Abstract

Modern processing plants and facilities demand a high degree of motor reliability. This paper seeks to present the most current, effective, and accepted methods of electrically testing and delineating trends for the operational health of electric motors. The benefits and features of modern high-voltage electrical test equipment and testing methodologies are also discussed.

Introduction: The Need for Motor Testing

The steady, safe, and efficient operation of electric motors is essential to the productivity of all plants and facilities. Some facilities, including electrical utilities, pulp and paper mills, and innumerable others, have many critical and/or expensive motors. A motor failure could be catastrophic, causing lost production and costly emergency repairs. For example, a motor failure at a nuclear plant can cost up to one million dollars a day for critical motors and may have a disastrous, long-lasting impact. Even failures at a wastewater treatment facility can have a huge, negative environmental effect and can be very costly.

Motors fail due to numerous operational circumstances including power condition, mechanical influences, and environmental hazards. According to recent IEEE and EPRI studies, at least 35 to 45 percent of motor failures are electrically related. Monitoring the motor’s “electrical health” is, unquestionably, an important and vital consideration. Determining a trend for the historical operating condition of a motor makes early detection of any decline in the motor’s health possible. Planning downtime and having only minor reconditioning repairs instead of a major rewind or replacement is far less expensive in both repair costs and lost production. Since electric motors begin deteriorating the instant they are started, it is necessary to monitor their operating condition on a routine, periodic schedule. Periodic monitoring and trend creation of collected and correctly diagnosed data provides the technician with evidence needed to prepare for downtime before a catastrophe occurs.

It is no longer practical to test a motor merely with a megohmmeter in order to determine its condition. Plants and facilities depend on a complete predictive maintenance program (PMP) to monitor their operations and plan their repair schedules. A good PMP requires both static (off-line) and dynamic (on-line)
testing with educated and trained technicians monitoring data routinely with quality equipment. Besides voltages and currents, on-line test equipment must be able to capture and determine trends for torque ripple and torque signatures as well as rotor-bar side bands. Off-line testing with modern, high-voltage test equipment is essential to getting reliable data. The voltages required to test motor windings correctly cannot be reached with impedance-based or low-voltage test equipment.

On-Line Testing

Effective dynamic test equipment must be able to collect and determine trends for all essential data affecting the operation of electric motors. Power condition (including voltage level, voltage unbalance, and harmonic distortion), current level and current unbalance, load level, torque signature, rotor-bar signature, effective service factor, and operating efficiency should be tracked and trends determined for them. On-line testing is performed at the motor’s motor control center (MCC), at the load side of a variable frequency drive or at an installed port, which allows for on-line testing without opening the MCC. Data is collected through a set of current transformers and corresponding voltage probes. The collected, processed, and analyzed data provides the technician with an overall view of the normal operational environment to which the motor is subjected on a daily basis and of how the motor is responding within this environment.

Often a motor is subjected to incoming power problems including low or high voltage, voltage unbalance, and harmonic distortion. Lower voltage causes higher current and, therefore, more heat. Higher voltage causes lower power factor and ultimately higher losses. A small amount of voltage unbalance creates an exponential amount of current unbalance which causes temperature increases. Harmonic distortion also causes thermal stress in motors. Any of these voltage problems can cause severe overheating in the motor, even without reaching an overload situation, and excessive heat is the insulation’s major enemy. Some motors are subjected to physical obstacles that cause undue stress. Overgreasing, misalignment, and overtightened belts all cause thermal stress.

Many motor failures can be traced to load related situations. Erratic torque signatures can be an indicator of load related problems. Broken or cracked rotor bars can also cause premature motor failures. On-line testing identifies these problems and routine delineation of their trends will reveal the rate of decline. The effective service factor is also an important test of the overall health of a motor. Two elements affect the service factor number: real operating power condition (voltage quality) and steady-state load conditions. The effective service factor number represents the thermal stress caused by these two conditions on the motor.

On-line testing can be used to create trends for all these motor conditions.

Dynamic testing schedules should be tailored individually according to operating time, criticality, and any other important element of operation. Generally, an on-line test should be performed at least quarterly. Motors beginning to show obvious decline or thermal overstressing should be monitored more closely until the motor can be statically tested or removed from operation and repaired. New and recently repaired motors should be tested as soon as they are returned to service in order to provide a historical record (or baseline) of their performance when the motor is at its “best.”

Off-Line Testing

In general, motors are quite reliable and, when correctly maintained, can be expected to provide at least one hundred thousand hours of continual operation. That is to say, a new motor operated within nameplate parameters should give at least eleven years of steady use. Unfortunately, motors are almost always subjected to a variety of damaging elements with the end result being a rise in operating temperature. Thermal aging of the insulation is the major cause of insulation failure. Years of testing and numerous studies have shown that, as a rule-of-thumb, “for every 10 degrees centigrade increase in temperature, the winding life is decreased by half.” (See Crawford.) Besides thermal problems, other causes of insulation failures include incoming line-related problems. Spikes caused by lightning and surges created by switching and contactor closing contribute to insulation breakdown. Motors are also subjected to mechanical influences, including bearing failure, environmental hazards, and magnet wire damage caused during the manufacturing process. Even the physical movements of the windings during startup cause wear to the insulation system — especially the magnet-wire insulation, as D.E. Crawford proved.

Figure 2 — Damaged Coil
Correct testing of all components of a motor requires a series of tests designed to emulate the conditions the motor will see in the field. It has been proven in numerous studies that low-voltage testing, including capacitance, inductance, impedance, etc., is not an effective tool in detecting weakness in the insulation. Quality off-line test equipment can perform winding resistance tests, insulation resistance tests, high potential tests, polarization index, and surge tests at IEEE-, NEMA-, and EASA-accepted standards. Top quality test equipment will automatically run a series of preprogrammed tests and provide a complete final report. This automatic equipment will stop testing before any damage is done to the windings.

The resistance test verifies the existence of dead shorts within the turn-to-turn coils, shows any imbalances between phases due to turn count differences, locates poor wire connections or contacts, and finds open parallel coils.

DC insulation resistance testing detects faults in groundwall insulation or motors that have already failed to ground. Weak groundwall insulation (prior to copper-to-ground failure) can only be found successfully with high potential tests. The groundwall insulation system consists of the magnet-wire insulation, slot liner insulation, wedges, varnish, and, often, phase paper. A dc high potential test should be performed at twice line voltage plus 1000 volts since motors will see voltage spikes of at least that level during each startup. High potential testing is necessary to verify winding suitability for continued service.

Surge testing detects potential faults in both interturn winding and phase-to-phase insulation systems. Turn-to-turn faults will not be seen by any other method of testing including megohmmeter and high potential tests. Potential faults can only be seen when the coils see more than 350 volts from turn-to-turn or coil-to-coil, as described by Paschen’s Law. The typical mechanism of fault progression is a turn-to-turn short causing excessive heat and progressing within seconds or minutes to copper-to-ground faults. Faults are much more likely to occur between turn-to-turn winding coils due to the added stress caused by bending and exaggerated during the winding process. The groundwall insulation is generally many times stronger and more capable of withstanding voltage spikes and other stresses.

Case Studies
- At a large wastewater treatment facility in Florida, 14 identical motors were scheduled for predictive maintenance. These motors were 40 horsepower aerators for a large treatment tank and operated continuously. Static tests were performed on all 14 with each receiving passing marks on all tests. When dynamic testing was completed, it was noted that 13 of the 14 motors were running within expected parameters at approximately 85 percent load while the remaining motor was running at just over 30 percent load. Further inspection revealed a sheared coupling on the motor running at reduced load. The operators had no way of detecting the problem, and the location of these motors made visual inspection difficult. The dynamic testing found a problem that was costing the customer in both wasted kilowatt usage and production.

- Twelve 60 horsepower pump/motors were tested at a large office building. Six were chilled water pump/motors and six were condenser water circulating pump/motors. All 12 were installed at the same time and ran continuously. Dynamic testing was performed one day on the motors, and all appeared to be operating within expected parameters. The motors were shut down for scheduled, annual, routine building maintenance. Static testing was planned for the following morning. Resistance tests appeared normal on all but two motors. These five motors were removed from service, disassembled, and inspected. Two were found to be extremely dirty, while three had no visual damage. All five were reconditioned, re-tested, and placed again in service. The off-line testing prevented five potential catastrophic failures and allowed the customer to dictate the downtime.
Conclusions

Integrating on-line and off-line testing into a PMP provides the technician with verification of his motor’s condition. Both technologies are necessary in order to have a complete picture of a motor’s health. Collecting both on-line and off-line data on a routine schedule allows for early warning of impending failures and opens the opportunity window for planned downtime. Performing resistance, high potential, and surge testing along with dynamic testing provides the technician with a total picture of the motor’s condition and allows him to track its rate of decline.

Modern test equipment includes enhanced and detailed reporting. Reports are easily generated, providing a written hard copy of test results and making diagnosing and comparing of data clearer and more accurate.

Setting up and managing a program to monitor the motors within any facility is essential to insure the safe and continued operation and production of the facility. In most cases, a correctly managed and operated PMP will save a plant or facility much more than it will cost to implement, administer, and manage.

References


Paschen, F., Paschen’s Law, 1889.


Timothy M. Thomas holds a Bachelor of Science degree in engineering science from Florida State University. He is currently working as an applications engineer at Baker Instrument Company in Fort Collins, Colorado. He has extensive field experience in gathering, compiling, diagnosing, and reporting on both static and dynamic motor circuit data and is proficient with Baker’s test equipment. He holds a certificate as a Level III Vibration Analyst. The previous nine years he worked as General Manager of an electric motor rewind shop in Florida where he set up and managed the predictive maintenance program. His main field of interest is predictive maintenance of electric motors and related equipment.