FAN ENGINEERING

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Information and Recommendations for the Engineer FE-1000

Speed Control For Fractional Horsepower Motors

As fan and blower use has evolved over the years, the way the speed is controlled has also evolved. For all practical purposes this article will explain speed control for the AC, induction, squirrel cage, asynchronous motor. Before attempting to explain the differences in speed controls you must have a basic understanding of AC motors. Below is a brief overview but it is recommended that you read other engineering topics on AC motors to fully understand how they operate.

Overview of AC Induction Motors

There are two major AC induction motor groups that are usually used in fans and blowers: the single-phase motor and the polyphase motor. In the polyphase group the one that is the most commonly used is the three-phase induction motor. In the single-phase motor group there are five different sub groups that are often used. They are split-phase, capacitor-start (CS is a variation of the split-phase motor), shaded pole, permanent split capacitor (PSC) and capacitor start-capacitor run (CSCR is a variation of the PSC motor).

Usually the split-phase, CS and CSCR motors are eliminated in variable speed control situations because they all have a start winding or a contact that needs to reach 75% of the motor's full load speed before it disconnects the start winding. Often this 75% is not reached when controlling the speed. If the start switch is not disconnected, the result is that the contacts or start winding will quickly burn out and the motor will overheat and shut down. We cannot eliminate these motors totally when deciding what induction motor to use, however, because there are still mechanical means of controlling the speed of a fan that will allow these motors to reach their full RPM. Or these motors could theoretically be used if they would never go slow enough to re-engage the starting contacts while running in normal operation.

The remaining motors, shaded pole, PSC, and polyphase, are the best choices when selecting a motor that will be speed controlled. The shaded pole motor is the most economical to use out of these three motors because of its inherent design, but it is only available in subfractional to 1/4 horsepower. This is not the only limitation it has; it also has a low starting and run torque and is inefficient. So for single-phase operation where the horsepower is greater than 1/4 and/or there is a high run torque, the PSC motor is usually used. Although this type of motor is one of the more expensive single-phase motors, it is very reliable, has good running and starting capabilities, and allows the option of controlling the speed through an electronic apparatus. The PSC motor functions the closest to the way the three-phase motor does which leads to the discussion of the three-phase motor.

The three-phase motor is available in fractional and integral horsepowers but in general its electrical savings does not outweigh its cost until you get into the integral horsepower range. It essentially operates in the same manner as a single-phase motor although instead of there being one hot electrical lead there are three. Controlling the speed can require a different control than the single-phase controller just because single-phase and three-phase function slightly differently.

Common Methods of Speed Control

Now with an idea of the types of fractional horsepower motors that are most commonly used in fans and blowers we can introduce the common methods of controlling their speed. There are four basic groups of speed control that are often used with fans and blowers. The simplest is the variable speed motor. The remaining three groups are passive device speed controls, solid-state controls, and mechanical devices. Each way is unique and is used throughout the industry but you must be careful when trying to match any speed control with a motor. Whatever the application may be, be sure to check with the motor manufacturer to be assured their speed control criteria is being met because some motor manufacturers will void their warranty if the motor is not approved for speed control. Also, be aware of all safety issues such as thermal overload protection as this needs to be part of the speed control system. There is often a substantial amount of heat generated at the motor when speed controllers are used. To prevent accidents or damage it is always recommended that a thermal overload protector either be part of the motor or of the controller itself.

A brief list of how an induction motor's speed can be changed other than mechanically is: affect the electrical frequency sine wave, change the number of motor stator poles, adjust the power input, or control the rotor slip. The formulas for motor speed that all speed control is based on are:

$$\text{horsepower (HP)} = \frac{\text{torque (lb.ft) x speed (rpm)}}{\text{5250 (constant)}}$$

$$\text{speed (RPM)} = \frac{\text{120 x motor supply frequency}}{\text{number of motor poles}}$$

Basic AC Electricity

To have a good understanding of the technical talk about speed controllers you must have a basic understanding of electricity. It is best to refer to other articles to explain this but for general purposes Figure 1 shows a single-phase AC frequency sine wave which is what most modern controllers affect in some way to control motor speed. In the U.S. if we were to look on an oscilloscope at the sine wave of single-phase line electricity we would see what is represented in Figure 1. The sine wave of three-phase electricity is represented in Figure 2.

Figure 1. Single-phase sine wave

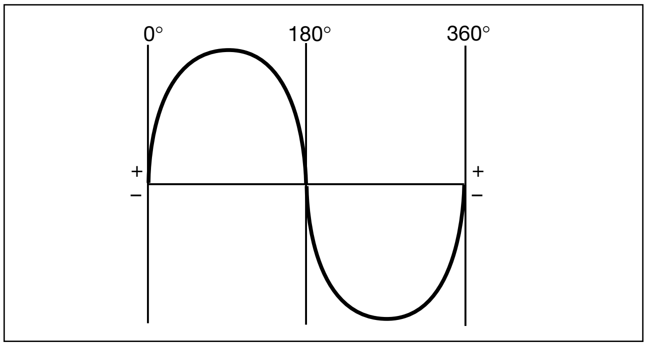
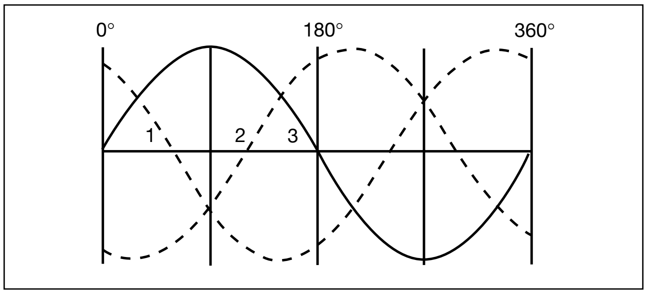


Figure 2. Three-phase sine wave



The humps that go up and down represent the current and the wave is described as going 360 degrees. In the U.S. this occurs 60 times per second and is referred to as 60 Hertz. In other parts of the world this speed is 50 times per second (50 Hertz). If you look at the horizontal line in the center, which is called the "zero line," you can see that a single sine wave crosses it 120 times a second. Since motors rotate in a direct relation to the electricity provided we can understand how speed controllers function by affecting the electrical input to the motor. The following are the several ways that motor speed is controlled throughout the fan and blower industry.

Multi-Speed Motors

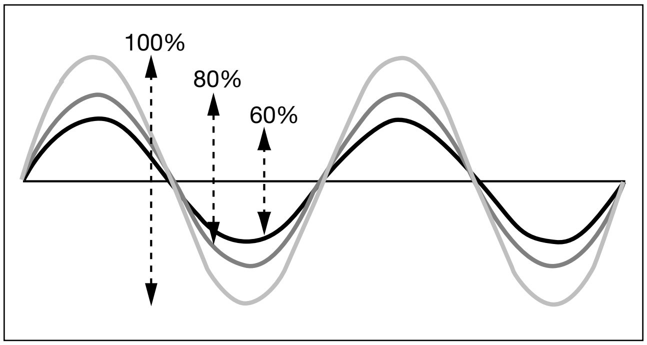
Most motor manufacturers offer motors that have more than one available speed without actually having a separate control to alter these speeds. Multi-speed motors use either a tapped winding or several windings that are alternated. Speed is changed manually with a switch or controlled through a circuit board. The motors normally used for multi speeds are the PSC and the shaded pole single-phase motor. The PSC motor is the most commonly used and can have either tapped or alternated windings. The shaded pole motor can be manufactured with tapped windings.

One limitation that multi-speed motors present to any fan situation is that the speed required for the application may not always be available since there are limitations to the combinations of speeds the manufacturers offer. The other downfall is that the switches that are used are often the inexpensive kind where the speed needs to be changed manually. These motors work well with fans that are used for exchanging a set amount of air without variations at a given time. This type of fan motor is relatively economical but an exact airflow is hard to match because of its speed inflexibility.

Passive Device Speed Controls

Passive device speed controls are often the cheapest to buy but are often the most expensive to use because of the way they waste electricity. They operate by controlling the motor's electromagnetic characteristics by altering the incoming voltage. This reduces the entire sine wave in amplitude which really is changing the frequency sine wave's height. Figure 3 shows the sine wave and the current present as a percentage when using a passive device speed control.

Figure 3. Reduction in sine wave amplitude



This is old technology and because of its efficiency rating it is being overtaken by more modern methods using switches that are more efficient and becoming affordable.

The most common motors used with passive device speed controls are the PSC, shaded pole, and the three-phase motor. Whichever motor is used, the load should never be greater than what the motor is rated for at startup when using the specific type of control or it will malfunction. This is usually 150-200% of the running torque at full speed. This control is often applicable with fractional horsepower motors where we usually don't have to worry about the load or the efficiency. Although passive device controls are cheap and reliable they usually require someone to manually operate them and exact speeds may be hard to achieve because of inconsistent voltage outputs. Below are the most common passive device controls used.

Series Resistors

Rheostat: When this device is activated it varies the voltage across the winding of a motor creating motor slip. Typically a rheostat consists of a resistance element equipped with two contacts, one that slides and one that is fixed. When the sliding contact moves along the resistance element towards the fixed contact, the distance is changed and so is the speed that the current leaves the element. This change in current speed can be translated into variable speed when a motor is attached in line. The disadvantage of this type of control is that the motor needs to start at a high speed and then be slowed down, otherwise the contacts will get too hot and burn out. Another disadvantage is that rheostats must be manually operated.

Potentiometer: The potentiometer is very similar to the rheostat except it has a resistance element that is attached to the circuit by 3 contacts instead of 2. The arrangement of the slide and how the current is changed are also slightly different. The ends of the resistance element are attached to two input voltage conductors of the circuit. The third contact, which is attached to the output of the circuit, is usually a movable contact that slides across the resistance element. The resulting resistance determines the magnitude of the voltage applied to the circuit that also can be translated to variable speed when a motor is attached in line. The disadvantages are the same as the rheostat.

Transformer: This may be used in place of a resistor and in general works in the same way. It consists of two coils of wire, electrically insulated from each other, and arranged so that a change in the current in one will change the voltage in the other. This decrease or increase in voltage is what varies the speed of the motor. The transformer has the advantage over the series resistors of not losing power wasted into heat on a low speed startup which also means that the load can be started at a slow speed. The disadvantages of this type of control are that they are usually large in size, need to be manually operated, and are not as economical as a series resistor.

Solid-State Controls

Over the past several years there have been huge advances in solid-state control technology and how it can be used to control motors. Most of the present product development being done on speed controllers involves solid-state controls. Some controls are even being incorporated into the motors themselves. Solid-state controls are usually very reliable, can give exact speeds and are becoming more economically feasible to use with fractional horsepower motors. In the past these types of controls were usually only used with integral horsepower motors where the electrical savings justified their expense. But the advances in electronic components along with decreases in cost have changed the way they are used today.

Most of the different styles of solid-state controls incorporate the varying of the electrical frequency and/or current to control the motor speed. They can even vary the frequency to be higher than the normal line frequency meaning we can increase the speed beyond what the motor is rated for.

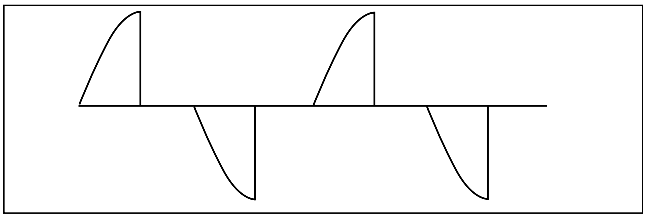
The motors commonly used with solid-state controls are the shaded pole, PSC and three-phase.

Even though these types of controls are more accurate than less complex controllers used in the past, in regards to speed and torque control there are still several disadvantages or problems that occur while using them. For example most manufacturers of these speed controls do not recognize the damages that can occur to a motor by changing the harmonic frequency. Some other disadvantages to be aware of are that a current over what is specified can be very harmful to the motor winding laminates, voltage spikes from the inverter can do a lot of damage to the windings, harmonics higher than what the motor parts have been tested for can damage bearings or laminates, sound and vibration can be altered creating their own damage, and of course there is a greater risk of fire. So be careful when matching a solid-state control with any motor and always ask the motor and control manufacturers about the consequences of using a controller.

Variable Frequency Drives (VFD) or AC Inverters

Triac: This type of control varies the speed of a motor by chopping part of the frequency sine wave in order to alternate the current frequency. A triac is really a switch that turns on but will not turn off until there is not current flowing through the device. To better understand this we should refer to Figure 1 and look at the frequency sine wave. We can see that the current does shut off on a standard 60 hertz cycle 120 times per second on a 60 Hertz frequency line when the wave is equal to the zero crossing line. This means that if we turn the switch on milliseconds from this zero point line the sine wave will be altered. See Figure 4.

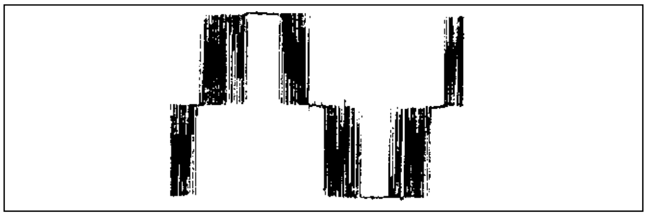
Figure 4. Chopped sine wave (Triac)



By altering this time that we switch this device on the sine wave will ultimately be affected and therefore change the speed of an induction motor. These devices are relatively inexpensive and can repetitively change the speed day after day in the same manner. Simple measurement techniques used in conjunction with this type of control often make it effective enough to justify its expense. The disadvantage of this control is that by chopping the sine wave in half it is essentially turning the motor on and off which damages the motor by generating a lot of heat at the windings. Some of the less expensive models of this control you may notice will buzz because they are not made well and the noise of this sine wave being chopped can actually be heard.

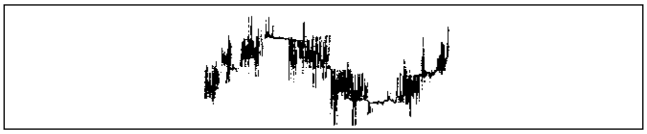
Pulse Width Modulation (PWM): This is a general purpose AC inverter that incorporates a complex circuit design into an electronic programming module to vary the frequency sine wave. It presently is the most popular VFD and has been since the prices of electronic components and circuitry were lowered allowing it to be sold at an economical price. One stipulation that there is to using this control is the motor must be three-phase, but the input power to the PWM can be either one- or three-phase. By converting the AC power to DC and then converting it back into AC the output closely approximates a sinusoidal (sine wave) current wave form allowing the variable speed control of any AC induction motor. Figure 5 represents the frequency sine wave and how it is affected with a PWM. A logic circuit and software control the switching to provide this variation in voltage and frequency.

Figure 5. Pulse width modulated sine wave (line voltage from inverter)



The disadvantage of the PWM inverter is that there is a potential danger of inverter-induced voltage spikes (see Figure 6) which can create serious damage to the motor. What happens is that when the inverter is rapidly switching it induces a voltage overshoot which when attached to a motor can cause voltage spikes that are three times higher than what the motor winding is rated for. Voltage spikes are accentuated by longer lines between the controller and the motor so it is important to have short lines. Voltage spikes can also cause high voltages to be induced in the rotor which can cause

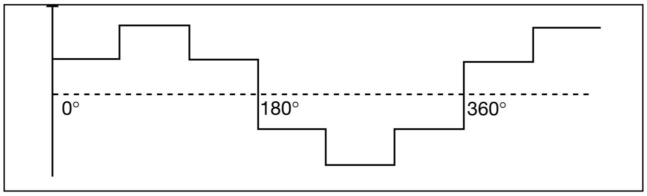
Figure 6. Inverter duty spikes (actual voltage at motor)



arcing in the bearings and result in short bearing life. These high voltages are not the only damaging thing because along with these spikes comes a phenomenon known as corona. Corona is a breakdown in air molecules in the air that is between the adjacent conductors in the motor winding. The resulting damage from corona and voltage spikes has been known to literally poke a hole in the motor's insulation. There are now inverter rated motors that offer extra insulation and corona treatment to protect from this but in any circumstance you should be aware of the wave form that the inverter is giving off and its compatibility with the motor before you use it. Also there are some PWMs that create more spikes than others and there are some PWMs that protect against spiking better than others do.

Current Source Six-Step Inverter: The six-step inverter was one of the first advanced motor controls used to control motor speed by varying the shape of the frequency sine wave. It was mainly used for high horsepower motors and is now replaced by the Pulse Width Modulator. It is named from the shape of the waveform that it generates. See Figure 7. The normal line voltage is rectified and fed into an inverter and produces an alternating square wave voltage that looks like six steps and takes the basic shape of the normal sine wave. This can be adjusted in height and is read by the motor as a change in frequency (speed). The disadvantages are similar to the PWM plus it is very expensive especially with fractional horsepower motors. The six-step inverter can also cause torque pulses in the motor resulting in increased vibration.

Figure 7. Six-step inverter sine wave



Vector Control: This allows an AC motor to act like a DC motor in relation to the speed and torque being linear. This is accomplished by allowing independent control of the field flux and rotor current. To do this the motor control must regulate the instantaneous magnitude and phase of the stator's current. This can be interpreted as torque or slip frequency. The biggest downfall of this type of control is that along with it being very expensive the exact speed of the motor must be known and programmed into the controller in order for it to function correctly. Since most of the motors we use in the fan and blower industry are asynchronous the exact speed is unknown.

Switched Reluctance: This method of motor controlling is very complex and also allows the motor to possess the qualities of both the DC and AC motor. The rotor position of the motor is the most important factor with this type of control. Because the position of the rotor is always a hard thing to measure cheaply in an asynchronous motor this controller hasn't been feasible to use until recently. It regulates the speed by measuring the current and voltage in each winding. From this the inductance (plus the speed and torque) can be estimated through complex software. This type of controller seems to be the most promising for the near future since a lot of work is being done to perfect it. This will undoubtedly make switch reluctance controlled motors a very popular method of speed control since the AC motor acts more like a DC motor. Most of us know this as the ultimate since torque and speed are directly related in a DC motor. The disadvantages known at this time are related to expense since this technology is just becoming popular. The latest breakthrough in this technology is that the position of the rotor is being determined without using a sensor which has decreased the cost significantly and has made it more reliable.

Mechanical Devices

Mechanical devices are some of the oldest forms of controlling the speed of fans and blowers. They can be used alone or with other types of controls. In most situations they have a lot of advantages over electrical forms of speed control. For example, you don't have to be concerned about electronics failing and having an expert figure which part has failed. With mechanical devices you can usually see which part has failed and most mechanical people could fix the problem if needed. Unfortunately the speeds are not usually adjustable during normal operation and the mechanisms require a lot of maintenance such as lubrication.

Sheaves: This is the most common form of controlling speed in a belt drive situation. There are even sheaves that are fully adjustable to where you can obtain exact speeds. But when sheave diameters are changed usually the belt length needs to be changed also. Sheaves have a tremendous advantage in a large fan or blower where the speed needs to be slower or faster than what standard motors offer or where direct drive cannot be used. They can also carry a large load easily as long as there is the correct belt tension on the sheaves. Most of us are familiar with this type of product and know it is not adjustable while the fan or blower is running which is a huge downfall. This arrangement is also usually one of the highest maintenance because of all of the parts.

Transmission Products (Gear Reducers, Gears, Clutches, etc.): This form of speed control is usually not used in fans and blowers but it should not be eliminated from consideration. Transmission products are familiar to most of us as being used in applications where, unlike fans, the load does not change when the speed is slowed down. These are usually reliable but often very expensive and cumbersome. They often require high maintenance and often need to be manually adjusted in order for the speed to change.

Conclusion

To properly select a speed control you must thoroughly understand how it will be managed, what kind of motor it can adapt to, and expense/efficiency limitations involved. As noted, some controllers may be less costly and not as user friendly as others but may still get the job done. Hopefully this paper will help you in determining which speed control and motor to use for your situation.

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