Pump ED 101

AC Motors Part 2 – Three Phase Operation

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Although there are a number of AC motor designs the induction motor is, by far, the most common and will be the topic of this column. We will also focus on the three phase design as it provides for a more intuitive understanding of induction and the magnetic fields that are produced. We will discuss the operation of single phase motors next month.

Components

The AC induction motor was invented by Nikola Tesla, the Serbian - American engineer who helped George Westinghouse win the war of the currents. Although his design has been enhanced over the years, simplicity is still its hallmark. The three phase motor consists of two basic parts – a stationary component known as a stator and a rotating component known as a rotor. The stator consists of coils of insulated wire wound about a laminated metal core that become electromagnets when power is applied. The rotor also has a laminated metal core with conductive aluminum bars set in slots. These bars produce an induced magnetic field that interacts with the ones in the stator. There is no contact between the rotor and stator and, unlike the DC motor there are no brushes or other commutative devices. Figure 1 shows the stator mounted inside the motor housing or enclosure and the rotor mounted on the motor shaft. The junction box on the top of the motor housing connects the incoming three phase power to the stator coils.

Induction

Just like the transformer, AC motors operate via the principle of induction. In our discussion of AC Power last fall, we learned that when voltage and current move through a coil of wire they give rise to a magnetic field. We also learned that the magnetic field produced can induce a voltage and current in a nearby coil and the result was a simple transformer. This phenomenon of inductance is not limited to just a nearby coil. It can occur in any metallic object. In the case of an AC motor the magnetic field that arises in the stator coils can induce a voltage and current in the conductive bars of the rotor. That voltage and current will give rise to its own magnetic field which then interacts with the field that produced it.

The speed at which the magnetic field moves (rotates) around the stator is known as the synchronous speed and depends upon the AC frequency and the number of poles in the stator. It is calculated by ($Ns = 120f / P$) where Ns is the synchronous speed, f is frequency and P is the number of poles in the stator. For a two pole motor operating at 60 Hertz the synchronous speed is 3600 RPM. If you increase the number of poles to four, speed is reduced to 1800 RPM. The speed at which the rotor rotates is known as the slip speed and will always be less that the synchronous speed in the stator. The reason for this is because no voltage and current is induced in the rotor when they travel synchronously. The actual slip speed depends upon the motor design and will vary by model and horsepower. For fractional HP motors at full load, slip speed can be as low as 95% of Ns while higher HP models can operate at 99% of Ns.

As we saw in my series on AC Power, the single phase AC sine wave reaches its peak voltage twice during one 360 degree cycle and these peaks occur at 180 degree intervals. In a three phase circuit phase 2 lags phase 1 by 120 degrees and phase 3 lags phase 2 by 120 degrees. When all three phases are flowing together voltage peaks every 60 degrees. This relationship is illustrated in Figure 2. The arrows show the 120 degree separation of the three phases and the vertical, colored lines show the phase voltages peaking every 60 degrees. This peaking relationship not only provides for a more uniform power supply but also can produce a rotating magnetic field in the stator of a three phase motor.

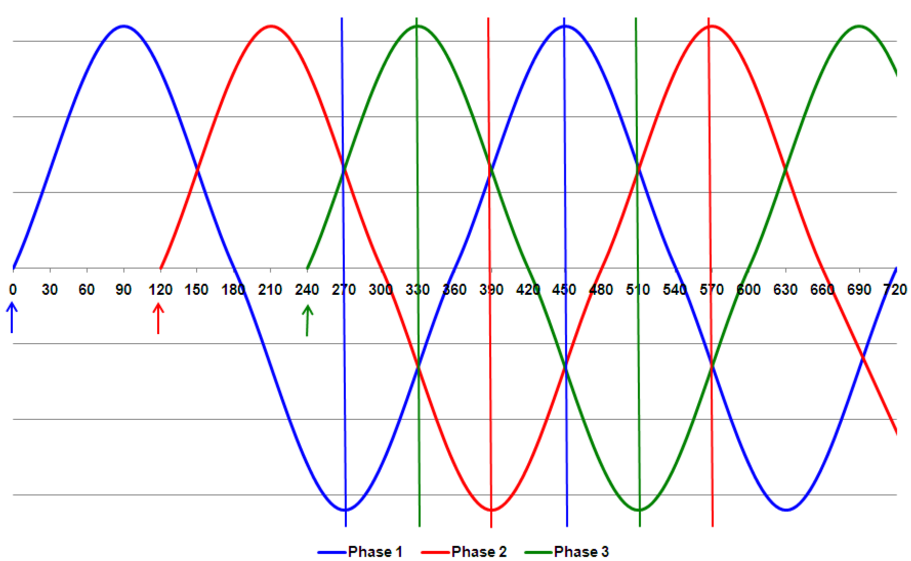
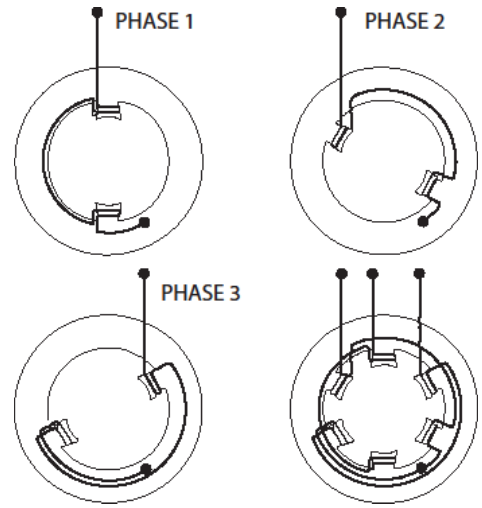


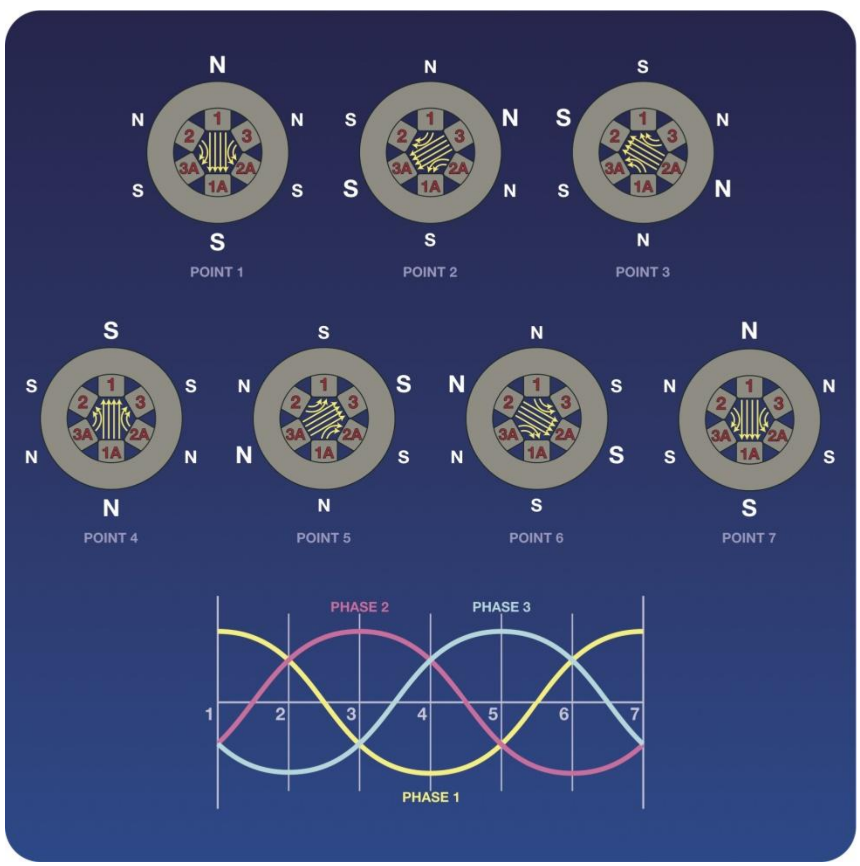
Figure 3 shows the pole placement for a three phase, two pole motor. As you will note, there are actually a total of six poles or two poles per phase. The phase 1 poles are located at 360 and 180 degrees while the phase 2 poles are at 300 and 120 degrees. The phase 3 poles are located at 60 and 240 degrees. The result is a total of six poles spaced 60 degrees apart. This 60 degree separation is not a coincidence. It is done specifically to take advantage of the 60 degree separation of the three phase voltage peaks. We will see why in the next section. Now, you may be wondering why the phase poles are in this particular sequence. The primary pole of phase 2 is to the left of the phase 1 primary and the primary pole of phase 3 is to the right. If you refer back to Figure 2 you will see that the peak following the phase 1 peak is phase 3 and the next peak is phase 2. Motors are wound in this fashion to provide a predictable rotational direction. In this particular case rotation would be clockwise. Reversing any two of the phase connections will change the phase peak relationships and cause the motor to rotate in the opposite direction. "Rolling" those connections (ie moving 1 to 2, 2 to 3 and 3 to 1) will not change the phase relationships and thus the direction of rotation will remain the same.



The Rotating Magnetic Field

We have seen how voltage peaks in a three phase circuit and how the stator poles are aligned to match those peaks but, why does the rotational magnetic field occur automatically? Figure 4 puts the linear flow of voltage peaks shown in Figure 2 and the pole locations shown in Figure 3 into a rotational perspective.

The stator images show the three sets of poles and their polarity from Points 1 through 7. The graph image shows the



phase voltage peaks for the same points. At Point 1, phase 1 is at its positive peak and a maximum magnetic field is generated in poles 1 and 1A. At Point 2, phase 3 is at its negative peak and the maximum magnetic field is generated in poles 3 and 3A. At Point 3, the maximum field has moved to poles 2 and 2A. If you study the other points you will see that this trend continues in a clockwise direction. Thus the three phases create an automatic rotating field in the stator. If any two of the incoming phase leads are switched the magnetic field will rotate in a counterclockwise direction.

As I mentioned earlier motor speed depends upon both frequency and the number of poles. Motor speed will change in direct proportion to a change in frequency. For example, at 30 Hz an 1800 RPM motor will rotate at 900 RPM. If an additional set of poles is added to each phase of the stator shown in Figure 3, its speed will also be decreased by 50%. The time required for one 360 degree rotation of the stator field is proportional to both frequency and the number of poles.

Three phase motors can also be designed to operate at two different speeds and the speed relationship depends upon the winding method employed. Two speed, single winding motors utilize a stator that is wound for a single speed but when the winding is connected in a different manner, the number of poles connected is also changed. For example in one connection four poles are connected but with the alternate connection, eight are connected. With this winding method there will always be a two to one speed relationship (1800 RPM / 900 RPM). Usually, the BHP at the low speed will be one quarter that of full speed, however, constant torque designs will maintain one half BHP at the lower speed.

Two speed, two winding motors are actually two motors wound on a single stator. Although these motors are typically larger and more expensive, they are not limited to the two to one speed relationship of single winding motors. For example, a four and six pole, two winding motor would produce speeds of 1800 RPM and 1200 RPM. In this example the BHP at the low speed will be two thirds that of full speed. Next month we will investigate the operation of single phase motors.

The sites below offer an on line tutorial on induction motors.
All About Circuits - http://www.allaboutcircuits.com/vol_2/index.html
Integrated Publishing - http://www.tpub.com/content/neets/

Joe Evans is responsible for customer and employee education at PumpTech Inc, a pumps & packaged systems manufacturer & distributor with branches throughout the Pacific Northwest. He can be reached via his website www.PumpEd101.com. If there are topics that you would like to see discussed in future columns, drop him an email.