COYNE

Electrical School

CHICAGO ~ ~ ILLINOIS

ESTABLISHED 1899

ARMATURE WINDING AND TESTING

Section Two

Principles of A C Motors and Generators
Single and Polyphase Machines
Winding Stators
Connecting Stators
Star and Delta Connections
Reconnecting for Changes in Voltage
Speed, Frequency, Phases
Insulating Varnish, Baking
Stator Troubles and Tests

ALTERNATING CURRENT WINDINGS

The previous section covered the windings for D. C. generators and motors only. This section will deal with the principles and windings of A. C. machines.

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

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

59. PRINCIPLES OF A. C. GENERATORS

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

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

In the Elementary Section on magnetic induction we learned that the direction of induced voltage in any conductor depends on the polarity of the field or direction of the lines of force, and the direction of movement of the conductor.

In Fig. 39-A and B we have another illustration of this to examine closely. At "A" the lines of force from the field poles are passing downward and the conductor is being moved to the right. This will induce in the wire a voltage that will tend to cause current to flow in at the end we are facing, or away from us, if this conductor is part of a closed circuit. Check this with the right-hand rule for induced E. M. F. in generators.

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

Try this rule also with Fig. 39-B, where the conductor is moving in the opposite direction, through the same direction of magnetic field; and you will find the induced voltage has reversed with the direction of the conductor movement.

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

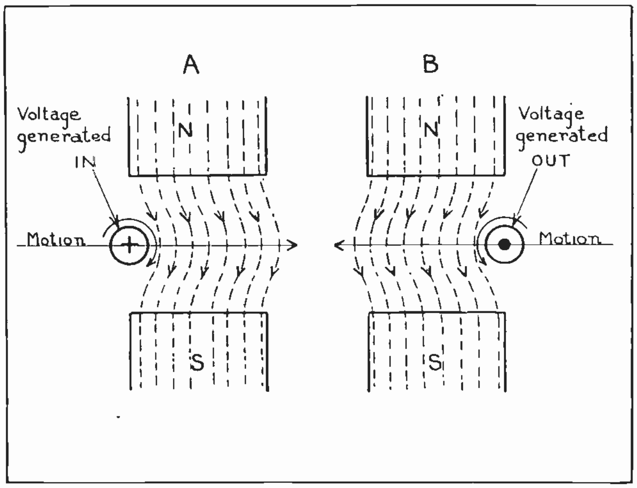

Fig. 39. This diagram illustrates the method of producing E.M.F. in conductors by cutting them through magnetic lines of force. Note carefully the direction of the induced voltage at both "A" and "B".

In Fig. 40-A we have two conductors of a coil, mounted in slots of an armature and revolving clockwise. In their position at "A" the conductors are not generating any voltage, as they are in the neutral plane and are not cutting across lines of force. At "B" the direction of induced voltage will be "in" at conductor "F" and "out" at "G"; so if the conductors are connected together at the back of the armature their voltages will add together.

In Fig. 40-C the conductors are both in the neutral plane again, so their induced voltage once more falls to zero.

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

A curve indicating the voltage generated is shown under these various steps of generation in Fig. 40. At "A" the voltage curve is starting at the zero line, as the conductors start to enter the field flux. At "B", where the conductors are cutting through the dense field directly under the poles, the curve shows maximum positive voltage. From this point it falls off gradually as the conductors pass out of the flux at the poles, until it again reaches zero at "C". Then, as the conductors each start to cut flux in the opposite direction, the curve shows negative voltage in the opposite direction or below the line, reaching maximum value at "D". At "E" the negative voltage has again fallen to zero.

60. CYCLES AND ALTERNATIONS

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

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

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

61. FREQUENCY OF A. C. CIRCUITS

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

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

For example, if a four-pole machine is rotated at 1800 R. P. M., the frequency of the current it produces will be 60 cycles per second. Its conductors will pass two pairs of poles per revolution, or 1800 × 2 = 3600 pairs of poles per minute. Then, as there are 60 seconds in a minute, 3600 ÷ 60 = 60 cycles per second.

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

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

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

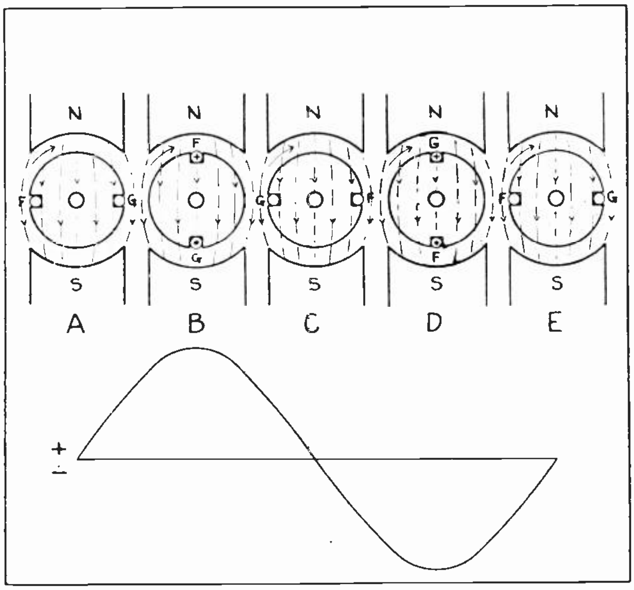

Fig. 40. The above diagram shows step by step the development of a complete cycle of alternating current voltage. Compare each of the generator sketches with the voltage of the curve directly beneath it.

62. REVOLVING FIELD ALTERNATORS

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

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

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

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

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

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

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

63. SINGLE PHASE CURRENTS

Fig. 41 shows a sketch of a simple revolving field alternator, with one coil in the slots of the stator or stationary armature. The circles in the slots show the ends of the coil sides, and the dotted portion is the connection between them at the back end of the stator. Inside the stator core is a double two-pole field core with its coil, and mounted on a shaft so it can be revolved.

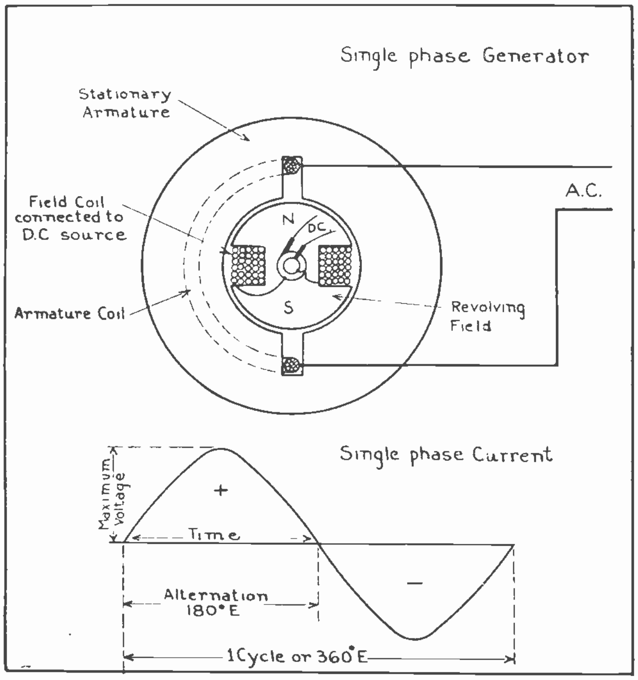

Fig. 41. Sketch of a simple single-phase alternator of the revolving field type, showing a single coil in the stator slots. The curve at the bottom of the sketch shows the single-phase alternating current which will be produced when the field revolves past the stator coil.

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

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

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

Fig. 42 shows a large alternator of the revolving field type, with 36 poles. Each revolution of this field will bring 18 pairs of poles past any given coil, and so produce 18 cycles per revolution. Then, if its speed is 200 R. P. M., 200 × 18 = 3600 cycles per minute, or 60 cycles per second.

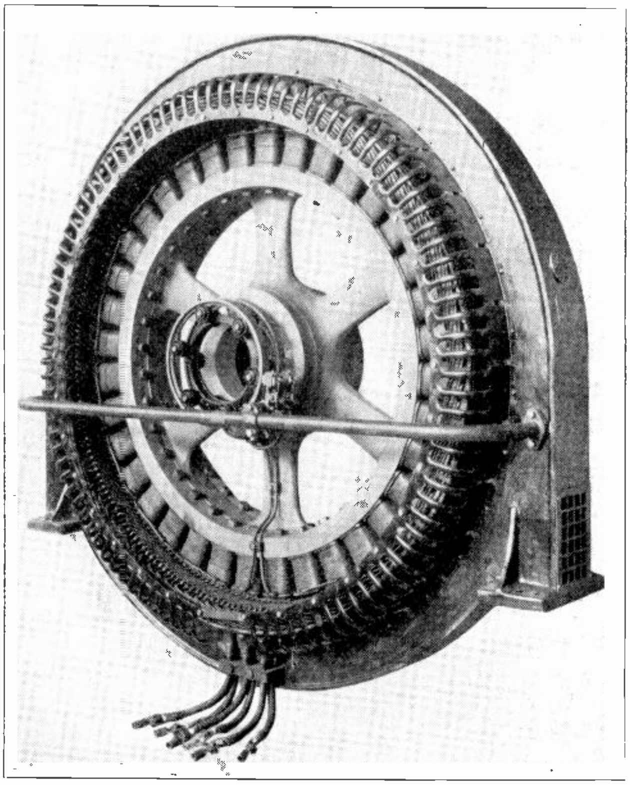

Fig. 42. This photo shows a large 36-pole alternator of the revolving field type. Examine its construction carefully as you study the explanation given on this page.

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

The generator shown in Fig. 41 will produce what is known as **Single Phase** alternating current, as shown by the curve in this same figure.

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

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

Even if the generator in Fig. 41 had a number of stator coils connected in series and just two leads connected to the group, it would still deliver single-phase current.

64. TWO PHASE CURRENTS

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

Fig. 43 shows a sketch of a simple 2-phase alternator, which has two separate coils placed in its stator at right angles to each other; or displaced 90 degrees from each other.

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

Instead, the voltages will come 90 electrical degrees apart, as shown in the curves in Fig. 43. The curve "A" shows the voltage generated in coil "A" as the poles pass its sides. As these poles rotate 90° farther their flux cuts across coil "B" and produces the voltage impulses shown by curve "B", which are all 90° later than those in curve "A".

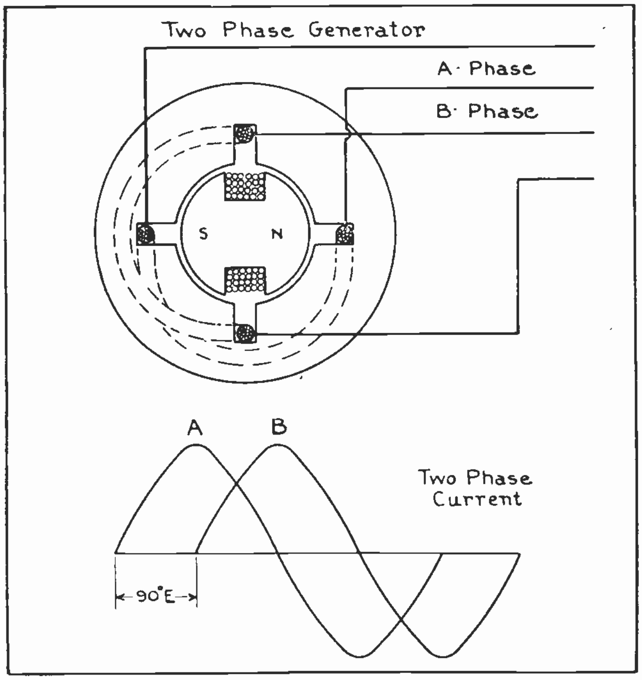

Fig. 43. Sketch of a simple two-phase A.C. generator or alternator. The curve at the bottom of the sketch shows the two-phase current that will be produced when the field revolves past the two coils in the stator.

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

So we see that a two-phase circuit is simply a circuit of two parts, or having two sets of alternations occurring 90 degrees apart. In the curve you will note that these alternations or impulses overlap each other, and that while one is at zero value the other is at maximum value. So with a circuit of this type there is always current flowing in one phase or the other as long as the circuit is alive. This feature is quite an advantage where the energy is used for power purposes, as these overlapping impulses produce a stronger and steadier torque than single-phase impulses do.

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

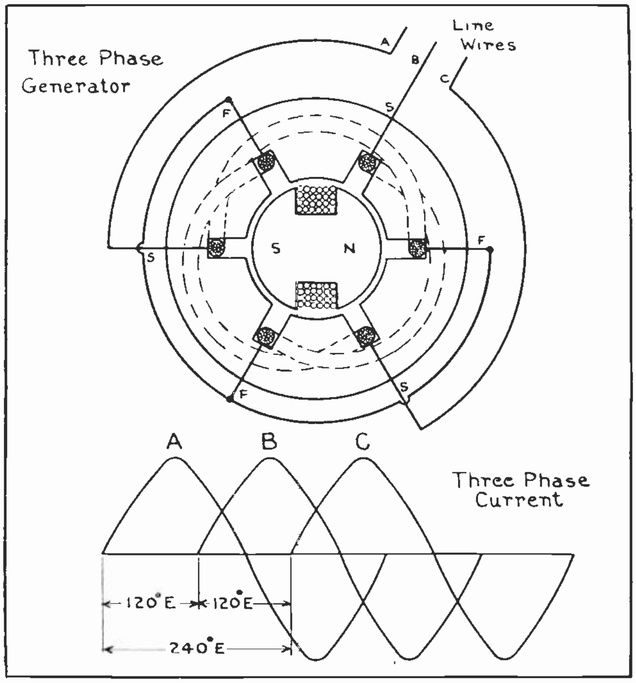

Fig. 44. This sketch shows the arrangement of the stator coils in a simple three-phase alternator and beneath it the curves for three-phase energy.

65. THREE-PHASE CURRENTS

Fig. 44 shows a sketch of a simple three-phase alternator, with three coils in its stator, and spaced 120 electrical degrees apart.

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

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

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

Additional features of single-phase and polyphase circuits and machines will be covered later. But,

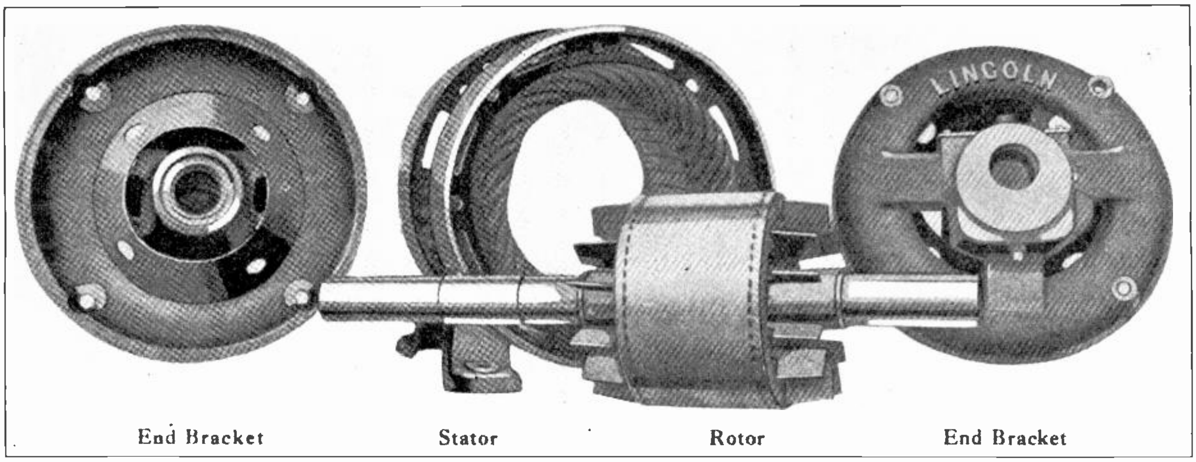

Fig. 45. Above are shown the more essential parts of an A.C. induction motor. Note carefully the construction of each part and the names by which they are called.

now that you know the difference between these forms of alternating current, you will be able to understand the various A. C. windings much easier.

66. CONSTRUCTION OF A. C. MOTORS

The most common type of A. C. motor is known as an **Induction Motor.** This name comes from the fact that the currents in the rotor are induced in it by the flux of the stator coils.

Fig. 45 shows the more important parts of an A. C. induction motor, with the names of each. Note that the stator coils are placed in the slots around the inside of the stator core very much as the coils of a D. C. armature are placed in slots around the outside of the armature.

67. ROTORS

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

The rotor shown in Fig. 45 is of the squirrel-cage type; and, instead of having wire windings, it has heavy copper bars buried in closed slots around its surface and all connected together by rings at each end.

Fig. 46 is a cut view of such a rotor, showing how the bars are imbedded in the core iron. The end rings are made of copper or brass; or, in some cases, of aluminum. The short blades on the end rings act as fans and set up an air draft to cool the rotor and machine windings while the motor is in operation.

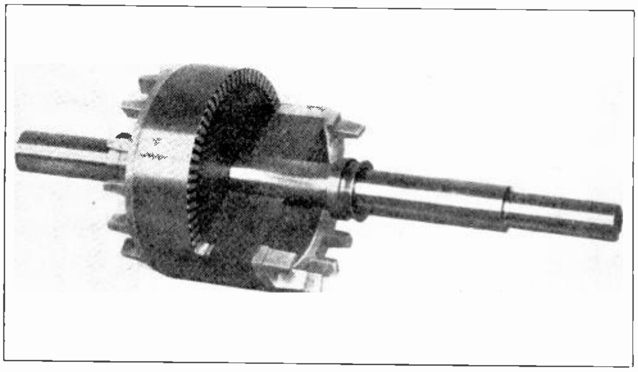

Fig. 46. This view shows a sectional view of a squirrel-cage rotor for an A.C. induction motor. Note the manner in which the copper bars are imbedded in the surface of the core.

Fig. 47 shows a slightly different type of squirrel-cage rotor, in which the ends of the bars can be seen projecting from the core ends. This rotor is also equipped with fan blades for ventilating the machine, and you can note the air space left between the laminations of the core. These spaces are also for cooling purposes.

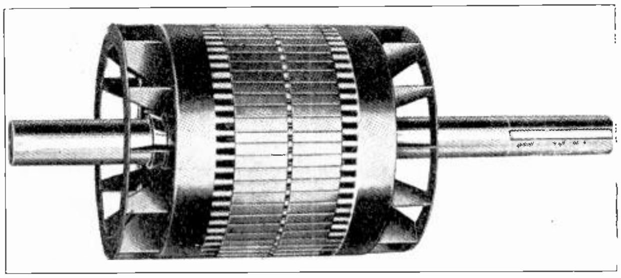

Fig. 47. Another style of squirrel-cage rotor showing the bars of the winding and also the ventilating fans.

The purpose of the end brackets shown in Fig. 45 is to support the bearings in which the rotor shaft turns. These bearings must always be in such condition, and the brackets so lined up, that they will support the rotor so that it does not rub or touch the stator core.

Fig. 48 shows in greater detail some of the smaller parts used in the construction of A. C. motors. In the center is shown the shaft to which the rotor core is keyed; and above this are a bearing sleeve, shaft key, oil ring, and stator coil. At the left end of the shaft is shown a rotor lamination, and beneath it an end ring and rotor bar. In the upper right-hand corner is a stator lamination, showing the shape of the slots and teeth; and below this is one of the frame rings used for clamping together and supporting the stator core laminations.

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

68. STATORS

Stators for A. C. motors are constructed of laminations which are stamped from soft iron. One of these was shown in Fig. 48. The slots are cut on the inside of the stator cores, instead of on the outside as with D. C. armatures.

Two types of these slots are shown in Fig. 49. This view also shows the slot insulation and method of protecting the coils and wedging them into the slots.

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

The partly closed slots shown at "A" in Fig. 49 are used on small stators where the wires are fed into the slots a few at a time. The open-type slots as shown at "B" are used on large stators which have their coils wound and insulated before they are placed in the slots.

69. TYPES OF A. C. WINDINGS

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

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

The poles are wound in a spiral form, as shown in Fig. 50. The wire is started in the two slots to

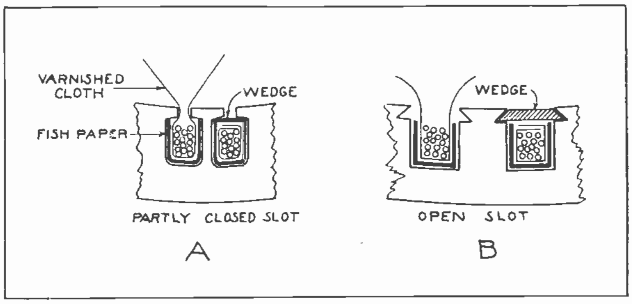

Fig. 49. The above diagram shows two common types of stator slots with the slot and coil insulation in place around the coils. Also note the wedge used for holding the finished coils in place.

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

70. SKEIN WINDINGS

Another method, which uses what is known as the **Skein Coil** for making spiral windings, is illustrated in Fig. 51.

In this method the long skein coil is first made up of the right number of turns and the proper length to form the several coils. The end of this skein is then laid in the center slots as shown at "A" in Fig. 51, and the long end given one-half

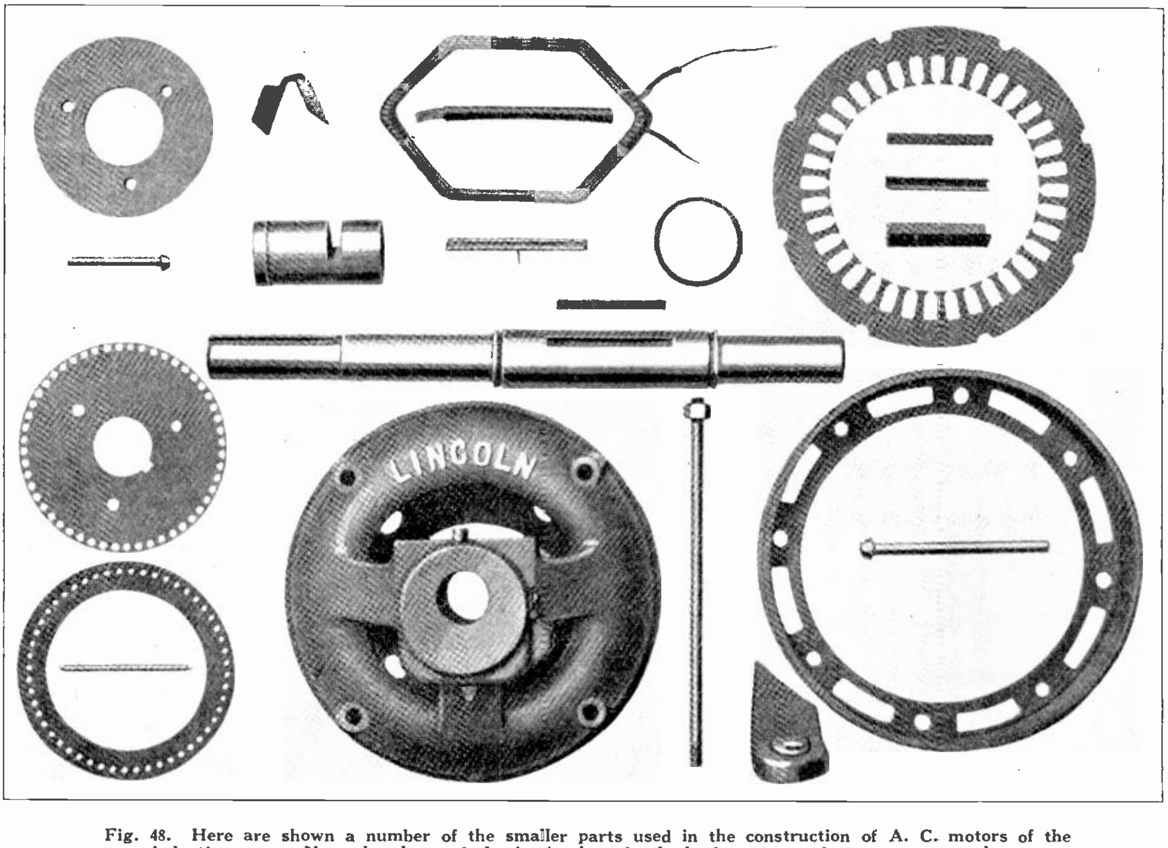

Fig. 48. Here are shown a number of the smaller parts used in the construction of A. C. motors of the induction type. Note the shape of the laminations for both the rotor and stator cores, and compare each of these parts with their explanations given on these pages.

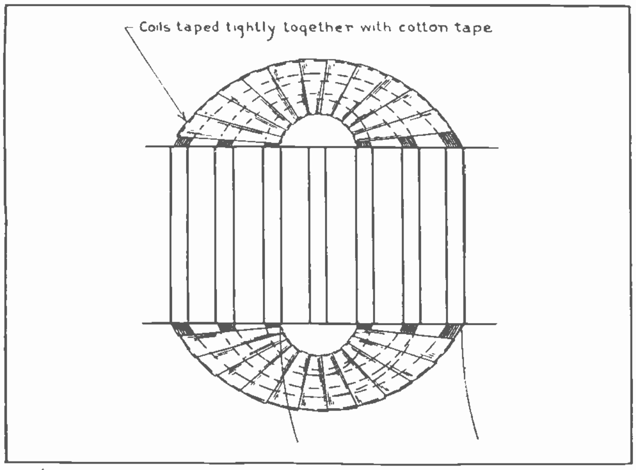

Fig. 50. This diagram illustrates the method of winding the coils for a spiral-type stator winding. Note how the wire continues from one coil to the other, as shown by the dotted lines under the tape at the lower end.

twist near the ends of the slots, as shown at "B". The remaining end is then laid back through the next two slots—at "C"—and again twisted one-half turn so its sides cross near the first coil end. Then the last loop is laid back through the outer two slots to complete the coils for this pole.

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

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

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

71. RUNNING AND STARTING WINDINGS FOR SINGLE-PHASE MOTORS

Single-phase A. C. motors of these small induction types generally have two windings called the **Running Winding** and **Starting Winding.** The first winding placed in the slots as we have just described is the running winding. The starting winding is always placed in the slots over the running winding coils after they are all in the slots. This starting winding is usually wound with wire about one-third as large as that used for the running winding, and with about half as many turns. The starting winding coils are displaced 90°, or exactly one-half the width of one pole, from the coils of the running winding.

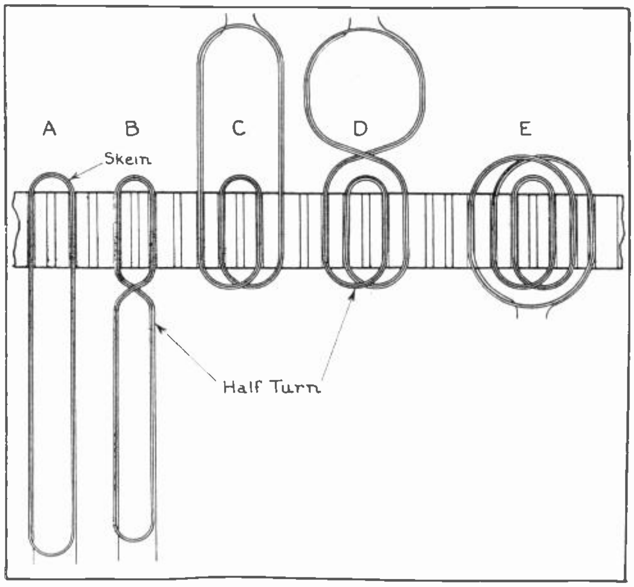

Fig. 51. Skein type windings as shown above are often used to save considerable time when winding a number of stators which are all alike. Note carefully the various steps of twisting the coil and laying it in place in the slots.

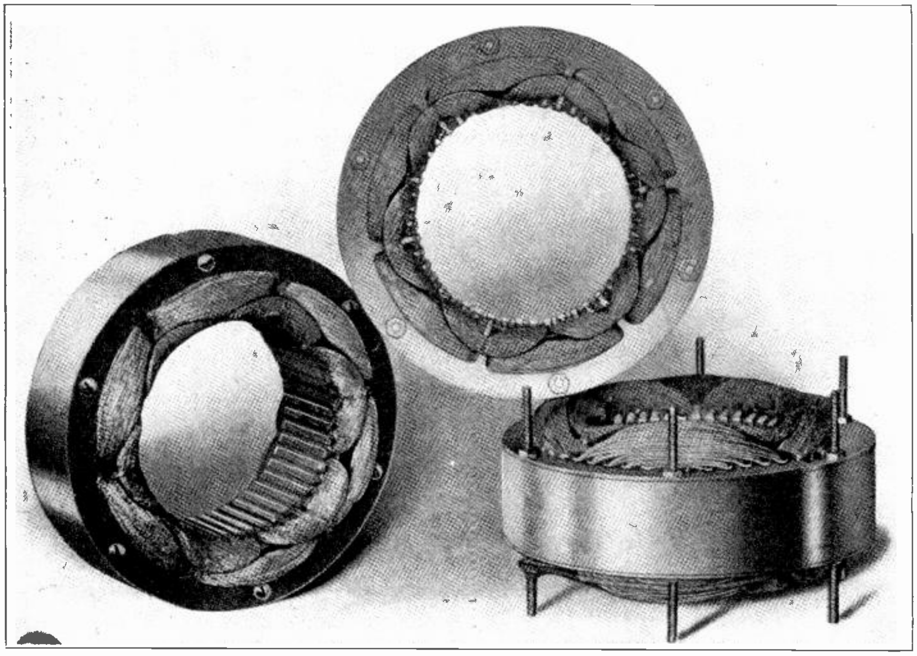

Fig. 52. On the left are shown several views of small single-phase stators for A.C. induction motors. Both the starting and running windings can be clearly seen in each of these views. Note how the starting winding overlaps the coils of the running winding about one-half their width or 90 degrees. This type of winding is known as a single-phase split-phase.

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

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

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

Fig. 52 shows several small stators and the positions of their starting and running windings.

72. CONNECTIONS OF STARTING WINDING

The starting and running windings are connected in parallel to the single-phase line, but a centrifugal switch is connected in series with the starting winding as shown in Fig. 53. This switch is arranged so that when the motor is idle it is held closed by springs.

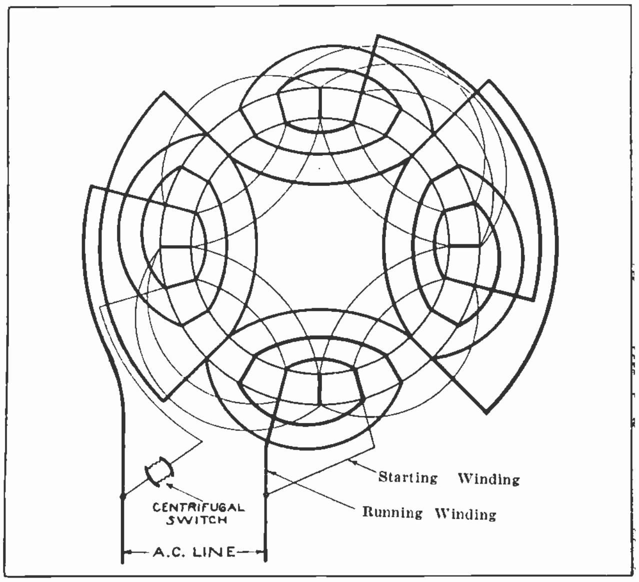

Fig. 53. The above diagram shows the complete circuits through both the starting and running windings of a single phase stator. Trace out each winding carefully and note how the coils are connected to produce alternate north and south poles around the stator.

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

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

Fig. 54 shows a simple sketch illustrating the method of connection of the starting and running windings to the line, and also the connection of the centrifugal switch. Remember that this switch must always be connected in series with the starting windings.

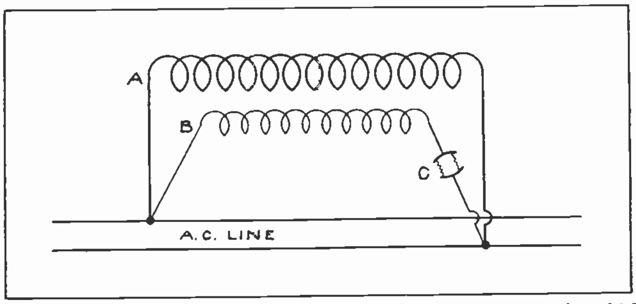

Fig. 54. This is a simplified diagram showing the manner in which the starting and running windings of a single phase motor are connected in parallel to the line. The centrifugal switch "C" is connected in series with the starting winding as shown.

73. CENTRIFUGAL SWITCHES

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

Fig. 55 shows a sketch of one of the common types of these switches. The two views on the left show the stationary element, which is mounted on the end bracket of the motor; and the view on the right shows the rotating element, which is mounted on the shaft of the rotor. On the stationary element we have two terminals, "B" and "B", to which the line and starting winding leads are connected. These semi-circular metal pieces are separated from each other; so that there is no circuit between them

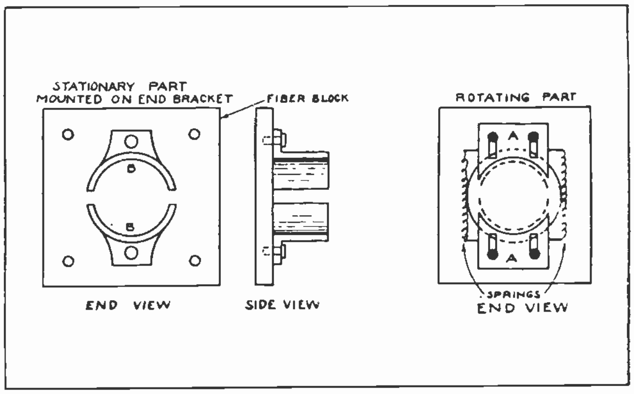

Fig. 55. These sketches illustrate the principle of a simple centrifugal switch, such as used for starting single phase motors. Examine each part closely as you read the explanations given on these pages.

except when the metal pieces "A" and "A" are drawn together over the cylinder formed by "B" and "B". This closes a circuit between them when the motor is idle. When the motor starts and begins to revolve at high speed the weight of the pieces "A" and "A" causes them to be thrown outward to the ends of their slots, thus disconnecting them from "B" and "B" and opening the circuit of the starting winding.

74. OPERATING PRINCIPLES OF TWO-PHASE MOTORS

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

Each of the windings in a two-phase machine, however, is of the same size wire and has the same number of turns. Instead of being wound with spiral coils, two-phase windings are generally made with diamond-shaped coils similar to those used in armatures. A section of a two-phase winding is shown in the lower left view of Fig. 56, and you will note the manner in which the three coils of each phase overlap in forming the winding for one pole of the motor.

In the upper view of this figure are shown the curves for two-phase current with alternations 90° apart. When this current flows through the two windings, it sets up poles that progress step by step around the stator so rapidly that it produces what is practically a revolving magnetic field. The progress of this field and the magnetic poles can be observed by tracing out and comparing the several views in Fig. 56. The dotted lines running vertically through the curves in the upper view indicate the polarity of the curves at that instant. These will be referred to as "positions".

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

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

At position No. 2 in the current curves, "B"-phase is still positive but "A" is changed to negative; so the current in the starting lead of "A"-phase will

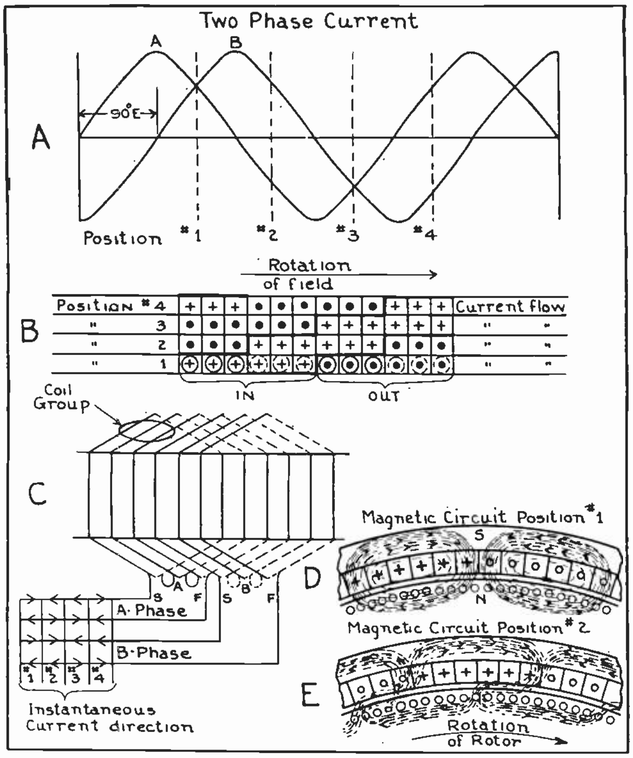

Fig. 56. The above diagrams show step by step the manner in which a revolving field is produced in a two-phase motor winding. Refer to each of the five sketches frequently when reading the descriptions in these columns. This figure illustrates a very important principle of induction motors and is well worth considerable study.

reverse as shown at position No. 2 and cause a reversal of the polarity around the "A" group. As this group covers the first half of the pole, these three slots will change in polarity. The first three slots of the second pole will also change and cause the pole to move over to the right three slots, as shown in position No. 2 of the field rotation sketch.

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

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

75. OPERATING PRINCIPLES OF THREE-PHASE MOTORS

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

If we observe the three-phase current curves in Fig. 57 we find that the alternations change polarity or cross the center line in the order A, C, B; A, C, B; etc. The coil groups should be wound in to correspond with these current changes, or in the order A, C, B; etc., as shown in Fig. 57.

A very interesting fact to know about three-phase systems is that at any given time the voltage or current curves above the zero line will exactly equal those below the line. For example, in Fig. 57 at position 1, A and B are each at about half their maximum positive value, while "C" is at full maximum negative value. A vertical line through these curves at any point will show the same voltage relation.

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

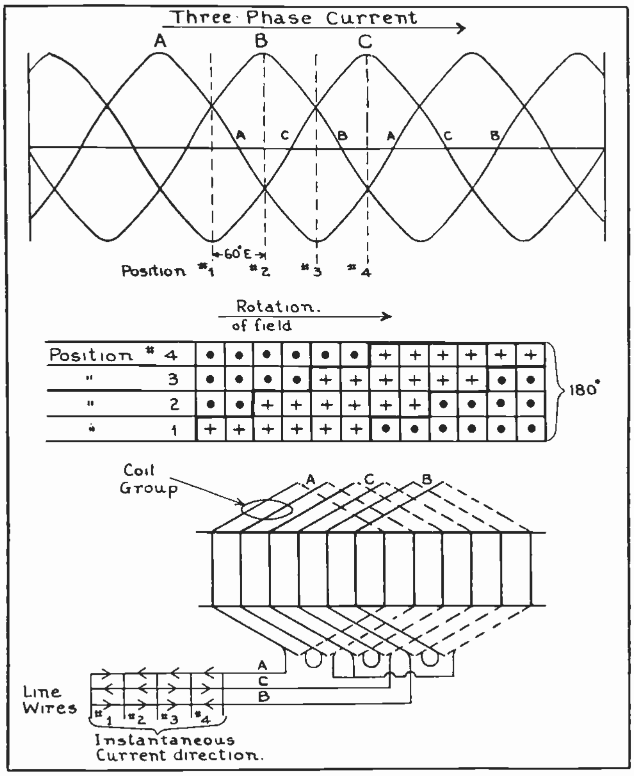

Fig. 57. The above diagrams show the development of the rotating field of a three-phase alternating current motor. Compare carefully the top, center, and lower diagrams and note the manner in which the field poles gradually advance in the slots as the current alternates in the three phases A, C, and B.

When these three currents flow through a three-phase winding, as shown in Fig. 57, three consecutive coil groups will be of the same polarity, and the next three groups will be of opposite polarity, thus building up alternate poles, N.S., N.S., etc.

Trace out and compare each of the positions 1, 2, 3, and 4 in Fig. 57 as was done in Fig. 56, and you will find how the field poles progress around the stator to produce a revolving magnetic field in a three-phase motor.

76. TERMS AND DEFINITIONS FOR A. C. WINDINGS

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

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

The formula for determining a coil group is:

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

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

The formula for determining full pitch coil span is:

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

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

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

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

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

The formula for determining the electrical degree per slot is:

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

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

77. LAP WINDINGS FOR A.C. MACHINES

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

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

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

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

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

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

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

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

78. TWO PHASE A.C. WINDING EXAMPLE

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

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

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

or, in this case,

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

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

A simple form of two-phase lap winding for two poles is illustrated in Fig. 58.

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

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

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

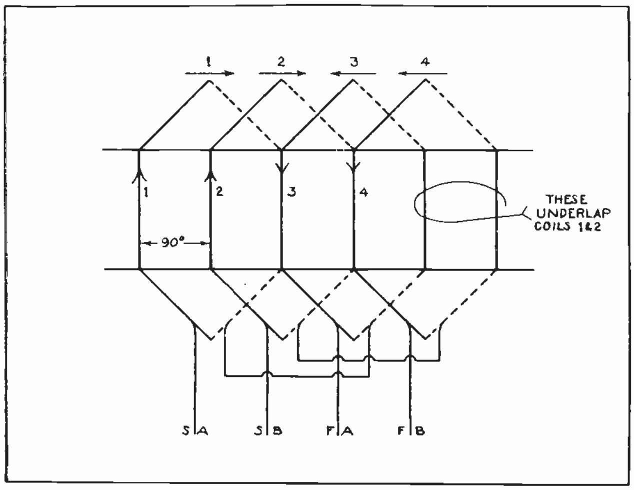

Fig. 58. This sketch shows the coils and connections of a simple two-pole, two-phase winding. Examine the connections of the coils carefully and note the direction of current in each coil.

79. COIL POLARITY IMPORTANT

When there is more than one coil per group the coils must be very carefully connected, as **all coils of the same group must be connected for the same polarity,** or, so that current flows in the same direction through all coils of this group. This is a very important rule to remember and is illustrated in Fig. 59.

The two coils in the group at "A" are properly connected; that is, the finish of one is connected to the start of the next; so that the flux will unite around the sides of these coils, as it should to produce the pole. The coils in group "B" are improperly connected, with the finish of one to the finish of the other. So in this case the current in the right hand coil is reversed. This causes the flux of the two coils to oppose and neutralize each other and therefore they cannot build up a strong magnetic pole in the stator core.

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

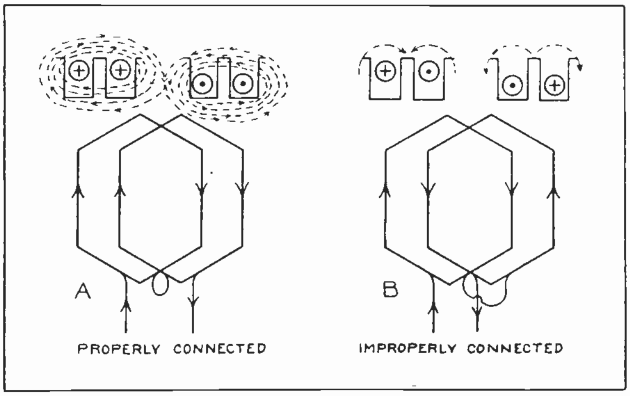

Fig. 59. Above are shown both the right, and wrong methods of connecting stator coils to obtain the right polarity. Note the conditions of magnetic flux set up in the slots with each connection.

Fig. 60 shows a simple two-pole, three-phase winding with one coil per phase group and three groups per pole. This winding only has one coil per group. Observe very carefully the method of connecting the coil groups together. You will note that they are connected to give alternate polarity —N, S, etc. Also note that there are two coil sides per slot, one lying on top of the other.

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

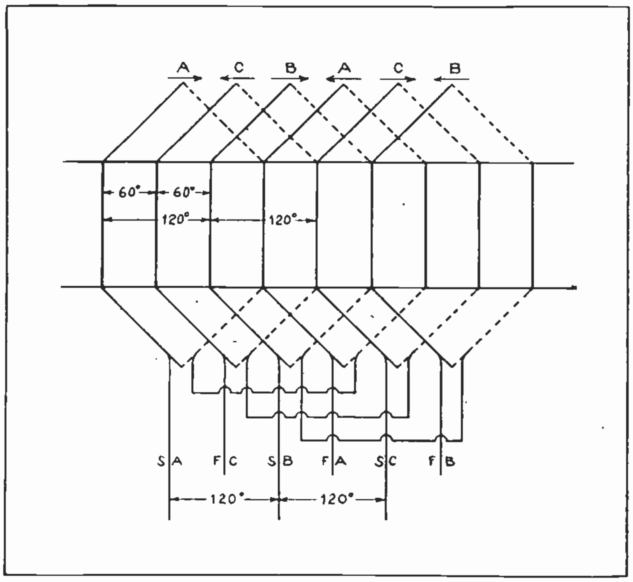

Fig. 60. This sketch shows a two-pole, three-phase winding. Note the spacing in degrees between the coil sides and line leads, and also the arrangement of the coil connections.

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

80. TYPES OF COILS FOR STATOR WINDINGS

Stators of 15 h. p. and under, and for less than 550 volts, usually have partly closed slots and are commonly wound with **"fed in"** or **"threaded in"** windings. For this type of winding we can use either the threaded-in diamond coil or what is known as a **basket coil.** Fig. 61 shows a coil of each type.

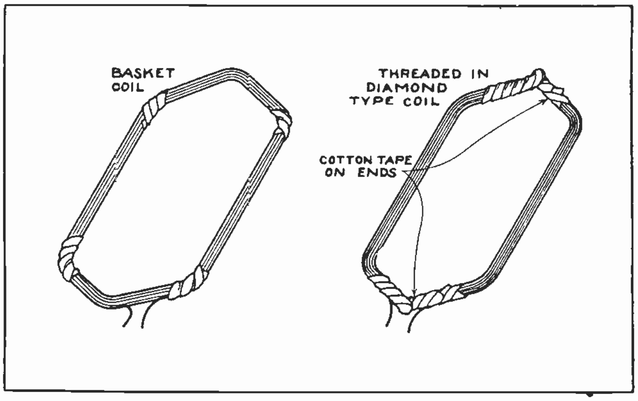

Fig. 61. Two common types of coils used in winding small stators with partly closed slots. These coils can be easily fed into the narrow slot openings.

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

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

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

81. PROCEDURE FOR WINDING A THREE PHASE STATOR

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

Let us apply the formula:

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

or, in this case,

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

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

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

or, in this case,

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

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

After the slots have been insulated, begin by placing one side of the first coil in any slot with the leads of the coil toward the winder, as shown in Fig. 62.

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

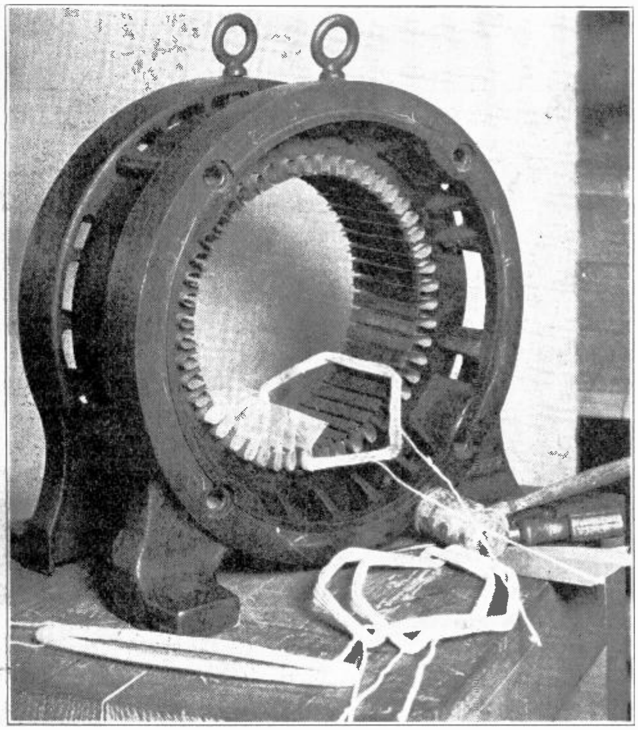

Fig. 62. This view shows a method of starting the first coil for a stator winding. The fish paper insulation is in all slots and the varnished cambric has been placed in several.

When the bottom side of the seventh coil is placed in the seventh slot, its top side is laid on top of the first coil, as shown in Fig. 63. The bottom of eighth coil is placed in the eighth slot and its top is placed on top of the bottom side of the second coil.

This procedure is followed until all the coils are in place, the bottom sides of the last six coils being slipped in under the first six coils, the top sides of which were left out of the slots. Fig. 64 shows a view of a stator from the back end, after the last

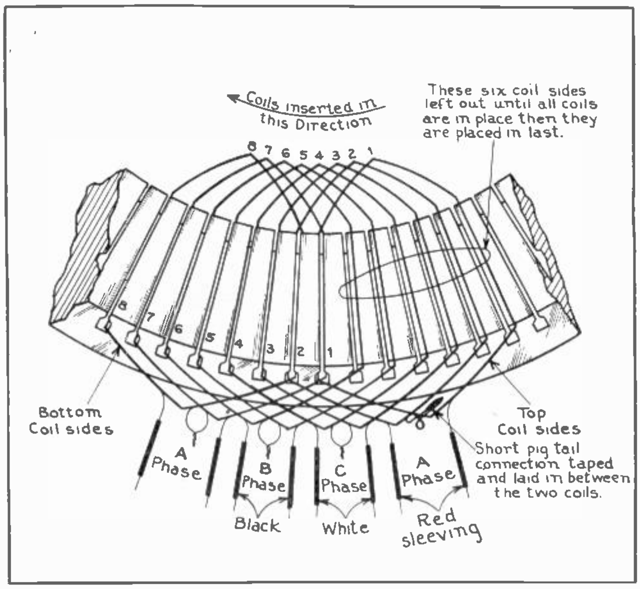

Fig. 63. This diagram illustrates the method of placing the first coils in a stator and the proper rotation for inserting them. Note the sleeving used for marking the leads of the different phase groups, and also the several coil sides which are left out of the slots until those of the last coils are inserted under them.

coils have been laid in under the top sides of the first coils. These top sides are now ready to be inserted in the slots and then the slot insulation can be trimmed, folded in over the coils, and the slot wedges put in place.

While the coils of the winding just described were laid in to the left of the first, or clockwise around the stator, they can be laid either clockwise or counter-clockwise, according to the shape of the end twist of the coils.

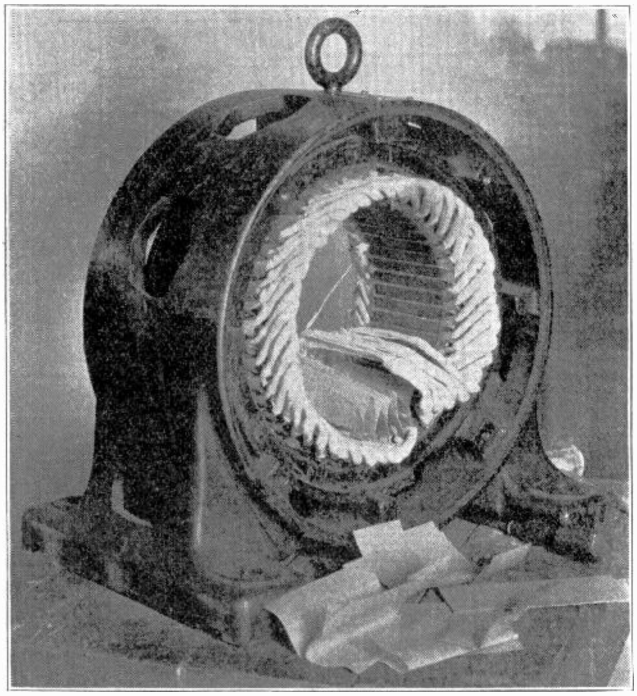

Fig. 64. This photo shows a stator winding nearly completed and ready for the top sides of the first coils to be placed in on the bottoms of the last coils which were inserted. The insulation has been neatly folded down over the coils in most of the slots.

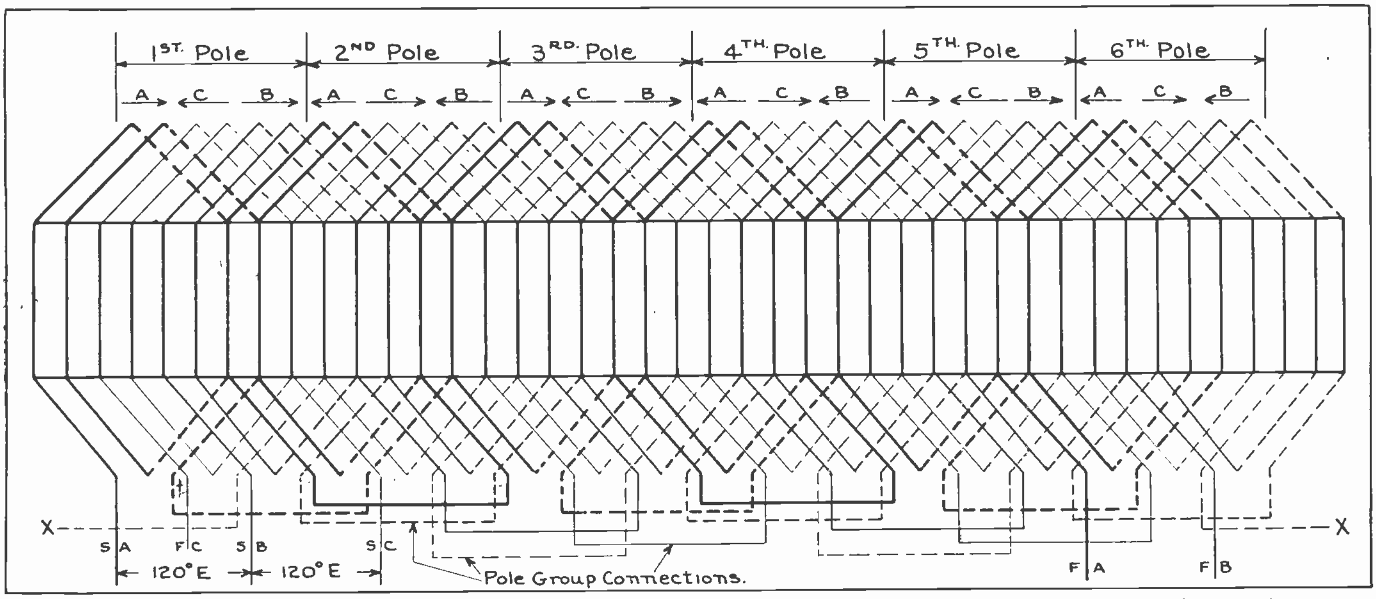

Fig. 65. Complete diagram of a three-phase, six-pole winding for a machine with 36 slots. The coils of each phase are shown in lines of different thickness in order that they may be easily traced through the winding. Trace these circuits very carefully and note the manner in which the coils are connected to obtain alternate N. and S. poles. Also note how the coil groups of each phase overlap to complete the three phases of each pole of the winding. Refer to this diagram frequently while studying the accompanying pages, and also at any time you may need it when connecting a three-phase winding.

82. MARKING AND CONNECTING COIL LEADS

In winding stators of small size it is general practice to connect the coils into groups as they are fed in the slots. You will notice in Fig. 63 that the bottom lead of the first coil is connected to the top lead of the second. The top lead of the first coil and the bottom lead of the second are identified or marked with sleeving of the same color. All of the following groups are connected together the same as the first; but the unconnected leads of the second group are marked with a different colored sleeving than the first, and the third group with still another color. For the fourth group we again use the same color as for the first, and from there on the colors are alternated on the other groups, the same as on the first three.

When all the coils of this 36-slot winding are in place there will be five more poles similar to the one in Fig. 63.

After the wedges are in the slots the pole group connections are made as shown in Fig. 65. This diagram shows the connections of the groups into a three-phase winding.

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

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

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

There will then be six leads left, three starts and three finish leads. In Fig. 65, these leads are marked SA, FC, SB, SC, FA, and FB, and you will note that they are all from top sides of coils. In selecting the starting leads for such a winding, we choose three groups which are close to the opening for the line leads in the frame or end-bracket.

Fig. 66 shows a complete connection diagram for a two-phase, four-pole winding with 24 slots. The coils are laid in the slots the same as for a three-phase winding. There are three coils per group and two groups in each pole. The coils are also connected into groups the same as for a three-phase winding, and the pole group connections made similarly, except with two groups per pole instead of three.

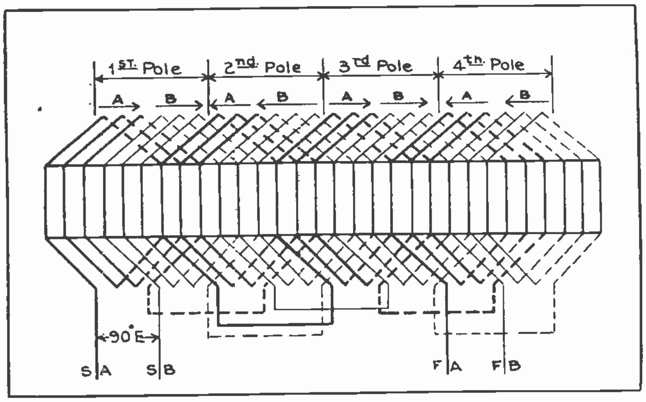

Fig. 66. Complete two-phase winding for a four-pole machine with 24 slots. Note the similarity between this diagram and the one in Fig. 65 as to the arrangement of coils and connections between pole groups; but also note that there are only two phase groups per pole, and the different spacing in electrical degrees between the leads in this winding and the three-phase winding in Fig. 65.

83. PROCEDURE FOR CONNECTING A 3 PHASE WINDING

Fig. 67 shows complete four-pole, three-phase winding in a stator with 48 slots. The coils are all in place, but no group connections have been made. You will note that all top and bottom leads are brought out at the points or ends of the coils, and all in the same position on the coils, in order to make a neat and systematic arrangement of the leads and to simplify the making of connections.

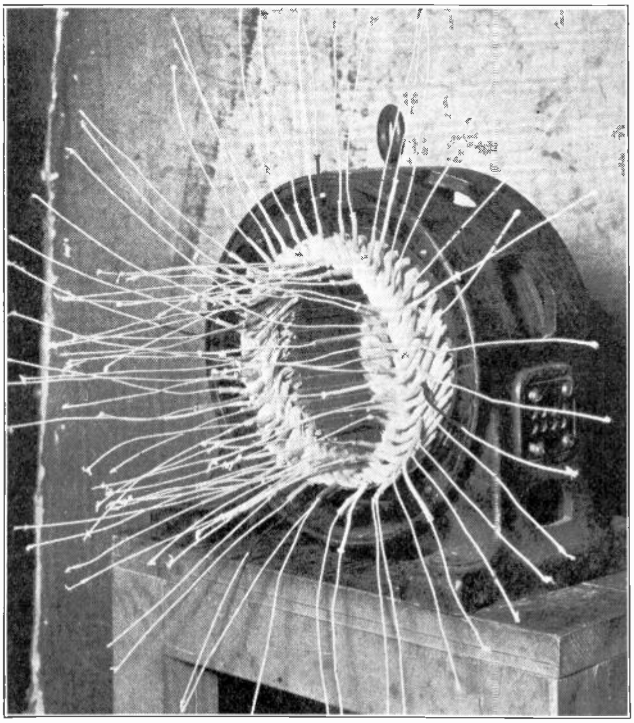

Fig. 67. The above photo shows a stator with 48 slots wound for four poles, three phase. The coils are all in the slots and the leads are marked with sleeving and ready for the connections to be made.

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

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

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

84. MAKING "STUB" CONNECTIONS

The next step will be to cut off all leads of the coil groups that are marked with the short sleeving, about 3 inches long. Strip the insulation from about 1½ inches of their ends; then connect them together, the bottom lead of one coil to the top of the next. This is shown in Fig. 68, and the pigtail splices of these coil groups can be plainly seen.

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

85. POLE AND PHASE CONNECTIONS

In Fig. 69 the coil-group connections have been soldered, taped, and folded down between the coil ends and the pole group leads have been connected together. The bottom lead of one group is connected to the bottom lead of the the next group of the same phase and color. The top lead of one group is also connected to the top lead of the next group of the same phase. This places all pole groups of each phase in series in the winding. These pole-group leads are commonly called **jumpers.**

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

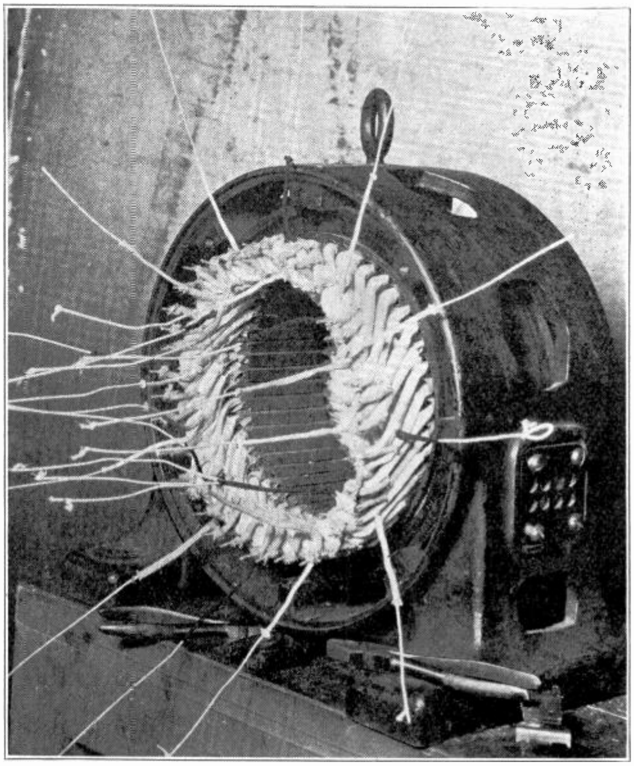

Fig. 68. This view shows the same stator as in Fig. 67, except that the coil group connections have been made. By looking carefully you can see the bare pig-tail splices of these connections around the winding. The pole group leads are not yet connected.

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

In Fig. 70 the three finish leads are shown connected together at the top of the machine, and the three start leads are connected to heavy rubber covered wires for the line leads.

The pole-group leads are now folded or pressed

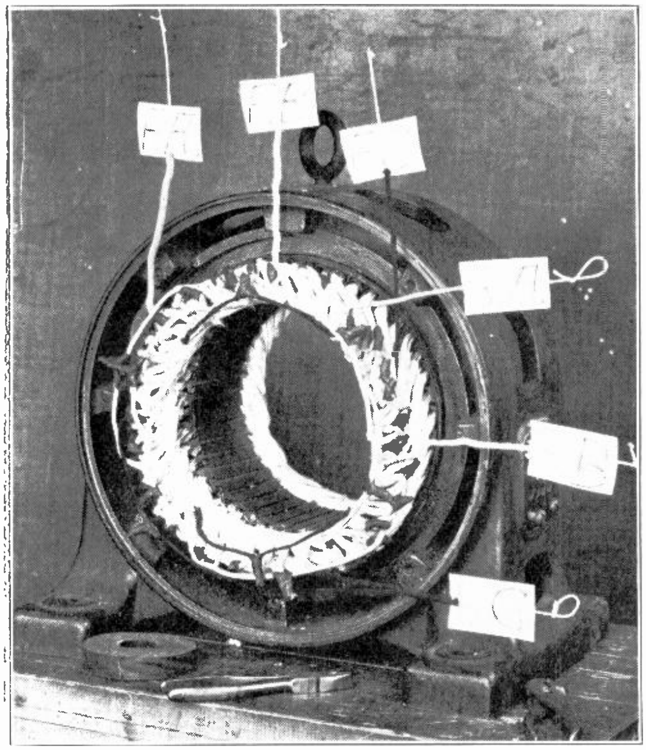

Fig. 69. Again we have the same stator as in the last two figures, but in this case the connections are one step farther along. The coil group connections have been soldered and taped, and the pole group connections are made, leaving only the start and finish leads of each phase. These are marked by the tags as shown.

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

86. UNEQUAL COIL GROUPING

The lap windings previously covered have all had equal coil grouping, that is, the same number of coils in consecutive groups. In some cases it is necessary to wind a stator with unequal coil groups in the winding. This is because the number of slots does not happen to be evenly divisible by the product of the number of poles and the number of phases. The unequal coil grouping to be used in such a case will have two or more groups in each pole, with unequal numbers of coils.

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

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

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

The tables in Fig. 71 show the manner in which this grouping will even up the coils per phase in the complete winding. These tables show unequal groupings which are commonly used in two and three-phase motors.

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

87. STAR AND DELTA CONNECTIONS

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

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

The left view in Fig. 72 shows the star connection for an A. C. winding. The three coils—A, B, and C—represent the three-phase windings of the machine and are spaced 120° apart. The center connection of this star is the point at which all three of the finish leads of the winding are connected together. The three outer ends of the coils are the starts, and are connected to the line wires.

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

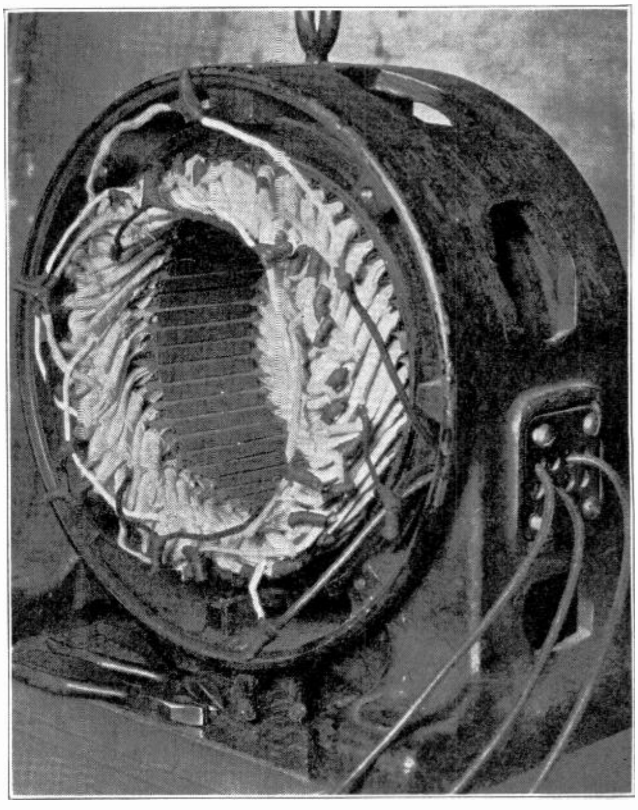

Fig. 70. The last step in the connections has now been completed and the starts and finishes of the first groups are connected to the line wires which are brought out through the right side of the frame.

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

The left view in Fig. 73 shows the delta connection for an A. C. winding. The three coils—A, B, and C—again represent the three-phase winding of the machine, and are connected together in a closed circuit with the start of "A" to the finish of "C", start of "C" to finish of "B", and start of "B" to finish of "A".

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

The sketch at the right in Fig. 73 shows the method of making the delta connection right on the leads of a winding.

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

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

48 SLOTS 6 POLES
3 PHASE

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

54 SLOTS 4 POLES
3 PHASE

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

54 SLOTS 8 POLES
3 PHASE

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

54 SLOTS 6 POLES
2 PHASE

Fig. 71. The above table shows unequal coil groups which can be used for two and three phase windings. Note how this arrangement of coils places an equal number in each phase when the winding is complete, even though there is not the same number in each phase of any one pole.

88. VOLTAGE OF STAR AND DELTA CONNECTIONS

By carefully comparing these two forms of connections in Figures 72 and 73, you will note that the delta connection has only half as many turns of wire between the line leads of any phase, as the star connection. We know that the number of turns or coils in series directly affects the voltage, so we can see that the star connection for a generator will produce higher voltage than the delta, and that the star connection when used on a motor will enable the motor to be used on higher line voltage.

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

As the star connection places twice as many coils in series between line wires as the delta connection, it might at first seem that it would give double the voltage of a delta connection. The voltage increase, however, will not be quite double, because the spacing of the two windings in the machine is 120° apart and consequently their maximum voltages occur at slightly different periods of time. The placing of the C phase winding between the windings of A and B phases, as explained in Art. 82, actually reverses its phase relation to the other two windings by 180 degrees; and in the star connection this produces voltages in series which are only 60 degrees displaced. So when two equal voltages which are 60 degrees apart are connected in series, their total voltage at any instant will not be double, but will be approximately 1.73 times the voltage of either one.

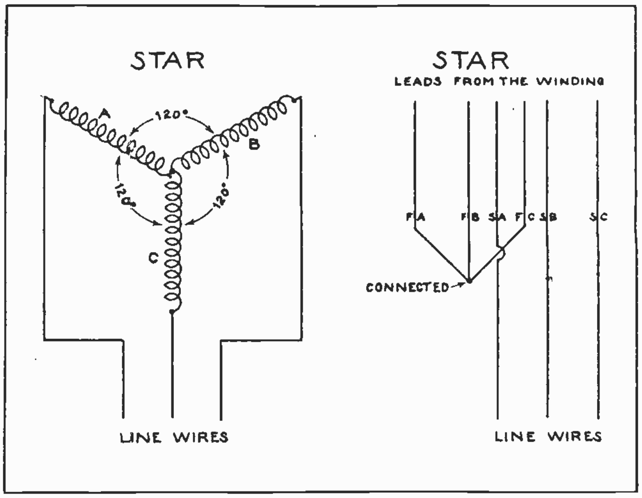

Fig. 72. The above two sketches illustrate the method of making star connections with alternating current windings. Note the phase displacement between the three windings on the left and also the manner in which two windings are placed in series between any pair of phase wires. The sketch at the right will be convenient for reference when connecting machine windings in this manner.

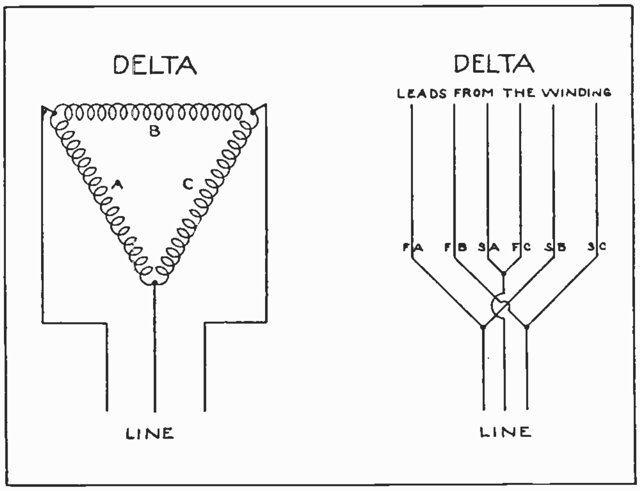

Fig. 73. These diagrams show the method of making delta connections for alternating current windings. The sketch on the left shows that with this delta connection two windings are in parallel between any pair of phase wires. The sketch on the right shows the manner of making a delta connection to the leads of a machine winding.

This value is obtained by vectorial addition instead of numerical addition. Fig. 74 shows how this can be done graphically or with lines drawn to scale and at the proper angles to represent the voltages to be added. The line from "B" to "A" represents 100 volts of one winding, and the line from "B" to "C" represents 100 volts of another winding 120° out of phase with the first. However, as one of the phases is reversed with respect to the other, we will draw a line in the opposite direction from B to D, to represent the voltage 180° displaced, or in the reverse direction to that shown by line B A. This voltage will then be 60° displaced from that in the other phase, shown by line B C.

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

Observation of Fig. 74 will show that a straight line drawn from A to C would be exactly the same length as the line from B to E. In many cases these vector diagrams are drawn in this manner by merely reversing the arrow on line A B and leaving off lines B D, C E, and B E.

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

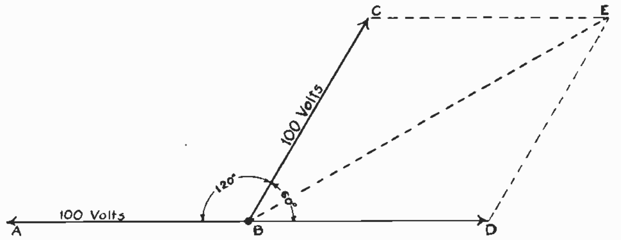

Fig. 74. The above diagram illustrates the method of adding together two voltages of windings connected in series but out of phase with each other 120°. The dotted line gives the correct sum of the two voltages shown by the solid lines.

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

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

89. FRACTIONAL-PITCH WINDING

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

By referring to Fig. 75, you will note that the length of the coil between its ends or points is reduced by making the coil span less than full pitch. In this figure the large coil which spans from slot 1 to slot 7 is assumed to be a full-pitch coil, so a coil laid in slots 1 and 6 will be a fractional-pitch coil and will have 83⅓% pitch. The shorter the coil ends are, the greater the mechanical strength of the coil.

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

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

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

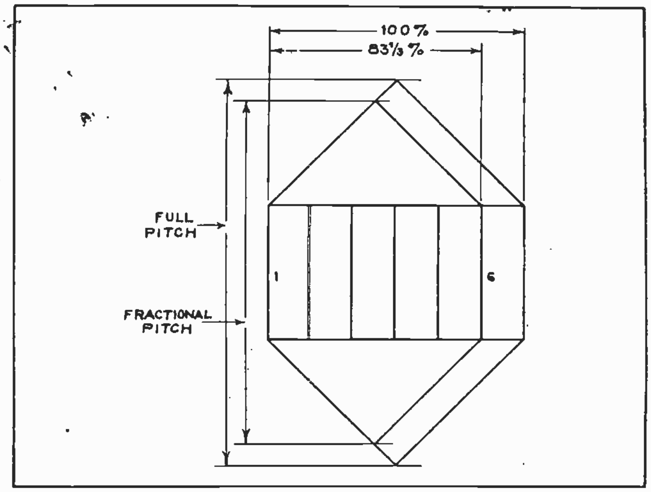

Fig. 75. Note how fractional-pitch windings make the coils shorter as their pitch is decreased. The shorter coils will have greater mechanical strength, which is one of the advantages of this type of winding.

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

90. SPECIAL POLE GROUP CONNECTION

Fig. 76 shows a system of connections very often used on three-phase motors. This system of connections will give the same results as the one previously described in this section and can be used on any two or three-phase winding. You will note that instead of connecting from the finish of a certain coil group to the finish of the next coil group of that phase, this finish lead is carried over to the start of the third coil group of that phase, skipping the second one and leaving it to be connected when the counter-clockwise connections are made. This produces the same polarity as though all coils of a certain phase were connected together in succession from finish to finish, start to start, etc.

Compare this method with that shown in Fig. 65. One of the advantages of this system is that on heavy windings it allows the end connections to fit more compactly against the coils and in a small space in the machine.

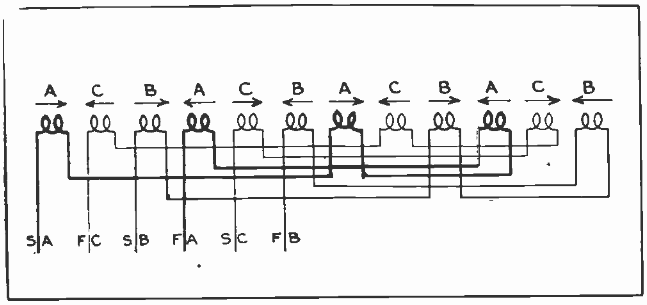

Fig. 76. This diagram shows a different method of connecting together the pole groups of the winding to allow a more compact arrangement of the leads on heavy windings. This method simply connects every other pole of one phase in a straight series group without crossing the leads; then connects back to get the remaining poles of those phases which were skipped the first time. These are connected in another straight series group and to the first group in a manner to produce alternate N. and S. poles throughout that phase.

91. ROTOR WINDINGS

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

Fig. 77 shows a diagram of a "phase-wound" rotor of four poles and 24 slots, wave wound. This type of winding is used very extensively on large rotors which have heavy coils made of copper bars, and the connecting system is practically the same as for all wave windings. This rotor can be used satisfactorily with either a two or three-phase stator winding.

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

92. CHANGING OPERATING VOLTAGE OF INDUCTION MOTORS

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

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

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

It is almost always permissable to reconnect a winding to operate on a lower voltage than it has been designed for; but, when reconnecting a machine to increase its operating voltage, the insulation should always be considered. The usual ground test for the insulation of such equipment is to apply an alternating current voltage of twice the machine's rated voltage, plus one thousand volts. This voltage should be applied from the winding to the frame for at least one minute and a test should be made after the winding is reconnected, or on any new winding

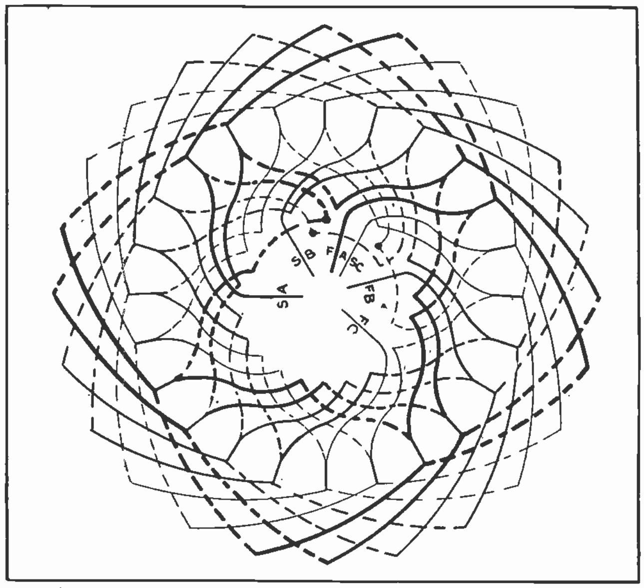

Fig. 77. This sketch shows a complete winding diagram of a 24-slot wave-wound rotor. Rotors with windings of this nature are sometimes called "phase-wound" rotors.

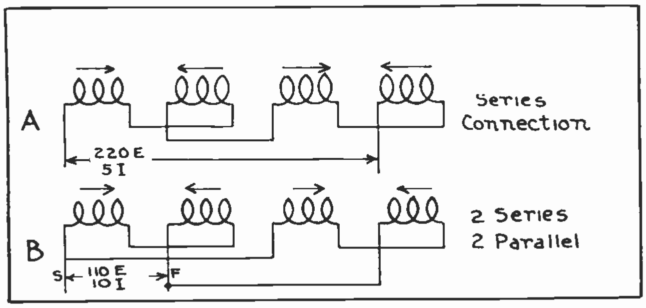

Fig. 78. The above diagram shows the method of reconnecting poles of the winding from series to series-parallel to be operated on a lower voltage.

before it is placed in operation. When a winding is changed for a different voltage it should be arranged so that the voltage on each coil group will remain unchanged.

Fig. 78 illustrates the manner in which this can be done. In the diagram at "A", 220 volts are applied to four coil groups in series, which places 55 volts on each group, and we will assume this voltage will cause 5 amperes to flow. The same winding is shown again at "B", reconnected for 110 volts, with two groups in series in each of two parallel circuits. When 110 volts are applied to these two parallel groups we will still have 55 volts per coil, and the same amount of current will flow. The rotating magnetic field will not be affected any differently as long as the amount of current per coil is not changed and the polarity of the coils is kept the same. This explains why it is not necessary to change the rotor winding when the winding in the stator is reconnected for a different voltage.

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

93. TEST FOR CORRECT POLARITY

In changing the connections of a three-phase winding one must be very careful not to connect the phases in a 60° relation instead of 120° as they should be. By referring to Fig. 79 we can see that it would be easy to connect the wrong end of the B-phase to the star point. This would reverse the polarity of the entire B-winding, and cause the stator winding to fail to build up the proper rotating field. The result would be that the motor would not develop any torque, and the winding would heat up and burn out if the reverse connection were not located and corrected at once.

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

94. EFFECT ON CURRENT WHEN CHANGING THE VOLTAGE

It is common practice among most manufacturers to design machines that can readily be connected for either of two common voltages. This is accomplished by a series or parallel arrangement which can be more easily understood by comparing Figs. 79 and 80. In the center of each of these diagrams is shown a small schematic sketch that illustrates in a simple manner the series or parallel arrangement of the coils. This center sketch in Fig. 79 shows that there are twice as many coil groups in series between the terminal leads as there are in the connection in Fig. 80. This means that if the winding in Fig. 79 is properly connected for 440 volts the one in Fig. 80 would be correct for 220 volts.

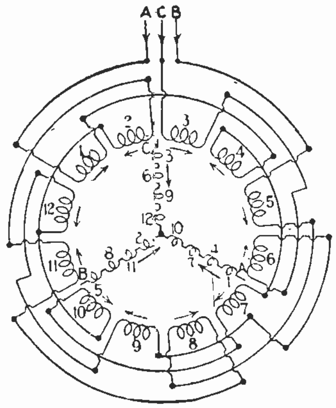

Fig. 79. This diagram shows a 3-phase, four-pole winding in which the pole groups in each phase are all four connected in series, and the three series groups connected star as illustrated by the diagram in the center. Don't confuse the inner and outer diagrams as they are entirely separate and each shows the same winding merely in a different manner.

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

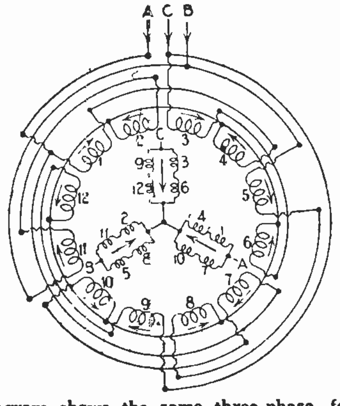

Fig. 80. This diagram shows the same three-phase, four-pole winding which was shown in Fig. 79, but in this case the four pole groups of each phase have been connected two in series and two in parallel, and then the phase groups connected star as shown by the center sketch.

By comparing the center diagrams in Figs. 79 and 80, we can see that this extra current can be carried all right by the windings as they are reconnected for the lower voltage in Fig. 80. In this connection there are two circuits in parallel which, of course, will have twice the cross-sectional area of copper that the single circuits in Fig. 79 had.

If the number of poles in the machine is evenly divisible by 4—as, for example: 4, 8, 12, 16, etc.—the winding may be connected in four parallel circuits, as shown in Fig. 81. By comparing this with the connections and voltages of Figs. 79 and 80, we find it will be proper to operate the winding in Fig. 81 at 110 volts, and four times the current which was used in the connection in Fig. 79; which should maintain the same horse power. The increased current in this connection is again provided for by the four circuits in parallel.

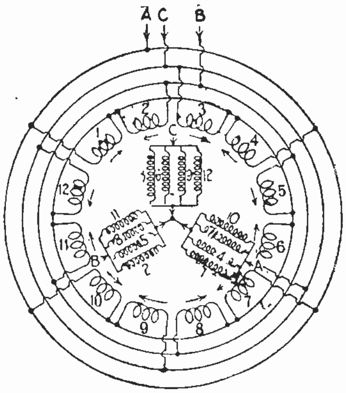

Fig. 81. Again we have the three-phase, four-pole winding. This diagram has all four poles of each phase connected in parallel and the three phase groups connected star as shown by the center sketch.

On this same principle, if the number of poles of a machine can be evenly divided by 6, it will be possible to reconnect the windings for either three or six parallel groups, as shown in Figs. 82 and 83.

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

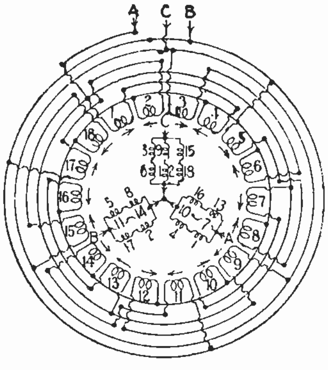

Fig. 82. This diagram shows a six-pole, three-phase winding with the six poles of each phase connected two in series and three in parallel, and then the three phase groups connected star.

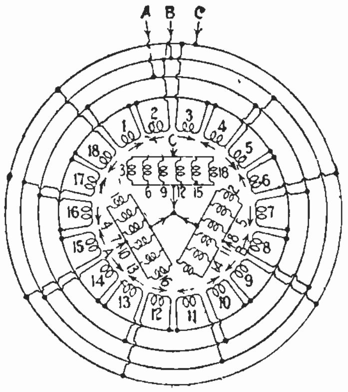

Fig. 83. In this case the six-pole, three-phase winding has all six poles of each phase connected in parallel and the three-phase groups connected star. These diagrams from 79 to 83 inclusive show additional practical applications of series and parallel circuits to obtain different voltage and current capacities of machine windings.

95. SPECIAL CONNECTIONS FOR CONVENIENT VOLTAGE CHANGES

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

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

Practically all repulsion induction motors that use a spiral type winding are provided with this arrangement for two voltages. Fig. 84 shows the windings and terminal block of such a machine and the manner of changing the connections for either 110 or 220 volts. Two poles are connected in series with leads 1 and 4 brought out to the terminal block, and also two poles in series with leads 2 and 3. By simply changing the connections of the line leads and one or two short jumper wires at these terminals, the winding can be changed to operate on either of the two voltages given.

A similar system is also used on two or three-phase motors. Fig. 85 shows the method of arranging the leads of a three-phase winding and the connections from the winding to the terminal block. The two small diagrams on the right-hand side of this figure show the method of changing the line and jumper connections to operate the motor on either 440 or 220 volts. In this figure the windings of the motor are represented by the coils arranged in the delta connection, with separate leads for each section of the winding brought out to the terminal block.

Fig. 86 shows a diagram of a star-connected stator winding, and the arrangement of the leads from the separate winding sections to the terminal block. The small sketches on the right-hand side of this figure also show the method of arranging the line leads and jumpers to change this machine for operation on either 220 or 440 volts.

96. CHANGE IN NUMBER OF PHASES

In certain emergency cases it is desirable to know how to change a motor from three-phase to two-phase operation, or vice versa. The following example will illustrate the procedure that should be used in making a change of this kind. Suppose we have a machine that is connected three-phase and has 144 slots in the stator and a 24-pole winding. The coils are connected 4-parallel delta for 440 volts, and we wish to reconnect them for operation on two-phase at the same voltage. 144 coils connected for three-phase would have 144 ÷ 3, or 48, coils per phase. This would be connected for four-parallel circuits, so there would be 48 ÷ 4, or 12, coils in series across the line.

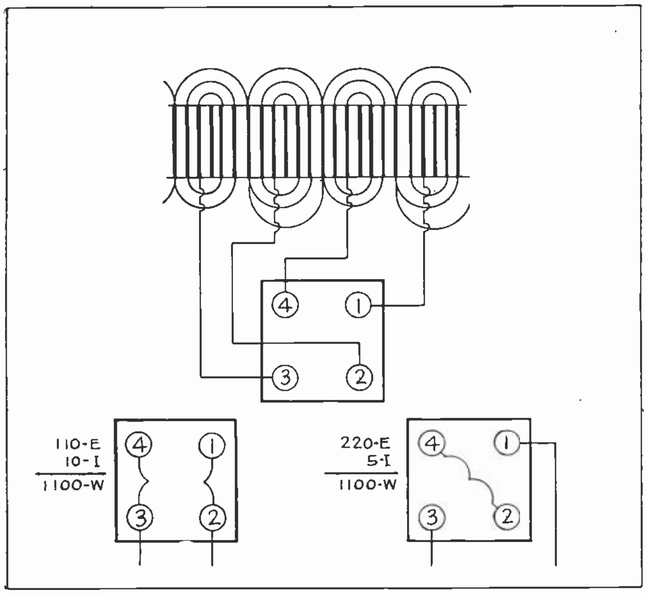

Fig. 84. This diagram shows how the terminals of a single phase winding can be arranged for convenient changing from series to parallel, so they can be operated on two different voltages.

Remember that these 12 coils are connected in series on 440 volts, so we would have approximately $36\frac{2}{3}$ volts applied to each coil in the original winding. This winding is to be regrouped for two-phase, which means that if it is connected single circuit there would be 144 ÷ 2, or 72, coils in series. To maintain the same voltage on each coil, the same number of coils must be connected in series across the line as before; or 72 ÷ 12 = 6 parallel circuits in which we must arrange the coils for the two-phase winding.

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

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

97. CHANGES IN FREQUENCY

Sometimes it is desired to change a motor which has been operating on one frequency so that it will operate on a circuit of another frequency. The

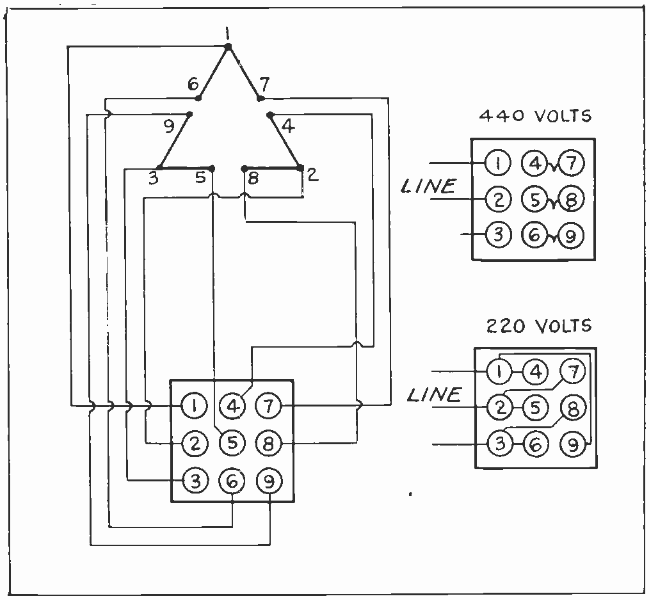

Fig. 85. Sketch showing the arrangement of the leads for a three-phase delta winding, and the manner in which they can be arranged on a terminal block for convenient voltage changes.

most common frequency for alternating current circuits in this country nowadays is 60 cycles, but occasionally a 25-cycle circuit or one of some other odd frequency is encountered.

We have learned that when an induction motor is running, a rotating magnetic field is set up in the stator and that it is this field which induces the secondary current in the rotor and produces the motor torque; also that this same rotating field cuts across the coils in the stator itself and generates in them a counter-voltage which opposes the applied line voltage and limits the current through

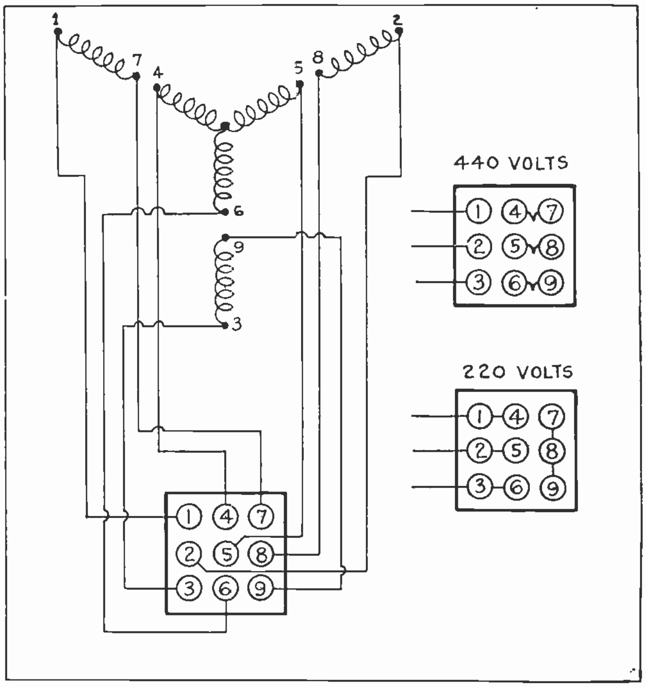

Fig. 86. The above diagram shows a winding which is connected star and has its leads all brought out to a terminal block for convenient change from 440 to 220 volts.

the winding. The speed of field rotation governs the strength of the counter E.M.F., and therefore regulates the amount of current which can flow through the winding at any given line voltage.

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

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

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

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

98. CHANGING NUMBER OF POLES AND SPEED

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

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

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

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

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

99. SPECIAL CONNECTIONS FOR CONVENIENT SPEED CHANGES

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

Fig. 87. shows a lap three-phase winding which may be connected for either two or four poles by changing the connections of its leads outside the motor. This winding will produce the same torque at both speeds and will develop twice the power when running as a two-pole motor and the higher speed than it will develop as a four-pole motor and operating at the lower speed.

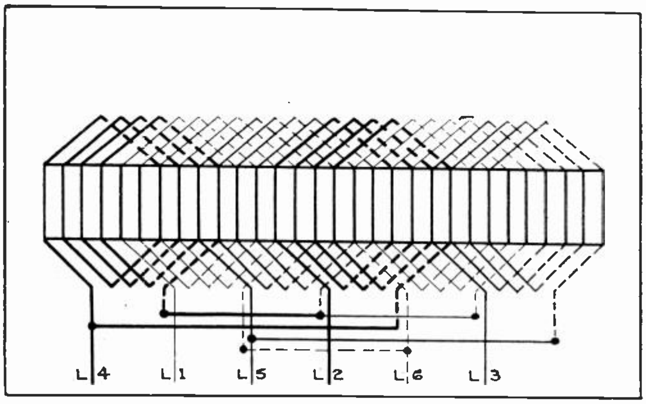

Fig. 87. A three-phase lap winding with six line leads brought out for convenient connection into either two or four poles. This enables the speed of the machine to be easily changed.

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

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

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

100. PROCEDURE OF RECONNECTING FOR CHANGE IN SPEED

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

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

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

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

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

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

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

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

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

We recall that the voltage changes with the sine of an angle of one-half the number of electrical degrees. One-half of 132 squals 66, and the sine of an angle of 66 degrees is .9135. This means that the correct voltage to apply to the new winding will be 476 × .9135, or 435 volts. This will be for all practical purposes near enough to the desired voltage.

101. USE OF INSULATING VARNISH AND COMPOUNDS ON WINDINGS

All windings, whether D. C. or A. C., should be thoroughly impregnated with a good grade of insulating varnish before they are put into service.

This varnish serves several very important purposes. When properly applied it penetrates to the inner layers of the coils and acts as extra insulation of the conductors, thereby increasing the dielectric strength of the insulation between them. This compound within the coils and in their outer taping, greatly reduces the liability of short circuits between conductors and of grounds to the slots or frame.

When a winding is thoroughly saturated with insulating varnish and this varnish is properly hardened, it adds a great deal to the strength of the coils and holds the conductors rigidly in place. This prevents a great deal of vibration that would otherwise tend to wear and destroy the insulation, particularly in the case of alternating current windings where the alternating flux tends to vibrate the conductors when in operation.

Insulating varnish also prevents moisture from getting in the coils and reducing the quality of their insulation; and it keeps out considerable dust, dirt, and oil that would otherwise accumulate between the coils. Keeping out moisture, dust, and oil greatly prolongs the life of the insulation.

102. AIR DRY AND BAKING VARNISHES

There are many grades of insulating varnish, some of which require baking to "set" or harden them, and others which have in them certain liquids or solvents which make them dry and harden very quickly when exposed to air. The first type are called **baking** varnishes and the latter are called **air dry** varnishes.

Good air-dry insulating varnish will set or harden in from 20 to 30 minutes, but it should be allowed to dry out thoroughly for about 24 hours before the windings are put in service. Air dry varnish is not considered quite as good as the better grades of baking varnish. Therefore, the latter should be used wherever a bake oven or some means of applying heat is available.

103. METHODS OF APPLYING INSULATING VARNISH

There are three common methods by which insulating varnish can be applied to coils and windings. These are: dipping, brushing, and spraying.

Dipping is considered the best method and should be used for all small windings of stators and armatures, and for armatures and stator coils and field coils. To dip these coils or windings, a pan or tank of the proper size and depth will be required. Before dipping the windings they should be thoroughly dried out in a bake oven at about 212° F., in order to drive out all moisture and to heat the coils so that when they are dipped the varnish will rapidly penetrate to their inner layers.

The coils should be allowed to remain in the varnish until all bubbling has ceased. When they seem to have absorbed all the varnish possible they should be slowly withdrawn from the tank at about the same rate as the varnish flows from them of its own accord. This will give them a uniform coating with the least possible accumulation of varnish at the lower end. They should then be allowed to drain until the varnish stops dripping and becomes partially set. The time required for this will depend on the size of the winding or coils.

When dipping a large number of small coils, considerable time can be saved by arranging a drip board set at an angle, so the coils can be hung above it and the varnish which drips from them will run down the board and back into the tank. With this method other coils can be dipped while the first set are draining.

After all the surplus varnish is drained from the coils they should be baked. When placing them in the oven it is a good plan to reverse their positions, so that any excess varnish on the bottom ends will tend to flow back evenly over their surface when first heated.

104. GOOD VENTILATION IMPORTANT WHEN BAKING

When a large number of coils are being baked at one time and practically fill the oven, trouble is sometimes experienced with insufficient ventilation. If the air inside the oven is not continually kept moving through the coils, and fresh air constantly supplied, the vapors from the varnish will cause a green coating to form on the surface of the coils and greatly decrease the insulating qualities of the varnish. With large ovens small fans are sometimes used to force an air draft and insure good ventilation. Small ovens are usually provided with a chimney at the top and an air inlet at the bottom, so the heated air can rise and provide its own circulation.

Fig. 88 shows an electrical baking oven and a large D. C. armature to which a coat of varnish has been applied and which is ready for baking. This

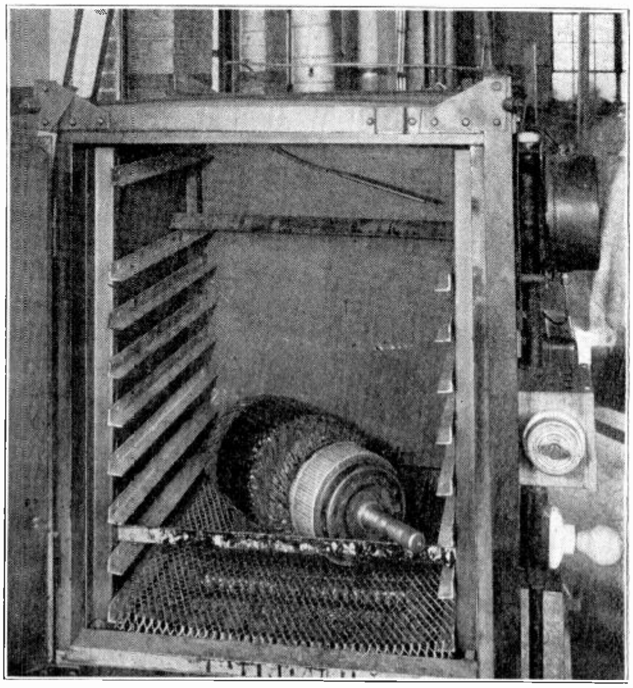

Fig. 88. This photo shows a D.C. armature in place in an electrical bake oven and ready for the insulating compound on the windings to be baked.

oven has an automatic temperature-control to keep the temperature uniform throughout the baking operation. Also note the ventilation chimney on top of the oven.

When applying the varnish with a brush, the winding should, if possible, be preheated to drive out the moisture and permit the varnish to flow deeper into the coils. Varnish can be applied with an ordinary paint brush, and this method is used where the dipping tank is not large enough to accommodate the winding, or where no dipping tank is available.

Spraying is used principally on large windings and gives a very good surface for a finishing coat.

The ends of coils should be given two or three coats of varnish as an added protection against mechanical damage and moisture, and to help prevent flash-overs to the frame of the machine.

105. PROPER TIME AND TEMPERATURES FOR BAKING

Fig. 89 shows a convenient table which gives the proper temperatures and approximate time in hours for baking insulating varnishes. You will note that when baking complete armature or stator windings more time is required to thoroughly bake the larger sizes. Also note that a slower baking produces a more elastic and better quality of insulation.

In emergency cases, where time is very inportant, the windings can be baked at the higher tempatures in a much smaller number of hours, but the varnish will be somewhat more brittle and inclined to crack or check when any strain is placed upon it. Never attempt to bake windings at temperatures very much higher than those given in the first column of this table, or you are likely to damage the insulation already on the coils. When a job doesn't need to be rushed, it is much better to bake it at the lower temperatures and for the longer periods given in the table, which will give a much more durable and dependable insulation.

In addition to the advantages already mentioned for this form of insulation, it also provides a smoother surface on the windings and coils, making them much easier to clean, either by means of a brush, compressed air, or by washing them with gasoline or some such solution to remove grease and oil.

Fig. 89-B shows a stator winding heavily coated with a solid mass of insulating compound applied by repeated dipping. Note the rugged protection this gives the winding. To remove a winding which has been treated in this manner it is necessary to heat it first, in order to soften the compound.

Size of Armature or Stator Core Diameter	248° F. Quick Baking	224° F. Elastic Baking	212° F. Extra Elastic Baking
Under 6 Inches	4 to 6 hrs.	6 to 8 hrs.	8 to 10 hrs.
6 to 12 Inches	12 hrs.	24 hrs.	36 hrs.
12 to 18 Inches	24 hrs.	36 hrs.	48 hrs.
18 to 24 Inches	36 hrs.	48 hrs.	60 hrs.

Fig. 89. This convenient table gives the proper temperature and time in hours for baking insulation of windings of different sizes.

106. TROUBLES OF INDUCTION MOTOR WINDINGS

By far the greater number of defects which occur in windings during service or operation are caused by short circuits, open circuits, and grounds. Water may have found its way into the coils, or oil from the bearings may have destroyed the quality of the insulation. Metallic dust and grit sometimes work into the windings and cause short circuits; or a static charge from a belt-driven machine may cause punctures or small pin holes in the insulation, which results in flash-overs and grounds.

Any one of the above mentioned faults is also likely to show up just after a motor has been rewound or repaired. So, if a machine doesn't operate properly after having been rewound, it is quite likely that some of the coils are connected wrong or that there is a short, open, or ground in some coils because of work carelessly done in the repair shop.

The average small induction motor when running properly is almost noiseless, and even in the larger motors only a uniform, gentle humming should be heard. This humming noise is due largely to vibration of core laminations, which are caused to vibrate slightly by the reversals of the magnetic field. This vibration will be in synchronism with the frequency of the alternating current in the windings. In addition to this humming, which is unavoidable even in the best of motors, there is also a slight whistling noise caused by the fan blades on the rotor, friction of the air with the revolving parts, and air passing through ventilation ducts. This air whistling is harmless and it will continue for a short period after the current is shut off and while the machine is still turning. If a motor is unusually noisy there is probably some defect responsible for the noise.

A deep, heavy growling is usually caused by some electrial trouble resulting in an unbalanced condition of the magnetic field in the windings.

If a shock is felt when the frame is touched it is quite sure evidence that one or more coils in the winding are grounded to the core or frame. This is a very dangerous condition with any voltage and particularly so with voltages above 220. A grounded coil on a 440-volt machine may result in a very dangerous shock, and it is for this reason that the frames of motors should be grounded when the machines are installed.

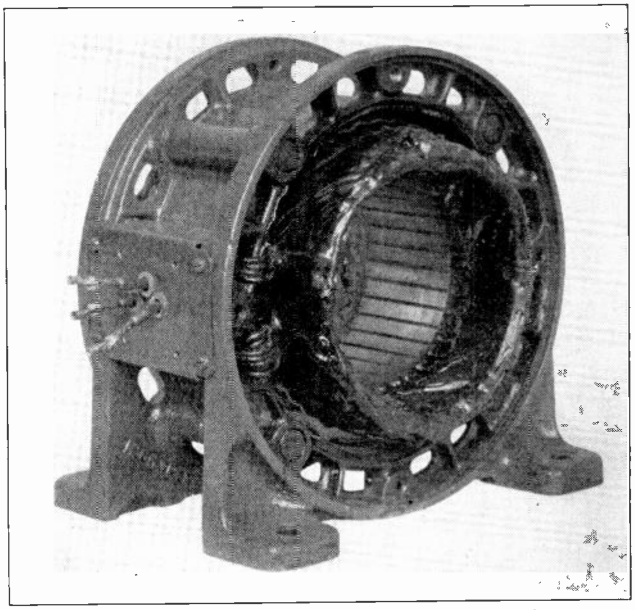

Fig. 89-B. The above photo shows a stator winding heavily impregnated with insulating compound. Note how insulation of this type affords mechanical strength and protection to the windings and would also prevent dirt, oil and moisture from getting in between the coils.

When the frames are grounded in this manner and a coil does become grounded, it will usually blow a fuse, thus indicating a defect at once.

Fig. 90 is a diagram of a three-phase winding in which are shown a number of the more common faults occurring in such windings. These faults are numbered and listed for your convenience in locating them.

1. The last coils in the second and fourth groups of phase "A" are grounded.

2. The last coil in the third group of phase "A" is shorted.

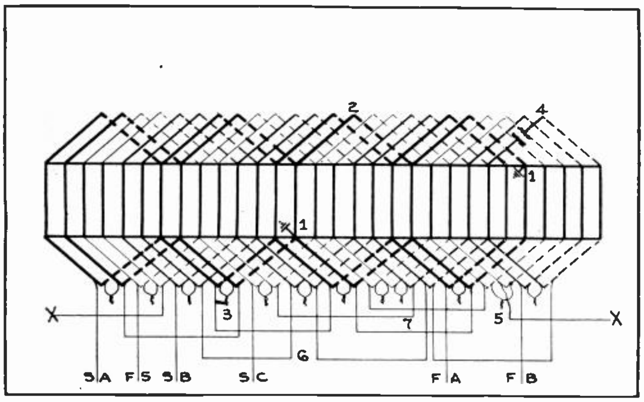

Fig. 90. The above is a diagram of a three-phase winding in which are shown a number of the more common faults that occur in stator windings.

3. The start and finish leads of the first coil in the second group of phase "A" are shorted together at the stubs.

4. The last coil in the fourth group of phase "B" is open.

5. The last coil in the third group of phase "C" is reversed.

6. The second coil group of phase "B" is reversed.

7. The second coil group of phase "C" and third coil group of phase "B" have wrong numbers of coils connected in them.

8. Another fault known as "reversed phase" occurs when the three starts are spaced in the wrong position. This fault is not shown in this sketch.

The following paragraphs describe in detail the methods of testing to locate these faults and also the method of correcting them.

107. GROUNDED COILS

The usual effect of one grounded coil in a winding is the repeated blowing of a fuse when the line switch is closed. Two or more grounds will give the same result and will also short out part of the winding in that phase in which the grounds occur. A quick and simple test to determine whether or not a ground it present in the winding, can be made with the test outfit shown in Fig. 91. This test set consists of several dry cells connected in series with a small test lamp and pair of test leads.

In place of the dry cells and low-voltage lamp, we can use two test leads connected to a 110-volt line and with a 10-watt lamp in series. In testing with such a set, place one lead on the frame and the other in turn on each of the line wires leading from the motor. The line switch should, of course, be open before making any test. If there is a grounded coil at any point in the windings the lamp will indicate it by lighting.

To locate the phase that is grounded, test each phase separately. In a three-phase winding it will be necessary to disconnect the start or delta connections. After the grounded phase is located the pole-group connections in that phase can be disconnected and each group tested separately. When the test leads are placed one on the frame and the other on the grounded coil group, the lamp will indicate the ground in this group by again lighting. The stub connections between the coils and this group may then be disconnected and each coil tested separately until we locate the exact coil that is grounded.

108. HIGH RESISTANCE GROUNDS

Sometimes moisture in the insulation around the coils, or old and defective insulation will cause a high-resistance ground that is difficult to detect with a test lamp. In this case we can use a test outfit consisting of a telephone receiver and several dry cells connected in series, as shown in Fig. 92. Such a test set will detect a ground of very high resistance, and this set will often be found very effective when the ordinary test lamp fails to locate the trouble.

109. REPAIRS FOR GROUNDED COILS

When the grounded coil is located it should either be removed and reinsulated, or cut out of the circuit, as shown in Fig. 93. At times it is inconvenient to stop a motor long enough for a complete rewinding or permanent repairs. In such cases, when trouble develops it is often necessary to make a temporary repair until a later time when the motor may be taken out of service long enough for rewinding or permanent repairs.

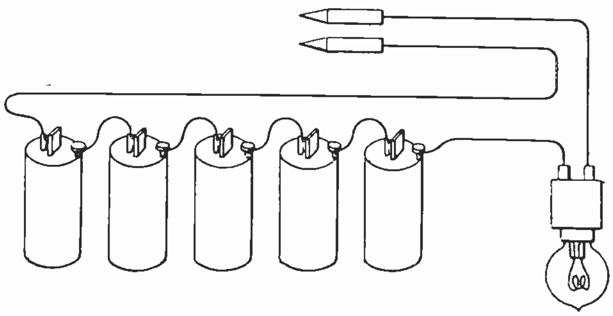

Fig. 91. Several dry cells in series with a low voltage test lamp and a pair of test leads or "points" make a very convenient test outfit for locating a number of the troubles in motor windings.

The sketch in Fig. 93 shows a coil group consisting of the three coils on the left. The single coil on the right is the first one of the following group which is not all shown in this sketch. Coil 2 is defective and the temporary repair will be the same whether the fault is a short, an open, or a ground. A jumper wire of the same size as that used in the coils, is connected to the bottom lead of coil 1, and across to the top lead of coil 3, leaving coil 2 entirely out of the circuit. Coil 2 should then be cut at the back of the winding, as shown by the dotted lines in the sketch. If the defective coil is grounded it should also be disconnected from the other coils, as shown on the diagram.

110. ONE OR MORE TURNS SHORTED TOGETHER

Shorted turns within coils are usually the result of failure of the insulation on the wires. This is frequently caused by the wires being crossed and having excessive pressure applied on the crossed conductors when the coils are being inserted in the slot. Quite often it is caused by using too much force in driving the coils down in the slots. In the case of windings that have been in service for several years, failure of the insulation may be caused by oil, moisture, etc. If a shorted coil is left in a winding it will usually burn out in a short time and, if it is not located and repaired promptly, will probably cause a ground and the burning out of a number of other coils.

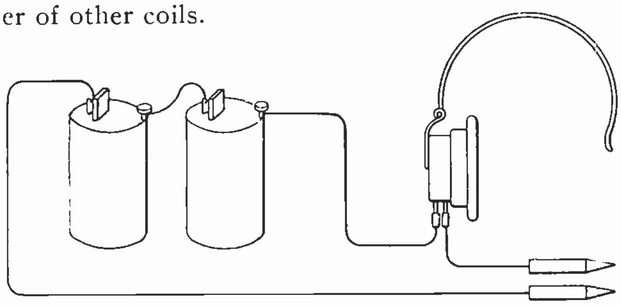

Fig. 92. A telephone receiver can also be used in series with dry cells and test leads for locating high resistance grounds occurring in windings.

One of the most practical ways of locating a shorted coil is by the use of a growler and thin piece of steel, similar to the method described for D. C. armatures. Fig. 94 shows a sketch of a growler in use in a stator. Note that the poles are shaped to fit the curvature of the teeth inside the stator core. The growler should be placed in the core as shown and the thin piece of steel should be placed the distance of one coil span away from the center of the growler. Then, by moving the growler around the bore of the stator and always keeping the steel strip the same distance away from it, all of the coils can be tested.

Fig. 95 shows a photo of a growler in use on a large stator. The steel strip is held over the slot the proper distance from the growler for the size of coils or coil span used in this case.

If any of the coils has one or more shorted turns the piece of steel will vibrate very rapidly and cause a loud humming noise. By locating the two slots over which the steel will vibrate, we can find both sides of the shorted coil. If more than two slots cause the steel to vibrate, they should all be marked and all shorted coils should be removed and replaced with new ones, or cut out of the circuit as previously described.

111. SHORTED COIL GROUPS

Sometimes one coil or a complete coil group becomes short circuited at the stubs or end connections. The test for this fault is the same as that for a shorted coil. If all the coils in one group are shorted it will generally be indicated by the vibration of the steel strip over several consecutive slots, corresponding to the number of coils in the group.

The stub connections should be carefully examined and those that appear to have poor insulation should be moved during the time that the test is being made. It will often be found that when the shorted stub connections are moved during the test the vibration of the steel will stop. If these stubs are reinsulated the trouble should be eliminated.

112. OPEN COILS

When one or more coils become open-circuited by a break in the turns or a poor connection at the stubs, they can be tested with a test lamp and dry cell such as previously shown and explained. If this test is made at the ends of each winding, an open can be detected by the lamp failing to light. The insulation should be removed from the pole-group connections and each group should be tested separately. After locating the coil group that is open, untape the coils between that group and test each coil separately. In making this test it is not necessary to disconnect the splices or connections.

In many cases the open circuit will be at the coil ends or stubs, due to a loose connection or broken conductor. If the trouble is at this point it can usually be located by careful observation and checking. If the trouble is a loose connection at the stub, it can be repaired by resoldering the splices; but if it is within the coil, the coil should either be replaced or have a jumper placed around it, as shown in Fig. 93, until a better repair can be made.

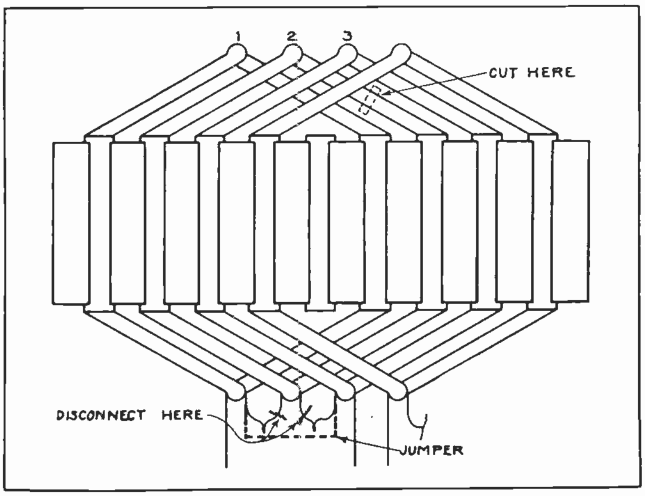

Fig. 93. This diagram illustrates the method of cutting out a defective coil with a jumper. In this manner a machine can be quickly repaired and kept in service until such time as the defective coil can be replaced.

113. REVERSED CONNECTIONS

Reversed coils cause the current to flow through them in the wrong direction. This fault usually manifests itself—as do most irregularities in winding connections—by a disturbance of the magnetic circuit, which results in excessive noise and vibration. The fault can be located by the use of a magnetic compass and some source of low-voltage, direct current. This voltage should be adjusted so it will send about one-fourth to one-sixth of full load current through the winding; and the D. C. leads should be placed on the start and finish of one phase. If the winding is three-phase, star-connected, this would be at the start of one phase and the star point. If the winding is delta-connected, the delta must be disconnected and each phase tested separately.

Place a compass on the inside of the stator and test each of the coil groups in that phase. If the phase is connected correctly, the needle of the compass will reverse definitely as it is moved from one coil group to another. However, if any of the coils is reversed the reversed coil will build up a field in the opposite direction to the others, thus cause a neutralizing effect which will be indicated by the compass needle refusing to point definitely to that group. If there are only two coils per group there will be no indication if one of them is reversed, as that group will be completely neutralized.

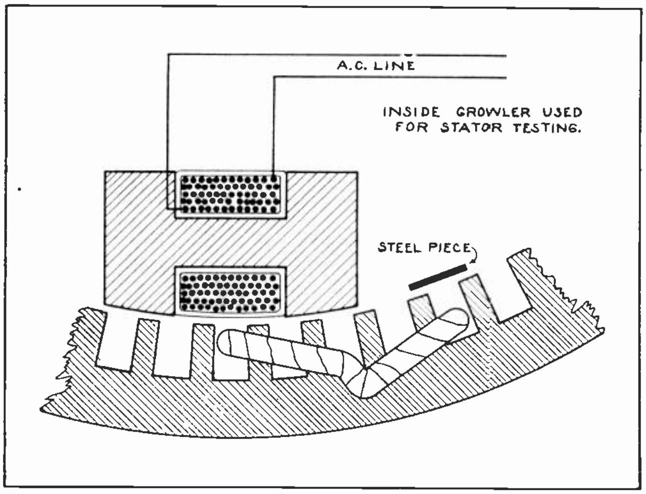

Fig. 94. The above view shows the manner in which a growler can be used to induce current in a shorted coil and indicate the short circuits by vibration set up in the steel strip at the right. This is a very simple and effective method of locating short circuits.

114. REVERSED COIL GROUPS

When an entire coil group is reversed it causes the current to flow in the wrong direction in the whole group. The test for this fault is the same as that for reversed coils. The winding should be magnetized with direct current, and when the compass needle is passed around the coil groups they should indicate alternately N. S., N. S., etc. If one of the groups is reversed, three consecutive groups will be of the same polarity. The remedy for either reversed coil groups or reversed coils, is to make a visual check of the connections at that part of the winding, locate the wrong connection, and reconnect it properly.

When the wrong number of coils are connected in two or more groups, the trouble can be located by counting the number of stubs on each group. If any mistakes are found they should be remedied by reconnecting properly.

115. REVERSED PHASE

Sometimes in a three-phase winding a complete phase is reversed by either having taken the starts from the wrong coils or by connecting one of the windings in the wrong relation to the others when making the star or delta connections. If the winding is connected delta, disconnect any one of the points where the phases are connected together, and pass current through the three windings in series. Place a compass on the inside of the stator and test each coil group by slowly moving the compass one complete revolution around the stator.

The reversals of the needle in moving the compass one revolution around the stator should be three times the number of poles in the winding.

In testing a star-connected winding, connect the three starts together and place them on one D. C. lead. Then connect the other D. C. lead and star point, thus passing the current through all three windings in parallel. Test with a compass as explained for the delta winding. The result should then be the same, or the reversals of the needle in making one revolution around the stator, should again be three times the number of poles in the winding.

These tests for reversed phases apply to full-pitch windings only. If the winding is fractional-pitch, a careful visual check should be made to determine whether there is a reversed phase or mistake in connecting the star or delta connections.

116. TESTING SPLIT-PHASE MOTORS

If a split-phase motor fails to start when a line switch is closed, the trouble may be due to one or several of the following faults:

1. Tight or "frozen" bearings.
2. Worn bearings, allowing the rotor to drag on the stator.
3. Bent rotor shaft.
4. One or both bearings out of alignment.
5. Open circuit in either starting or running windings.
6. Defective centrifugal switch.
7. Reversed connections in either winding.
8. Grounds in either winding or both.
9. Shorts between the two windings.

117. TIGHT OR WORN BEARINGS

Tight bearings may be caused by failure of the lubricating system; or, when new bearings are installed, they may run hot if the shaft is not kept well oiled.

If the bearings are worn to such an extent that they allow the rotor to drag on the stator, this will usually prevent the rotor from starting. The inside of the stator laminations will be worn bright where they are rubbed by the rotor. When this condition exists it can generally be easily detected by close observation of the stator field and rotor surface when the rotor is removed.

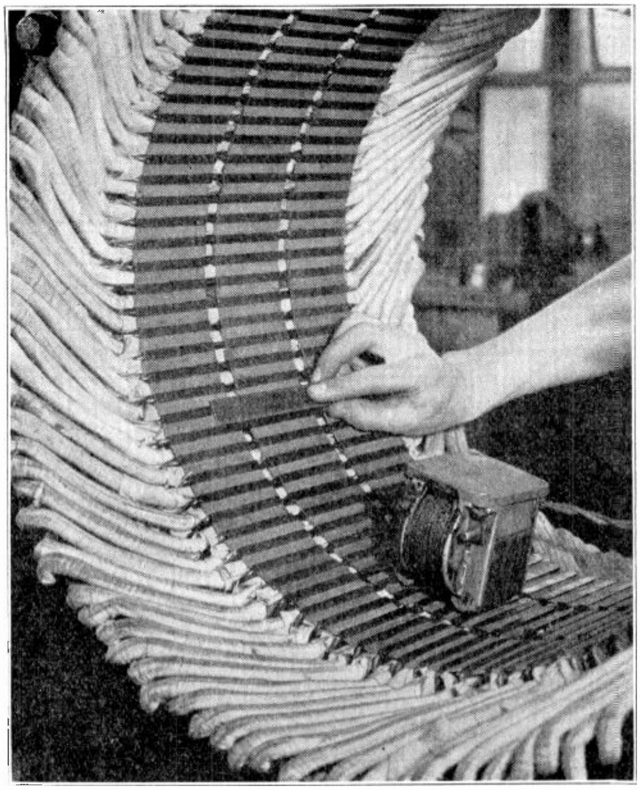

Fig. 95. This photo shows a growler in use in a large stator. Note the size and shape of these coils and the position of the steel strip which is just the width of one coil from the center of the growler.

118. BENT SHAFT AND BEARINGS OUT OF LINE

A bent rotor shaft will usually cause the rotor to bind when in a certain position and then run freely until it comes back to the same position again. An accurate test for a bent shaft can be made by placing the rotor between centers on a lathe and turning the rotor slowly while a tool or marker is held in the tool post close to the surface of the rotor. If the rotor wobbles it is an indication of a bent shaft.

Bearings out of alignment are usually caused by uneven tightening of the end-shield plates. When placing end-shields or brackets on a motor, the bolts should be tightened alternately, first drawing up two bolts which are diametrically opposite. These two should be drawn up only a few turns, and the others kept tightened an equal amount all the way around. When the end shields are drawn up as far as possible with the bolts, they should be tapped tightly against the frame with a mallet and the bolts again tightened.

119. OPEN CIRCUITS AND DEFECTIVE CENTRIFUGAL SWITCHES

Open circuits in either the starting or running winding will cause the motor to fail to start. This fault can be detected by testing across the start and finish of each winding with a test lamp.

A defective centrifugal switch will often cause considerable trouble that is difficult to locate, unless one knows where to look. If the switch fails to close when the rotor stops, the motor will not start when the line switch is closed. Failure of the switch to close is generally caused by dirt, grit, or some other foreign matter getting into the switch mechanism; or by weakened springs on the switch. The switch should be thoroughly cleaned with gasoline and then inspected for weak or broken springs.

If the winding is on the rotor, the brushes sometimes stick in the holders and fail to make good contact with the slip rings. This causes sparking at the brushes. There will probably also be a certain place where the rotor will not start until it is moved far enough for the brush to make contact on the ring. The brush holders should be cleaned, and the brushes carefully fitted so they move freely with a minimum of friction between the brush and the holders. If a centrifugal switch fails to open when the motor is started, the motor will probably growl and continue to run slowly. This is also likely to be caused by dirt or hardened grease in the switch.

120. REVERSED CONNECTIONS AND GROUNDS

Reversed connections are caused by improperly connecting a coil or group of coils. The wrong connections can be found and corrected by making a careful check of the connections and reconnecting those that are found wrong. The test with D. C. and a compass can also be used for locating reversed coils. Test the starting and running windings separately exciting only one winding at a time, with the direct current. The compass should show alternate poles around the winding.

The operation of a motor that has a ground in the windings will depend on where the ground is, and whether or not the frame is grounded. If the frame is grounded then when the ground occurs in the winding it will usually blow a fuse. A test for grounds can be made with a test lamp and dry cells, or a 110-volt lamp and leads. One test lead should be placed on the frame and the other on a lead to the winding. If there is no ground the lamp will not light. If it does light, it indicates a ground due to a defect somewhere in the insulation.

121. SHORT CIRCUITS

Short circuits between the two windings can also be detected by the use of a test lamp. Place one of the test leads on one wire of the starting winding and the other test lead on the wire of the running winding. If these windings are properly insulated from each other the lamp should not light. If it does light, it is a certain indication that there is a short between the windings. Such a short will usually cause part of the starting winding to burn out. The starting winding is always wound on top of the running winding; so, if it becomes burned out due to a defective centrifugal switch or a short cir-

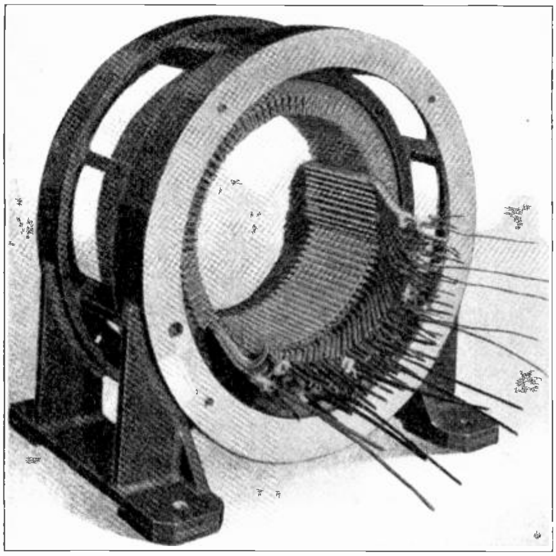

Fig. 96. The above photo shows a stator partly wound with factory-made coils. Coils of this type can be purchased ready made from many manufacturers so they can be quickly and conveniently inserted, and speed up repairs of the machines.

cuit, the starting winding can be conveniently removed and replaced without disturbing the running winding.

Single phase motors are very simple to rewind, and in many localities there are a great number to be rewound or repaired each year. Many of them need only to have the centrifugal switches cleaned and adjusted, or fitted with new springs. Others have only a loose or grounded connection which can be quickly repaired.

Many of our graduates start a fine business of their own, or make considerable money in their spare time from their regular job, by repairing small motors of fans, washing machines, and others. With a few lbs. of wire and a little insulation material many men do this work right at home in their own basements or garages.

In many cases you can get old motors of both small and large sizes, that the owners have planned to discard because they did not know they could be rewound or knew no one nearby who could rewind them. Such cases are splendid opportunities for you to get additional experience and practice and to get started in this line of work if you choose.

In any case, let us again emphasize the importance of applying the instruction covered in this section, and keeping familiar with it by frequent reference to its pages, for any question or problem of this nature which you may have.

You are very likely to find a knowledge of armature winding, connecting and testing very valuable on some job when you least expect it.

Welcome every opportunity to get added experience of this nature, and if you do your work properly in this department of the shops and use this Reference Set frequently, you should be able to make a definite success of any job of armature winding or testing.

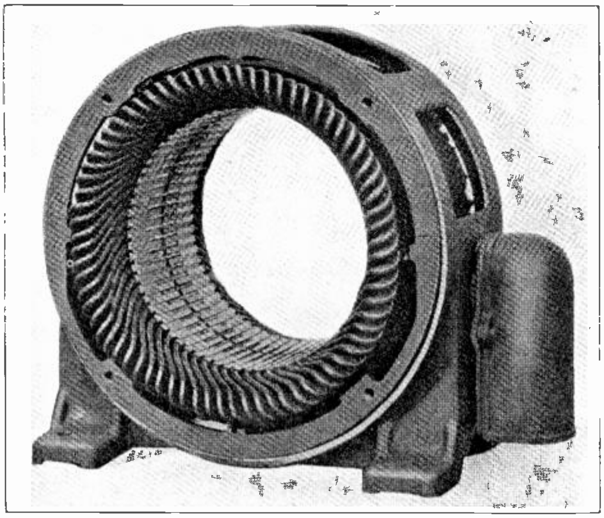

Fig. 97. This view shows the neat appearance of the stator in which the coils are of the proper size and shape and carefully placed in the slots.