Modern Motor Testing Offers Maintenance Professionals Increased Efficiency

A motor supplying compressed air in a smelting plant fails, a motor necessary to pump petroleum products goes offline in a petrochemical plant, a motor essential to the operation of the number one line in a manufacturing plant goes down on the third shift. Each failure is unexpected, and, all are costly. Downtime can cost plants thousands, even hundreds of thousands of dollars per hour in lost productivity due to unexpected failures.

These situations can be avoided if an effective predictive maintenance program is in place. A motor rarely, if ever, fails when it is not critical to your operation. However, you can minimize these costly outages by implementing a proactive testing program. An important part of this program is the testing of the insulation system.

Traditional maintenance practices for repair or replacement of critical pieces of equipment upon failure has become unacceptable to most maintenance professionals. Therefore, predictive maintenance programs are an essential component to maintaining motor reliability. But what makes up a complete predictive maintenance program? Even though many failures are mechanically related, for this article we will focus on tests that deal with electrical failures. There have been several theories developed about the use of electrical test equipment. Low Voltage vs. High Voltage testing has confused the maintenance professional. With statements from industrial equipment manufacturers discrediting each other concerning safety and viability of testing procedures, who is the maintenance professional to believe? With the amount of defamatory statements that have been made, where does the truth about testing really lie?

Since the 1980's, the advances in high voltage equipment have enabled testing to be performed as a highly standardized evaluation of the electrical health of an entire motor insulation system. Standard organizations such as IEEE, IEC, EASA and NEMA have published works to verify the safety and reliability of the impulse (surge) test as a mechanism to predict faults within turn-to-turn or phase-to-phase insulation.

Modern High-Voltage Testing

The cornerstone of high voltage testing is the impulse (surge) test. The test is done on a de-energized machine to detect incipient cable faults, winding faults (both to earth and turn-to-turn), winding contamination and partial discharges between turns and to earth. This is done with low energy, high voltage impulses microprocessor controlled with instantaneous fault detection. The question that is always asked about impulse testing is: - Can properly performed modern impulse testing damage my motor? The answer to that is a resounding NO!

Advances in microprocessor controlled testing equipment have taken out human error in testing. Vintage 1980 instrumentation required that the user self regulate the test voltages, making the user entirely responsible for controlling the test, simply making it impossible to provide an instantaneous trip if a problem was found. Modern testing equipment operates much more efficiently. The microprocessor controlled instantaneous trips allow winding condition to be evaluated without compromising dielectric integrity. The addition of field developed PASS/FAIL test criteria makes the testing extremely repeatable. Every impulse is digitized and compared to the previously applied pulse. If any weakness is detected the test is immediately stopped, preserving dielectric. The level of weakness is then stored for future reference.

Many electric motor maintenance professionals are successfully using the technology that has been developed over the last 20 years to improve the reliability of their rotating machinery. Modern impulse testing is used to evaluate the integrity of the turn-to-turn and phase-to-phase insulation, and is proven to give advance warning of impending motor failure. Due to the low energy levels involved, the applied power is not capable of carbonizing motor insulation, or welding copper. Motor life remains, and time is available for competent repair or replacement of the machine. Since the fault was detected before the insulation to ground was compromised, major repair jobs are now just minor overhauls.

Motor Stress

Electric windings are subjected to multiple types of stresses while in operation. These stresses contribute to the failure mechanisms of these windings. These include electrical, mechanical, thermal, and environmental stresses. The majority of winding faults are caused by a combination of these stresses acting on the stator windings.

The windings of an electric motor are subject to mechanical – physical – and contamination stresses during everyday operation. Each time a motor is started, electromagnetic forces cause the coils to shift and bend. The movement forces the windings to rub against each other, slowly deteriorating the insulation.

Normal operation also sets up vibration in the windings. This movement also causes physical damage to the aging insulation. Even the natural harmonics present in 60Hz power can create enough movement in the windings to cause abrasion to insulation between the copper coils.

One of the most potentially damaging factors affecting motor operation is thermal stress. Many factors can lead to excessive heat build up in the windings. A 10 degree C increase in temperature cuts the life of the insulation in half. Poor cooling – inadequate or non-functioning fans, clogged or blocked cooling vents are all common causes of failures due to thermal overload.

Most mechanical problems create excessive heat that can cause premature weaknesses in the winding insulation. Mechanical deficiencies such as current and voltage imbalance, bearing wear, and overloading situations aggravate the stress affecting the electrical systems. Motors in an environment that experience drastic swings in ambient temperature are also susceptible. The rapid cooling and heating of the windings cracks the insulation from expansion and contraction.

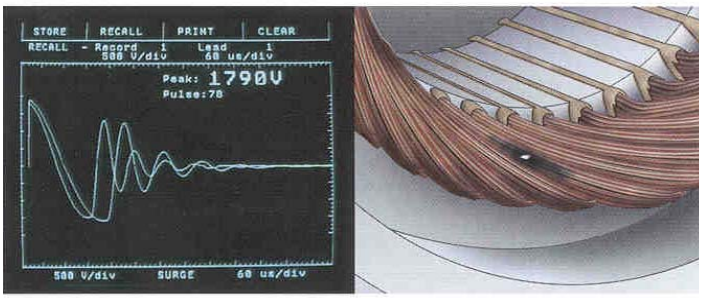
Electrical stresses are caused by voltage variances – abnormal voltage levels present in the windings. A motor experiences severe over-voltage spikes each time it is started. These over-voltage spikes stress insulation, weakening it each time it is started.

Anatomy of a Surge Test

The surge test is a specialized electrical test designed to find weaknesses and deficiencies in the insulation of a motor's windings that may be overlooked by other electrical testing methods such as the megohm test and lower voltage impedance tests.

The test instrument applies brief pulses of energy to the windings. These pulses are nearly identical in shape to the steep-fronted pulses that a motor's windings see during startup because of transient spikes and the output from variable frequency drives.

The surge test creates a voltage distribution across the turns. The resonant wave is simultaneously created on modern test equipment displays and the instrument looks for the slightest bit of instability (shown as a shift to the left on the instrument display). Instability of this



waveform indicates weaknesses in the turn insulation. Results from the test can indicate weaknesses in the windings, differences in impedance, or deficiencies in the turn-to-turn insulation system. The surge test is the only test capable of identifying these turn-to-turn weaknesses, unlike traditional megohm tests, capacitance, or low voltage

Well over 80 percent of electrical failures begin with weakness in the turn insulation. As the electrical insulation of windings is weakened, its dielectric strength is decreased. If the dielectric strength decreases enough, breakdown between turns begins to develop. If the breakdown persists in the turns of the windings it becomes a fused short – welded.

At this point the welded short creates tremendous heat due to an autotransformer effect. The heat created by these shorted turns quickly burns through the groundwall insulation – *slotliner* – and causes immediate grounding to the core and shutdown of the motor.

Voltage Levels

Testing parameters vary widely from standard to standard; however, they all reach the same conclusion. High voltage testing is necessary to verify the dielectric strength of electric motor insulation. The following tables indicate the formulas and voltage levels for NEMA MG-1, IEEE 522, IEC 34-1, and overall Industrial Rule of Thumb for testing voltage levels.

NEMA – MG-1

New Motor Test Voltage = 1000 + 2 times rated voltage of motor
In Service Test Voltage = 75% of New

Motor	New Motor	In Service
480V	1960	1470
575V	2150	1613
2300V	5600	4200
4160V	9320	6990
6900V	14800	11100
13800V	28600	21450

IEEE 522 – Surge Voltage Form Wound Coils

New Motor Test Voltage = 3.5 per unit, where $V_{line}/1.73$ = One Per Unit, or 480V/1.73 = 277 volts for one per unit.
In Service Test Voltage = 75% of new test voltage.

Motor	New Motor	In Service
480V	1372	1029
575V	1643	1232
2300V	6573	4900
4160V	11888	8916
6900V	19718	14789
13800V	39437	29578

IEC 34-15 Surge Voltage Form Wound Coils

New Service Test Voltage = $4E_L + 5000V$

In Service Test Voltage = 65% of New

Motor	New Motor	In Service
480V	6900	4498
575V	7300	4745
2300V	14200	9230
4160V	21640	14066
6900V	32600	21190
13800V	60200	39130

Industrial Rule of Thumb

New & In Service Motors = $2E_{line} + 1000V$

Motor	Voltage
480V	1960
575V	2150
2300V	5600
4160V	9320
6900V	14800
13800V	28600

Predictive Maintenance

Unexpected failure from weaknesses and subsequent breakdown of the insulation of windings can be minimized by the use of high voltage electrical testing in a scheduled predictive maintenance program. Modern high voltage test equipment has been shown to be safe and reliable to predict potential problems or minimize motor failures. Without the use of predictive maintenance techniques, motor failure will cause unscheduled outages and cost hundreds of thousands of dollars in lost productivity and downtime.

References:

NEMA Standards Publication No. MG 1-1987, Motors and Generators, National Electrical Manufacturers Association, Washington, DC.

IEEE 522-1992 Standard. Guide for Testing Turn-to-Turn Insulation on Form Wound Stator Coils for Alternating Current Rotating Electric Machines, IEEE Power Engineering Society, 1992.

IEC 34-15 Rotating Electrical Machines, Part 15: Impulse Voltage withstand levels of Rotating AC Machines with Form Wound Stator Coils, International ElectroTechnical Commission (IEC), 1995-01 Second Addition.