Electrical Tech Note — 312

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Induction Motors

Introduction: An electric motor is a device that converts electrical power to mechanical power. The most common type of electrical motor in use operates on the principle of electro-magnetic induction. There is a relationship between current flow and a magnetic field. Current flow causes a magnetic field to form around a conductor. The greater the current flow, the greater the strength or density of the magnetic flux produced. If a conductor and a magnetic field are moving with respect to each other, a current will flow in the conductor. This is called a magnetically induced current. This current flow is directly proportional to the rate at which the conductor is passing across a magnetic flux. The key factors are flux density and velocity at which the conductor is traveling at a right angle to the magnetic flux. The other magnetic principle involved in operation of an induction motor is the attraction and repulsion between magnetic poles. Like poles will repel (North repels North and South repels South), and opposite poles will attract (North and South attract). Refer to *Tech Note 217* for a thorough discussion of fundamentals of electro-magnetism.

How a rotating magnetic field induces current into a squirrel cage: For most applications, it is desirable to provide mechanical power in the form of a rotating shift. Electrical power is converted to a twisting force or torque. A magnetic flux will be present in the space between the
North and South poles of a magnet. In Figure 312.1 the magnet is mounted on an axis so it can rotate with an open space in the middle. If the magnet is rotated, the magnetic flux in the space in the center will also rotate. Any conductor suspended in the space will be exposed to a moving magnetic flux. By constructing a set of conductors in the form of a cylinder such as shown in Figure 312.1, the cylinder can be mounted to a shaft that will rotate. The cylinder consists of horizontal conductors connected together at each end by a circular collar. A circuit must be completed for current to flow, so if current flows in one of the horizontal conductors, it can complete the circuit by flowing in other horizontal conductors. The cylinder resembles a hamster exercise wheel or in years past it was called a squirrel cage. Induction motors to this day are still called squirrel cage motors.

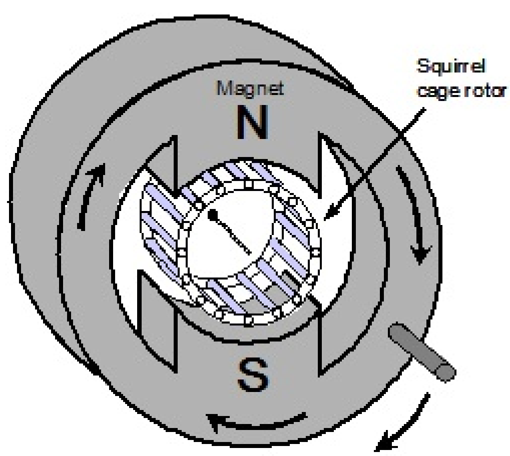

***Figure 312.1** The basic parts of an induction motor are a metal cylinder resembling a squirrel cage mounted on a shaft that will turn, and is surrounded by a magnet that can be made to rotate about the same axis.*

Refer to Figure 312.1 with the metallic squirrel cage mounted within a magnet that will rotate. By spinning the magnet, magnetic flux will cut across the horizontal conductors of the squirrel cage. This action results in a current flowing in the squirrel cage conductors. The moving magnetic flux induces a current to flow in the squirrel cage.

A magnetic flux can be made to rotate without any moving parts by placing three windings on a steel core each offset by an angel of 120° as shown in Figure 312.2. By energizing the windings with 3-phase power, a magnetic pole will appear at one winding, and one-third of a cycle later the pole will appear at the next pole, and then at the third pole. The magnetic poles will make one complete revolution of the device each cycle. If the windings are supplied with a 60 Hz 3-phase supply, the magnetic field will rotate around the device at 3600 rpm. The outer steel portion of the device that contains the windings is called the stator of the motor. If a squirrel cage is placed inside the stator and permitted to turn on a shaft, a current will flow in the squirrel cage the same as for the rotating magnet of Figure 312.1.

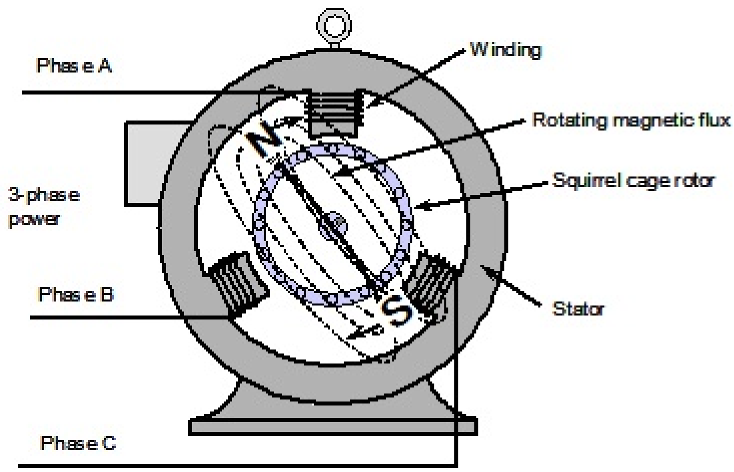

Figure 312.2 *A rotating magnetic flux can be achieved by placing three windings on a steel core (stator) and energizing the windings with 3-phase power.*

Current will be induced in opposite sides of the squirrel cage rotor as the magnetic flux rotates. Figure 312.3 shows the induced current flow in the squirrel cage. Use the right hand rule to determine the direction of current flow in the squirrel cage conductors. The thumb points in the direction the squirrel cage is moving with respect to the magnetic field. If the magnetic flux is rotating in a clockwise direction, the squirrel cage will appear to be rotating in a counter-clockwise direction with respect to the magnetic flux. Point the index finger of the right hand in the direction of magnetic flux from North to South. Point the thumb of the right hand in the direction the squirrel cage is moving with respect to the magnetic flux. Bend the second finger of the right hand at a right angel and it will point in the direction the induced current will flow in the squirrel cage conductor.

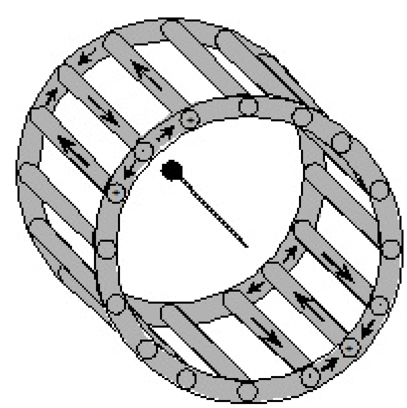

Figure 312.3 *Current will be induced to flow in the conductors of the squirrel cage as the magnetic flux rotates and cuts across the squirrel cage conductors. For this illustration, the rotating flux North pole is at the top and the South pole is at the bottom.*

Note in Figure 312.3 that the current at the top of the squirrel cage forms two loops and also two loops at the bottom. Another right hand rule states that if current flows in a loop, a magnetic field will be created by that current flow. To find the North and South pole created by the loop current flow, imagine grasping the loop with the right hand with the fingers pointing in the direction the current is flowing around the loop. The thumb of the right hand will point in the direction of the North pole created by the current flow.

Figure 312.4 is an end view of the squirrel cage surrounded by the stator and the rotating magnetic field. Note particularly the rotating magnetic pole and the magnetic poles created by the induced current flow in the squirrel cage rotor. The magnetic field of the squirrel cage rotor will follow the rotating magnetic field of the stator.

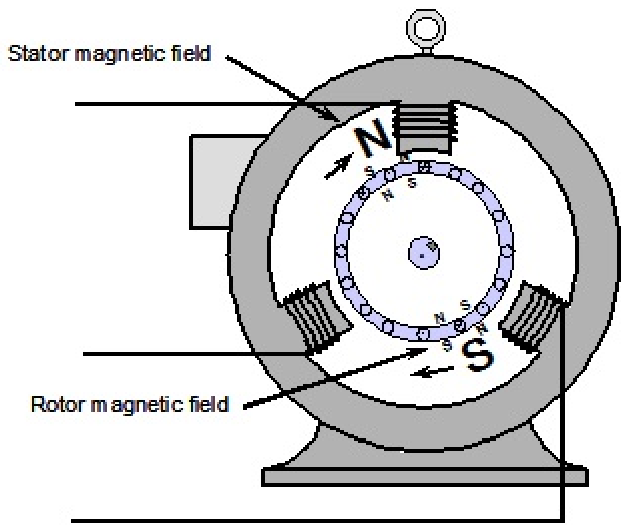

Figure 312.4 *This end view of an induction motor shows the magnetic poles created by the induced current flow in the squirrel cage rotor with respect to the rotating magnetic flux of the stator.*

The squirrel cage rotor will never catch up with the rotating magnetic field of the stator. If it does, the squirrel cage conductors will not cut through a magnetic flux and there will be no current to sustain rotation. The net result is that with an induction motor there is always rotor **slip**. The greater the load applied to the rotor shaft, the greater the torque needed to power the load. More rotor current is needed to get increased torque. More rotor current is obtained by the rotor slowing down (increased slip). Therefore, an ac induction motor is a nearly constant speed device, but the rotor will slow down as load is applied, and it will speed up as load decreases.

Stator Poles: The motor previously described is a 2-pole motor. Even through there are actually three windings on the stator, there are only two rotating magnetic poles, one North and one South. The rotating poles make one complete revolution every cycle which for a 60 Hz supply means the magnetic field is rotating at 3600 rpm. Twice as many poles can be installed in the stator so there are actually two sets of field magnetic poles which take two cycles of the supply power to make one complete revolution of the field poles. This is called a 4-pole motor and it has a field rotation of 1800 rpm. A 6-pole motor has a field rotation of 1200 rpm.

Reversing Motor Shaft Rotation: In the case of a 3-phase motor the stator field will rotate either clockwise or counter-clockwise depending upon the sequence of the electrical supply. All that needs to be done to reverse motor shaft rotation is to switch any two input 3-phase leads.

This will send the current to the motor stator windings in the opposite direction. The phase conductors in a building are given the labels **A**, **B**, and **C** depending upon how they are arranged in the electrical panels. There will be three phase wires arranged in the panel either horizontally or vertically. The left or top phase wire is labeled **A**, and the bottom or right phase wire is labeled **C**. The middle phase wire is labeled **B**. These phase wires should be labeled with color tape so they will not be accidentally interchanged if disconnected during servicing. It is recommended that throughout a building the same phase be placed in the same lug location in every panel to maintain consistent phase identification.

Inrush Current: A motor is somewhat unique in that it draws a very high current the moment power is applied and the rotor is not yet turning. The current during starting will generally range from 5 to 6 times the full-load current when the motor is running. This is illustrated in Figure 312.5. Motor circuit overcurrent protection must be capable of allowing short duration inrush current to pass while sensing overloads slightly higher than the full-load current.

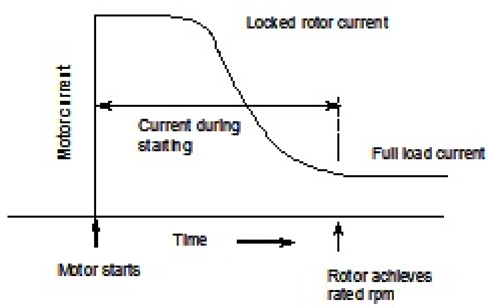

Figure 312.5 *Inrush current drawn by motors during starting is from 5 to 6 times the level of full-load current for the motor.*

The current flowing through the stator windings is limited by the resistance of the windings, the inductive reactance of the windings, and a reverse voltage induced into the windings by the magnetic flux of the rotor. The induced current in the squirrel cage of the rotor produces a strong magnetic field around the rotor. Once the rotor is spinning at high speed, the rotor magnetic flux will pass across the stator windings, as shown in Figure 312.6, and induce a reverse voltage in the stator windings. The reverse voltage induced into the stator windings by the spinning rotor becomes significant when the rotor reaches about 80% of full operating rpm. It is this reverse voltage caused by the spinning rotor that reduces the initial inrush current down to the full-load running level. If a motor is powering a hard starting load, the high inrush current may persist for several seconds. This causes significant heating of the conductors and components of the circuit.

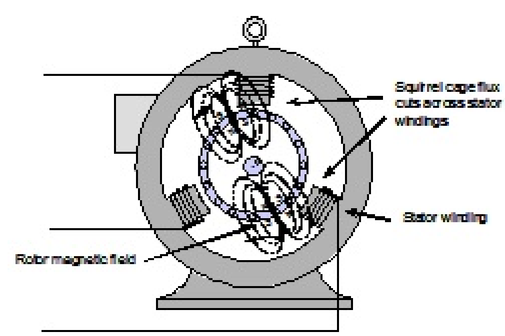

Figure 312.6 *The induced current in the squirrel cage of the rotor produces a rotor magnetic field that cuts across the stator windings as the rotor turns, and induces a reverse voltage into the stator windings that limits current drawn by the motor.*

Motor Winding Configurations: The windings in a 3-phase motor can be connected either in a delta configuration or in a wye configuration as illustrated in Figure 312.7. Generally they are connected in a wye configuration. High horsepower motors will be manufactured for only one voltage. The power is proportional to the voltage times the current. The motor windings must be capable of carrying the current. To keep the current as low as possible, high horsepower motors run at high voltages. Typical 3-phase motors operate at 480 volts. Motors in the range of several hundred horsepower generally operate at up to nearly 5000 volts.

Motors rated several horsepower and smaller are frequently manufactured to operate at two voltage levels. These are called dual voltage motors. There are two sets of windings for each phase as shown in Figure 312.7. When operated at the higher voltage, the windings are connected in series. When operated at the lower voltage, the windings are connected in parallel. A typical dual voltage 3-phase motor is rated for operation at 240 or 480 volts. Numbers on motor winding leads are an industry standard. The trade organization that maintains electrical equipment industry standards is the National Electrical Manufacturers Association (NEMA). Motor lead wires will be numbered by the manufacturer, and there will be a connection diagram provided to shown how the leads are to be connected for high voltage and for low voltage.

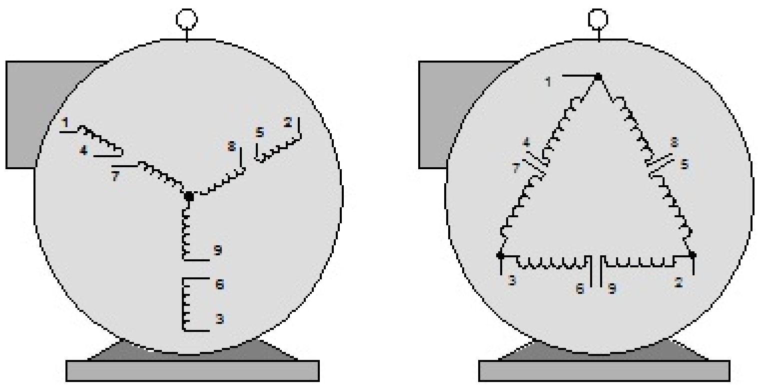

Figure 312.7 *A typical 3-phase motor has three windings connected either is a wye or a delta configuration with an industry standard numbering system for the winding leads.*

Conclusions: When 3-phase power is supplied to the stator windings of a 3-phase motor a magnetic field is created that rotates at a constant speed depending upon the number of windings in the motor and the frequency of the supply. Common field rotations are 3600 rpm for a 2-pole motor and 1800 rpm for a 4-pole motor. Inside the rotor is an aluminum structure that resembles an exercise wheel for a pet squirrel, thus the name squirrel cage motor. The rotating stator magnetic field induces a current to flow in the aluminum rotor squirrel cage. The induced current in the squirrel cage creates a magnetic field of it's own which interacts with the rotating magnetic field of the stator. Due to magnetic forces the rotor will follow the rotation of the stator magnetic field. The majority of electric motors are of this induction type. For many applications these 3-phase induction motors are operated from a variable frequency drive (VFD).