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Predictive Motor Maintenance

A primer on static, dynamic and online motor testing

Abstract

This paper presents current methods of electrical test and trend analysis of the operational health of electric motors in the context of successful predictive maintenance programs. The benefits and features of these various types of test equipment and motor testing methodologies are conveyed in the context of motor/machine "systems", which accounts for conditions that can impact the health of a motor, but can be external to the motor itself. This paper outlines the concepts of static motor testing, or testing on a motor that is not running, as well as dynamic motor monitoring, which involves performing analysis on motors while they are in service, or operating within their application environment. It also covers an emerging type of online dynamic monitoring involving a permanently-installed networked motor analyzer that enables maintenance professionals to monitor motor system conditions from any web-accessible computer.

Introduction

Predictive maintenance programs are crucial to an organization's ability to avert unplanned or unnecessary downtime that can adversely affect its ability to produce or operate. Unlike time-based or run-to-failure approaches to maintenance management, condition-based programs are ideally geared to pay for their cost of implementation by extending the service lives of motors and rotating equipment, averting costly unplanned downtimes and minimizing the costs of replacing expensive equipment. Predictive maintenance programs are most effective when all available means of measuring health and analyzing health trends of electric motors, cables, power quality and load are rigorously implemented.

In other words, safe and continuous operation of plants and facilities drives revenue and profit, and depends upon high motor reliability. Predictive maintenance of motor systems is a necessity when it comes to supporting reliability objectives that in turn support a company's or organization's business objectives. The power generation industry, as an example, ranks at the top of this requirement for uninterrupted operation and safe, continuous production. A number of motors run equipment that is ancillary to the production or health of a company (e.g., one of a few rooftop motors for an HVAC system, which won't have an immediate impact on the HVAC system if it stops working). Other motors, however, are critical to a company's ability to conduct business; that is, they are motors that drive such things as conveyor systems, fluid pumps, or production-line machinery that a company relies upon to generate revenue and profit every day.

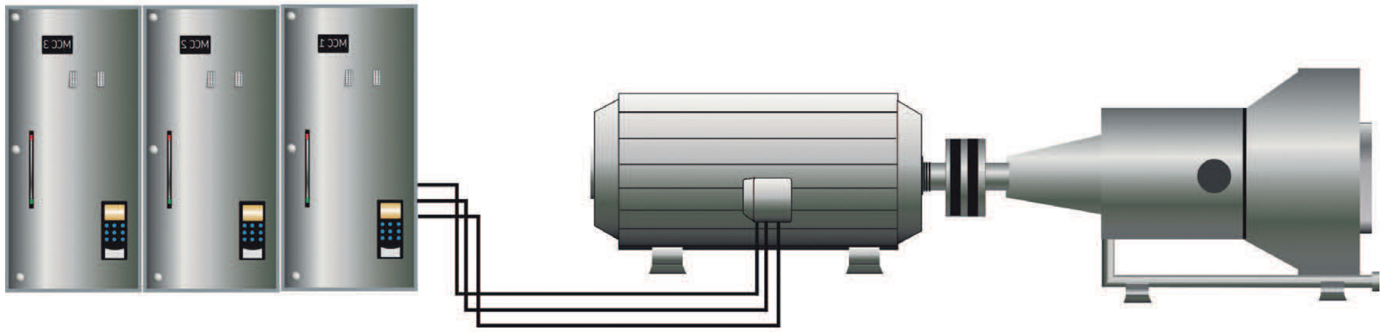

Fig. 1. A typical motor, or machine system consisting of power supply, motor and load

Motor systems

Motors, whether used to drive conveyors, pumps, cooling fans, or any other machinery, are best viewed as core parts of "systems." These are often referred to as "motor systems," or sometimes "machine systems" (see Fig. 1). These systems include the motor, the source of the motor's power, and the equipment or machinery driven by the motor.

Electric motor test equipment today is generally categorized into two types: static motor test equipment and dynamic motor test equipment. The first type is capable of simulating "real world" situations when motors are off-line. The second type is used for safely acquiring accurate and valuable health data across a working motor system, or a motor's in-service environment.

Static motor test data provides visibility into the integrity and condition of a motor's insulation and motor circuit. Modern equipment helps maintenance technicians predict or identify imminent failures *before* they cause costly unplanned downtime of motors and the rotating machinery they support. The most effective static test equipment is capable of testing the components of motors at voltage levels similar to those the motor will see in its normal operation without destructive currents.

Static testing should include the surge test, which is the most effective method of insuring the integrity of a motor's turn-to-turn insulation. The best static motor analyzers produce trend logs and reports, which allow technicians to track any decline or degradation to a given motor's health.

The latest dynamic test equipment can locate and identify problems that adversely impact motor health and life that are on either side of the motor within the motor system. These are generally power-related issues and load problems, but can include vibration, or circuit condition problems within a motor while the motor is in-service.

Dynamic motor analyzers can often calculate speed and torque, define rotor bar problems, and measure distortion. Dynamic motor testing can also identify a number of mechanical issues, such as bearing problems or motor shaft misalignment. Dynamic testing helps isolate the mechanical (system) issues from electrical (internal to the motor) while providing valuable information to discern root-causes of motor failures.

The goal of a predictive maintenance program is almost always to reduce unscheduled downtime. An effective predictive maintenance program is measured by how well it works to predict imminent failures and identify potential problem areas before they fail and create expensive recovery costs for an organization. They should also work to determine the root causes of failures and, ultimately, save money by extending the service life of motors and rotating equipment. This is why electrical testing of motors is such a critical component of predictive maintenance. Static and dynamic analysis, along with trend data acquisition and analysis, provides the information technicians need to make good decisions regarding use or maintenance of a given motor.

Off-line testing

Static testing (or off-line testing of motors in their static, powered-down state) is commonly performed just once in a given period of months, usually up to a year. It's also performed opportunistically during outages when a motor is shut down for other reasons.

Off-line testing is often used as a quality assurance measure when receiving new, reconditioned or rewound motors from a supplier or motor shop. This is to assure they work as expected before they are stored or returned to service. Tests of these motors serve to prove the motor shop is doing its job properly, and they create new baselines for future trend analysis.

Static motor test equipment can troubleshoot motor problems or failures. Any time a problem occurs, the motor involved should first be tested for insulation integrity. Out-of-spec voltages, motor loads and contaminants are examples of problems that can adversely impact a motor's internal insulation.

Typical static tests include winding resistance, meg-Ohm, polarization index (PI), DC step voltage and surge testing. These tests should be performed in that sequence with modern, state-of-the-art test equipment. These types of surge-test analyzers can reproduce "real world" experiences without causing damage to a given motor's insulation system, and underscore the importance of testing motors at voltage levels and conditions a motor experiences in normal, everyday operation.

Winding resistance tests confirm that a motor's phases are balanced; such tests discern shorts and opens in the motor's windings as well as high, out-of-spec resistance connections. A static meg-ohm test can determine if the motor's windings are grounded or contaminated. The megohm meter is probably the most-used test instrument in the field but it has its limitations. Meg-ohm testing is usually performed at voltages slightly above line voltage.

It is important to note that a meg-ohm test can determine if a motor is bad, but can not confirm the motor is good. Low meg-ohm results are an indication of impending failure, but high meg-ohm values do not ensure that a motor is free of other faults. A polarization index (PI) test can also confirm poor/degraded insulation within a motor, but while it can indicate when a motor's insulation is old and brittle, it does not find potential turn-to-turn faults.

A DC step-voltage test involves exposing the entire winding to voltage equal to that commonly seen at start up or shut down, and looks for weak ground-wall insulation. Weak or damaged cable problems can also show up during this test, and it may be necessary to separate the motor at its junction box in order to determine the root cause of the problem. DC step-voltage testing is commonly performed at double the line voltage plus an additional 1000 volts, but has no adverse impacts on the motor or motor insulation when properly applied.[1]

Lastly, once a motor has passed all the other tests, a surge test should be applied. Surge testing is the only way to locate weak turn-to-turn insulation. These copper-to-copper faults are the primary cause of more than 80 percent of all winding-related failures, and they will go undetected if not for the surge test. Most motors, when allowed to run to failure, will "blow" to ground in a slot. That is because a slot provides a ready path to steel, but most such shorts will have started as a copper-to-copper/turn-to-turn fault.[2] Locating the weak insulation before they become hard-welded faults allows a maintenance professional time to plan for repairs before a catastrophic failure causes unscheduled down time, expensive repairs and lost production. Once these turn-to-turn faults have become hard-welded faults, a motor typically only has about fifteen more minutes of service life.

On-line (dynamic) monitoring

Dynamic, or on-line monitoring is performed while the motor is powered on and working within its normal system or application. Data collection with dynamic motor testers is safe, fast and nonintrusive. Dynamic testing provides information regarding power quality and conditions such as voltage levels, unbalances and distortion. A small amount of voltage unbalance coupled with minor harmonic voltage distortion may result in a NEMA (National Electrical Manufacturers' Association) de-rating that will not be seen with simple multimeters and amp probes. Current levels and current unbalances also affect motor performance and monitoring them is essential when trending motor health.

Dynamic testing can and should be performed more often than off-line testing with a frequency of testing similar to vibration analysis. The concept is relatively new compared to static testing, but it has rapidly emerged as a common, standard condition monitoring approach.

Besides electrical issues with motors that the technology can monitor, many mechanical issues with a motor and its system are also discernable with data that dynamic analyzers can collect. Torque and current spectra have proven to be highly useful in determining mechanical issues, including bearing faults, looseness (vibration or misalignment) and eccentricity. Again, considering a motor is part of a motor/machine system with three coponents (power source, load source, and the motor itself), a good dynamic analyzer provides relevant condition information about all three. Many motor problems are created by adverse or mismatched loads, or by poor supply power. Without a means of analyzing data from monitoring across a motor system, the true root cause of motor failure often goes undetected. The

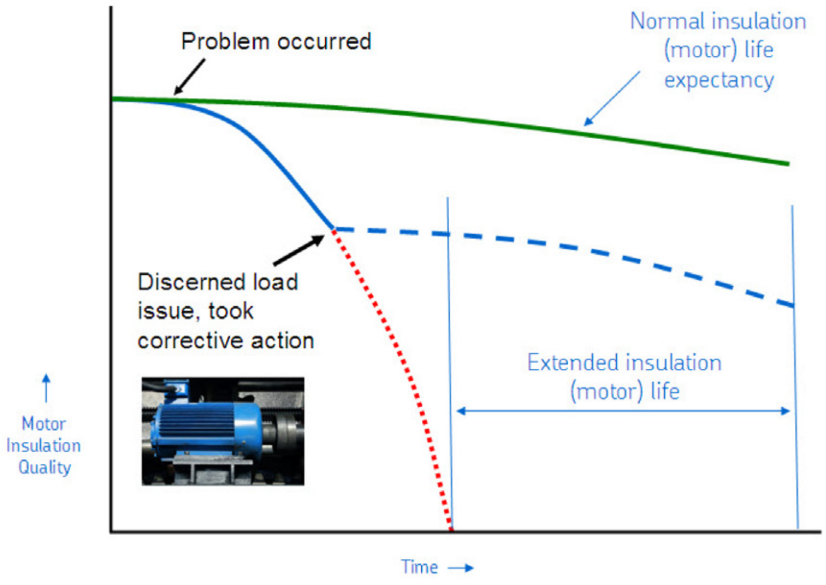

Fig. 2. Extending motor life with PdM testing

ability to acquire and define such adverse impacts as torque provides a maintenance professional the means to separate the mechanical from the electrical issues, improve decision-making concerning repair or replacement, and otherwise extend the service life of the motor (see Fig. 2).

Dynamic testing provides health information about motor systems across power source, motor and load source. It monitors power quality and conditions such as voltage levels, unbalances and distortion. Current levels and current unbalances also affect motor performance and monitoring them is essential for analyzing motor health trend data.

Another challenge with electric motors is tracking the condition of their rotors. Today's dynamic motor analyzers help predict rotor bar failures or potential failures if the load is relatively steady. A pump, fan or blower operating at a steady frequency will show very clear rotor bar signatures that make rotor fault diagnoses easier than ever before. During normal operation a motor's rotor is stressed by its load. Torque waveform analysis provides a picture of those stresses and when they reach levels out of spec for the motor, they can be an indicator of a number of mechanical problems. Cavitations and belt flapping, for example, are easily seen in a torque waveform signature. Motor analyzer manufacturers continue to improve upon the ability of test equipment to discern other mechanical motor system issues earlier and with greater accuracy.

Nearly all modern static and dynamic testers are portable. Static testers can be used in a shop or easily carried into the field. Dynamic testers are by nature used in the field (wherever running motors are located), but often test via a motor control center. However, emerging new technology has spawned a dynamic motor analysis tool known as an online motor analyzer that is permanently installed, and in proximity to the locations of up to 32 motors via motor busses within MCCs. The concept is to perform all of the same tests a portable dynamic motor tester does, but with the additional benefits of continuous monitoring and viewing the status of a given motor from a central office location—or for that matter, anywhere in the world with a PC and a good Internet connection.

This technology enables maintenance professionals to make better decisions faster than the "spot-testing" method of testing that is characterized by route-running once every few months to yearly. It captures information that can't otherwise be captured in a single testing session performed with a portable tester. Alerts can be set to flag maintenance professionals of the need to investigate and/or replace critical motors the online analyzer is monitoring. Moreover, the trend data from months of monitoring provides valuable insight that informs predictive maintenance planning and helps prioritize resources and actions. Finally, because the monitoring is effectively performed remotely, online dynamic analyzers all but eliminate safety hazards associated with testing in-service motors in the field.

Dynamic monitoring also provides efficiency information allowing maintenance professionals to make wise and practical decisions when confronted with choices to repair or replace a given motor. Improving efficiency by just two percent may result in thousands of dollars in excessive annual energy costs.

Conclusions

Static and dynamic testing of electric motors is critical for successful implementation of predictive maintenance programs. Static testing is the most effective means of measuring the integrity of the motor's insulation system, and can be used as well for quality assurance when a motor is out of service. Dynamic testing provides valuable information about motor systems, including power condition, load, and the motor, including physical aspects that can affect the life or operation of the motor. Online motor monitoring adds the dimension of gathering motor system health data at regular intervals throughout the day, 365 days a year. Combined, they present a comprehensive picture of motor and motor system health that can be a foundation for successful predictive maintenance programs. They provide the full spectrum of motor condition information required to accurately diagnose and predict imminent failures and as a result solidify electrical motor testing's place as an essential part of a complete predictive maintenance program.

1 Gupta, Stone, and Stein, "Use of Machine HIPOT testing in Electric Utilities." 0-7803-7180-1 IEEE, 2001 (IEEE Dielectrics and Eletrical Insulation Society)

2 R.M. Tallam, T.G. Habetler, R.G. Harley, "Transient Model for Induction Machines with Stator Winding Turn Faults." IEEE Transactions on Industry Applications, Vol. 38, No. 3, May/June 2002.

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