

AC Motor Testing and Predictive Maintenance

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Abstract- The key to fully understanding condition-based monitoring of AC electric motors is to determine the capabilities and limitations of each technology. With this knowledge, the maintenance and reliability technician can make decisions with a known degree of reliability. In this paper, we will discuss some of the primary methods of motor testing along with their capabilities, how they are applied and pass/fail (where possible) and trending limits. The basis for this discussion will be “IEEE P1415: Draft Guide for Induction Machinery Maintenance Testing and Failure Analysis.”

Introduction

The requirement for an inclusive AC induction machinery standard has been needed that outlines known condition-based testing technologies and their capabilities. For the past nine years, an IEEE Power Engineering Society Standards Committee has been in the process of developing the “Guide for Induction Machinery Maintenance Testing and Failure Analysis,” designated IEEE P1415. At the time this paper was drafted, IEEE P1415 was in the final stages of voting to become an IEEE Standard.

What makes this particular standard unusual is that it provides an overview of both electrical and mechanical test methods and provides test limits where possible. In many cases, it splits a particular technology into sub-tests. For instance, an MCA test that involves resistance, impedance, inductance, phase angle, current/frequency and insulation to ground is broken into individual tests such as: Winding Resistance, Insulation Resistance, Phase Angle, Phase Balance (Inductance and Impedance) and Variable Frequency. The purpose is to both cover existing technologies and provide room for future technologies that may use different combinations.

Electrical Motor Diagnostics Defined

One of the most troublesome areas that has come along with our modern times is keeping track of definitions. For instance, on-line can mean using the internet or while equipment is running. Lately, the concept of Electrical Motor Diagnostics has been considered as only the technologies of Motor Circuit Analysis (MCA) and Electrical or Current Signature Analysis. However,

in 2004, the Institute of Electrical Motor Diagnostics (IEMD) defined Electrical Motor Diagnostics as all technologies used to test or evaluate the condition of the electric motor system or capable of being used in motor system maintenance and management programs.

Motor system maintenance and management was then defined:

“Motor system maintenance and management is the philosophy of continuous improvement of all aspects of the motor system from incoming power to driven load. It involves all components of energy, maintenance and reliability from system cradle to grave.”

The result of these definitions is that a broader scope of technology is encompassed, providing the concept of a broader range of tools available for electric motor health diagnosis. This definition, combined with the IEEE P1415 gives us the slate of technologies that are to be explored with this paper. However, the focus will be on the motor only, including:

- Stator winding and core
- Rotor winding and core
- Vibration and noise
- Bearings and shafts
- Structure and frame
- Ventillation
- Accessories.

Condition-Based Technologies

The following technologies are covered by the proposed standard:

- AC High Potential: Is a pass/fail test applied at twice the rated voltage plus 1,000 volts for new insulation systems and 125-135% of motor nameplate voltage for existing insulation systems.
- Acceleration Time: Increased or decreasing starting times may indicate problems with power supply, motor or load.
- Bearing Insulation: Evaluation of the insulation integrity of the bearings for purposes of reduced shaft currents and resulting bearing damage. Performed following IEEE Std 43-2000.

- Bearing Temperature: Measured by RTD, thermocouple or bulb-type thermometer. Temperature limits vary but generally fall in the range of 90-100C for alarm and 105-120C for shutdown.
- Capacitance: Measurement is trended and values to ground increasing over time indicate surface contamination, high humidity, high temperature or insulation breakdown.
- Core Loss (Loop Test): Test performed during motor repair to evaluate the interlaminar insulation of the stator core. No spot should be greater than 10C than the ambient core temperature.
- Coupling Insulation: Performed to ensure that no shaft currents flow into driven equipment. Performed following IEEE Std 43-2000.
- Current Demodulation: Used in motor current signature analysis as a method of removing the fundamental frequency from current FFT spectra.
- Current Running: Can be used as an indication of load. Pulsating current, measured with an analog current probe, is an indicator of rotor bar problems.
- Current Signature Analysis: Used to provide analysis of electro-mechanical condition and driven equipment condition. Requires analysis of current FFT spectra.
- Current Starting: Inrush and starting current is evaluated for anomalies.
- DC High Potential: DC High Potential is a trendable test when leakage is recorded. Uses twice the voltage plus 1,000 volts time 1.7 as the maximum applied. If, while increasing voltage, the leakage value increases very quickly, then the test has failed.
- Dielectric Absorption: Is a ratio of the DC insulation resistance readings of the 60 second value to the 30 second value. A ratio of 1.4 or greater, in pre-1970 insulation systems, is considered acceptable. Otherwise, trending is required. Reference IEEE Std 43-2000.
- Dissipation Factor and Power Factor: Are both tests that use an alternating current voltage at the rated voltage of the motor being tested. The trended value should not exceed a change of 2% over the period of test.
- Grease Analysis: Used to trend and evaluate deterioration of lubrication properties of grease.
- Growler: Used to evaluate the condition of rotor bars when the rotor is removed from the electric motor.
- Insulation Resistance: Measures the insulation value between conductors and ground after 1 minute. The applied voltage is less than the motor rated voltage with a temperature corrected result of 5 MegOhms for random-wound machines and 100 MegOhms for form-wound machines. Reference IEEE Std 43-2000.
- Oil Analysis: Used to evaluate the degradation of the lubricating properties of oil. Can also be used to detect excessive mechanical wear in equipment.
- Partial Discharge: Is a measurement of capacitive discharges within the electrical insulation itself. This value is trended generally on machines over 6,000 Vac.
- Phase Angle: The timed measurement between the peak voltage and current at about 7Vac applied to a coil. When two coils are compared, the value should be within one digit of both results.
- Phase Balance (Inductance and Impedance): Used to detect severe winding unbalances or to compare in order to detect winding contamination. Test results are compared phase to phase to determine if the pattern is the same, or not.
- Polarization Index: The ratio of the 10 minute insulation to ground test and the one minute insulation to ground test. A ratio of 2 or more is required on pre-1970 insulation systems. Reference IEEE Std 43-2000.
- Single Phase Rotor Test: 10 percent of the motor nameplate voltage is applied across one phase of the motor. The rotor is turned and current values taken. Variations of 3%, or more, of the current value through 360 degrees of rotation identify probable broken rotor bars.
- Shaft Grounding Current: A measurement of the shaft current. Can identify that shaft currents are not flowing through the shaft grounding system.
- Shaft Testing: Magnetic particle, liquid penetrant and ultrasonic examination are used to evaluate the condition of the motor shaft material.
- Shaft Voltage: Voltage measurements taken from the shaft of the motor. Variations in the voltage value indicate problems with the motor.
- Speed: Uses measurements of motor RPM in order to determine if potential motor or load problems exist.
- Surge Test: High frequency, high voltage impedance-based test used to check the turn-to-turn dielectric strength of the insulation system. Waveforms compared with deviations indicating faults.
- Surge PD: Variation of the surge test, evaluates partial discharges that result from the high voltage, fast rise-time test.
- Thermography: Utilizes an infrared camera to compare the background (ambient) to the test component. Defects can cause a high temperature rise at the point of fault.

- Torque Analysis: Uses three phases of voltage and current in order to calculate torque. The value is then displayed and analyzed as torque FFT spectra.
- Ultrasound/Ultrasonic: Used to detect bearing and other electro-mechanical defects on motors. Also used to detect other motor system opportunities.
- Variable Frequency: Using about 7 Vac, the motor current is measured then the applied frequency doubled and the resulting current compared to the initial current result. The value should be no more than one to two digits different between phases.
- Vibration: FFT spectra of vibration information is used to trend and detect mechanical and some electrical faults.
- Voltage Balance: Voltage measurements used to detect voltage unbalance defects in the supply.
- Voltage Distortion: Harmonic content of voltage. If this value is too high, rotor and stator heating will occur.
- Voltage Drop: Is a trended measurement of the voltage drop when starting a large electric motor. Changes may indicate electric motor defects.
- Voltage Level: Voltage measurements are used to ensure that the supply voltage remains within +/- 10% of nameplate voltage.
- Voltage Spikes: Monitoring voltage spikes allows the ability to evaluate supply and control conditions.
- Winding Resistance: Used to detect broken wires and loose connections.
- Winding Temperature: Winding temperature can be trended over time in order to determine if overload conditions or insulation failure is going to occur.

Each of the tests is described, effectiveness determined (ie: Effective for trending?), online or offline, typical test frequencies, any precautions or considerations and related standards cited.

Application of Combined Technologies

As previously mentioned, the technologies cited can be used individually or in combination. The use of multi-technologies allows for a more accurate analysis of the condition of a machine.

An important part of the understanding of the application of any testing technology is also the knowledge that findings represent a probability of the type of fault being diagnosed. For instance, an insulation resistance test that shows a very low test result may be a failed insulation system, winding contamination, high humidity, improper testing procedure or a damaged instrument. It is common that

the call is made based upon the experience of the user. For instance, if a 480Vac motor tests at 0.5 MegOhms to ground, based upon the experience of the user, they may state that the insulation system has failed or that there is high humidity. The corrective action taken, if any, may be incorrect as a result.

Instead, by understanding the technologies and practices available, how they are applied and what the results may mean (including the probability of the different results), the maintenance and reliability technician now can select the combination of tools to improve confidence in findings. For instance, using the above example, a combination of insulation resistance, phase balance, phase angle and variable frequency testing are used. The low insulation value is coupled with out of tolerance phase angle and variable frequency and the impedance and inductance phase balances do not match. The most likely result would be an insulation failure with the corrective action being a rewind or motor replacement.

Another benefit of evaluating condition, or trending, with multiple technologies is the ability to more accurately estimate remaining life. As a result, many technology manufacturers now combine multiple technologies into single package solutions.

Case #1: DC Thruster Analysis

Electrical signature analysis of DC machines provides a solid picture of both the driven equipment, motor and DC drive. In the case of marine thrusters, the DC allows for variable speed to propellers that are used to position a vessel. The challenge of analyzing thrusters is the ability to detect problems in the gears, bearings, seals and propeller with resulting cavitation, which directly affect vibration test results.

By using a combination of Voltage Signature Analysis and Current Signature Analysis (Electrical Signature Analysis - ESA), the results can be compared and the driven equipment evaluated. In one recent case, vibration analysis was performed on a thruster followed by ESA. ESA identified a strong running speed signature that would signify an extreme unbalance, severe misalignment or bent shaft. A review of vibration data provided additional input that suggested the result was a bent shaft.

Case #2: Generator Analysis

An operating generator on board an ocean-going vessel tripped offline, due to high temperature several times during loaded operations. Infrared thermography determined that the cooling system was operating

satisfactorily. MCA was utilized and it was determined that a developing winding short coupled with an insulation to ground fault was developing. Following an online test, performed with ESA, it was determined that there was a rotating field problem, as well. Another MCA test was performed and the rate of insulation failure was determined.

Utilizing the information provided by these tests, it was determined that the generator could operate in a derated condition for approximately three months. This allowed the vessel to fulfill its next mission. The generator was rewound, due to insulation failure, during the next dry-dock period, as scheduled.

Conclusion

The identification of technologies available for motor condition-based testing, their limits and capabilities provide a powerful tool for electrical motor diagnostics. The hoped for publication of IEEE P1415, "Draft Guide for Induction Machinery Maintenance Testing and Failure Analysis," anticipates the need for a full electrical and mechanical test standard for electric motor condition testing. Utilizing the combined capabilities of the technologies, early and accurate analysis and remaining life estimation can be performed.

About the Author

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Bibliography

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