When it comes to motors, how hot is hot?

Temperatures that are too high affect machine performance, life

By Jim Bryan
EASA Technical Support Specialist

We often hear from members that a customer has reported that a motor that has been repaired is now running hot. We always ask how hot and the reply frequently is: "Well, I can't hold my hand on it!" Let's think about that answer for a minute. The typical human can tolerate about **60-65° C (140-150° F)** depending on calluses, threshold of pain, how many people are watching, etc. **Remember that number as we discuss typical motor operating temperatures.**

NEMA MG1-2009 12.43 (see **Figure 1**) defines temperature rise for motors in a maximum ambient of 40° C. **Two notes here:** 1. Since the standard uses Celsius, we will not convert all the temperatures to Fahrenheit for sake of simplicity. 2. Ambient temperature, frequently abbreviated "Amb." or "AMB" on a motor nameplate, refers to the surrounding air temperature. Some confuse this with the expected temperature rise of the motor, which it is not.

We will focus on the Class F (155° C) temperature rating since it is a popular choice today. The allowable maximum rise ranges from 105-115° C for each of the various parts of the motor depending on the motor configuration.

The winding embedded in the slot is almost always the hottest part of the motor. If the motor our customer has reported has a 1.15 service factor, the maximum rise is 115° C (see **Figure 1**, item a. 2.) plus the 40° C ambient means the total winding temperature can reach 155° C.

Motor construction

The surface of the motor where the customer tried to lay his hand will be somewhat cooler depending on the motor construction. Compared to the winding hot spot, a large cast iron, totally enclosed, fan cooled (IP 54) motor may have a difference of 20-25° C at the surface. Rolled steel frame motors with their surface much closer to the winding may only see a 10-15° C difference. The difference in contact area between flat rolled steel and ribbed cast iron surfaces will affect the amount of heat transferred to our customer's hand as well. The temperature difference for an open drip-proof motor (IP 12) is often much greater, as much as 60° C. The same is true of Weather-Protected I (WP I) or Weather-Protected II (WP II) enclosures.

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Of course the motor designer is not going to use the entire margin he has and make the motor run right at the maximum temperature allowed. **Figure 2** on Page 4 illustrates the effect of temperature on the life of the insulation system. Basically, for every 10° C rise in operating temperature, the insulation life is reduced by one-half. So the ultimate design is an optimization of life, function and cost to produce and maintain efficient operation of the motor.

Suppose our design operates with a 65° C rise, which is a very conservative design by most standards. If it is a hot summer day of 35° C (95° F), the winding total temperature will be 65 + 35 = 100° C. Our motor is constructed such that the surface is about 20° C cooler than the winding so the surface is 100 – 20 = 80° C (176° F); much too hot to safely touch!

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Class of Insulation System (see 1.65)	A	B	F*	H*†
Time Rating (shall be continuous or any short-time rating given in 10.36)				
Temperature Rise (based on a maximum ambient temperature of 40°C), Degrees C				
a. Windings, by resistance method				
1. Motors with 1.0 service factor other than those given in items a.3 and a.4	60	80	105	125
2. All motors with 1.15 or higher service factor	70	90	115	...
3. Totally-enclosed nonventilated motors with 1.0 service factor	65	85	110	130
4. Motors with encapsulated windings and with 1.0 service factor, all enclosures	65	85	110	...
b. The temperatures attained by cores, squirrel-cage windings, and miscellaneous parts (such as brushholders, brushes, pole tips , etc.) shall not injure the insulation or the machine in any respect				

Figure 1. Maximum temperature rise for motors. (From *NEMA MG1-2009 12.43.*)

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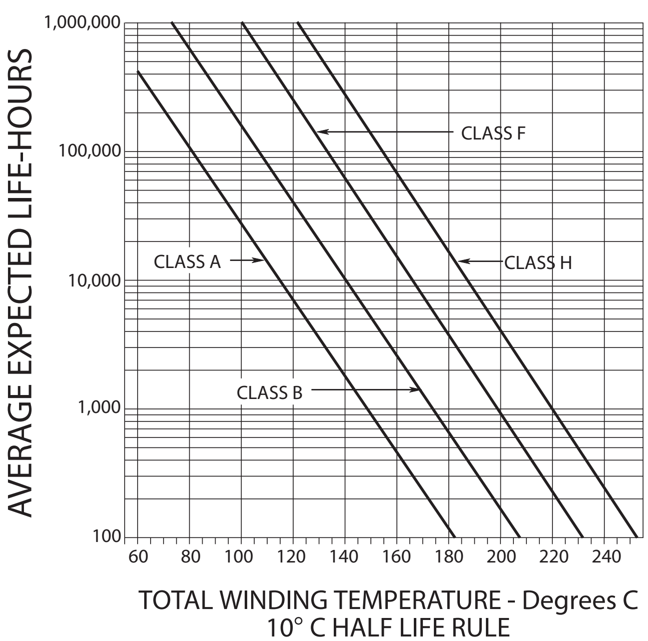

Figure 2. Insulation life vs. temperature.

Remember, since we chose a conservative design, many motors are going to be much warmer.

As is the case with many governing standards, there appears to be a contradiction. ***NEMA MG1 12.56*** and **Table 12-8**, just a few pages after the previously cited reference, lists much different temperatures for the same insulation classes as shown in **Figure 3**.

"Thermally Protected" motors

The temperatures in **Figure 3** refer to motors that are "Thermally Protected." Thermally protected is defined as having the words "Thermally Protected" on the nameplate of the motor indicating that the motor is provided with a thermal protector. A thermal protector is a device that is an integral part of the machine which, when properly applied, protects the machine from dangerous overheating. So this is the exception to the rule: if the motor has this added, special layer of protection, the higher temperatures ***may*** be allowed. This application is generally reserved for smaller motors. Once again, unless there are application considerations that make it necessary, the designer will not use the entire margin he has and make the motor run right at the maximum temperature allowed.

Sometimes an application requires that a motor be housed in an enclosure for noise abatement or other reasons. Special care should be given to control the ambient temperature ***inside*** the enclosure where the motor is located. If there is auxiliary cooling air provided equivalent to the volume of air that the motor's integral fan supplies, the cooling is usually adequate.

If the driven equipment is also contained in the enclosure, it may also contribute to the motor temperature rise. Compressors generate large amounts of heat as the gas is compressed. For example, one large application involved over 100 medium motors (details vague to protect the innocent). The motors drove compressors, each of which were contained in a large enclosure. The compressor had a radiator to cool the gas as it was compressed and liquefied. Unfortunately, the cool air was drawn into the enclosure through the radiator by a fan on the same motor that drove the compressor and then exhausted on the opposite side. Ambient temperatures as high as 70º C were measured inside the enclosure. Not only did this thermally stress the winding insulation to the limit, but many of the bearings failed when the lubricant was overheated and evacuated the bearing housings.

Table 12-8
WINDING TEMPERATURES

Insulation System Class	Maximum Winding Temperature, Degrees C
A	140
B	165
F	190
H	215

Figure 3. Maximum temperatures in Thermally Protected motors. (From *NEMA MG1-2009*.)

Conclusion

Temperature is often the Number 1 enemy of the electric motor. Care must be taken in the design, application and maintenance of these machines to optimize their performance and life. All that said, it is unsafe to lay your hand on a motor to see if it is too hot; get a thermometer instead. ■

