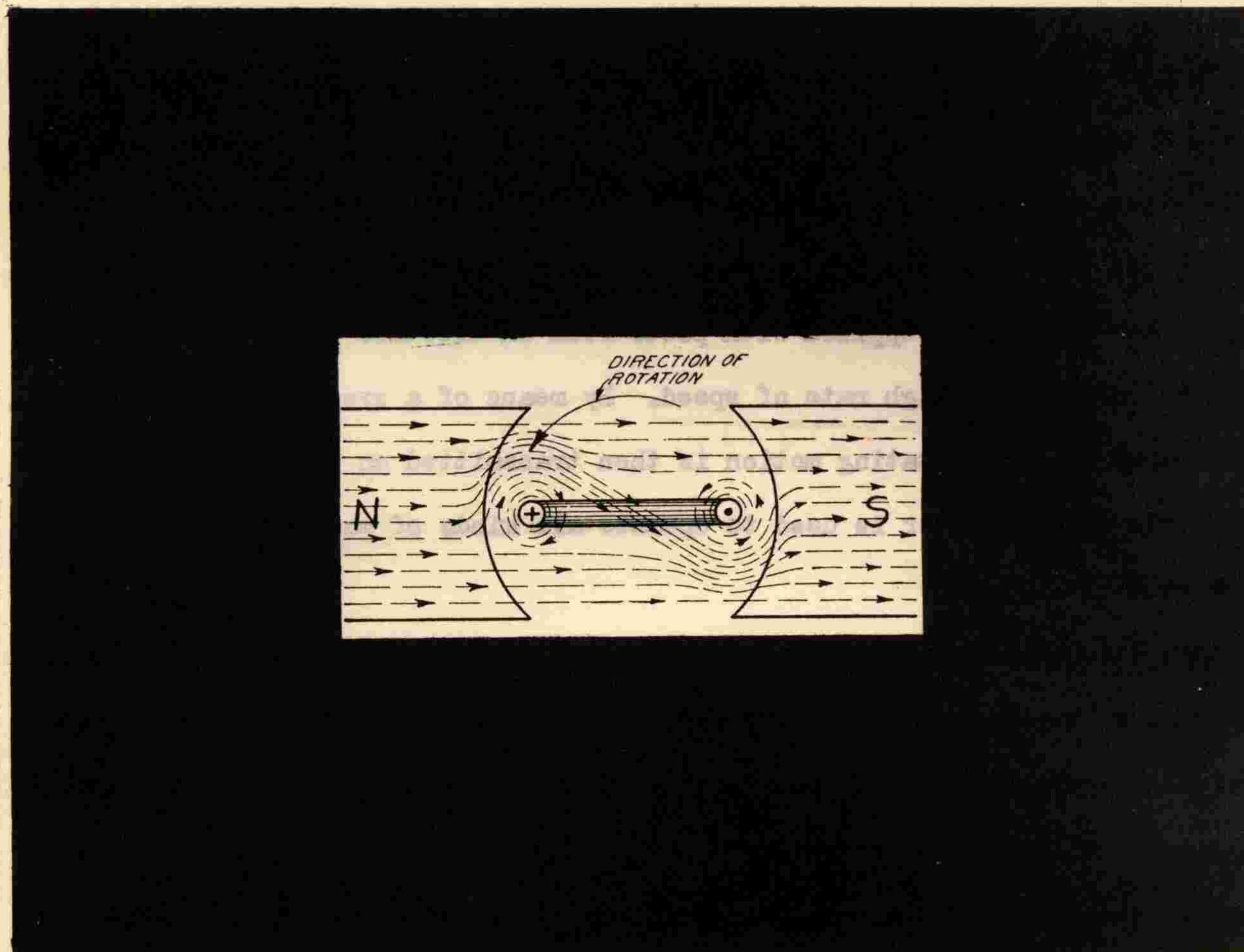

LESSON 62 R

DIRECT CURRENT MOTORS

RADIO-TELEVISION TRAINING SCHOOL, INC.
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No other electrical machine is used in greater numbers or in more different forms and applications, than is the electric motor. It is used commercially in all sizes, ranging from one-tenth up to 10,000 horse power and more. The electric motor is a machine for converting electrical energy into mechanical energy, that is, it is supplied with power from an electric power line and caused to rotate at a high rate of speed. By means of a system of belts, levers, or gear wheels, this rotating motion is then transmitted on to other apparatus, and in this way the motor is used to operate all kinds of machinery and to do useful work.

One form of motor is used for operating on direct current circuits, while another form differing somewhat in construction is used on alternating current circuits. However, the principles of operation of all these motors are fundamentally the same, no matter how large or how small they are, and whether D. C. or A. C., and if the basic principles are once clearly understood, they can readily be applied to every type and form of motor.

CONSTRUCTION AND ACTION OF THE D. C. MOTOR

In its general appearance and mechanical construction the direct current motor is similar to the direct current generator. In fact, practically all direct current machines can be used interchangeably either as motors or generators. The operation of the two machines, as we shall presently see, is also closely related.

The phantom view shown in Fig. A illustrates very clearly the mechanical arrangement and construction of a modern direct current motor. It consists of a circular field frame or yoke on the inner surface of which are mounted the field poles with their coil windings. At the center rotates the armature with its windings placed in slots on the outer surface, and the ends of the coils brought out to a commutator mounted on one end of the shaft. The brushes and brush rigging are also clearly shown. The fan blades on the left end of the armature serve to ventilate and cool the motor by blowing a continuous stream of air through the interior.

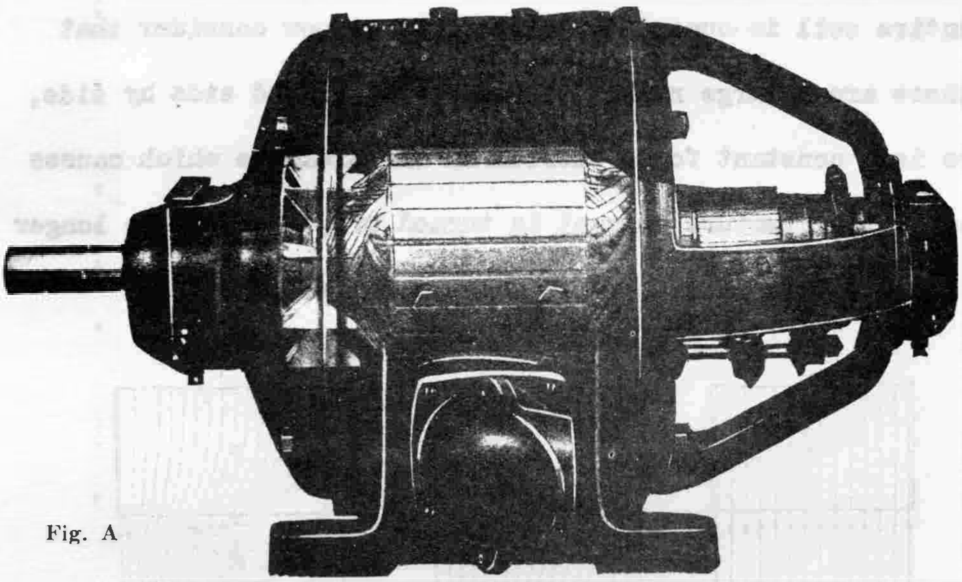
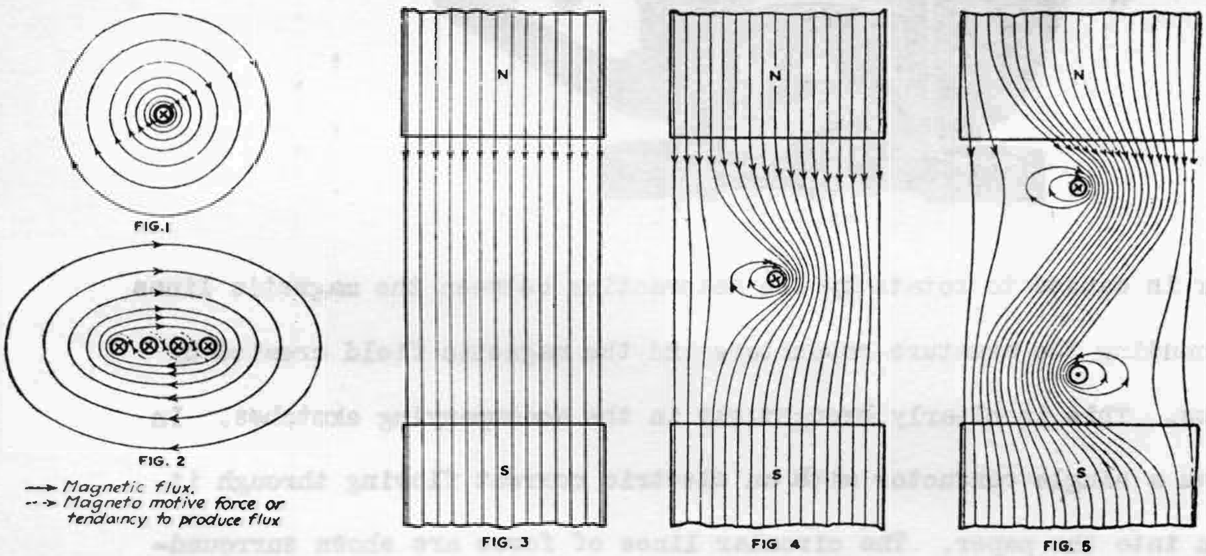


Fig. A

The motor is caused to rotate by the interaction between the magnetic lines of force surrounding the armature conductors and the magnetic field created by the field poles. This is clearly brought out in the accompanying sketches. In Fig. 1 is shown a single conductor with an electric current flowing through it in a direction into the paper. The circular lines of force are shown surrounding it in a clock-wise direction. In Fig. 2 is shown the effect of placing a number of these conductors next to each other, the lines of force combine and form a common field around the group. Fig. 3 illustrates the uniform magnetic field existing between a powerful N and S field pole of a machine. The lines of force leave the N and enter directly into the S pole. If the conductor shown in Fig. 1 is now placed into this uniform field, the lines become distorted as is shown in Fig. 4; and if we remember that lines of force act like stretched rubber bands constantly trying to shorten and straighten out, we can see that the wire will be caused to move to the left. We will now take a coil of wire with a current flowing through it and place it into the magnetic field as in Fig. 5. The upper side at which the current enters the coil is pushed to the left and the lower side at which the current comes out is pushed to the right; in other words, the entire coil is cuased to rotate. If we now consider that on a motor armature there are a large number of such coils placed side by side, we will see that there is a constant force exerted on the armature which causes it to rotate. As soon as the armature current is turned off, there is no longer any force exerted on the armature conductors, and the motor stops.



FIGS. 1 TO 5. ACTION OF CURRENT-CARRYING CONDUCTORS ON MAGNETIC FIELD

TYPES OF D.C. MOTORS

Direct current motors can also be divided into three general classes according to their electrical characteristics, namely series, shunt and compound. In all these three types the armatures may be the same, the essential difference being in the field windings and in the manner these are connected to the armature.

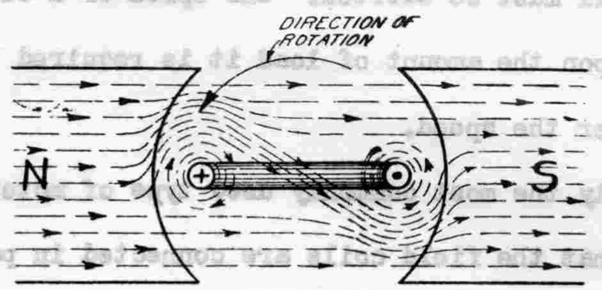
In a series motor the field windings consist of a comparatively small number of turns of rather large wire, and are connected in series with the armature so that the entire current taken by the motor flows through them. There There is therefore, but a single path through the entire machine. A series motor can always be recognized by the large wire used for the field coils. This type of motor is not used so very extensively, chiefly for cranes and hoists or where a very heavy starting pull must be exerted. The speed of a series motor is not constant, but depends upon the amount of load it is required to pull -- the lighter the load the greater the speed.

The shunt motor is probably the most commonly used type of motor, and derives its name from the fact that the field coils are connected in parallel or shunt with the armature. There are, therefore, two electrical paths through this machine, one through the field and one through the armature circuit. The field coils are wound with a large number of turns of rather small wire, and it is this fact which readily enables one to recognize a shunt machine. Since the field winding is connected directly across the power lines as will be shown in the wiring diagrams a little later, the field current and field strength of a shunt motor remain practically constant, no matter how much load is on the motor. The speed of a shunt motor is also practically constant for all loads, being only slightly less at full load than no load. These features make the shunt motor applicable to a large number of drives where a heavy starting pull is not necessary and where a nearly constant speed is wanted at all loads. Shunt motors are always used for driving motor-generator sets.

The compound motor has two sets of field windings, one consisting of a few turns of large wire connected in series with the armature, and the other consisting of many turns of smaller wire connected in parallel with the armature. The machine is, therefore, a combination of the series and shunt motors, and is employed for all service where a rather heavy starting pull but constant running speed is needed.

Some motors are also provided with special auxiliary poles placed between the main field poles. These are known as commutating poles or interpoles, and are used in order to produce sparkless operation under different conditions of load and speed. They are, therefore, used chiefly on variable speed motors.

DIRECTION OF ROTATION



LONGITUDINAL SECTION THROUGH MOTOR

Fig. 5A

A further study of Fig. 5A will show that the direction in which the armature of a motor is caused to rotate depends both upon the direction of the field magnetism and the direction in which the electric current flows through the coils. If the field magnetism were reversed so that the pole on the right became a north pole and the one on the left a south pole, the lines of force would extend from the right to the left. They would then be distorted so that the armature coil would be caused to rotate in the oppostie dir^ction.

Likewise, if the field magnetism were left unchanged but the direction of current flow through the armature reversed, the magnetic field also would be distorted so that the direction of rotation would be reversed. But on the other hand, if both the field magnetism were reversed as well as the current flow through the armature, then the magnetic distortion would remain unchanged as it is illustrated in the figure, and the direction of rotation would not be effected. This brings out the important facts that the direction of rotation of a motor can be reversed by changing the direction of the current either through the field or through the armature circuit, but not through both.

Merely interchanging the two power wires leading to the motor will not change the direction of rotation. Reverse the connections to the field circuit without affecting the armature leads, or reverse the connections to the armature without affecting the field leads, if the direction of the motor is to be reversed. Changing the polarity of the supply lines will reverse both the armature and field and, therefore, will not affect the direction of rotation. In other words, the direction of rotation is determined, entirely by the manner in which the field circuit is connected with respect to the armature.

TORQUE OF A MOTOR

By the torque of an electric motor is meant the amount of rotating pull or turning effort that the motor exerts. It is evident from Fig. 5A that if the magnetic field were stronger, the armature would be caused to rotate with greater force and, therefore, the torque would be greater. Also, if a greater current is sent through the armature, more lines of force will encircle the armature conductors, causing a stronger magnetic reaction, that is a greater torque. Therefore, the torque or turning force of a motor depends directly upon two factors, the strength of the magnetic field and the strength (number of amperes) of the armature current. This means that the amount of electric power that a motor draws from the line depends entirely upon the amount of load it is required to pull. As the load on the motor is increased, more current will be drawn from the line so that a stronger magnetic action (greater torque) will be had.

COUNTER ELECTROMOTIVE FORCE OF A MOTOR

As the armature of a motor rotates in its magnetic field, the conductors cut the lines of force just as if the armature were being driven as a generator, and there is induced in the winding a voltage or electromotive force. The presence of this electromotive force can easily be shown by means of the following simple experiment. Connect an electric lamp of the same voltage rating as the line on which the motor is being operated, directly across the armature terminals and bring the machine up to normal speed. Then without opening the field circuit disconnect the armature and the lamp will continue to burn brightly. Of course, as the armature slows down the lamp will glow dimmer and dimmer. The lamp continues to burn due to the current sent through it by the electromotive force generated in the armature as it rotated in the magnetic field.

This voltage, however, is opposite to the applied voltage of the line and it is known as the counter-electromotive force (counter meaning back or against). That this voltage is opposite to the applied voltage can also be shown in the above experiment. Connect a suitable zero-center voltmeter across the armature terminals with the lamp; and at the instant the armature is disconnected from the line, the voltmeter pointer will be seen to swing over to the other side of the scale showing that the voltage is acting in the opposite direction to the line voltage.

It is the difference between the applied voltage and the counter-electromotive force that is effective in causing current to flow through the armature and operate the motor. For example, if the applied voltage is 120 volts, and the counter-electromotive force is 100 volts, then 20 volts are effective in sending current through the armature.

Just how this counter-electromotive force operates can easily be seen from a careful reading of the following sentences. As the motor armature is caused to rotate by the magnetic reaction, it will tend to speed up and run faster and faster. But as it rotates there is developed in the winding an E.M.F. which opposes the applied voltage. As the armature speeds up, this counter-voltage approaches the applied voltage, and soon a condition is reached where the difference between the applied and counter voltages is just great enough to send sufficient current through the armature to cause it to rotate at a constant speed. If the load on the motor increases, more turning effort is required, that is more current must flow through the armature. The motor will at once slow down a little. This decreased speed cuts down the counter E.M.F. and enables the applied voltage to send the required greater current through the armature. If the load becomes less, the armature would at once tend to speed up, and at a higher speed a greater counter E.M.F. will be induced. This cuts down the armature current, and as a result of the lesser torque the speed of the motor will again become steady. A motor, therefore, automatically regulates its own speed as well as the amount of current drawn from the line. In other words, a motor will always operate at such a speed that the difference between the applied voltage and counter E.M.F. will cause enough current to flow in order to enable the motor to pull its load at the required speed.

MOTOR SPEED CONTROL

It was just brought out how an electric motor regulates its own speed according to the amount of load it is required to pull. It is the counter-electromotive force that really is the important factor. As in any case, the value of this counter-electromotive force depends upon the strength of the magnetic field and the speed of rotation. If the field is weaker, the armature must turn faster in order to develop the necessary counter-voltage; while if the field is made stronger, the armature need not turn so fast.

The above facts at once suggest a method for varying the speed of a motor. If a suitable rheostat is connected in series with the shunt field circuit, the field strength can be varied at will within certain limits. If the speed of the motor is to be increased, the field is weakened by cutting resistance into the circuit, but if the motor speed is to be decreased, the field strengthened by cutting resistance out of the circuit.

After all resistance has been cut out of the rheostat, the speed cannot be decreased further, for it is not possible to strenghten the field any more by cutting down the resistance of the circuit. But if the speed must be lowered, a suitable rheostat is connected in series with the armature. This rheostat reduces the voltage supplied to the armature, and in this way cuts down the speed of rotation.

In general then the speed of a motor is varied by changing the resistance of the shunt field circuit -- increasing the resistance weakens the field and causes the motor to run faster, while decreasing the resistance strengthens the field and causes the motor to run slower. If the motor speed is to be greatly decreased, a suitable rheostat is connected in series with the armature circuit. These principles apply to both the shunt and compound motors.

MOTOR STARTING BOXES

The resistance of the armature circuit of a motor is ver low, generally less than one-tenth of an ohm. Therefore, if a motor at rest were to be started by connecting it directly across the line, an excessively large starting current would flow that would not only be harmful to the motor but also cause serious disturbances in the line. For this reason it is necessary to connect a suitable resistance in series with the motor during the starting period, and as the motor comes up to speed this resistance is gradually cut out.

The motor armature at standstill develops no counter-electromotive force, and, therefore, the full line pressure is effective in sending current through the armature circuit. But as the armature speeds up, this counter-electromotive force also comes on and opposes the line voltage, thereby decreasing its effectiveness in sending current through the circuit. The starting resistance limits the amount of initial current rush, but at normal speed the motor automatically controls the current flow, for it always runs at such a speed that the difference between the applied and counter-voltage will send sufficient current through the armature to enable the motor to pull its load at the desired speed.

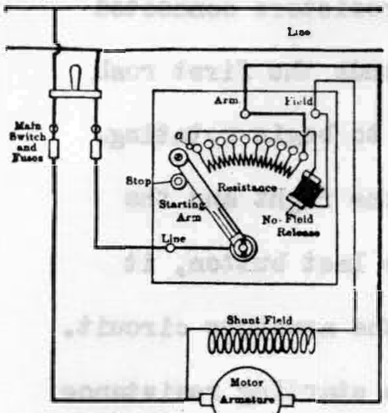


Fig. 7

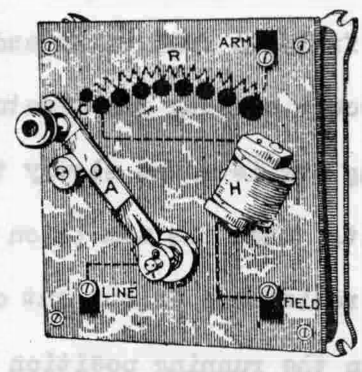


Fig. 6

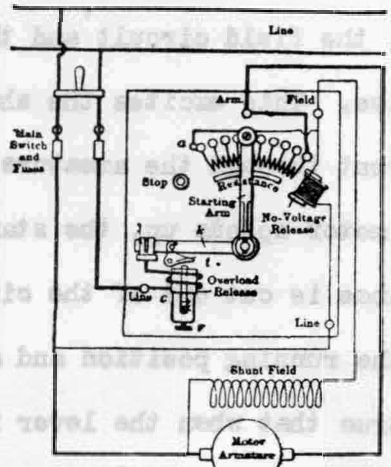


Fig 8

A motor starting box is a device containing a number of resistances so arranged that they can be inserted in series with a motor during the starting period, and then by means of a movable lever gradually cut out as the motor speeds up. These starting boxes are made in various sizes for the different size motors. The general appearance of a hand operated starting box is illustrated in Fig. 6, while in Fig. 7 is shown the internal circuit arrangement of the box and the method of connecting it to a shunt motor. This box is known as a 3-point starting box because three electrical connections are made to it. From the supply lines the current first flows through a main switch and fuses which serve to protect the motor against harmful overload, for if the current exceeds a safe value, the fuses melt and disconnect the motor from the lines. One side of the line is then connected directly to an armature terminal, and one end of the shunt field is also connected to this same point. The other side of the line is brought to the terminal on the starting box marked "line". Another terminal on the box is marked "arm" and this is connected to the other side of the motor armature, while the third terminal on the box marked "field" is connected to the remaining free end of the shunt field. This arrangement puts the field directly in parallel with the armature circuit.

When the starting arm is moved to the first button "a", both circuits are closed, the field circuit and the armature circuit with the resistors connected in series. This excites the shunt field to full value and sends the first rush of current through the armature circuit causing the armature to begin rotating. As the motor speeds up, the starting arm is moved slowly to the right and the resistance is cut out of the circuit. When the arm is on the last button, it is in the running position and all resistance is cut out of the armature circuit. It is true that when the lever is in the running position the starting resistance remains in the shunt field circuit, but this resistance is so low compared to the high resistance of the field circuit, that it produces no appreciable effect. The arm is held in position by an electromagnet labelled "no voltage release" in the figure.

When the motor is to be shut down, only the line switch needs to be opened, for as soon as this is opened, the magnet loses its magnetism and the starting arm is brought back to the off position by means of a coiled spring on the turning shaft. Never should a motor be shut down by pulling the starting lever away from the holding magnet.

When a motor is being put into operation, the starting lever should never be moved to the "on" position too rapidly or too slowly. From 10 to 20 seconds time should be given the motor to come up to speed, depending upon the size of the motor and the amount of load it is pulling. If the arm is moved over too quickly, an excessive current will be drawn and the fuses will be blown or the circuit breaker tripped. This is because the armature has not developed enough counter-voltage to cut the current down to a safe value. If the arm is moved too slowly, the starting resistors will become too warm and are likely to be burned out. These resistors are designed only for short time duty.

THE NO-VOLTAGE OR NO-FIELD RELEASE

It is a serious condition if the field of a direct current motor suddenly becomes very weak or the field circuit becomes opened entirely, for not only will the motor then draw a dangerously heavy current but it will also develop such a high rate of speed that it may tear itself to pieces. The reason for the heavy current drain is the very low counter-voltage due to the weakened field. At the same time it will keep on turning faster in an attempt to develop the required counter-voltage.

To prevent such a condition, the starting boxes are provided with what is known as a no-field release. This release is merely the electromagnet that was referred to previously and that holds the starting arm in the "on" position against the tension of the coiled spring. The coil of this electromagnet is connected in series with the field circuit, and in case the field becomes too weak or the circuit becomes opened entirely, the magnet loses its holding power and the lever at once returns to the off position. In this way the motor is constantly protected.

Sometimes the device is also known as a no-voltage release, for since it is connected directly across the line in series with the shunt field, it will also allow the starting lever to return to the "off"position in case the line voltage fails. This is very important protection, for if the line voltage should fail or be off a while and then come on again after the motor has come to a standstill, full voltage would be thrown across the low resistance armature circuit. Some damage would inevitably result, either to the motor itself or to the supply lines. With the starting lever returned to the "off" position as soon as the voltage fails, the necessary starting resistance would be connected into the motor line before the motor could be started again. Sometimes when the main line switch is opened the lever will not return to the off position immediately but will hold on a short time due to the current sent through the circuit by the counter-voltage.

An overload release is another protective device with which some starting boxes are equipped. This is likewise an electromagnet but is connected in series with the line feeding the armature circuit. It is clearly shown in the starting box illustrated in Fig. 8. If the load should become so large that the motor draws an excessive current the plunger of the magnet is pulled up and strikes the catch. This releases the arm K, which in turn breaks the current at J. With the circuit broken, the no-voltage release at once allows the starting lever to return to the "off" position. This type of motor starting box thus protects the motor both against overload and no-voltage or power failure.

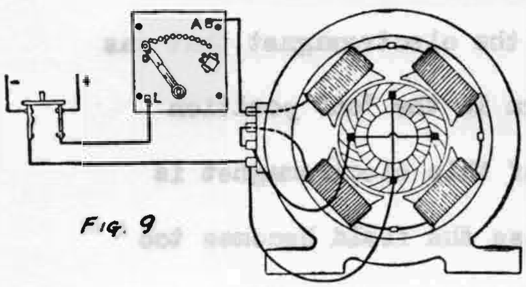


FIG. 9

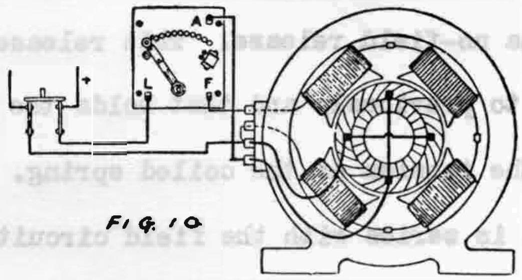


FIG. 10

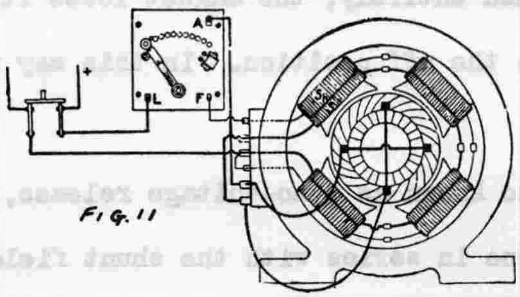


FIG. 11

The correct methods of connecting a 3-point starting box to the different types of D.C. motors are illustrated in Fig. 9, 10, and 11. In Fig. 9 which illustrates a series motor the field terminal on the starting box is not used. Fig. 10 illustrates a shunt motor and Fig. 11 a compound motor.

AUTOMATIC MOTOR STARTERS

Automatic motor starters serve the same purposes as the hand operated boxes described previously, except that they are operated by means of an arrangement of electromagnets. In this way the human element is eliminated entirely, and the motor is always started under the most favorable electrical conditions. Another advantage is that the starter can be located near the motor in a position that might be very inconvenient as far as the operator is concerned, but since the starters are controlled entirely by one or more push-buttons located in handy places, the location of the starter is of little account.

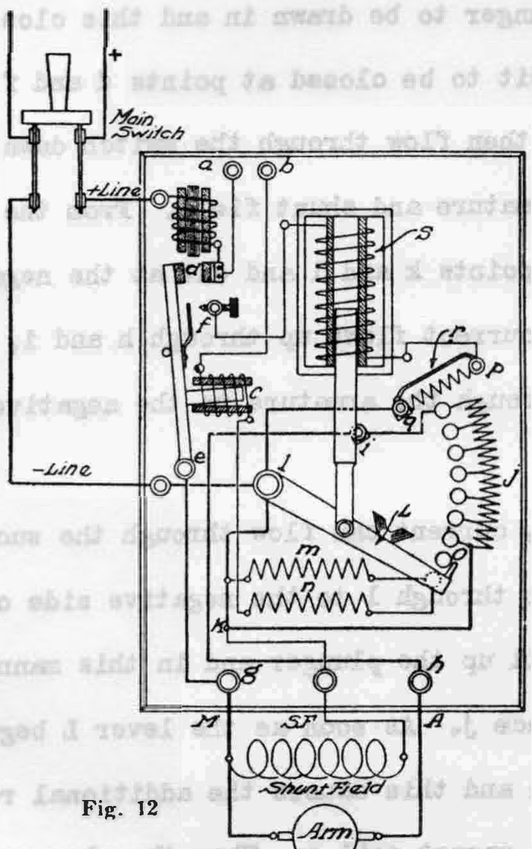


Fig. 12

A solenoid type automatic starter is illustrated in Fig. 12. A glance at the sketch will reveal that essentially the starter is similar to the hand operated starters, but that the operating lever is drawn over the resistance contacts by means of a plunger in a strong suction magnet. Of course, there are a few more accessory parts on the starter which are necessary to make the entire mechanism automatic in operation. The starter is provided with seven electrical terminals: two at the left to which the line is connected, two at the top to which a standard motor starting button is connected, and three at the bottom to which the motor armature and shunt field are connected as is shown in the illustration.

When the push-button circuit across a and b is closed, current can flow from the positive side of the line through the blow-out coil (to be described later), through the push-button, on through magnet c, through resistance n, and out through the moving arm to the negative side of the line. The current flowing through coil c causes the plunger to be drawn in and this closes the main electric switch causing the circuit to be closed at points d and f. With the circuit closed at d, current can then flow through the switch down to e, on to terminal g, and into the motor armature and shunt field. From the shunt field the current flows directly up to points k and l and out at the negative side of the line. From the armature the current flows up through h and i, through the starting resistance j, and out through the armature to the negative side of the line.

With the circuit closed at f, current can flow through the suction magnet S, through the armature r, and out through l to the negative side of the line. The magnet S at once begins to pull up the plunger and in this manner draw the lever L over the starting resistance j. As soon as the lever L begins to move up, it leaves the first contact button and this causes the additional resistance m to be connected in series with the magnet coil c. When the plunger is completely in, the lever rests on the last button and all starting resistance is cut out of the circuit. At the same time the flexible copper bridge at L connects across the two points i and q and positively shorts the starting resistance out of the circuit. Also the little arm o at the end of the starting lever raises the bar r and in this manner cuts the resistance up in series with the coil of the suction magnet s. In other words, as much current is not required through s to hold up the plunger as is needed to pull in the plunger and draw up the starting lever. This completes the starting operations. To stop the motor merely open the push-button circuit across a and b. This de-energizes the magnet c and permits the main switch to open. At once the coil s lets go, and the plunger and lever L returns to the starting position.

To control the rate at which the plunger is drawn in and the starting resistance cut out, a dash pot is employed. This dash pot consists of a cylinder within which moves a piston. At one end of the cylinder is a small adjustable needle valve through which the air can escape as it is being compressed by the piston. In other words, the piston cannot move in any faster than the air can get out. This dash pot is attached to the movable starting lever, therefore, the lever can be drawn up only so fast and no faster. If a greater force is exerted on the dash pot piston, the air is merely compressed more and greater resistance offered. Since the rate at which the motor is started is dependent entirely upon how fast the air can escape out of the dash pot, this type of motor is known as a time-limit starter. If the needle valve is opened further, the air can escape faster and the motor is started in a shorter period of time.

The blow-out coil referred to above is merely a powerful electromagnet the magnetic field of which blows out the arc that forms when the main electric switch opens. The arc across the contacts is sustained by current flow, and the magnetic field of the blow-out coil reacts upon this current and as a result quenches the arc.

CARE AND MAINTENANCE OF ELECTRIC MOTORS

As with any electrical or mechanical device, the life and performance of an electric motor depend upon the care and attention it receives. The two main things to observe are that the bearings be kept well oiled and the commutator bright and clean. It is a simple matter to inspect and oil the bearings at regular intervals. The commutator should be kept free from oil and dirt, for any accumulations will cause arcing or sparking, and this in turn will cause the surface to become rough and pitted. If the commutator does require smoothing, only fine sandpaper should be used. Emery cloth must not be used, for emery is a conducting material, and if any collects between the commutator segments it will cause a short circuit. Oil and dirt should also be kept out of the field windings, for these cause the rubber and insulating material to corode and to break down eventaually.

At the same time a motor should not be misused in operation. Although a motor can stand a small overload for a short time, it should not be overloaded continuously, for this will cause it to overheat and to burn out sooner or later. If a hand operated starting box is used, the starting lever should never be moved over too quickly or too slowly. Starting the motor too quickly will draw an excessive current and may cause the motor to burn out, while moving the lever too slowly will cause the starting resistors to over heat. If an automatic starter is used, the dashpot should be set so that the motor will be brought up to normal speed in the proper time interval.

If upon attempting to start a motor the armature fails to rotate and a severe flash is received at the starter button, or the fuses blow and the circuit breaker trips, it is a sign that there is an open in the field circuit. Either a part of the field winding is open or burned out, or else the trouble may lie in the motor field rheostat. At least, something is wrong with the field circuit, for due to the absence of the counter voltage, there is nothing to limit the current flow. Of course, it might also be that a bearing is frozen and that it prevents the armature from turning over.