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Using Advanced Modeling Techniques to Simplify, Improve and Reduce Costs of Condition Monitoring

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Artesis have developed new, advanced modeling techniques to provide a new approach to the predictive maintenance of three phase systems, including electric motors, generators, transformers, and the equipment or process driven by them. Requiring no special sensors, the Artesis MCM (Motor Condition Monitoring) system measures only voltages and currents. It improves maintenance planning by detecting impending mechanical and electrical failures at an early stage through continuous monitoring, and provides extensive diagnostic information. The primary function of the system is to provide early warning of progressively deteriorating machine and process conditions to prevent unplanned downtime, and improve productivity. The patented Artesis core technology stems from a decade-long research effort, which previously has been applied in the United States to the Space Shuttle Main Engine, helicopter engines and gas turbines. Artesis MCM is an inexpensive device yielding accurate maintenance decision information that can be used by less skilled personnel, eliminating many of the shortcomings of both vibration and current signature analysis systems.

Artesis MCM – a new approach to condition monitoring

In today's competetive business environment and low profit margins, manufacturers are faced with the growing production demands while cutting the cost of manufacturing. One pervasive cost that drags down productivity is the unplanned equipment and manufacturing process downtime. Unexpected failure of processes and machinery in industrial environments is always undesirable, and when these processes are critical such failures often lead to lost production and costly repairs. Condition monitoring provides early warning of impending equipment failure to prevent costly downtime and damage to process equipment. It achieves this by analyzing data gathered from the equipment in order to recognize fault characteristics sufficiently early to minimize failures and unscheduled interruptions in production. An increasingly widespread trend is the integration of continuous condition monitoring with predictive maintenance capabilities to factory automation systems.

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; and ultrasonic analysis of bearing wear.

A major application of condition monitoring is the maintenance of electric motor driven systems such as pumps, compressors, fans, presses, and many other types of machinery. Such equipment is ubiquitous throughout industry with a wide range of motor power ranging from a few Watts up to a few Megawatts. Vibration analysis of such equipment involves mounting sensors on the motor and driven machine and measuring the vibration energy spectrum using an external data acquisition and analysis unit, typically a PC or hand-held device. A

mechanical fault developing within the system will be detected as a change in the vibration energy in specific frequency ranges. A highly-trained engineer can recognise these changes by monitoring outputs from the analysis system, typically presented as spectrum or trend plots. Meaningful analysis requires the observation of measurements made over a long period of time, most often manually. This makes the approach expensive and difficult to use for the following reasons:

- Cost - both the sensors and their associated electronics are expensive.
- Ease of installation - the mounting position of the accelerometers on the motor has to be carefully chosen for maximum sensitivity. Also mounting sensors can be a problem in inaccessible places.
- Ease of use - data gathering and analysis is time-consuming and the interpretation of the data requires skill and training
- Repeatability - data obtained for vibration systems may have repeatability problems, especially when different people are used for data collection or when loading conditions differ. Also background vibration can interfere with the measured signal
- Comprehensive coverage - vibration analysis is effective in the detection of mechanical faults, but are not applicable for the majority of electrical faults
- Advance warning - the threshold values used are affected by the operating conditions of the equipment. Therefore, many continuous vibration monitoring systems use higher threshold values which may reduce warning time.
- Integration to factory automation systems - a significant majority of vibration systems are portable and cannot easily be integrated to factory automation systems for continuous monitoring.

So although vibration analysis is the traditional technique used in industry, it is expensive, notoriously difficult to use, and requires high levels of expertise both in acquiring the data and interpreting results. There has been a persistent and increasing demand for inexpensive, simple to use condition monitoring technologies and products that can be integrated to factory automation systems with maintenance planning capabilities.

Motor current signature analysis has sometimes been used to overcome some of the shortcomings of vibration based systems. This approach is based on analysis of the line current supplied to a motor. The variances in the stator-rotor air gap are reflected back in the motor's current through the air gap flux affecting the counter electromotive force, so that current carries information related to both mechanical and electrical faults. Faults will therefore exhibit a change in the frequency spectrum of the current at specific frequencies.
Data acquisition is simple in current signature analysis since only electrical signals are measured. It also provides comprehensive coverage; both mechanical as well as electrical faults are detected. However, the interpretation of the data requires expert personnel and is as time consuming as vibration analysis. Just like vibration analysis, current signature analysis is an output assessment only. So it can be difficult to determine whether an abnormal signature is due to a problem in the motor or to unexpected harmonics in the supply voltage.

Artesis MCM was developed to eliminate the shortcomings of both vibration and the current signature analysis systems, by taking a radically different approach. Artesis MCM uses a model-based fault detection and diagnostics technique in which the expected dynamic behaviour (model) of the three phase system under varying conditions, such as load, is determined and compared with the measured dynamic behavior to monitor abnormalities.

Artesis MCM first learns about the motor-driven system to which it is connected for a period of time by acquiring and processing real-time data. Data is analysed using a set of advanced system identification algorithms in order to allow the calculation of expected dynamic behaviour and model parameters. Changes in the parameters of the system can then be used to indicate any abnormalities developing in the system. Further processing of these parameters is used for fault diagnosis.

As opposed to traditional vibration and current signature analysis, this approach is based on a cause-effect (input-output) relationship and is therefore immune to ambient or input noise. Additionally, the difference between expected and actual behaviour filters out and enhances only abnormalities generated by the system allowing the presentation of both earlier and more accurate alerts. The expert system approach eliminates the need for database or record keeping, expert personnel, and time-consuming data gathering and analysis. It provides comprehensive fault coverage (mechanical and electrical as well as the driven system), although it measures only voltages and currents.

Artesis MCM uses the electric motor of the equipment as a sensor. Any faults in the equipment that affect the motor or the three phase system are also monitored by Artesis MCM.

Artesis MCM addresses many of the objections raised by the use of vibration-based and current signature analysis systems:

- Cost - Artesis MCM and its accessories are inexpensive
- Ease of installation – Industry-standard current and voltage transformers can be used as sensors. These sensors are inexpensive, easily installed and familiar to all electrical maintenance personnel. Artesis MCM can be used anywhere an electric motor driven systems can be operated. Since the sensors and main unit are usually mounted in control cabinets. Artesis MCM unit does not need to be in close proximity to the monitored system
- Ease of use - The expert system approach makes it possible for Artesis MCM to automatically establish a database and monitor changes in these parameters. Fault levels are presented on a simple and intuitive sliding scale by the device itself, reducing dependence on highly-skilled specialists.
- Repeatability - Artesis MCM results are highly repeatable. There are no external or background effects that can interfere with the capability of Artesis MCM to monitor systems.
- Comprehensive fault coverage - Both electrical and mechanical faults can be detected using a single device.
- Advanced warning – Alarm thresholds are not affected by the operating conditions of the system, allowing Artesis MCM to provide early and accurate alarms.
- Integration to factory automation systems - Artesis MCM units are easily connected to an external acquisition system for continuous monitoring using industry-standard network cabling. This, together with its simple method of fault indication, makes Artesis MCM an ideal device for use with factory automation systems.

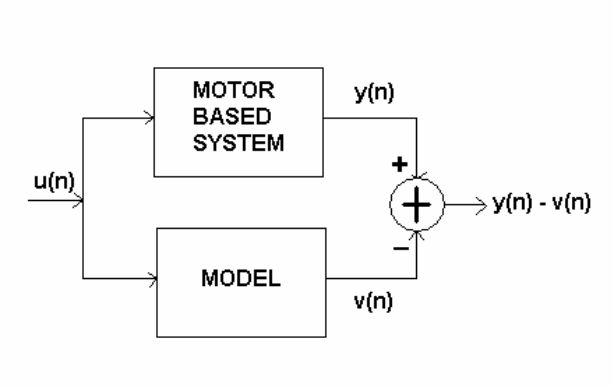
A comparison of Artesis MCM with vibration and current signature analysis is given below:

FEATURES	Artesis MCM	Current Signature Analysis	Portable Vibration Analysis System	Continous Vibration Analysis Systems
nexpensive ?	Yes	No	Yes	No
Simple to install and acquire data ?	Yes	Yes	No	No
Simple to use?	Yes	No	No	Yes
Can be used by untrained personel?	Yes	No	No	Yes
Comprehensive fault coverage, both mechanical and electrical?	Yes	Yes	No	No
Lower thresholds/ advanced warning of faults?	Yes	Yes	Yes	No
Maintenance planning capability with continuous monitoring?	Yes	No	No	Yes
Integration to factory automation systems?	Yes	No	No	Yes

How Artesis MCM works

Artesis MCM has been developed to meet manufacturers' need for a condition-monitoring product that can provide simple and accurate maintenance scheduling information, without the need for interpretation by highly trained personnel. The technology used for the detection of impending mechanical and electrical faults is a proven, patented technology that has been previously employed in aerospace applications.

Artesis MCM uses model-based fault detection and diagnosis techniques. The principle of this approach, as illustrated below, is to compare the dynamic behaviour of the mathematical model of the machinery or process with the actual, measured dynamic behaviour.



In Figure 1, u(n) is the input voltage to both the mathematical model and the actual motor-based system. y(n) corresponds to the output of the motor-based system, the measured currents, and v(n) is the current calculated by the mathematical model. So y(n)-v(n) is the difference between the measured and calculated currents. The model consists of a set of differential equations, which describe the electromechanical behavior of the motor. The real-time data acquired from the system is processed by system identification algorithms for the calculation of model parameters. Faults developing in the motor or in the motor-driven system affect the model parameters, allowing the motor itself to be used as a condition monitoring sensor.

Artesis MCM first learns the characteristics of the motor-based system for a period of time by acquiring and processing the motor data. The results of the processed data are stored in its internal database and a reference model is established. This reference model is represented by the values of a number of model parameters, in terms of both mean values and standard deviations. While monitoring, Artesis MCM processes the acquired motor data and compares the results to the data stored in its internal database. If the results obtained from the acquired data are significantly different from the reference model, Artesis MCM indicates a specific fault level. The level of the fault is determined by taking into account the magnitude and the time duration of the difference.

In total, Artesis MCM monitors and compares 22 different model parameters, which are classified into three groups. The first group, the eight 'electrical parameters', are the network equivalent parameters and are correlated to the physical parameters of the motor, like inductances and resistances. These parameters are sensitive to electrical faults developing in the motor. Artesis MCM evaluates and analyzes the differences between the model parameters at any instant and the average value of the same parameters that are obtained during the learn stage. These differences are normalized with respect to their standard deviations obtained during the learn stage. So the processed values indicate the number of standard deviations they are away from the average values obtained during the learn stage. If they exceed threshold values, an alarm is given. Changes in their values are associated with faults that are developing in the system, an isolation problem in winding affecting the parameters associated with resistances for example. This would allow Artesis MCM to detect the isolation problem at an early stage. Though they are primarily used to detect electrical problems, they also can indicate mechanical problems. For example, an imbalance or gear problem would cause dynamic eccentricity in the air gap, resulting in a change in the induction parameters and therefore in the model parameters. By monitoring the changes in these model parameters imbalance can be detected very early, avoiding damage to other machine components such as bearings.

In addition to the above parameters Artesis MCM also monitors the supply voltage as well as the load conditions. If the supply voltage changes abnormally, has imbalance or very high harmonic content then it issues a Watch Line alarm. Similarly if the load conditions do not match with the conditions observed during the learn stage then it issues a Watch Load alarm. The Watch Load alarm means that either the load conditions have changed or there is a fault developing in the system. If the user determines that there is a change in the process, then he can add this new load condition into the conditions observed during the learn period.

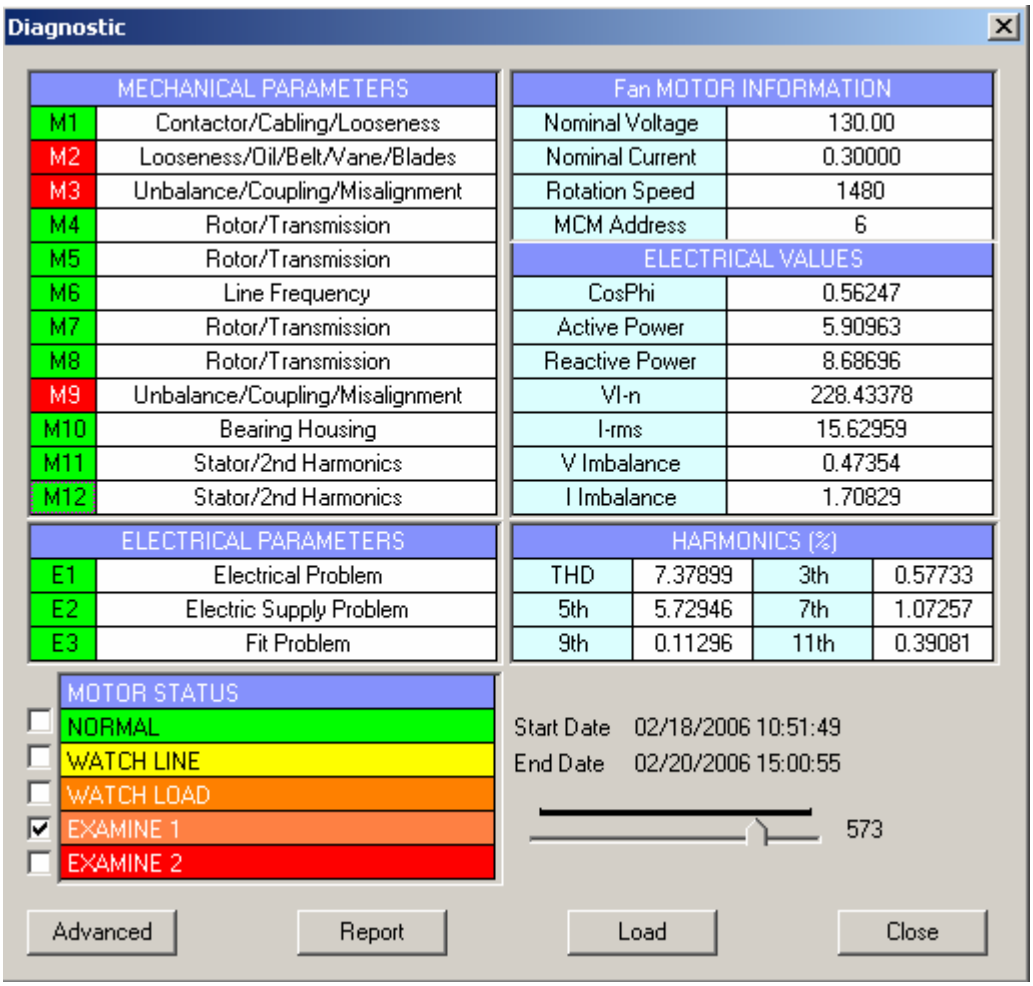
Using the measured three phase voltage and current signals, Artesis MCM also calculates a set of physical parameters such as rms-values of three phase voltage and current, powerfactor, etc. This set also includes parameters such as total harmonic distortion, harmonic content of the incoming signal and voltage imbalance which give an idea about the quality of supply power. Active and reactive power parameters in this set might be used for energy consumption estimations. It combines many measurements that are of interest to both production and maintenance operators in a single device.

For all its sophistication, Artesis MCM is supplied as a small, instrument suitable for installation on motor control panels. Selected measurements can be displayed on the LCD screen of the device, and alarms are presented using LED 'traffic lights' for ease of use.

Integrating Artesis MCM into Enterprise Systems

Artesis MCM can be integrated with its own desktop application, MCMSCADA, which is used for trending and diagnostics. MCMSCADA also provides the user with reports outlining fault status, diagnostics as well as relevant parameters about the operation of the equipment during a selected period. In addition to trending, MCMSCADA also obtains the frequency intervals of mechanical parameters and determines the corresponding faults, such as bearing problems, imbalance, looseness, etc. which are then presented to the user. Average values obtained for energy consumption (voltage, current, active power, reactive power and power factor) as well as the power supply quality (THD, harmonics, voltage imbalance and current imbalance) are also provided as shown in the screen display below. Artesis MCM can automatically send this report when an alarm occurs and at selected periods using e-mail. MCMSCADA allows electric motor-based machinery, equipment and processes in a plant to be monitored from several different computers at remote locations.

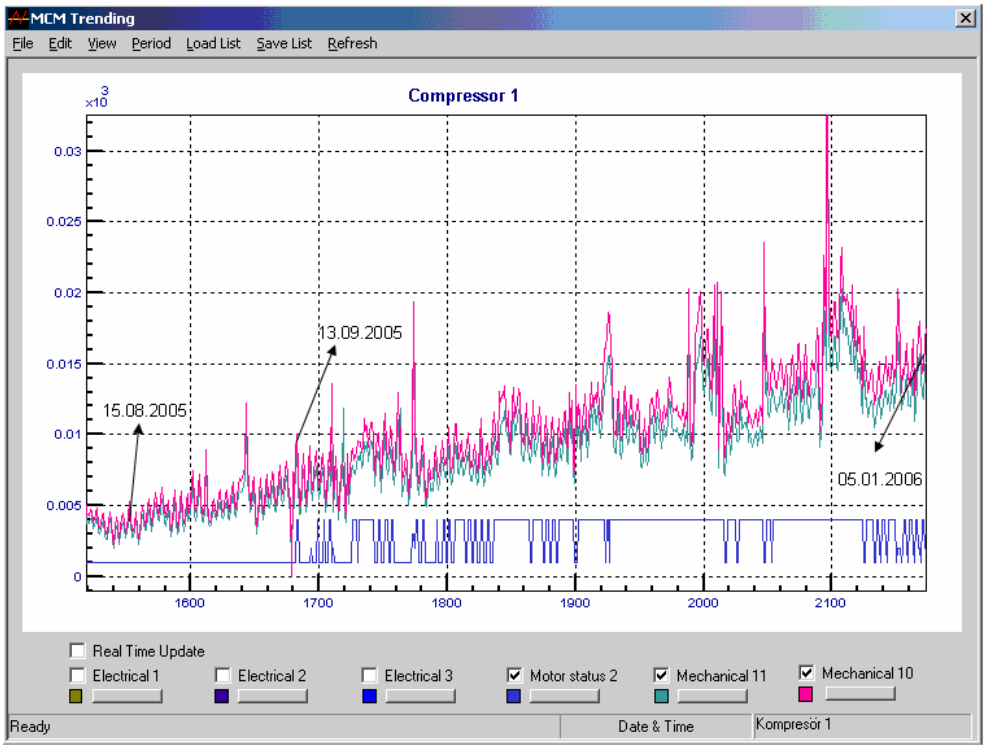
Alternatively, Artesis MCM can be integrated to factory automation and maintenance management systems using the standard Modbus communication protocol.



Artesis MCM – Examples of Use

The technology has been successfully deployed in a wide range of industries, some of which have successfully applied condition monitoring for many years (like power, primary metals, and petrochemical processing). They have found Artesis MCM very attractive as an addition to existing systems, particularly for remote or inaccessible machinery and for equipment where it has been difficult to justify the higher cost of traditional approaches. The automated diagnostic capabilities of Artesis MCM have allowed such customers to extend their condition monitoring programs at minimum cost and without increasing the load on already-stretched analysts. As they have got to know the technology better, many have been surprised at its ability to give long advanced warning of mechanical faults like bearing degradation, soft foot, imbalance and misalignment, as well as electrical problems such as insulation or capacitor defects.

In this example, which shows the measurement trend from a compressor, Artesis MCM has correctly identified a developing bearing fault and provided a 3 month warning to allow the successful planning of a maintenance intervention. This trend also shows that Artesis MCM was aware of the incipient defect for a full month before considering it sufficiently serious to alert maintenance staff.



However, MCM has also been especially successful in industries that have not been tradition users of condition monitoring. Examples of this include the food and beverage, building services, water treatment, automotive, marine and general manufacturing sectors. One manufacturer of washing machines has been using Artesis MCM to monitor coveyor and fan systems in the paint shop, where equipment failures has been leading to many defects requiring expensive rework. This has resulted in a reported increase in productivity by 50%, and a reduction in customer complaints by 25%, allowing the system to pay for itself in well under a year. Similarly, water industry customers have been able to reduce maintenance costs by 10% through reductions in emergency repairs, deferred interventions, and reduced spares stocks.

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