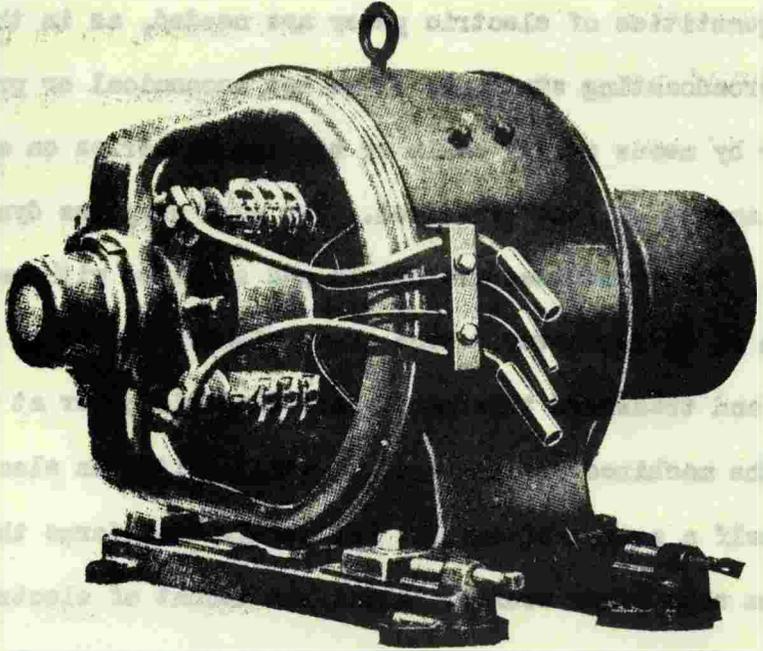


INCREASED EFFICIENCY



**LESSON
63 R**

DIRECT CURRENT GENERATORS



RADIO-TELEVISION TRAINING SCHOOL, INC.

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DIRECT CURRENT GENERATORS

Where great quantities of electric power are needed, as in the larger transmitting and broadcasting stations, it is not economical or practical to produce this power by means of dry cells or storage batteries on account of the high cost and amount of labor involved. For such purposes dynamo-electric machines are used. These machines are driven and supplied with mechanical power by some form of "prime-mover," such as an electric motor or gas engine or steam turbine, and transform this power into electric power at whatever pressure or form the machines are designed to deliver it. An electric generator is thus not in itself a source of energy, but merely transforms the energy supplied to it from some other source. Also, the amount of electric power that a machine can deliver, depends upon the amount of mechanical power supplied to it.

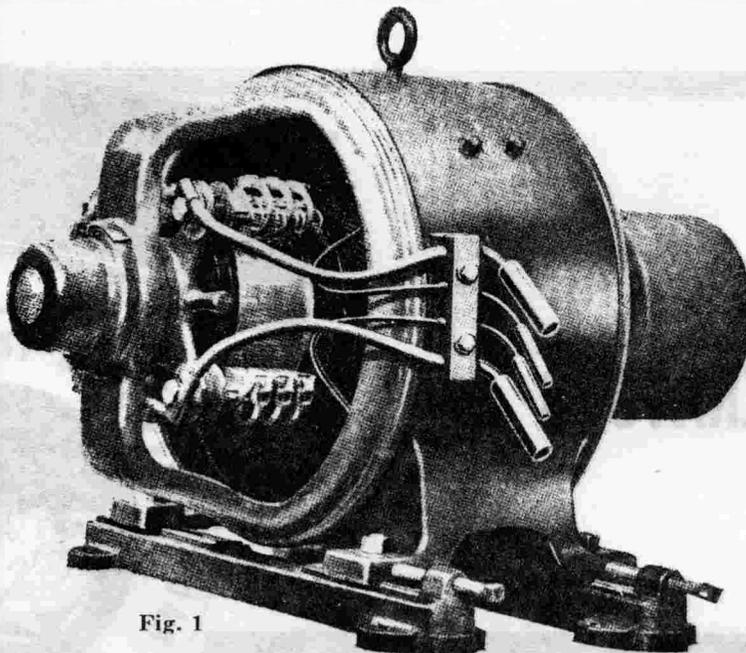


Fig. 1

Electric generators are designed to deliver either direct or alternating current, and are classified either as direct or alternating current generators. The basic principles of the two types of machines are the same, and they differ only in their mechanical construction as is necessary to produce either direct or alternating current. A small direct current generator is illustrated in Fig. 1.

OPERATING PRINCIPLES OF THE D. C. GENERATOR

The action of the electric generator is based upon the principles of electromagnetic induction, that is, whenever an electrical conductor is cut by magnetic lines of force there is induced within the conductor a voltage or electromotive force which causes a current to flow when the circuit is closed. The generator thus consists essentially of two parts: a magnetic field structure, and a series of loops or coils of wire wound upon an iron core and forming the armature. In order that the voltage induced in these coils can be applied to an external circuit, the armature is also provided with a commutator on which slide a number of contact brushes. By means of this sliding contact the internal circuit of the machine is connected to the external circuit to which the electric power is to be supplied.

The operation of the direct current generator can easily be understood with the aid of Fig. 2A. Here are illustrated two magnetic field poles N and S, between which rotates a rectangular loop of wire. As the loop is turned in the direction indicated by the curved arrow, the wires cut across the magnetic lines of force which extend horizontally from N to S. As a result there is induced in the wire a voltage or electromotive force (abbreviated E.M.F.).

Closer study will reveal that this E.M.F. is a variable one, and that its value at any instant will depend upon the position of the wires and the direction in which they are moving. For example, when the coil is in the vertical position

as shown in the figure, the conductors B C and A D are moving parallel with the lines of force, that is they are not cutting any lines and no voltage is induced in them. But as soon as the coil begins to tip forward a little, the wires begin to cut the lines and a small voltage is set up. As the coil tips forward more, the wires cut the lines faster and the voltage increases until when the coil is in the horizontal position, the lines are being cut at right angles and maximum voltage is induced. When the coil is turned further, the voltage again becomes less; and when it is in the vertical position with conductor B C at the bottom, the voltage returns to zero. The conductor B C then begins to move upward and cut the lines of force again, but this time in the opposite direction. The voltage thus again increases but in the opposite or negative value. It reaches its maximum when the coil is in the horizontal position, and again diminishes to zero as the coil becomes vertical and the conductor B C returns to its original starting position.

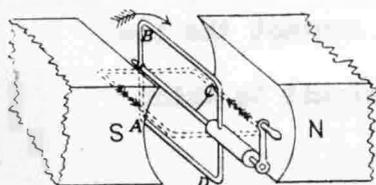


Fig. 2A

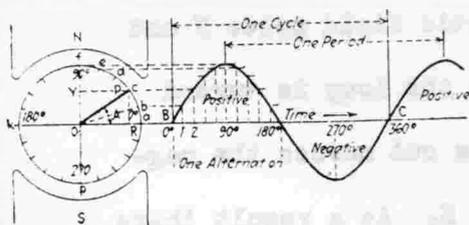


Fig 2B

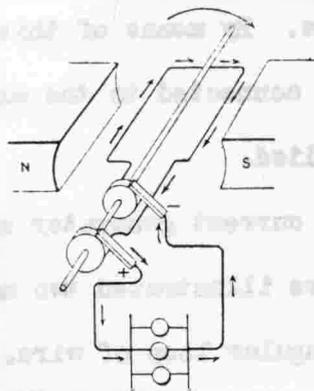


Fig 2C

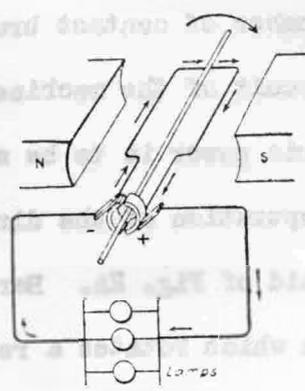


Fig 2D

As the armature makes one complete revolution or turns through 360 electrical degrees, the induced voltage undergoes four changes. These are illustrated in

Fig. 2 B. During the first quarter revolution the voltage increase from zero to maximum, during the second quarter it decreases back to zero, in the third quarter it increases again but in the reverse direction, and during the fourth quarter it returns to zero once more. During the next revolution the entire process is repeated. Such a complete set of values through which the induced voltage passes successively is known as a cycle.

Although the voltage induced in such a rotating coil is inherently alternating, it can be supplied to the external circuit either as alternating or direct (continuous) current. In the first case the coil is connected through a pair of slip rings as illustrated in Fig. 2 C, and in the second case through a commutator as in Fig. 2 D. A commutator is merely a form of rectifying device, consisting of a split metallic ring over which slide two brushes. One commutator segment is connected to one side of the coil, and the second segment to the other side of the coil. The brushes are placed so that the instant the direction of the voltage changes, contact is made with another segment. As a result one brush is always in contact with that commutator segment in which the voltage acts in one direction and the other brush with the segment in which the voltage acts in the opposite direction. The voltage in the external circuit always acts in one direction, and is direct.

Instead of only one armature coil as used in the previous illustration, practically any number can be used uniformly spaced; and if these are all connected in series, the total voltage will be the sum of the voltages induced in all of the coils. There will also have to be proportionately more commutator segments, depending upon the number of coils and the number in which they are connected.

CONSTRUCTION OF COMMERCIAL D. C. MACHINES

The construction of a modern direct current generator was illustrated in

Fig. 1. As shown, the field structure consists of a circular iron ring called the frame or yoke, and from this frame extend toward the center a number of iron projections called the field poles. These field poles are always of an even number, and each is provided with a coil or wire called the field winding. All these field coils are connected in series, and are wound in such a direction that when a direct current is sent through them the adjacent field poles will be of opposite polarity, that is, one will be a north pole and the next one a south pole, etc.

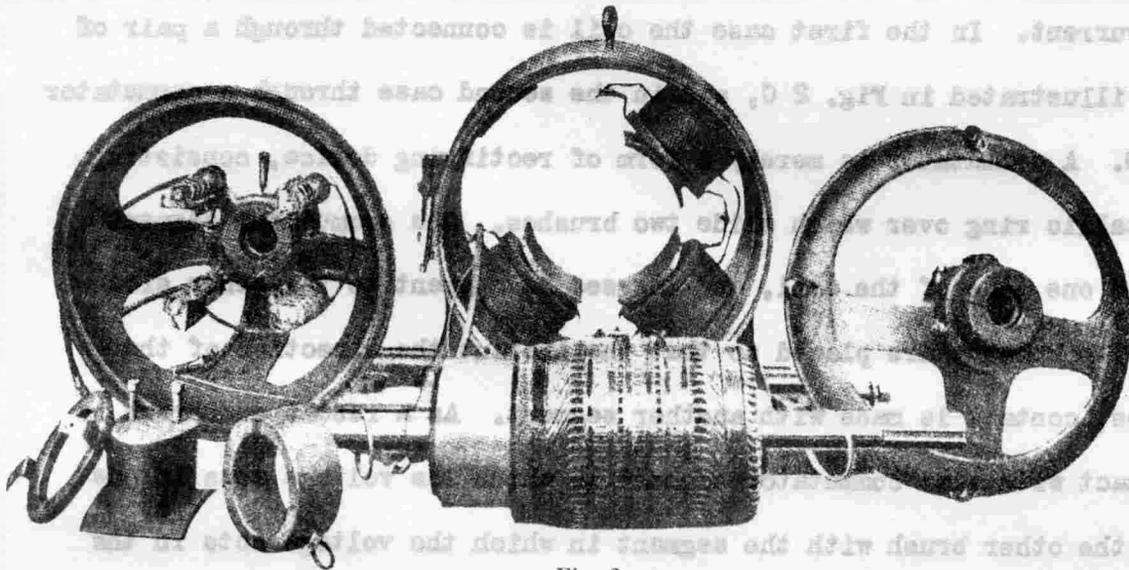


Fig. 2

The construction of the armature can be more clearly seen in the dismantled view of a generator illustrated in Fig. 2. The armature consists of an iron drum built up of a large number of thin laminations (layers) mounted on a central steel shaft. Into slots on the outer surface of the armature is placed the armature winding, which consists of a series of interconnected coils of wire. This armature is caused to rotate at the center of the machine, and as it does so the conductors of the armature winding cut the magnetic lines of force that enter the armature from each field pole, with the result that there is induced in each conductor a small voltage. Since all of the coils are connected together, the voltages in all the individual wires are added on to each other and

therefore a high electrical pressure is obtained.

The commutator is built on one end of the armature, and consists of a number of copper bars securely mounted but insulated from the shaft and from each other. To each bar are connected the beginning of one armature coil and the ending of another. Over these copper bars slide a number of carbon brushes which are held in a brush rigging mounted to one end of the machine frame. There are always as many groups of brushes as there are field poles. Also each adjacent group of brushes is of opposite polarity, that is, one is positive and the next one is negative. As the armature rotates and has a voltage induced in the winding, these brushes make contact with successive commutator bars and are thus at the same electrical pressure as the bars they touch. All the groups of brushes which are positive are connected together, and also those that are negative. One common wire is then taken off from the positive sets and one from the negative sets, and it is to these two wires or terminals that connection to the external circuit is made.

DESCRIPTION OF THE

An electric generator consists of three essential parts: a magnetic field structure for providing the magnetic lines of force, an armature which contains the conductors that cut these lines of force, and a commutator with its brushes for connecting the internal circuit of the machine to the external circuit.

TERMINAL VOLTAGE OF A GENERATOR

The function of the field structure of an electric generator is to supply the magnetic lines of force. Although permanent magnets could be used for this purpose (in which case the machine would be called a magneto), the magnetic field supplied would not be strong enough to cause a sufficient voltage to be induced. The field poles of all modern electric generators are in the form of powerful electromagnets. An additional advantage gained is that the strength of the electromagnet field poles can be regulated at will, and this is an important feature

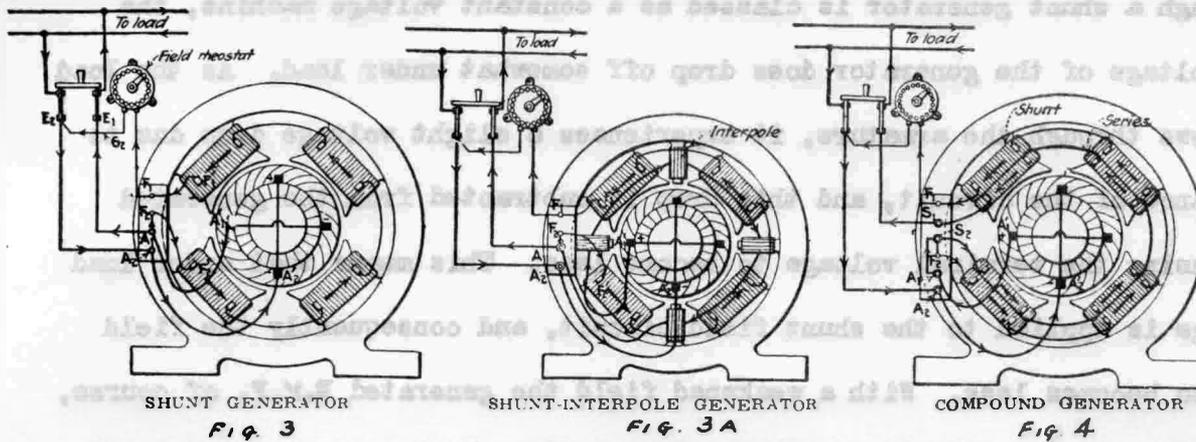
when it is desired to regulate the terminal voltage of a generator.

The terminal voltage or electromotive force of a direct current generator depends upon three factors, the magnetic strength of the field poles, the speed of rotation of the armature, and the number of coils connected together in the armature winding. Every machine is designed by the builders to be operated at a certain speed, which is indicated on the name plate of the machine as so many revolutions per second (R.P.M.). Since the speed of rotation cannot be changed and the number of armature coils is permanently fixed, the only way of varying the terminal voltage is by altering the strength of the field poles. This is accomplished by connecting a suitable rheostat into the field circuit. This rheostat controls the strength of the field current and of the field poles themselves. Cutting resistance into the circuit weakens the field strength and cuts down the voltage, while cutting out resistance strengthens the field current and increases the voltage.

SHUNT GENERATORS

The exciting current for magnetizing the field poles of a generator can be supplied either from some external source or by the generator itself. In one case the machine is said to be separately excited and in the other self-excited. The latter method is used with practically all direct current generators. In a self-excited machine the field windings can be connected either in series or in parallel with the armature, and generators are classified as series or shunt machines. Series generators now have only a very limited commercial application, but shunt generators are used very extensively. They are sometimes also known as constant potential machines because they generate a practically constant terminal voltage whether only lightly or fully loaded. A shunt generator can always be recognized by the fact that the field coils consist of a large number of turns of small wire. The field current required amounts to from one to five per cent of the total armature current, depending upon the size of the machine. The general field and

armature connections for a shunt machine are illustrated in Fig. 3. The rheostat shown in the field circuit is used for regulating the strength of the field current.



The general field and armature connections for a shunt machine are illustrated in Fig. 3. There are four terminals on the machine, two for the armature and two for the field circuit. The current leaves at the positive terminal A-1 and immediately divides, part flowing to the load and part entering the field circuit at F-2. After flowing through the four field coils, the current leaves the field circuit at F-1, flows through the field rheostat, and enters the main line again at E-2. The entire field circuit is then in parallel or shunt with the main load circuit. This means that the same voltage is applied to the field circuit as to the load. The field rheostat, it was explained, serves to control the terminal voltage of the machine by regulating the strength of the field current. As long as the speed of the machine remains steady and the rheostat is once properly set, no further adjustment of it should be necessary.

LOADING A SHUNT GENERATOR

A shunt-connected generator is loaded by connecting the various electrical appliances directly across the armature terminals as is illustrated in Fig. 3. However, a greater load should not be thrown on the machine, that is more current should not be drawn, than that for which it was designed. Excessive load will cause a generator to overheat, and excessive heat will cause the insulation to

break down or some wire to melt or burn out. Over-heating is always a sign of overloading.

Although a shunt generator is classed as a constant voltage machine, the terminal voltage of the generator does drop off somewhat under load. As the load current flows through the armature, it experiences a slight voltage drop due to the resistance of the circuit, and this drop is subtracted from the generated E.M.F., causing the terminal voltage to become less. This means that under load less voltage is applied to the shunt field circuit, and consequently the field current also becomes less. With a weakened field the generated E.M.F. of course, also is lower. As a result the terminal voltage of a shunt generator drops off slightly as the load comes on and rises again as the load is removed. This condition could be corrected by adjusting the field rheostat, but this would mean continuous adjusting with a varying load. The change in terminal voltage is not very great in a well designed machine. For example, if the voltage at no load is 120 volts, it would not drop much below 114 volts at full load.

The shunt machine shown in Fig. 3 A has in addition to the regular field poles a set of smaller poles known as interpoles. These interpoles are wound with a few turns of large wire and are connected in series with the armature so that the entire line current flows through them. The function of these interpoles is to make the operation of the machine more stable. They counterbalance the magnetic distortion that occurs under load and which is commonly known as armature reaction. Sparking at the brushes also is eliminated.

COMPOUND GENERATORS

Compound-wound generators are used when a more constant terminal voltage is desired than is possible with a shunt machine. A compound generator has in addition to the regular shunt field winding a second winding consisting of a few turns of large wire wound on each field pole. This winding is connected in series

with the armature and the total armature current flows through it. The series winding is always arranged so as to help or boost the shunt field winding, and the machine is said to be cumulative compound wound. As long as no current is being supplied to the external circuit of the generator, the machine acts as a shunt machine, but as soon as current flows through the armature the series winding strengthens the shunt winding and the terminal voltage increases. The amount of this voltage increase is generally calibrated so that it just balances the internal voltage drop in the machine, and the terminal voltage remains practically constant. It can also be calibrated so as to actually increase the terminal voltage as the load increases. This is important in cases where the electric current must be transmitted a considerable distance, for the increase in terminal voltage will then counterbalance the voltage drop occurring in the line, and the voltage at the consumer's end remains unchanged. The general connections for the field and armature circuits of a compound wound generator are illustrated in Fig. 4.

Shunt generators are used for storage battery charging and in small power plants where only smaller quantities of power are developed, while compound generators are used in practically all larger power plants.

HOW A GENERATOR BUILDS UP ITS VOLTAGE

Since a shunt or compound generator is said to be self-exciting, the question arises as to how the machine does start to generate. When a generator has been in operation and it is shut down, the field circuit is opened. But the field poles do not lose all of their magnetism, they retain a small amount depending upon the magnetic qualities of the iron used in the core. This magnetism which is retained after the exciting current is turned off, is known as residual magnetism. It ordinarily amounts to about 5% of the normal field magnetism.

It is this residual magnetism which enables a machine to get started when it is put into operation again. As the armature is caused to rotate, the conductors cut the lines set up by the residual magnetism, and there is induced in the winding a small voltage. In a 120-volt machine this initial E.M.F. probably would amount to 5 or 6 volts. This voltage causes a small current to flow through the field circuit, and the magnetism of the field poles is at once increased. The stronger field induces a larger voltage, and this in turn further strengthens the field current, etc. The operation continues until the saturation point of the iron is reached, that is until a further increase in field current produces no further increase in the magnetization of the poles. At first the increase in magnetization with the rise in field current is very great; but as the saturation point is reached, the rate of increase rapidly becomes less. From 10 to 20 seconds are usually required for a machine to reach its normal voltage. The entire process of a generator attaining its normal voltage when put into operation is known as "building up."

Another important point this brings up is that a definite relation exists between the connections of the field winding to the armature and the direction of rotation. When a machine is brought up to speed and the shunt field connections are to be made, it may be that the initially induced E.M.F. will either aid or oppose the residual magnetism, depending upon in which direction the current is sent through the field windings. In one case the machine can build up and in the other it cannot. To determine which connection is correct, the machine is brought up to normal speed and a voltmeter connected across the armature terminals. The instrument will give a small reading due to the residual magnetism. The field terminals are then connected, and if the voltage at once decreases, it is a sign that the residual magnetism is being opposed. The connections must then be reversed in order to enable the machine to build up.

When a machine has been idle for some time and has lost its residual magnetism, or when a new machine is to be put into operation the first time, it is necessary to supply it with field current from some external source in order to get it started. A number of dry cells connected in series or a storage battery connected across the field terminals will usually send enough current through the circuit in order to start the magnetization of the poles. After the action is once started, the remainder will take care of itself.

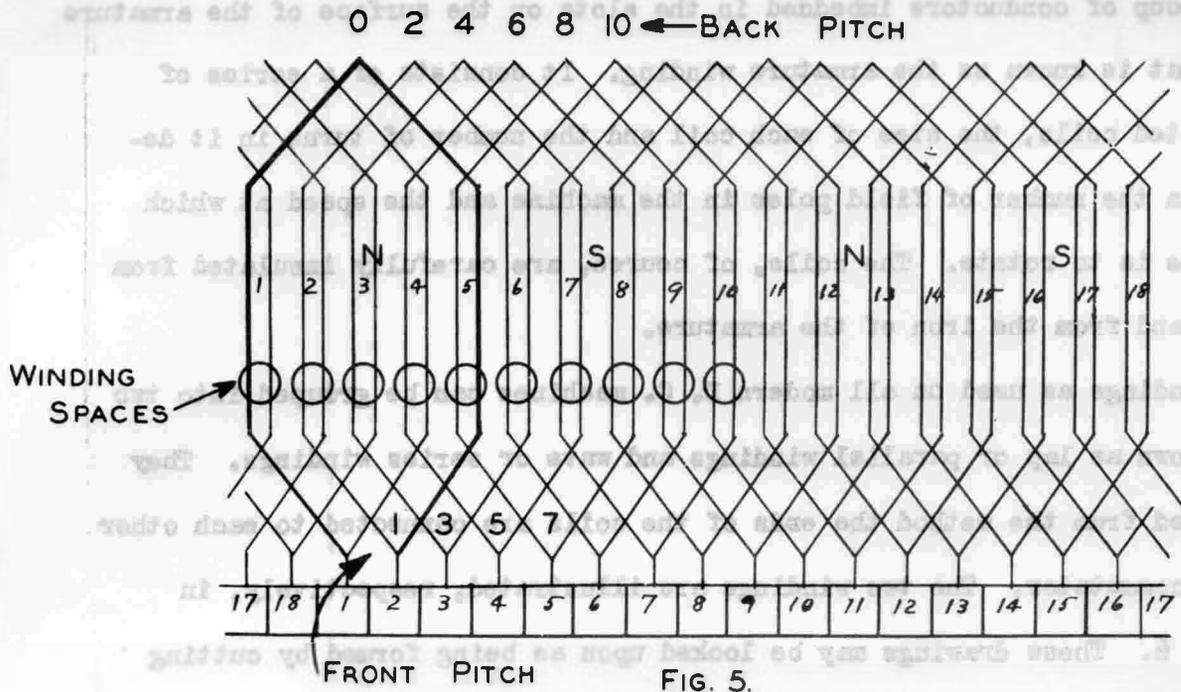


FIG. 5.

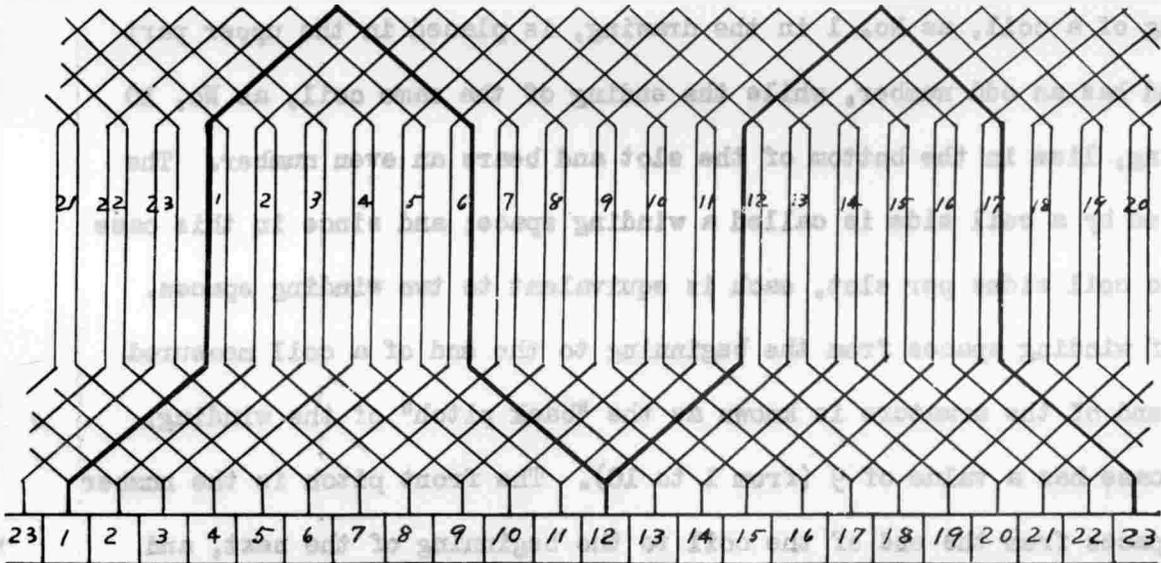


FIG. 6.

ARMATURE WINDINGS

The group of conductors imbedded in the slots on the surface of the armature comprise what is known as the armature winding. It consists of a series of interconnected coils, the size of each coil and the number of turns in it depending upon the number of field poles in the machine and the speed at which the armature is to rotate. The coils, of course, are carefully insulated from each other and from the iron of the armature.

The windings as used on all modern D. C. machines can be grouped into two classes, known as lap or parallel windings and wave or series windings. They are so called from the method the ends of the coils are connected to each other and to the commutator. The two windings are illustrated, respectively, in Figs. 5 and 6. These drawings may be looked upon as being formed by cutting into an armature parallel to the shaft and then spreading the winding out flat.

Fig. 5 illustrates a lap winding for a 4-pole machine, the armature having 18 slots and two coil sides placed in each slot. In a winding of this kind the beginning of a coil, as No. 1 in the drawing, is placed in the upper part of a slot and has an odd number, while the ending of the same coil, as No. 10 in the drawing, lies in the bottom of the slot and bears an even number. The space occupied by a coil side is called a winding space; and since in this case there are two coil sides per slot, each is equivalent to two winding spaces. The number of winding spaces from the beginning to the end of a coil measured at the rear end of the armature is known as the "back pitch" of the winding, and in this case has a value of 9 (from 1 to 10). The front pitch is the number of winding spaces from the end of the coil to the beginning of the next, and in Fig. 5 has a value of 7 (from 10 to 3). The commutator pitch is the number of commutator bars from the beginning to the end of a coil; in Fig. 5 it has a value of 1.

It can also be seen from the figure that the beginning and ending of each

coil lie in corresponding positions under the North and South field poles, and the voltage induced in each side is in opposite directions but additive in effect. Also, due to the fact that the coils are interconnected as they are, the voltages induced in all the coils under each pair of N and S poles are added onto each other; so that if the brushes are located as shown, one will be positive and one negative, that is the current will flow out of the armature winding at one brush (the positive) and enter it again at the other one (the negative). The same condition exists under each pair of field poles, and the two positive brushes and the two negative brushes are connected together, the common leads then forming the positive and negative terminals of the machine.

In Fig. 6 is illustrated a wave winding for a 4-pole direct current generator. Here the successive coils instead of lapping back over each other as in a lap winding, advance or progress around the armature; and from the wavy nature of the winding it is known as a wave winding. By counting the number of winding spaces spanned at the rear and front ends of the armature, it can be seen that the back pitch is 11, the front pitch 11, and the commutator pitch 11. Opposite sides of each coil again are in corresponding positions under N and S field poles, and the voltages induced in them are also additive in effect. Although only one pair of brushes would really be needed in this case, it is common practice to use as many pairs as there are pairs of field poles.

Lap or parallel windings are generally employed in all machines of low terminal voltage (up to 250 volts) and of large current capacity; while the wave windings are used in higher voltage machines that are not required to supply such large currents.

A COMPLETE D. C. GENERATOR INSTALLATION

A complete generator installation includes not only the electric machine

itself and its prime mover (driving motor), but also the control panel, commonly known as the switchboard. This switchboard consists of a slate or marble slab an inch or more thick and is mounted in a vertical position on a suitable iron framework. On this panel are mounted the necessary switches and meters by means of which the operation of the generator can be controlled. In a larger installation two or even more panels are used. In such a case the first panel is called the generator panel and has mounted on it the necessary apparatus for controlling the generator itself. The remaining panels are known as feeder or distribution panels. On these panels are mounted merely a number of switches that are connected to the various circuits to which electric energy is to be supplied by the generator.

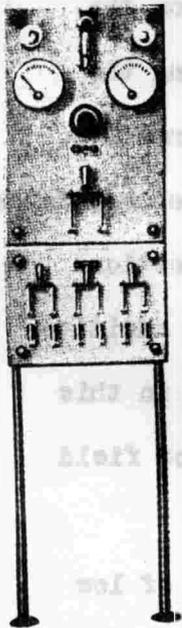


Fig. 7

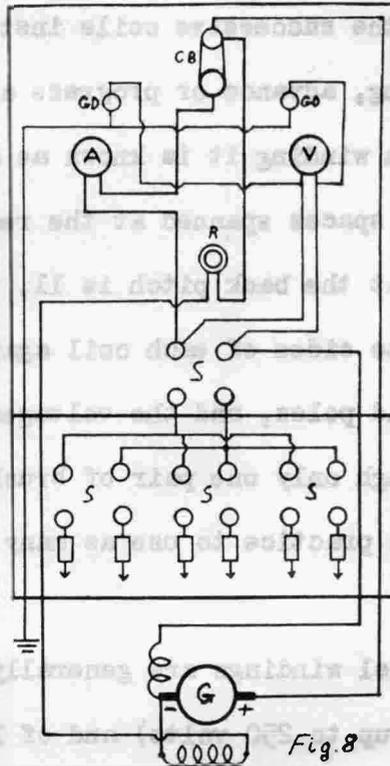


Fig. 8

In the average installation the entire switching and control apparatus is mounted on a single panel. A typical combination generator and feeder panel is illustrated in Fig. 7, and a wiring diagram of the connections as made on the rear is shown in Fig. 8. In the center of the panel is seen the main

generator switch. When this switch is open, the generator is entirely disconnected from the system. At the top of the panel is a circuit breaker marked CB in Fig. 8. This circuit breaker is merely a protective switch that is opened automatically by means of an electromagnet. If the load current becomes greater than can be safely carried by the generator, the electromagnet becomes strong enough to raise an iron plunger; and as this plunger comes up it trips the breaker and the contacts are quickly separated by means of a strong spring. Directly below this breaker are two meters, one a voltmeter to indicate the terminal voltage of the generator, and the other an ammeter to indicate the amount of current that is being drawn. Below the meters is a knob or hand wheel that operates the shunt field rheostat which is mounted on the rear of the panel. At the bottom of the board is the feeder section on which are mounted three double-pole feeder switches, each switch being protected with a pair of fuses. To the lower ends of the fuse clips are connected the circuits which are to be supplied by the generator.

The wiring system of the panel is really quite easy to trace. From the positive terminal of the generator a wire runs to the under side of the circuit breaker, and from the lower side of the breaker through the ammeter to one of the upper clips of the main switch. The other upper clip is connected through the series field to the negative side of the generator. From the upper side of the circuit breaker another wire reaches off which leads to the field rheostat, and from the rheostat to one side of the shunt field. The other side of the shunt field is then connected to the negative terminal of the generator. The voltmeter is connected directly across the upper clips of the main switch and consequently always indicates the voltage that is available at the switchboard. The three feeder switches have the upper clips connected directly across the output of the main switch, and the lower clips are connected through fuses

to the circuits which are to be supplied.

The two lamps marked GD are ground detector lamps and at once show up a ground in case one occurs on either side of the system. The two lamps are connected in series across the line and their midpoint grounded. Normally both lamps will burn only dimly. But should a ground occur let us say on the positive side of the line, the lamp connected between this line and the ground will be short-circuited and go out, and full line voltage will be impressed across the other lamp causing it to burn brightly. The lamps thus give a constant indication of the condition of the line. Each lamp should have the same voltage rating as the pressure in the line.

PRACTICAL OPERATION OF D. C. GENERATORS

When a generator is to be put into operation, a thorough inspection should first be made of the machine to see that everything around it is clear -- no tools or other materials lying on or near it. The oil cups should be inspected and kept well filled with the proper lubricating oil. The commutator should be kept clean and bright, and no grease or oil should be allowed to accumulate on the windings.

The main line switch on the panel is opened and all resistances cut into the field rheostat. The generator is then brought up to normal speed by starting the driving motor or engine, as the case may be. If the panel is provided with a field switch, this is closed now and the field rheostat adjusted until the voltmeter registers normal voltage. The main switch can now be closed, and lastly the feeder switches supplying the various branch circuits.

When a generator is to be shut down, the main line switch is first opened so that all circuits are disconnected from the machine. All resistance is next cut into the field rheostat, and lastly the field switch is opened. The prime mover is then shut down by turning off the driving power.