; **D,** sneak current fuse; fig. **E,** W. U. pattern; fig. **F,** Bell telephone style. When an open fuse "blows" as a result of overloading, the rupture is accompanied by a flash, and by spattering of the fused material. With large currents this phenomenon is a source of danger, and the use of enclosed fuses is accordingly recommended whenever the rating of the fuse exceeds 25 amperes.

people nearby. The danger of these open fuses has been overshadowed by their cheapness, reliability and ease of renewal; therefore they unfortunately are still used on some switchboards. The general form of a link fuse is shown in fig. 4,087.

Link fuses should only be used when mounted on slate or marble bases and enclosed in dust tight fireproof boxes or cabinets. Such boxes also protect the fuses from air currents which may affect the blowing. The boxes are, of course, not used in switchboard work, but in order to protect the operators in such cases, the fuses should preferably be mounted on the back of the boards. Link fuses may be used for voltages not over

250, and are listed in capacities up to 1,000 amperes. There are no standardized ratings for this type fuse, due to the special nature of the services for which it is intended.

Edison Plug Fuse.—The Edison plug fuse was one of the early forms developed to confine the throwing of molten metal and to smother the arc. This type of fuse cannot be very accurate in operation because of the short length of the fuse element. However, because of its comparative cheapness, it



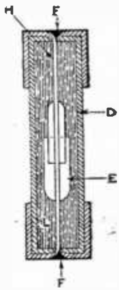


FIG. 4,093.—Section of Edison type plug fuse construction. *It consists* of a cylindrical porcelain body A, in which the fuse strip B, is placed. One end C, of the strip is soldered to the screw shell which surrounds the body and which forms one of the contacts. The other end D, of the strip is soldered to the center contact in the bottom. The top cover is spun in place on the body and is fitted with a mica window E, by which it is possible to tell at once when a fuse on the circuit has blown, as the blowing discolors this window. These plugs screw into the receptacles on the fuse block and, whenever a fuse blows, a new plug must be inserted. Standard plug fuses are intended for the protection of circuits having a maximum current of 30 amperes.

FIG. 4,094.—Cartridge fuse. Its construction is explained on page 2,309.

FIG. 4,095.—Metropolitan plug fuse; renewable type. *In construction,* the fuse is fitted with a brass and mica cap so that the operator can determine in a moment which circuit has blown. The plug proper is made of porcelain. These fuses are listed by the Underwriters' Laboratories and are for use on voltages not exceeding 125 volts, but including 3 wire circuits with grounded neutral having 250 volts between outside wires.

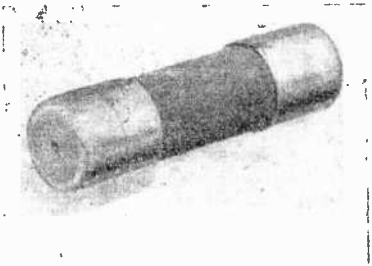
is used extensively when extreme accuracy is not required. The construction of this type fuse is shown in fig. 4,093.

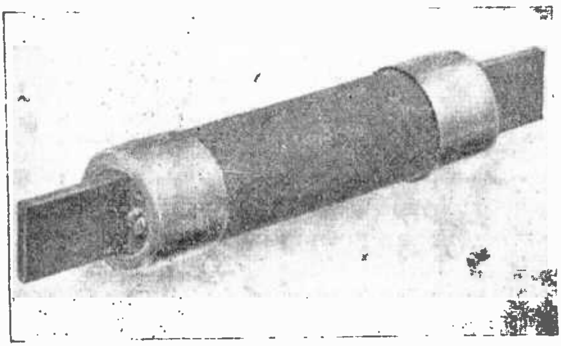
Cartridge Fuses.—There are two types of cartridge fuse classified with respect to the fuse, as being:

1. Non-renewable, or
2. Renewable.

In 1887 the non-renewable cartridge enclosed type fuse was developed. This type, with such modifications as are demanded in its manufacture and use, is still used and will always be applicable for certain installations.

FIGS. 4,096 and 4,097.—Chicago non-renewable cartridge fuses. Fig. 4,096, ferrule type; fig. 4,097, knife blade type. Non-renewable cartridge fuses should be applied to circuits where the interruptions do not occur often. *The indicator* consists of a small high resistance wire, in parallel with the fuse strip, passing over a white circle in the center of the label. As soon as the circuit is broken, this wire produces a black smudge in the white circle, making it very distinguishable.



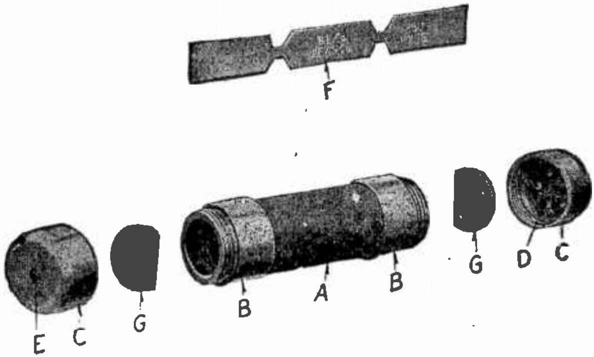


FIGS. 4,098 and 4,099. —Westinghouse renewable cartridge fuses. Fig. 4,098, ferrule type; fig. 4,099, knife blade type.

Non-renewable cartridge enclosed fuses have the fusible element incased in a fibre tube filled with a non-inflammable material and closed at the end with ferrules. On arcing, part of the fusible element is vaporized, and the filling compound absorbs or chills and condenses this vapor, rendering it non-conducting and thereby extinguishing the arc.

The ends of the ferrules of the larger fuses are provided with vents to relieve the internal pressure. These fuses have gradually replaced the major part of the open link fuses in use.

The construction of a cartridge fuse is shown in fig. 4,094.



Figs. 4,100 to 4,105.—Westinghouse ferrule type renewable cartridge fuse disassembled. ***The parts are:*** A, special hard bone fibre tube; B, brass ferrules rigidly fastened to the tube and which cannot be turned off when refilling the fuse; C, removable caps, constructed so as to vent and cool the hot gases sufficiently to prevent pressure and flashes; D, holes through which the hot gases enter the venting system; E, holes through which the gases escape from the fuse at a safe temperature; F, drop out type of link; G, loose washers.

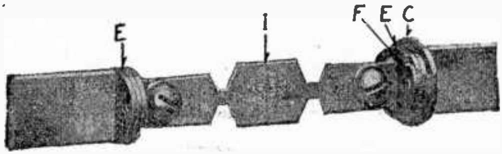
It consists essentially of one or more strips of fusible metal H, enclosed in a fiber tube D, filled with a powdered insulating substance L. This substance serves to absorb the heat liberated when the fuse is blown and condenses the vapor of the molten metal, breaking the continuity of the electric circuit. The ends F, of the fuses are soldered or riveted to metal contacts which also serve to seal the tube, thus holding in the filling compound.

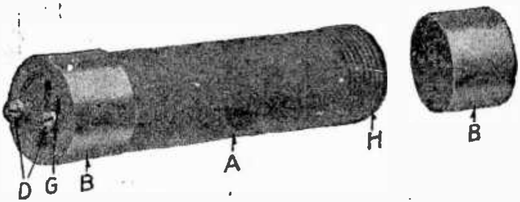
Renewable cartridge fuses of various types may be divided into two general classes:

1. Those using a renewal consisting of a bare link without any powder filling;

2. Those using a renewal with the fusible element enclosed in a powder filled tube.

The demand for a renewable fuse exists because of the necessity for a reliable fuse with a cheap renewal. Obviously a renewal using a link only is considerably cheaper than a renewal using a powder filled tube. Extra renewals do not require much storage space.

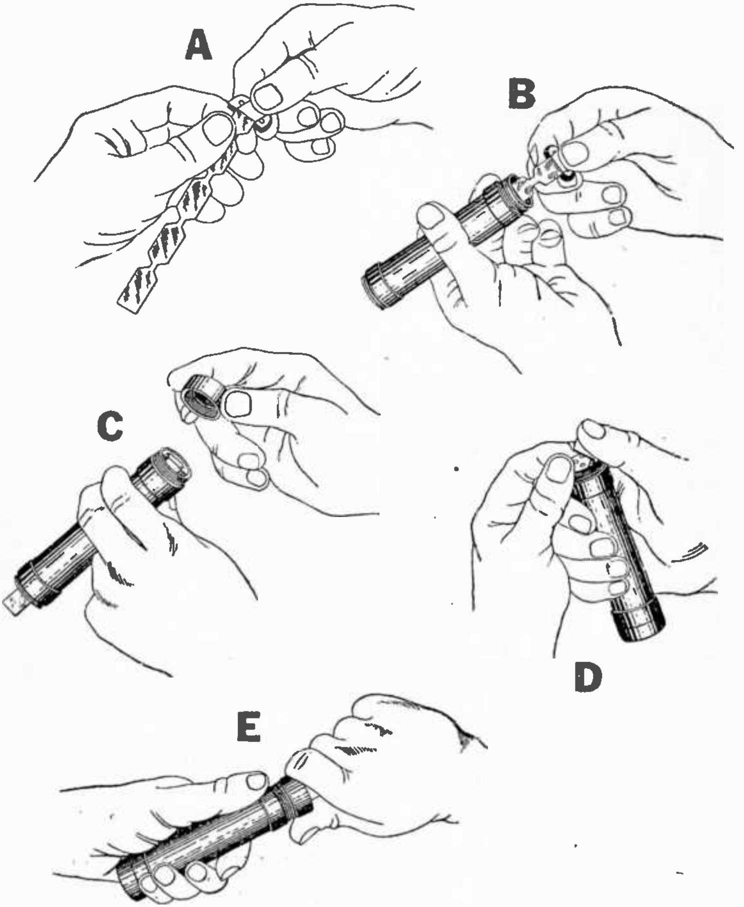




FIGS. 4,106 to 4,108.—Westinghouse knife blade type renewable cartridge fuse disassembled. *The parts are:* A, special hard bone fibre tube; B, removable caps; C, removable washers; D, screws attached to removable washers and used to fasten removable washers to fixed washers; cannot become detached from the removable washers; E, fixed washers constructed to vent and cool the hot gases sufficiently to prevent excessive pressure and flashing; F, opening through which hot gases enter the venting system; G, holes through which hot gases escape from the fuse at a safe temperature; H. centering means; I, drop out type of link.

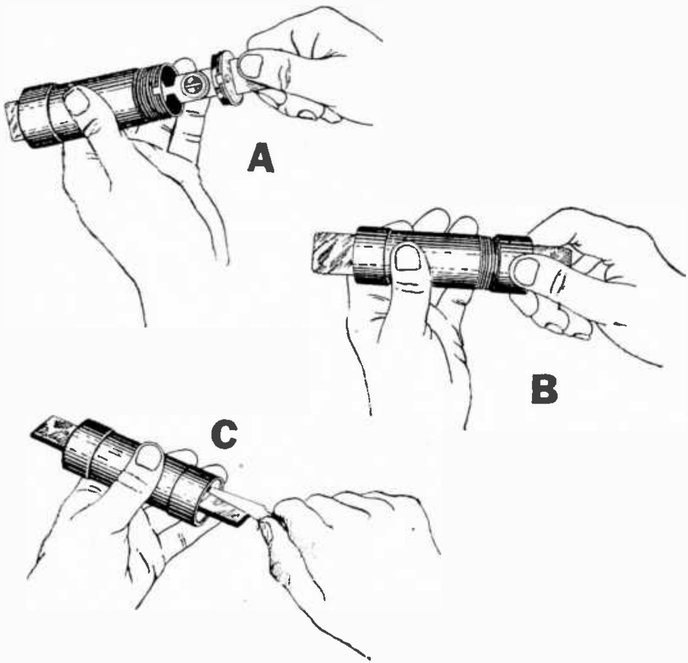
Since air is a more quiescent conductor than the filling compound, a bare link can be calibrated more accurately. There is no powder to slag on overloads or to be thrown off on short circuits.

On short circuit the destructive energy is proportionate to the time required to open and a few thousandths of a second make a great difference. The slightly delayed action of the powder filled fuse is not sufficient to offer decided advantages on overload, but is liable to wreck the



FIGS. 4,109 to 4,113.—Method of renewing fuse in a ferrule type cartridge fuse.

NOTE.—*The castings of enclosed fuses* shall be sufficiently tight so that lint and dust cannot collect around the fusible link and become ignited when the fuse is blown. For non-renewable fuses the fusible wire shall be attached to the terminals in such a way as to make it difficult for it to be replaced when melted.



FIGS. 4,114 to 4,116.—Method of renewing fuse in a knife blade type cartridge fuse.

NOTE.—*Enclosed fuses* shall be classified to correspond with the different classes of cutouts and shall be so designed that it will be impossible to put any fuse of a given class into a cutout which is designed for a current or voltage lower than that of the class to which the fuse belongs.

NOTE.—Enclosed fuses shall be marked with the words "N. E. Code Std." All fuses shall be marked with the ampere capacity. On ferrule contact fuses this marking shall be on the tube or ferrules, and on knife blade fuses on the tubes or caps. In addition to the above marking each cartridge enclosed fuse shall be provided with a paper label, red for 600 volt fuses, navy blue for 250 volt fuses of 15 amperes or less capacity and green for 250 volt fuses of over 15 amperes capacity. The label for cartridge fuses shall bear the following: the name or trademark of the manufacturer and the voltage for which the fuse is designed.

NOTE.—Plug fuses of 15 amperes capacity or less shall be distinguished from those of larger capacity as follows: by a hexagonal opening in the cap through which the mica or similar window shows; or by a hexagonal shaped recess in the top of fuses having porcelain or moulded composition tops, and when labels are used with such plug fuses the labels shall also be hexagonal in shape and fill the recess; or on plugs having solid metal caps, by a hexagonal impression either raised or lowered on the caps.

renewal when short circuited, so that it cannot be withdrawn from the casing, or if it can be, a messy casing remains.

The drop out link is the type of bare link most commonly used. The use of this link, together with an enclosing casing and the proper terminals, all of which make a renewable fuse, was patented. The patents are owned and controlled by the Economy Fuse and Mfg. Company. The link has a plurality of restricted areas which melt more quickly than the larger areas. It is usually made of sheet metal with the sides notched. The large portions quickly radiate the heat away from the decreased parts so that the cross section of the decreased parts is much less than otherwise would be required to carry the rated current. When this element blows, the melting and volatilization of the metal occur only at the restricted parts.

The intermediate parts immediately drop away from the remainder of

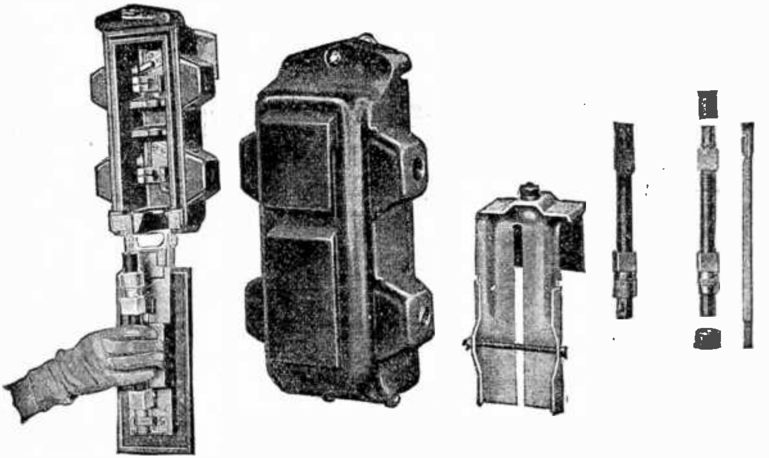


FIG. 4,117.—General Electric expulsion type fusible primary cutout opened. The cutouts operate on the expulsion principle. The pressure of gas generated by the melting of the fuse inside the explosion chamber clears the holder of unmelted portions of the fuse link and of conducting gases, and extinguishes the arc. The link holder extends into a tapered opening in the bottom of the cutout so that the gases are expelled clear of the housing. The interlocking gas barrier prevents the possibility of the terminals becoming short circuited by any conducting gas. It is important that only the fuse links designed for these cutouts be used. Ordinary fuse wire or other makeshifts may defeat the expulsion principle of operation.

FIGS. 4,118 to 4,124.—General Electric expulsion type fusible primary cutout. Fig. 4,118, cutout closed; figs. 4,119 to 4,124, details of fuse and holder.

the link without melting. The gases released are, therefore, reduced to a minimum.

Expulsion Fuses.—By definition an expulsion fuse is one designed to be blown *in a confined space such as an explosion chamber*. A fuse blown under such condition has the property of quickly opening the circuit and projecting the arc from the

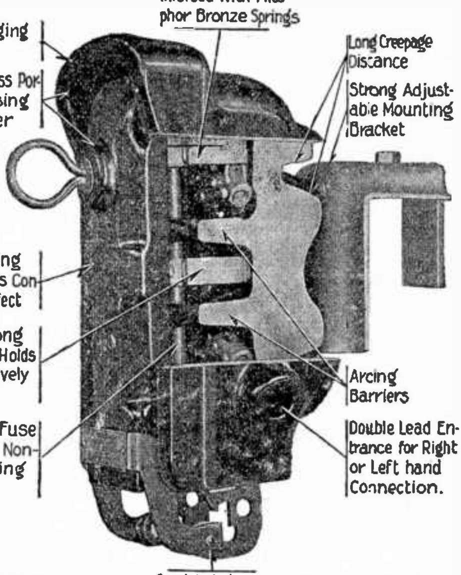


FIG. 4,125.—Westinghouse expulsion type primary fuse cutout. 150 amperes, 7,500 volts. This type is intended for outdoor pole mounting for the protection of distribution transformers. *In construction*, the expulsion fuse tube is mounted permanently on the porcelain door. The door swings vertically from a hinge at the bottom of the box, and can be removed for re-fusing, by lifting from the housing when in the open position. The door snaps into position when closed and is held securely in place at all times, thus doing away with the use of a latch, and also the possibility of the door being unlatched and left open during a short circuit.

open end of the chamber. The line current is opened at approximately the zero point of the current wave, as in an oil break switch. The arc is ruptured under pressure and no surging takes place so that synchronous apparatus is not apt to be thrown out of step as is often the result with open fuses.

Expulsion fuses are made for voltages from 2,500 up to 110,000 and their design differs necessarily with the voltage and make. One type, in

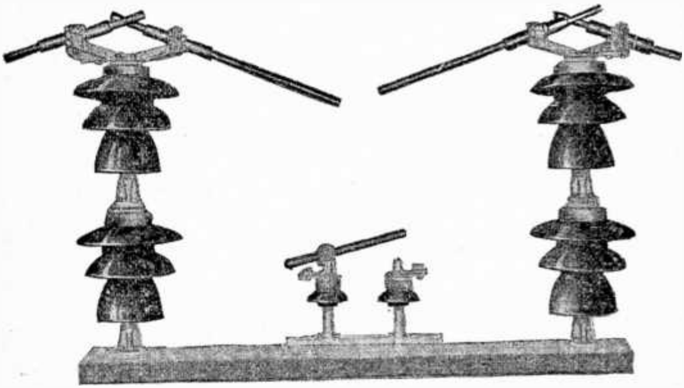


FIG. 4,126.—Westinghouse expulsion fuses; outdoor form upright mounting. Comparative sizes of 4,500 and 110,000 volt fuses. On slow overloads the melting of the fuse element does not generate gas at a sufficiently rapid rate to insure the required expulsive action. There is, therefore, a tendency for the arc to hold, without opening the circuit. Therefore, the fuses should be filled with refills of sufficiently large ratings to positively insure against blowing on overload, yet to readily take care of short circuits. This type of fuse differs from other types of fuses in that an air gap is interposed in the circuit, when the fuse link is blown. This feature is highly important, since it prevents leakage, such as occurs on high voltages in damp weather in the one tube type. This type is designed for short circuit protection only.

general, consists of a reinforced fibre tube, one end of which is closed by a hollow metal receptacle, termed the expansion chamber. The fuse wire or ribbon is enclosed within an asbestos tube in order to protect the insulating tube from injury. It is secured to a plug in the bottom of the expansion chamber and from this is passed through the expansion chamber and tube connected to a terminal block at the upper end of the tube.

The cross section of the fuse in the expansion chamber is slightly reduced so that the point of rupture and the force of the explosion come inside the bulb, and therefore, do not injure the tube. When the fuse blows, the explosion and consequent expansion of the gases formed in the bulb project the arc and open the circuit.

New fuses can be removed with a wooden handle without danger to the operator. The device is insulated from the ground by high voltage insulators.

There are a number of engineering requirements that should be carefully considered before deciding upon the use of expulsion fuses. They should not be used:

1. When the capacity of the system exceeds the rupturing capacity of the fuses;

2. Where the gases ejected by the blowing of the fuse are objectionable;

3. Where short interruption of service due to the time necessary to replace fuses is an objection;

4. Where overloads or short circuits are frequent and circuits have to be operated selectively after a time limit.

In all such cases, automatic oil switches should be used.

Characteristics of Fuses.—Fuses differ from plain overload circuit breakers in that they are governed by both the time and quantity of the current, while the overload circuit breaker is governed solely by the quantity of the current.

The circuit breaker is set to open at a certain fixed current and will open immediately at any greater current, but a smaller current will not cause it to open no matter how long it may continue.

Standard fuses, however, will open the circuit at as small an overload as 25% in a certain time, and in a proportionately shorter time at greater overloads.

The time element is dependent upon the capacity of the fuse as well as on the amount of overload, the relatively greater amount of metal in the larger sizes of fuses requiring a longer time to reach the maximum temperature.

Fuse Limitations.—The quantity of gas generated and of molten metal thrown out when a fuse blows, depends upon the amount of power interrupted by the fuse and upon various other conditions. Realizing that there were limitations beyond which the use of fuses created a severe fire menace, the Underwriters established certain requirements that should be met by all cartridge enclosed fuses.

Underwriters' Requirements.—When the Underwriters test a fuse it is placed on a system of its rated voltage and on one capable of delivering 10,000 amperes on short circuit condition. An easily flammable material, such as absorbent cotton, is placed entirely around the fuse, and covers the vents. The fuse must blow without igniting this material, bursting the tube, blowing off the ferrules or end caps, or moving the fuse sufficiently to injure the cutout base. If a cartridge fuse do not meet this requirement, to use it creates a severe fire menace.

Fuses must carry a 10% overload indefinitely. The fuse which does not meet this requirement causes an unwarranted number of burn outs and interruptions.

At 50% overload fuses must blow within the following time limit:

1 to 30 amperes	1 minute
31 " 60 "	2 minutes
61 " 100 "	4 "
101 " 200 "	6 "
201 " 400 "	12 "
401 " 600 "	15 "

The fuse which does not meet this requirement does not protect the apparatus sufficiently, and may cause the loss of valuable equipment.

Precautions.—To avoid trouble the following precautions should be taken in the selection and use of fuses:

1. Use only fuses approved by the Underwriters. If such fuses blow, correct the trouble before installing new fuses.

2. See that the fuse terminals and the fuse clips are clean, that good contact is made between the fuse terminals and clips, and that the clips are securely fastened to the bases.

3. Use only the renewals intended for a renewable fuse.

4. Do not use ordinary fuse wire or other material for renewals. To do so will cause a severe fire menace.

5. When renewing a renewable fuse, see that the links and contacts are clean, and that the links are securely fastened.

6. Do not omit any part, as each part is necessary to make the fuse 100% safe.

TEST QUESTIONS

1. *What is a fuse?*
2. *Name two general classes of fuses.*
3. *Describe the various types of open link fuses.*
4. *How should open link fuses be used?*
5. *What is a plug fuse?*
6. *Why is a plug fuse not an accurate one?*
7. *What is the feature of plug fuses?*
8. *Describe the construction of a plug fuse.*
9. *Name two types of cartridge fuse.*
10. *Describe the construction of a cartridge fuse.*
11. *Name two types of renewable cartridge fuses.*
12. *Describe the construction and operation of an expulsion fuse.*
13. *What is the adaptation of expulsion fuses?*
14. *Give the characteristics of fuses.*
15. *Describe the limitations of fuses.*
16. *Give the Underwriters' requirements for fuses.*
17. *State a few precautions to be taken with fuses.*

CHAPTER 76

Circuit Breakers

The importance of circuit protective devices, commonly called circuit breakers, is fully recognized. The duty of a circuit breaker is *to protect the apparatus in an electrical circuit from undesirable effects arising from abnormal conditions, by automatically breaking the circuit.* Accordingly a circuit breaker

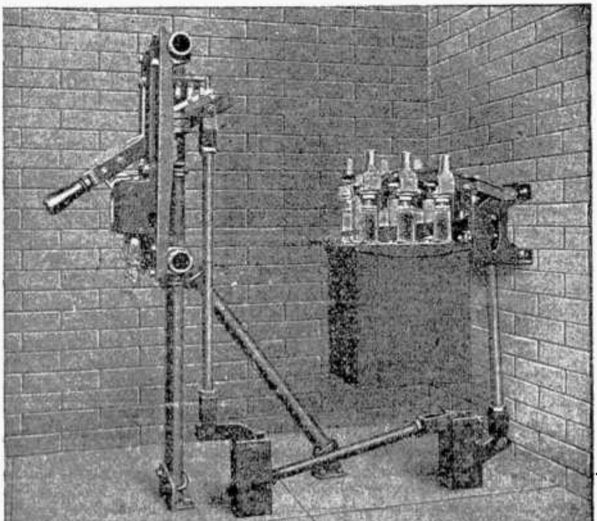


FIG. 4,127.—Westinghouse three pole, single handle, single throw, 200 ampere, 4.500 volt, remote control breaker. One supporting leg and the brace of the cover plate supporting framework has been removed so as to show details of construction.

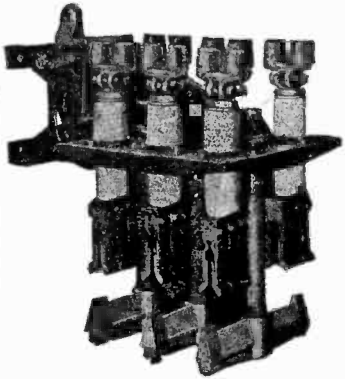


FIG. 4,128.—Westinghouse indoor, three pole, single throw 800 ampere. 2,500 volt circuit breaker unit. The breaker is held in the closed position by a latch on the handle which engages a notch in the cover plate. The setting of the handle disengages the latch and opens the breaker. The breakers are supported by bolting the breaker frame proper to a panel, to a panel bracket, to a flat, vertical surface, or to 1½ in. pipe by the addition of two pipe mounting brackets. Single tank construction containing all poles is used on these breakers.

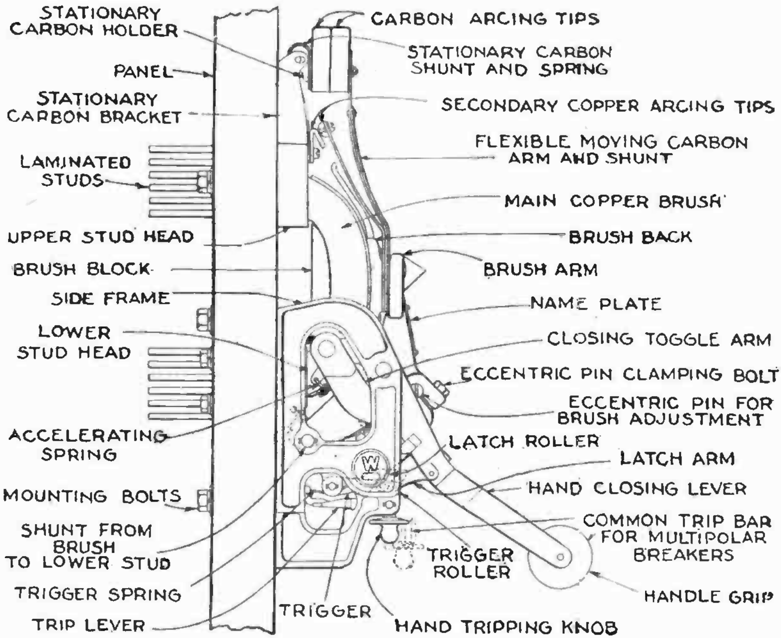
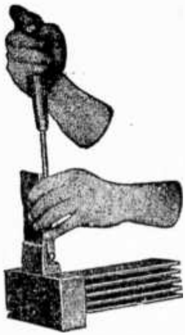


FIG. 4,129.—Westinghouse 3,000-4,000 ampere carbon circuit breaker without overload trip, showing the principal parts.



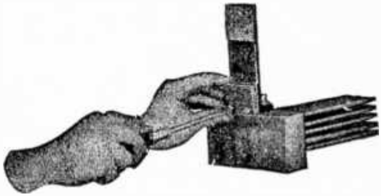
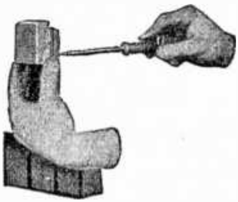


FIG. 4,130.—***How to assemble an air circuit breaker 1.*** Method of assembling bracket to upper stud.

FIG. 4,131.—***How to assemble an air circuit breaker 2.*** Attaching stationary contact plate to bracket.



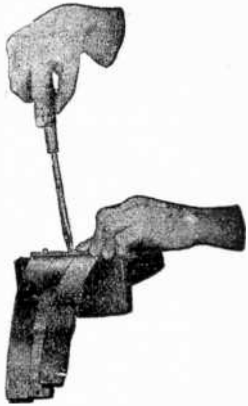


FIG. 4,132.—***How to assemble an air circuit breaker 3.*** Method of attaching stationary carbon burning tip to bracket.

FIG. 4,133.—***How to assemble an air circuit breaker 4.*** Method of attaching the laminated connection to the lower stud.

NOTE.—The accompanying series of illustrations showing ***how to assemble a circuit breaker,*** are here given to illustrate the general procedure in assembling, but relate in particular to solenoid operated air circuit breakers made by the General Electric Co.

must comprise a switch in combination with electrical control devices designed to act under abnormal conditions in the circuit.

By definition then, a circuit breaker is *a device which automatically opens the circuit in event of abnormal conditions in the circuit.*

Much explanation on the construction and operation of circuit breakers is given in the chapter on D. C. Auxiliary Apparatus beginning on page 845.

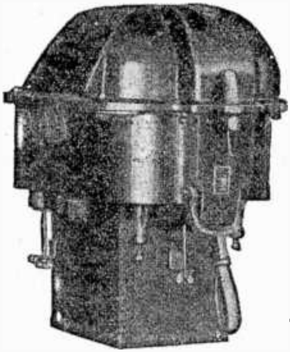
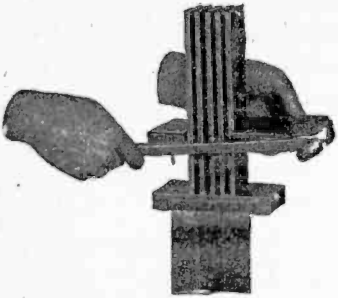


FIG. 4,134.—Westinghouse indoor, three pole, single throw, 300 ampere, 750 volt oil circuit breaker, full automatic with overload trip. The principal application of this breaker is for the protection of slip ring motors in industrial installations where a breaker of rather high current carrying and interrupting capacity is required and where an enclosed breaker is required in order to keep out moisture, dust and dirt. When the breaker is used with slip ring motors and squirrel cage motors it is recommended that it be equipped with inverse time limit attachments so as to prevent the breaker opening when the motor is started and tripping on momentary overloads. An under voltage release attachment should also be used so that the motor will be disconnected from the line upon failure of the power supply.

This matter should be reviewed before reading this chapter.

Application and Selection of Oil Circuit Breakers.—It is generally conceded that for opening large amounts of *a.c.* power and for controlling all *a.c.* high voltage circuits, nothing is superior to oil circuit breakers. There are three fundamental reasons for this:



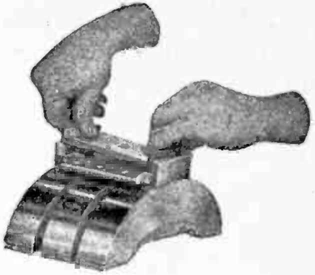
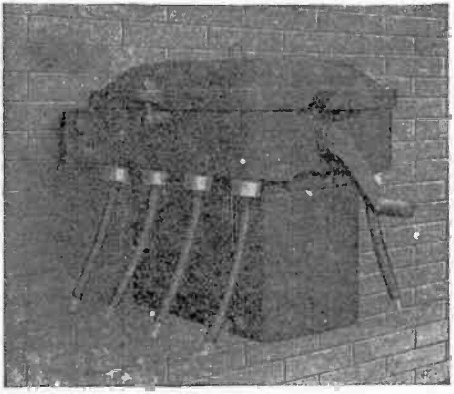
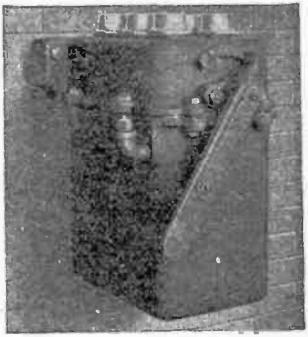


FIG. 4,135.—*How to assemble an air circuit breaker 5.* Method of attaching overload magnet frame.

FIG. 4,136.—*How to assemble an air circuit breaker 6.* Placing the brush insulation in position.





FIGS. 4,137 and 4,138.—Westinghouse circuit breakers. Fig. 4,137, outdoor form; fig. 4,138, sub-way form. Capacity, 4,500 volts, 200 amperes. *The outdoor form* is adapted for controlling lines where they enter buildings, for branch feeders from the main lines and for sectionalizing feeders. It is enclosed in a weather proof case, provided with lugs for facilitating the mounting of the breaker on a pole. The leads are brought out underneath the top part of the case through sealed bushings which prevent the entrance of rain or moisture to the interior of the switch. *The subway form* is intended for mounting in subways, manholes, or other places where a breaker may be required to operate submerged. The subway form of breaker is made two, three or four pole, single and double throw. These breakers are essentially knife switches submerged in oil and arranged for external operation. The main moving contacts are extended so as to engage an auxiliary arcing piece which is mounted on, or attached to, the stationary contact jaw. This auxiliary contact takes the final break, thus preventing any burning of the main contacts. The arcing pieces are inexpensive and readily replaced when worn or burned away.

1. The fact that this type of breaker terminates the *a.c.* wave at its normal zero value, eliminating excessive surges in the connected circuits;

2. The compactness of form of this apparatus;

3. The fact that this type of apparatus properly designed reduces the fire and life hazards to a minimum.

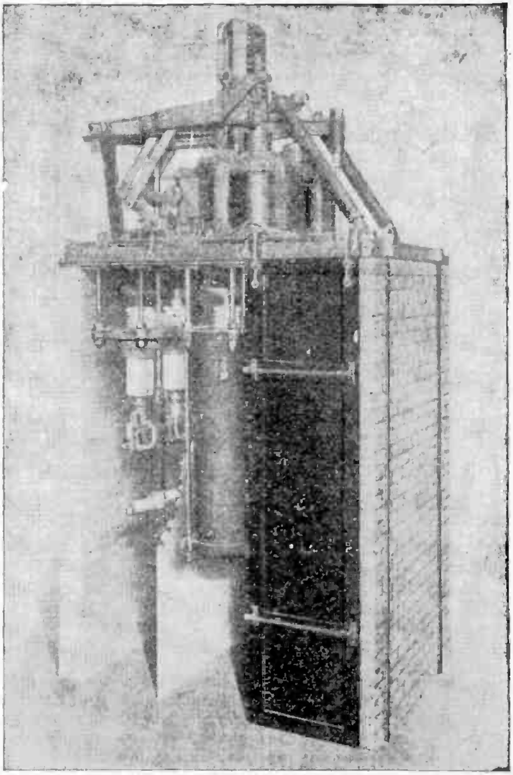


FIG. 4,139.—Westinghouse electrically operated oil circuit breaker horizontally arranged leads, 600 amperes, 15,000 volts showing breaker mounted on structure with two doors and one tank removed. The multiple type electrical solenoid operating mechanism, having closing tripping, accelerating and shock absorbing features self contained, is mounted on the top of the bed plate from the under side of which the individual pole units are supported. The lift rods of each pole unit are connected to a common operating lever, actuated through a toggle lever by the solenoid operating mechanism. Powerful accelerating springs are provided as an integral part of the operating mechanism to assist gravity in forcing the breaker to the open position. Air cylinder dash pots absorb the momentum of the mechanism in closing and opening. The bed plate is also equipped with leather bumpers to support the weight of the moving contacts and rods after the air cylinder dash pots have brought the breaker to rest in the open position and without shock. The flange at the top of the tank engages the flange on the expansion chamber or the steel supporting frame of the circuit breaker top casting. This construction securely and positively interlocks the parts and prevents distortion or opening at the upper end of the tank in case of high internal pressure. Steel tie rods attached to the circuit breaker top casting, support the tank by means of a cradle in which the bottom of the tank rests.

When an oil circuit breaker is opened under load, *an arc is formed between the stationary and the moving contacts*, the size of the arc depending upon the voltage, the amount of current and rate of contact separation.

The heat of the arc disintegrates some portion of the arcing contacts and some of the oil surrounding the contacts, forms a gas bubble, the size of which depends on the amount of current flowing and on the duration of the arc. If this gas bubble be immediately carried away from the contacts, and the contacts have been sufficiently separated, the arc will persist only until the next zero of the current wave. The ability of the bubble to leave

FIG. 4,140.—***How to assemble an air circuit breaker 7.*** Method of fastening the brush support to the brush.

FIG. 4,141.—***How to assemble an air circuit breaker 8.*** Attaching the movable carbon burning tip to secondary spring.

the contacts depends upon the relative specific gravity of the gas and oil, and the head, volume, and viscosity of the oil. Oil having high specific gravity and sufficient head will exert enough pressure to force the gas bubble up and away from the contacts, irrespective of their position.

The relation of the horizontal section of the oil to the cross sectional area of the contact and terminal arrangements will also determine the ease with which the gas bubble will clear itself of the contacts. If there be a liberal clearance for oil around the contacts and if the oil movement be unimpeded, the pressure of the head of oil will force the bubble out into the free oil space, up to the expansion chamber, and clean cool oil will displace the gases.

The selection of an oil circuit breaker for application to an electrical system or circuit requires a knowledge of the characteristics of the breaker and of the system or circuit.

Breakers are usually classified according to:

1. Their rated voltage;
2. Rated current;

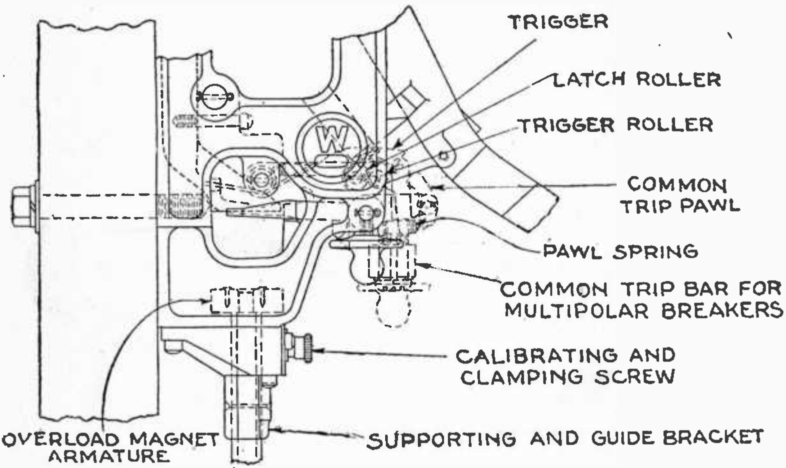
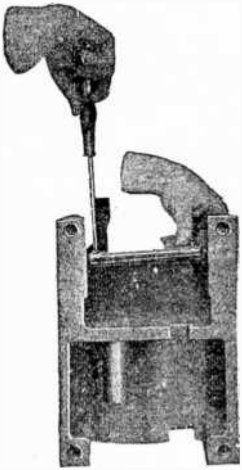


FIG. 4,142.—Westinghouse carbon circuit breaker plain overload *trip attachment.* It is used to trip a breaker whenever the current in the circuit which the breaker protects exceeds a certain predetermined safe value. *It consists of* a coil in series with the line, the ampere turns of which act on a magnetic circuit consisting of a stationary portion and a movable iron armature. When the ampere turns of the series coil are great enough, or in other words when the current through the series coil reaches a certain value, the magnet armature is attracted to the stationary portion and this movement serves to trip the breaker latch. The amount of current required in the series coil of a given overload trip device to cause it to trip the breaker is necessarily dependent upon the air gap between the movable armature and the stationary magnet. Various tripping points can be obtained by varying this gap.

3. Rated frequency;
4. Interrupting capacity;
5. Momentary-current carrying capacity.

Systems may be classified according to their normal operating voltage, normal current, normal frequency and current transients.

The rated voltage of a breaker is *the maximum voltage in r.m.s. volts between any two wires of any circuit to which the* breaker should be connected. When referred to the breaker, it is a function of its insulation strength and of the safety factor desired.



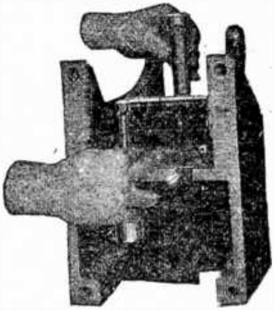


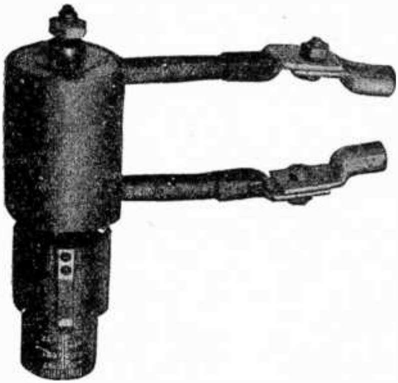
FIG. 4,143.—*How to assemble an air circuit breaker 9.* Attaching the buffer to the solenoid magnet frame.

FIG. 4,144.—*How to assemble an air circuit breaker 10.* Assembling closing and tripping pins.

Under short circuit conditions alternators develop instantaneously many times their normal load current, while the sustained short circuit current is approximately two and a half to three times normal, or even higher with turbine alternators.

Hence, circuit breakers of the so called instantaneous type must be capable of rupturing the circuit when the current is at a maximum, whereas, non-automatic switches, or circuit breakers with time limit relays will be required to interrupt only the sustained short current circuit. The reason is evident, since the delay in opening the switch allows the current to approach the sustained short circuit conditions

Attachments.—Low voltage, high voltage and shunt tripping devices are generally made up as attachments to circuit breakers, and are so arranged that they can be applied to the breaker without changing it in any way. Auxiliary switches are also made up as attachments. These switches are either *circuit closing, circuit opening*; or *combined circuit closing and*



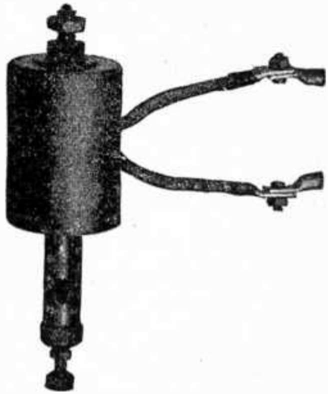


FIG. 4,145.—Westinghouse series or transformer trip coil with inverse time limit attachment complete.

FIG. 4,146.—Westinghouse series or transformer trip coil attachment or shunt trip attachment complete.

circuit opening, depending upon the particular service they have to perform.

Auxiliary switches are named according to the position, open or closed, which they take when the circuit breaker is open.

For instance, a circuit closing switch is one that is in the closed position when the circuit breaker is open and a circuit opening switch is one which is in the open position when the circuit breaker is open.

Circuit closing auxiliary switches are generally provided with a means for setting them in the open position at the will of the operator, when the circuit breaker is open. This arrangement is such that as soon as the circuit

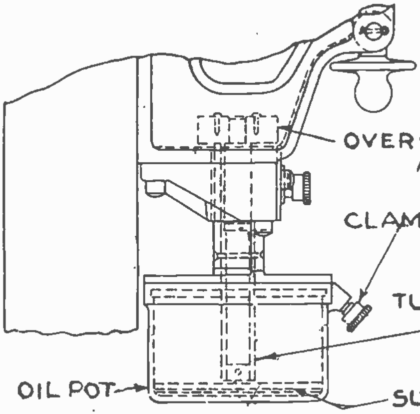


FIG. 4,147.—Westinghouse carbon circuit breaker inverse time limit overload attachment It will trip on practically any overload impulse above its setting unless this impulse lasts only an extremely short time. There are times, however, especially in starting a motor, when the tripping of a circuit breaker on short time overloads is undesirable. For cases of this kind inverse time limit attachments are provided. This inverse time limit attachment is of the sucker type. The sucker which is a smooth surfaced metal disc is attached to the overload armature and normally rests on the smooth bottom surface of a pot containing a small quantity of oil (approximately ⅛ in. deep). The resulting sucker action retards the starting of movement of the overload armature and unless the overload which occurs be very heavy, a considerable time will elapse before the armature can move

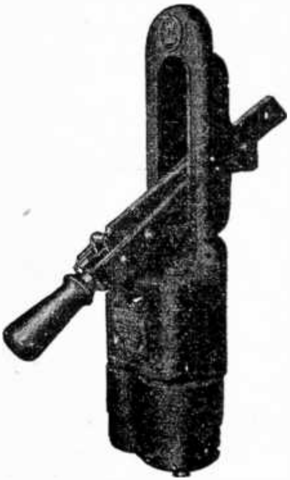


FIG. 4,148.—Westinghouse single handle, single throw cover plate complete with two transformer trip coils and direct trip attachments.

breaker is again closed, the switch automatically assumes its normal operating condition and is ready to close the circuit when the breaker opens again. Circuit closing auxiliary switches are used for ringing alarm bells or lighting lamps to announce the automatic opening of a circuit breaker. They are also used for closing the coil circuit of the shunt trip attachment of another circuit breaker for the purpose of interlocking.

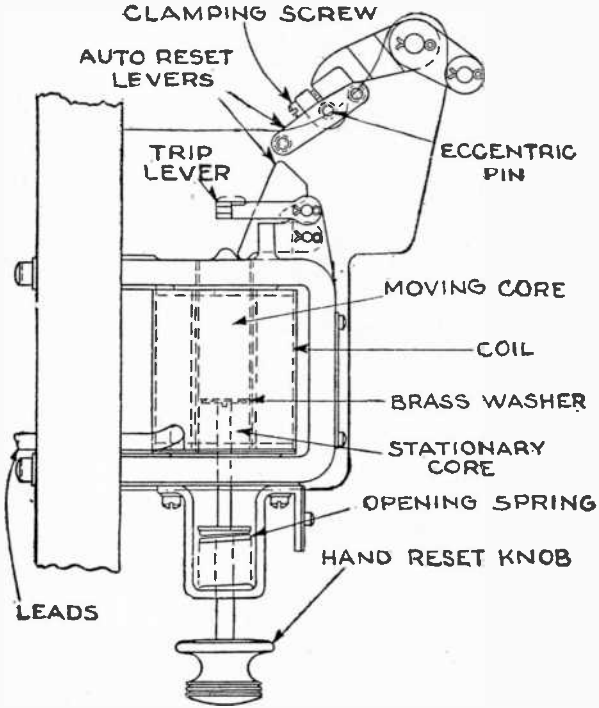


FIG. 4,149.—Westinghouse carbon circuit breaker under voltage release attachment. Used as an automatic trip when the supply voltage drops to a predetermined value. The mechanism consists of a solenoid type of magnet the movable core of which is held to the stationary core against a strong spring. When rated voltage is applied to the coil of the magnet, sufficient current flows through it to hold the movable core against the resistance of the spring, but when the voltage drops to less than 50% of normal the pull of the magnet is no longer great enough and the spring propels the movable core upwards, thus tripping the breaker. For use on *d.c.* the magnet is made of solid iron but for *a.c.* service the iron parts are laminated.

Circuit opening auxiliary switches are used for opening the circuits of shunt trip and low voltage attachments and like service.

Combined circuit closing and circuit opening auxiliary switches are, as their name indicates, used to perform the functions of both circuit closing and circuit opening switches.

High Speed Circuit Breakers.—This type was designed to protect synchronous converters, dynamos, motor generator sets, motors, and feeders from flashover or strains and damage resulting from short circuit or heavy overload conditions.

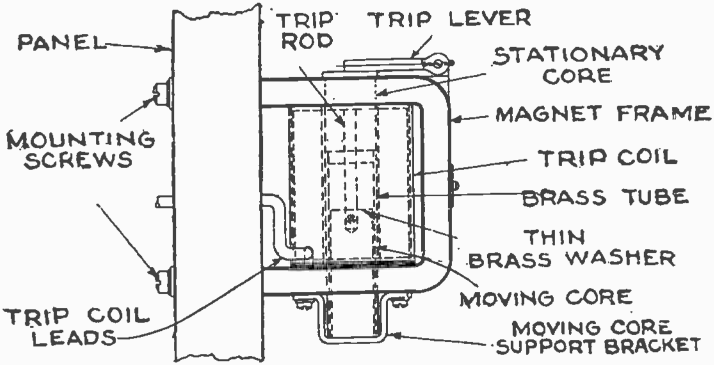
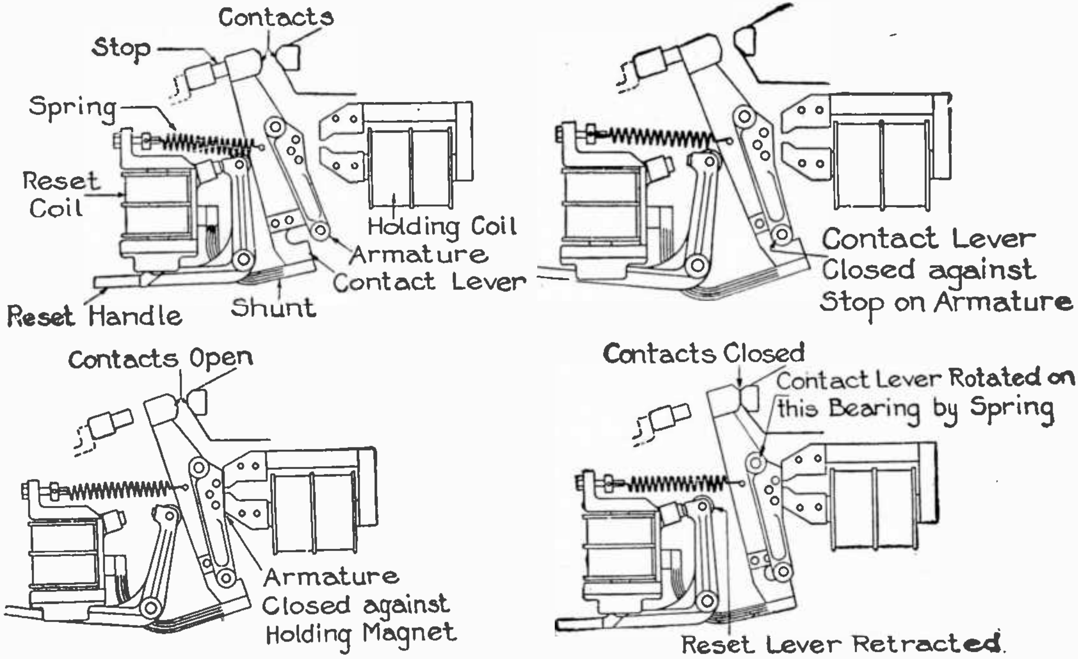


FIG. 1,150.—Westinghouse carbon circuit breaker shunt trip attachment. *Used* in tripping by means of a push button from some distant point or is sometimes used with circuit closing relays for tripping the breaker. The shunt trip magnet is of the solenoid type, the movable core of which is pulled toward the stationary core when the shunt coil is energized. Movement of this core trips the circuit breaker and the coil is immediately cut out of circuit by an auxiliary contact on the circuit breaker when the latter opens. This is necessary since the shunt trip coil is short time rated and would soon burn out if the voltage were applied for any length of time. The total movement of the trip magnet core or that part which is used to move the trigger of the breaker should be just enough to trip this trigger free of the latch lever. This adjustment should be taken care of when mounting the attachment on the panel. A brass washer is placed between the movable and stationary cores to prevent "freezing." This permits the moving core to return to its normal position after the coil is de-energized and it is then ready to again perform its tripping function. Absence of this brass washer will permit sufficient residual magnetism to hold the movable core against the stationary core, even after the coil is de-energized, and it will then be impossible to trip the breaker open by means of the shunt trip until the movable core is forcibly retrieved or until the residual magnetism disappears and the core drops back of its own accord. The standard range of coil voltage over which the shunt trip mechanism operates is 56% to 112% of normal rated coil voltage.



FIGS. 4,151 to 4,154—General Electric high speed trip circuit breaker showing operation of the resetting mechanism. Assume the breaker to be in the open position, as in fig. 4,151 when the resetting mechanism is energized the roller of the resetting lever strikes against the contact arm, rotating it around the top bumper or stop as a pivot until the casting at the bottom of the arm strikes against the main bearing pin, as shown in fig. 4,152. Both arms are then rotated around the main bearing pin by the pressure of this roller, until the holding arm reaches the *closed* position. The holding armature is retained by the holding coil

For the protection of dynamos and synchronous converters the recommended practice is to connect the high speed breaker in the negative side of the dynamo then under short circuit conditions the circuit breaker opens very quickly, cutting into the circuit resistance which is connected across the terminals of the breaker. This resistance cuts down the current to a value within the commutating capacity of the dynamo or converter. The opening of the breaker actuates a tripping circuit which opens the

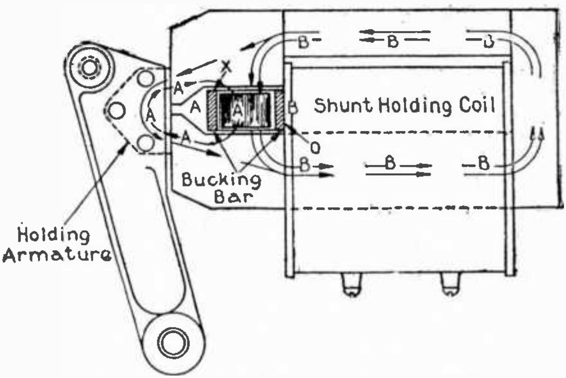
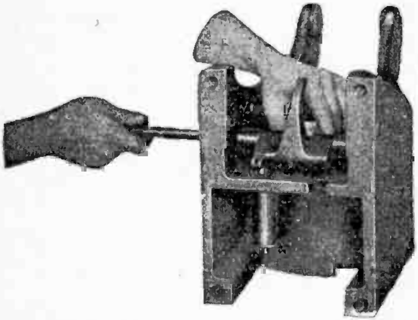


FIG. 4,155.—General Electric high speed trip free circuit breaker. ***In construction*** a contact arm is held in a closed position against powerful springs by an armature excited from a magnetic circuit of a shunt coil. A series coil, commonly called the "bucking bar" which carries the current of the main circuit, is located in such a way as to exert in the holding armature a magnetic force which is in opposition to the magnetic force from the shunt holding coil. ***In operation*** as the main current increases, the magnetic flux is shifted from the holding armature to the iron in the loop of the "bucking bar," here shown, thus reducing the armature flux sufficiently so that at a main current equivalent to the tripping point of the breaker, the contact arm is released. With such an arrangement the holding armature is released almost instantaneously after the tripping point has been reached, resulting in high speed operation. When the contacts of the breaker open, the arc is blown upward by powerful blowout coils on arcing horns mounted in the arc chute. When the arc has been lengthened sufficiently it collapses completely, thereby opening the circuit.

FIGS. 4,151 to 4,154.—*Text continued.*

but the contact arm is held from making contact by the resetting mechanism as shown by fig. 4,153. As the resetting mechanism is released, the contact arm is rotated to the closed position by the pull of the main springs which are attached to the contact arm below the pivot pin. The resetting mechanism therefore, must be retracted before the main circuit can be closed, thus permitting the breaker to immediately trip in case of an overload or short circuit, as shown in fig. 4,154. The bottom of the arm is held approximately stationary, when opening quickly, by the weight of a heavy copper casting and flexible copper shunts which are attached to this end.

circuit breaker on the positive side of the dynamo. This positive breaker may be a high speed breaker arranged to trip on a reversal of dynamo current. This insures the maximum protection. The operation of a high speed breaker is shown in 4,155.



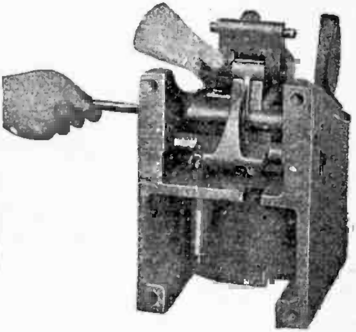
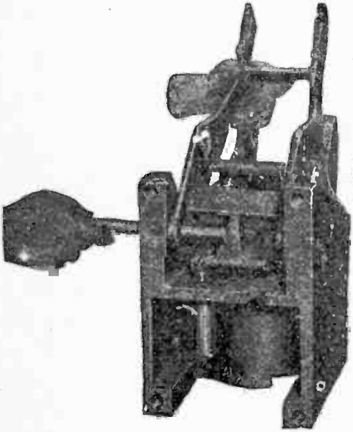


FIG. 4,156.—*How to assemble an air circuit breaker 11.* Attaching tripping lever to solenoid mechanism.

FIG. 4,157.—*How to assemble an air circuit breaker 12.* Attaching upper and lower tripping toggle links.



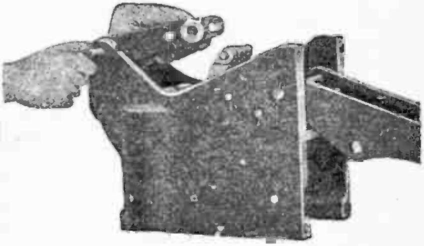


FIG. 4,158.—*How to assemble an air circuit breaker 13.* Attaching the brush support to solenoid magnet frame.

FIG. 4,159.—*How to assemble an air circuit breaker 14.* Attaching the main toggle links to solenoid magnet frame.

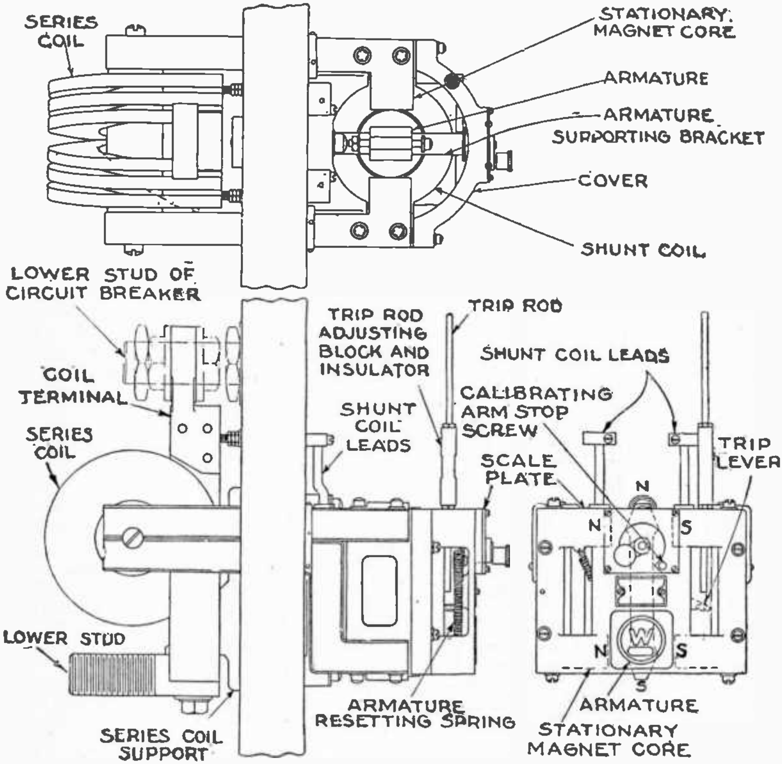


FIG. 4,160 and 4,161.—Westinghouse carbon circuit breaker reverse current trip mechanism. Used to protect a circuit against reversal of power or reversal of current. ***It consists of*** a stationary magnet energized by a series coil and a movable iron armature energized by a shunt coil, or vice versa. For a given shunt coil voltage the armature acts in a way similar to a permanent magnet. This armature is pivoted midway between two pairs of poles on the series magnet and will be attracted to one pair or the other depending upon the relation of shunt and series ampere turns. When the series current is flowing in the normal direction the armature is attracted to one pair of poles against an adjustable cam. When the current reverses, the shunt coil current still remaining the same in direction, the armature is attracted to the other pair of poles and if the reversal of current be as large or larger than the setting, the armature will move over and trip the breaker. The amount of current reversal required depends upon the air gap relation between the stationary and armature poles. This relation may be varied by means of an adjustable cam. It is evident that voltage must be applied to the shunt coil in one particular direction. When the coil is incorrectly connected the reverse current attachment will trip the breaker open when current flows in

Automatic Network Circuit Breakers.—Briefly a network consists of *a number of sources of power interconnected in such a manner that any or all of the power sources* may be *drawn upon to feed into any one of the power consuming stations.*

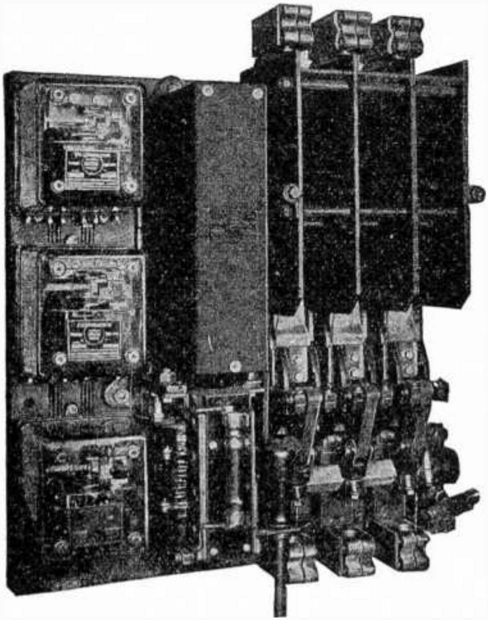


FIG. 4,162.—Westinghouse automatic network circuit breaker. *It has* three poles, and three relays for use on three phase circuits; on two phase and single phase service, the middle pole is left idle. The relays are the master relays which control the operation of the circuit breaker. Two of these are required for single phase and two phase; and three, for three phase service. In addition to the carbon circuit breaker, closing coil, mechanism relay or master relays, there are required reactive shunts, tungsten lamps, an auxiliary switch, a thermal operating indicator with its auxiliary switch, and emergency fuses. The complete network unit is mounted on a suitable slate base.

FIG. 4,160 and 4,161.—*Text continued.*

the normal direction. In this case the leads should be reversed. The armature of this device is retrieved by means of a light spring after tripping. However, the shunt coil must be cut out of circuit to accomplish this, when the breaker opens. This is done by means of an auxiliary switch on the breaker. Two screws, one at each end of the calibration scale, prevent the calibration cam moving beyond its range.

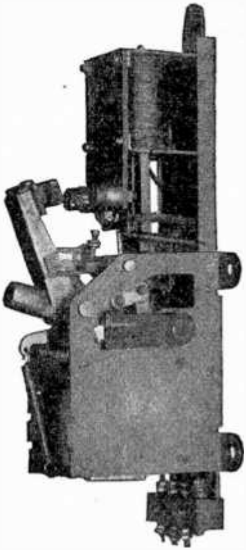


FIG. 4,163.—Operating mechanism. *It consists of* a closing coil and a relay mounted within a network breaker housing. It is equipped with a socket by means of which the breaker can be operated by hand when required. Placed just above the closing coil is the under voltage release attachment which, together with the operating mechanism, is enclosed in a metal housing as a protection against dirt and insects. The reactive shunts are composed of bundles of laminated iron, stacked on a copper bar, and mounted under the poles of the carbon breaker. The size of the shunt, or the amount of laminated iron, depends on the ampere rating of the network unit. The purpose of the reactive shunt is to limit the rate of the flow of the current through the relay current coils, which would have to be especially designed to carry an extremely wide range of current if connected directly in the line or across a non-inductive shunt. Owing to the saturation of the iron, the percentage of line current which the relay coils receive decreases rapidly with the increase of current flowing through the breaker. Furthermore, since the iron is saturated at a comparatively low value of current, the shunt reactance drop for a large line current does not reach an excessive value. The Tungsten lamps are of the standard miniature base type, and when hot, have about ten times the resistance as when cold. Therefore the current in the phasing coils does not increase in direct proportion to the impressed voltage. The impressed voltage varies from a few volts (when the transformer voltage is in phase with, and slightly higher than, the network voltage) to twice the full line voltage. It is obvious that some method of this nature is essential in order to secure sufficient sensitivity on low voltages and yet protect the coils against excessive currents on high voltages. The aux. switch A, (fig. 4,165) is a small contact making device which is closed upon energizing the under voltage release coil. It is mounted as part of the operating mechanism, between the closing coil and the mechanism relay. The closing of the auxiliary switch contacts completes a circuit across the line, through the closing coil of the operating mechanism, thereby causing the main breaker to close. It is so arranged that it will open as soon as the breaker is latched in, and thereby de-energize the closing coil.

A secondary network is *an interconnected low voltage system in which common mains, fed by a number of distribution transformers located at separate points are used to supply energy to numerous customers.*

A secondary network may be single phase, two wire; single phase, three

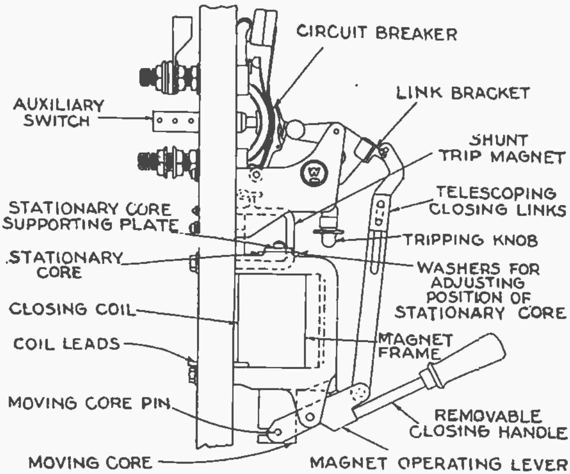


FIG. 4,164.—Westinghouse carbon circuit breaker solenoid closing mechanism. The closing solenoid coils have a short time rating and in order to avoid burning them out must be cut out of circuit as soon as the breaker is closed and latched. This is ordinarily done by means of a control drum switch and a small contactor which is connected in series with the closing coil. When the control drum switch is turned to the "on" position, the contactor closes and energizes the closing coil. After the breaker is closed, the operator cuts off the closing coil by allowing the control drum switch to return to neutral position. This releases the contactor, which in turn opens the closing coil circuit. Telescoping closing links are provided which permit the closing magnet to retrieve by gravity after the breaker is closed.

wire; two phase, three wire; two phase, five wire; three phase, three wire, or three phase, four wire.

When a fault develops in a transformer or feeder supplying a secondary network, the network will feed back into the fault. If this condition continue, the heavy feed back current will result in a decided drop in voltage and may cause considerable damage to the transformer or feeder at fault.

Special protective devices of the reverse power type should be employed. to disconnect the transformers and network. They should, however, be non-automatic on overload, as it is usually desirable to permit low voltage troubles to burn themselves clear. To make possible, therefore, the satisfactory operation of *a.c.* secondary networks, the *a.c.* automatic network circuit breaker has been developed.

A typical *a.c.* automatic network circuit breaker consists of

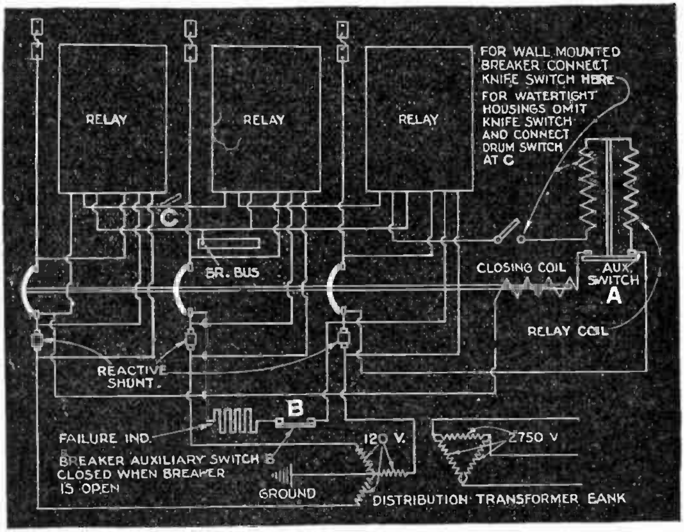
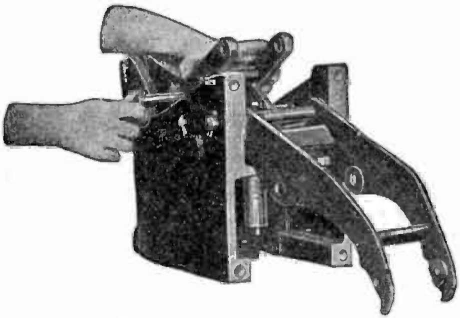


FIG. 4,165.—Wiring diagram showing connections for 500 ampere, 3 pole, 3 phase Westinghouse automatic network circuit breaker unit. The thermal operation indicator consists of a resistor tube surrounding a phial of wax. When the circuit breaker is opened, the resistor is connected across the distribution transformer by means of the auxiliary switch B. If the transformer be energized, and the circuit breaker fail to close, the resistor heats, causing the wax to melt and run down the sides of the phial. This action provides a reliable record of the failure of the network unit to close. In the closed position, the breaker is locked and can only be opened manually. The neutral position leaves the breaker and mechanism free to operate normally, while the open position blocks the main breaker contacts open, and in addition, opens a series switch in the operating relay mechanism coil circuit. This gives double assurance against closing.

an electrically closed and tripped carbon circuit breaker with a group of relays as illustrated in fig. 4,162.

Care of Circuit Breakers.—A reasonable amount of attention should be given to circuit breakers to obtain the best results. All bearings must be lubricated so that the moving parts will work without undue friction or wear. To determine if it be necessary to make adjustment, an impression should be taken on



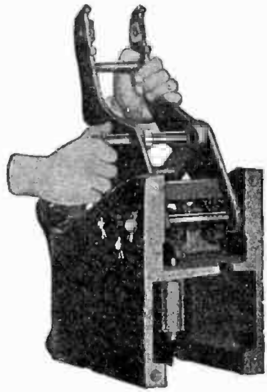
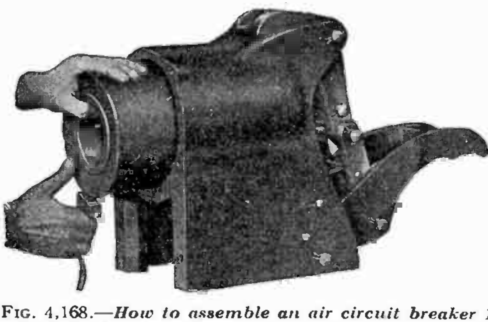


FIG. 4,166.—*How to assemble an air circuit breaker 15.* Connecting the toggle links to the main toggle.

FIG. 4,167.—*How to assemble an air circuit breaker 16.* Connecting the links to the brush support.



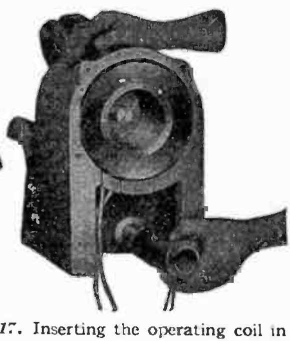


FIG. 4,168.—*How to assemble an air circuit breaker 17.* Inserting the operating coil in the solenoid magnet frame.

FIG. 4,169.—*How to assemble an air circuit breaker 18.* Inserting the trip coil in the solenoid magnet frame.

paper by closing the brush with the paper inserted between the brush and the contact block, after first having rubbed the contact surface of the brush and block with vaseline as shown in fig. 4,181. As little vaseline as possible should be used, but care should be taken to see that the entire surface is covered.

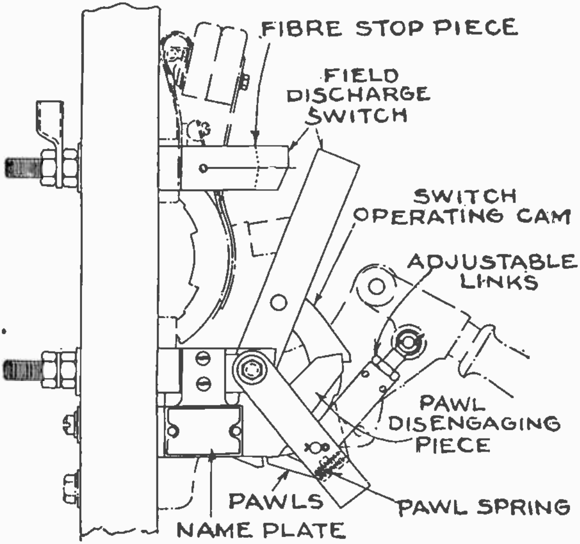
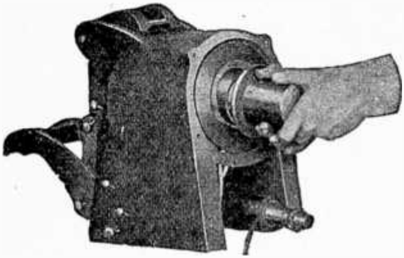


FIG. 4,170.—Westinghouse carbon circuit breaker. Field discharge attachment. Field discharge circuit breakers are used to protect the shunt fields of large separately excited dynamos. The standard arrangement consists of a single pole or two pole hand or solenoid operated carbon circuit breaker without overload trip, but equipped with shunt trip, auxiliary switch and field discharge attachments. The field discharge attachment, when the breaker opens, connects a resistor across the dynamo shunt field and thus discharges whatever voltage may have been induced in this winding when it was disconnected by the breaker from its normal voltage supply. If this were not done, the excessive voltages induced in the field winding would break down its insulation.

If brushes be found to make only partial contact and this condition cannot be corrected by increasing the tension of the brush, no attempt should be made to improve the contact by filing the surface of the brush or the contact block, nor should sand paper or emery be used for the purpose, as the contacts are almost sure to be injured by such procedure.

It has been found that, when a circuit breaker is allowed to remain closed



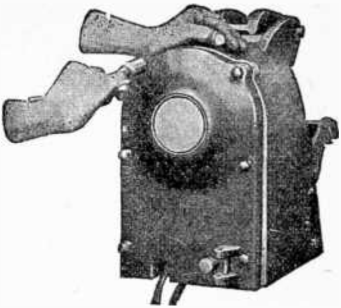
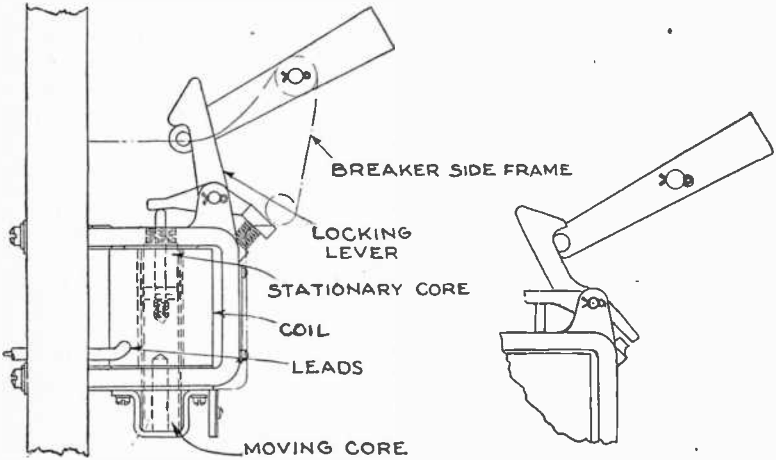


FIG. 4,171.—*How to assemble an air circuit breaker 19.*—Attaching the plungers and collars.

FIG. 4,172.—*How to assemble an air circuit breaker 20.* Attaching the cover to the solenoid magnet frame.



FIGS 4,173 and 4,174.—Westinghouse carbon circuit breaker electric lockout attachment. There are times when it is desired to lock a breaker in the open position when certain conditions exist. For this purpose a lockout attachment is provided which either latches the breaker open or else interposes an arm which opposes the movement of the brush. Depending upon requirements the coil may lock the breaker open when energized or it may be so arranged as to lock the breaker open when de-energized.

for long periods, the contact surfaces gradually oxidize, and that this oxidation greatly increases the resistance of the contacts, and heating results. The design of the circuit breaker is frequently thought to be the cause of this heating, while, as a matter of fact, if the circuit breaker had been frequently operated, no such trouble would have been experienced. In order to insure against trouble of this kind, arrangements snould be made to have the circuit breaker opened and closed vigorously at least once a week, for a dozen times or so. This would impose no real hardship on the attendant, and would save repair and replacement bills.

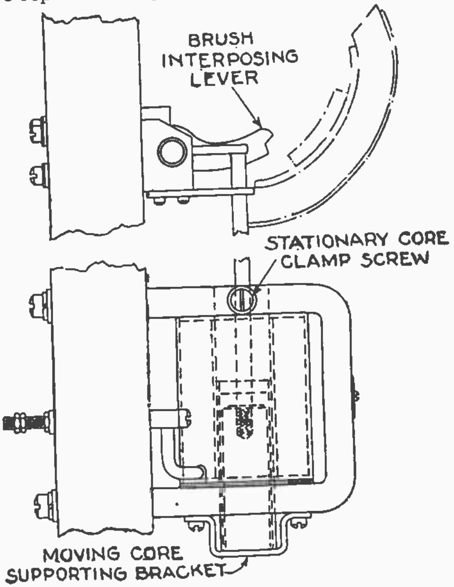
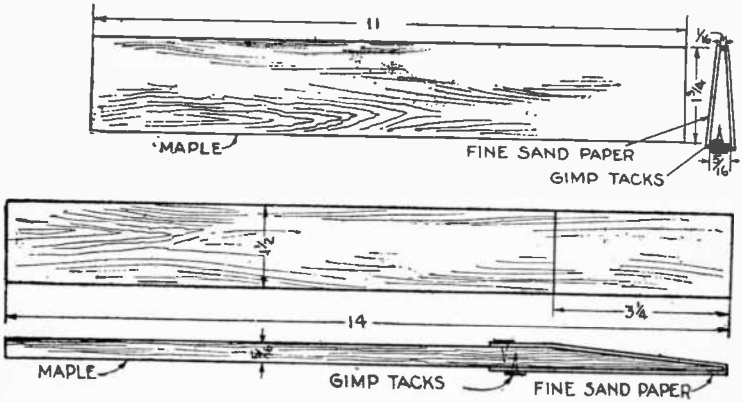


FIG. 4,175.—Electric lockout attachment, arranged to lockout when coil is de-energized.

In operation, the circuit breaker is closed electrically by means of an *a.c.* solenoid, and is tripped electrically by means of an undervoltage coil (mechanism relay). The contacts of the master relays are connected in series with the coil of the mechanism relay, so that, when these contacts are opened, the coil is energized and, when the contacts are closed, the coil is de-energized, When the mechanism relay coil is energized, it closes an auxiliary switch *A*, in series with the closing coil. This switch connects the closing coil across the line and causes the circuit breaker to close automatically. The instant the circuit breaker is latched, however, this same auxiliary switch cuts off the closing coil so that it is on the line only during the closing operation. As long as the mechanism relay coil is energized, the circuit breaker remains closed. When the mechanism relay coil is de-energized, which occurs when the master relay contacts open, the circuit breaker trips.



FIGS. 4,176 to 4,179.—Sand paper holder. ***Care of circuit breaker*** main contacts. In regard to heating, the main brush is the vital part of the circuit breaker. When in good condition it should carry rated current at a temperature rise not exceeding 30° C. above ambient temperature. While it is true that overheating may be due to any one of a number of other causes, it is due in a large majority of cases to poor condition of the main brush contacts. Assuming that the current flowing through the brush is no more than its normal rating, abnormal temperature may be due to: 1, insufficient contact pressure; 2, poor electrical contact between brush and stud head. For the first case an adjustment is provided so that proper contact pressure can be obtained. An eccentric pin in the closing toggle when unclamped and turned by means of a screw driver so as to move the brush closer to the studs will give whatever increased pressure is required, as in fig. 4,129. In the second case poor electrical contact may be due either to copper oxide formation on the contact surface or else to failure of some of the brush laminations to touch the stud head. It should not be assumed that when a circuit breaker stays closed for a long time that it needs no attention. Oxides form just the same and the circuit breaker should be opened occasionally so that the upper and lower brush contacts and stud heads may be cleaned with fine sand-paper. A good way to hold the sandpaper is here shown. To determine whether the brush and stud heads be making good contact mark the brush contact surfaces with a soft pencil. Place thin pieces of paper under the brush and then close the circuit breaker. An imprint on the paper of every lamination of the brush indicates good contact. On the other hand, blank spaces here and there will indicate that some of the laminations are not touching. In this case it will be necessary to refit the brush very carefully by means of a file until it makes a good contact.

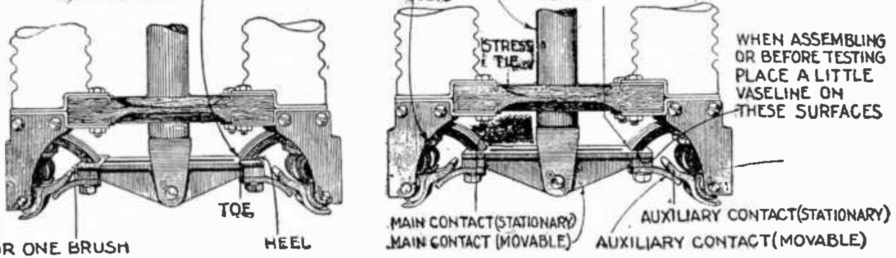
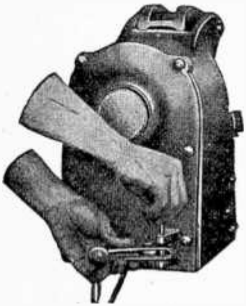


Fig. 4,180 and 4,181.—General Electric oil circuit breaker contacts showing method of obtaining contact impression. Fig. 4,180 shows the proper condition of the contacts when the breaker is latched closed. Make contact adjustment by means of the adjusting nuts which hold the unit pole operating rod to the main lever of the unit pole operating mechanism, but do not draw blades up too far and thereby strain the laminations. Do not alter the adjustment of the bolts which hold the brush to the stud unless the toe of the brush fail to make contact ahead of the other laminations.

The automatic operation of the circuit breaker is controlled by the master relays.

These relays are designed to open the circuit breaker under conditions of reverse energy flow; that is, when current flows from the network to the feeder. They are designed to prevent automatic reclosing of the circuit breaker, unless the voltage and phase relations between the network and distribution transformers be correct. These relays are the single phase induction type with revolving copper disc. Two independent sets of coils serve to actuate the disc. One set, the current coils, is connected across a special reactance shunt, and in conjunction with the regular voltage coil, produces a revolving magnetic field which causes the copper disc to rotate,



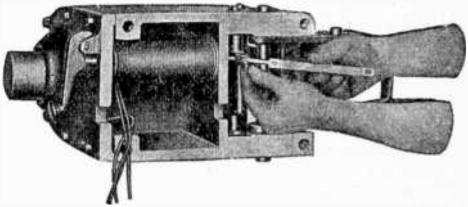


FIG. 4,182.—*How to assemble an air circuit breaker 21.* Attaching trip lever to solenoid magnet frame.

RIG. 4,183.—*How to assemble an air circuit breaker 22.* Assembling overload trip lever to the tripping link.

its direction depending on the direction of the energy flow. The current coils are in circuit only when the circuit breaker is closed, and consequently influence the operation of the relay while the line current is flowing.

Under the condition of normal energy flow, from the distribution

NOTE.—*Insufficient contact pressure.* If the contact pressure be not enough, it is obvious that tightening the nuts is the remedy. Insufficient contact area may be due to untrue surfaces on the nuts, studs or bus bars or terminals, or too small or too few nuts. Contact surfaces that were true when made may become untrue by being battered, raising high spots on the surface. When the amount of battering is small and the surface is plain, the best way is to carefully file off the high spots. If the amount of battering be large, it is best to machine the surface. Where it is the threads on the studs that are battered, they can usually be partially restored by filing away the high spots with a small three-cornered file.

transformers to the network, the current coils in conjunction with the voltage coil maintain the relay contacts in the closed position.

On the reversal of energy flow the copper disc revolves in the opposite direction, opening the relay contacts, which de-energizes the under voltage release coil.

This trips the circuit breaker open, disconnecting the transformers and network.

FIG. 4,184.—*How to assemble an air circuit breaker 23.* Method of placing the upper contact stud in position on panel.

FIG. 4,185.—*How to assemble an air circuit breaker 24.* Method of placing lower stud and overload magnet frame in position on panel.

The other set, the phasing coils, take the place of the current coils when the circuit breaker is opened.

They are connected directly across the circuit breaker, and in effect measure the *vectorial sum* of the transformer and network voltage.

If the transformer voltage be slightly higher than the network voltage, and in phase with it, these coils, in conjunction with the voltage coil, will cause the relay disc to revolve to the contact closing position. causing the circuit breaker to close.

A transformer voltage, equal to, or less than the network voltage, or out of phase with it, will cause the relays to revolve to the contact opening position, the circuit breaker remaining open.

Should the network circuit breaker fail to close, the wax in the phial of the thermal operated indicator will melt, indicating its failure. Failure of the

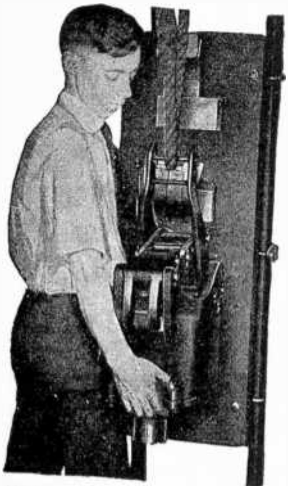
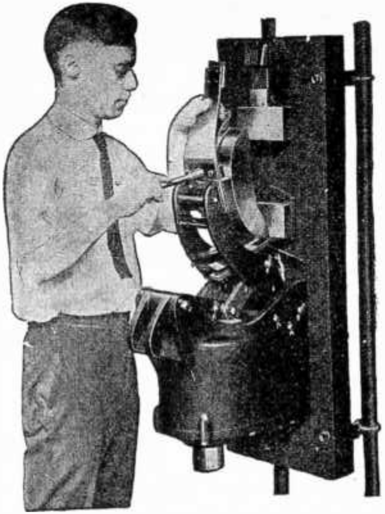


FIG. 4186.—*How to assemble an air circuit breaker 25.* Method of placing solenoid and operating mechanism in position on panel.
FIG. 4187.—*How to assemble an air circuit breaker 26.* Assembling brush to brush lever.

circuit breaker to open, or the reversal of current can be detected at the sub-station by feed back indication. Fuses provide ultimate protection in case the unit fails to open on a high voltage feeder fault or short circuit.

The mechanism relays will trip the circuit breaker on drop in the voltage due to a secondary short circuit immediately adjacent to the distribution transformers.

The general practice is to supply no protection against ordinary secondary short circuits, but to depend on the current to burn them clear.



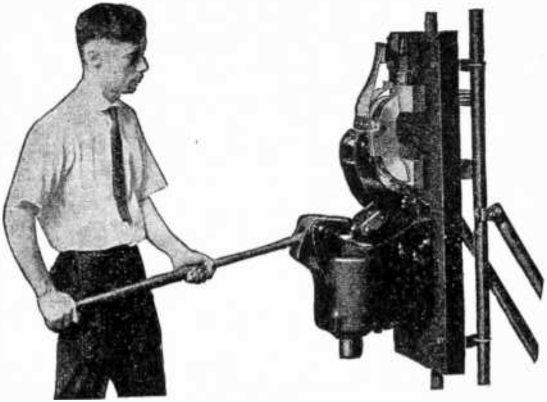


FIG. 4,188.—*How to assemble an air circuit breaker 27.* Attaching secondary spring to brush.

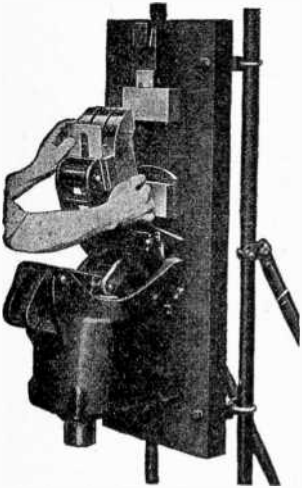
FIG. 4,189.—*How to assemble an air circuit breaker 28.* Closing solenoid operated air circuit breaker with hand lever.

Therefore, sufficient feeders of proper capacity must be connected to the network, so that the failure and the removal from service of one of the feeders will not affect the continuity of the service.

It will be seen from the foregoing description that the network circuit breaker of each feeder opens when the feeder station circuit breaker is opened at the sub-station.

This affords a means of disconnecting the transformers during light load periods. It will be seen also that the network unit breaker closes automatically to reconnect the transformer to the system when the station feeder breaker is again closed. This results in enabling the station attendant to operate the system so as to eliminate light load iron losses and secure the maximum transformer efficiency.

It will further be noted that the transformers on a feeder



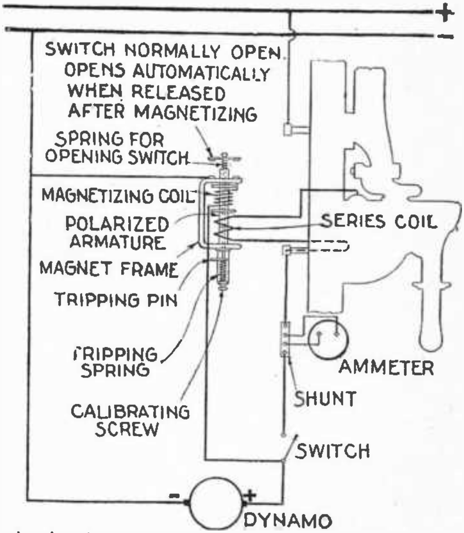


FIG. 4,190.—*How to assemble an air circuit breaker 29.* Adjusting brush for perfect contact condition.

FIG. 4,191.—Connection diagram for General Electric reverse current air circuit breaker for capacity up to 600 amperes.

FIGS. 4,192 to 4,194.—Impressions made on paper showing proper contact condition. Each lamination of the hub will leave a distinct impression for its total length if contact be good.

circuit will be automatically disconnected from the network in the event of a primary short circuit, and thus clear the trouble from that part of the distribution system. This permits operating the network from the other feeders.

TEST QUESTIONS

1. *What is the difference between a circuit breaker and a switch?*
2. *Describe an oil circuit breaker.*
3. *What happens when an oil circuit breaker opens a loaded circuit?*
4. *Give classifications of circuit breakers.*
5. *What is the difference between a circuit closing, and a circuit opening circuit breaker?*
6. *Describe the under voltage release attachment.*
7. *What is an inverse time limit overload attachment?*
8. *Describe a shunt trip attachment.*
9. *What are high speed circuit breakers used for?*
10. *Describe the operation of a high speed trip circuit breaker.*
11. *Describe in full detail how to assemble a circuit breaker.*
12. *Describe a reverse current trip circuit breaker.*
13. *What is a network?*
14. *Describe the operation of an automatic network circuit breaker.*
15. *Describe the solenoid closing mechanism.*
16. *Describe the method of caring for circuit breakers.*

17. *What happens to the contact surface when a breaker is allowed to remain closed a long time?*
18. *How are the contact surfaces put in proper condition?*
19. *What is the object of an electric lockout attachment?*
20. *What results from insufficient contact pressure and area?*

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