Artesis – Simplifying Predictive Maintenance

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Abstract

Maintenance is now a critical management issue. The cost of maintenance may represent as much as twenty percent of fixed manufacturing costs, and driving it down has a significant impact on profitability. Additionally poor maintenance practices result in frequent breakdowns and unnecessary interventions that can halve equipment productivity. Predictive maintenance was first introduced to address both of these challenges by providing advance warning of equipment faults through the use of condition monitoring systems.

Despite the successful application of predictive maintenance in some industries, it is estimated that less than one percent of potential users have been able to deploy it successfully. The major reason for this is that existing condition monitoring systems are simply too complex and expensive for most people. Artesis has successfully developed a new approach based on advanced, patented technology that makes the benefits of predictive maintenance accessible to the widest range of users for the first time.

Focusing on the full range of machinery driven by three phase electric motors, as well as generators and alternators, the Artesis system does not require specialized sensors. Instead, its model-based approach allows it to detect and diagnose electrical and mechanical problems based only on measurements of current and voltage taken from the supply cables. This makes installation much simpler and faster than is typical of conventional systems. The system trains itself in a few days, and is then able to provide the user with concise information about any developing faults, recommended actions, and the probable time to failure.

By simplifying the implementation of predictive maintenance, the Artesis system is increasingly recognized as the preferred approach for many types of equipment in industries ranging from oil and gas to facilities management.

1. Background

Although the benefits of predictive maintenance are widely accepted, the proportion of companies taking full advantage of the approach remains relatively small. For many potential users, the complexity and cost of traditional condition monitoring systems remains a significant obstacle.

When the Artesis team was first challenged to find a way of solving this problem, customers said that it would need to take an innovative approach to avoid the shortcomings of traditional systems. So the solution had to be very simple and inexpensive, easy to install, and provide flexible links to existing systems. And importantly, it had to avoid putting a heavy setup and analysis burden on busy maintenance staff.

Artesis responded by focusing an intense development effort on the most common form of machine – the whole range of equipment driven by three-phase electric motors. The result is Artesis MCM (Motor Condition Monitor), a device that combines inward sophistication with outward ease of use. It brings the benefits of predictive maintenance to the widest possible range of users.

The 'model-based fault detection' approach used by Artesis MCM is not only innovative, but unique in its field. The advanced algorithms used in the product were originally developed under a NASA contract (1, 2, 3, 4) and are the subject of careful patent protection. Developing this mathematical process into a practical tool required a considerable development effort, which included tests on several million electric motors to ensure the accuracy and repeatability of the diagnostics.

Artesis has succeeded into harnessing an innovative (5), advanced technology to provide a simpler, more effective, and more affordable condition monitoring solution that has sparked a predictive maintenance revolution.

2. Overview

Traditional techniques for predictive maintenance have relied on observing trends in the levels of a number of key measurements over time. By selecting the range of measurements carefully, the skilled analyst was able to spot significant changes and get some idea of the fault that might be causing them. The analyst was often confused when the measurements were altered as a result of operational changes, such as speed or load changes, rather than a developing fault. Setup and analysis costs have typically pushed such systems beyond the reach of many potential users.

Artesis MCM takes a completely different approach, based on the use of mathematical models of the equipment being monitored. It uses measurements of voltage and current signals only, allowing it to be installed in the motor control cabinet without long cable runs. Once installed, it automatically initiates a self-learning phase during which it builds up a reference mathematical model. This model includes information about all electrical and mechanical characteristics of the motor and its driven system. This requires no input from the operator at all, and covers all operating states experienced during training, such a different speeds and loads.

When the reference model is complete, Artesis MCM switches to a monitoring mode in which a new model of the system is created every ninety seconds. This new model is then compared statistically with the reference model, and potential faults are identified and characterized. The system is then able to assess the severity of the problem and produce a series of local indications to suggest what action should be taken. Diagnostic information is also sent to a connected computer where detailed information is presented to the maintenance group – including the specific fault, the recommended action, and an estimate of time to failure. Electrical and mechanical problems are diagnosed, including common faults like insulation breakdown, damaged rotor bars, imbalance, and bearing defects.

Key to the successful development of Artesis MCM was to ensure that the advanced technology being used was invisible to the user. In fact, once the system has been installed the user has very little to do other than respond to information being provided to him by the system. Such information can be communicated as local traffic lights, control system inputs, computer displays, or emails, covering virtually any location.

So successful has Artesis MCM proved at monitoring motor-driven systems, that the core technology has now been extended to provide equivalent cover for generators and alternators through the introduction of the Artesis PCM (Plant Condition Monitor).

3. Challenge

In today's competitive business environment, manufacturers are faced with the growing production demands while cutting the cost of manufacturing. One pervasive cost that drags down productivity is low asset effectiveness resulting from breakdowns and unnecessary maintenance interventions. In the US alone the combined cost of excess maintenance and lost productivity has been estimated at $740B, so the potential justification for implementing better approaches is huge.

The predictive maintenance approach has long been recognized as being capable of reducing such costs, and a wide range of condition monitoring technologies have developed to allow it to be implemented in industrial environments. Such technologies work by analyzing data gathered from the equipment in order to recognize fault characteristics sufficiently early to minimize both failures and unscheduled interruptions in production.

Vibration analysis is the most common method of condition monitoring, representing 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.

These traditional approaches have been deployed successfully in a number of key industries. They suffer however from important limitations that have made them inaccessible to the great majority of the organizations that should be able to achieve the benefits of predictive maintenance. In fact industry estimates suggest that somewhere between one in a hundred and one in a thousand potential users have been able to deploy condition monitoring up to this time. So why, despite the universally acknowledged benefits of predictive maintenance, have so few companies achieved successful deployment?

Firstly, the diversity of condition monitoring components has made it very difficult for most people to configure. Correct selection of different types of sensor, cabling, data acquisition and processing equipment, and software has been a complex and daunting process even when only one vendor is involved. With multiple vendors, this task requires an effort level that few companies are willing or able to address.

Secondly, 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 effective. Setting up the condition monitoring software system is also a cumbersome activity. It often requires long manual entry of asset, sensor, and data processing information and the establishment of 'baseline' levels that can be taken to represent normal behavior for the equipment being monitored. This then allows alarm levels to be painstakingly set up for each measurement. This largely manual process becomes even more burdensome when baselines and alarms must be configured for a range of speeds, loads, or operating conditions – a situation encountered in most installations.

Thirdly, even when all these tasks have been completed the system requires considerable time and effort to deliver results. The required outputs are quite simple from the user's standpoint: a clear indication of which items of equipment are developing faults, the type of fault, the action that should be taken, and the timescale for that action. Obtaining these outputs however require time for rising trends to be detected and considerable analysis and interpretation on behalf of the user. The skills and person-hours needed to do all this are often not available to a typical maintenance organization.

System costs have typically been unacceptably high. Portable systems have been relatively inexpensive to buy, but prohibitively expensive to operate. Online systems have avoided the high personnel costs of portable systems, but are very expensive to buy and install. Automated, 'intelligent' systems have sought to reduce the analysis burden, but have been extremely expensive and tough to set up.

As a result of these problems, there has been an increasing demand for simple, effective, and inexpensive condition monitoring systems that allow the great majority of organizations to benefit from the adoption of predictive maintenance without sacrificing diagnostic capability. Satisfying this requirement has been the cornerstone of the development of the Artesis system.

4. Response

Artesis MCM was developed to meet a market requirement for a condition monitoring product that can provide simple and accurate maintenance scheduling information, without the need for interpretation by highly trained personnel. It aims to be very simple to install, set up, and operate, and to require little or no user intervention until an equipment fault is detected.

The benefits of the Artesis approach can best be summarized by taking a look at the contrast with conventional technology in each of the three problem areas previously described.

Firstly, the Artesis system is extremely simple to configure. Artesis MCM monitor units are available for fixed or variable speed drives, and 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. A suitable standard adaptor is then

selected to link each unit to the software package, typically using network or wireless devices.

Secondly, during installation each Artesis MCM unit only requires connection to the motor supply cables and so does not have to be positioned close to the equipment being monitored, which might be in a hazardous or remote location. This provides all the benefits of having an online system without the cost and complexity of extensive cabling. The Artesis MCM units are typically installed in the motor control center by means of a square cutout in the front panel, following which connections are made to sensors, power supply, and communication devices. A relay output is also available to control visual or audible alarm equipment, or to provide a simple input to a plant data acquisition system. Once the Artesis MCM unit is switched on, it requires minimal user configuration before entering an automated 'learn' mode during which the complete normal operating condition of the connected system is established. This process accommodates the full range of speeds and loads experienced by the system, and covers electrical, mechanical, and operational characteristics of the motor, coupling, and any type of driven equipment (typically including pumps, fans, compressors, and conveyors). When this is complete, after a few days, the Artesis system creates a complete Condition Assessment Report for the connected equipment. This report identifies any existing mechanical, electrical, or operational problems and recommends corrective actions and how soon such actions should be carried out. Unlike conventional systems, this information is provided to the user immediately without having to wait for data trends to be collected and analyzed over an extended period. From this point on, the Artesis system provides automated condition monitoring cover for the connected equipment.

Artesis

CONDITION ASSESSMENT REPORT

Company : Exco Corp
Coordinator : Dan Jones
Equipment : Feed pump #3

Analyst : John Wood
Date : 25 August 08

Performance Summary

- [ ] Motor and machine status is working as expected.
- [ ] WATCH LINE. Temporary changes in supply voltage cause this alarm. If alarm is persistent check; harmonic levels, capacitor, isolation of cables, motor connector or terminal slackness, contacts of the contactor.
- [ ] WATCH LOAD. If the process is not altered deliberately, check; leakages, valve & vane misadjustments, pressure gauge fault, manometer, filters getting dirty (fans, compressors). If the process is altered deliberately, MCM/PCM should be updated.
- [x] PERFORM MAINTENANCE. There are indications of mechanical and/or electrical developing faults as shown below. Maintenance should be scheduled as per severity level.

Severity Level

- [ ] Caution
- [x] Low
- [ ] Medium
- [ ] High
- [ ] Urgent

Energy Efficiency

- [ ] Power factor (CosPhi) is below 0.80.

Current and Voltage

- [ ] The average RMS value of the current phases exceed 5% of the nominal current values. Monitor for increased hot spot temperature.
- [ ] Voltage variation is beyond normal limits. Its source should be determined and corrected.

Current Harmonic Distortion

- [ ] There is evidence of harmonic distortion. If Total Harmonik Distortion (THD) is more than 10%, this causes heating, and vibration. Increase of third harmonic causes heating in stator winding. If the fifth harmonic increases, this causes vibration. Harmonic filters can be used for very high values if it is proper and economical.

Current and Voltage Unbalance

- [ ] Current unbalance is more than 5%. Check for stator looseness, short circuit, isolation, partial discharge etc. faults.
- [ ] Voltage unbalance is more than 5%. Voltage unbalance causes heating by increasing the current unbalance more. It should be checked and remedied.

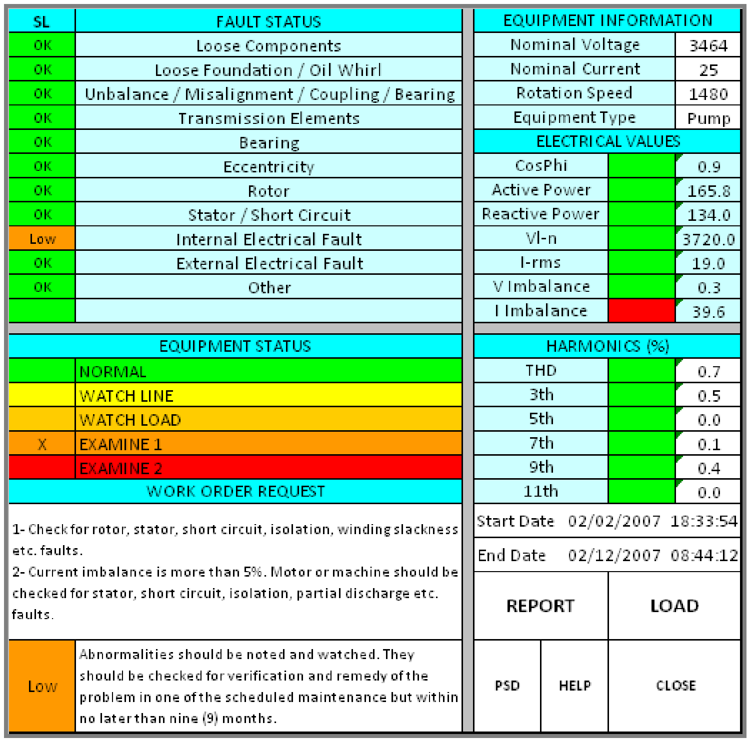
Electrical Fault Indications

- [ ] There is evidence of internal electrical fault. Check for rotor, stator, short circuit, isolation, winding slackness etc. faults.
- [ ] There is evidence of external electrical fault. Cables, contactor, compensation system, and motor connection should be checked.
- [ ] Stator, short circuit, slackness, isolation, and partial discharge etc. faults should be checked.
- [ ] Rotor and rotor bars (slackness, crack etc.) should be checked.

Mechanical Fault Indications

- [x] There is evidence of misalignment/unbalance. Motor or machine should be checked for misalignment, unbalance, bearing, coupling, and motor shaft etc. faults.
- [ ] Transmission element; coupling, driven equipment, belt, pulley, gear box, and propeller of fan and pump etc. should be checked.
- [ ] Bearing(s) should be checked.
- [ ] Loose motor foundation and loose motor component should be checked.

Thirdly, the Artesis system is almost entirely automatic in normal operation. Every 90 seconds it compares the current operating condition of the equipment with the normal condition established during the learn mode. If a problem is detected, traffic lights on the front panel of the Artesis MCM monitor unit change color to indicate the type and severity of the fault. More detailed information is presented by the Artesis MCMSCADA software package which provides the user with a concise, accurate description of any developing faults, recommendations for maintenance actions, time to failure, and a wide range of electrical characteristics.

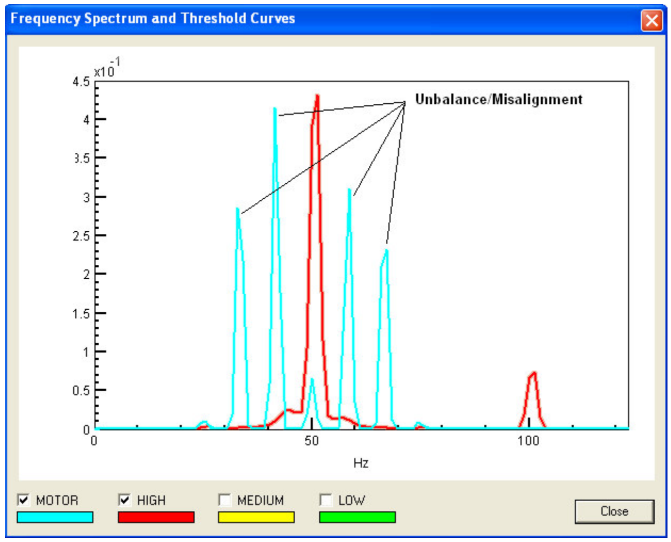


This diagnostic display includes a recommendation about the timescale for completing maintenance interventions, based on the severity level assessed by the system. Such recommendations are based on the results of many similar assessments in the field (6) and represent an average behavior for similar types of equipment. Because of possible specific conditions applying to each individual piece of equipment, this information is considered advisory and the user should of course check abnormalities as soon as possible.

Severity Level (Magnitude)	Action and Timescale
OK (1-3)	Equipment is performing normally
Low (3-4)	Faults should be noted, verified, and corrected within 9 months or during earlier scheduled maintenance
Medium (4-5)	Faults should be noted, verified, and corrected within 6 months or during earlier scheduled maintenance
High (5-6)	Maintenance intervention should be carried out as soon as possible, but definitely within 3 months
Urgent (>6)	Maintenance intervention should be carried out as soon as possible

Many users of the Artesis system spend much of their time in the field, away from their office workstations. To keep them up to date with the condition of their equipment, MCMSCADA can send emails or SMS messages when a new fault is detected. These messages contain a summary condition report, prompting the user to check details on MCMSCADA itself, which can be installed on any computer with a network connection to the system database.

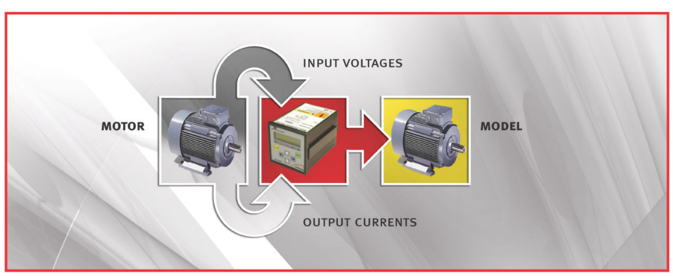
Although MCMSCADA excels at providing the user with actionable information in a concise, practical form some advanced users choose to make use of the more complex displays that it can also provide. Trend plots can be used to show how faults have been developing over time for example, and Power Spectral Density displays indicate the way the system has used information about the frequency content of the measured signals.



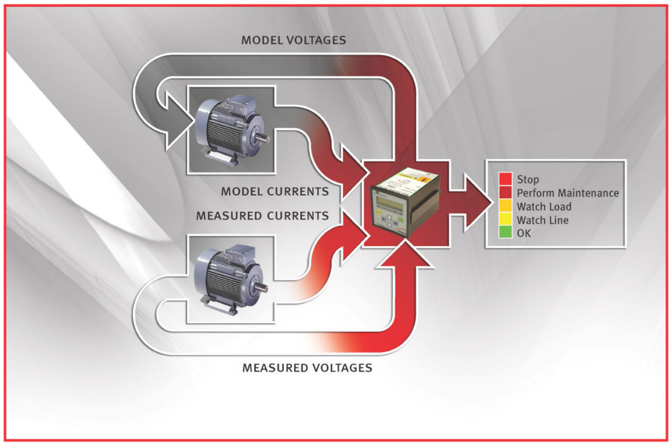
5. Technology

Although the Artesis system is simple to implement and operate, the technology behind it is both sophisticated and unique. By combining advanced model-based fault detection and intelligent diagnostics, the system is able to deliver outstanding results with minimal user intervention.

The principle of the Artesis approach is to build a mathematical model of the motor-driven system that it is connected to, and then to compare the dynamic behavior of that model with the actual, measured dynamic behavior. The model consists of a set of differential equations, which describe the electromechanical behavior of the motor-driven system, including the full range of mechanical, electrical, and operational characteristics.



During learn mode Artesis MCM acquires real-time data 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, eliminating the need for manual set up of multivariate alarms. When completed this model represents the normal operating condition of the connected equipment. In normal operation Artesis MCM produces a series of new mathematical model of the system and by comparing the parameters in this new model with those in the reference model developing faults can be accurately detected and diagnosed. This model-based approach effectively allows the motor itself to act as an advanced condition monitoring sensor, and is not confused by pre-existing faults in the equipment.



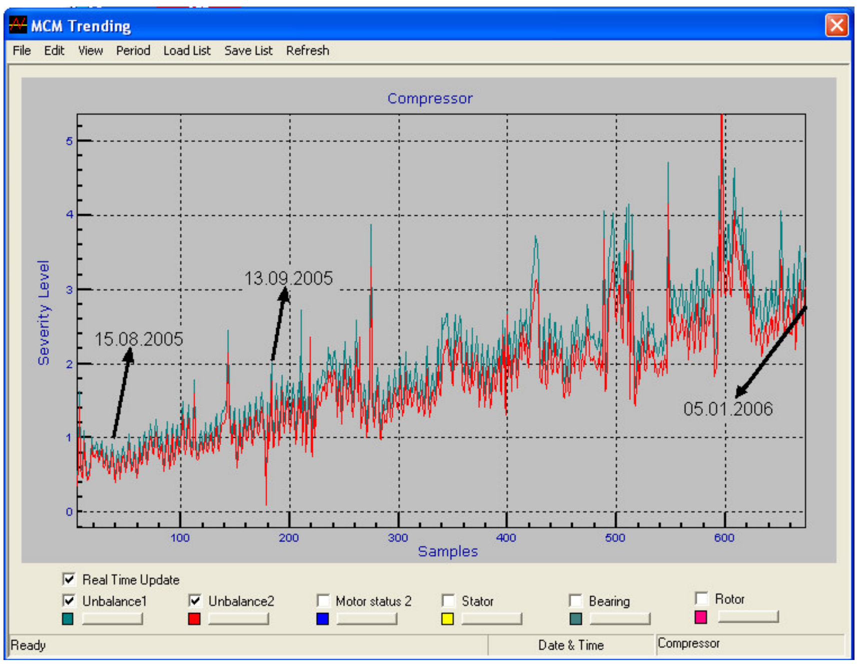
Artesis MCM monitors and compares 22 different model parameters, which are represent a wide range of electrical, mechanical, and operational faults. In addition to recognizing problems with the electrical supply, internal electrical problems like insulation breakdown are monitored. Mechanical faults identified by the system include foundation and coupling looseness, imbalance and misalignment, and bearing deterioration. Operational problems leading to changes in load or electrical characteristics are also recognized. The model-based approach has proved very sensitive to early-stage faults, but is not vulnerable to false alerts.

In addition to its diagnostic capabilities, Artesis MCM also provides the user with a wide range of electrical parameters. These include active and reactive power, allowing the system to be used for energy consumption assessments. Parameters like total harmonic distortion, supply harmonic content, and voltage imbalance also provide a valuable power quality analysis capability.

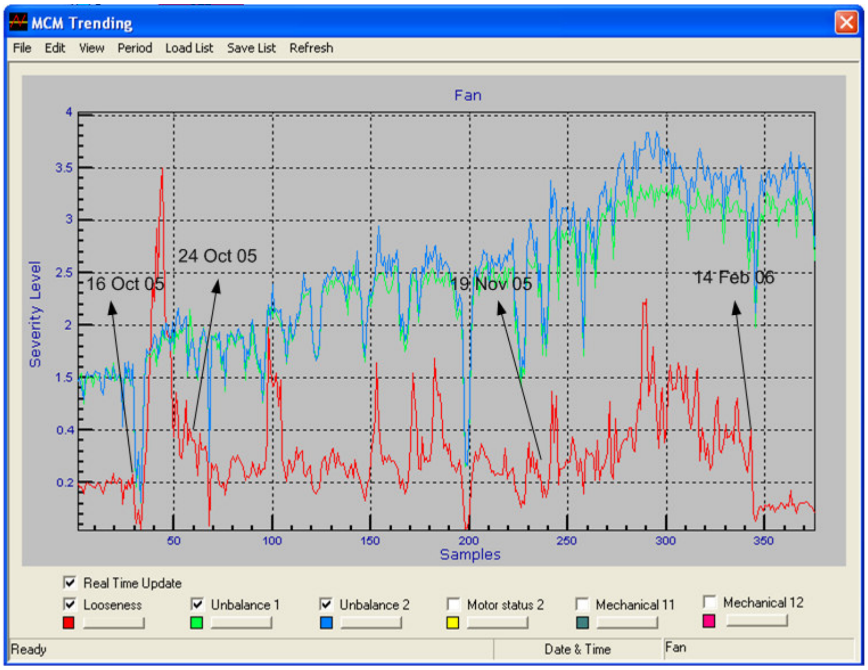
6. Experience

Artesis MCM has now been deployed successfully in a very wide range of industries around the world. Several examples of use are presented here to illustrate how the system works in practice.

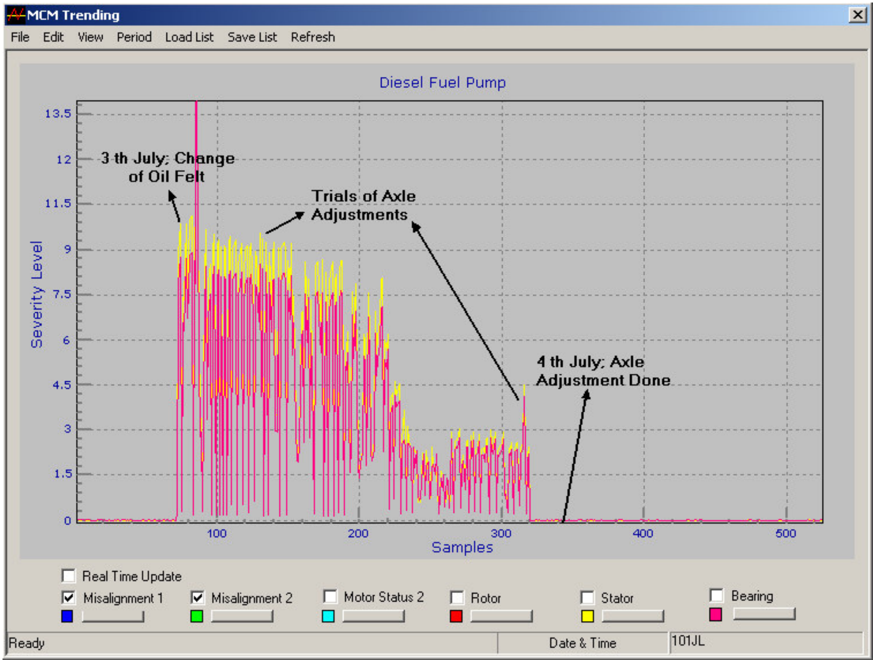
In this first example, the system was applied to a compressor at an automotive parts factory. The graph shows changes in mechanical parameters associated with bearing problems, and is annotated for clarity. It is important to recognize that this information is typically not viewed by the user, but is used by the system to provide concise fault diagnosis. So in this case, we can see that 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 exactly what was required for timely maintenance intervention. Actually, the trend graph shows that the system had 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.



This second example shows the ability of Artesis MCM to manage two developing fault conditions simultaneously. Here the system has been monitoring tower fans at a car plant, where it had been selected to avoid the high cost of sensor cabling to these inaccessible machines. The red trend line shows a gradual deterioration in the integrity of the supports for one of these 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 presenting an increasing imbalance shown by the blue and green trends. Correctly interpreted as less severe than the support problem, this imbalance was easily corrected by cleaning immediately after the support intervention, avoiding the bearing problems that can often be caused by such deterioration.



The third example demonstrates the ability of Artesis MCM to help maintenance supervisors manage the effectiveness of interventions. In this case the system was being used to monitor a large pump in a petrochemical facility (another very typical application). Following routine maintenance in July, the system reported a very severe level of misalignment and recommended immediate action. The maintenance management team issued a work order for this remedial action, which was quickly carried out by the local team. However, it was clear from the analysis provided by Artesis MCM that the precision of this activity was not adequate and a repeat work order was issued. This second precision alignment intervention succeeded in bringing the equipment back to its normal operating condition.



7. Conclusions

Over the past few years, Artesis MCM has been installed by many companies that have previously been aware of the benefits of predictive maintenance, but had found it too complicated and expensive. Early customers worked very closely with Artesis to refine the system, contributing significantly to the present high dependability and robustness of the solution.

Customers now enjoying the benefits of the Artesis system work in a very wide range of industries, including the utilities, power, petrochemical, and manufacturing sectors. They have successfully used the system on many different types of equipment, including the complete spectrum of pumps, fans, compressors, and conveyors. New applications are appearing all the time, examples being escalators and moving walkways, turbine and diesel alternators, and drilling systems. Many have started with healthy skepticism that such an inexpensive, autonomous system can perform as well for them as for other customers. But with each new implementation, the effectiveness of the approach becomes even more widely accepted.

Because the Artesis system is convenient to install, avoiding both the need to install equipment close to the equipment itself and long cable runs, it is increasingly being specified for supply as part of new equipment. This has also led to joint development projects with equipment manufacturers to embed Artesis technology in their own products.

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