Single Phase Motor Starting

Pump ED 101

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Although there are many different electric motor designs, a characteristic that is common throughout is that they are wound for either three phase and single phase power. The three phase motor has several inherent advantages including a lower current draw per phase, an ability to create more torque, and smoother running. But, its ability to begin rotating of its own accord is a major advantage. Despite the fact that the three phase motor has two additional phases, and the windings associated with them, the single phase motor is a more complex machine.

Once running, however, the single phase motor works just like its three phase counterpart except that it does so without the advantages of the two additional phases. Notice that I said, "once running". Starting a single phase motor is not as simple as starting its three phase counterpart as it requires several additional components. Since we have established that the three phase motor is the simpler of the two, lets begin our discussion by showing how it starts rotating from rest.

Three Phase Motors

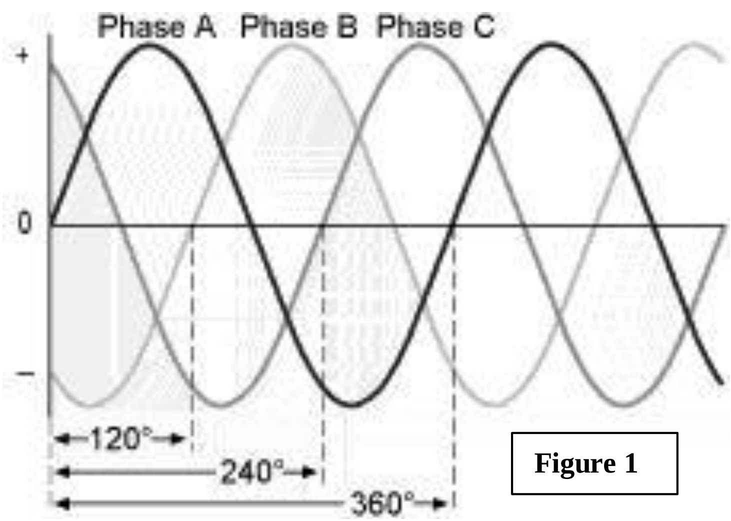


Figure 1

The three phase power curve shown in Figure 1 consists of three separate single phase curves evenly separated by 120 electrical degrees. Each curve completes its 360 degree motion sixty times each second. The beauty of the three phase curve is that, at every point on the X axis, two of the curves have either a positive or negative value. It does not matter whether the values are positive of negative. After all, power is measured in watts (volts x amps) and a minus voltage times a minus current equals a positive watt. The importance of this point will be seen when we review figure 3.

Figure 2 shows the windings of a two pole, three phase stator. Although it is a two pole design, there are actually two poles per phase for a total of six. As you can see, each pole is separated by 60 degrees from its neighbor on either side. Its synchronous speed is 3600 RPM (one rotation per 360 degree sine wave cycle times 60 cycles per second times 60 seconds). Its actual speed (slip speed) is a bit less and depends on the motor manufacturer's design.

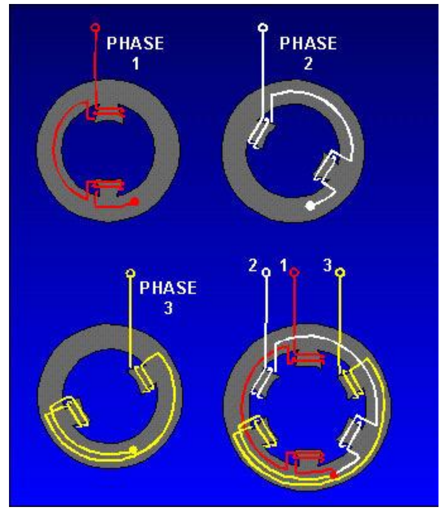


Figure 2

Now Figure 3 may appear a bit complex but don' let it confuse you. What it illustrates is that the three phase power curve actually creates a rotating magnetic field in the stator. If you look at the arrows that illustrate the rotor motion, you will see that they are rotating clockwise and, at every point on the X axis the stator creates a magnetic field that induces a counteracting field in the rotor. It is this rotating field that causes the three phase motor to start rotating from rest and continue to rotate as long as power is supplied to the stator. The multiple poles create the high torque and smooth running that is characteristic of the three phase motor. If this were a four pole motor (1800 RPM) the magnetic field would rotate about twelve distinct poles (four per phase) creating even higher torque. Lower speed motors must do more work per rotation than a higher speed motor of the same HP rating if their output per unit time is to be the same. See the "Puzzler" and "The AC Induction Motor" for more on this and other motor topics.

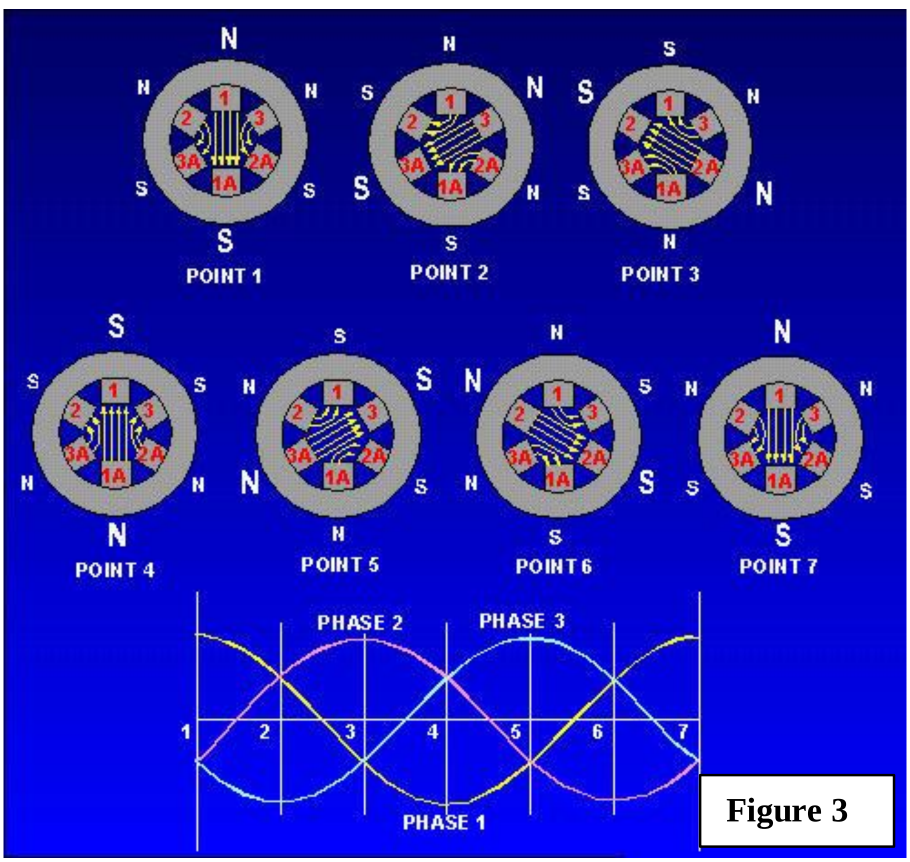


Figure 3

Single Phase Motors

Figure 4 shows a single phase sine wave. Notice that the single phase curve, unlike its three phase cousin, consists of only one wave form. Lets take a look at the motor stator that utilizes this power source.

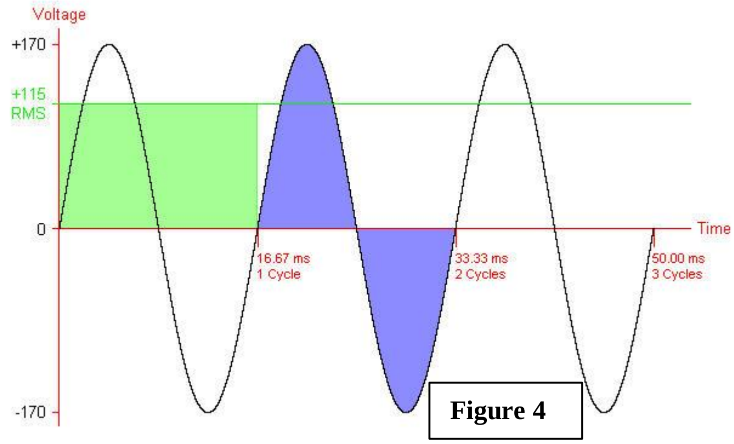
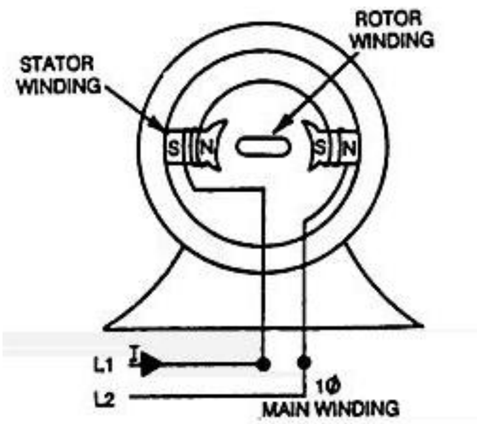


Figure 4



In Figure 2, we saw the cross section of a 3 phase, 2 pole motor. It contained 2 poles per phase for a total of six. Figure 5 is a cross section of a two pole, single phase motor. As you can see there are only two poles separated by 180 degrees. Let's take a look at the rotating field it creates.

Figure 5

Figure 6 shows the magnetic field created by the stator as the single phase curve moves through its 360 degree cycle. The picture on the left shows the stator fields as the single phase wave form rises. The left hand pole has a North polarity while the right hand one has a South polarity. As the wave begins its downward movement (right hand picture) the two stator poles change polarity and the left one becomes South while the right changes to North. This alternation from North to South (and vice versa) continues as the single phase wave progresses.

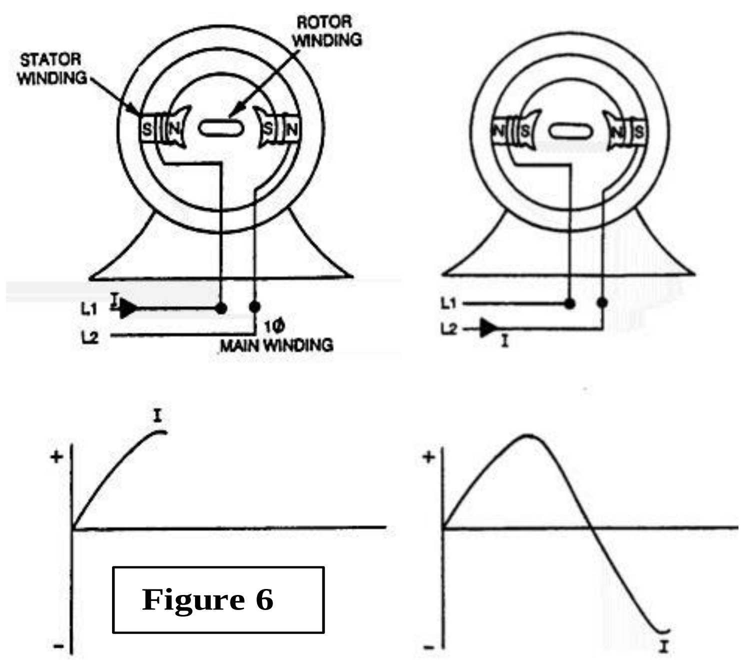


Figure 6

Referring to this as a rotating field is really a misnomer because the single phase curve does not create a rotating field. It simply oscillates between the two poles. Since there is not a true rotating field the motor's rotor will remain stationary (you have probably witnessed a "humming" single phase motor that has failed to start due to faulty starting components). Now if you were to spin the shaft with your hand, in either direction, the motor would start and continue to rotate at its two pole speed. The reason it will continue to rotate is due to the changing polarity of the stator poles and the momentum developed by the rotor. The rotor's momentum allows it to rotate past the "dead" areas of the stator and reach the pole areas where induction can reoccur. (A four pole (1800 RPM) single phase motor will overcome these dead areas and start on its own.) Check out the Franklin Electric "Puzzler" (Tesla meets Newton) to learn more about how momentum affects the operation of single phase, 4" motors.

Since this method of motor starting is probably unacceptable to most of us so lets take a look at some alternative starting methods.

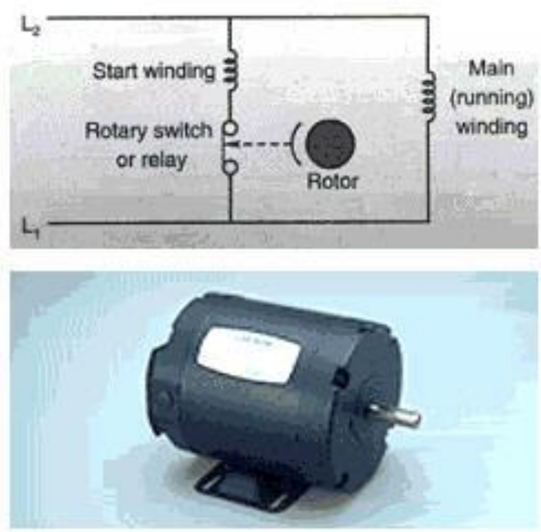
Single Phase Starting Methods

In this section we will take a look at the four most common single phase motor designs. Their names imply the starting method that each employs. Although there are a number of other designs, these are the ones that are most common to centrifugal pumps. We will take a look at how they initiate rotation and list the operating characteristics of each.

Split Phase

The split phase, or resistance start, motor is probably the simplest industrial duty motor and is the design employed by Franklin two wire, submersible motors. As seen in Figure 7, it has two sets of windings – a start winding and a run or main winding. Each start and run pole is separated by 90 degrees and the windings are wired in parallel.

Figure 7



The start windings are made of smaller wire than that used in the run windings and its smaller diameter creates more resistance to electrical flow. This higher resistance lets the current in the start winding develop a magnetic field before one is developed in the run winding (due to a smaller CEMF). The result is two different fields about 30 degrees apart. It would be better if they were evenly spaced – say 90 degrees – but even this small angle is enough to get the motor started.

Figure 7 also shows that the start winding is connected in the circuit by a normally closed switch. When power is applied to the motor, both the start and run windings are energized. When the motor reaches about 75% of its rated speed the switch disconnects the start winding from the circuit and the motor will continue to rotate on the run winding alone. The reason for the switch is that the parallel design of the start and run windings draw quite a bit of current during starting and, if the start windings were left in the circuit, the motor would overheat and eventually destroy the stator. In above ground motors a centrifugal switch is employed. In the Franklin submersible motor a thermal BIAC switch is used to drop the start winding from the circuit.

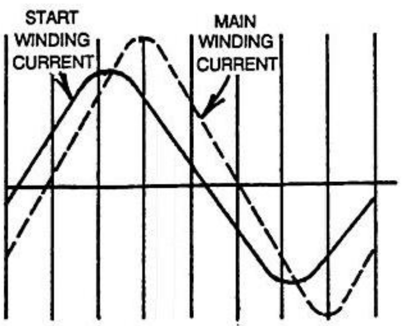


Figure 8 shows the current curves of the start and run windings of a split phase motor. Although the start winding current is less than that of the run winding, it still creates an additional magnetic field slightly ahead of that of the run winding.

Figure 8

Figure 9

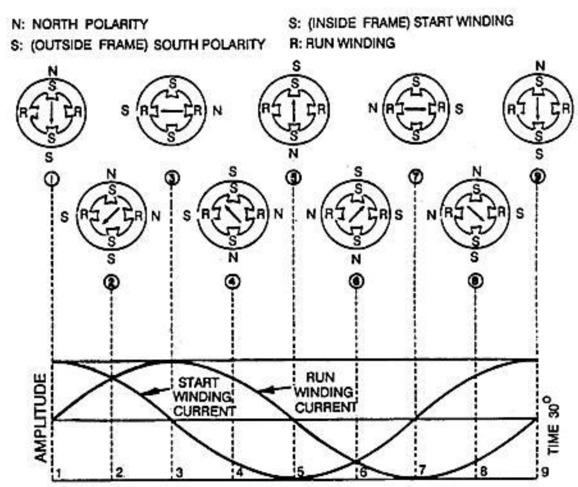


FIGURE 17-15. Start and Run Winding Magnetic Field.

Figure 9 shows something very different than that earlier, so called, single phase rotating field. It is truly a rotating field and, although not as efficient as that produced by three phase power, it is able to start the motor. The rotating field is generated by the current normally associated with the run winding and the leading current (and induced magnetic field) of the start winding.

The split phase motor is a low cost design and is available from 1/20 to 1.5 HP and is usually found on low end centrifugal pumps and fans. It produces low starting torque (100-175% of run torque) and requires a very high starting current (700-1000% of run current). Thermal protection is more difficult due to higher winding temperatures during starting and the frequency of starts must be limited to prevent insulation damage.

Capacitor Start

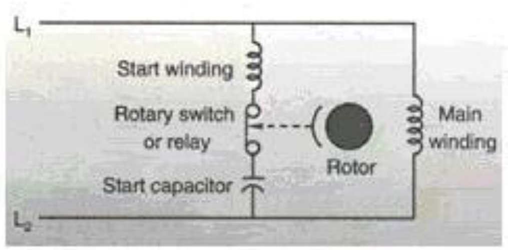


Figure 10

Figure 10 is a schematic of the capacitor start motor. The stator windings in the capacitor start motor are exactly the same as the split phase motor except that the start winding wire is normally sized. The stator poles are spaced 90 degrees apart and a normally closed switch is employed to activate and deactivate the start windings. In the Franklin submersible motor a current switch replaces the centrifugal switch used in above ground motors.

The difference between the split phase and cap start motor is that there is a capacitor in series with the start winding. Unlike the split phase motor which uses resistance to effect a small difference in the start and run winding magnetic fields, the capacitor start motor takes advantage of the capacitor’s inherent ability to cause current to lead voltage in a typical sine wave. We will not go into it here but a properly sized capacitor can create almost any angle one wishes between the start and run magnetic fields. Again, it must be disconnected from the circuit after the motor reaches about 75% of its rated speed to keep from over heating the stator and capacitor.

Figure 11 shows the capacitor start current peaks of the start and run windings separated by 90 degrees (which is ideal). Notice too that, unlike the split phase current curves, the start winding current is similar to that of the run winding.

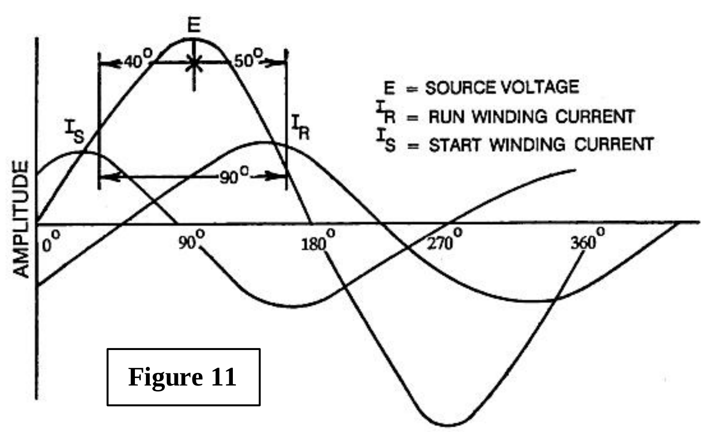


Figure 11

FIGURE 17-23. Capacitor Starting Current and Run Winding Current.

The capacitor start motor is more costly than the split phase and is typically available from ¼ to 3HP. It has a higher starting torque (200-400% of run torque) and requires less starting current (400-575% of run current). Its lower starting current also allows a higher frequency of starts than does the split phase motor.

PSC

Well, if a capacitor can produce the proper angle between the magnetic fields of the start and run windings, would it not be beneficial to keep it in the circuit while the motor is running? After all it should allow smoother running and more running torque. The answer, of course, is yes and there are a couple of ways to accomplish this.

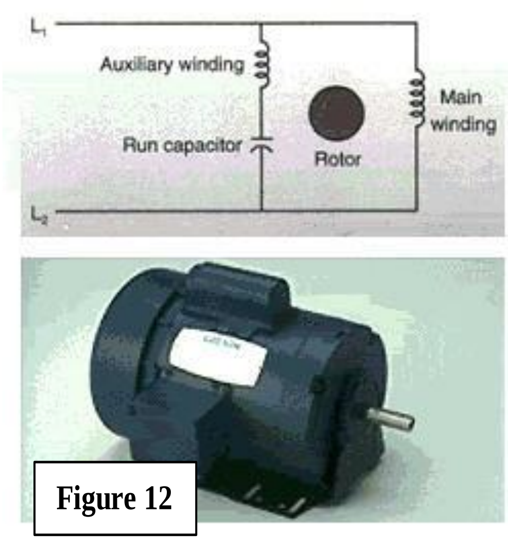


Figure 12

The permanent split capacitor (PSC) motor, seen in Figure 12, is probably the most reliable single phase motor made. It has a run type capacitor in series with the start winding (now refereed to as the auxiliary winding) but does not require a switch to disconnect it. Because the capacitor is designed for continuous use, it cannot be sized to provide the starting boost of start capacitor. Still, the PSC motor has a starting torque similar to split phase motors but at a much lower starting current.

The reason that two wire submersible motors do not utilize this, far better, design is because it is difficult to house the capacitor within the motor. It would require a separate enclosure on the surface and, even though there would be no switch in the enclosure (as in the typical Franklin control box) a third wire would be required and thus defeat the whole purpose of the two wire motor.

The PSC motor is less costly than the cap start motor because a switch is unnecessary. Horsepower ranges from ¼ to 1 and starting torque is low (30-150% of run torque). It requires the lowest starting current of any design (less than 200% of run current) and can withstand a very high cycle rate. It is the most reliable motor available.

Cap Start Cap Run

The capacitor start, capacitor run motor combines the best features of the capacitor start and PSC motors. As you can see in Figure 13, the run capacitor is always in series with the auxiliary (start) winding. But during starting a start capacitor, connected by a normally closed switch, is also in the circuit. This configuration provides the starting boost of the capacitor start motor with the smooth running and higher running torque of the PSC motor.

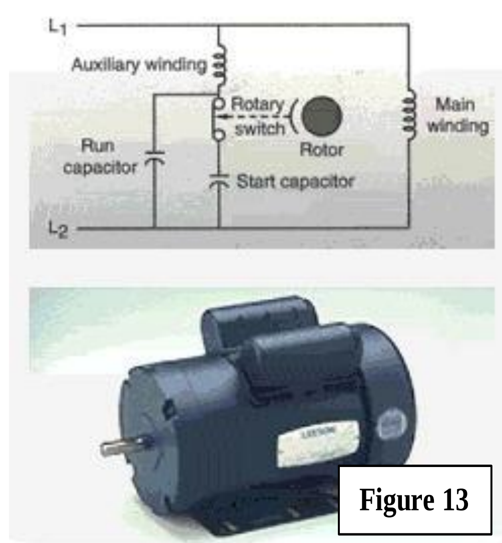


Figure 13

In the case of above ground motors, a centrifugal switch removes the start capacitor from the auxiliary winding once speed reaches about 75%. Franklin submersible motors use a current switch to perform the same function.

The cap start / run motor is the most costly but combines the best features of the cap start and PSC motors. They are usually available from 1-15 HP and offer high starting and breakdown torque while providing smoother running characteristics at higher horsepower ratings.

Summary

Starting torque is not really an issue with most centrifugal pumps because they are "variable" torque machines. By this I mean that the torque required is proportional to rotational velocity of the impeller. Unlike positive displacement pumps, which require high torque during starting, centrifugals require little initially but require more as rotational velocity increases. The PSC motor is ideal for a single phase, centrifugal pump but is limited to about 1HP due to the increasing inertia of the motor rotor and pump rotating element as motor and pump horsepower increase. If it were not for the additional cost of 3 wire submersible cable it would replace the Franklin 2 wire motor in an instant. The cap start motor is the next best step but, again, rotor and pump inertia requires the smoother running capability of the cap start / run design as HP increases.

For more information on electric motors and electric power download the "Puzzler" on the Education page at http://www.pumped101.com .