Session Thirteen:
Simplifying Predictive Maintenance

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Abstract

Condition based maintenance enables a more proactive approach to the management of assets. Despite the widespread application of condition monitoring techniques, it has been estimated that less than one percent of the benefits of advanced failure warning delivers the expected benefit, savings and risk reduction.

The reasons are many and include existing condition monitoring systems are simply too complex and expensive for many applications, are applied to the wrong equipment or at the wrong assessment intervals and require the development and maintenance of specialist skills and technicians.

This paper details emerging technology that makes it cost effective to obtain the benefits of predictive maintenance across a much wider range of plant.

Using a model-based approach to detect and diagnose electrical and mechanical problems, the model works only on measurements of current and voltage taken from the supply cables.

The technology is applicable to the full range of machinery driven by three phase electric motors, as well as turbine driven generators and alternators. The model is able to provide concise information about developing faults, recommended actions, and the probable time to failure of not just the motors powering the equipment, but of the equipment driven by the motors.

Introduction

The Asset Partnership is a specialist Asset Management Consultancy working with capital intensive organisations to:

- Maximise the sustainable capability of existing assets
- Reducing asset ownership cost and risk
- Optimising Capital Outlay

From time to time we come upon emerging technology which achieves a quantum step forward in the management of physical assets. This paper is derived from a paper by Ahmet Duyar of Artesis and details a new approach to condition monitoring of rotating equipment.

Neither the author nor PwC's The Asset Partnership claim credit for the development of the technology. We have however written the paper in the light our own firsthand experience installing and utilizing the outputs of the MCM technology in the Australia context.

Background

Maximising the sustainable capability of assets and reducing the asset ownership costs and risks requires that the custodians of our assets employ the best techniques available to manage their assets. It is widely accepted that the most cost effect methods require the conduct of the right maintenance at the right time and in the right manner. But much of our maintenance is initiated because of a growing unease about the condition of our equipment. This unease can be alleviated by the use of condition monitoring techniques but many of the techniques are simply not cost effective on smaller plant. The result is that in the US today it is estimated that the combined cost of excess maintenance and lost productivity is in excess $740Billion.

Condition based maintenance or predictive maintenance has long been recognized as being capable of reducing such costs, and a wide range of condition monitoring technologies have developed and are being developed to provide the asset custodian with a better insight into the health of their assets.

For rotating equipment, vibration analysis is the most common method of condition monitoring representing some 85% of all systems sold. Other technologies include infrared (IR) thermography used to detect temperature changes in bearings and shafts; tribology or lubricating oil analysis; motor current signature analysis for electric motors; and ultrasonic analysis of bearing wear.

Without doubt, these approaches have been successfully deployed in many organisations. The application of condition monitoring technology has generated great improvements in the way in which we minimise intrusive maintenance and maximise the plant performance and reliability but for many, the applications are out of reach and for many, the wrong technology is applied to the wrong assets.

The reasons are three fold:

The diversity of condition monitoring components usually makes the application of the technology difficult for most organisations, particularly smaller facilities.

Installation requires the correct selection from a myriad of sensors, correct attachment of the sensors, selection and installation of the cabling, purchase or rental of data acquisition and processing equipment and software, and the development and maintenance of the skills required to manage and interpret the data when it is collected. For many organisations this is a complex and daunting process even when only one vendor is involved. With multiple vendors, the task requires an effort level that few are willing or able to address.

The implementation of such systems is far from straightforward. Online systems require sensor installation, significant cabling often involving long cable runs, and complex integration of data processing systems. Even portable systems typically require the installation of many transducer mounting points to be really effective.

Once installed the management of data can be labour intensive and require the establishment of 'baseline' levels for a range of speeds, loads, or operating conditions to represent normal behaviour.

Even when all these tasks have been completed, the system requires considerable time, effort and skill to sift through the data and deliver results. The recipient of the information has simple needs, 'tell me what plant is in trouble, why and how long have I got' yet the effort required to satisfy this requirement can be very very substantial. Often, because of the massive amounts of data involved, the information is more like 'you have a problem and better go and look at it' with the result intrusive maintenance is initiated when in fact such action may not have been required.

Obtaining good diagnosis requires time for rising trends to be detected and time to undertake the considerable analysis and interpretation. The skills and time needed to do all this is often not available.

There is no doubt that the benefits of predictive maintenance are widely accepted, yet the proportion of asset owners taking full advantage of the approach, particularly for midsize and smaller assets remains relatively small. The return on investment is simply hard to justify and for many potential users, the complexity and cost of traditional condition monitoring systems remains a significant obstacle. They would love to apply condition monitoring technology but the costs are prohibitive.

Ahmet Duyar of Artesis responded to this need by focusing on the most common form of machine; equipment driven by three-phase electric motors and instead of trying to do what others do cheaper, identified and developed and alternate method of asset health assessment.

A 'model-based fault detection' approach was developed using advanced algorithms developed under a NASA contract. Developing this mathematical process into a practical tool required considerable development effort and extensive testing to ensure the accuracy and repeatability of the diagnostics.

Technology Overview

Traditional techniques for predictive maintenance have relied on observing trends of a number of key measurements. By selecting the range of measurements carefully, the skilled analysts were able to spot significant changes and develop some idea of the fault that might be causing them. The analysis could often become confusing and complex when measurements were altered as a result of operational changes including rotational speed or load changes. Many a time conventional condition monitoring has misdiagnosed a developing fault because of an change to the operation of the equipment.

The method taken by Ahmet Duyar takes a completely different approach and is based on the use of a mathematical model to assess the monitored equipment.

The tactic is to build a mathematical model of the motor and the driven system derived from voltage and current measurements and to compare the dynamic behaviour of that model with the actual, measured dynamic behaviour.

The model consists of a set of differential equations, which describe the electromechanical behaviour of the motor and the driven system, including the full range of mechanical, electrical, and operational characteristics.

During ‘learn mode’, real-time data is acquired from the physical equipment before applying advanced system identification algorithms to calculate a set of model parameters. The mathematical model takes into account all speed and load variations experienced during the learn mode period and thereby eliminates the need for manual set up of multivariate alarms. This ‘learned’ model represents the normal operating condition of the equipment.

Under normal operation the data collection algorithm produces a new mathematical model of the system every 90 seconds and, by comparing the learned parameters in the new model, developing faults can be accurately and quickly detected and diagnosed. This model-based approach effectively allows the three phase motor to act as an advanced condition monitoring sensor which is not confused by pre-existing faults in the equipment.

The model is able to recognise 22 different parameters covering a wide range of electrical, mechanical, and operational faults including problems. Such problems include electrical supply, internal electrical problems such as insulation breakdown, mechanical faults such as foundation and coupling looseness, imbalance and misalignment, bearing deterioration and operational problems which may be the unintentional overloading of plant which may cause accelerated wear and damage.

The significant advantage of this model-based approach is that it is very sensitive to early-stage faults but is not affected by to false alerts.

Because the model is based upon voltage and current triggers the technology monitors energy consumption, total harmonic distortion, supply harmonic content and voltage imbalance and provides a valuable power quality analysis capability.

Diagnostic information can also be downloaded to a connected computer for more detailed analysis and interpretation.

One of the great benefits of this approach is that sophisticated condition monitoring data interpretation skills are not required, although the data can be extracted for detailed analysis and scrutiny. In fact, once the system has been installed, the user has very little to do other than respond to information being provided by the system. The health of the monitored equipment can be communicated as local ‘traffic lights’ on the unit, control system inputs, computer displays or emails.

The technology offers a number of very significant benefits including:

- Simple to install and configure.
- Suitable for fixed or variable speed applications
- Suitable for high or low voltage. For low voltage installations, only current transformers or transducers are required and for high voltage systems suitable voltage transformers are added.
- Easily linked to the software package using network or wireless devices
- Simple connection. Requires connection to the motor supply cables and so does not have to be positioned close to the equipment being monitored. This provides all the benefits of having an online system without the cost and complexity of extensive cabling.

Experience

The Artesis Motor Condition Monitor (MCM) is now commercially available and deployed successfully in a wide range of industries around the world. The following are some brief case studies.

a. Case Study1 – Compressor System – Factory Air

Installed in early 2005, the system identified and change in mechanical parameters. The user was first alerted to a possible bearing defect on 13 September, but at a relatively-low severity level. Action was recommended at the beginning of January, and the bearing was changed on 5 January, confirming the diagnosis. This 3 month warning window provided sufficient warning of the impending failure to allow for a timely and planned maintenance intervention. It is worth noting from the trend graph that the system detected early signs of the fault about a month before issuing its initial warning, showing both the sensitivity of the method and its ability to avoid excessive alarms.

b. Case Study 2 – Cooling Tower Fans

Cooling tower fans are typically difficult to monitor unless permanent condition monitoring equipment is installable. In many applications, such and expense is not justifiable. The data collected indicated two developing fault conditions. The first was a gradual deterioration in the integrity of the supports for one of the fans, following an incident in October. Although the system recommended the user to monitor the situation from that time, it did not suggest maintenance intervention until February. At that time, maintenance staff inspected the fan and discovered a loose bolt that was quickly remedied.

Throughout this period, the system was also a second developing fault of increasing imbalance Because the fault was less severe than the support problem, the imbalance was left in place until the next maintenance opportunity and easily corrected by cleaning when the unit was shut down to correct the loose support. The result was a return to balanced running and the avoidance of a bearing failure from shaft imbalance.

c. Case Study 3 – Diesel Generator

A diesel engine is used to drive a 720 Amp, 380 Volt generator at 1500 RPM. Shortly after the 'learn' stage the MCM gave an alarm, first at the second level and later at the fourth level as both mechanical and electrical parameters changed. During this time, the existing monitoring system of the generator gave no warning. Continued operation resulted in the failure of the generator. Interrogation of MCMSCADA diagnostic report indicated that a fault due to a either eccentricity or imbalance in a coupling or gearbox. A strip down showed that the rotor was touching the stator which caused multiple fault alarms including imbalance and electrical failure.

d. Case Study 4 – Mill Motor

MCM units are installed on a Mill Motor. Following the 'learn' period, the MCM detected some existing failures, transmission and unbalance. The mill was left in service however several months later MCM gave a "Rotor" fault alar. The Engineer confirmed the alarm with an independent vibration measurement. With the vibration confirmed a strip down found broken bars on the rotor.

e. Case Study 5 – Steel Mill Fume Fan

A "Watch Load" alarm was provided and on April 15, 2009. When the current trending was examined, it could be seen that motor current had been reducing since November 17, 2008 which indicated increasing filter blockage. An attempt was made to clean the filter with compressed air on May 25, 2009, but on restart, the "Watch Load" error reappeared just after 1 month after maintenance operation. On August 20, 2009 the filter was replaced and the alarm disappeared as the motor current returned to the nominal value.

f. Case Study 6 – Deep Well Pump

Immediately following the 'learn' phase an alarm was provided of a fault in the 'other' category. No accurate diagnosis could be made but a strip down located severe cavitation damage on the pump impeller.

g. Case Study 7 – Deep Well Pump

Three of low voltage generators have been monitoring by PCM units in a sugar producing company. MCMScada software pointed out "Internal Electrical Failure" and "External Electrical Failure" on 06th February 2010. The maintenance team checked the generator with infrared thermal cameras and found out one of the brushes of the excitation circuit is almost run out.

Conclusion

The technology developed by Ahmet Duyar of Artesis represents an exciting new phase in condition monitoring. Previously the domain of high end technology for condition monitoring has been dominated by expensive equipment and large scale plant. The lower end of condition monitoring for smaller plant such pumps, fans, etc. have been left to plant walk arounds by operators and maintainers using the human senses or hand held equipment.

This technology now provides cost effect condition assessment capability for a wide range of plant and equipment and can only make the role of the reliability Engineer much easier.

References

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