MODULE 03

FOR B1 & B2 CERTIFICATION

ELECTRICAL FUNDAMENTALS

Aviation Maintenance Technician Certification Series

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REVISION LOG

VERSION	EFFECTIVE DATE	DESCRIPTION OF CHANGE
001	2014 08	Module Creation and Release
002	2016 10	Format Updates
003	2017 03	Content Updates and Subject Clarification
004	2019 07	Fine tuned Sub-Module content sequence based on Appendix-A. Updated layout and styling.

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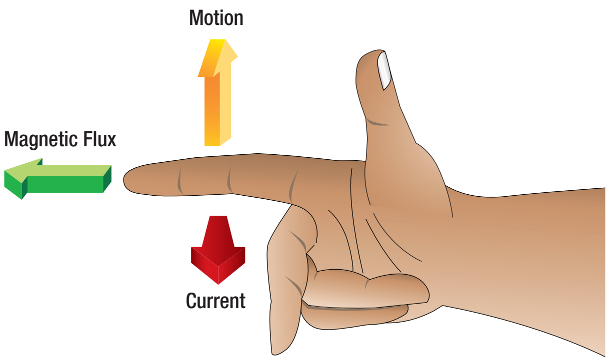

Figure 12-24. Right-hand motor rule.

The amount of torque developed in a coil depends upon several factors: the strength of the magnetic field, the number of turns in the coil, and the position of the coil in the field. Magnets are made of special steel that produces a strong field. Since there is torque acting on each turn, the greater the number of turns on the coil, the greater the torque. In a coil carrying a steady current located in a uniform magnetic field, the torque will vary at successive positions of rotation, as shown in ***Figure 12-25***. When the plane of the coil is parallel to the lines of force, the torque is zero. When its plane cuts the lines of force at right angles, the torque is 100 percent. At intermediate positions, the torque ranges between zero and 100 percent.

BASIC DC MOTOR

A coil of wire through which the current flows will rotate when placed in a magnetic field. This is the technical basis governing the construction of a DC motor. ***Figure 12-26*** shows a coil mounted in a magnetic field in which it can rotate. However, if the connecting wires from the battery were permanently fastened to the terminals of the coil and there was a flow of current, the coil would rotate only until it lined itself up with the magnetic field. Then, it would stop, because the torque at that point would be zero.

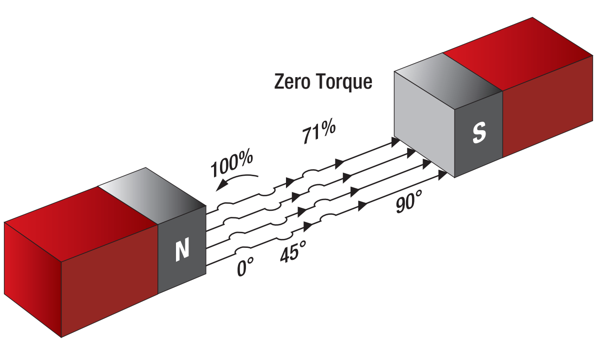

Figure 12-25. Torque on a coil at various angles of rotation.

A motor, of course, must continue rotating. It is therefore necessary to design a device that will reverse the current in the coil just at the time the coil becomes parallel to the lines of force. This will create torque again and cause the coil to rotate. If the current reversing device is set up to reverse the current each time the coil is about to stop, the coil can be made to continue rotating as long as desired.

One method of doing this is to connect the circuit so that, as the coil rotates, each contact slides off the terminal to which it connects and slides onto the terminal of opposite polarity. In other words, the coil contacts switch terminals continuously as the coil rotates, preserving the torque and keeping the coil rotating. In ***Figure 12-26***, the coil terminal segments are labeled A and B. As the coil rotates, the segments slide onto and past the fixed terminals or brushes. With this arrangement, the direction of current in the side of the coil next to the north-seeking pole flows toward the reader, and the force acting on that side of the coil turns it downward. The part of the motor, which changes the current from one wire to another, is called the commutator.

Position A

When the coil is positioned as shown in ***Figure 12-26A***, current will flow from the negative terminal of the battery to the negative (–) brush, to segment B of the commutator, through the loop to segment A of the commutator, to the positive (+) brush, and then, back to the positive terminal of the battery. By using the right-hand motor rule, it is seen that the coil will rotate counterclockwise. The torque at this position of the coil is maximum, since the greatest number of lines of force is being cut by the coil.

Position B

When the coil has rotated 90° to the position shown in ***Figure 12-26B***, segments A and B of the commutator no longer make contact with the battery circuit and no current can flow through the coil. At this position, the torque has reached a minimum value, since a minimum number of lines of force are being cut. However, the momentum of the coil carries it beyond this position until the segments again make contact with the brushes, and current again enters the coil; this time, though, it enters through segment A and leaves through segment B. However, since the positions of segments A and B

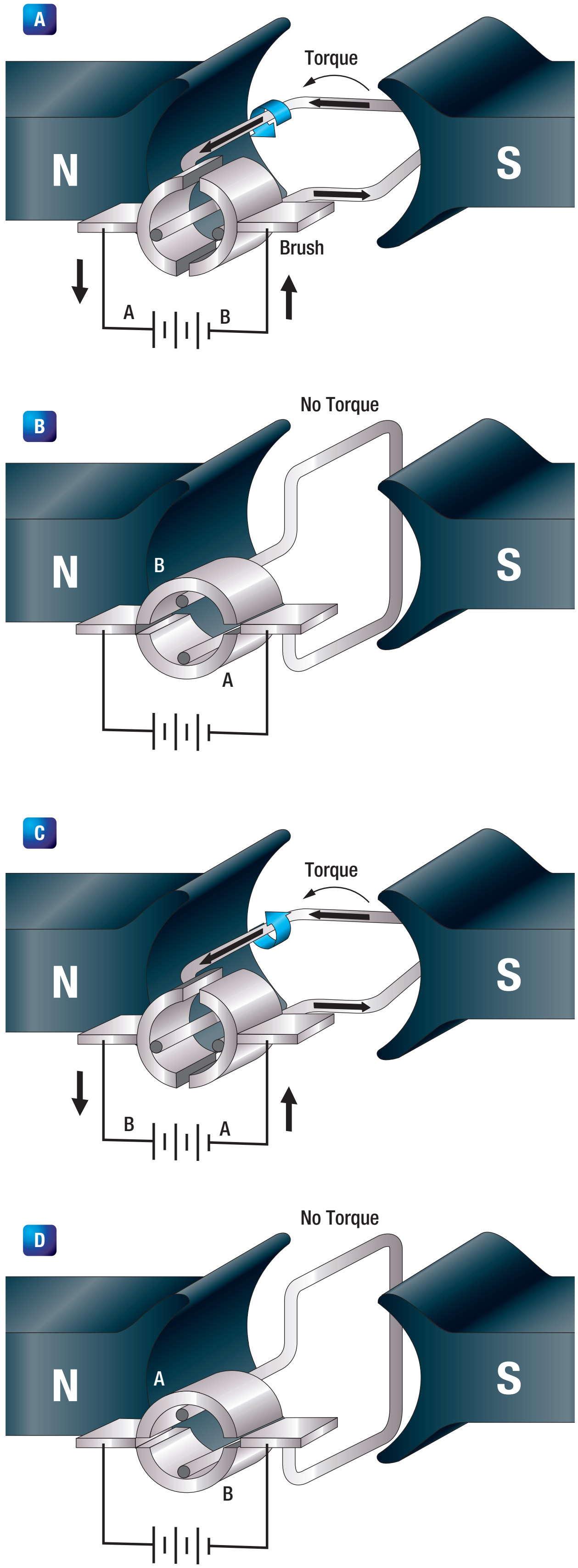

Figure 12-26. Basic DC motor operation.

have also been reversed, the effect of the current is as before, the torque acts in the same direction, and the coil continues its counterclockwise rotation.

Position C

On passing through the position shown in ***Figure 12-26C***, the torque again reaches maximum.

Position D

Continued rotation carries the coil again to a position of minimum torque, as in ***Figure 12-26D***. At this position, the brushes no longer carry current, but once more the momentum rotates the coil to the point where current enters through segment B and leaves through A. Further rotation brings the coil to the starting point and, thus, one revolution is completed. The switching of the coil terminals from the positive to the negative brushes occurs twice per revolution of the coil.

The torque in a motor containing only a single coil is neither continuous nor very effective, for there are two positions where there is actually no torque at all. To overcome this, a practical DC motor contains a large number of coils wound on the armature. These coils are so spaced that, for any position of the armature, there will be coils near the poles of the magnet. This makes the torque both continuous and strong. The commutator, likewise, contains a large number of segments instead of only two. The armature in a practical motor is not placed between the poles of a permanent magnet but between those of an electromagnet, since a much stronger magnetic field can be furnished. The core is usually made of a mild or annealed steel, which can be magnetized strongly by induction. The current magnetizing the electromagnet is from the same source that supplies the current to the armature.

DC MOTOR CONSTRUCTION

The major parts in a practical motor are the armature assembly, the field assembly, the brush assembly, and the end frame. (***Figure 12-27***)

Armature Assembly

The armature assembly contains a laminated, soft iron core, coils, and a commutator, all mounted on a rotatable steel shaft. Laminations made of stacks of soft iron, insulated from each other, form the armature core. Solid iron is not used, since a solid iron core revolving in the magnetic field would heat and use energy needlessly. The

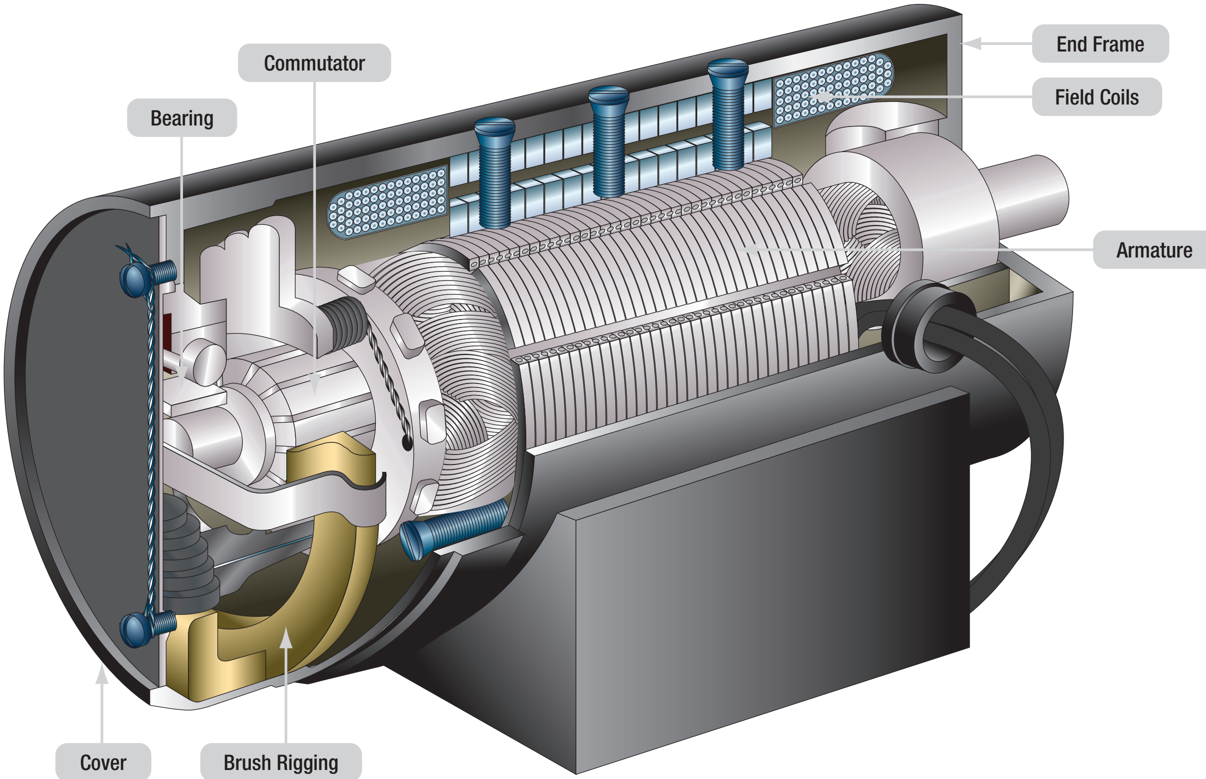

Figure 12-27. Cutaway view of practical DC motor.

armature windings are insulated copper wire, which are inserted in slots insulated with fiber paper (fish paper) to protect the windings. The ends of the windings are connected to the commutator segments. Wedges or steel bands hold the windings in place to prevent them from flying out of the slots when the armature is rotating at high speeds. The commutator consists of a large number of copper segments insulated from each other and the armature shaft by pieces of mica. Insulated wedge rings hold the segments in place.

Field Assembly

The field assembly consists of the field frame, the pole pieces, and the field coils. The field frame is located along the inner wall of the motor housing. It contains laminated soft steel pole pieces on which the field coils are wound. A coil, consisting of several turns of insulated wire, fits over each pole piece and, together with the pole, constitutes a field pole. Some motors have as few as two poles, others as many as eight.

Brush Assembly

The brush assembly consists of the brushes and their holders. The brushes are usually small blocks of graphitic carbon, since this material has a long service life and also causes minimum wear to the commutator. The holders permit some play in the brushes so they can follow any irregularities in the surface of the commutator and make good contact. Springs hold the brushes firmly against the commutator. A commutator and two types of brushes are shown in ***Figure 12-28***.

End Frame

The end frame is the part of the motor opposite the commutator. Usually, the end frame is designed so that it can be connected to the unit to be driven. The bearing for the drive end is also located in the end frame. Sometimes the end frame is made a part of the unit driven by the motor. When this is done, the bearing on the drive end may be located in any one of a number of places.

TYPES OF DC MOTORS

They differ largely in the method in which their field and armature coils are connected. There are three basic types of DC motors:

1. Series motors,
2. Shunt motors, and
3. Compound motors.

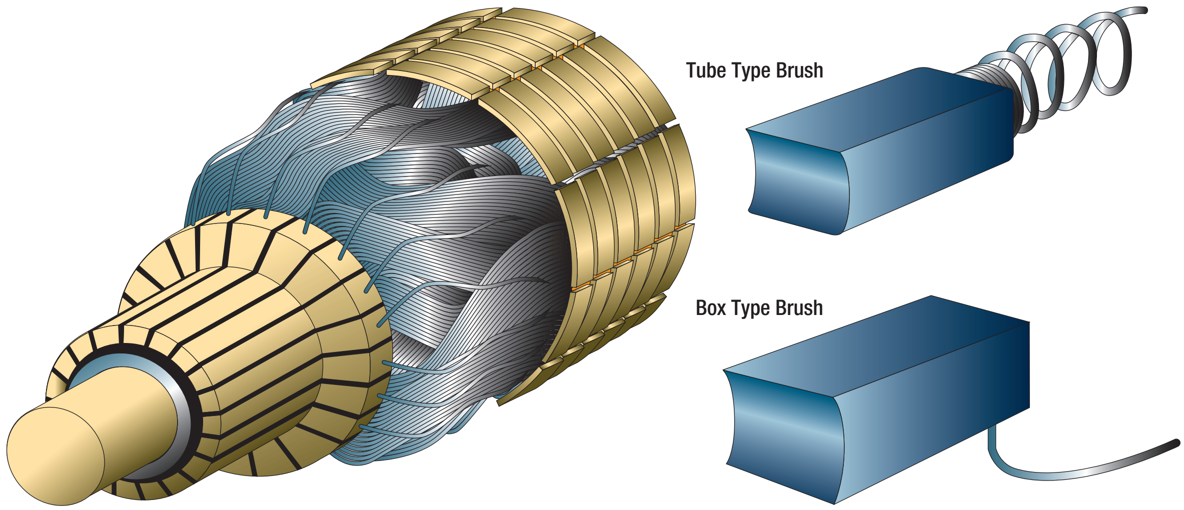

Figure 12-28. Commutator and brushes.

SERIES DC MOTOR

In the series motor, the field windings, consisting of a relatively few turns of heavy wire, are connected in series with the armature winding. Both a diagrammatic and a schematic illustration of a series motor are shown in ***Figure 12-29***. The same current flowing through the field winding also flows through the armature winding. Any increase in current, therefore, strengthens the magnetism of both the field and the armature.

Because of the low resistance in the windings, the series motor is able to draw a large current in starting. This starting current, in passing through both the field and armature windings, produces a high starting torque, which is the series motor's principal advantage.

The speed of a series motor is dependent upon the load. Any change in load is accompanied by a substantial change in speed. A series motor will run at high speed when it has a light load and at low speed with a heavy load. If the load is removed entirely, the motor may operate at such a high speed that the armature will fly apart. If high starting torque is needed under heavy load conditions, series motors have many applications. Series motors are often used in aircraft as engine starters, and for raising and lowering landing gear, cowl flaps and wing flaps.

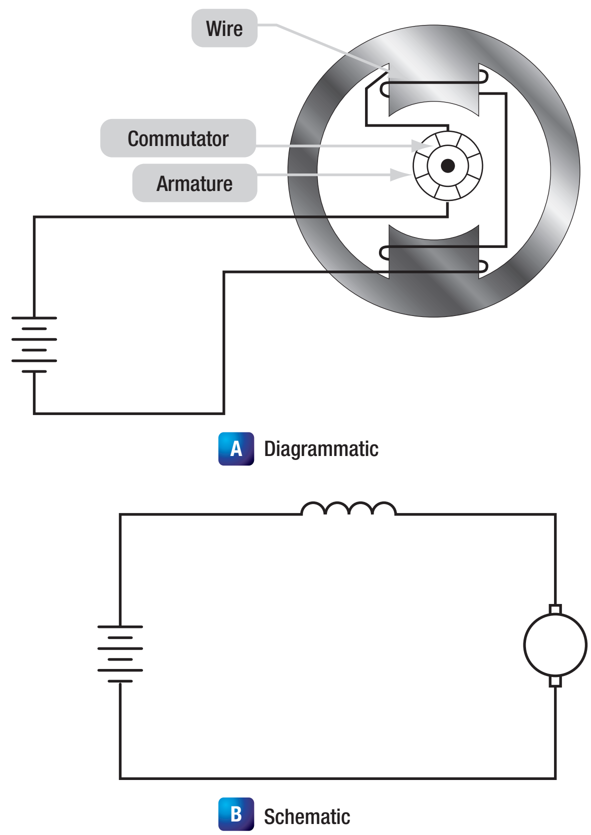

Figure 12-29. Series motor.

SHUNT DC MOTOR

In the shunt motor, the field winding is connected in parallel or in shunt with the armature winding. (***Figure 12-30***)

The resistance in the field winding is high. Since the field winding is connected directly across the power supply, the current through the field is constant. The field current does not vary with motor speed, as in the series motor and, therefore, the torque of the shunt motor will vary only with the current through the armature. The torque developed at starting is less than that developed by a series motor of equal size.

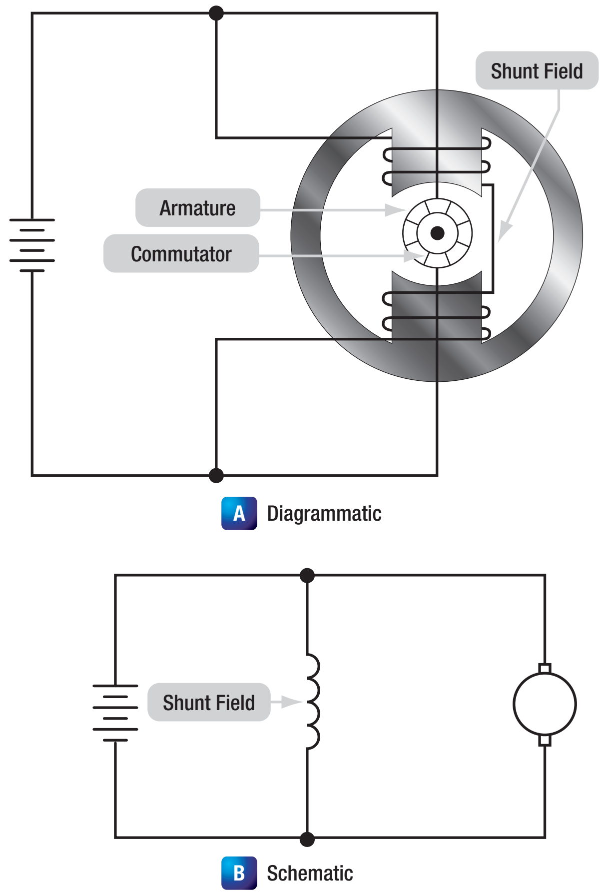

Figure 12-30. Shunt motor.

The speed of the shunt motor varies very little with changes in load. When all load is removed, it assumes a speed slightly higher than the loaded speed. This motor is particularly suitable for use when constant speed is desired and when high starting torque is not needed.

COMPOUND DC MOTOR

The compound motor is a combination of the series and shunt motors. There are two windings in the field: a shunt winding and a series winding. A schematic of a compound motor is shown in ***Figure 12-31***. The shunt winding is composed of many turns of fine wire and is connected in parallel with the armature winding. The series winding consists of a few turns of large wire and is connected in series with the armature winding. The starting torque is higher than in the shunt motor but lower than in the series motor. Variation of speed with load is less than in a series wound motor but greater than in a shunt motor. The compound motor is used whenever the combined characteristics of the series and shunt motors are desired.

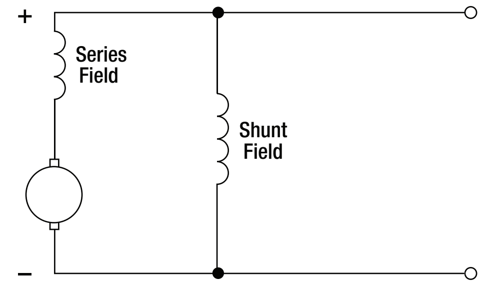

Figure 12-31. Compound motor.

Like the compound generator, the compound motor has both series and shunt field windings. The series winding may either aid the shunt wind (cumulative compound) or oppose the shunt winding (differential compound). The starting and load characteristics of the cumulative compound motor are somewhere between those of the series and those of the shunt motor. Because of the series field, the cumulative compound motor has a higher starting torque than a shunt motor. Cumulative compound motors are used in driving machines, which are subject to sudden changes in load. They are also used where a high starting torque is desired, but a series motor cannot be used easily.

In the differential compound motor, an increase in load creates an increase in current and a decrease in total flux in this type of motor. These two tend to offset each other and the result is a practically constant speed. However, since an increase in load tends to decrease the field strength, the speed characteristic becomes unstable. Rarely is this type of motor used in aircraft systems. A graph of the variation in speed with changes of load of the various types of DC. (***Figure 12-32***)

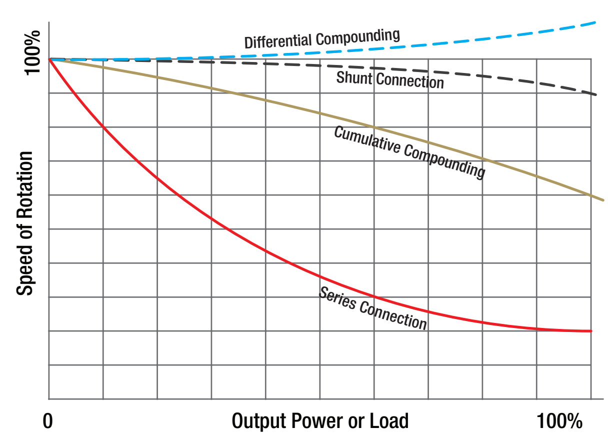

Figure 12-32. Load characteristics of DC motors.

OPERATIONAL FACTORS OF DC MOTORS

Electric motors are called upon to operate under various conditions. Some motors are used for intermittent operation; others operate continuously. Motors built for intermittent duty can be operated for short periods only and, then, must be allowed to cool before being operated again. If such a motor is operated for long periods under full load, the motor will be overheated. Motors built for continuous duty may be operated at rated power for long periods.

COUNTER ELECTROMOTIVE FORCE (EMF)

The armature resistance of a small, 28-volt DC motor is extremely low, about 0.1 ohm. When the armature is connected across the 28-volt source, current through the armature will apparently be:

$$I = \frac{E}{R} = \frac{28}{0.1} = 280 \text{ amperes}$$

This high value of current flow is not only impracticable but also unreasonable, especially when the current drain, during normal operation of a motor, is found to be about 4 amperes. This is because the current through a motor armature during operation is determined by more factors than ohmic resistance. When the armature in a motor rotates in a magnetic field, a voltage is induced in its windings. This voltage is called the back or counter EMF (electromotive force) and is opposite in direction to the voltage applied to the motor from the external source.

Counter EMF opposes the current, which causes the armature to rotate. The current flowing through the armature, therefore, decreases as the counter EMF increases. The faster the armature rotates, the greater the counter EMF. For this reason, a motor connected to a battery may draw a fairly high current on starting, but as the armature speed increases, the current flowing through the armature decreases. At rated speed, the counter EMF may be only a few volts less than the battery voltage. Then, if the load on the motor is increased, the motor will slow down, less counter EMF will be generated, and the current drawn from the external source will increase.

In a shunt motor, the counter EMF affects only the current in the armature, since the field is connected in parallel across the power source. As the motor slows down and the counter EMF decreases, more current flows through the armature, but the magnetism in the field is unchanged. When the series motor slows down, the counter EMF decreases and more current flows through the field and the armature, thereby strengthening their magnetic fields. Because of these characteristics, it is more difficult to stall a series motor than a shunt motor.

REVERSING MOTOR DIRECTION

By reversing the direction of current flow in either the armature or the field windings, the direction of a motor's rotation may be reversed. This will reverse the magnetism of either the armature or the magnetic field in which the armature rotates. If the wires connecting the motor to an external source are interchanged, the direction of rotation will not be reversed, since changing these wires reverses the magnetism of both field and armature and leaves the torque in the same direction as before.

One method for reversing direction of rotation employs two field windings wound in opposite directions on the same pole. This type of motor is called a split field motor. ***Figure 12-33*** shows a series motor with a split field winding. The single pole, double throw switch makes it possible to direct current through either of the two windings. When the switch is placed in the lower position, current flows through the lower field winding, creating a north pole at the lower field winding and at

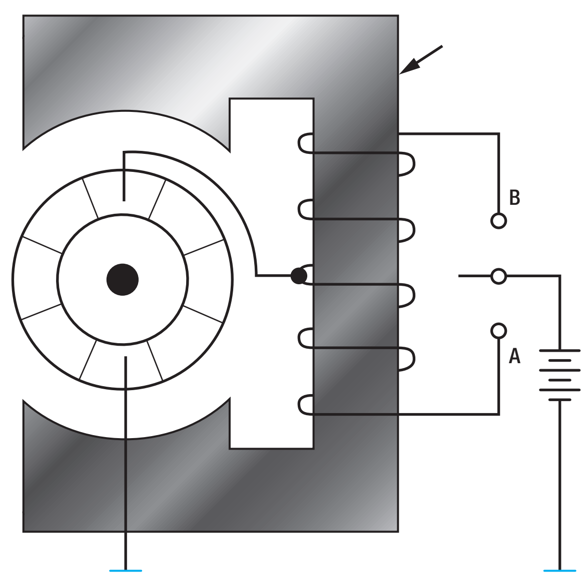

Figure 12-33. Split field series motor.

DC MOTOR/GENERATOR THEORY

the lower pole piece, and a south pole at the upper pole piece. When the switch is placed in the upper position, current flows through the upper field winding, the magnetism of the field is reversed, and the armature rotates in the opposite direction. Some split field motors are built with two separate field windings wound on alternate poles.

The armature in such a motor, a four pole reversible motor, rotates in one direction when current flows through the windings of one set of opposite pole pieces, and in the opposite direction when current flows through the other set of windings.

Another method of direction reversal, called the switch method, employs a double pole, double throw switch which changes the direction of current flow in either the armature or the field. In the illustration of the switch method shown in ***Figure 12-34***, current direction may be reversed through the field but not through the armature.

When the switch is thrown to the "up" position, current flows through the field winding to establish a north pole at the right side of the motor and a south pole at the left side of the motor. When the switch is thrown to the "down" position, this polarity is reversed and the armature rotates in the opposite direction.

MOTOR SPEED

Motor speed can be controlled by varying the current in the field windings. When the amount of current flowing through the field windings is increased, the field strength increases, but the motor slows down since a greater amount of counter EMF is generated in the armature windings. When the field current is decreased, the field strength decreases, and the motor speeds up because the counter EMF is reduced. A motor in which speed can be controlled is called a variable speed motor. It may be either a shunt or series motor.

In the shunt motor, speed is controlled by a rheostat in series with the field windings. (***Figure 12-35***) The speed depends on the amount of current that flows through the rheostat to the field windings. To increase the motor speed, the resistance in the rheostat is increased, which decreases the field current. As a result, there is a decrease in the strength of the magnetic field and in the counter EMF. This momentarily increases the armature current and the torque. The motor will then automatically speed up until the counter EMF increases and causes the armature current to decrease to its former value.

When this occurs, the motor will operate at a higher fixed speed than before. To decrease the motor speed, the resistance of the rheostat is decreased. More current flows through the field windings and increases the

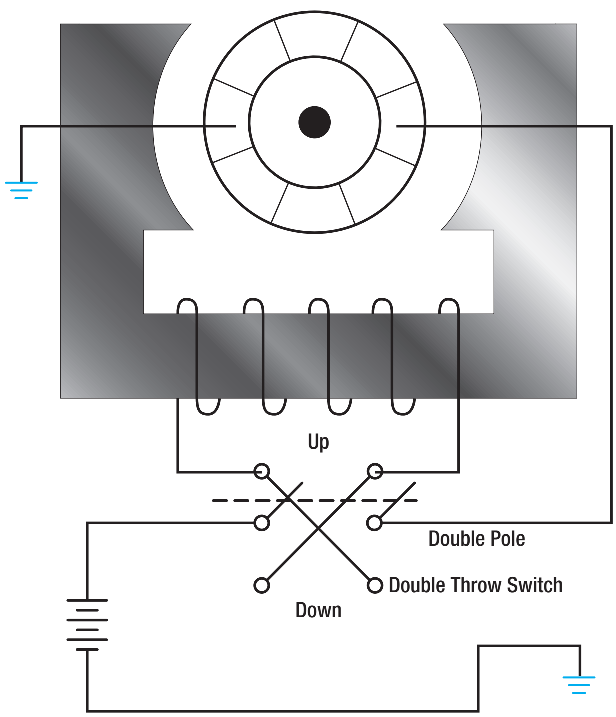

Figure 12-34. Switch method of reversing motor direction.

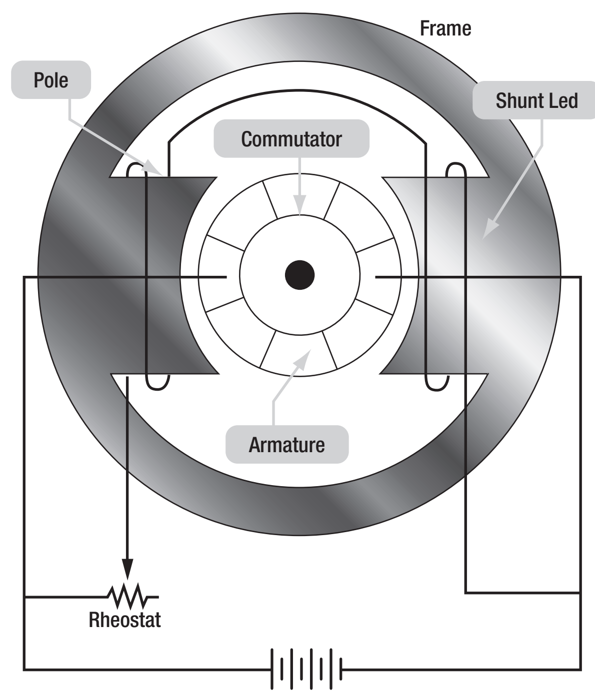

Figure 12-35. Shunt motor with variable speed control.