COYNE
Electrical School
CHICAGO ~ ~ ILLINOIS
ESTABLISHED 1899

ELECTRIC REFRIGERATORS

Refrigeration Principles
Construction, Operation and Care
of Domestic Refrigerators

ELECTRIC REFRIGERATION

Electric refrigerators have come into such general use in homes in the last few years that this field is well worth the attention of every student.

These machines are being manufactured and sold by the millions for home use alone, there being over a million of one manufacturer's make now in service.

In addition to those in homes there are thousands of larger units in commercial establishments such as drug stores, soda fountains, meat markets, florists, and other places where low temperatures are needed to preserve things.

Many large packing houses and ice-making plants also have their refrigeration machines operated by electric motors.

The numerous small units create a lot of work for electrical men in the care and servicing of their motors, switches, fuses, etc.; and in the larger plants it is often an advantage for the maintenance electrician to have a knowledge of refrigeration principles.

In addition to servicing domestic refrigerators, there are great opportunities in selling these units, and for those who like sales work and have a good knowledge of electric refrigeration this.is an excellent field.

217. PRESERVATION OF FOODS BY LOW TEMPERATURES

It is commonly known that foods of various kinds, particularly meats, vegetables, fruits, and milk, will keep much longer without spoilage or decay if they are kept in places of low temperature. In temperatures below 50 degrees Fahrenheit (50° F.) the destructive bacteria cannot grow or multiply. Therefore, foods can be kept fresh and safe for use for many days in such cold places, while without refrigeration they would spoil in a few hours of hot summer weather, or even in a well heated house in the winter. Thus the saving in preserving foods will more than pay for refrigeration, and a number of added conveniences, such as preparation of delicious cold desserts, can be obtained.

Ice boxes have for many years been used for this purpose in homes. Mechanical refrigerators are fast replacing them, however, and deserve the great popularity which they have acquired.

They are much cleaner and more convenient, and provide a dryer and more even cold temperature which is more effective in food preservation.

Their cost of operation is generally a little less than for ice, and their advantages are well worth their higher first cost. Fig. 253 shows a large size home type electric refrigerator of a popular make.

218. REFRIGERATION PRINCIPLES

While these units are called electrical refrigerators, the electricity does not enter directly into the refrigeration process, but is used to provide the power to drive the compressors in these machines.

Refrigeration is simply a process of removing some of the heat from an enclosure where we do not want it, to some other place where it does no harm.

There are a number of ways in which this can be done. Heat always has a tendency to flow from points of high temperature to surrounding points of lower temperature. Heat escapes from a stove by **radiation** through the air, into metal pots and pans by the heat **Conductivity** of the metals, and throughout liquids or gases by **Convection**, or the motion it sets up in them. If we place an electric fan so it blows air across the top of an electric heater, this air absorbs some of the heat and carries it away from the heater. Thus we find heat can be transferred from point to point by various methods.

In refrigeration we call the medium used to transfer the heat, a **Refrigerant.**

A refrigerant is a liquid or gas that will readily absorb heat, carry it with it in motion, and give up this heat later when desired. These properties in liquids depend to a great extent on their boiling or evaporation temperatures.

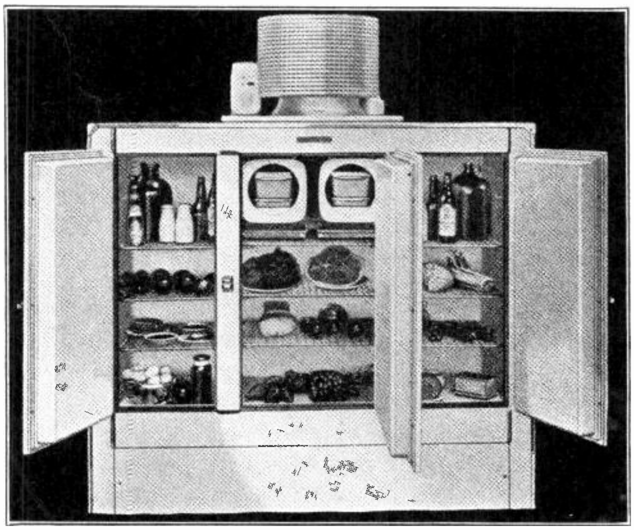

Fig. 253. A large sized electric refrigerator for use in the home. The arrangement of the refrigerating unit on the top of the cabinet provides maximum space for food storage.

Ordinary air can be used as a refrigerant, so let's use it for a simple illustration.

First try to answer these questions in your mind; why does a tire pump get hot when used to compress air? Why does a cylinder in which air has been stored under high pressure, get icy cold if the air is let out suddenly?

To answer these, let us first remember that all normal air or atmosphere, even that which feels cold to us, has a certain amount of natural heat in it. Then if we compress a large volume of this air into a very small space we concentrate its heat, thus raising the temperature of this smaller volume. Therefore, continued use of the tire pump to compress air soon heats the pump.

Another good example of the heat that can be produced by compressing air, is that Diesel engines use a highly compressed jet of air to ignite their fuel oil.

Now if we were to force a very large volume of air suddenly into a strong steel cylinder by means of a powerful compressor, the cylinder would get very hot; because, remember, we have concentrated the heat of the air, as well as the air itself.

If we close this air in the cylinder with a valve, the cylinder soon cools off by loss of its heat to the lower temperature atmosphere around it. After it has cooled the air inside it will be at the normal temperature of the surroundings. Now if we let 99 per cent of this air rush out of the cylinder quickly it will carry with it about 99 per cent of the heat which it still contains. This leaves the inside of the cylinder very cold, possibly many degrees below zero. So we see that air can be used to remove heat from a chamber, by a process of compression and expansion.

Air, however, is not an efficient refrigerant, as it requires too high pressures to accomplish refrigeration economically with it.

219. COMMON REFRIGERANTS

Some of the more common refrigerants in use are:

Sulphur Dioxide, Methyl Chloride, Carbon Dioxide, and **Ammonia.**

These materials when in liquid form will evaporate or boil at very low temperatures. Sulphur dioxide for example will boil at about 14 degrees F., at atmospheric pressure. You will note that this temperature is below the freezing point of water, and recall that water requires 212 degrees F., to boil.

At higher pressures sulphur dioxide will not boil at such low temperatures; for example, at 55 lbs. pressure it requires 90 degrees F. to make it boil. If it is placed under a vacuum it will boil at less than 14 degrees F. Sulphur dioxide is the most commonly used of all refrigerants for home type units. It is a dark brown liquid of a somewhat syrupy appearance, and has a very bad odor. This is considered an advantage as it is easy to detect leaks if they should occur in a refrigerator using it. The chemical symbol for sulphur dioxide is SO_2. Other reasons for its popularity as a refrigerant are that it is one of the safest and least harmful in its effects, if some should leak out; and it does not attack metals of the compressor and tubing as some other solutions do. In addition it has somewhat of a lubricating property, and, being a stable chemical, remains good indefinitely in use.

Ammonia is commonly used in large refrigerating and ice-making plants where operators are on hand to attend to the equipment.

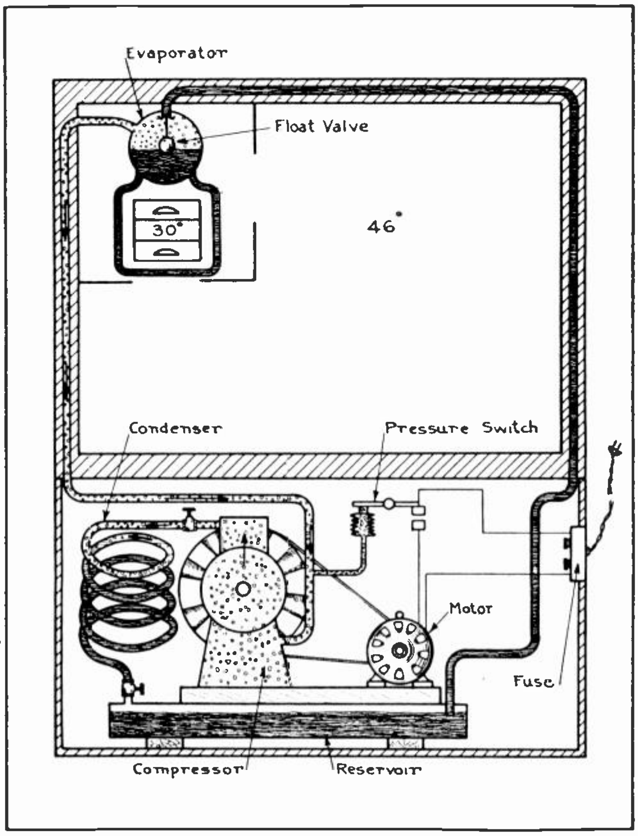

Fig. 254. This diagram shows the circulation of the refrigerating solution and also illustrates the general principles of the refrigeration cycle.

220. ABSORPTION OF HEAT BY EVAPORATION

We have learned that rapid expansion of gases creates a low temperature at the point at which they expand. The same thing is true of expansion of liquids due to evaporation. When refrigerant solutions boil or evaporate rapidly they absorb heat from the air in doing so. If we allow sulphur dioxide or some other refrigerant to expand in a chamber inside of an insulated refrigerator box and absorb some of the natural heat from the air in the box, and then pump this vapor outside, the box will be cooled and refrigeration is accomplished.

The box must be insulated with heat insulation, and have tight doors to keep heat from leaking in too rapidly from the outside air of higher temperature.

This is done by using thick walls filled with cork or other cellular or fibrous materials which do not readily conduct heat. The doors are equipped with air-tight sealing strips at their edges. As long as the doors of such a box are kept closed it does not require so much power to keep it cool.

221. REFRIGERATION CYCLE

After the refrigerant, by its expansion and evaporation into a gas, has absorbed heat from inside the box, this gas is compressed and condensed into liquid; then made to release its heat outside the box, and used over again in a repeated cycle. To drive the compressors electric motors are used, and for home type units they range from ⅙ to ¼ or ½ h. p.

Now let us trace out the complete refrigeration Cycle of one of the more common units, which will cover the same general principles as used by most of the others.

Fig. 254 shows the important parts in the liquid circuit, which are as follows: **Compressor, Evaporator, Condenser, Reservoir,** and **Connecting Tubing.**

In the evaporator and its tubes we have liquid SO_2. As it absorbs heat from the air in the refrigerator the liquid evaporates or boils, creating sulphur dioxide gas. This gas flows under its own pressure, out through the left pipe toward the compressor. As long as the compressor is idle this gas cannot escape beyond it, and therefore, gradually builds up pressure as evaporation continues. Note that this gas pressure is also applied to the bellows or "sylphon" of the pressure switch. When the evaporation pressure builds up to about 5 lbs., the thin metal bellows expands enough to snap the switch closed, and start the motor which drives the compressor.

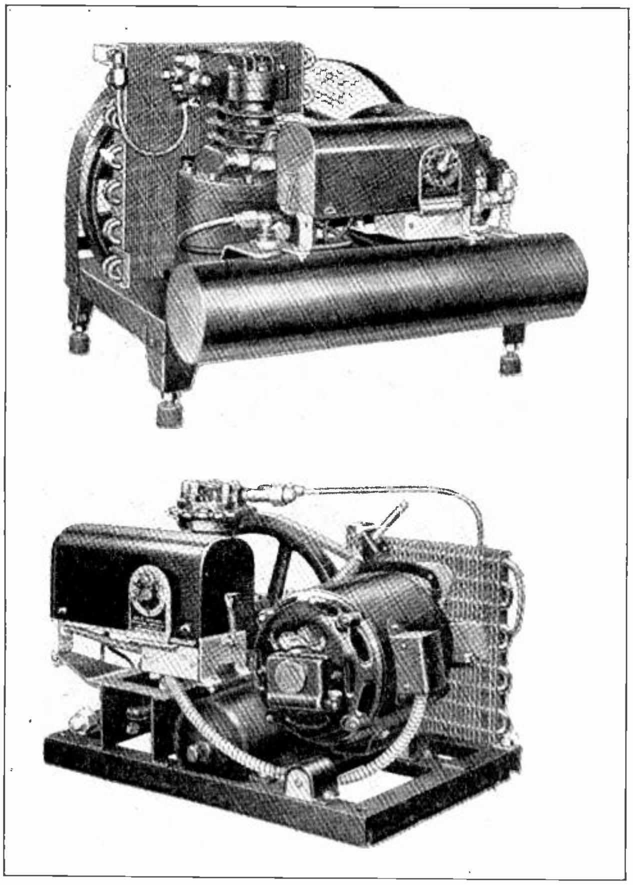

Fig. 255. Above are shown two complete refrigerator units including the compressor, motor, condenser, reservoir, and control box.

The running compressor sucks in the gas from the evaporator line and compresses it to about 55 lbs. pressure, forcing it into the coils of copper tubing called the condenser.

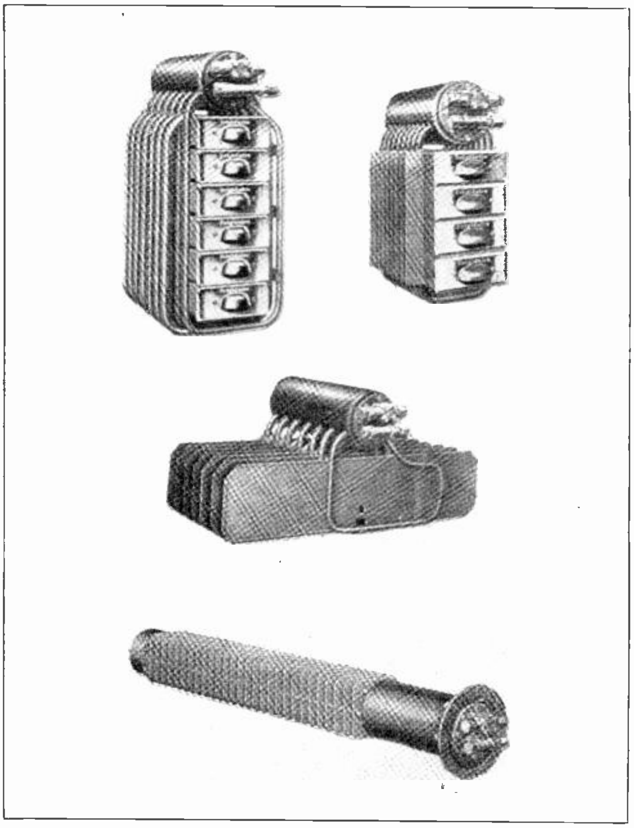

Fig. 256. Several types of evaporator units. Note the coils of tubing and metal fins which are used to aid in absorbing the heat from the air.

222. RELEASING HEAT BY COMPRESSION

When the gas is thus compressed, its temperature is raised to about 110 degrees, which causes it to give up its heat through the copper tubing to the outside air of lower temperature.

A set of fan blades on the driving wheel of the compressor forces air through the coils and assists in cooling them and carrying away the heat.

When the gas is thus chilled it condenses back into liquid and is forced on into the reservoir again in liquid state, but still under 55 lbs. pressure.

After the compressor has run long enough to reduce the gas pressure to about a 9″ vacuum, or less than atmospheric pressure, this causes the sylphon bellows to collapse and open the switch, stopping the motor and compressor.

If the temperature in the refrigerator is still too high, the evaporator will soon build up enough gas pressure to start the compressor again, and the cycle is repeated as often as necessary to keep the desired temperature in the box. Fig. 255 shows two complete compressor units with their condensers and reservoirs. The pressure switches are in the boxes with the curved tops, and on the side of these boxes are convenient adjustment dials to control the temperature.

When the liquid level in the evaporator is lowered by evaporation, the float valve allows fresh liquid SO_2 to again enter from the reservoir line, where it has been held under pressure.

Ordinarily the liquid in the reservoir will not boil, as it requires about 90° to boil it at 55 lbs. pressure. This same feature acts as a safety control to prevent the evaporator from building up too high pressures if the motor and compressor should fail. When the gas builds up to 40 lbs. pressure, evaporation stops, unless the room and box temperatures are above 75° F. When the compressor reduces the gas pressure to the 9″ vacuum, the liquid SO_2, of course, boils easier and faster at this low pressure.

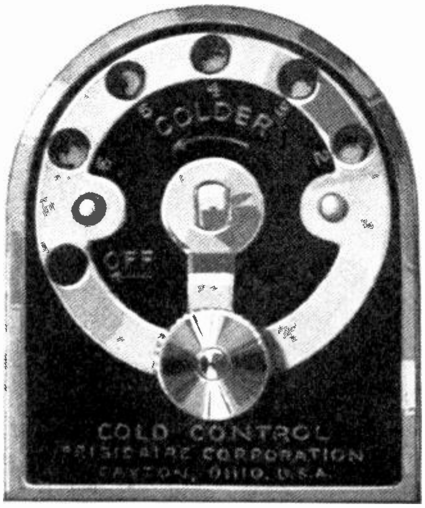

Fig. 256-A. This convenient form of temperature adjustment enables the housewife to easily control the temperature in the refrigerator, and to quickly freeze desserts when desired.

223. TEMPERATURE ADJUSTMENTS

The pressures at which the switch will operate to start and stop the motor, can be adjusted by screws on the switch lever and contacts, or by the convenient adjusting dials now used on some units. This regulates the temperature at which the refrigerator will be kept.

The coldest spot in the box is between the rows of tubes below the evaporator. In the trays located here we can freeze ice cubes, ice cream, or other desserts. Fig. 256 shows several types of evaporator units. The metal fins on some of them are made of copper or some metal that conducts heat well, to aid the liquid in the tubes in absorbing the heat from the air.

The compressor unit in this type refrigerator is hung in springs or set on rubber feet to reduce vibration, and should always be kept level.

A "cold control" or convenient adjusting device is provided on some of these units to enable the housewife to change the box temperatures for quick freezing or chilling of desserts.

Some refrigerators use thermostatic switches instead of varying gas pressures to start and stop the motor at given temperatures. Others use mercury switches as shown in Fig. 257. These consist of a small glass tube in which are sealed a pair of electrodes and a small quantity of mercury. The tube is mounted so it can be tilted by a pressure bellows or thermostat. When it tilts one way the electrodes are immersed in the mercury, closing the circuit. When the tube is tilted the opposite way the mercury runs to the other end of it and leaves the electrodes separated and the circuit open.

Many of the refrigerator units used for commercial installations, and some of those for homes, use water to cool the condenser coils. These must be connected to a water pipe so a little water can run through the coils continuously while the machine is operating. Fig. 258 shows a unit of this type.

224. REFRIGERATOR TROUBLES

If a refrigerator unit is properly installed, leaks in the piping very rarely occur. For detecting leaks of sulphur dioxide, ammonia is commonly used. Moving a small cloth or brush which is wet with ammonia, slowly along the pipe line will disclose a leak of SO_2 by creating a white smoke or steam when their vapors come together.

Occasionally a float valve will stick and prevent the machine from starting. Tapping the evaporator cylinder with the knuckles will often loosen it.

Blown fuses are probably one of the most common troubles, but they can easily be tested and replaced.

The switch should be kept properly adjusted and its contacts kept clean and bright.

Where D. C. motors are used they are generally of the compound type, and the small single phase A. C. motors are of the repulsion type. Larger units use three-phase A. C. motors. All of these motors will be explained in a later section.

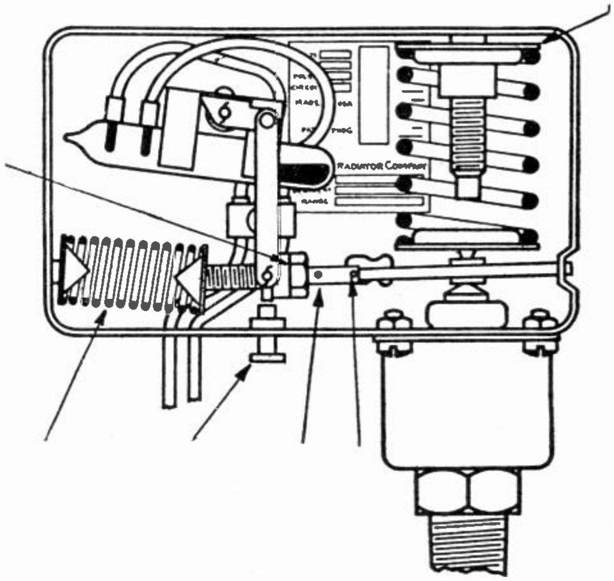

Fig. 257. This diagram shows the use and operation of a mercury switch for controlling a refrigerator motor.

Refrigerator motors should be kept well oiled, and their commutators and brushes kept in good condition.

Fig. 259 shows two compressor units for larger refrigerators.

One of the leading makes of refrigerators has its compressor and motor entirely enclosed and actually immersed in the refrigerant solution in the evaporator and reservoir unit, which are all mounted compactly on top of the box. Such a unit is shown in Fig. 253. This type has the advantage of being very silent in operation, and the working parts are guaranteed for a very satisfactory period.

225. USE OF BRINE SOLUTIONS

Some refrigerators use a brine solution around their coils, to transfer the heat from larger areas to them, and to act as a sort of "cold reservoir". The large ice plants use a brine solution to carry the heat from the freezing vats to the absorption and compressor units. But, in general, the same fundamental principles apply to all of them, and if you well understand these points just covered you should be able to easily obtain an understanding of almost any type you may encounter.

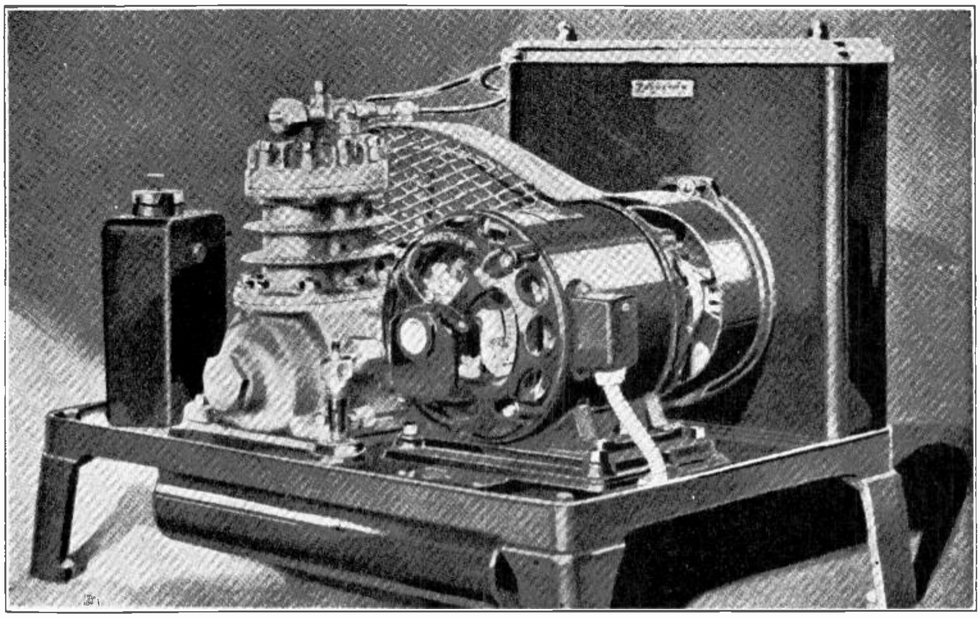

Fig. 258. The above view shows a refrigerator unit of the type which uses running water for cooling the condenser. The condenser coils are enclosed in the case at the rear right corner.

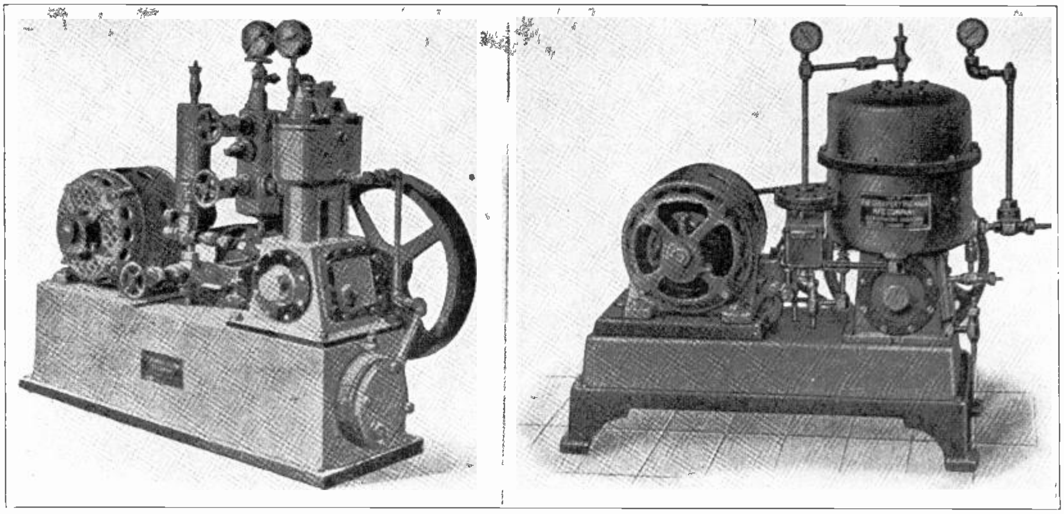

Fig. 259. Two refrigerator units of the large size for use in commercial establishments such as meat markets, soda fountains, etc.

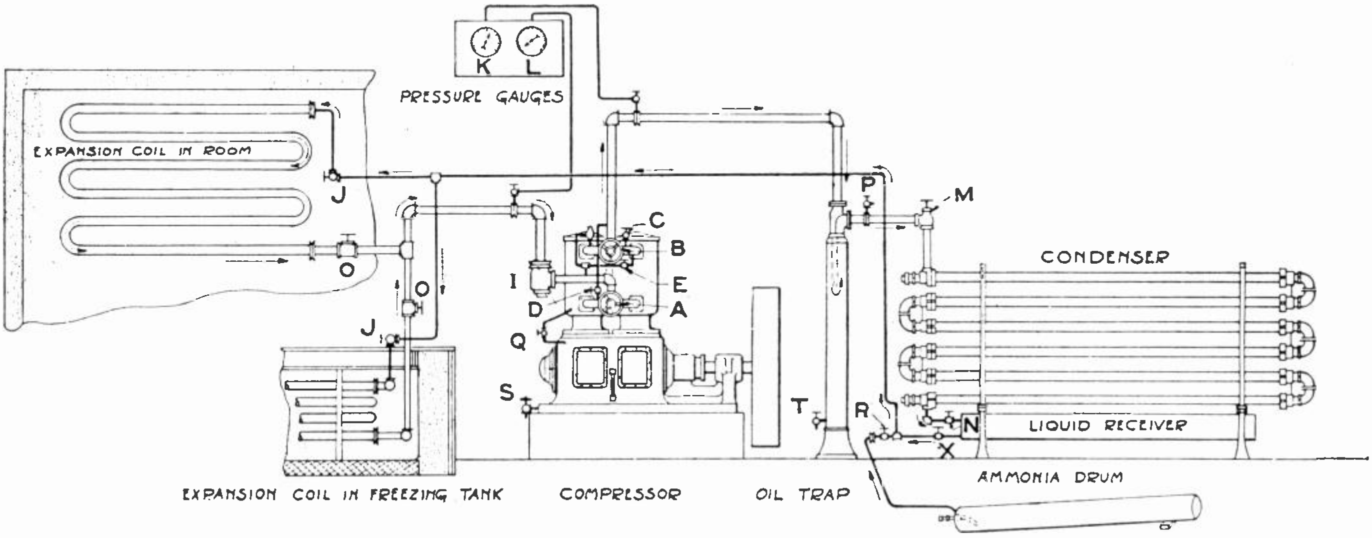

Fig. 260. This diagram shows the arrangement of a large refrigerating system such as used in packing plants and cold storage houses. These plants use ammonia as the refrigerant. Ammonia flows through the pipe shown by the small solid line, and as shown by the arrows, to the expansion valve "J." Here it is allowed to expand through the large coil and absorb heat from the room to be cooled, at the upper left. A branch is also taken to the expansion coil in the freezing tank at the lower left. This coil could absorb the heat from a brine solution, and freeze ice cakes or water in tanks immersed in this brine. The compressor then draws the expanded gas from both of these coils and compresses the gas to concentrate its heat and raise its temperature, and then forces it into the condenser coils shown at the right. In a plant of this type cool water is run over the condenser coils to chill the gas back into a liquid, and carry away the heat from it.

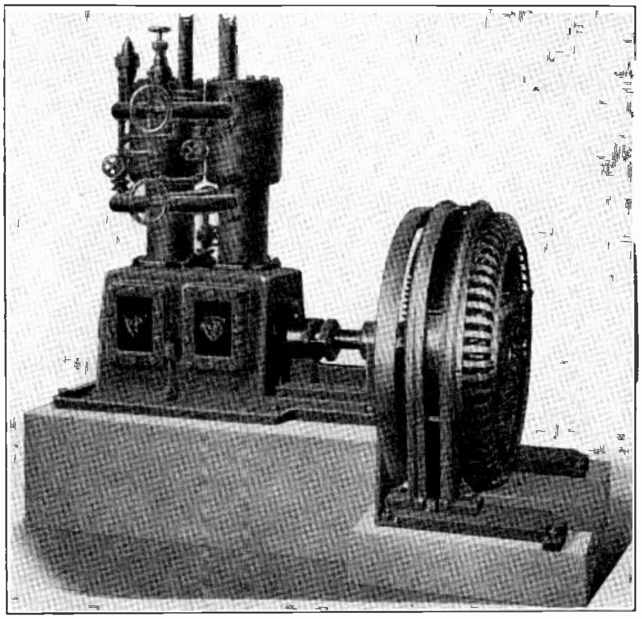

Fig. 261. This view shows one of the large types of compressors used for refrigeration and driven by a powerful electric motor. Some large refrigerating plants and ice plants use dozens of motors of this type, and often of several hundred horse-power each.

COYNE
Electrical School
CHICAGO ~ ~ ILLINOIS
ESTABLISHED 1899

ARMATURE WINDING AND TESTING

Section One

Direct Current Armatures
D. C. Motor and Generator Principles
Magnet Wires, Insulations, Coil Winding
Lap Windings, Wave Windings
Element Windings, Multiplex Windings
Rewinding Old Armatures
Armature Testing
Emergency Repairs

ARMATURE WINDING AND TESTING

Section One

D. C. ARMATURES

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

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

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

Fig. 1 shows a large group of motors for overhauling and rewinding in a modern repair shop, and Fig. 2 shows a section of the winding department in this same shop.

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

Fig. 1. This photo shows a view in a modern electric repair shop. Note the great number and variety of electrical motors and generators which go through this shop by the thousands each year. They are tested, rewound, reinsulated, and generally repaired before going back in service.

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

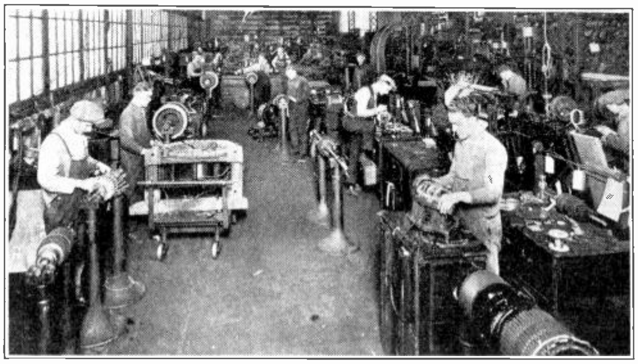

Fig. 2. This view shows a section of the Armature Winding Department of the same shop shown in Fig. 1.

There are actually thousands of electricians in the field today who do not know how to locate and repair such faults, and instead must take motors out of service and send them out to be repaired. In many cases windings are pulled apart unnecessarily to find troubles that could have been easily located by a test, without even removing the armature from the machine. It is needless to say that the maintenance electrician who knows how to systematically test for and locate these troubles, and can make quick repairs and put a machine back in service with the least delay, is the man who gets the best jobs and the best pay.

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

1. GENERATORS AND MOTORS

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

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

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

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

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

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

2. FIELD POLES

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

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

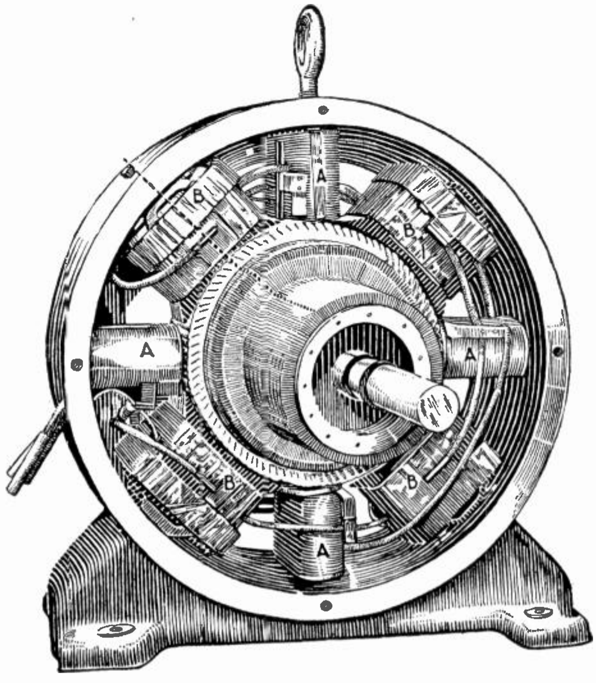

Fig. 3. This view of a D.C. generator with the front bearing bracket removed shows the field poles, armature, and frame very clearly.

3. ARMATURES

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

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

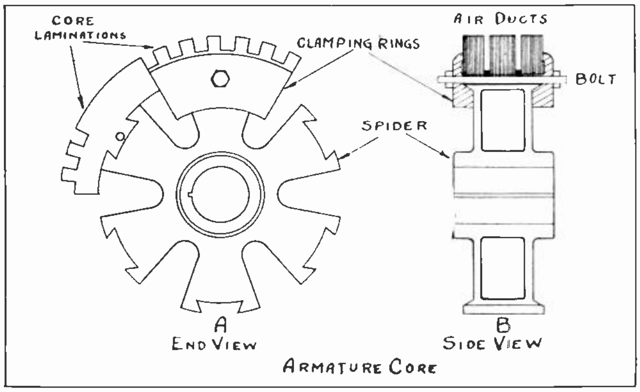

Fig. 4. The view at "A" shows the manner in which core laminations are assembled on a spider to make up the large armatures. At the right is a sectional view, showing the manner in which the laminations are assembled and clamped to the spider rim, and the air ducts which are left for ventilation and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

Small armatures are often constructed of laminations in the form of complete disks which merely have a hole through their center for the shaft, and possibly bolt holes for clamping them. This makes a core which is solid clear to the shaft. In the larger machines it is not necessary to have the entire core solid, so the laminations are assembled like the rim of a wheel, on the outside ends of short spokes, as shown in Fig. 4-A. This wheel or center framework is called the **Spider**, and the sections of core laminations are dovetailed into the spider, as shown in the figure. Heavy clamping rings at each end of the group, and drawn tight by bolts, hold the entire core in a solid, rigid unit.

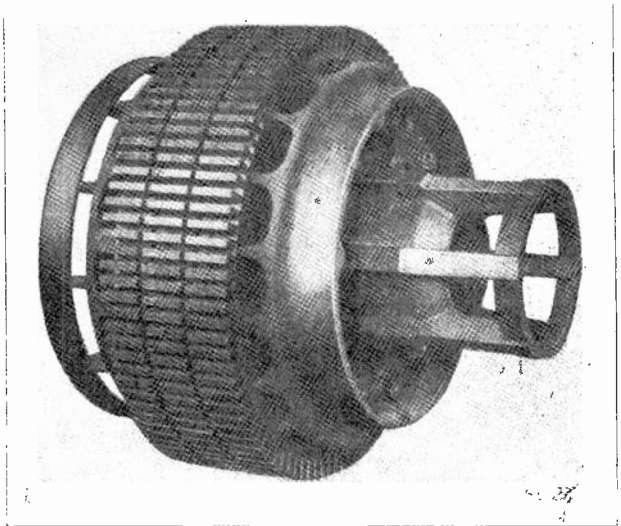

Fig. 5. Completely assembled D.C. armature. Note the manner in which the laminations are clamped together by the heavy end rings, and also note the slots around the armature core in which the coils will be laid.

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

Fig. 5 shows a completely assembled core of this type without the shaft or the commutator.

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

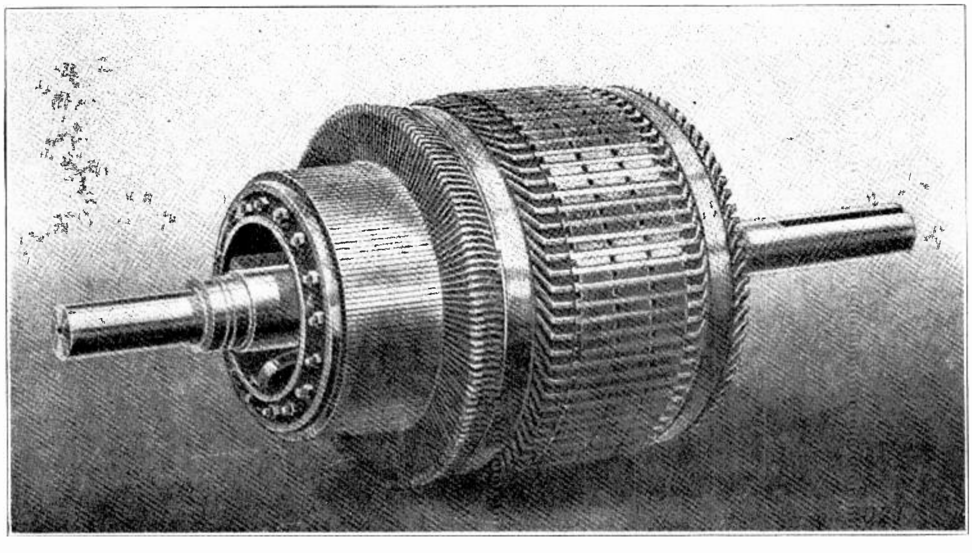

Fig. 6. The view at the left is a photo of a large D.C. armature for a 150 KW, belt driven generator. The commutator is at the left and the bars or segments can be plainly seen. Note how the armature coils are held in the slots by wedges and the band wires around each end of the armature. (Photo Courtesy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

4. ARMATURE SLOTS

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

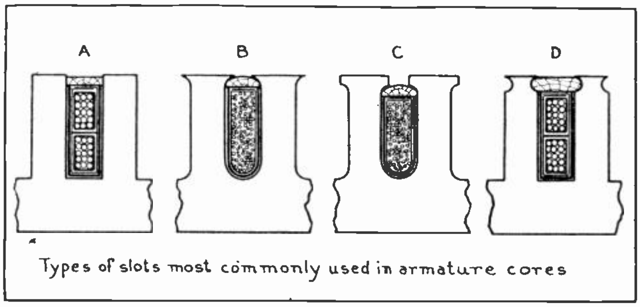

Fig. 7. The above diagram shows four common types of armature slots. Note carefully the manner in which the coils are arranged and insulated, and also the wedges which hold them in the slots. The wedge in the slot at "A" would be held in place by band wires around the armature.

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

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

5. COMMUTATORS

Commutators are constructed of a number of segments or copper bars, mounted in the form of a cylinder around the shaft. They are mounted near to the end of the armature core, so the coil ends can be connected to each of these bars. Between each bar and the next is placed a thin mica strip or segment, which keeps them entirely insulated from each other.

See Fig. 8-A, which is an end view of such a commutator. B— and B+ are the brushes which rest on the commutator surface F. "R" is the clamping nut, and at "U" are shown slots in the segments where the coil leads are attached. The black lines at "M" are mica insulating strips.

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

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

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

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

Fig. 9 shows a large engine-driven D.C. generator from the commutator end. This commutator is mounted on a spider and you can note the brushes resting on its outer surface. Part of the field poles can also be seen around the left side of the frame.

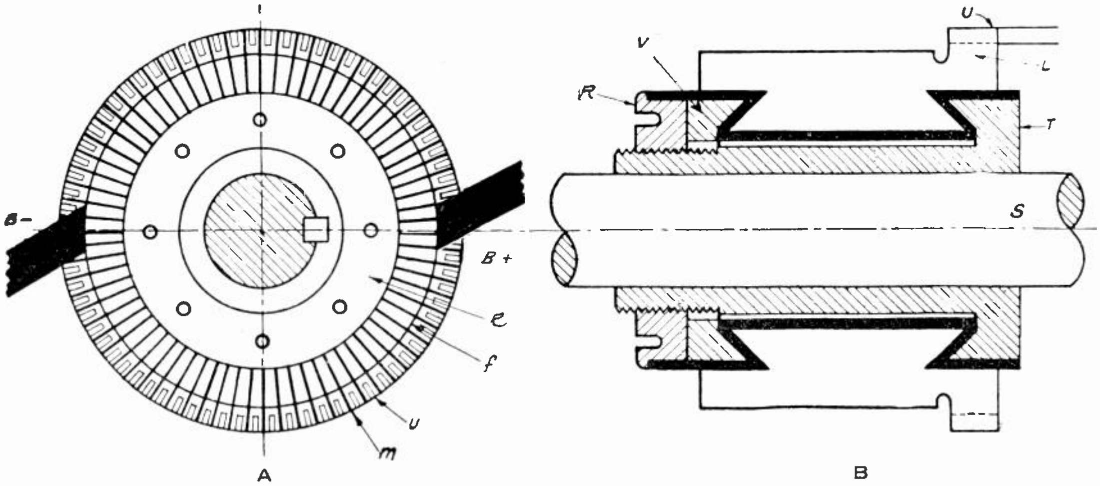

Fig. 8. At "A" is shown an end view of a commutator, illustrating the manner in which the bars or segments are assembled and kept separated by strips of insulation between them. At "B" is a sectional view showing how the commutator segments are clamped and held in place by clamping rings which fit in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

Machines of this type are made in sizes ranging from less than 100 horsepower to many thousands of horsepower, and small motors are made in sizes down to ¼ horsepower and less.

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

6. OPERATING PRINCIPLES OF GENERATORS AND MOTORS

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

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

7. GENERATION OF VOLTAGE

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

You will also recall from the section on elementary electricity that a generator operates on the principle of magnetic induction, and that the voltage is produced by the wires or conductors cutting magnetic lines of force.

Fig. 10 shows a diagram of a very simple form of D.C. generator, consisting of two field poles marked "N" and "S", and one armature coil connected to two commutator segments, which are in contact with the positive and negative brushes. These brushes are to collect the current from the commutator bars as the coil and the commutator revolve on the armature. If we revolve the coil rapidly through the magnetic flux between the north and south poles, a voltage will be generated in the coil; and if there is a complete external circuit through the lamps or load as shown, this voltage will cause current to flow out through this circuit and back through the armature coil continuously, as long as the rotation continues and the circuit remains closed. As the coil revolves, either side of it passes first the north pole and then the south pole, and cuts through the lines of force first in one direction and then the other. Therefore, the

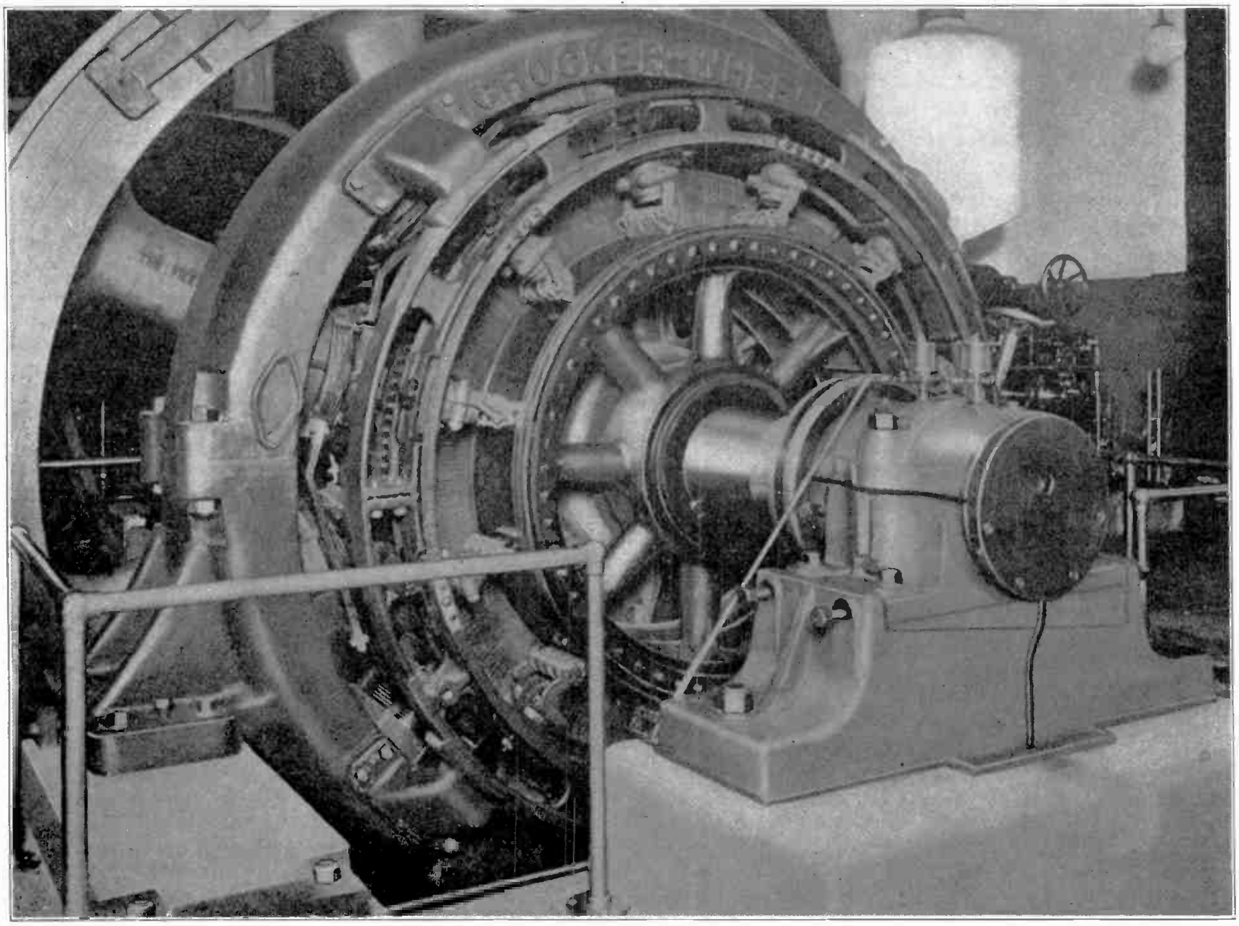

Fig. 9. This photo shows a large 400 KW. 225 volt D.C. generator which is direct connected to a steam engine. This machine is designed to run at 110 R.P.M. and, therefore, it has a larger diameter than those which operate at higher speeds. This generator has 12 field poles and 12 sets of brushes. (Photo Courtesy Crocker-Wheeler Electric Company.)

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

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

8. COMMUTATOR ACTION

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

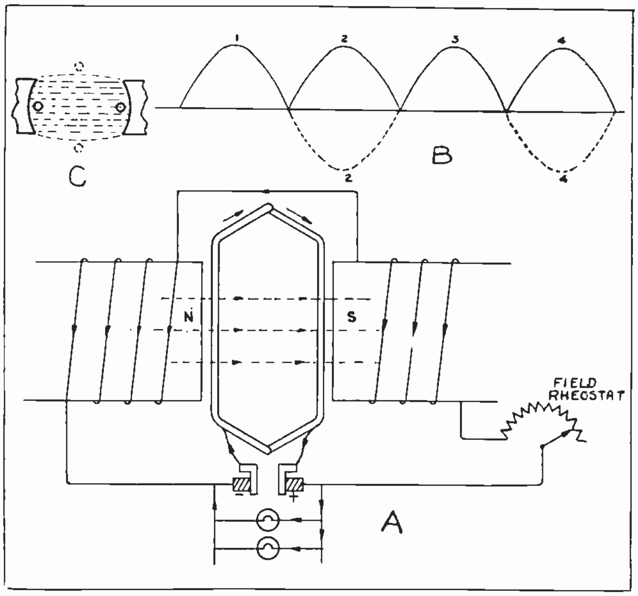

Fig. 10. The above diagram shows the principles of a simple D.C. generator. Note the manner in which the field coils are connected to the brushes, and the rheostat used for controlling the amount of field current.

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

9. VOLTAGE CURVES. PULSATING DIRECT CURRENT

We learned in a previous section that the voltage or current of any circuit can be conveniently represented by curves, as shown at "B" in Fig. 10. These curves show the variation and direction of the voltage that would be produced by this simple generator.

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

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

Large generators are never constructed with only one coil on the armature, but usually have a considerable number of coils placed in the slots around the armature surface, and connected to as many commutator segments. The use of this greater number of coils produces impulses closely following each other, and in fact overlapping, so that the variation or pulsation of current, as shown in Fig. 10-B, is considerably reduced.

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

10. FACTORS THAT DETERMINE MACHINE VOLTAGE

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

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

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

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

If a simple generator, such as shown in Fig. 10, has one volt produced in each side of its coil, then the pressure at the brushes will be 2 volts; because the two sides of the coil are in series, and their voltage adds together. If we were to increase the number of turns in this coil from one to ten, the pressure at the brushes would be 20 volts, because all ten turns would be in series and their voltages would add. So we find that the number of turns per coil in an armature winding will regulate the voltage produced.

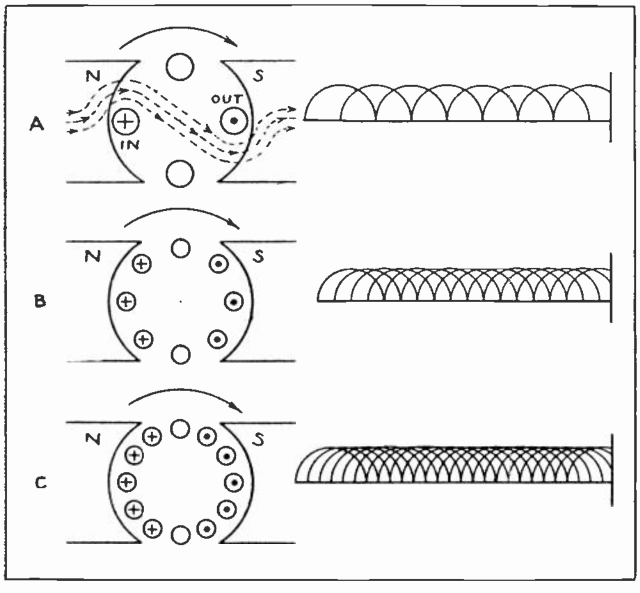

Fig. 11. The above diagram shows the voltage curves for three simple generators with different numbers of conductors in their armatures. Note how the greater number of conductors produces direct current of a more constant value.

11. ARMATURE FLUX AND ITS ACTION IN GENERATORS

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

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

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

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

12. MOTOR PRINCIPLES

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

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

13. COUNTER E. M. F. IN MOTORS

We must remember that as the motor rotates its armature conductors will still be cutting lines of force of the field. As the conductors of the motor in Fig. 10 are revolving in the same direction they did in the generator, this voltage induced in the

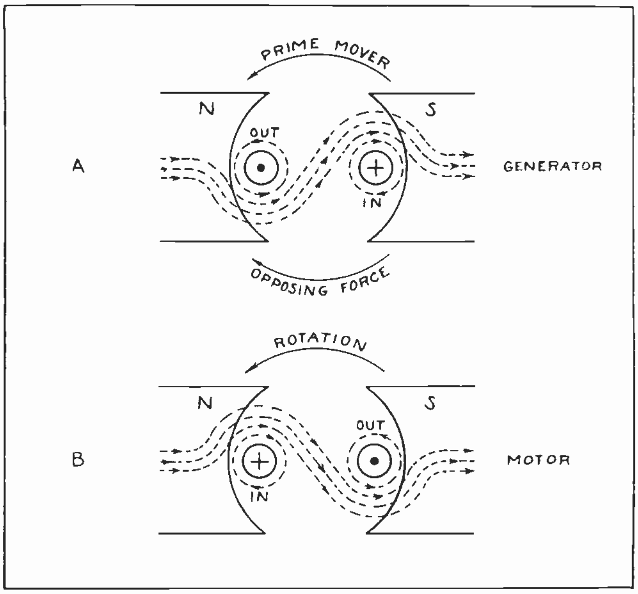

Fig. 12. This sketch shows the manner in which motor torque is produced by the reaction between the flux of the armature conductors and the field flux. Examine both "A" and "B" very carefully, and check the direction of current in the conductors, the direction of flux around them, and the direction of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

coils will be in the opposite direction to the applied line voltage. This voltage, which is always generated in the coils of any motor during operation, is therefore called **Counter Electro-Motive Force,** and usually referred to as counter E. M. F., or counter voltage.

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

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

Applying Ohms law, or E ÷ R = I, we find that 110 ÷ ¼ = 440 amperes. Actually a motor of this size would ordinarily draw only about 10 amperes when operating without mechanical load; so we can see to what a large extent the current must be controlled by the counter voltage.

This counter voltage can be determined in the following manner. We know that I × R = E, so 10 × ¼ = 2½ volts, or the voltage required to force 10 amperes through the armature resistance. If we subtract this from the applied voltage we find the counter voltage, or 110 — 2½ = 107½ volts, counter E. M. F.

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

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

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

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

15. ARMATURE COILS

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

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

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

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

16. NUMBER OF TURNS AND SIZE OF WIRE

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

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

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

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

17. WIRE INSULATION

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

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

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

The plain enamel insulation is generally used only on the very small wires, but combined enamel and cotton or silk coverings are used on quite large wires.

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

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

It is well to **Use Wires With Sufficient Insulation to Protect Them From Short Circuits in the Finished Coils.** However, we must also remember that the **Thicker Insulations Require More Space and, Therefore, Allow Fewer Turns in a Slot of Any Given Size.**

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

The table in Fig. 13 gives the diameters of magnet wires from No. 14 to No. 44 B. & S. gauge. These diameters are given for the bare wires and also for wires with various insulations. The table also gives the areas and weights of these wires, and in the right-hand section some additional data which is very convenient in calculating and winding various coils.

Size B.&S. Gauge	Diam. bare wire in in.	Metric equiv in. M.M.	Diam. enam. wire in in.	Diam. S.C.E in in.	Diam. S.S.E. in in.	Diam. S.C.C. in in.	Diam. D.C.C. in in.	Diam. S.S.C. in in.	Diam. D.S.C. in in.	Area Cir. Mils.	Ohms per 1,000 ft.	Ohms per pound	Feet per ohm	Feet per pound
14	0641	1.628	.0661	.0711	.0681	.0691	.0741	.0661	.0681	4107	2.521	.2028	396.6	80.44
15	.0571	1.450	.0590	.0640	.0610	.0621	.0671	.0591	.0611	3257	3.179	.3225	314.5	101.4
16	.0508	1.291	.0526	.0576	.0546	.0558	.0608	.0528	.0548	2583	4.009	.5128	249.4	127.9
17	.0453	1.150	.0471	.0521	.0491	.0503	.0543	.0473	.0493	2048	5.055	.8153	197.8	161.3
18	.0403	1.025	.0419	.0469	.0439	.0453	.0493	.0423	.0443	1624	6.374	1.296	156.9	203.4
19	.0359	.9116	.0375	.0425	.0395	.0409	.0449	.0379	.0399	1288	8.038	2.061	124.4	256.5
20	.0320	.8118	.0335	.0385	.0355	.0370	.0410	.0340	.0360	1022	0.14	3.278	98.66	323.4
21	.0285	.7229	.0299	.0344	.0319	.0330	.0370	.0305	.0325	810.1	12.78	5.212	78.24	407.8
22	.0253	.6438	.0267	.0310	.0287	.0296	.0336	.0273	.0293	642.4	16.12	8.287	62.05	512.2
23	.0226	.5733	.0239	.0282	.0259	.0269	.0309	.0246	.0266	509.5	20.32	13.18	49.21	648.4
24	.0201	.5106	.0213	.0256	.0233	.0244	.0284	.0221	.0241	404.0	25.63	20.95	39.02	817.6
25	.0179	.4547	.0191	.0234	.0211	.0222	.0262	.0199	.0219	320.4	32.31	33.32	30.95	1031
26	.0159	.4049	.0170	.0210	.0190	.0199	.0239	.0179	.0199	254.1	40.75	52.97	24.54	1300
27	.0142	.3606	.0152	.0192	.0172	.0182	.0222	.0162	.0182	201.5	51.38	84.23	19.46	1639
28	.0126	.3211	.0135	.0175	.0155	.0166	.0206	.0146	.0166	159.8	64.79	133.9	15.43	2067
29	.0113	.2859	.0122	.0162	.0142	.0153	.0193	.0133	.0153	126.7	81.70	213.0	12.24	2607
30	.0100	.2546	.0108	.0148	.0128	.0140	.0180	.0120	.0140	100.5	103.0	338.6	9.707	3287
31	0089	.2268	.0097	.0137	.0117	.0129	.0169	.0109	.0129	79.70	129.9	538.4	7.698	4145
32	.0080	.2019	.0087	.0127	.0107	.0120	.0160	.0100	.0120	63.21	163.8	856.2	6.105	5227
33	.0071	.1798	.0077	.0117	.0097	.0111	.0151	.0091	.0111	50.13	206.6	1361	4.841	6591
34	.0063	.1601	.0069	.0109	.0089	.0103	.0148	.0083	.0103	39.75	260.5	2165	3.839	8311
35	.0056	.1426	.0062	.0102	.0082	.0096	.0136	.0076	.0096	31.52	328.4	3441	3.045	10480
36	.0050	.1270	.0055	.0095	.0075	.0090	.0130	.0070	.0090	25.00	414.2	5473	2.414	13210
37	.0045	.1131	.0050							19.83	522.2	8702	1.915	16660
38	.0040	.1007	.0044							15.72	658.5	13870	1.519	21010
39	.0035	.0897	.0039							12.47	830.4	22000	1.204	26500
40	.0031	.0799	.0035							9.888	1047	34980	.9550	33410
41	.0028	.0711	.0031							7.845	1333	54000	.7630	42000
42	.0025	.0633	.0028							6.250	1680	87400	.6050	52800
43	.0022	.0564	.0025							4.850	2120	132000	.4670	66400
44	.0020	.0502	.0023							4.000	2670	212500	.3850	82600

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

Bare Wire—Sizes No. 30 and larger, 1% plus or minus. Sizes No. 31 and finer .0004" plus or minus.

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

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

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

Winding Data Based on Actual Winding Space

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

Method of Determining Actual Winding Space

Let D = outside diam. finished coil
d = inside diam. finished coil
L = overall length finished coil
An = Actual winding space low tension coil without cotton tape
At = Actual winding space low tension coil taped with cotton tape.
Ah = Actual winding space high tension coil

Then

$$A_n=(L-\tfrac{1}{4})\left[\frac{(D-\tfrac{1}{16}")-(d+\tfrac{1}{16}")}{2}\right]$$

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

$$A_h=(L-\tfrac{1}{4})\left[\frac{(D-\tfrac{1}{16}")-(d+\tfrac{1}{16}")}{2}\right]$$

Fig. 13. The above table gives some very valuable data, which will be of great help in determining the number of turns of any given size wire which can be placed in a slot of a certain area. Observe the thickness of the various types of insulation on these wires.

18. TYPES OF COILS

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

Fig. 14-A shows a **Diamond Type Coil** before and after pulling or shaping. The unfinished loop coil consists of three wires wound in parallel the desired number of turns, and after the coil is wound a layer of cotton tape is wound over it, with each turn lapping over the last by half its width. The coil is then pulled with a coil spreader into the shape shown in the lower view at "A".

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

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

The coil at "A" is called a three element coil, while the one at "B" is a five element coil. The coil shown at "C" in Fig. 14 is known as the Eickemeyer type. The upper view shows it before taping, and the lower view after it has been taped and shaped. At "D" is shown a single turn coil of copper ribbon or bar, shaped into a wave coil with a diamond twist on the back end.

19. COIL AND SLOT INSULATION

In addition to the insulation on the wires themselves it is also necessary to insulate the coils and entire winding from the slots and armature core. The insulations used for this purpose serve both to protect the coils from mechanical injury from contact with slot edges, and also to electrically insulate them from the slots.

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

20. FIBRE AND PAPER INSULATIONS

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

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

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

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

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

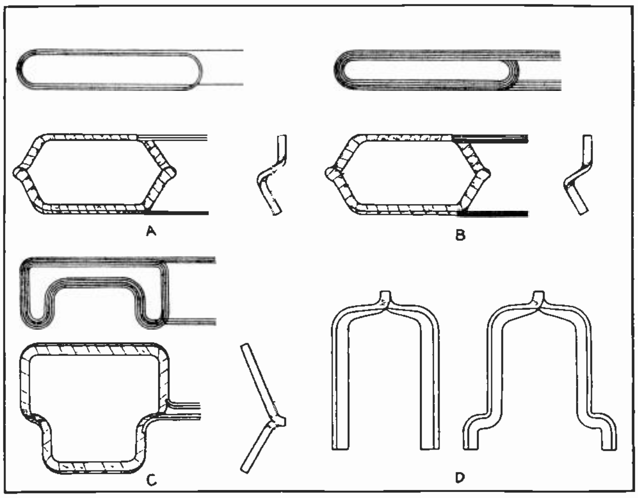

Fig. 14. This diagram shows several of the more common types of armature coils, both in the rough loop form and in the finished taped form.

21. VARNISHED CLOTH INSULATIONS

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

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

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

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

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

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

22. HEAT-RESISTING INSULATION

For **Heat Resisting** and **High Quality Electrical Insulation** we use **Mica, Micanite, Mica Paper**, and **Mica Cloth.**

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

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

The following examples can be used as suggestions, however:

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

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

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

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

23. WINDING COILS

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

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

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

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

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

Special machines can be obtained for winding and shaping coils of various sizes, and these are generally used in large repair or manufacturing shops. Fig. 15 shows an adjustable coil winder, for making coil loops of various sizes.

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

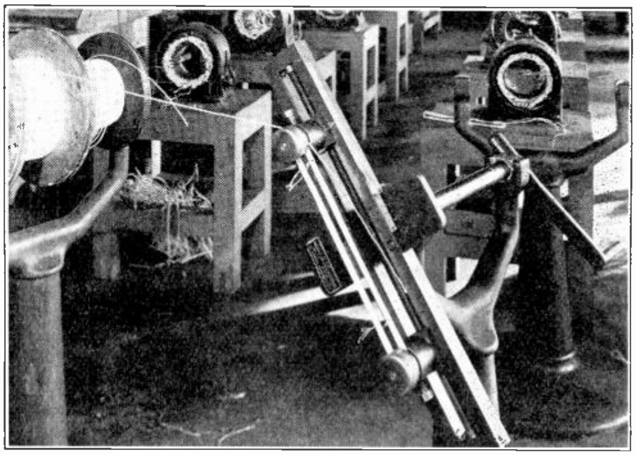

Fig. 15. The above view shows a coil winder which can be used for winding coil loops of different sizes, by adjusting the end pins along the slide. When the crank is turned the wire is wound directly from the spool into the slots on these end pins.

Fig. 16 shows several of these forms which can easily be made from pieces of board. At "A" is shown a flat board with 6 nails or wood pins driven in the proper shape to make a plain diamond coil. By moving the nails or pins, coils of most any desired size and shape can be made.

In Fig. 16-B is shown a method of placing another thick piece of board on the first one and driving the nails for the points of the coil, in the edge of this board at an angle. When the wires are wound over the corner of this board and down under these end nails, it shapes the twist in the coil ends as shown.

Fig. 16, C and D, show how an adjustable winding form can be made, which can be rotated on a large center bolt by means of a crank. This enables a coil to be rapidly wound, by allowing the wire to

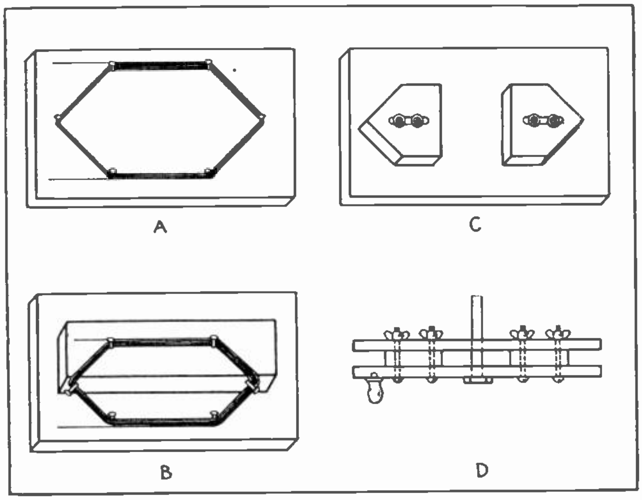

Fig. 16. Simple board forms can be made as shown above for winding coils of various sizes. These are very economical and easy to make, and a very handy device for the small repair shop to have.

run directly from a spool into this form as it is rotated; similarly to the coil winder shown in Fig. 15.

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

24. TAPING AND SHAPING OF COILS

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

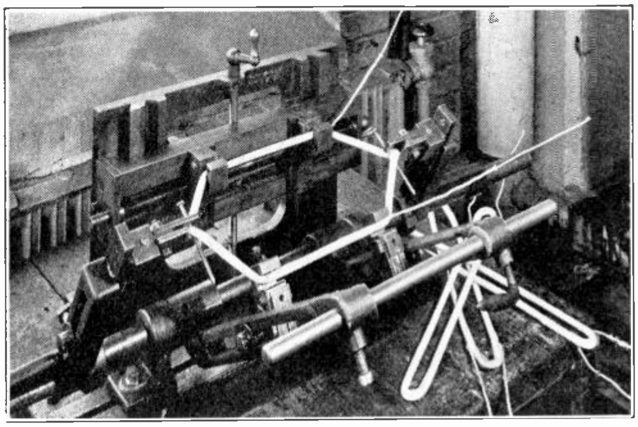

Fig. 17. This photo shows a coil shaping machine, which is used for pulling diamond coils into the proper shape and putting the twist in the ends as shown. This machine is adjustable to shape coils of different sizes

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

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

Remember that to make a neat and well balanced winding it is very important to get all coils of the same size and shape, and the ends twisted uniformly and evenly. Fig. 17 shows a coil shaping machine used for shaping and twisting the coils before they are placed in open type slots.

Fig. 18 shows several coils in various stages of completion. The first coil at the left is just a plain coil loop of the proper length, before taping or shaping. In the center are three of these coil loops already taped. The two coils at the right are completely taped and shaped. Note the sleeving placed

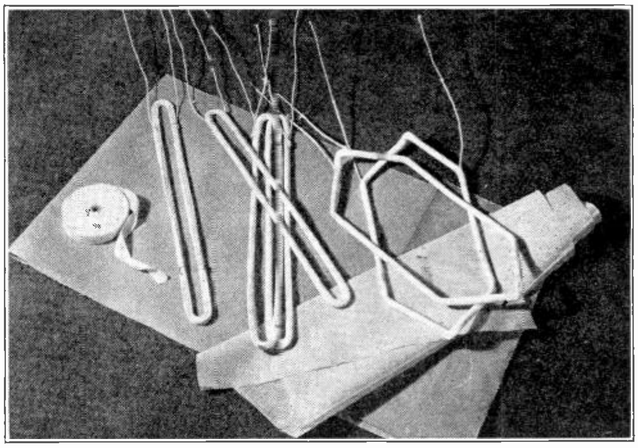

Fig. 18. Above are shown several armature coils, both in the unfinished loops and the completely taped coils. Also note the roll of cotton tape and the varnished cambric used for insulating the coils and slots.

on the coil leads for marking and protection. A roll of cotton tape such as used for these coils is also shown, and underneath the tape and coils are shown a sheet of fish paper and a roll of varnished cambric such as used for slot insulation.

LAP AND WAVE WINDINGS

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

Fig. 19 shows a section of a lap winding. Starting with the coil at the left, trace the path of current through this coil as shown by the arrows, and then on through the next coil, etc. The coils are all alike but the one on the left is drawn with heavier lines to make it easier to trace the first one. Examining this diagram, we find that each coil overlaps the next as we trace the cricuit through them; thus the name **Lap Winding.**

Fig. 19-B shows the method of connecting coils for a wave winding. Starting at the left lead, trace the path of current through the two coils shown by the heavy lines. Note the location of the north and south field poles, which are shown by the dotted rectangles and marked "N" and "S". We find, by tracing the circuit through, that each coil in this circuit is separated from the last by the distance of one pair of poles, and you will note the wave-like appearance of the two coils traced in heavy lines, and from this appearance the name **Wave Winding** is derived

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

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

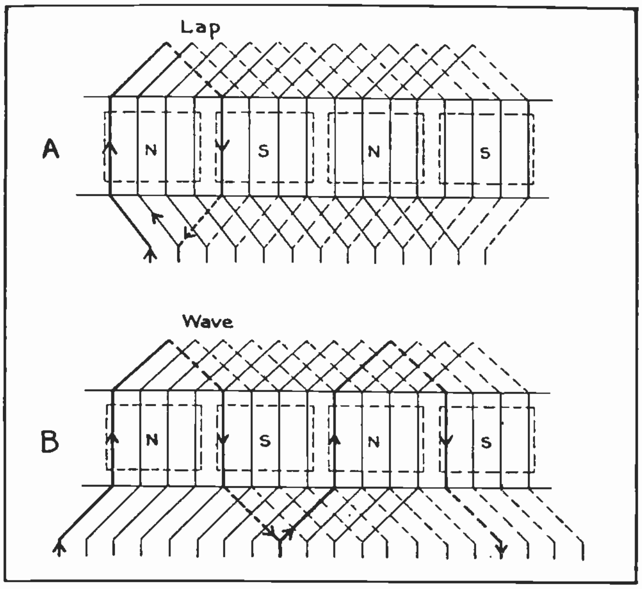

Fig. 19. The two above diagrams show the connections for a lap winding at "A", and a wave winding at "B". Observe carefully the manner in which the leads are brought out from the coils to the commutator bars.

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

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

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

Fif. 20. This convenient table gives the number of brushes and circuits, and the brush spacing for lap and wave windings with different numbers of poles.

The table in Fig. 20 gives the number of brushes, brush spacing, and the number of circuits for lap and wave windings with different numbers of poles. These figures are given for **Simplex** windings, which will be explained later.

25. CURRENT FLOW THROUGH A LAP WINDING

Fig. 21 shows a complete four-pole winding of the lap simplex type. This diagram shows the position of the field poles by the dotted lines and markings "N" and "S". It also shows the direction of current flow through the armature conductors under each pole and the position of the brushes with relation to those of the poles. Note that the two negative brushes are connected together in parallel and the two positive brushes connected the same. This winding is drawn out in a flat plan view so that you can more conveniently trace the entire circuit and see all the coils. The last six slots on the right have only one coil side in each, while all the other slots have two coil sides in each.

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

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

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

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

By comparing this winding with the sketch at A in Fig. 19, we can see that it is nothing more than a number of coils all connected in series, with the finish of one coil attached to the start of the next, etc.

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

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

26. COIL SPAN

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

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

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

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

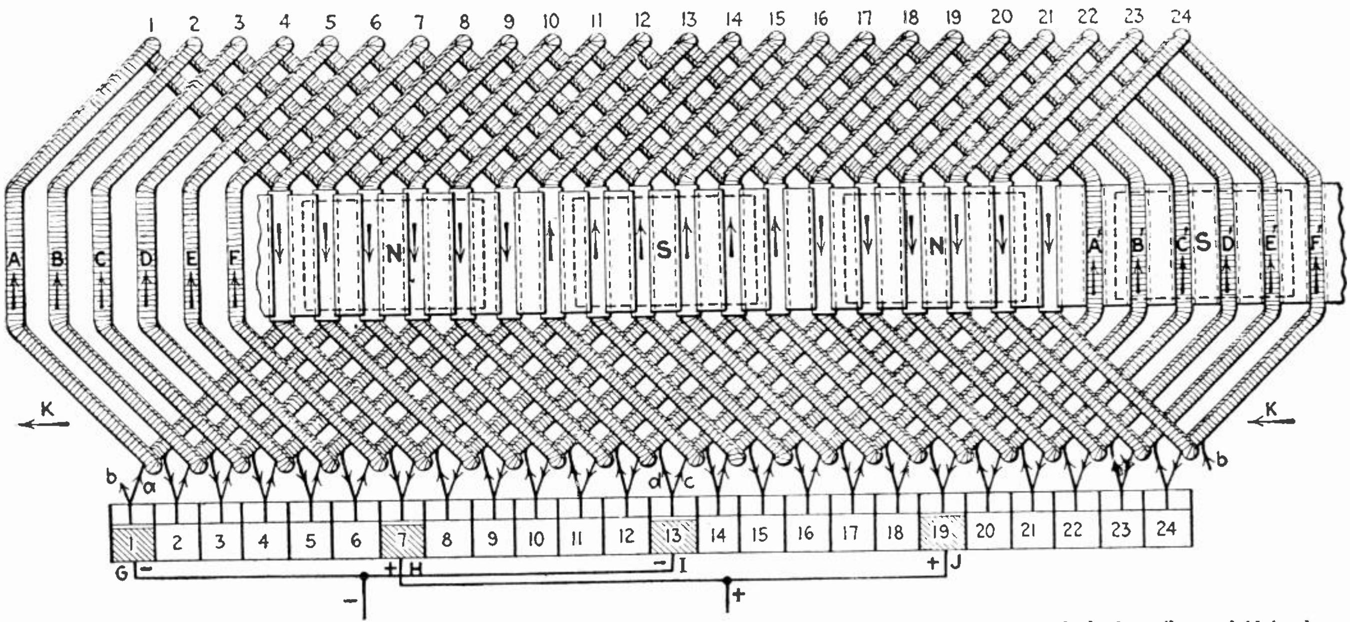

Fig. 21. The above diagram shows a complete four-pole lap winding of the Simplex type. Note the manner in which the coils are laid in the slots, with one side of each coil in the bottom of a slot and the other side in the top of its slot. Also trace out this winding carefully with the instructions given on these pages.

27. PREPARING AN ARMATURE FOR WINDING

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

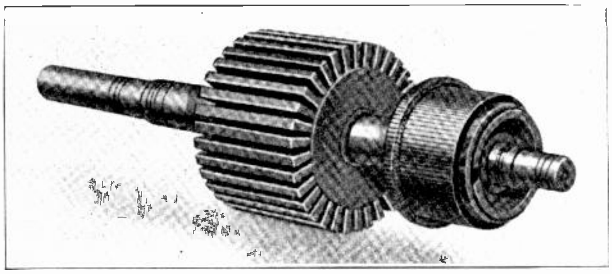

Fig. 22. The above photo shows a D.C. armature prepared for winding. The slots are cleaned and smoothed out, and the necks of the commutator bars have been slotted to receive coil leads.

Fig. 22 shows an armature with the core and commutator prepared for winding, and in Fig. 23 is shown an armature with the insulation placed in the slots. Note that this slot insulation is allowed to project slightly at the ends of each slot, to protect the coils at these sharp edges; and also out of the tops of the slots a short distance, to make it easier to slide the coils in, and to protect them from scratching or damaging the insulation while they are being placed in the slots. Also note the insulation wrapping on the coil support ring at the left end of the armature. All such metal parts against which the coils may rest should be thoroughly insulated by wrapping with fish paper or varnished cambric and tape, before any coils are placed in the slots.

28. INSERTING COILS FOR A LAP WINDING

By referring to several sketches in Fig. 24, the method of laying coils in place in the slots can be observed. In the three views at "A" the coils are wound in from the left to right, as shown by the arrow. Note carefully the manner in which each coil overlaps the last, and the manner in which the diamond shaped ends of the coils allow them to fit closely and neatly together, if they are properly shaped and twisted at the ends. In order to obtain a satisfactory winding job, it is essential that all coils be exactly the same size, and uniformly fitted in the slots and at their ends. Care and practice on these points are necessary to make a rugged and well-balanced winding.

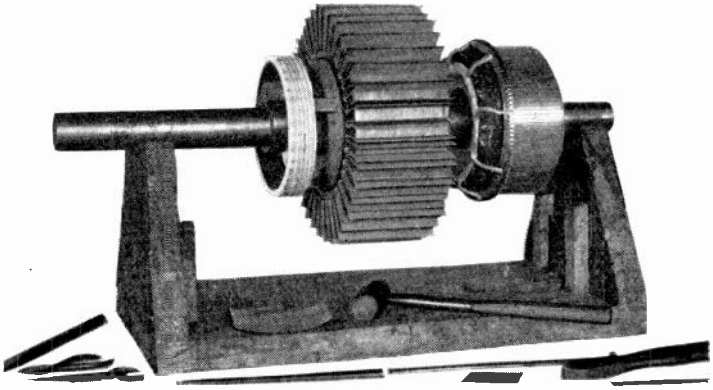

Fig. 23. This armature has the slot insulation in place ready to receive the coils, and you will also note that the coil support ring at the left end has been wrapped with insulating tape. The armature is mounted in a stand and free to revolve so it will be more convenient to place the coils in all the slots.

The coils at "B" in Fig. 24 are wound into the slots in the opposite direction around the armature, or to the left when facing the commutator end. Armatures may be wound in either direction, as it makes no difference in their operation. The direction in which the coils are placed in depends on the shape of the twist or curl at their ends, and the important point to remember is that if the coils are shaped as shown at "A", they must be laid in the slots to the right, in order to get their ends to fit together compactly. If the twists on the coil ends are made in the opposite direction, as at "B", then the coils must be laid in the armature to the left.

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

After the bottom side of the first coil is in place in the slot, (leave the top of this coil out for the present), the lower coil lead should be brought out to the commutator and driven into the slot in the proper segment. The angle of this lead, or whether it connects to a segment in line with the center of the coil as in Fig. 24, or is connected straight out to a bar in line with the side of the coil, depends upon the position of the brush with relation to the field poles.

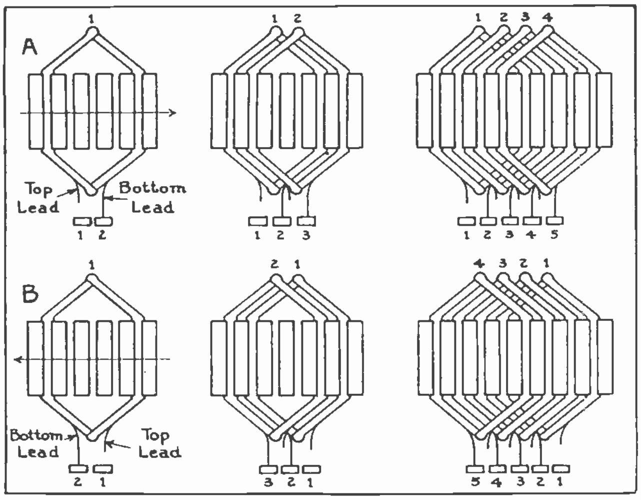

Fig. 24. The above diagrams show the method of laying coils of a lap winding in the slots. Note the direction the coils are laid in or progress around the core, according to the shape of the twist at their ends.

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

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

29. CONNECTING THE COILS

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

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

The top lead of coil No. 2 in Fig. 24 will connect to segment No. 2, with the bottom lead of coil No. 1.

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

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

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

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

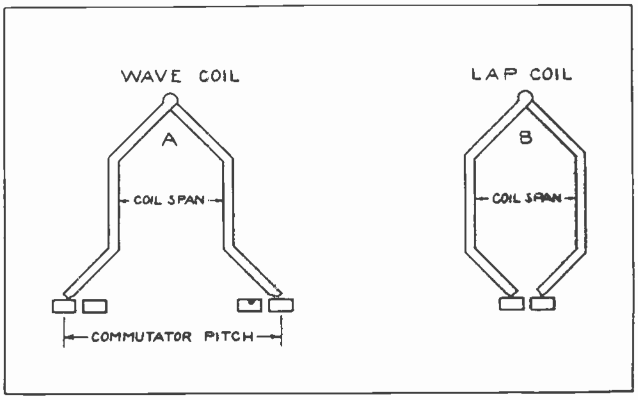

Fig. 24-C. At "A" is shown a coil for a wave winding and at "B" a coil for a lap winding. Note the difference in the way their ends or leads are brought out to the commutator bars, and the manner in which either side of the wave coil is braced in two directions by the angle of its front and back connections.

30. WAVE WINDINGS

The shape of wave-wound coils, their connections, and the manner in which they differ from lap windings, has already been explained. Wave windings have the advantage of their coils being more securely braced and held in place by the way they are arranged in the armature. This is due to the manner in which the coil ends are bent in the opposite direction from the coil side in the slot, while those of the lap winding are bent in the same direction as shown in Fig. 24-C.

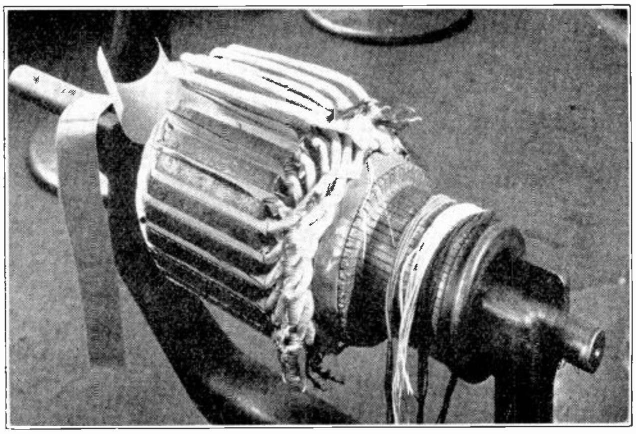

Fig. 24-D. This photo shows an armature completely wound, with the exception of laying in the last top coil sides, and connecting the leads to the commutator.

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

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

Fig. 25 shows a diagram of a complete wave winding. By tracing the coils, we find that there are only two circuits in parallel between the positive and negative brushes, but that there are eight coils in series. Two brushes are all that are needed to complete the circuits through all coils, but more brushes may be used, if desired, in order to reduce the current intensity in each brush. There can be as many brush groups as there are poles.

In Fig. 25, the two coils indicated by X and X are at present short circuited by the positive brush. Each pair of coils must reverse in polarity as they move from one pole to the next, and this current should reverse when the segments connecting these coils are shorted by the brush or, in other words, the brush should short circuit the coil as it passes through the neutral plane in the center of the space between two poles.

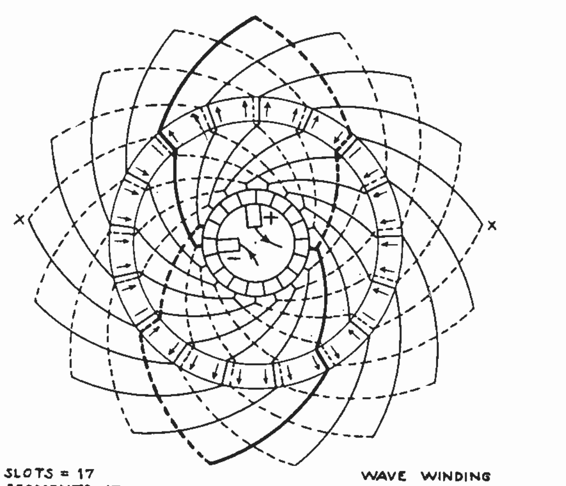

Fig. 25. This diagram shows a complete four-pole wave winding for an armature with 17 slots. Note the coil span and commutator pitch, and trace out the two coils shown with heavier lines.

31. PROCEDURE FOR WAVE WINDINGS

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

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

For a progressive wave windings—

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

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

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

For retrogressive wave windings—

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

32. PROGRESSIVE AND RETROGRESSIVE

In Fig. 25 the coil sides which lie in the tops of the slots are shown by solid lines, while those which lie in the bottoms of the slots are shown by dotted lines. If we start at the negative brush and trace the top lead of the upper coil shown in the heavy lines, we find that the bottom lead of the second coil in this circuit connects to a commutator bar just to the right of the one at which we started, and if we trace on around the next pair of coils we arrive at a bar one more step to the right. This is known as a **Progressive Winding,** and applies to **either lap or** wave windings.

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

33. INSERTING COILS OF A WAVE WINDING

Fig. 26 shows the procedure of laying in the coils for a winding such as shown in Fig. 25. At "A" the first coil is placed in the slots and the bottom lead brought out to its commutator segment. The proper point for this first connection can be found by locating a commutator segment that is in line with the center of the coil as shown at "A". Then divide by 2 the commutator pitch which has previously been determined, and count off this number of bars to the right of the center bar, which has been located. This will locate the proper bar to connect the bottom lead of the first coil to. This distance is shown from "A" to "B" in Fig. 26-A.

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

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

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

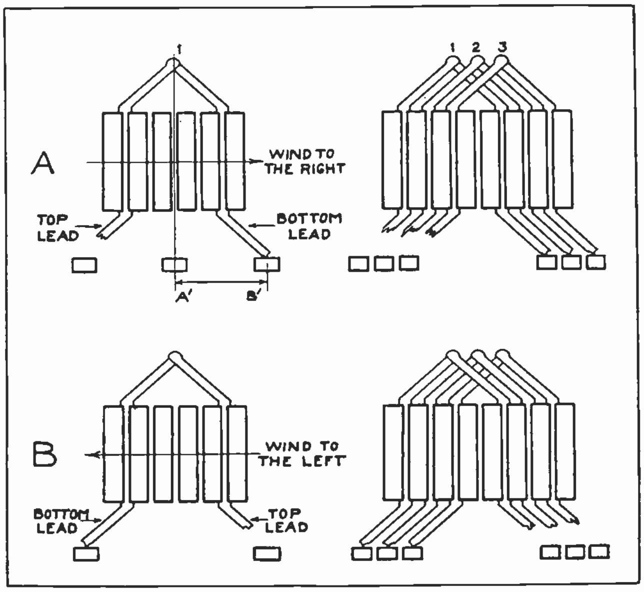

Fig. 26. The above views show the method of laying the coils of a wave winding in the slots. One side of each coil should go in the bottom of the slots, and the other sides in the tops of slots, and the coils should be laid in in the directions as shown and according to the shape of the twist on their back ends.

34. DETERMINING COMMUTATOR PITCH AND CONNECTING THE COILS

The armature shown in Fig. 25 has 17 slots and 17 commutator segments and is connected simplex. We will use it for an example to determine the commutator pitch.

We have learned that:

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

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

In which:

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

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

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

We should remember that all armatures cannot be wound wave. The commutator pitch formula determines whether a winding can be connected wave or not. When a commutator pitch is a whole number and a fraction the winding cannot be connected wave.

35. ELEMENT WINDINGS

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

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

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

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

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

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

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

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

36. WINDING SMALL ARMATURES

In the following paragraphs we will explain in detail the method of winding a small armature having 12 slots and 24 segments.

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

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

In winding the first coil the number of turns will depend on the size of the armature and its voltage rating. If this number is taken from coils in an old winding, the turns in one of the old coils should be very carefully counted.

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

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

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

To avoid mistakes these loops should be marked with cotton sleeving which is slipped on over them as they are made. Red sleeving could be used on the first loop of each slot, and white sleeving on the second, which will make it easy to locate the first and second loops for each slot. This winding would be used in a two pole frame, and has two circuits with 12 coils in each. If 110 volts were applied to this winding the voltage between adjacent commutator segments would be 110 ÷ 12, or $9\frac{1}{6}$ volts, which is not too high between adjacent bars. If this same armature had a commutator of only 12 segments, the voltage between bars would be 110 ÷ 6, or $18\frac{1}{3}$ volts, which is too high for this sized armature.

37. ELEMENT WINDINGS FOR LARGE ARMATURES

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

In Fig. 27-A are shown the coils for two-element armatures. These coils are wound with two wires in parallel; and when the coil is completed, two small coils or elements are in each bundle. These two elements are taped together with cotton tape. The top and bottom leads of one element are marked with sleeving of one color, and those of the other element are both marked with sleeving of another color.

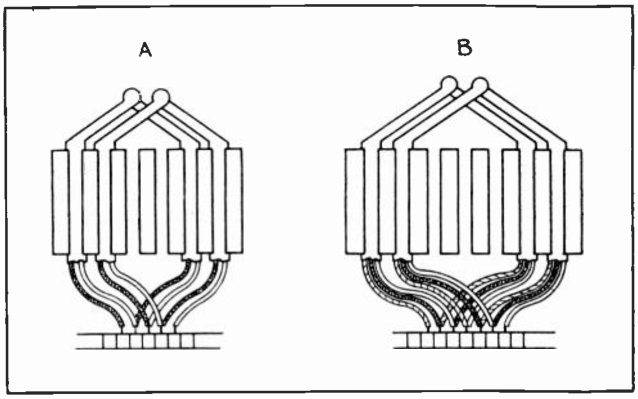

Fig. 27. The diagram at "A" shows the connections of lap coils for a two element winding. At "B" are shown the connections for a three element winding. Note how the separate windings in each coil are connected to two separate commutator bars.

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

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

Fig. 27-B shows the coils for a three-element winding having three wires wound in parallel in each coil, and the leads marked with three separate colors. Three colors are alternated when the bottom leads are connected in, each succeeding coil being connected similarly. The top leads are connected around the armature in the same direction as the bottom leads were, and the colors alternated in the same manner.

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

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

38. CHANGING AN OLD MOTOR FOR NEW CONDITIONS

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

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

It will be necessary, however, to change the field coil connections also. If they were formerly connected two in series and two in parallel, as in Fig. 28-A, they could be reconnected all in series, as shown in Fig. 28-B, and would then operate satisfactorily on 220 volts.

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

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

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

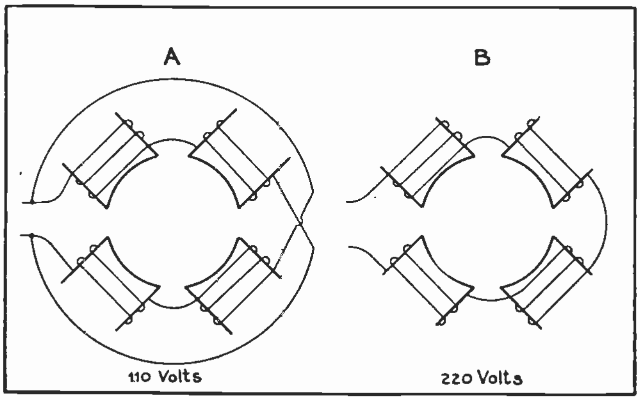

Fig. 28. The above diagram shows the methods of changing the field pole connections from parallel to series to be able to operate them on higher voltage.

39. MULTIPLEX WINDINGS

In some cases, where armature windings are designed to carry very heavy currents and at lower voltages, the connections can be arranged to provide a greater number of circuits in parallel through the windings. Windings connected in this manner are called **Multiplex Windings.** Those which we have covered so far have been **Simplex Windings;** and, in the case of the lap windings described, they have had the start and finish leads of each coil connected to adjacent bars of the commutator. Fig. 29-A shows a coil of a lap winding connected in this manner. With simplex connections a lap winding will have only as many circuits in parallel as there are field poles.

If we simply move the finish lead of a coil one segment further from the starting lead, and use a wider brush to span two bars instead of one, we have provided twice as many circuits through the winding, or two circuits for each pole. This is called a **Duplex Connection** and is shown in Fig. 29-B.

If we move the leads one more segment apart, we provide 3 circuits per pole, and have what is known as a **Triplex Connection,** as shown in Fig. 29-C. In this case the brush must be wide enough to span three commutator segments.

Fig. 30 illustrates the difference between simplex and duplex connections, with simplified winding diagrams. These sketches are laid out to show the winding in a straight form. On the actual armature the ends of this winding would come together at the points marked X and X.

In Fig. 30-A is shown a simplex connection with the start and finish leads of each coil connected to adjacent segments. If we start at the positive brush and trace the circuit to the left to the negative brush, we will pass through 12 coils in series; and the same will be true of the other circuit traced to the right from the positive brush to the point X, which in reality connects back to the negative brush in the actual winding. So we find we have two circuits in parallel between the brushes, and each of these circuits consists of 12 coils in series. If we assume that each coil is wound with a sufficient number of turns to produce 10 volts and with wire of a size that will carry 5 amperes, then this winding will produce 120 volts between brushes and have a total capacity of 10 amperes.

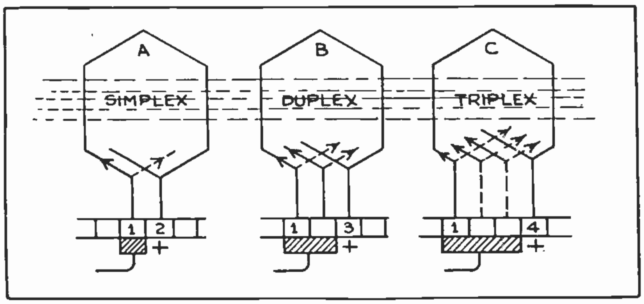

Fig. 29. "A" shows the connections for a coil of a simplex lap winding. "B" shows the connections for a duplex lap winding, and "C" those for a triplex lap winding.

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

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

In the lower sketch of Fig. 30-B, we have simply moved the start and finish leads of each coil one bar farther apart, which in effect makes two separate windings, or 4 circuits in parallel between the positive and negative brushes. In this diagram we have lengthened the coils of one section simply to make them easier to trace separately from the other. Tracing through any one of these four circuits from the positive to negative brush, we now find there are only six coils in series. So the voltage of this winding will be 10 × 6, or 60 volts. But as we now have four circuits in parallel between the positive and negative brushes, the current capacity of this winding will be 4 × 5, or 20 amperes. The wattage of either winding will be the same, however.

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

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

40. NEUTRAL PLANE—IMPORTANT TO COMMUTATION

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

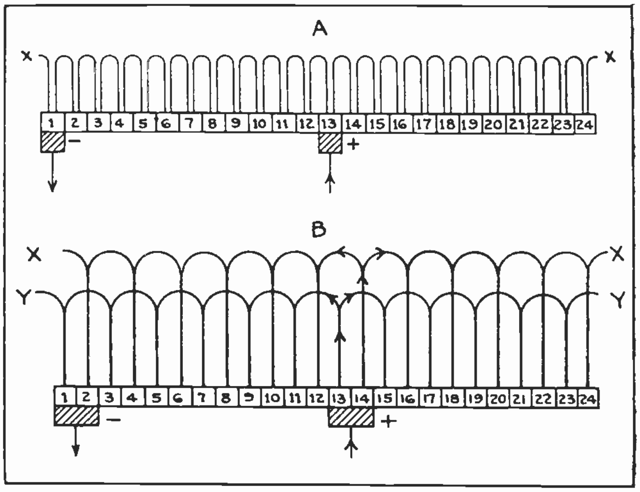

Fig. 30. At "A" is shown a simplified diagram of the circuit in a winding connected simplex lap. At "B" the winding is connected duplex, doubling the number of circuits from positive to negative brush.

41. SYMMETRICAL AND NON-SYMMETRICAL CONNECTIONS

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

Fig. 31-A shows this condition on a machine which has the brush located in line with the center of the field pole, and you will note that the leads are of equal length and brought out from the slots to the two bars in the center of the coil span. If the brushes of the machine are located at a point between the field poles, the coil leads must be carried to one side in order to be connected to the segments at the time they are short circuited by the brush.

Fig. 31-B illustrates this condition. One lead is

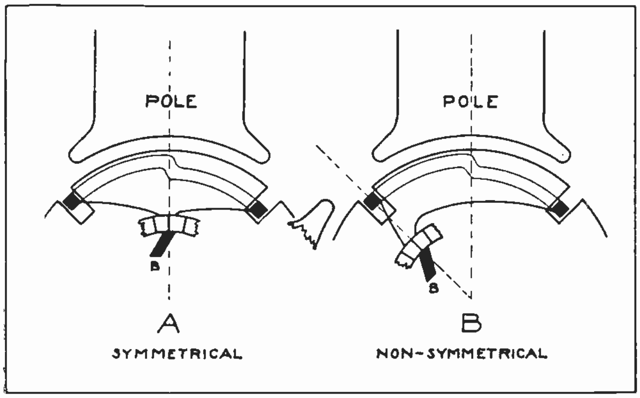

Fig. 31. Note the position of the brushes with respect to the poles, and also the shape of the end connections of the above lap winding coils for symmetrical and non-symmetrical windings.

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

Whether the brushes are located in line with the center of the field poles or in line with the neutral plane depends, to quite an extent, on the mechanical design of the machine. In some cases the brushes are much easier to get at for adjustment and replacement, if they are located as in Fig. 31-B.

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

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

42. COLLECTING DATA FROM OLD WINDINGS

When rewinding any armature, care should be taken to collect sufficient data while dismantling the old winding to enable you to put in the new winding correctly. It is a very good plan to mark the slots and commutator segments from which the first coil and leads are removed. This can be done with a prick-punch or file, as shown in Fig. 32. One small punch mark can be placed under the slot that held the top coil side, and two dots under the slot that holds the bottom side of the same coil. The top leads are then traced out to the commutator, and each bar that they connect to should be marked with one dot. Next trace the bottom leads to the commutator, and each of the bars they connect to should be marked with two dots. This can be done with both lap and wave windings, and is a positive way of keeping the core and commutator marked, to be sure to replace the coils and connections properly.

If necessary, you can also make a sketch or diagram of the first few coils removed. This sketch can be made similar to the ones in Fig. 32, and can show the exact coil span, commutator pitch, etc.

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

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

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

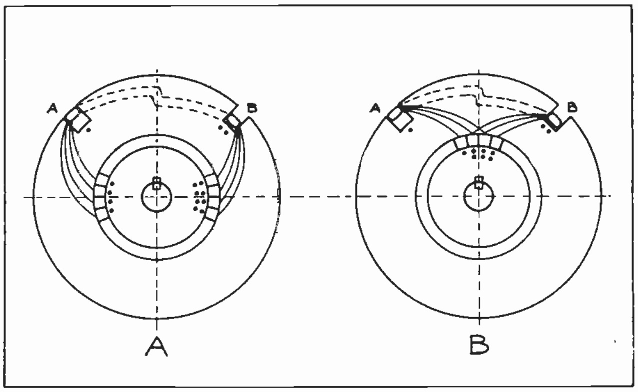

Fig. 32. A very simple and sure way of marking the commutator and armature when removing an old winding is shown above. Compare these sketches carefully with the instructions given, so you will be able to replace windings correctly.

43. BANDING ARMATURES

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

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

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

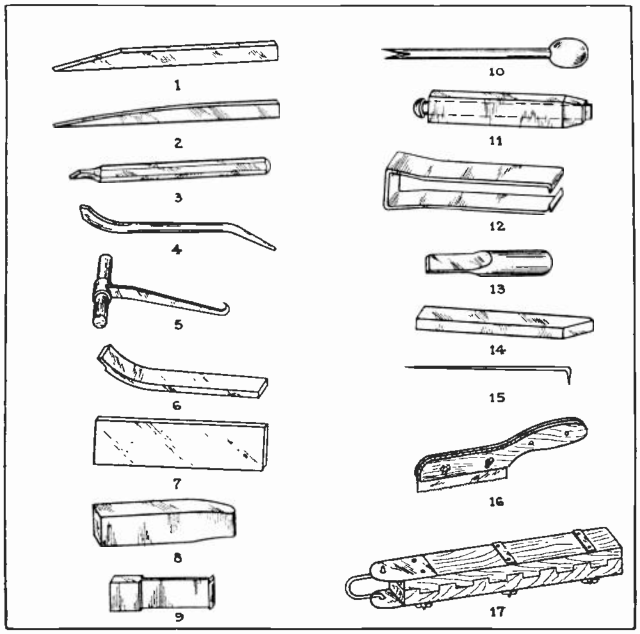

Fig. 32-C. Above are shown a number of the more common tools used in armature windings. No. 1 is a stripping tool for stripping open slot armatures and stators. No. 2—coil lifter for lifting coils from the slots. No. 3—lead lifter for lifting coil leads from commutator risers. No. 4—lifting tool for prying tight coils from slots. No. 5—coil hook to break coil ends loose from insulating varnish. No. 6—coil puller for sliding top sides of coils into slots. No. 7—fibre slot drift for driving coils into slots. (4 thicknesses needed: 3/16", 5/16", 7/16", 9/16") No. 8—fibre coil shaper for shaping coil ends after coils are in slots. No. 9—steel slot drift for driving coils to the bottom of partly closed slots. No. 10—push cutter for trimming edges of slot insulation. No. 11—wedge driver for driving wedges into partly closed slots. No. 12—wire scraper for removing insulation from ends of coil leads. No. 13—lead drift for driving coil leads into commutator risers. No. 14—one sided chisel to cut off leads at risers. No. 15—commutator pick for picking out short circuits between segments. No. 16—under cutting saw for under cutting commutator mica. No. 17—banding clamp for placing tension on banding wires while winding them.

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

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

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

44. ARMATURE TESTING

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

A growler is constructed of laminated iron in the form of a core, around the center of which a coil of insulated wire is wound, as shown in Fig. 33. When this coil is connected to an alternating current supply it sets up a powerful alternating magnetic field at the two poles of the growler.

Growlers are made with poles shaped at an angle, as shown in the illustration at "A", so that small and medium sized armatures can be laid in these poles. Growlers are also made with poles shaped as shown in Fig. 33-B, so they can be conveniently used on the inside of large alternating current windings, as will be explained later.

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

45. GROWLER OPERATION AND USE

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

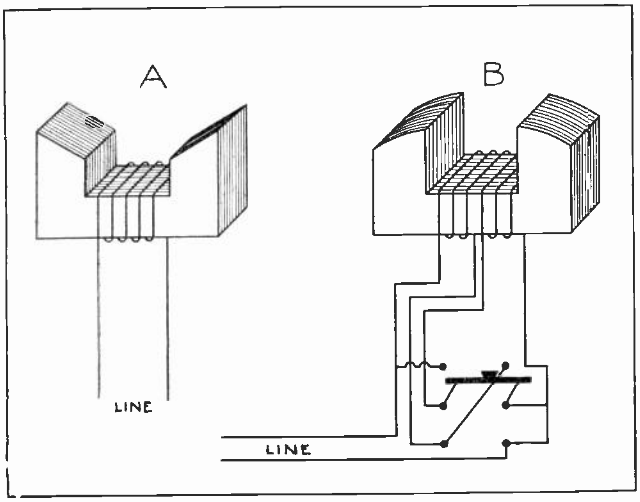

Fig. 33. Two types of "growlers". The one at "A" is for testing armatures, and the one at "B" for use inside of stator cores. Note the switch and double coil arrangement of the growler at "B", which can be used to connect the coils in series or parallel to vary the strength of the growler flux.

right angles to the growler flux. This secondary current, which is flowing in the armature coil will set up alternating flux around it and in the teeth or edges of its slots.

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

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

A low-reading ammeter, with a scale ranging from $2\frac{1}{2}$ to 10 amperes, is quite commonly used with a growler. A rheostat should be connected in series with a meter and a pair of test leads, as shown in Fig. 34. These test leads consist of two pieces of flexible wire several feet long to the ends of which are attached a pair of sharp test points or spikes. Sometimes these points are made of flat spring steel or brass and are attached to a wood or fibre hand-piece in a manner that permits them to be adjusted close together or farther apart. This makes it convenient to test adjacent commutator bars or bars farther apart.

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

46. GROWLER INDICATIONS ON WAVE WINDINGS

When testing wave-wound armatures, if one coil is shorted the indication will show up at four places around the armature. Fig. 35 shows a winding for a four-pole wave armature in position for testing in a growler. The heavy lines represent two coils which complete a circuit between adjacent commutator bars, 1 and 2. The top side of one of these coils and the bottom side of the other connect at bar 10. It will be seen from this diagram that a short circuit between bars 1 and 2 would cause our steel strip to vibrate over the four slots shown by the small double circles.

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

47. COMMON ARMATURE TROUBLES

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

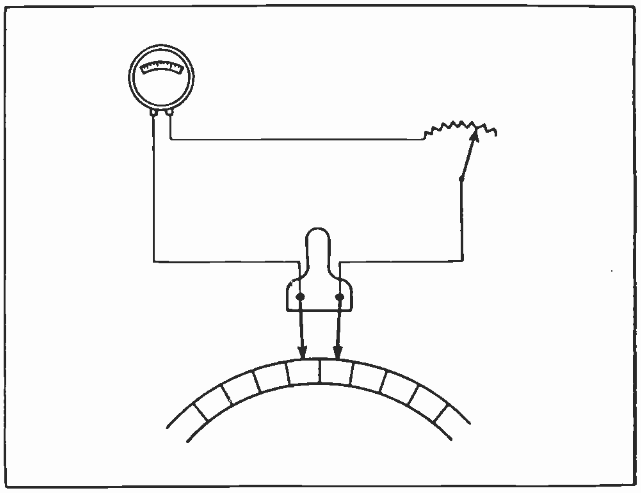

Fig. 34. This sketch shows connections of an ammeter and rheostat with test points on a "hand-piece". Meter and test leads of this sort are used for locating faults in armature windings.

Fig. 36 is a simplified drawing of a two-pole, 24-coil, lap winding in which are shown a number of the more common faults which might occur in armature windings, as follows:

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

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

Coil 19 has an open circuit.

Coil 5 is connected in reverse order.

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

Coils 6 and 9 are shorted together.

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

Coil 13 has a short between its commutator bars.

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

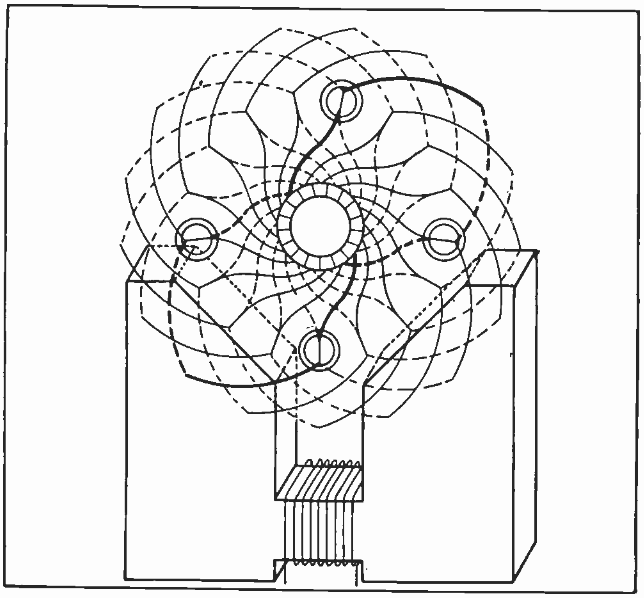

Fig. 35. The above diagram shows the coils of a four-pole wave armature which is in place in a growler for testing.

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

48. SHORT CIRCUITS

In Fig. 36 we found that coil 1 had a short circuit within the coil, which is probably the result of broken or damaged insulation on the conductors. To test for this fault, we will place the armature on the growler and close the switch to excite the growler coil. Place the steel strip over an armature slot which is at least the distance of one coil span from the center of the growler core. Now turn the armature slowly, keeping the steel parallel with and over the slots. When the slot containing coil 1 is brought under the steel, the induced current flowing in this local short circuit will set up flux between the teeth of this slot, which will attract and repel the steel strip, causing it to vibrate like a buzzer. This indicates that that coil is short circuited. Mark this slot with a piece of chalk and proceed with the test. Again rotate the armature slowly and test each slot, at all times keeping the strip over slots that are in the same position with respect to the growler. When the slot which contains the other side of the shorted coil is brought under the steel strip, it will again vibrate. Mark this slot. The two marked slots should now show the span of the exact coil which is shorted.

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

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

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

49. LOOSE COIL LEADS

In testing for loose coil leads, such as shown on coils 20 and 21 in Fig. 36, the steel strip would not vibrate at any slot due to this fault; but, in testing between commutator bars with the hand-piece, when the ammeter leads are placed on the commutator bars to which these coils are connected, the reading between them and adjacent bars would drop to zero, indicating an open circuit.

50. OPEN CIRCUIT

In testing for an open circuit, such as shown in coil 19 in Fig. 36, the steel strip would, of course, give no indication of this fault. So we must locate it by again testing around the commutator with the hand-piece. When these leads are placed across the bars to which the open coil is connected, we will get a very low reading. The reason that any reading at all is obtained is because there are always two paths for the current to travel through the winding, unless it is open at some other coil also.

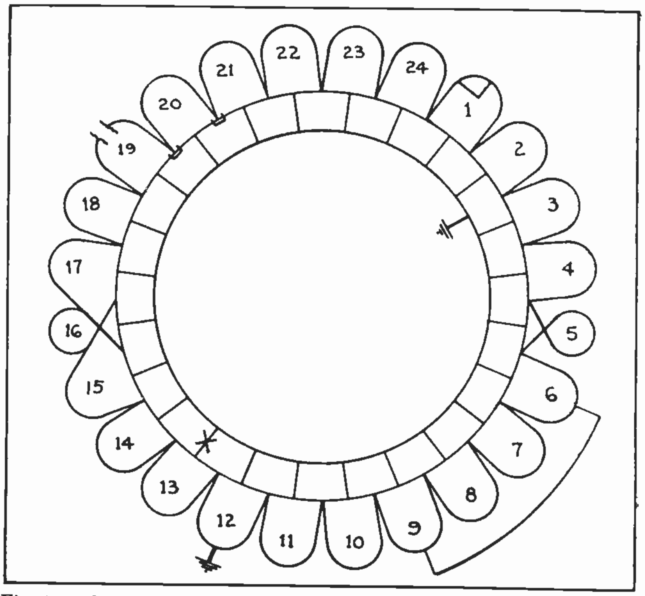

Fig. 36. This diagram of a two-pole lap winding shows a number of the more common faults which may occur in armature coils and at the commutator segments.

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

If there are three coils of the armature in the active flux of the growler and one side of coil 19 is one of these, then there will be three good coil sides working against two good coil sides with their induced voltages; and, since coil 19 is open circuited, the reading would be about 1/3 normal. The exact amount of this reading, however, will depend upon the pitch of the coils and the size of the armature. The main point to note is that one open circuit in an armature does not necessarily give a zero reading, unless the coil sides on each side of the test points are perfectly balanced electrically.

51. REVERSED COIL

In testing for a reversed coil such as No. 5 in Fig. 36, the steel strip will not vibrate at any slots, and testing from bar to bar with the ammeter leads on adjacent bars will not show up this fault either; because the induced current is alternating and the motor will not indicate the reversed polarity of the coil. So, in testing for reversed coils, we should spread the test points on the hand-piece far enough apart so they will touch bars 1 and 3. In this manner we will get a reading of two coils in series. Then, when we place the test points on bars which are connected to coils 4 and 5, or 5 and 6, two coils will be in series in each case; but, as the voltage in one will be opposite in direction to that in the other, the reading will be zero.

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

52. GROUNDED COILS

Coil 12 in Fig. 36 is grounded. The steel strip or vibrator will not indicate this fault, nor will the bar to bar test with the ammeter leads. To locate a ground we should place the test leads one on the commutator and one on the shaft or core of the armature. If the first test is made between the bar of coil 8 and the shaft, we would obtain a very high reading on the ammeter, because this would give the reading of the 4 coils in series between the grounded coil and this bar.

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

53. SHORTS BETWEEN COILS

In Fig. 36 coils 6 and 9 are shorted together, which places coils 6, 7, 8, and 9 in a closed circuit, through the short and the coil connections to the commutator bars. In this case the steel strip will vibrate and indicate a short circuit over each of the slots in which these coils lay. A bar to bar test with the ammeter leads would not give a definite indication, but the readings on these bars would be lower than normal.

54. REVERSED LOOPS

In the case of coils 15, 16, and 17 in Fig. 36, which are properly connected to each other but have their leads transposed or placed on the wrong commutator bars, the steel strip will not vibrate or give any indication. The bar to bar test with the ammeter leads would, however, show double readings between bars 1 and 2, normal readings on bars 2 and 3, and double reading again on bars 3 and 4. This indicates that the coils are connected in the proper relation to each other, but that their leads are crossed at the commutator bars.

55. SHORTED COMMUTATOR SEGMENTS

In the case of coil 13 in Fig. 36, which is short circuited by a short between its commutator bars, the steel strip would vibrate and indicate a short circuit over both slots in which this coil lies. The bar to bar test of the ammeter will give a zero or very low reading across these two bars, depending upon the resistance of the short circuit between them.

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

56. GROUNDED COMMUTATOR SEGMENTS

The commutator bar to which coils 2 and 3 are connected in Fig. 36, is grounded to the shaft. The steel strip will not indicate this fault. Testing with the ammeter leads between other commutator bars and the shaft would show high readings on the meter; but, as we test bars that are closer to the grounded one, the reading falls lower and lower, and will be zero when one test lead is on the grounded bar, and the other on the shaft.

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

57. GALVANOMETER TESTS ON ARMATURES

We have mentioned that a galvanometer and dry cell can be used to test armature windings for open circuits and short circuits in coils. You will recall, from the description of a galvanometer in an earlier section on elementary electricity, that this instrument is simply a very sensitive voltmeter which will read a fraction of one volt. Fig. 37 shows a method of making galvanometer tests on armatures. Two leads from a dry cell should be held against bars on opposite sides of the commutator and kept in this position as the armature is rotated. This will send a small amount of direct current through the coils of the winding in two paths in parallel.

If the positive lead in Fig. 37 is on the right, a current will flow from this lead through the commutator bar to the right side of the winding. If all coils of the winding were closed and in good condition, the current would divide equally, part flowing through the top section of the winding to bar 3 and the negative lead, and the other part flowing through the lower section of the winding to the same bar and lead. When this current is flowing through the armature and we test between adjacent bars with the galvanometer, the instrument reads the voltage drop due to the current flowing through the resistance of each coil. So the galvanometer test is quite similar to that with the ammeter leads and growler.

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

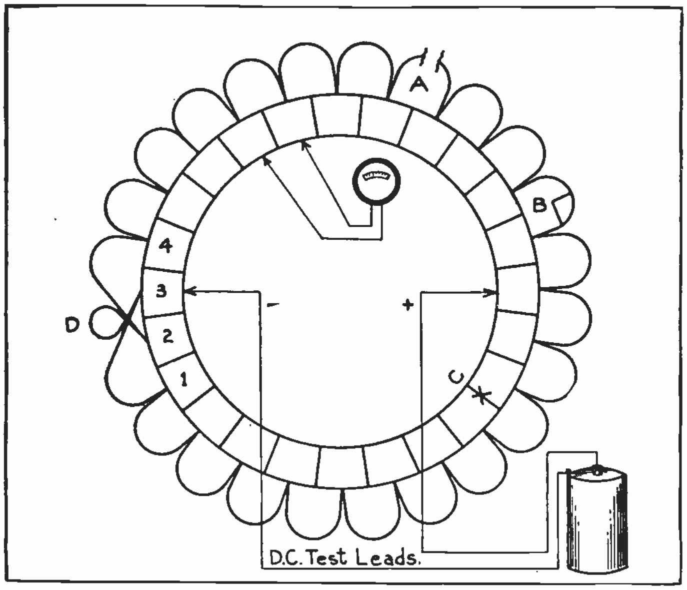

Fig. 37. This diagram shows the method of testing with a galvanometer and dry cell to locate various faults in an armature.

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

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

58. CUTTING OUT FAULTY COILS

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

Fig. 38 shows the manner in which an open circuit coil can be cut out with such a jumper. For each coil that is cut out of a winding a slightly higher current will flow through the other coils of that circuit. The number of coils that can safely be cut out will depend on the position in which they occur in the armature.

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

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

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

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

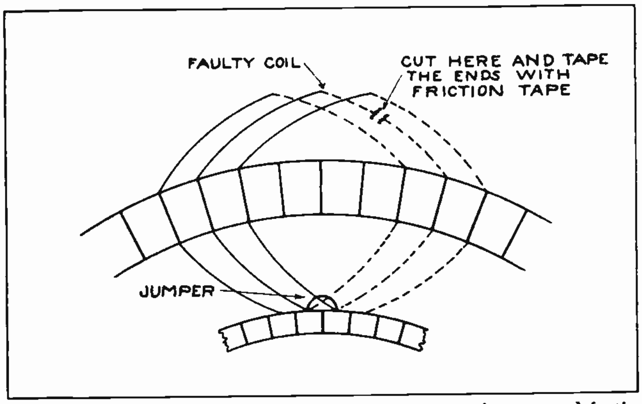

Fig. 38. The above diagram shows the method of cutting out a defective coil, and completing the circuit through the winding with a jumper at the commutator bars to which this coil connects.

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

While you are actually winding armatures in the department in the shops, you will be able to observe and put into practice many of the important things covered in this Reference Set.

If you get the important points covered in the intensely practical lectures on this subject, and do your work on the windings thoughtfully and carefully, you should be able to quite easily rewind or repair armatures, or locate their troubles when necessary on the job.

Remember that the important points are to get the proper number of turns of proper sized wire per coil, proper coil and slot insulation, and proper connections to the commutator.

By referring to this Reference Set and your lecture and shop notes, you will find dependable information on all these points.

Be sure to get acquainted with the use of the growler, and methods of testing armatures while you are in the Armature Department in the shops; and remember that care and neatness are essential to produce satisfactory armature windings which will be free from faults when completed.