THE CAUSE, ANALYSIS & PREVENTION OF ELECTRICAL & MECHANICAL FAILURE IN THREE PHASE ELECTRIC MOTORS

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The three phase squirrel cage induction electric motor built today is the most efficient electric motor that the industry has ever produced. It is the product of over one hundred years of evolution in materials and design of rotating electrical apparatus.

Technology has allowed the manufacturer to reduce the physical size of the electric motor while increasing its efficiency. Concurrent with this reduction in frame size per horse power, we have experienced a product that is more sensitive to aberrant line, load and operating conditions than the more massively built product of previous generations.

This paper will explore the conditions that compromise the electrical and mechanical life expectancy of the modern state-of-the-art electric motor.

To illustrate the changes in NEMA frame sizes of electric motors, let us evaluate the evolution of a 5 HP 1800 RPM squirrel cage open drip motor over the last four decades.

In 1950, this motor was in a 254 original NEMA frame and weighed approximately 195 lbs. With the NEMA redesign of 1952, this same 5 HP motor was condensed into a NEMA 215 frame and weighed 127 lbs. With the NEMA redesign of 1965, the 5 HP motor was further condensed to the smaller and current 184 frame weighing 88 lbs.

The same 254 frame that was able to accomodate a 5 HP 4 pole motor in 1950, today accomodates a 15 HP 4 pole electric motor. The larger mass of the older apparatus represented a considerable heat sink for all the conditions that cause motor thermal failures. Consequently, the original NEMA and 1952 rerated motors were more forgiving of all the detrimental conditions that result in motor failures and particularly premature failure.

The apparatus we use today is quite a different piece of equipment from that of yesteryear and a higher level of concern for its application and aberrant operational conditions must be considered if we are to maximize the design life and our return on capital investment.

In order to preserve our investment in our rotating apparatus, it is incumbent that we understand the conditions that impact the electrical and mechanical life expectancy of the current vintage state-of-the-art electric motor.

We will focus on five critical areas:

1. Electrical
2. Mechanical
3. Thermal
4. Environmental
5. Application

Electrical Stresses

There is a relationship between insulation life and the voltage stresses applied to the motor insulation system. These stresses can be identified by the nature of the failure.

1. Phase to phase
2. Turn to turn
3. Turn to ground

Voltage transients and surges result in reduced winding life or premature failures of electrical rotating apparatus. These transient and surge voltages can be caused by any of the following conditions:

1. Lightning strike - direct or indirect
2. Contactor switching
3. Capacitor switching
4. Repetitive arcing

Rotating AC machines operating from a distribution system will be exposed to all the above conditions which result in transient and steep front voltage surges of substantial magnitude. To acceptably cope with such transients and steep front waves, lightning arrestors and surge protection capacitors should be installed at the motor terminals with critical attention given to connecting lead lengths.

Mechanical

Over 50% of all rotating electrical apparatus failures are mechanical in nature and are precipitated by bearing or shaft fatigue. Mechanical failures can be identified by the following:

1. Improper lubrication of anti-friction bearings
   A. Over lubrication
   B. Under lubrication
   C. Grease incompatibility

Bearing housing cavity fill is a function of the speed ratio of the operating speed of the motor divided by the limiting speed of the bearing. The lower the ratio, the higher the cavity fill and the higher the ratio, the lower the cavity fill. On most NEMA frame motors, a good rule of thumb for bearing cavity fill would be 40% - 50% fill. Bearing lubrication intervals for anti-friction bearings depend on the severity of service and motor RPM. The more severe applications with higher speed motors require higher relubrication intervals.

In general, bearing manufacturers recommend that lubricants not be mixed because of incompatibility problems. The user must determine which lubricants are compatible with each other. If in doubt about the compatibility of certain greases, ask your lubrication vendor. If it is necessary to co-mingle lubricants, be careful not to combine different oil bases or thickeners. Do not mix a mineral oil based grease with a synthetic oil based grease. Likewise, a grease with a lithium thickener should not be mixed with one containing a sodium thickener.

2. Improper belt tension creating bearing and shaft stresses

Over tension of V-belt drives is a product of either worn sheaves or belts requiring excessive drive tension in order to transmit motor torque to the driven machine. Sometimes stress can be caused by using too small a drive sheave or placing the sheave on the end of the shaft causing an overhung load condition.

On sleeve bearing motors, mechanical problems are usually associated with misalignment, bed plate problems, soft foot and under lubrication.

If you desire to protect your electric motor from a catastrophic mechanical failure, bearing RTD's and vibration monitors should be considered.

Thermal Degradation of Insulation Systems

Test procedures can be used to determine the effects of temperature on the life of the winding insulation system. But as a rule of thumb, for every 10° C increase in operating temperature beyond the insulation thermal design, the insulation life will be reduced by one-half. Conversely, if the operating temperature is reduced 10° C below the insulation thermal maximum, the insulation life is doubled.

Once the insulation system has lost its dielectric and physical integrity, it can no longer resist the normal dielectric, mechanical and environmental stresses that the motor is subjected to.

Some of the causes of thermal degradation and premature winding failures are:

1. High voltage

Voltage more than 10% above motor rated voltage will cause the motor stator to magnetically saturate. This causes the motor current and temperature to increase. A decrease in power factor is associated with high voltage.

2. Low voltage

According to NEMA standards, all motors are to operate on +- 10% of rated voltage. Although the motor will operate with +- 10% of rated voltage, the horsepower of the motor varies at the square of the applied voltage variation. Power is a product of volts times amperes times 1.73. The load on an electric motor is determined by the driven machinery. When voltage decreases, the current must go up for the product to equal the same value.

3. Cycling

During starting, the locked rotor current will be four to seven times the normal full load current. If a motor is subjected to repeated starts within a short period of time, the winding temperature will rapidly increase. Most motors should not be cycled on-off more than ten times an hour. Starting limitations on large motors may allow only one start with a cool down to ambient temperature. Totally enclosed motors are more sensitive to short cycling than open type motors. If in question, ask your motor manufacturer concerning cycling limitations.

4. Unbalanced voltage

A very small amount of unbalanced voltage will cause an excessive increase in winding temperature. As a rule of thumb, for a 3 1/2% voltage unbalance, the winding temperature will increase 25%.

5. Overloading

The winding temperature will increase as the square of the overload.

6. Obstructed ventilation

Heat generated in the rotor and stator is dissipated by conduction, convection and radiation. Anything which will obstruct the flow of air through or over the motor or that will impede the radiation of heat from the motor surface will cause an increase in winding temperature.

7. Ambient temperature

NEMA calls for standard motors to be designed to operate at a maximum of 40°C/104°F. When ambient temperatures are encountered above 40° C, the motor load must be reduced. If load is not reduced in high ambient conditions, the motor insulation life will be compromised.

8. High altitudes

NEMA calls for standard motors to be designed to operate up to 3300 ft. above sea level. If altitudes above 3300 ft. are encountered, the motor load should be reduced. If the load is not reduced at high altitudes, the motor insulation life will be compromised.

9. Primary and secondary single phasing

Single phase operation of a three phase motor is the maximum condition of voltage unbalance. It can result from an open phase on either the primary or secondary side of the distribution transformer.

Environmental Conditions

Another term for environmental condition might be contamination. Contamination in the presence of the operating electric motor can have the following consequences on the motor:

1. Reduction of heat dissipation with a consequent increase in operating temperature and compromised insulation life

2. Premature bearing failure

3. Degragation of the insulation integrity causing shorts and grounds in the insulation system

Misapplication of Torque Design

Motor rotor designs A, B, C, D & F have to do with the motor torque produced on starting, the magnitude of locked rotor current and full load slip. Problems will be experienced when motor design types are misapplied.

If an electric motor is designed, built, applied, installed, operated and maintained properly, the effects of the stresses we have reviewed can be mitigated and the motor will function throughout its electrical and mechanical design life. However, each of these elements varies from user to user and so does the anticipated life of the motor.