The magnetic field of the current follows the rotating magnetic field. As the loop turns, it rotates the motor shaft. In practice a number of closed-loop conductors are used for the armature.

Rotating conductors in the armature will fall slightly behind the rotating field. That is necessary because if they were in exact synchronization with the rotating magnetic field there would be no relative motion between the field and the armature. Consequently, there would be no induced current flow. When the armature follows behind in an ac induction motor, it is called slippage.

Figure 7-22 shows a more efficient set of conductors for the armature of the motor in Fig. 7-21. This illustration shows straight conductors between end conductors. They are arranged in a circular pattern. This type of armature is called a "squirrel cage." It is used in squirrel cage induction motors.

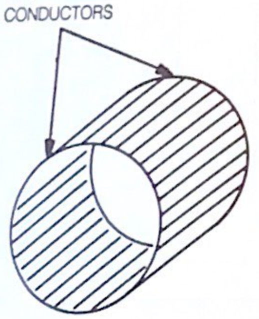

Fig. 7-22. The squirrel-cage rotor operates by magnetic fields produced in the current-carrying conductors.

The Capacitor Start Motor. So far we have reviewed two ways of obtaining a rotating magnetic field. One is by rotating a permanent magnet and the other is by using two-phase ac power. Two-phase ac power is not readily available today, and a rotating magnet does not make a highly efficient motor.

An ac motor that will run on single phase is illustrated in Fig. 7-23. It is called a capacitor start motor. Instead of delivering two individual phases to the windings, one of the windings is connected in series with a capacitor. That capacitor shifts the

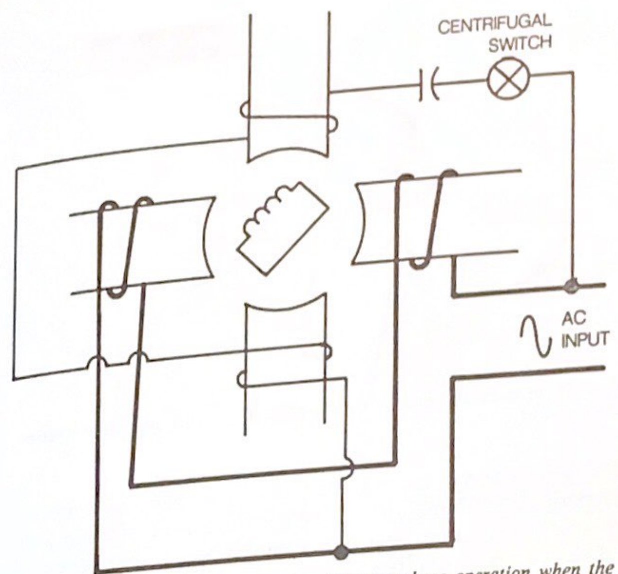

Fig. 7-23. The capacitor start motor provides two-phase operation when the motor is first started.

phase of the ac current in the capacitor start windings and accomplishes essentially the same thing as the two-phase motor.

In practice, the capacitor is only needed for starting the armature. Once it comes up to speed it is only necessary to use a single phase, synchronized so that it produces a thrust at exactly the right moment. For that reason, the capacitor start motor has a centrifugal switch. When the motor comes up to speed the switch is automatically opened and the capacitor and capacitor-start windings are removed from the circuit.

Another way of getting a rotating field is illustrated in Fig. 7-24. In this case, the field pole is split into two sections. A copper ring surrounds one of the pole pieces. Note that the pole is laminated. This is characteristic of ac field poles. It reduces the problem of eddy currents.

An ac current is induced in the single-turn coil of the shaded pole by the increasing and decreasing field of the larger

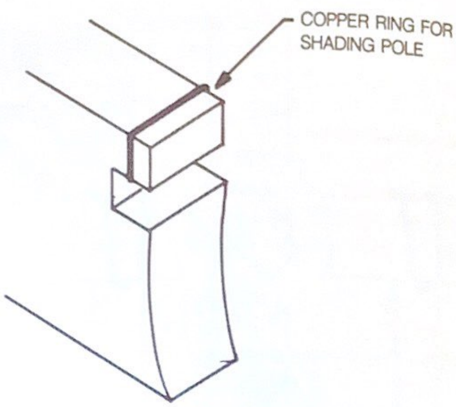

Fig. 7-24. In some ac motors, shading poles are used to produce a rotating magnetic field.

pole. The induced current is out of phase with the inducing magnetic field. Therefore, its magnetic field is out of phase with the field of the main pole. The overall result is that there is a sufficient amount of phase difference to produce rotation in the armature.

Three-Phase AC Motors and Generators. Instead of using a single pair of poles as shown in Fig. 7-21, it is possible to use three individual poles. Each pole is energized by one of the phases of three-phase power. So, there is a rotating magnetic field. Three phase ac is very popular in industrial systems. If a rotating magnet (or electromagnet) is rotated inside the three coils, a three-phase voltage is generated.

Figure 7-25 shows a basic three-phase generator and a basic three-phase motor. Permanent magnets are used in these designs, but electromagnets are used in larger units.

The Synchronous Motor. When a permanent magnet is used for the armature of a motor as in Fig. 7-26, it is not necessary to have a slippage. Therefore, the armature keeps pace with the rotating magnetic field. This arrangement is called a synchronous motor.

Synchronous motors are used in electric clocks and other systems where the ac power frequency determines the speed of rotation. Electric clocks often use a combination of a shading

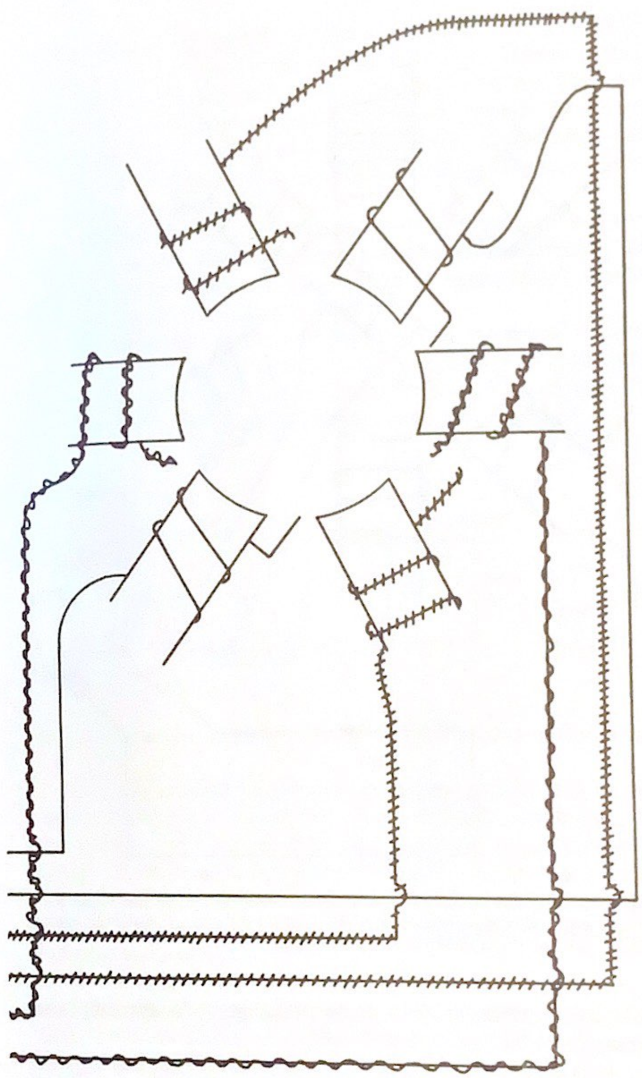

Fig. 7-25. Three-phase power is used in larger motors to produce the rotating magnetic field.

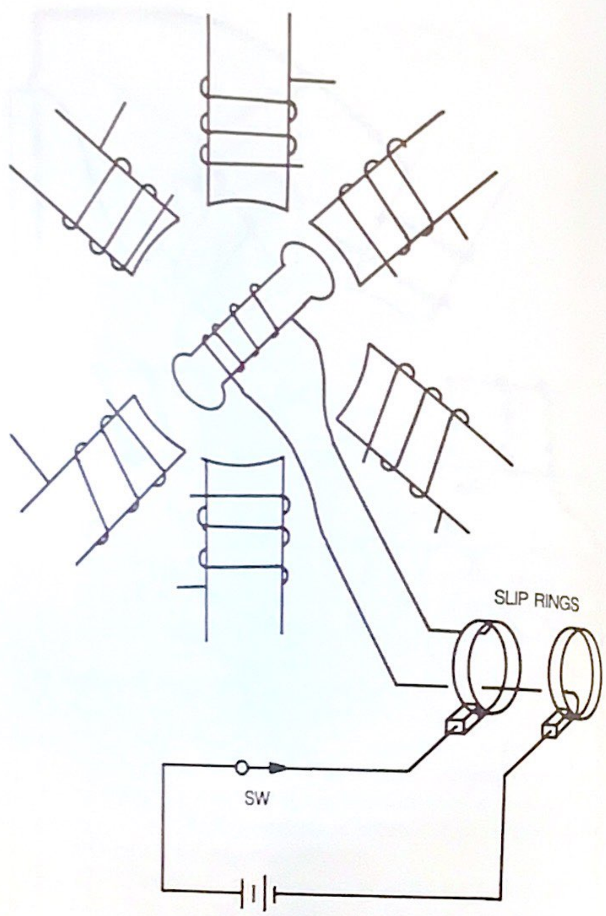

Fig. 7-26. This illustration of a synchronous motor shows that dc is supplied to the armature when the motor is up to full speed. Very often a smaller dc motor is used to get full speed in the large synchronous motor.

pole and a rotating permanent magnet in a specially constructed synchronous motor.

In a early days of electric clocks, there was no shading pole and the motor was brought up to speed with a manual thumb wheel. That produced a problem not characteristic of today's

clocks. The clock could be started backward or forward depending on how you moved the thumb wheel. If the clock did not have a sweep second hand you might not notice. You could be late for work if you started the clock improperly after the ac power was off as a result of a thunderstorm. The shading pole, then, provides the correct automatic starting direction for the electric clocks made today.

AC/DC Devices. Some types of devices will work on either ac or dc. They are usually made with laminated iron material for reducing eddy currents in ac applications. But the laminations do not interfere with dc.

Consider the actuator in Fig. 7-27. It has a coil wrapped around a hollow nonmagnetic material. Inside the nonmagnetic material there is a spring and a chamber for the plunger. The plunger is made of soft iron with a steel ring attached.

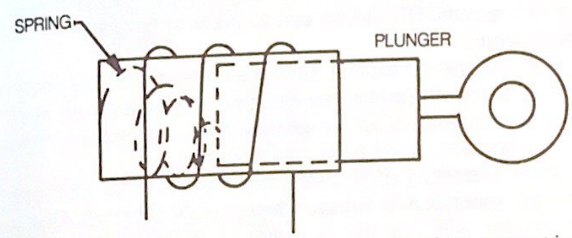

Fig. 7-27. An actuator can be made to operate on either dc or ac current input.

If dc is applied to the coil, a magnetic field will be produced. That magnetic field will attract the soft iron plunger and the plunger will move into the chamber, compressing the spring. If the ring is connected to some device that is to be moved, this action will complete the cycle of operation. When the current is interrupted, the spring will return the plunger and the ring to its zero position.

Now suppose the current is reversed in the coil. There will be a magnetic field again, and the actuator will go through the same cycle as described before, because the soft iron plunger will be attracted to a north magnetic pole or to a south magnetic pole. It does not make any difference.

Suppose now a low frequency ac current flows through the

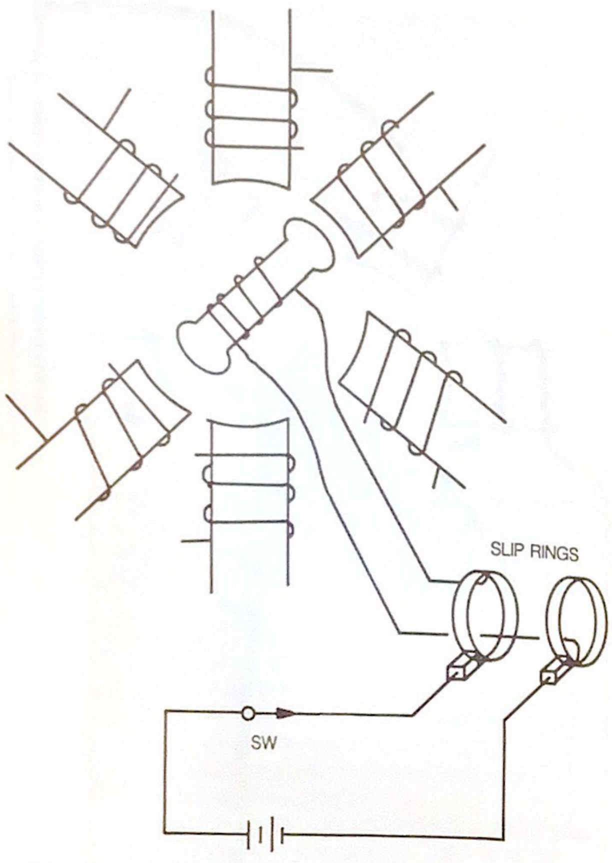

Fig. 7-26. This illustration of a synchronous motor shows that dc is supplied to the armature when the motor is up to full speed. Very often a smaller dc motor is used to get full speed in the large synchronous motor.

pole and a rotating permanent magnet in a specially constructed synchronous motor.

In a early days of electric clocks, there was no shading pole and the motor was brought up to speed with a manual thumb wheel. That produced a problem not characteristic of today's

clocks. The clock could be started backward or forward depending on how you moved the thumb wheel. If the clock did not have a sweep second hand you might not notice. You could be late for work if you started the clock improperly after the ac power was off as a result of a thunderstorm. The shading pole, then, provides the correct automatic starting direction for the electric clocks made today.

AC/DC Devices. Some types of devices will work on either ac or dc. They are usually made with laminated iron material for reducing eddy currents in ac applications. But the laminations do not interfere with dc.

Consider the actuator in Fig. 7-27. It has a coil wrapped around a hollow nonmagnetic material. Inside the nonmagnetic material there is a spring and a chamber for the plunger. The plunger is made of soft iron with a steel ring attached.

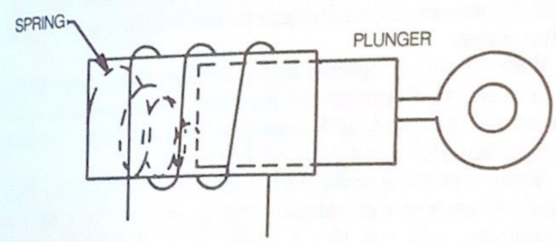

Fig. 7-27. An actuator can be made to operate on either dc or ac current input.

If dc is applied to the coil, a magnetic field will be produced. That magnetic field will attract the soft iron plunger and the plunger will move into the chamber, compressing the spring. If the ring is connected to some device that is to be moved, this action will complete the cycle of operation. When the current is interrupted, the spring will return the plunger and the ring to its zero position.

Now suppose the current is reversed in the coil. There will be a magnetic field again, and the actuator will go through the same cycle as described before, because the soft iron plunger will be attracted to a north magnetic pole or to a south magnetic pole. It does not make any difference.

Suppose now a low frequency ac current flows through the coil. On one half-cycle the plunger is pulled in by a north pole. On the next half-cycle it is pulled in by a south pole. The current reverses back and forth with the applied ac and both half-cycles attract the plunger. There are relays and reed switches that will operate on either ac or dc. Their operation is based on this same principle.

SUMMARY

Both ac and dc motors and generators are used in industrial systems. AC motors and generators are usually made with simpler construction. Also, ac power is readily available for ac motors. AC generators can be made without the need for carbon brushes. The speed and torque of ac motors is not as easily controlled as they are for dc motors.

DC motors can be made with specific characteristics. They are especially important in portable applications where batteries power the motors. DC motors can be made to have a very high startup torque.

Both ac and dc motors and generators operate on basic laws and effects. Examples are: Faraday's law, Lenz' law, electromagnetic induction, and magnetics. Also, Ampere's law and the right hand/left hand rules are important.

Some interesting applications make use of the fact that a dc motor will generate a dc voltage when its shaft is turned. Also, a dc generator will run like a motor if dc is applied to its terminals.

Using dc motors as generators, and dc generators as motors has an important limitation. The neutral axis is different for the two devices. For efficient operation, some means is necessary to shift that neutral axis or minimize its effect.

Interpoles are sometimes used to straighten out the flux lines in dc motors and generators. This reduces the problem of the neutral axis.

AC motors have laminated cores for their fields. This reduces the problem of eddy currents. Both ac and dc motors and generators produce a countervoltage that limits armature current, and in some cases, field currents.

When large dc motors are first started, there is no countervoltage. Therefore, some method is needed to limit current in the armature until the motor is up to speed. A manual starter —or its electronic equivalent—is needed for that purpose. Even though your interest is primarily in electronics, you should understand the operation of motors and generators.

SELF TEST

1. Which type of motor will self destruct if operated without a mechanical load?
   (A) synchronous.
   (B) series-wound dc.

2. Countervoltage is the result of:
   (A) Lenz' law.
   (B) the right-hand rule.

3. One method of minimizing the effects of the neutral plane is to use:
   (A) consequent poles.
   (B) interpoles.

4. Manual starters for dc motors provide:
   (A) maximum armature current during startup.
   (B) minimum armature current during startup.

5. An alternator, like those used in cars, has:
   (A) an ac output.
   (B) a rectified dc output.

6. When the field current of a dc generator is produced by the generator it is called a:
   (A) self-excited generator.
   (B) self-biased generator.

7. In a capacitor-start motor, the capacitor:
   (A) is used to provide two-phase starting power.
   (B) is switched into the circuit when the motor has reached full speed.

8. Which of the following is used as an armature in some types of ac motors?
   (A) buck winding.
   (B) squirrel cage.

9. Which type of motor must operate with slippage?
   (A) induction motor.
   (B) synchronous motor.
10. You can get a rotating field in an ac motor by using:
   (A) a capacitor start arrangement.
   (B) three-phase power delivered to three sets of windings.
   (C) Both choices are correct.
   (D) Neither choice is correct.

ANSWERS TO SELF TEST

1. (B)
2. (A)
3. (B)
4. (B)
5. (B)
6. (A)
7. (A)
8. (B)
9. (A)
10. (C)