Application of Machine Diagnostics as Part of a Maintenance Strategy

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Introduction

What is the impact of critical equipment failures at your facility? How do you define whether something has failed?

That is the key, isn't it? Bearings or insulation begins to degrade significantly. However, the machinery continues to operate, although less effectively than when it is not as worn, until it seizes or catastrophically ceases to operate at all. The purpose of planned maintenance is to perform tasks to meet a life determined by the designer.

Condition-based and predictive maintenance are methodologies used to determine and even effect the reliability of the equipment. Predictive maintenance (PdM) is used to identify the changing conditions that alert the owner to an increasing risk of functional failure, or when the equipment will cease performing as required. Condition-Based Maintenance (CBM) is used to make planned maintenance decisions based upon tests and inspections. Both are utilized to control or manage the costs associated with the equipment life-cycle and productivity.

From a reliability and maintenance perspective, the purpose of PdM and CBM are to perform some type of maintenance action prior to functional failure. In reality, these methods are used as a management tool to determine risk of failure and possibly to pre-plan for functional failure. For instance, if a gearbox is detected as wearing and expected to fail, a replacement may be purchased and parts staged on a planned versus expedited basis.

Considering the risk-based decision making of these programs, decisions must be made employing proper and cost-effective tactics. The application of a Reliability Centered Maintenance (RCM) process is part of a maintenance and reliability strategy to identify high risk conditions and the methods that can be used to address them within the rules and context of the application and business.

The selection of technologies and methods are based upon their ability to detect different conditions. For instance, insulation to ground testing would not be applied to detect bearing degradation. If a technology can easily detect early conditions of the failing gearbox in our earlier example, then that may be relevant to be used. On the other hand, if there are other methodologies that may detect the fault in a slightly later condition, but has more applications, then it may be determined the cost effective approach.

What else may need to be identified in order to determine if an inspection or testing methodology is cost effective?

- The number of potential applications;
- Cost of the technology vs applications (cost/application) which may also encompass training and personnel, or outsourcing;
- How soon can faults be detected;
- Training lag-time (learning curve); and,
- Accuracy.

In this paper we are going to discuss several technologies that are relevant to electric machines including insulation systems and cabling, motors and generators, transformers, AC and DC, controls, couplings, and driven equipment. In effect, the entire motor system from power generation to the driven load utilizing low-impact technologies. Visual and other inspection types would be covered under other literature.

Technologies

There are a broad base of technologies that can provide the type of diagnostic and prognostic capabilities needed in a maintenance strategy. The best methodologies can be applied to both prognostics and diagnostics and we will cover those, including:

- Motor Circuit Analysis (MCA): defined as low voltage testing technologies;
- Electrical Signature Analysis (ESA): different than motor current analysis or motor current signature analysis, ESA utilizes voltage, current and torque in order to view the complete circuit;
- Vibration Analysis: by far one of the most popular diagnostic and prognostic

technologies utilized. It uses movement in order to provide data;

- Infrared Analysis: used, in the context of this paper, to detect problems such as loose connections and other conditions that generate heat, including misalignment and bearing problems; and,
- Ultrasonics: utilized based upon the sound pressure put off by different types of faults.

It is important to understand the distinction behind each type of technology and their field applications. First we will outline each technology in reasonable detail and then will identify where they are used.

Electrical Signature Analysis

There are a number of technologies in place, at this time. These range from simple current data that is used to review a Fast Fourier Transform (FFT) spectra of frequency versus some type of amplitude, similarly to vibration. This methodology is relatively time consuming and can generate false positives.

A proper ESA technology utilizes voltage and current FFT, RMS voltage and current, voltage and current waveforms, circuit impedance, balance and torque. Most data collectors are power analyzers allowing the technician to look closely at power conditions including voltage and current harmonics. With all of the provided data, a good analyzer will also produce a reasonably good spot efficiency of an electric machine.

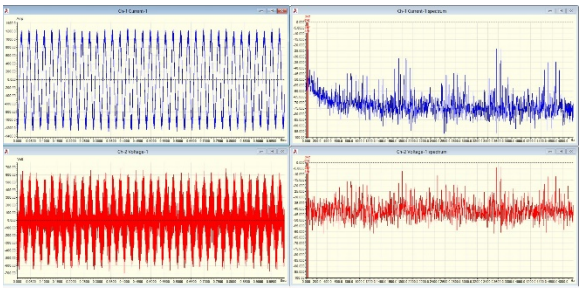

Figure 1: Voltage and Current Raw and Spectra

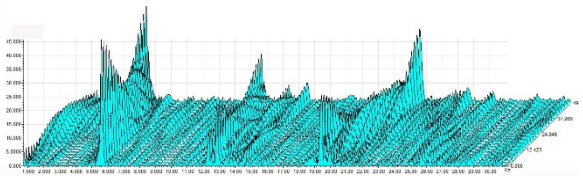

Figure 2: ESA Waterfall Spectra for Analysis

A benefit of ESA analysis is that the alarms are related to the peak voltage and current and normally counted down from the peak in dB, or relative energy related to the associated voltage and current. A higher voltage than current peak will indicate that the source of the information is upstream from where you are testing and a higher peak in current will indicate the source is downstream. This is important when testing in environments that have similar pieces of equipment.

The association of peak voltage and current to peaks related to conditions being investigated means that changes in load and speed have a very limited effect on the amplitude. This means that test results can be compared without resorting to maintaining a specific speed or load.

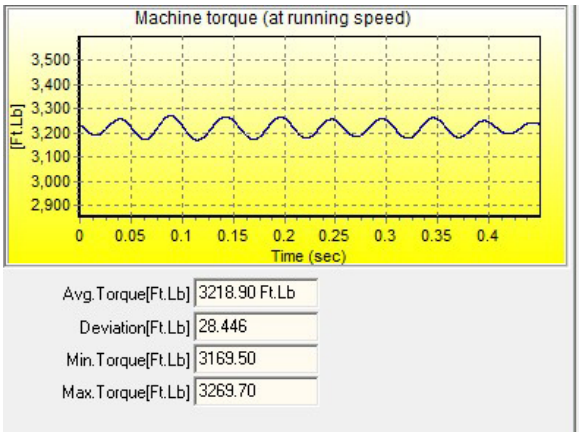

Figure 3: Machine Torque Ripple

The torque ripple provide information related to what is happening at the shaft. A significant ripple will indicate twisting and untwisting of the shaft or coupling that will cause the weaker part of the system to fail. Using all of the information together can assist the analyst in determining where this is coming from and possibly how to correct for it.

ESA uses the air gap of the machine as the transducer relying upon movement of the rotor side-to-side just as with vibration analysis. With the more direct source being the air gap, the ESA analyst can look at an entire machine and powertrain, as well as incoming power conditions, with a single reading. In addition, these readings can be taken from a motor control center significantly reducing the time to collect data.

The full benefit of ESA is similar to that of vibration analysis. While some great information can come from pattern recognition, the more information available, the greater the accuracy of the system. Knowing rotor bars, stator slots, equipment characteristics (ie: gearbox info and teeth), bearing information and similar data, the faults can be picked out relatively quickly.

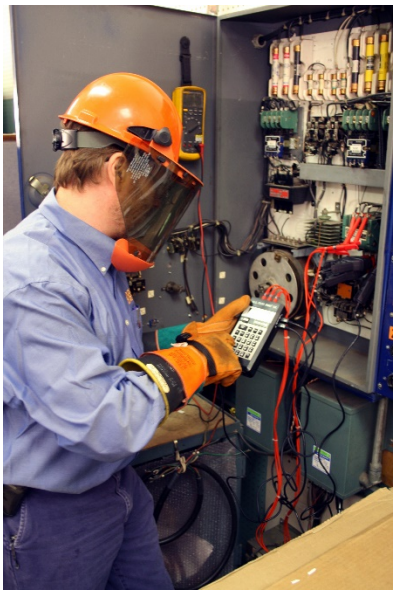

Figure 4: A technician using the ALL-TEST Pro OL ESA instrument (Courtesy: Dreisilker Electric)

One area that ESA runs into limitations is early bearing failure. This remains a primary domain of vibration analysis. Other conditions include determining if 1X RPM readings are due to unbalance, misalignment or a bent shaft. However, when used as the primary detection method, when problems are detected, vibration may be brought in to perform the diagnostics.

When used in a situation where regular data will be collected, it may be beneficial to use ESA plugs that attach and can be connected to without opening the panel. Also, in medium and high voltage applications (greater than 750 Volts), CTs and PTs may be used as the data collection points.

ESA is used in all applications including AC and DC machines with MotorDoc LLC holding a patent pending on Generator and Powertrain analysis.

Motor Circuit Analysis

While common tools such as an insulation resistance tester may be used to detect one component of the motor winding without putting it in danger and high voltage tests may detect other conditions, while having the potential of 'finishing off' weakened insulation, MCA uses a series of low impact measurements to look at the inductance and capacitance of the circuit. The technology we are focusing on for this paper utilized a 4-wire kelvin resistance, dissipation factor, capacitance, insulation resistance, inductance, impedance, phase angle (ie: power factor), and varies the frequency output in order to see the effect on inter-turn capacitance referred to as I/F (current/frequency response). Such testing identifies the complete insulation system as well as the rotor and air gap of the machine. These tests can only be performed while the machine is de-energized but can be taken from the motor, disconnect or motor control center.

Figure 5: MCA being performed with an ALL-TEST Pro 5 on a completed motor

Figure 6: ALL-TEST Pro 5 testing an assembled form-wound stator

The latest MCA devices, such as the one pictured in Figure 6, provide both the automated fault detection (good/caution/bad) as well as the data necessary to do more advanced diagnostics. Software pinpoints the potential problem as well as providing the ability to load routes, compare data over time and advanced trending.

MCA is used to identify cable problems, DC machine issues, transformer faults, in addition to AC motor and generator faults.

Vibration Analysis

Is a huge animal to tackle. While ESA and MCA are new technologies based upon ideas that trace back to the early 1900s, they have only been available on the market since the mid-1980s. Vibration analysis came into the commercial market in the 1940s and 1950s and a great deal of time and research has been spent on understanding vibration and resonance. As a mature technology, vibration is primarily utilized to look at mechanical systems, although has a capability of detecting issues in the electrical spectrum.

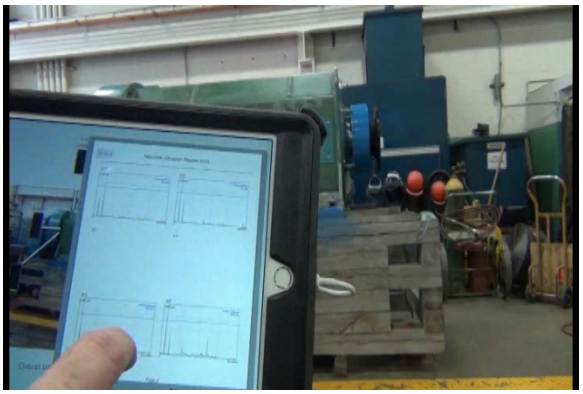

Figure 7: Using GTI Predictive VibeRMS App and Wireless Accelerometer to certify the condition of a wind generator in a repair facility

Modern technology allows for immediate sharing of data across the cloud through smart devices such as iPads, iPhones and other smart phone systems. In addition, many of these new applications, such as the one shown in Figure 7, can automatically identify faults in a machine. This includes the ability to have the software perform phase analysis, vibration analysis, identify natural frequency, field balancing and other related capabilities requiring a minimum of experience resulting in a shorter learning curve for the basics.

The ability to perform advanced vibration techniques, high pass filters and other capabilities are still necessary in order to obtain the full power of vibration analysis. A majority of the advances in this field are in relation to data analysis and wireless technology. In addition, the ability to quickly analyze, include a picture of what is being tested (or show where testing is to occur on routes) can be emailed from anywhere.

Vibration analysis' greatest strength is still in the mechanical realm.

Infrared Analysis

Is an extremely valuable and visual tool. When looking at electrical or mechanical systems related to electric machinery systems and transformers, a few degrees comparison between the background and the point being evaluated can be significant. Usually performed for loose connections or to detect bearing temperature,

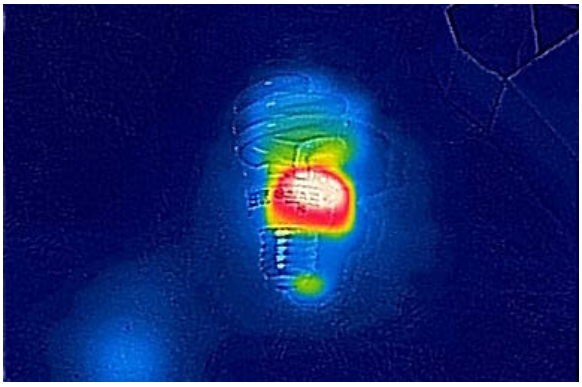

Figure 8: A burned out fluorescent light bulb

Figure 9: Motor Stator during Hot Spot Core Testing

The power of infrared is the ability to visually show others what the condition of a piece of equipment is.

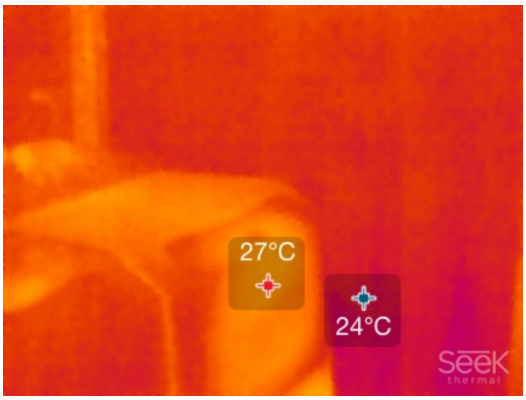

Figure 10: Auto-Spot Detection with GTI Predictive

Ultrasonics

Ultrasonic analysis is also an older technology. However, the FFT analysis of sound is about as recent as MCA and ESA technologies. The concept of sound and spectra allows the analyst to identify the type of problem while also being able to filter out background noise. Another benefit of ultrasonics is that it is very directional, meaning that someone looking for an air leak, for instance, will be able to pinpoint it relatively easily.

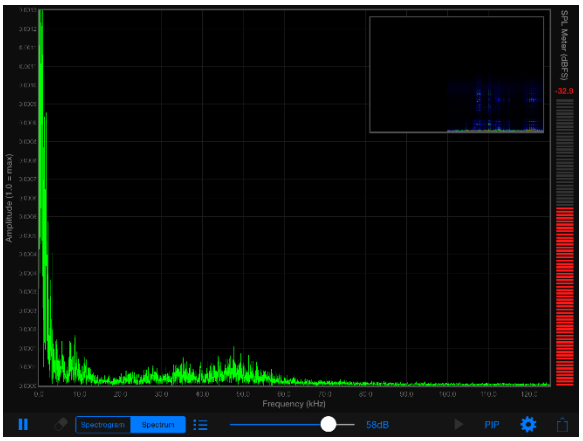

Figure 11: GTI Predictive Ultrasonics on iPad

Primary uses of ultrasound with electric motor systems range for partial discharge and corona for high voltage systems to arcing, bearings, compressed air and steam system issues within the remainder of the system. Ultrasound is an outstanding addition to the overall electrical motor diagnostics and prognostics toolkit.

How Do These Work Together

Each of the technologies discussed have strengths and weaknesses and some 'crossover' between them. This provides the analyst with the ability to confirm a potential problem by using a second technology. For instance, if the maintenance strategy is to perform ESA on running equipment, then when something is detected, a second technology such as vibration, infrared or ultrasonics can be brought in.

However, it requires that the analyst understand which technologies can be applied to detect different types of issues. In Table 1, each of the discussed technologies and the potential issues that can be detected. An X indicates that it is both trend able and will perform diagnostics, T indicates trend able, D is diagnostic, and blank indicates that it is not intended for prognostics or diagnostics.

Table 1: Comparison of Technology

Fault	ESA	MCA	Vibe	Infra	Ultra
Power Quality	X				
Control Transform	X	X		X	
Power Transform	X	X	D	X	D
Cable Faults	T	X		D	D
VFD Problems	D		D	D	D
Loose Connections	D	X		X	D
Stator Grounded	D	X		D	
Stator Shorted	D	X		D	D
Rotor Grounded	D	X	D	D	D
Rotor Shorted	D	X	D	D	D
Air Gap Eccentricity	X	X	X		
Bearing Fault	X		X	X	X
Unbalanced Rotor	X		X		
Other Vibration	X		X		
Natural Frequency	X		X		
Arcing, Corona, PD	X		D		X
Electrical Discharge	X		D		X
Shaft Current	X		D		D
Belt or Sheave	X		X	X	X
Direct Coupling	X		X	X	X
Mis-alignment	X		X	X	
Pump Impellor	X		X		
Fan Problems	X		X		
Motor Efficiency	X				
System Efficiency	X				

Conclusion

There are multiple technologies that can be applied to detect a majority of problems in your motor system. The motor system, itself, includes everything from the motor and generator power train to transformers, controls, cabling and couplings.

This white paper is the first in a series related to the proper application of electrical motor diagnostics. The series will continue with case studies associated with each of the technologies.

Understanding the capability of each technology helps the manager or reliability professional in the development of a strategy that is cost and application effective.

About the Author

Howard W Penrose, Ph.D., CMRP is the president and owner of MotorDoc LLC, the Web-Editor-in-Chief of the IEEE Dielectrics and Electrical Insulation Society and PES Materials standards group, and an officer of the Society for Maintenance and Reliability Professionals. He has won many awards from end users related to motor management and motor diagnostics programs, has designed and performed forensics on machines of all types including hybrid and wind technology. He is a Certified Maintenance and Reliability Professional, a UAW Local 1981 writer's union journalist, life member of MENSA, and member of the Vibration Institute and other organizations. Dr. Penrose is the author of 'Electrical Motor Diagnostics,' 'Physical Asset Management for the Executive,' and numerous other published books on industrial and commercial systems.

More Information

MotorDoc LLC is an unrestricted USA distributor for GTI Predictive Technology and ALL-TEST Pro, as well as an SMRP Approved Tier 1 Training Provider for electrical motor diagnostics and motor system maintenance and management.

MotorDoc LLC provides instruments, training and consulting, including field diagnostics and prognostics, and industry best practice development.

For more information contact us at info@motordoc.com or www.motordoc.com.