Variables To Consider When Making Motor Frequency Changes Between 50, 60 Hz

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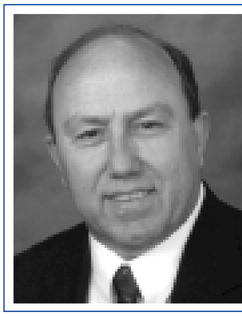
We in the apparatus repair business don't always realize how global our work is until a customer sends in a motor to be redesigned for use on a different frequency. The most common frequency conversion requests are between 50 and 60 hertz (Hz). Motors intended for use in North America typically are rated at 60 Hz, whereas most of the remainder of the globe uses 50 Hz.

The speed of a three-phase motor is determined by the number of poles and the frequency. As much as we are aware of this relationship, it remains a mystery to most end users. How often have you had a customer simply request changing a 4-pole motor from 50 to 60 Hz? They want to maintain the speed at about 1500 rpm. Not only is it impossible, there are other considerations related to the type of load that must be taken into account.

Frequency Change On Pump Or Fan

Changing the frequency from 50 to 60 Hz on a pump or fan increases the operating speed, and consequently increases the load on the motor and driven equipment. That is because fan and pump load varies by the cube of the speed. A 50 Hz motor operating on 60 Hz power will attempt to rotate at a 20% increase in speed. The load therefore becomes 1.2^3 (1.2 x 1.2 x 1.2) or 1.73 times greater (173%) than on the original frequency. Redesigning a motor for that much of an increase in horsepower is simply not realistic; the motor magnetic material would be driven into saturation long before reaching the 73% increased horsepower level. There are very few motors that can be redesigned for a horsepower increase of 30% or greater.

The typical solution when increasing speed due to a change in frequency is to modify the driven equipment so that the increased horsepower requirement falls within the motor's capability. Using the common examples of fans and pumps, the diameter of the fan wheel or impeller can be trimmed to provide the same performance at 60 Hz as the unit had at 50 Hz. The original equipment manufacturer should be consulted before making such a modification. Not all pumps and fans behave exactly in accordance with the cube rule, thus the OEM may specify a diameter value that differs from the rule. For fans and blowers, the diameter change follows a 5th power rule. That discussion is one that usually takes place between the end user and the OEM, i.e., the motor rebuilder frequently does not modify the driven equipment.



What should you ask your customer when he or she sends a motor for a frequency change? In addition to the new frequency and voltage, you'll want to know the new horsepower requirement. The customer should specify the required horsepower capability, and we as rebuilders can then determine if the motor can develop the necessary horsepower.

Questions To Ask Customer

What should you ask your customer when he or she sends a motor for a frequency change? In addition to the new frequency and voltage, you'll want to know the new horsepower requirement. The customer should specify the required horsepower capability, and we as rebuilders can then determine if the motor can develop the necessary horsepower. In our communication with the customer we also must be sure to explain that the speed change, and the impact it will have on the load requirement, is beyond our control. It is better for the customer to understand what he or she will receive, in terms of motor speed and horsepower, before the conversion is undertaken.

Much of what has been stated so far applies to conversions from 50 to 60 Hz. What if the conversion is from 60 to 50 Hz? The speed will be reduced and, almost always, the horsepower re-

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quirement will be reduced. The cube rule that applies to fans and pumps makes this an "easy" conversion for the motor. The horsepower requirement at 50 Hz will theoretically be only 58% of that needed at 60 Hz for the same application. There are other factors to consider, such as the inertia of the driven load. If the impeller or fanwheel is relatively large, it may take more horsepower to get it up to speed in a time frame that doesn't overheat or damage the motor. Constant torque conversions, such as for conveyors, do not usually introduce other concerns such as inertia, unless the application must start with a larger than normal load.

Heat Dissipation To Consider

In addition to torque and horsepower considerations, there is the issue of heat dissipation. Frequency changes from 50 to 60 Hz cause an increase in speed, and the motor cooling fan will theoretically produce 20% more airflow. The fan airflow varies directly with the speed, as long as there are no other variables such as a change in friction loss. A rule of thumb is that temperature rise is proportional to watts loss divided by airflow in cfm or m^3/sec. Therefore the 20% increase in airflow more than makes up for the increased losses associated with the higher horsepower rating at the higher frequency. Conversely, when reducing speed, the lower horsepower usually results in reduced losses. However, the reduced airflow often results in a net increase in temperature. For that reason, it is best to increase the insulation by one class. Thus, if the insulation class for the original 60 Hz rating was Class B, use at least a Class F insulation system for the 50 Hz redesign.

Let's take a look at some of the most common frequency change requests. We'll begin with the 380 V 50 Hz to 460 V 60 Hz conversion. Most conversions from 50 to 60 Hz, or vice versa, involve applications with a constant or variable torque characteristic. For constant torque applications, such as conveyors, the horsepower requirement at 50 Hz will be 5/6 of that needed at 60 Hz. If the motor is rated 380 V 50 Hz and it is now going to be used on 460 V 60 Hz, should it be rewound, or will it be useable as-is? Mathematically, the horsepower in this case is within 1% of the ratio of the speed change, as explained in the graphic at the top of the next column.

Torque is proportional to: $(E_2/E_1) \times (F_1/F_2)$

Where:
E_1 = Original voltage rating
E_2 = New voltage rating
F_1 = Original frequency
F_2 = New frequency

Inserting the values from this example:

Torque change = (460/380) x (50/60)
= 1.009 [about a 1% increase]

That means that the torque will be almost constant at either frequency, and from that perspective, the motor need not be rewound. Further, since the airflow increase more than offsets the losses associated with the higher horsepower at 60 Hz, the motor should operate at a lower temperature. Also, the rated current will be only slightly higher, so the I^2R losses of the stator and rotor will not change appreciably. Magnetically, the flux levels are almost unchanged, therefore the core losses will not measurably increase. The friction and windage losses will, however, be greater due to the increased speed. Not only is the motor capable of operating at the higher frequency and voltage without rewinding, it may run cooler and possibly be more efficient.

What will happen if the scenario is reversed, that is, if the motor is to be used on 50 Hz? Using a 460 V 60 Hz motor on 380 V 50 Hz will of course reduce the speed by the ratio of 5/6 (50/60). The horsepower will also be reduced in proportion to the speed change, within the same 2% tolerance as for the speed increase. The torque will remain constant, so from the torque perspective a rewind would not be necessary. However, the impact of the losses on temperature rise must also be considered, as it was for the speed increase. At the lower frequency and speed the flux levels will remain virtually unchanged, as will the stator and rotor currents. The variable is again the friction and windage loss. Friction and windage are reduced; however, a negative byproduct of reducing windage is the reduction of airflow. The 17% reduction in speed equates to a 17% reduction in airflow.

Consider Airflow, Losses, Temperature

However, the rule of thumb about airflow,

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losses and temperature rise tells us that for the same watts loss and a 17% reduction in airflow, the temperature will rise about 20%. We might at first assume that the watts loss will be less because of reduced friction and windage; however, the increased temperature rise results in increased I^2R losses in both the stator and rotor. Figuring out the exact change with two independent variables, temperature rise and winding resistance is a complex issue beyond the scope of this article.

For simplicity we shall assume they offset each other. That means that the motor will run 20% hotter. Let's assume the winding is Class B and had a temperature rise of 60 degrees C at the 60 Hz rating. The 20% increase would add 12 degrees C to the temperature of the winding. Using another rule of thumb, that every 10 degrees C increase in temperature reduces winding life in half, we know that this winding will have less than half its normal life at the reduced frequency and speed. The right thing to do is to rewind to a higher temperature class; this will more than make up for the increased temperature's effect on winding life.

We don't want to leave the impression that all frequency changes work out as well as the two examples above. For our final example, we'll perform a frequency change with a voltage value brought about by a change in an international standard. Some of us may recall that a few decades ago in the U.S. the voltage standards changed. For example, the 440 V motor rating became the 460 V motor rating. The International Electrotechnical Commission (IEC) has made a similar change that affects many countries in Europe and elsewhere. The former 380 V standard rating has been changed to 400 V.

Following the same steps as in the examples above, let's consider a change from 400 V-50 Hz to 460 V-60 Hz.

Torque is proportional to: $(E_2/E_1) \times (F_1/F_2)$

Where:
E_1 = Original voltage rating
E_2 = New voltage rating
F_1 = Original frequency
F_2 = New frequency

Inserting the values from this example:

Torque change = (460/400) x (50/60)
= 0.958 [about a 4% reduction]

The horsepower increase in this case will be effectively reduced because of the voltage change ratio. See the graphic in the left column for the mathematics involved in determining this value. If the 60 Hz value were 480 V, the horsepower would have changed in proportion to the frequency change, that is, it would have increased by 20%. The horsepower in this example will only increase about 15% if the motor is not rewound. The mathematics behind these relationships are given in the graphic below.

Relationship between speed, horsepower and torque:

HP = (T x rpm)/K

Where:
T = Torque
Rpm = speed
K= a constant factor depending on the units of measurement

Speed is proportional to frequency, therefore at 60 Hz, speed will be (60/50) 1.20 times faster than at 50Hz.

If T is constant (and K is a constant), we can think of them as having a value of 1.0 before and after the frequency change. Since speed increases by 1.20, then the change in HP can be calculated as:

HP = (1 x 1.20)/1 = 1.20

For the case where torque is reduced about 4%, the formula becomes:

HP = (0.958 x 1.20)/1 = 1.15

If torque must be maintained, or increased, a rewind and redesign will be necessary. The airflow will increase, and that will help cool the motor although the losses will be higher if the winding is redesigned for increased torque. That new winding will have higher magnetic flux densities, with associated higher losses. The friction and windage losses will also be greater due to the increased speed. The motor may run cooler at the higher speed; however, the efficiency will be somewhat reduced due to the higher magnetic flux levels.