

Temperature Monitoring Is Key To Motor Reliability

Written by Thomas H. Bishop, Electrical Apparatus Service Association
Thursday, 01 July 2004 19:12

Regularly checking the operating temperature of each critical motor will pay dividends.

It is no secret that heat kills electric motors. But it is easy to forget that exceeding the rated operating temperature by as little as 10 C (18 F) can shorten the life of a three-phase induction motor by half.

The first step to prevent unexpected shutdowns and extend motor life is to determine the temperature rating of the motor. The National Electrical Manufacturers Association (NEMA) defines this rating for three-phase induction motors in its standard Motors and Generators, MG 1-2003. Temperature rating also can be found on the motor's original nameplate. Once the temperature rating is known, the temperature rise can be measured directly using sensors or an infrared temperature detector, or indirectly using the resistance method.

Key terms

Ambient temperature is the temperature of the air (or other cooling medium) that surrounds the motor. The difference between the ambient temperature and that of a motor operating under load is the temperature rise (temperature rise = hot temperature – ambient temperature).

NEMA rates insulation according to its ability to withstand overall temperature. For example, a Class B insulation system is rated 130 C, while a Class F system is rated 180 C. Since the maximum ambient temperature according to NEMA MG 1-2003 is normally 40 C, one would expect the temperature rise limit for a Class B system to be 90 C (130 C – 40 C). But NEMA also builds in a safety factor, primarily to account for hot spots—i.e., parts of the motor winding that may be hotter than the location at which the temperature is measured. See [Fig. 1](#).

[Table 1](#) shows the temperature rise limits for NEMA medium electric motors based on a maximum ambient temperature of 40 C. In the most common speed ratings, the NEMA designation of medium motors includes ratings of 1/2–500 hp for 2- and 4-pole machines, and up to 350 hp for 6-pole machines.

Temperature rise limits for large motors—i.e., those above medium motor ratings—differ based on the service factor (SF). [Table 2](#) lists the temperature rise for motors with a 1.0 SF; [Table 3](#) applies to motors with 1.15 SF.

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Resistance method

The resistance method is useful for determining the temperature rise of motors that do not have embedded detectors—e.g., thermocouples or resistance temperature detectors (RTDs). Note that temperature rise limits for medium motors in Table 1 are based on resistance. The temperature rise of large motors can be measured by the resistance method or by detectors embedded in the windings as indicated in Tables 2 and 3.

To find the temperature rise using the resistance method, measure the lead-to-lead resistance of the line leads with the motor cold—i.e., at room (ambient) temperature. Be sure to record the ambient temperature as well. Then run the motor at rated load long enough for the temperature to stabilize (up to 8 hours sometimes) and measure the hot resistance in the same way.

Plug the cold and hot resistance measurements into the following equation to find the hot temperature then subtract the ambient temperature from the hot temperature to obtain the temperature rise.

$$T_h = [(R_h/R_c) \times (K + T_c)] - K$$

where:

T_h = hot temperature

T_c = cold temperature

R_h = hot resistance

R_c = cold resistance

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$K = 234.5$ (a constant for copper)

Example: An unencapsulated, open drip-proof medium motor with a Class F winding and a 1.0 service factor has a lead-to-lead resistance of 1.02 ohms at an ambient temperature of 25 C, and a hot resistance of 1.43 ohms. The hot winding temperature would be:

$$T_h = [(1.43/1.02) \times (234.5 + 25)] - 234.5 = 129.3 \text{ C (round to 129 C)}$$

The temperature rise equals the hot winding temperature minus the ambient temperature, or in this case:

$$\text{Temperature rise} = 129 \text{ C} - 25 \text{ C} = 104 \text{ C}$$

Notice that the calculated temperature rise of 104 C in the example is just 1 deg below the limit for Class F (105 C) in Table 1. Although that is acceptable, it is important to keep in mind that any increase in load will result in excessive temperature rise and serious thermal degradation of the motor's insulation system. Further, if the ambient temperature at the motor installation were to go above 25 C, the motor load would have to be reduced to avoid exceeding the machine's total temperature (hot winding) capability.

Determine temperature rise using detectors

Motors equipped with temperature detectors embedded in the windings are usually monitored by directly reading the output of the detectors with appropriate instrumentation. Typically, the motor control center has panel meters that indicate the temperatures sensed by the detectors.

If the embedded detectors are not connected to the controls, a handheld temperature meter can sense the output of the detector leads while the motor is operating. The output temperature displayed is the hot winding temperature at the location of the sensor. If a handheld temperature detector were to read 129 C as in the example above, the same concerns about the overall temperature would apply.

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How do you determine the operating temperature of a motor winding that does not have embedded detectors? For motors rated 600 V or less, it may be possible to open the terminal box (following all applicable safety rules) and access the back of the stator core iron laminations with a thermocouple (see [Fig. 2](#)). The stator lamination temperature will not be the same as winding temperature, but it will be closer to it than the temperature of any other readily accessible part of the motor.

If the lamination temperature minus the ambient temperature exceeds the rated temperature rise, it is safe to assume that the winding is also operating beyond its rated temperature. For instance, had the stator core temperature in the above example measured 136 C, the temperature rise for the stator would have been 136 C – 25 C, or 111 C. That exceeds NEMA's limit of 105 C for the winding, and the winding can be expected to be hotter than the laminations.

The critical limit for the winding is the overall or hot temperature. Again, that is the sum of ambient temperature plus the rise. In large part, the load determines the temperature rise because the winding current increases with load. A large percentage of motor losses and heating (typically 35–40 percent) are due to the winding I²R losses. The “I” in I²R is winding current, and the “R” is winding resistance. Thus the winding losses increase at a rate that varies as the square of the winding current.

Adjusting for ambient

The ambient temperature also may be a factor. If it exceeds NEMA's usual limit of 40 C, the motor must be derated to keep the total temperature within the overall or hot winding limit. To do so, reduce the temperature rise limit by the same amount that the ambient exceeds 40 C.

For instance, if the ambient is 50 C and the temperature rise limit in Table 1 is 105 C, decrease the temperature rise limit by 10 C (50 C – 40 C ambient difference) to 95 C. This limits the total temperature to the same amount in both cases. That is, 105 C + 40 C = 145 C, and 95 C + 50 C = 145 C.

Regardless of the method used to sense winding temperature, the total or hot spot temperature is the real limit, and the lower, the better. Each 10 C increase in operating temperature shortens motor life by half, so check motors under load regularly. Do not let excessive heat kill motors before their time. **MT**

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Shutdown and Alarm Range Based on Insulation Systems

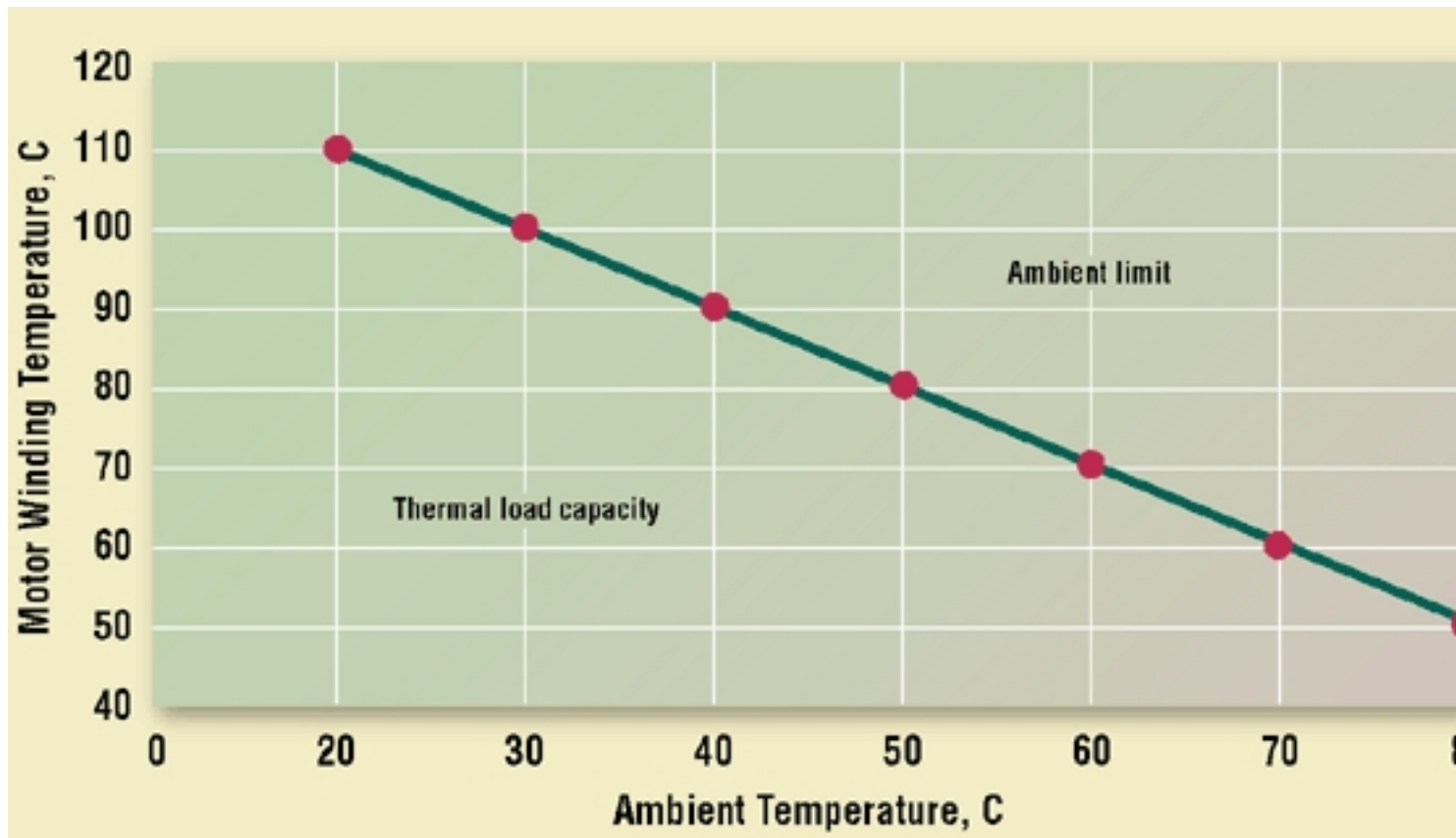


Fig. 1. Hot spot temperature vs ambient and rise for Class B insulation system. Note that at 40 C ambient (horizontal axis), the rise is 90 C (vertical axis). The sum of the ambient and temperature rise will always be 130 C for a Class B insulation system.

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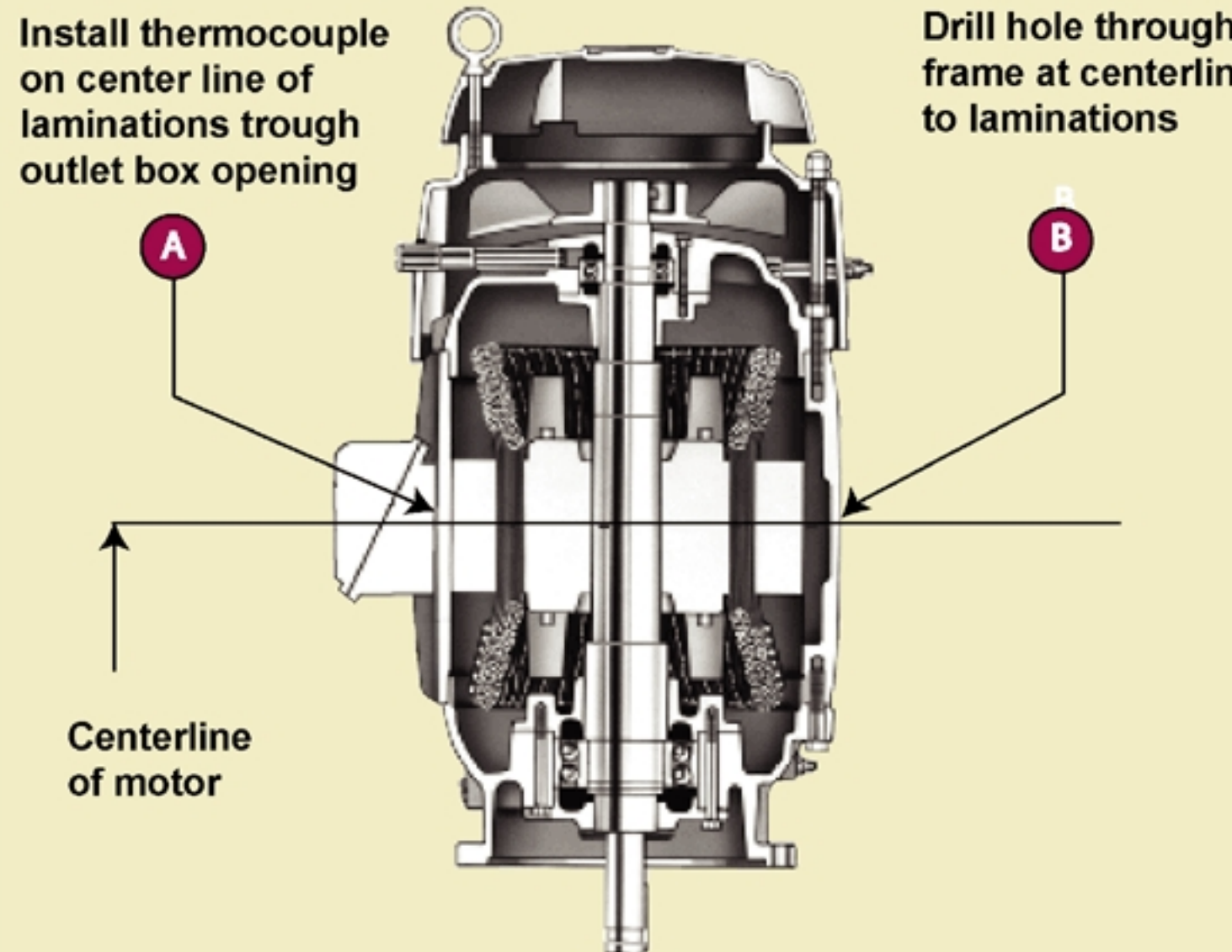


Figure 1 It is possible to determine the approximate temperature of the winding with
Table 1. Temperature rise by resistance method for medium induction motors based
on
a maximum ambient temperature of 40 C

Insulation Class and Temperature Rise C
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Motor Type

A

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B

F

H

1

Electric motors with 1.0 service factor (SF) other than those in 3 or 4.

60

80

105

125

2

All electric motors with 1.15 or higher SF

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70

90

115

3

Totally-enclosed nonventilated electric motors with 1.0 SF

65

85

110

130

4

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Electric motors with encapsulated windings and with 1.0 SF, all enclosures

65

85

110

(Ref. NEMA MG 1-2003, 12.43).

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Table 2. Temperature rise for large motors with 1.0 service factor at rated load

Insulation Class and
Temperature Rise C

Motor Rating

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Method of Determination

A

B

F

H

1

All hp (kW) ratings

Resistance

60

80

105

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125

2

1500 hp (1120 kW) and less

Embedded detector

70

90

115

140

3

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Over 1500 hp (1120 kW) and 7000 V or less

Embedded detector

65

85

110

135

4

Over 1500 hp (1120 kW) and over 7000 V

Embedded detector

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60

80

105

125

(Ref.: NEMA MG 1-2003, 20.8.1).

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Table 3. Temperature rise for large motors with 1.15 service factor at rated load

Insulation Class and Temperature Rise C
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Motor Rating

Method of Determination

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A

B

F

H

1

All hp (kW) ratings

Resistance

70

90

115

135

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2

1500 hp (1120 kW) and less

Embedded detector

80

100

125

150

3

Over 1500 hp (1120 kW) and 7000 V or less

Embedded detector

75

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95

120

145

4

Over 1500 hp (1120 kW) and over 7000 V

Embedded detector

70

90

115

135

(Ref.: NEMA MG 1-2003, 20.8.2).

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