Electrical Tech Note — 313

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Single-Phase Induction Motor Types

Introduction: Applying single-phase current to the winding of a squirrel cage induction motor does not produce a rotating magnetic field. The magnetic poles of the field will simply flip-flop from end to end as the current progresses through an ac cycle. Because the squirrel cage of the rotor does not see field rotation, the rotor does not turn. Typical single-phase induction motors have an auxiliary winding through which the current passes at a different time than the current flowing through the main winding. The current flow through the winding is affected by the value of resistance and inductive reactance of the winding. The current is shifted in time with respect to the supply voltage as shown in Figure 313.1. If the auxiliary winding has a different value of resistance and inductive reactance than the main winding, then the current passing through the auxiliary winding will be shifted in time with respect to the current flowing through the main winding. The magnetic poles will appear at the auxiliary winding and main winding at different times, thus creating a rotating magnetic flied. For more about capacitance and inductance in an ac circuit please review Tech Note 221.

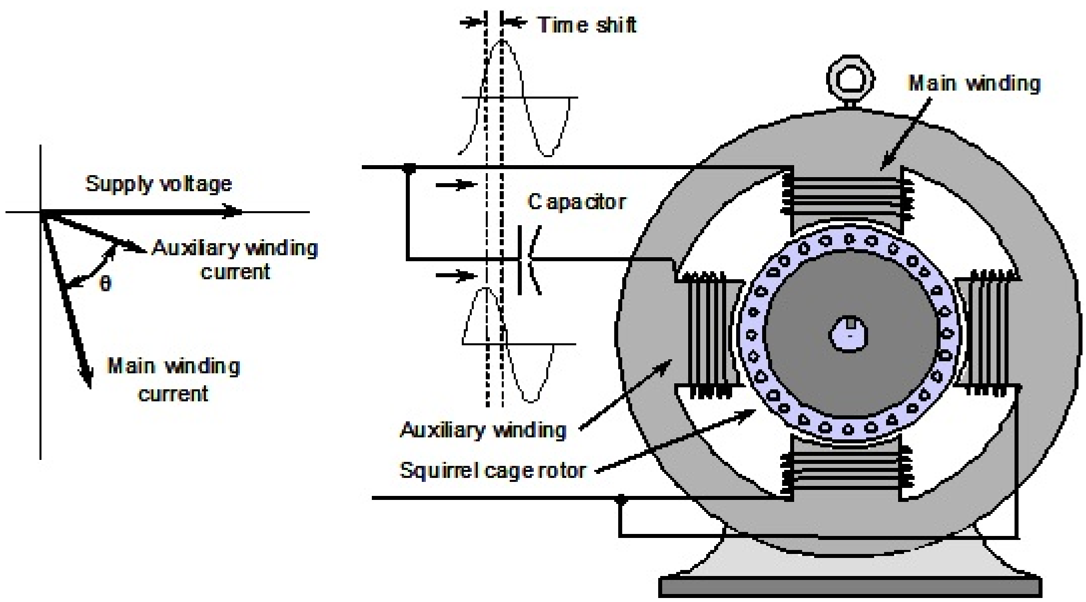

Figure 313.1 The capacitor in the auxiliary winding shifts the current ahead of the current in the running winding so there will be stator magnetic field rotation during starting.

Auxiliary Winding Rating: Once the rotor has obtained nearly full speed it will continue to rotate without having a rotating magnetic field. This means the auxiliary winding can be disconnected. A centrifugal switch attached to the shaft is used to disconnect the auxiliary winding. When the auxiliary winding is intended to be disconnected, it is not required to be rated for continuous duty. This reduces cost. Single-phase electric motors are named for their method of starting. Locked rotor and pull-up torque are dependant upon the type of auxiliary winding. This must be considered when specifying a single-phase induction motor for an application. The following are the common types of single-phase induction motors.

Split-Phase Start Induction Motor: The split-phase start, induction motor has an auxiliary starting winding with higher resistance and lower inductive reactance than the main running winding. The current through the auxiliary winding, having less inductive reactance, will lead the current in the main running winding. This is illustrated in the phasor diagram of Figure 313.2. These phasors are vectors spinning counter-clockwise. The current through the auxiliary winding and the running winding are shifted in time from each other and the magnetic poles appear at the windings at different times. Split-phase motors are inexpensive to build. This method of starting results in relatively low starting torque. Split-phase motors are suited only for fairly easy starting loads. The auxiliary winding is not rated for continuous operation. If the motor is used on an application where it must start frequently, the auxiliary winding may overheat and fail. A centrifugal switch on the shaft disconnects the auxiliary winding when it reaches approximately 80% of full speed. Figure 313.2 also shows a schematic diagram of the windings of a single-voltage split-phase start, induction run single-phase motor. The direction of rotation of motor shaft for this type of motor is accomplished by reversing the auxiliary winding leads with respect to the running winding leads. Rotor direction is reversed by connecting T1 and T8 to one supply wire and T2 and T5 to the other supply wire.

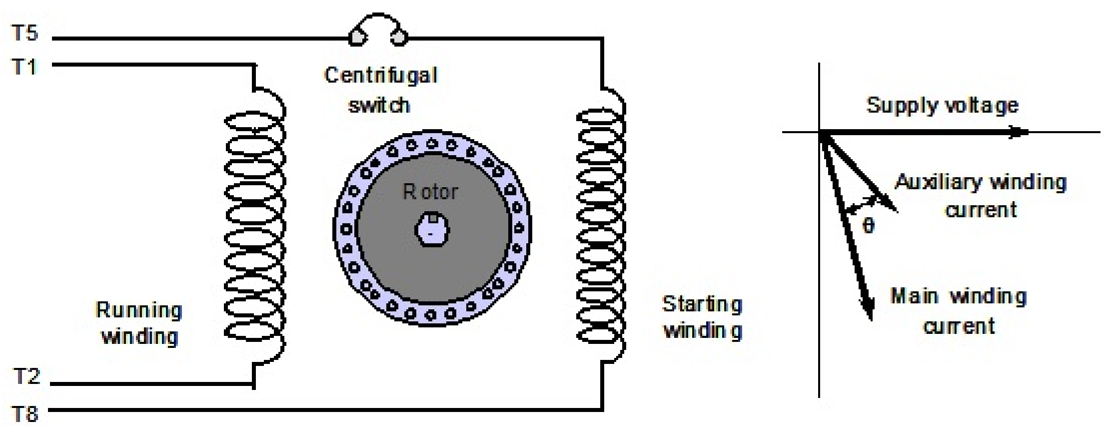

Figure 313.2 Less inductive reactance and more resistance in the auxiliary winding of a split-phase motor causes the auxiliary winding current to be shifted in time ahead of the running winding current to achieve magnetic field rotation during starting.

Capacitor-Start Induction-Run Motor: A schematic diagram of a capacitor-start, induction run motor is shown in Figure 313.3. A high value capacitor installed in series with the auxiliary winding shifts the auxiliary winding current ahead of the running winding current to achieve magnetic field rotation during starting. The current phase shift between the auxiliary winding and the main running winding is greater for a capacitor-start motor than for a split-phase motor. A capacitor-start motor has moderate starting torque, higher than a split-phase motor, and is suited for many applications. Generally the capacitor can be seen inside a small cylindrical enclosure on the side of the motor. Sometimes the capacitor is installed inside the motor and is not obvious. These capacitors are of the dry electrolytic type and are not rated for continuous duty. If the motor is started frequently, the capacitor will overheat and fail. A centrifugal switch disconnects the auxiliary winding and capacitor when the motor reaches approximately 80% of full speed. The direction of rotation of motor shaft for this type of motor is accomplished by reversing the auxiliary winding leads with respect to the running winding leads.

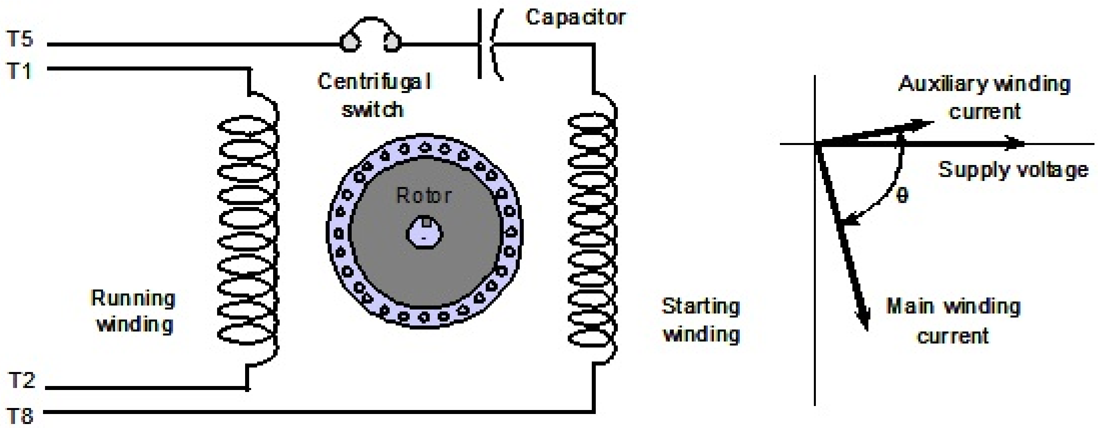

Figure 313.3 The capacitor in the auxiliary winding of a capacitor-start motor shifts the current in the auxiliary winding ahead of the current in the running winding to achieve magnetic field rotation during starting.

Permanent-Split-Capacitor Induction-Run Motor: The permanent-split-capacitor induction motor is similar to the capacitor-start induction-run motor except the capacitor is of the oil filled continuos duty type and stays energized as long as the motor is running. The value of capacitance is much lower than for a capacitor-start motor. This motor can be started much more frequently than a capacitor-start motor. Because the value of capacitance is quite small, the current through the auxiliary winding is only shifted a small amount with respect to the current through the main winding. This is illustrated in the phasor diagram in Figure 313.4. The starting torque for these motors is small. This type of motor is well suited for loads such as fans where the starting torque requirement is small. There is no centrifugal switch for this type of motor since the auxiliary winding is continuously energized. A schematic diagram of a permanent split capacitor induction motor is shown in Figure 313.4. The direction of rotation of motor shaft for this type of motor is accomplished by reversing the auxiliary winding leads with respect to the running winding leads.

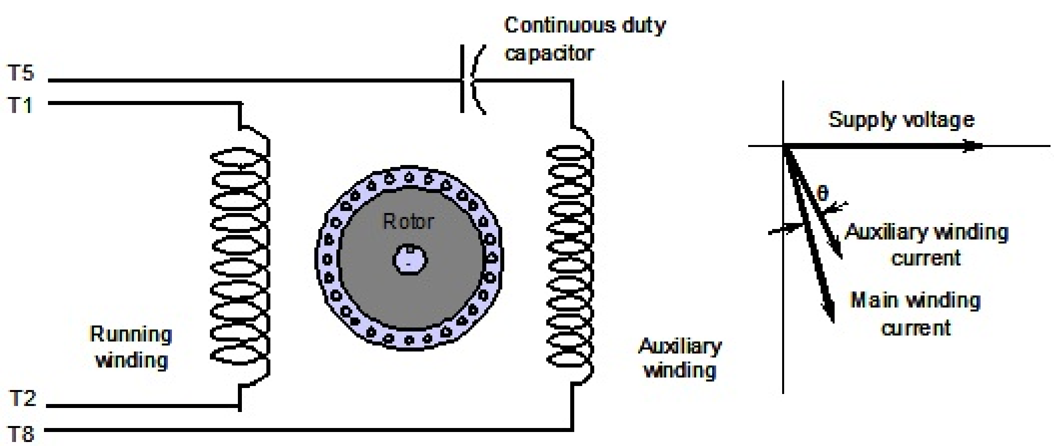

Figure 313.4 The permanent-split-capacitor induction motor has an auxiliary winding continuously energized. There is no centrifugal switch. Because capacitance is low, auxiliary winding current shift compared to the running winding current is small.

Repulsion-Start Induction-Run Motor: The repulsion-start induction motor does not depend upon a rotating magnetic field for starting. Windings are placed on the rotor and specific circuits are completed on the rotor to position the rotor magnetic field such that it will be repelled by the stator magnetic field. The rotor field is always placed in the optimum position using a contact device on the shaft called a commutator and brushes. There is a centrifugal switch attached to the rotor that shorts out the segments of the commutator and permits the windings on the rotor to operate similar to a squirrel cage. At full speed, the repulsion-start motor operates as an ordinary induction motor. This type of motor is capable of developing very high starting torque. There is no starting winding. These motors are expensive to build and are no longer manufactured. A schematic diagram of a repulsion-start induction-run motor is shown in Figure 313.5. There are many of these motors still is use, and therefore, it is important to recognize them and understand how they work. Reversing the direction of shaft rotation is accomplished by changing the rotor circuit so the rotor will be repelled by the field in the opposite direction. The rotor direction is reversed by moving the brush bracket to the alternate position.

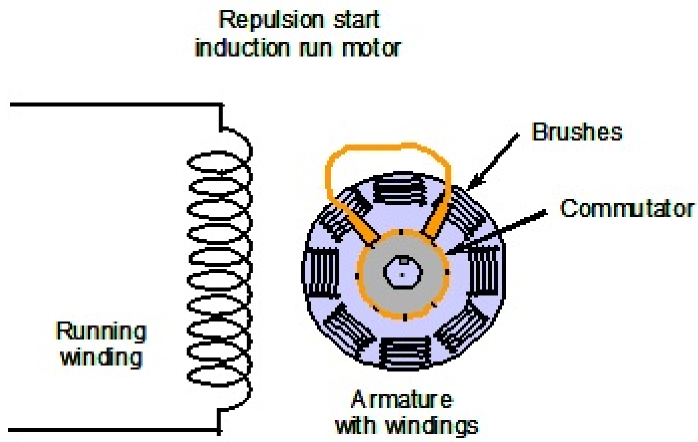

Figure 313.5 A repulsion start induction run motor has windings on the armature, and a commutator and brushes that specifically align the rotor magnetic field with that of the stator to achieve high starting torque.

Capacitor-Start, Capacitor-Run Induction Motor: The capacitor-start, capacitor-run induction motor uses a high capacitance in the auxiliary winding to achieve a time shift of current in the auxiliary winding with respect to the current in the main running winding. A phasor diagram of the auxiliary winding current and the main running winding currents during starting and running is shown in Figure 313.6. There are two separate capacitors in the auxiliary winding. During starting, an electrolytic starting capacitor is connected in parallel with a continuous duty oil filled capacitor. When the rotor achieves about 80% of full speed, a centrifugal switch disconnects the electrolytic capacitor, and the auxiliary winding remains energized and operates in series with the continuous duty capacitor. A schematic diagram of the capacitors and windings of this dual-value capacitor motor is shown in Figure 313.6. The dual-value capacitor motor is made for loads that require high starting torque. This type replaces the repulsion-start motor that is no longer manufactured. The direction of rotation of motor shaft for this type of motor is accomplished by reversing the starting winding leads with respect to the running winding leads.

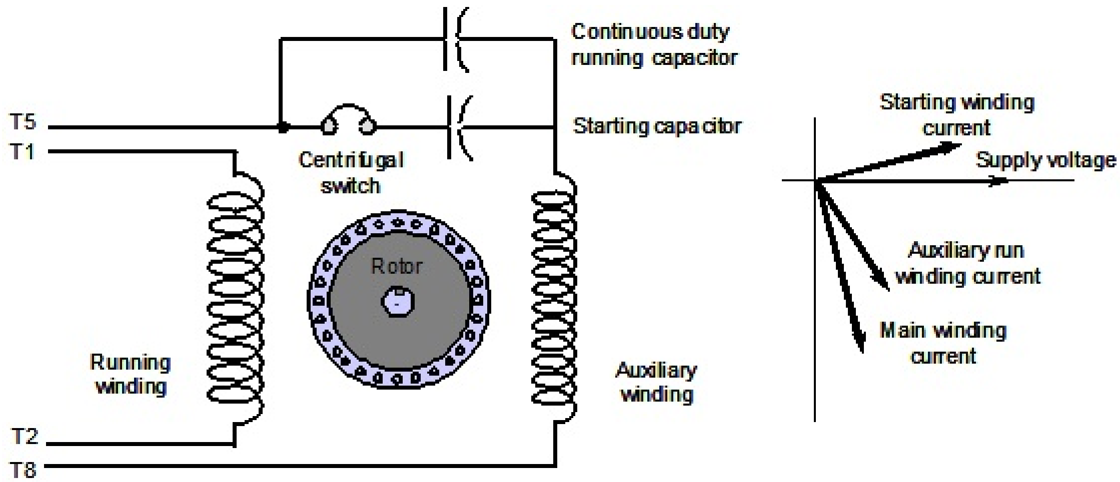

Figure 313.6 The dual-value capacitor motor provides high capacitance in the auxiliary winding for starting, and leaves the auxiliary winding energized during running with a low value of capacitance.

Shaded-Pole Motor: The shaded-pole induction motor is constructed with a winding on one leg of a rectangular laminated steel core with a section cut out of the other leg of the core for the squirrel cage rotor as shown in Figure 313.7. The impedance of the winding is generally high enough for it to be self protected from overcurrent even at locked-rotor. Adjacent to the rotor, a slot is cut in the magnetic core so that a loop of copper wire can be installed. When the magnetic flux through the core is either building up or collapsing, a current will be induced into the loop of wire installed in the core. This technique is called shading of the magnetic pole. Utilizing the principle of Lenz' law, the magnetic field created by the current in the pole shading coil opposes the magnetic field in the magnetic core.

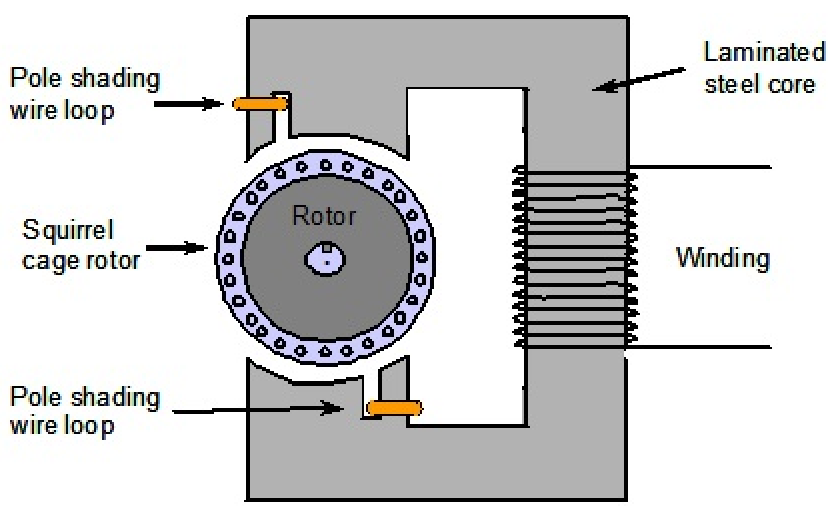

Figure 313.7 The shaded pole motor has one winding in one leg of a rectangular magnetic core with a loop of wire installed in notches cut into the core adjacent to the squirrel cage rotor.

The build up of the magnetic flux in the magnetic core is resisted by the shading of the poles. The collapse of the magnetic flux in the magnetic core is impeded by the shading of the poles. The net result is that the shading of the poles causes the magnetic pole, North or South, to move slightly across the pole face during each half cycle of the alternating current sine wave. The North and South poles of the core rotate across the face of the core next to the squirrel cage rotor. The motor is inexpensive to manufacture. A shaded-pole motor has very low starting torque. If the rotor bearings get very dry, the additional friction can prevent the rotor from turning. Before replacing a shaded-pole motor that will not turn, lubricate the bearings and check for a broken wire in the main winding.

An enlarged view of the core of a shaded-pole motor is shown in Figure 313.8. There is a view of a half cycle of current above the three views of the core. As the current increases and the magnetic flux is building up in the core, a current is induced in the shading loop. The shading loop current produces a magnetic field that is opposite to the magnetic field building up in the core. The magnetic flux and magnetic pole are pushed to the side of the steel core away from the shading loop.

Once the current reaches a maximum at the top of the cycle, the magnetic flux in the core is no longer moving and the current in the shading loop stops. The magnetic flux becomes more evenly distributed across the core as shown in the center diagram of Figure 313.8. The magnetic pole is now located in the center of the core. The magnetic pole moved from the side of the core pole to the center of the core.

When the current begins to decrease towards zero for the sine wave half cycle, the magnetic flux in the core is now collapsing. The moving flux induces a current in the shading loop. The shading loop current creates a magnetic flux that resists the collapse and the core flux will decreases slower near the shading loop than elsewhere in the core. The magnetic pole then moved from the center of the core to the side of the core with the shading loop as shown in the right hand diagram of Figure 313.8. Through-out a half cycle, the magnetic pole move across the face of the pole creating rotation of the magnetic flux for the squirrel cage rotor to follow. The direction of shaft rotation is not possible to reverse unless slots are cut in the other side of the core poles, and the shading loops are physically moved.

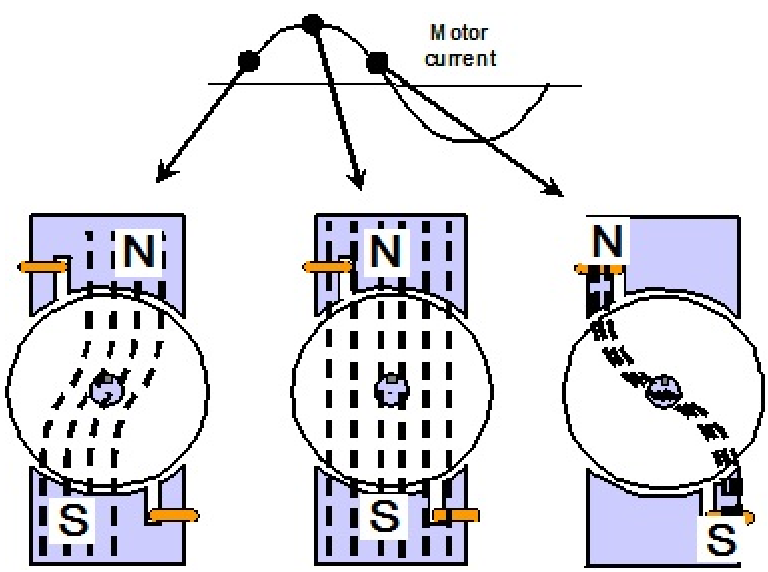

Figure 313.8 This enlarged view of the core of a shaded-pole motor next to the squirrel cage rotor shown the movement of the core magnetic flux as it is influenced by the current induced into the shading loop during a half cycle of the alternating current applied to the winding.

Motor Current: A single-phase motor is supplied power with two wires. In the case of a 3-phase motor there are three supply wires. A single-phase motor and a 3-phase motor of the same horsepower rating and operating at the same supply voltage will not draw the same current. In the case of the single-phase motor there are only two wires supplying the current while in the case of the 3-phase motor there are three wires. The current ratio between a single-phase motor supply current and a 3-phase motor supply current of the same voltage and horsepower rating is 1.73 to 1. If a single-phase, 230-volt, 10-horsepower motor draws approximately 50 amperes at full load, a 3-phase, 230-volt, 10-horsepower motor will draw only approximately 28 amperes at full load.

The power that is produced by an electric motor is proportional to the produce of the voltage and current. This is true with other electrical loads as well. The size of wire and the size of components in the circuit such as the motor controller must be rated to handle the current drawn by the motor. It is cost effective and energy efficient to minimize the current required to supply the motor. Many motors rated from a fraction of a horsepower up to several horsepower are dual voltage motors. This means they have two sets of main windings so they can be supplied at a lower voltage or a higher voltage. In the case of a single-phase dual voltage motor the typical operating voltages are 120 volts and 240 volts. A dual voltage capacitor-start induction-run motor is shown in Figure 313.9. Notice there are two sets of main windings and one starting winding. For more information on connecting and reversing single-phase dual-voltage motors refer to Tech Note 103. Since the horsepower rating of a motor is proportional to the produce of voltage and current, when the voltage of a motor is doubled, the current is reduced to half. In the case of a ½ horsepower single-phase motor, it draws a full-load current of 9.8 amperes at 120 volts and only half as much, 4.9 amperes, when operated at 240 volts.

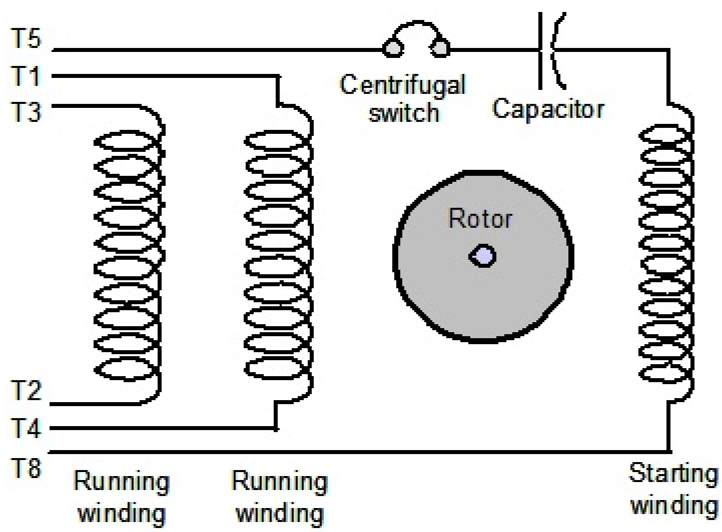

Figure 313.9 A dual-voltage single-phase electric motor has two main windings and a single auxiliary winding. When operated at the lower voltage (120 volts) all of the windings are connected in parallel, but when operated at the higher voltage (240 volts) the two main windings are connected in series with the auxiliary winding connected in parallel with one of the main windings.

Conclusions: An alternating current induction motor operates on the principle that a rotating magnetic field is created by the stationary windings in the frame or stator of the motor. This rotating magnetic field cuts across aluminum conductors build in the form a cylinder in the rotor and induces a current flow in these aluminum rotor conductors. The magnetic field created by current flow in the rotor follows the rotating magnetic field of the stator. With 3-phase power supplied to the three stator windings of a 3-phase motor a rotating magnetic field results. In the case of a single-phase motor a rotating magnetic field is not produced by the stator. In order to create magnetic field rotation in a single-phase motor, an auxiliary winding is added to the stator and the electrical properties of this auxiliary winding are altered to shift the auxiliary current sine wave out of phase with the main winding current sine wave. This action results in a rotating stator magnetic field for the rotor to follow. Once the rotor has nearly achieved full speed, this auxiliary winding is often disconnected with a centrifugal switch. Single-phase motor types are named for the method of starting the motor.

Starting torque varies widely depending upon the method used to start a single-phase motor. This is a very important factor to consider when selecting a single-phase motor for an application. The auxiliary winding and electrical components that are a part of the auxiliary winding may not be rated for continuous duty. This is important to minimize manufacturing cost. If a single-phase motor is required to start and stop frequently, there may not be sufficient cooling time between starts and the auxiliary winding may overheat. Starting winding failure is a common failure pont of single-phase motors. Single-phase motors powering heavy loads usually need a continuously rotating stator magnetic field when running. This can be accomplished by designing the auxiliary winding and components for continuous duty.

A 3-phase motor shaft rotation can easily be reduced by simply reversing any two supply leads to the motor. This will cause the stator magnetic filed to reverse direction of rotation. With a single-phase motor stator magnetic field rotation is created with the auxiliary winding. In the case of a single-phase motor it is necessary to reverse the leads of the auxiliary winding with respect to the leads of the main winding in order to reverse the direction of shaft rotation.