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THREE-PHASE SYSTEMS

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Principles of Three-Phase Motors
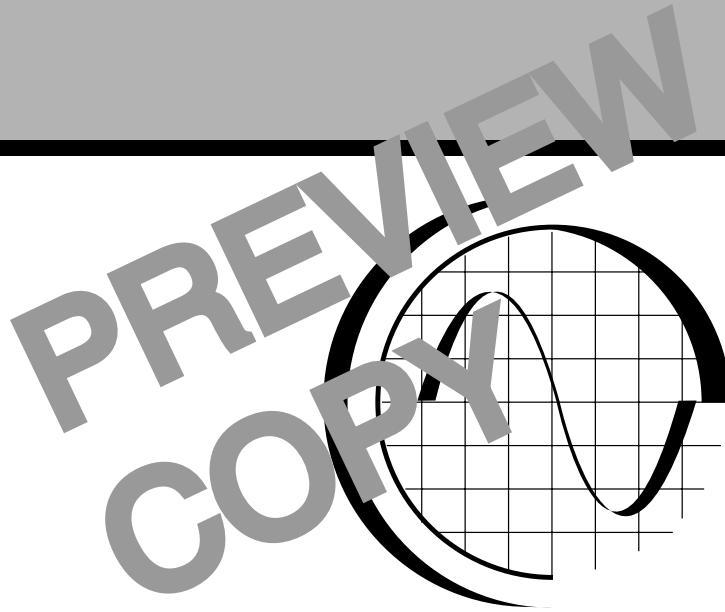
TPC Training Systems

20801

Lesson

1 *Principles of Three-Phase Motors*

TOPICS

Induction Motors
Squirrel-Cage Rotors
Rotating Field
Pole-Phase Relationships
Development of Torque
Rotor Speed and Slip

Rotor Frequency
Rotor Resistance and Reactance
Rotor Current and Potential Difference
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Variations in Torque

OBJECTIVES

After studying this lesson, you should be able to…

·   Describe a squirrel-cage rotor.
·   List the factors that determine the strength of the magnetic field in an induction motor.
·   Discuss pole-phase relationships.

·   Demonstrate how to reverse the rotation direction of the magnetic field.
·   Discuss the relationship between rotor speed and frequency.

KEY TECHNICAL TERMS

Stator   1.01   the stationary part of a motor
Rotor   1.01   the rotating part of a motor
Synchronous speed   1.35   the speed at which the magnetic field rotates in an induction motor

Slip speed   1.35   the difference between the synchronous speed and the speed of the rotor
Slip   1.35   the ratio of the slip speed to the synchronous speed, expressed in percent

Three-phase induction motors are simple in construction and versatile in the loads they can carry. For these reasons, induction motors are often used in the plant.

Many factors can affect induction motor performance. In order to troubleshoot and maintain these motors, you must have a complete understanding of their basic operating principles.

This lesson concentrates on the motor's rotor and the stator. It explains the creation of the rotating magnetic field, pole-phase relationships, and the development of torque. Other important areas include rotor resistance and reactance, rotor speed and frequency, and rotor current and potential difference.

Induction Motors

1.01   All induction motors, and all other kinds of motors, consist of a stationary part and a revolving part. The stationary part is called the *stator*, and the revolving part is called the *rotor*.

1.02   The induction motor gets its name from the fact that the rotor is not connected electrically to the source of power. The current in the rotor is not produced by connecting the conductors across a power supply. It is *induced* in the rotor by the magnetic field of the stator.

1.03   Induction motors are simple in construction. They can be built to carry any specified load. The stator consists of an aluminum or cast-iron frame with a laminated iron core. The stator windings are conducting coils fitted into slots in the core.

1.04   The coils are distributed around the stator and connected to form *pole-phase groups*. The pole-phase groups are joined in either a Y or a delta connection for three-phase induction motors, and in series for single-phase induction motors.

1.05   Two kinds of rotors are used. One is called the squirrel-cage rotor, shown in Fig. 1-1. The other is called the wound rotor, shown in Fig. 1-2. Both kinds of rotors have laminated iron cores with slots. The difference is in how the conductors are joined. The conductors in a squirrel-cage rotor are solid bars parallel to the shaft and connected to each other at each end by a shorting ring. A wound rotor has three coils of wire connected to each other by resistors.

Squirrel-Cage Rotors

1.06   The winding of the squirrel-cage rotor consists of copper or aluminum bars. The bars are either cast or pressed into slots. These bars are short-circuited at both ends of the rotor by connecting them to heavy copper or aluminum rings.

1.07   When copper is used for the winding of a squirrel-cage rotor, the bars are pushed into slots from the end of the rotor. The bars are connected to the end rings by bolts or rivets, and then brazed, silver-soldered, or welded together.

Fig. 1-1. Squirrel-cage rotor
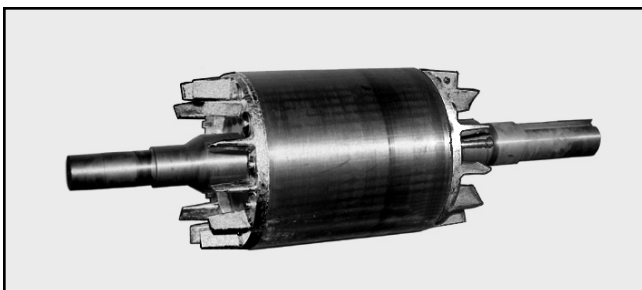
Fig. 1-2. Wound rotor
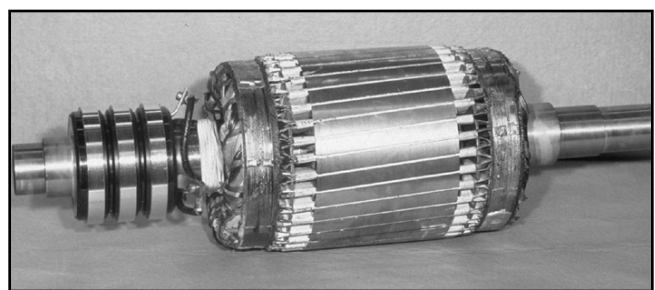
1.08   The bars are not always parallel to the shaft. Sometimes they are *skewed*—placed at an angle to the shaft. This arrangement gives more uniform starting torque, reduces noise when the motor is running, and prevents the rotor from aligning with the stator and locking in one position at starting.

1.09   Aluminum squirrel-cage windings are single die castings. After the punched laminations are stacked, molten aluminum is forced into molds fitted onto the rotor end plates. These molds may also form

the end rings and fan blades as a single unit with the rotor winding. The outer surface of the rotor is ground to a size that leaves a small air gap between the rotor and the stator.

Rotating Field

1.10   The induction motor depends on a rotating magnetic field to make the rotor turn. In a three-phase motor, this rotating field is created by the current in a single set of stator windings. No special starting

Fig. 1-3. Rotation of stator field in a three-phase two-pole motor
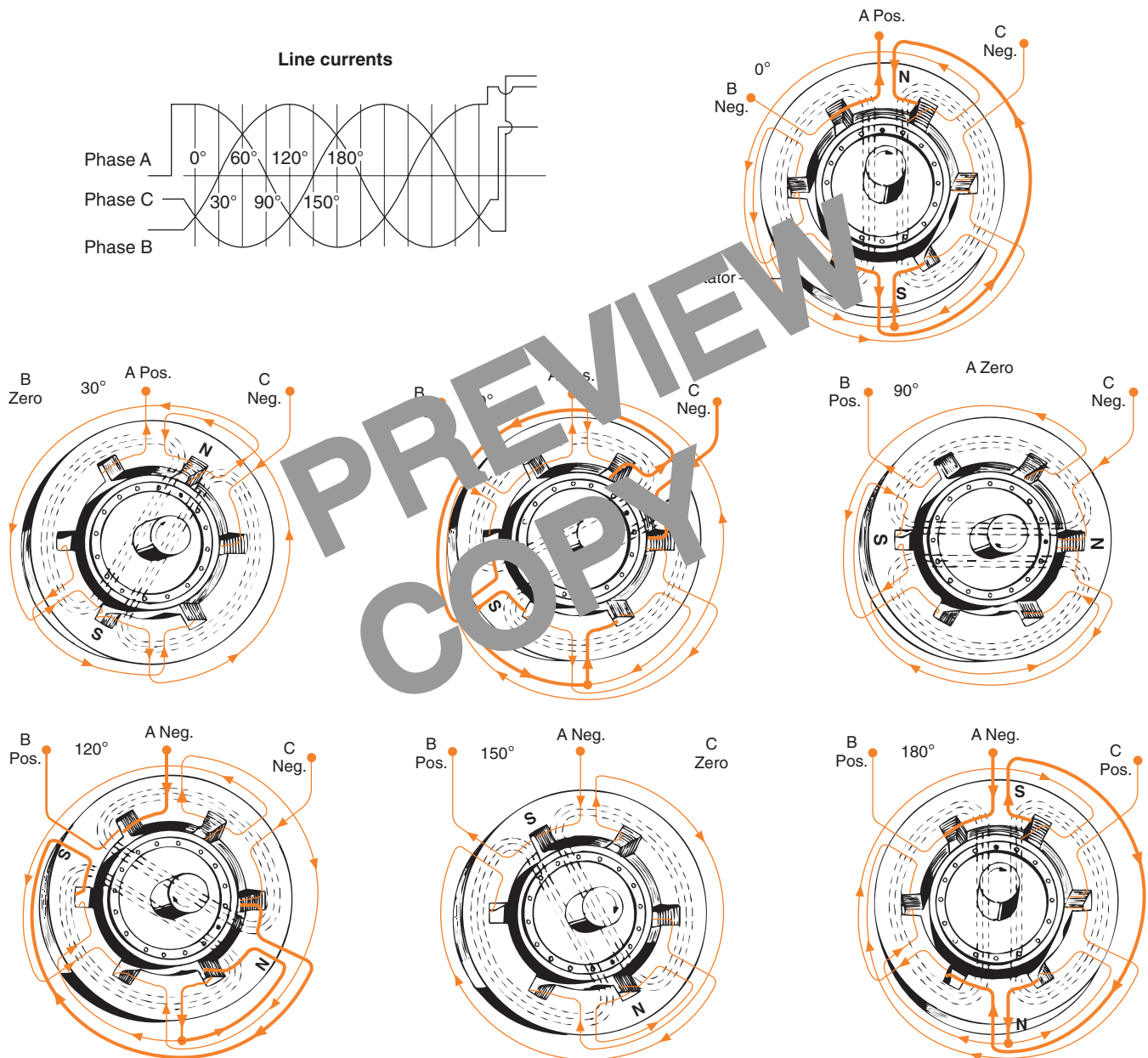
winding or switching mechanism is required for starting the motor.

1.11   The rotating magnetic field cuts across the conductors of the rotor and induces current in the conductors. The force exerted by the magnetic field on the charges moving in the rotor causes the rotor to turn.

1.12   The strength of the magnetic field depends on the amount of current in the conductors of the stator and on the shape of the iron core. The field has definite poles, determined by the direction of alternating stator current at any instant.

1.13   The magnetic field alternates according to a sine curve, because the stator current alternates according to a sine curve. It alternates at the line frequency, reaching a maximum first in one direction and then in the opposite direction.

1.14   As an example of how the magnetic field rotates in a three-phase motor, consider a two-pole motor that has six stator sections. Diagrams of the stator of this motor are shown in Fig. 1-3.

1.15   The stator has six coils, one for each section. The coils are placed in the slots of the stator, and the leads are connected to each other and to a three-phase supply. The current varies in each coil as the current varies in each phase of the supply.

1.16   The result is a magnetic field of uniform strength that rotates 360 *electrical* degrees during each cycle of the supply. The field in this motor also rotates 360 *mechanical* degrees during each ac cycle, because it has only two poles. If it had more poles, it would rotate only a fraction of 360 mechanical degrees during each ac cycle.

1.17   The dashed lines in the diagrams in Fig. 1-3 show the magnetic field in the stator every 30° of the ac cycle. The whole sequence of seven diagrams covers the time from the beginning of one half-cycle of the ac power supply to the beginning of the next half-cycle.

1.18   The coils are connected in such a way that their combined magnetic field always has only two poles. As the current varies in the coils, the north and south poles of the field rotate in a clockwise direction.

1.19   As the magnetic field rotates clockwise about the stator, it cuts across the bars in the squirrel-cage rotor. The magnetic field passes through the air gap at right angles to the surface of the rotor.

1.20   As long as the rotor remains stationary, the motor acts like a transformer with a short-circuited secondary winding. The rotor bars are like the secondary winding of a transformer, and the stator coils are like the primary winding.

1.21   The stator currents are identical in each phase of a three-phase motor. They have the same magnitude, and they all lag their potential differences by the same angle. The potential differences are 120 electrical degrees apart, so the currents are also 120 electrical degrees apart. The sine curves representing the three currents are included in Fig. 1-3.

1.22   To reverse the rotation direction of the magnetic field, just reverse any two leads of a three-phase motor. Reversing any pair of leads—A and B, B and C, or C and A—has the same result. The sequence of peak currents changes from A-B-C-A-B-C-A-... to C-B-A-C-B-A-C-.... The reversal of sequence changes the rotation of the magnetic field from clockwise (CW) to counterclockwise (CCW).

Pole-Phase Relationships

1.23   An eight-pole motor requires four cycles of the ac supply to produce one mechanical revolution of the magnetic field. One cycle is required for each pair of poles. This relationship between the number of poles and the number of cycles exists for single-phase motors as well as three-phase motors.

1.24   In a three-phase winding, each magnetic pole is formed by the combined effect of three coils, one in each phase. A four-pole, three-phase motor has 12 coils. The coils overlap one another because of the way they fit into the slots of the stator. All the coils that together form one pole make up a group called a *pole-phase group*.

1.25   The following mathematical equation enables you to calculate the synchronous speed at which the magnetic field rotates:

$$S = \frac{120f}{P}$$

where S = synchronous speed of the rotating field, in revolutions per minite

f = frequency of the power supply, in Hz

P = number of poles.

For example, a two-pole motor connected to a 60 Hz power supply produces a magnetic field that rotates at a synchronous speed of 3600 rpm.

1.26   In a two-pole motor the winding is so arranged as to form two poles—one north pole and one south pole. If the windings are arranged for four poles, the field has two north poles and two south poles. The poles in a four-pole motor are arranged as shown in Fig. 1-4.

1.27   Stator windings can be connected to form a field with two, four, six, or any other even number of poles. The poles always exist in pairs—a north pole and a south pole—regardless of how the stator windings are connected.

Development of Torque

1.28   Think of a rotor with four conductors placed inside a stator, as shown in Fig. 1-5. The stator is supplied by polyphase currents. The stator currents produce a four-pole alternating magnetic field. The field is indicated by the arrows in the air gap. This field rotates counterclockwise at the motor's synchronous speed.

1.29   At a certain instant, each of the rotor conductors lines up with a stator pole where the magnetic field strength is maximum. If the rotor is stationary,

the conductors have currents induced in them as the field sweeps by.

1.30   The rotor conductors are short-circuited at both ends. Therefore, charge can flow in the conductors. The direction in which the electrons move is indicated by the following symbols on the rotor conductors:

- An X on the rotor conductor represents the tail of an arrow pointing away from you, into the page.

- A dot represents the tip of an arrow pointing toward you, out of the page.

1.31   If you use the left-hand rule relating to the directions of electron flow, magnetic field, and force, you can see that the force on the rotor conductors is in the same direction as the rotation of the magnetic field. However, the rotor does not rotate as fast as the magnetic field. It rotates slower than the motor's synchronous speed.

1.32   The torque on the rotor depends on how fast the rotor drifts backward through the rotating magnetic field. Within limits, increasing the difference in speed between the rotor and the magnetic field increases the amount of torque.

1.33   The rotor runs at a speed at which the torque exerted on it by the field exactly equals the torque exerted on it by the load the motor is driving.

- If the load increases, the rotor slows down and therefore gets *more* torque from the magnetic field.

Fig. 1-4. Magnetic field in a four-pole motor
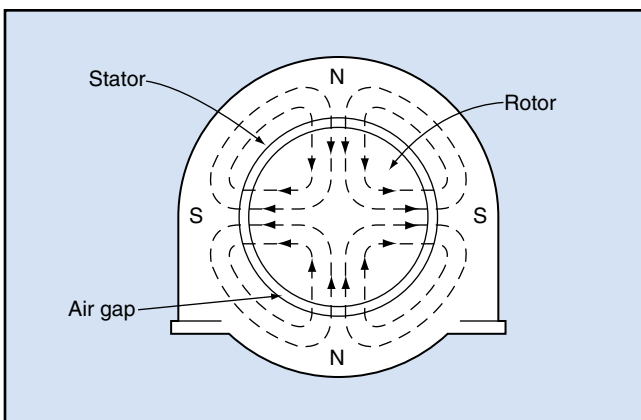
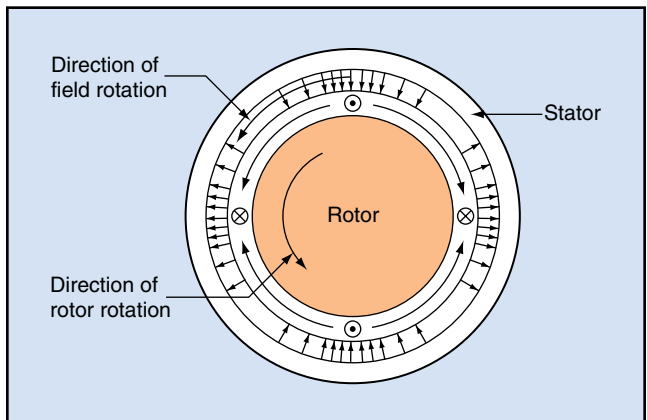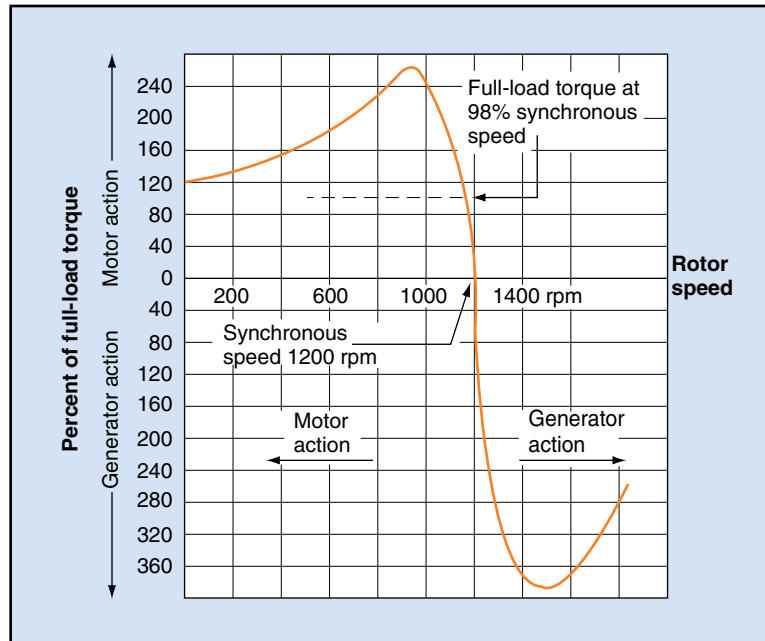**Fig. 1-5. Magnetic field strength around air gap**

Fig. 1-6. Torque in an induction motor

- If the load decreases, the rotor speeds up and therefore gets *less* torque from the magnetic field.

1.34   A typical induction-motor torque curve is shown in Fig. 1-6. Torque, measured as a percentage of the *full-load torque* (abbreviated FLT), is plotted against the motor's speed.

- The locked-rotor torque for the induction motor in this example is 120% of the full-load torque.

- As the rotor speed increases, the motor's torque rises, reaching 245% of FLT at about 900 rpm.

- The torque drops to 100% of FLT at 98% of synchronous speed (2% slip).

- At synchronous speed (1200 rpm), the motor develops zero torque.

If you drive the rotor above the synchronous speed, the motor acts as a generator and delivers power to the source.

The Programmed Exercises on the following page will tell you how well you understand the material you have just read. Before starting the exercises, remove the Reveal Key from the back of your book. Read the instructions printed on the Reveal Key. Follow these instructions as you work through the Programmed Exercises.

1-1. The stationary part of a motor is called the _____. The rotating part is called the _____.	1-1. STATOR; ROTOR Ref: 1.01
1-2. The difference between the squirrel-cage rotor and the wound rotor is in how the _____ are connected.	1-2. CONDUCTORS Ref: 1.05
1-3. The induction motor depends on a rotating _____ to make the rotor turn.	1-3. MAGNETIC FIELD Ref: 1.10
1-4. The strength of the magnetic field in an induction motor depends on the amount of _____ in the stator conductors, and on the shape of the _____.	1-4. CURRENT; IRON CORE Ref: 1.12
1-5. How many cycles of the ac supply are required to produce one mechanical revolution of the magnetic field in an eight-pole motor?	1-5. FOUR Ref: 1.23
1-6. Stator windings can be connected to form a field with any _____ number of poles.	1-6. EVEN Ref: 1.27
1-7. Is the force on the conductors in the same direction as the rotation of the magnetic field, or in the opposite direction?	1-7. SAME Ref: 1.31
1-8. The rotor runs at a speed at which the torque from the _____ exactly equals the torque from the _____.	1-8. MAGNETIC FIELD; LOAD Ref: 1.33

Rotor Speed and Slip

1.35   The speed at which the magnetic field rotates is called the *synchronous speed* of the motor. The difference between the speed of the magnetic field and the speed of the motor's rotor is called the *slip speed*. A common way of expressing this difference is to express the slip speed as a percentage of the synchronous speed. This percentage then is called simply the *slip* of the motor.

$$\text{Slip} = \frac{\text{slip speed}}{\text{synchronous speed}}$$

$$= \frac{\text{synchronous speed} \pm \text{rotor speed}}{\text{synchronous speed}}$$

1.36   For example, suppose the rotor of a four-pole, 60 Hz motor runs at 1725 rpm. The motor's synchronous speed is 1800 rpm. What is the slip of the motor? The answer to this question is arrived at as shown below:

$$\text{Slip} = \frac{1800 \pm 1725}{1800}$$

$$= \frac{75}{1800}$$

$$= 0.04167$$

$$= 4.2\%.$$

Rotor Frequency

1.37   The rotating magnetic field of the stator induces an alternating current in the conductors of the rotor. If the rotor is stationary, the frequency of the current is the same as the frequency of the power supply. If the rotor turns in the same direction as the field, each conductor is cut less frequently by the rotating magnetic field.

1.38   The frequency of the alternating current in the rotor decreases as the rotor rotates nearer the synchronous speed of the motor. One cycle of rotor current occurs in the time it takes for one pair of stator poles to pass a given rotor conductor. The rate at which the stator poles pass any such conductor

equals the frequency of the power supply multiplied by the slip of the motor, as shown by the following equation:

$$f_R = f_P \times \text{slip}$$

f_R = frequency of the current induced in the rotor

f_P = frequency of the power supply to the stator.

In solving the equation, you must convert the slip from a percent to a decimal fraction.

1.39   For example, suppose a six-pole motor is running on a 50 Hz power supply with a 5% slip. What is the frequency of the current induced in the rotor?

$$f_R = f_P \times \text{slip}$$

$$= 50 \text{ Hz} \times 0.05$$

$$= 2.5 \text{ Hz}$$

1.40   The amount of current induced in the rotor is also proportional to the slip, if the stator field strength remains constant. The induced current is proportional to the rate of cutting, which depends on the speed at which the field passes the conductors in the rotor.

1.41   The frequency and magnitude of the current induced in the rotor both diminish as the rotor speeds up. Both become zero if the rotor reaches synchronous speed.

1.42   Suppose the rotor of a six-pole 60 Hz motor runs at a speed of 1152 rpm. What is the frequency of the current induced in the rotor?

Synchronous speed

$$S = \frac{120f}{P}$$

$$= \frac{120 \times 60}{6}$$

$$= 120 \text{ rpm}$$

Slip

$$\text{Slip} = \frac{\text{synchronous speed} - \text{rotor speed}}{\text{synchronous speed}}$$

$$= \frac{1200 - 1152}{1200}$$

$$= \frac{48}{1200}$$

Rotor frequency

$$f_R = f_P \times \text{Slip}$$

$$= 60 \text{ Hz} \times 0.04$$

$$= 2.4 \text{ Hz}$$

Rotor Resistance and Reactance

1.43   The *resistance* of a rotor depends on the composition and size of the rotor conductors. The *inductive reactance (X_L)* depends on the rotor's inductance (*L*) and on the frequency of the rotor current. The inductance has a constant value, but the frequency varies with the speed of the rotor. The rotor has no significant amount of capacitance, so there is no capacitive reactance.

1.44   Rotor frequency depends upon slip. Therefore, rotor reactance varies directly with slip. On starting, the slip is 100% because the rotor is at a standstill. The rotor frequency then equals the stator frequency. At this instant, the inductive reactance of the rotor is at a maximum.

1.45   As the rotor comes up to speed, the slip decreases until the rotor reaches its running speed. At maximum no-load speed, the slip for a standard induction motor is less than 1%. Therefore, the rotor reactance at maximum no-load speed is less than 1% of the reactance at standstill.

1.46   If you know the standstill reactance, you can calculate the rotor reactance for any rotor speed. You simply multiply the standstill reactance by the slip, because the reactance is proportional to the rotor frequency, and the rotor frequency is proportional to the slip.

$$X_R = X_S \times \text{slip}$$

where X_R =   reactance of the rotor at any speed

   X_S =   reactance of the rotor at standstill

Rotor Current and Potential Difference

1.47   When a squirrel-cage induction motor is energized, it is, electrically, similar to a transformer with a short-circuited secondary winding. The stator is an iron core with coils connected in series to a three-phase power source. The rotor consists of a number of bar conductors in an iron core which are short-circuited by the end rings. The currents induced in the rotor bars depend on the rotating magnetic field produced by the stator currents.

1.48   At any given instant, the various rotor bars have different currents induced in them. This condition exists because the magnetic field varies around the stator. The field is stronger at each pole than it is between the poles. The current induced in a given conductor depends on the field strength. As a result, charge circulates among the rotor bars of a squirrel-cage rotor, and among the windings of a wound rotor.

1.49   The potential difference across each rotor bar varies according to the position of the bar compared to the poles of the stator field and according to the speed of the bar compared to the rotating field. Figure 1-7 shows the distribution of induced potential differences across the bars in the rotor of a four-pole motor.

- In the *perspective view,* the relative magnitudes of the potential differences in the conductors are indicated by the lengths of the heavy lines. The arrowheads indicate the directions of the potential differences.

- In the *end view,* the magnitudes and directions of the potential differences are indicated by the sizes of the dots (arrowheads, pointing upward out of the page) and X's (tails of arrows pointing downward into the page).

1.50   The magnitudes and directions of the currents in the rotor bars are shown by the arrows in Fig. 1-8.

Fig. 1-7. Induced potential differences
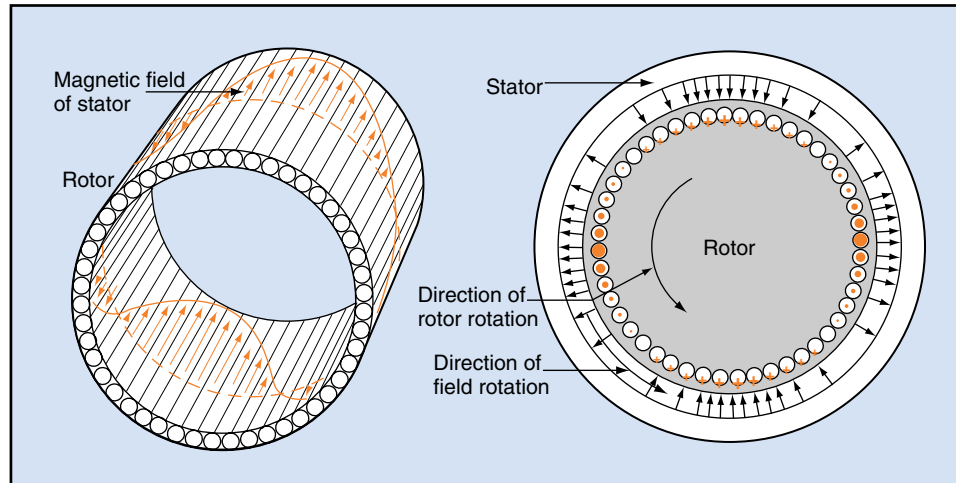
You can see both the lengths and the directions of black arrows in the perspective drawing. The end view shows dots and X's for directions. Notice that the current lags the potential difference.

1.51   The rotor current varies *directly* with the induced potential difference. But it varies *inversely* with the rotor impedance (the vector sum of the resistance and the reactance of the rotor).

1.52   As the motor speeds up and the rotor frequency decreases, the impedance decreases. If the potential difference were to remain constant, the current would increase. But the potential difference decreases as the rotor speed more nearly matches the synchronous speed. Therefore, the current decreases.

However, it does not decrease in proportion to the decrease in potential difference.

1.53   An example shows how the current in one rotor bar decreases as the rotor goes from a standstill to the maximum no-load speed. Suppose a rotor is at a standstill and one of the bars has the following characteristics:
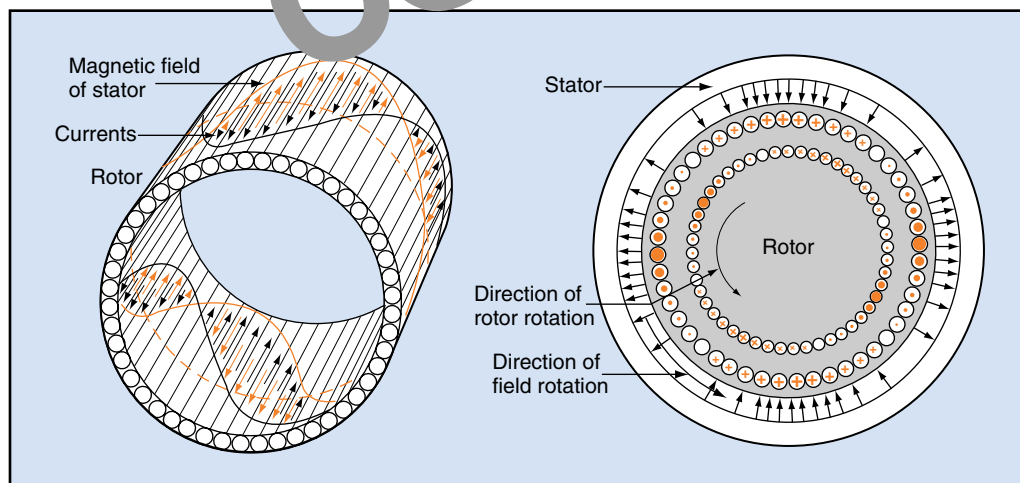
$$R = 2 \ \Omega$$

$$X = 8 \ \Omega$$

$$E = 10 \text{ V}.$$

Combining R and X, you can calculate the impedance of the bar:

Fig. 1-8. Induced current and potential difference

$$Z = \sqrt{R^2 + X^2}$$

$$= \sqrt{2^2 + 8^2}$$

$$= \sqrt{68}$$

$$= 8.25 \ \Omega.$$

Applying Ohm's law, you can calculate the current in the bar. The equation for the calculation is as follows:

$$I = \frac{E}{Z}$$

$$= \frac{10 \ V}{8.25 \ \Omega}$$

$$= 1.2 \ A.$$

1.54   When the rotor reaches no-load speed, both the inductive reactance and the potential difference are reduced to only 1% of their former values. The resistance remains unchanged:

$$R = 2 \ \Omega$$

$$X = 0.08 \ \Omega$$

$$E = 0.1 \ V.$$

Combining R and X vectorially, you can calculate the impedance of the bar:

$$Z = \sqrt{R^2 + X^2}$$

$$= \sqrt{2^2 + 0.08^2}$$

$$= \sqrt{4.0064}$$

$$= 2.0016 \ \Omega.$$

Using this value in Ohm's law, you can now calculate the current in the bar:

$$I = \frac{E}{Z}$$

$$= \frac{0.1 \ V}{2.0016 \ \Omega}$$

$$= 0.05 \ A.$$

1.55   Notice that although the potential difference and inductive reactance both decreased by 99%, the current did not remain constant. Instead, it decreased by only 96%. The reason is that the resistance remained constant.

Power Factor of Induction Motors

1.56   When considering the power factor of an induction motor, remember that the induction motor is electrically equivalent to a transformer with a short-circuited secondary winding. In a transformer, the power factor of the load connected to the secondary winding is the same power factor reflected back through the primary winding to the source. The rotor power factor of the induction motor is also reflected back to the source of supply through the stator windings.

1.57   The stator current has three components:

- a *magnetizing component* that produces the flux, which lags the potential difference by 90 electrical degrees

- an *iron-loss component* resulting from hysteresis and eddy-current losses, which is in phase with the potential difference

- a *load component* that is reflected back to the source with the same power factor as the rotor current.

1.58   At no load, the stator current is almost entirely a magnetizing current. The phase angle is nearly 90°, so the power factor is almost zero. When the motor starts, the rotor current is high but the power factor is low because of the high inductive reactance of the rotor. The rotor current reflected into the stator at this low power factor does not improve the already-low power factor of the stator.

1.59   As the motor comes up to its maximum no-load speed, the rotor current decreases to a very low value. The rotor power factor approaches one, because of the decrease in the inductive reactance of the armature. However, at maximum no-load speed, the stator power factor is not improved much by the high power factor in the rotor, because the rotor current is much smaller than the magnetizing current in the stator.

1.60   The power factor of the stator improves as load is added to the motor. The rotor current increases so the motor can carry the load. The slip also increases, which in turn increases the rotor frequency and the inductive reactance. But even at full load, the slip seldom exceeds 10%, and so the power factor of the rotor does not decrease greatly.

1.61   The high-load current at a high power factor is reflected to the stator, improving the motor's power factor. In general, the power factor of an induction motor increases with the load until the maximum power factor is reached at full load.

1.62   If you increase the load on the motor beyond the full-load point, the increase in slip has a greater effect on decreasing the power factor than on increasing the current.

Induction-Motor Torque

1.63   Torque is created by the force exerted by the magnetic field of the stator on the current in the rotor. The torque depends mainly on three factors:

*   the strength of the magnetic field

*   the current in the rotor conductors

*   the phase angle between the magnetic field and the rotor current.

1.64   Maximum torque is always developed when the phase angle is 45°. The power factor of the rotor is then the cosine of 45°, .707 or 70.7%. This condition occurs whenever the reactance and the resistance of the rotor are equal.

1.65   The effects of the current and the power factor are opposite, but they vary differently with the rotor speed. The result is that torque increases as the motor speeds up, and then decreases to zero when the motor reaches synchronous speed. Figure 1-9 is a graph showing the variation in the torque and the stator current as the motor speeds up. Notice that the horizontal axis indicates the slip rather than the actual speed of the rotor:

*   When the motor starts, the slip is 100% (at the left on the graph).

Fig. 1-9. Current and torque variation
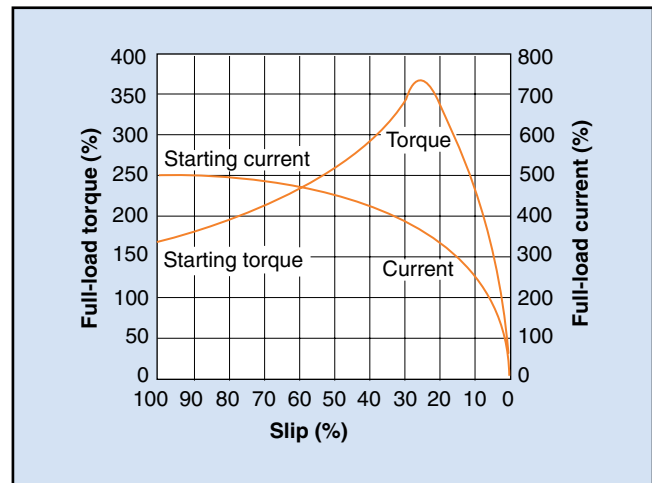
*   When the motor runs at the synchronous speed, the slip is zero (at the right on the graph).

1.66   As the slip decreases, the rotor current decreases and the rotor reactance increases. The combined effect of rotor current and power factor produces the greatest torque at the point where the rotor's reactance equals its resistance.

Variations in Torque

1.67   If you double the potential difference applied across the stator coils of an induction motor, the stator current and the strength of the magnetic field both double. The greater field strength doubles the current in the rotor.

1.68   The combined effect of doubling the field strength and doubling the rotor current is to multiply

Fig. 1-10. Reconnecting pole-phase coils

Series-Y connection   **Parallel-Y connection**
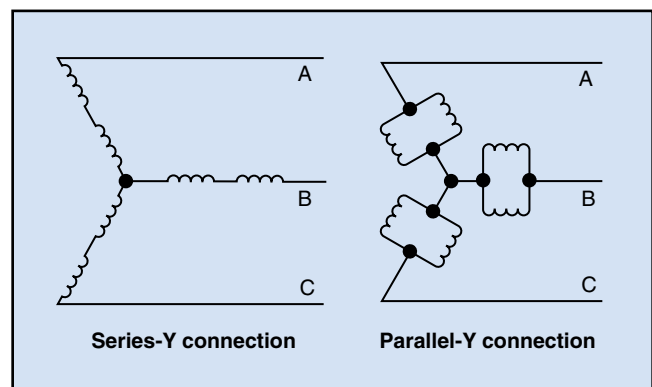
the torque by four. In other words, the torque varies as the square of the potential difference applied across the stator coils.

1.69   The torque can also be increased by reconnecting the motor windings. For example, a motor with stator windings connected in a series-Y can be reconnected in a parallel-Y, as shown by the diagrams in Fig. 1-10, on the previous page.

1.70   Reconnecting the coils in parallel doubles the current in the stator, just as when the potential difference is doubled. This rewiring can be done only when the motor and windings are designed for it.

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1-9. The speed at which the _____ rotates is called the synchronous speed of the motor.	1-9. MAGNETIC FIELD Ref: 1.35
1-10. Slip speed is the difference between the speed of the _____ and the speed of the _____.	1-10. FIELD; ROTOR Ref: 1.35
1-11. The rotating magnetic field of the stator induces a(n) _____ current in the conductors of the rotor.	1-11. ALTERNATING Ref: 1.37
1-12. The frequency and magnitude of the current induced in the rotor both become _____ if the rotor reaches synchronous speed.	1-12. ZERO Ref: 1.41
1-13. The inductive reactance of a rotor depends on the rotor's _____ and on the frequency of the rotor _____.	1-13. INDUCTANCE; CURRENT Ref: 1.43
1-14. What are three components of the stator current?	1-14. MAGNETIZING, IRON LOSS, LOAD Ref: 1.57
1-15. Maximum torque in an induction motor is developed when the phase angle between the magnetic field and the rotor current is _____°.	1-15. 45 Ref: 1.64
1-16. The coils should be reconnected in parallel only when the motor and _____ are designed for it.	1-16. WINDINGS Ref: 1.70

Answer the following questions by marking an "X" in the box next to the best answer.

1-1. The difference between the squirrel-cage rotor and the wound rotor is in

☐ a. how current is induced in the conductors
☐ b. how the conductors are connected
☐ c. their pole-phase groups
☐ d. all of the above

1-2. What makes the rotor turn in an induction motor?

☐ a. The flywheel
☐ b. The rotating magnetic field
☐ c. The starting winding
☐ d. The switching mechanism

1-3. If the potential differences in a three-phase motor are 120 electrical degrees apart, how far apart are the currents?

☐ a.   90 electrical degrees
☐ b. 120 electrical degrees
☐ c. 240 electrical degrees
☐ d. Depends on the phase angle

1-4. If three ac cycles are required to produce one mechanical revolution of the field, how many poles does the motor have?

☐ a. Two
☐ b. Three
☐ c. Four
☐ d. Six

1-5. The difference between the speed of the magnetic field and the speed of the rotor is called the

☐ a. slip
☐ b. slip speed
☐ c. synchronous speed
☐ d. none of the above

1-6. The rotor of a motor runs at 1710 rpm, and the synchronous speed is 1800 rpm. What, approximately, is the motor's slip?

☐ a.   5%
☐ b.   95%
☐ c. 105%
☐ d.   90 rpm

1-7. What happens to the frequency and magnitude of the current induced in the rotor when the rotor reaches synchronous speed?

☐ a. Both become zero
☐ b. Both increase
☐ c. Both remain unchanged
☐ d. One increases, and the other decreases

1-8. The rotor frequency depends on the

☐ a. amount of slip
☐ b. inductive reactance
☐ c. rotor conductors
☐ d. rotor inductance

1-9. If you increase the load on a motor beyond its full-load point, the greatest effect of the increase in slip is in

☐ a. decreasing the current
☐ b. decreasing the power factor
☐ c. increasing the current
☐ d. increasing the power factor

1-10. All the factors listed below have a part in determining the amount of torque developed by a motor, *except* the

☐ a. current in the rotor conductors
☐ b. phase angle between the field and the current
☐ c. strength of the magnetic field
☐ d. way current is induced in the rotor

SUMMARY

The three-phase induction motor is different from other motors in that its rotor is not connected electrically to the source of power. Either squirrel-cage rotors or wound rotors are used in induction motors. The current in the rotor is induced by the magnetic field of the stator. The strength of the induced magnetic field depends on the amount of the current in the conductors of the stator and on the shape of the iron core.

The force on the rotor conductors is in the same direction as the rotation of the magnetic field. The rotor runs at a speed at which the torque exerted on it by the field exactly equals the torque exerted on it by the load the motor is driving. To reverse the rotation direction of the magnetic field, you must reverse any two leads of a three-phase motor.

The speed at which the field rotates is called the motor's synchronous speed. The difference between the synchronous speed and the speed of the rotor is called the slip speed.

Both the current and the potential difference in an induction motor decrease as the rotor speed begins to match the synchronous speed. However, the current and the potential difference do not decrease in proportion to each other.

Answers to Self-Check Quiz

1-1.   b.   How the conductors are connected. Ref: 1.05

1-2.   b.   The rotating magnetic field. Ref: 1.10

1-3.   b.   120 electrical degrees. Ref: 1.21

1-4.   d.   Six. Ref: 1.23

1-5.   b.   Slip speed. Ref: 1.35

1-6.   a.   5%. Ref: 1.36

1-7.   a.   Both become zero. Ref: 1.41

1-8.   a.   Amount of slip. Ref: 1.44

1-9.   b.   Decreasing the power factor. Ref: 1.62

1-10.   d.   Way current is induced in the rotor. Ref: 1.63

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