Excessive Heat In Electric Motors: A Common Root Cause of Insulation Failure

Introduction

Maintenance professionals widely accept predictive maintenance (PdM) as a significant means of cost savings. However, preventive maintenance (PM) is still viewed as a viable option when it comes to motor maintenance. This assertion is based upon the inability of conventional technologies used over the past decade to perform credible root cause analysis. With respect to the diagnostic electrical tool-belt, the days of the handheld multi-meter and the meg-ohm meter as sole tools in cost effective maintenance are over. Modern on-line motor monitoring technologies permit easy assessment of the entire motor/machine system, which includes power source, motor and the load placed upon the motor. By focusing on the entire motor system instead of one or two components, true troubleshooting solutions become available.

Of heat and motor life expectancy

Maintenance experts agree that excessive heat will cause rapid deterioration of the winding insulation within motors. The common rule states that, for every 10°C of additional heat to the windings, motor insulation life is cut in half. For example, a motor that would normally last 20 years in regular service is running 40°C above rated temperature; under these conditions, the motor would only have a life of about 1/16 of its expected span, or a little more than one year to run until it failed.

Many articles and studies written over the years agree with this rule. Leading standards organizations have come to the conclusion that 30 percent of motor failures result from insulation failure, and 60 percent of those are caused by excessive heat in the motor.

There are typically five main reasons a motor will overheat. These items include excessive load placed upon the motor, a poor power condition, a high effective service factor, excessive stops and starts, and environmental influences.

Excessive voltage

Stator current is a frequently used measurement of load level but it can easily be masked by an overvoltage condition. A common mistake is made in the practice of operating at an over-voltage in order to reduce the stator current. The intention is to proportionally reduce the introduction of heat. It has been shown that in motors ranging from 10 to 200 hp that the decrease of losses obtained by operating at a 10 percent over-voltage would typically only be about one to three percent. Though the current of a motor may vary considerably with application of excessive voltages, any heat in the motor will not decrease. A 10 percent (or greater) load error can be introduced simply due to reliance upon stator current readings to assess probable load and expected heat levels. Under full-load conditions, this can mean life and death to a motor.

In an example taken from a coal-fired power plant in the United States, a 7,000 hp 6.6 kV motor was running at just 7 percent over-current, but with an 8 percent over-voltage. Two identical applications had previously undergone unscheduled outages within the previous 12 months. When the stator current of this motor was analyzed, a mild overload was detected. However, over-loading of nearly 20 percent was determined after looking at the true load to the motor. This explains why these motors were failing. Costs for repairs to each of these motors ran in the hundreds of thousands of dollars, underscoring the critical importance of performing root-causes analysis in context of the motor's operational environment.

In real-world applications, perfect voltage conditions are rare. Losses, and not current level alone, are a cause of excessive heat. These losses are not only destructive to windings, they contribute to bearing damage as well.

This underscores the need for accurate knowledge of operational load level. Only accurate load-level calculations can provide reliable measurements of excessive losses and consequential overheating conditions with a motor.

Power condition

Because power conditions are often poor within industrial facilities, electric motors need to be derated in order to maximize useful life. NEMA MG-1 sections II and IV specify what voltage quality, as a function of balance and distortion, allows what level of percentage load.

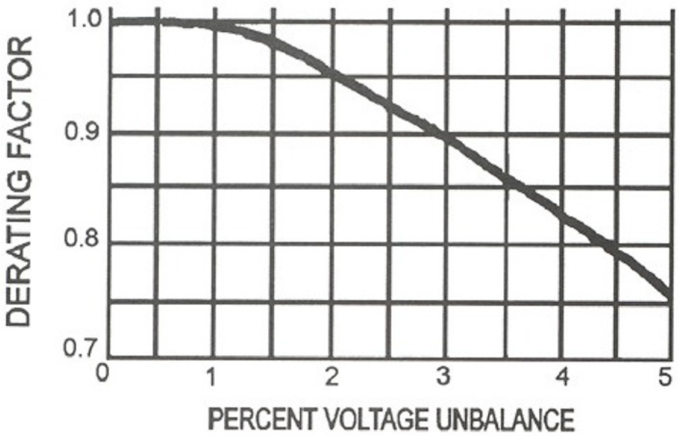

Figure 1: NEMA derating curve

Figure 1 shows the NEMA derating curve for percentage of unbalance. This figure is defined in the following formula:

$$\text{\% Unbalance} = \frac{\text{100 x maximum voltage deviation from average voltage}}{\text{Average voltage}}$$

The use of the derating curve is best described as the higher the level of unbalance, the lower the acceptable level of steady state load. For example: If a 100 hp motor had an unbalance factor of three percent, the motor would need to be derated to 0.9, or to 90 percent of its capacity (meaning 90 hp).

The increased use of variable-frequency drives (VFDs) is revealing they have detrimental effects upon electric motors, and largely due to the condition of power within manufacturing facilities. Figure 2 shows the voltage that a VFD (running at nearly a six-pulse mode) will send to the motor. The distorted currents are the motor's reaction to poor power condition. Very severe distortions are evident. This scenario shows a NEMA derating of 0.7, which allows the motor to be operated at 70 percent output.

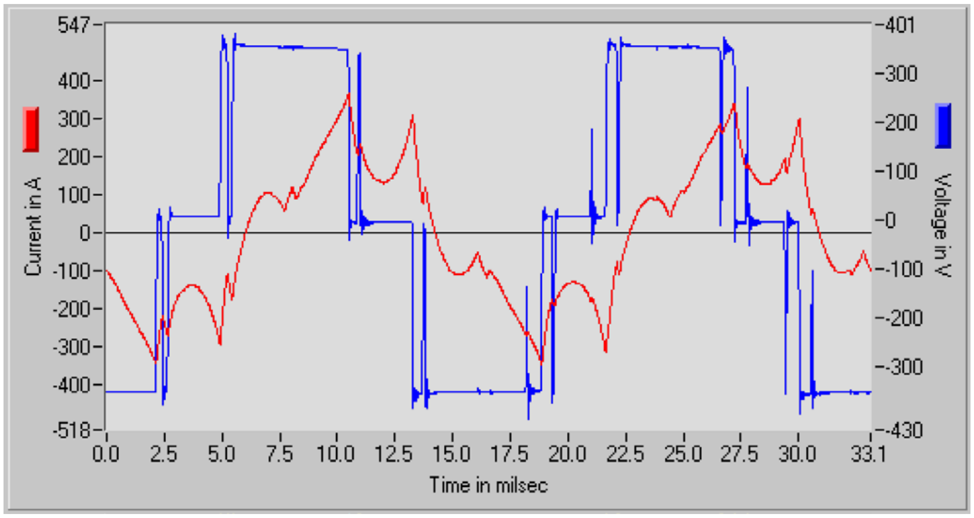

Figure 2: Extreme distortion in a slow-switching VFD (50 hp, 4-pole)

Effective service factor

It is not a trivial matter to bring voltage and current level, operating speed and input power standards to the field. There haven't been accurate measurement-based load estimation methods available—that is, until lately. The key to finding the most frequent reasons of overheating is proper load level identification. To perform this, it is crucial to have the best possible accuracy in the estimation of load level. This can be obtained by looking at only currents and voltages. In the past, less accurate methods lead to major miscalculations, in particular in cases where voltage conditions weren't optimal. Unfortunately, these conditions are all too common in the field. The formula for calculating effective service factor is:

$$\text{Effective service factor} = \frac{\text{\% Load}}{\text{\% NEMA derating}}$$

Effective service factor is beneficial because it offers the combination of professional standards and real life applications, which in turn enables a solid determination of stress on any particular motor-load application. With the use of a dynamometer, a 300 hp motor under test was running at nearly full load, (99.7 percent). Voltage distortion was poor due to a previously-unidentified SCR defect in the power supply. The resulting NEMA derating factor of 0.85 rendered an effective service factor of 1.17, which signaled an alarm condition. Regardless of the nameplate service factor, any motor that operates above 1.0 s.f. is under stress. A service factor greater than 1.0 signifies a motor's capacity for overload only for short periods of time, not longer steady-state operation. Again, because poor voltage conditions are frequent and can be caused by a variety of reasons, NEMA specifies the load level that is permitted for poor voltage conditions. Only preventive maintenance on-line tools capable of accurate calculations of operating load can ensure that a plant operates with healthy limits.

Frequent starts and stops

Table 1 displays the maximum number of starts and stops for line-operated motors as a function of rating and speed. This underscores the importance of limiting the frequency of startups, which place the most stress on a motor during operation. A number of well-documented cases of recurrent motor failure were related to increases it the horsepower rating of the motor. This often shortened time between failures, but the root cause of the failure was really the high number of starts and stops. This makes it very important to closely monitor the number of starts, which can be as frequent as hourly for small or medium motors, and daily for larger motors.

HP	2-Pole		4-Pole		6-Pole	
	A	C	A	C	A	C
1	15	75	30	38	34	33
5	8.1	83	16.3	42	18.4	37
10	6.2	92	12.5	46	14.2	41
15	5.4	100	10.7	46	12.1	44
20	4.8	100	9.6	55	10.9	48
50	3.4	145	6.8	72	7.7	64
75	2.9	180	5.8	90	6.6	79
100	2.6	220	5.2	110	5.9	97
200	2.0	600	4.0	300	4.8	268
250	1.8	1000	3.7	500	4.2	440

A = Maximum number of starts per hour

C = Minimum rest or off time in seconds between starts

Today's on-line motor monitoring equipment helps ensure full compliance to professional standards. It identifies reasons of failure when faced with an operation that does not comply with standards by including these standards into long-term unsupervised monitoring.

Environmental conditions

Thermography is frequently used to determine the heat electric motors are operating under. Poor thermal conditions such as high ambient temperature, clogged ducts, etc., are typical examples of non-electrically induced temperature stress to both the motor and insulation system. Chemical abrasive substances in the air, wet operation, and high-altitude operation are a few common environmental stresses.

Conclusion

Bearing and winding failures are the most common motor failures. The fundamental reason is excessive heat. Today's preventive maintenance practices frequently limit on-line electrical measurements to interpreting current levels. While tremendously valuable, this method is inconclusive when it comes to failures caused by excessive winding heat. The best way to ensure successful preventive maintenance and monitoring is to test according to NEMA and other professional standards. Effective service factor is a reliably good measurement that allows difficult standards to be interpreted for day-to-day plant operation. Even though instrumentation has not been available to monitor the frequency of starts and stops, it is an important aspect to consider in management for motor integrity. Automated assessment is necessary to effectively ensure motor health.

The more successful root cause analysis of motor failure or stress, the more suitable predictive maintenance becomes for plant management. This point represents good news for business; since electrical on-line monitoring technology has successfully become an equal partner with vibration in maintenance management to maximize plant operation and uptime.

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