Enhanced diagnostic capabilities by integration of digital models into a condition monitoring system

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Siemens VAI Metals Technologies has now become part of Primetals Technologies, which is a joint venture company of Siemens, Mitsubishi Heavy Industries and partners.

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Summary
Offline simulation is often used by plant builders for the design of metallurgical plants and to ensure that performance expectations are met. Whereas some simulation models cover operations across the complete plant (e.g., throughput calculations), smaller simulation models focus on individual topics such as closed-loop control, vibration behavior and the functionality of single components. The concept of using offline simulation in an online mode for plant operation is not new. Nonetheless, the necessary steps for its application are complicated and time-intensive. These require extensive technological know-how, the buildup of digital models (using, for example, Matlab or Simulink) and the compilation of software that is ready to be used in the automation platform or in a condition monitoring system.

As a plant builder with IT competency, Primetals Technologies has mastered this challenge and has defined a concept known as Control Builder. As described in this paper, it allows the reuse of offline digital models or simulations in the condition monitoring system (CMS). These digital models support condition-based maintenance activities by providing deep insight into parameters that cannot be measured directly (soft sensor methods), or by comparing complex operation states with design parameters. An example is the monitoring of hydraulic closed-loop control and the associated cylinder to determine the degenerative status of valves or if internal cylinder leaks are evident. Key performance indicators (KPIs) that are the output of such simulations can be further monitored with the CMS, and they also serve as an additional indicator for root causes.

Key Words
Condition Monitoring, Predictive Maintenance, Analysis, Model based, Diagnostic, Machine to Machine Interface, Simulation, process monitoring

Introduction
The key to successfully improving the efficiency of a production facility or its individual equipment is the collection, analysis, and interpretation of all relevant data. A fully integrative condition monitoring system – in conjunction with a competent maintenance service – helps to visualize the plant’s condition and serves as the basis for predictive and focused maintenance activities.

But how will you monitor systems and functions that are not covered by the supplier of your condition monitoring system? How will you monitor your latest technology and your unique system?

With an open condition monitoring system that allows you to implement your own analysis and a service for generation of customized libraries you are free to optimize the maintenance to your needs.

Predictive maintenance
There are different strategies for maintenance. The reactive maintenance (run into failure), the preventive maintenance (e.g. time based replacement), the proactive maintenance (why did it fail again) and the predictive maintenance (condition based replacement or repair). All strategies together should be used for an optimal maintenance.

The success of predictive maintenance is based on the quality of the condition information that will be available for the equipment, the automation functions or the process. This information will be delivered mainly by condition monitoring systems that allows data to be collected from multiple sources through different interfaces. With predefined analysis the condition will then be calculated and in case of an upcoming wear an alarm message will be generated. The condition information should be designed to give as much information to the reader, so that a decision can be made. This could also be the decision to forward the information to a specialist for a detailed analysis.

From data to information
Condition monitoring systems (CMS) are used over a long period of time to monitor single components like motors, hydraulics, gears or single functions. This leads into a various number of different systems from different suppliers with different user interfaces that are spread over the entire plant. Each system has specialized functions to give the optimal condition
and the best potential for detailed analysis and diagnostics. Some of them are integrated in the automation system; others are stand-alone systems. This presents a major challenge for the maintenance teams, as the information required for predictive maintenance is provided by several CM systems with different content and are normally not adaptable to new requirements that are coming up during the lifetime of the plant (refer to figure 1).

**Figure 1: Too much data given to the maintenance staff. To less flexibility for CM information.**

PRIMETALS Technologies offers a condition monitoring system to provide the maintenance staff with the best information. One part of it is the evaluation system that collects the data and evaluates the condition and the other part is an information system that gives an easy access to all information via one web based interface, called Information Broker. The connection between both parts is realized with a machine-to-machine interface. Each condition-information logs on automatically at the information system and delivers all necessary information like:

- Name of information
- Description of monitoring function
- Status as "traffic light" and text message
- Location of monitored equipment (e.g. customer specific code)
- Location of evaluation system
- Graphical report or snapshot of trends and curves

With this interface the system can be enlarged very easily and also existing systems or systems from other suppliers can be integrated in the Information Broker. So all needed information would be supplied and accessible within one system (Figure 2).

**Figure 2: One system with all condition information, connected by a machine-to-machine interface**

**Data collection**
Data will be collected out of the classic automation pyramid or out of mechatronic systems if we look into future architectures [1] (figure 3) and converted into condition information.

In the classic way the data will be collected directly from the PLCS with their specific communication interface. For time critical analysis the data will be pushed by the PLC and collected out of the process image. For non-time critical analysis the data could be pulled from the CMS by using read commands. For future architectures the data will be provided by the mechatronic systems by using standard interfaces like OPC UA or other interfaces that will be specified in the future as part of the concept Industry 4.0. This interface allows to browse through all accessible data and to choose the data that should be streamed by the CMS.

**Evaluation of condition**
Most condition monitoring systems have predefined functions and can only be extended by the user to a limited function or some fundamental adjustments. But it is precisely in complex facilities that experienced maintenance engineers tend to know exactly which analysis functions are needed to determine the condition of the system. In many cases there are also research departments working on this problem. In order to turn these functions into a condition monitoring system that is suited to the industry it is normally necessary to collaborate with
the system manufacturer, which usually means an outflow of know-how, as well as resulting in development periods that are incompatible with requirements within plants.

The evaluation system from PRIMETALS Technologies could be described as a programmable condition monitoring system (PCMS) that allows the user to design his own analysis. Like many plant operators let do the programming of the PLCs their engineers the monitoring of specific equipment, functions or processes could be done in a similar way with the PCMS.

Besides the standard monitoring functions, the PCMS offers a platform to build customized analysis with:
- Online system for continuous monitoring
- Offline system for sequential monitoring based on the time stamps of the data
- Graphical engineering of monitoring functions with a big library of analysis and calculation blocks
- Script language for programming of sequences for monitoring

Converting your employee’s knowledge into condition monitoring functions

If your employee sees a changing of process data or behavior of the plant, he or she knows exactly that something will come up. And even if you do not know the reason for a fault, your specialists can analyze the behavior afterwards in your PDA (process data analyzer) system and try to find out what happens. Why do not turn this knowledge into a monitoring function (figure 4)?

Now there are two possibilities to implement the monitoring functions in the evaluation system.

1. Monitoring function will be designed in the evaluation system
2. Monitoring function will be designed in Matlab code, Matlab Simulink or C++ code and then converted into a monitoring function.

Design of monitoring functions in the evaluation system

An example for the design of monitoring functions in the evaluation system is the monitoring of roller tables. The function could be build up out of a view standard block for arithmetic and analysis.

**Requirement:** Find out if the friction of the roll becomes so high that the motor is not able to drive it continuously.

**Abstract description:** If the friction becomes too high, the motor current and the temperature will raise.

**Implementation:** First the signals and the relation between the status signals and the process signals have to be analyzed. The motor current shows many peaks and could not be used directly with an alarm band. With a moving average of the motor current and a coupling of the temperature level a KPI could be calculated. This KPI will be monitored with a warning and an alarm level.

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from the past and at different mechanics. In the online system the equipment is now monitored continuously.

Design of monitoring functions in the Matlab Simulink or C++ code

An example for a more complex monitoring function is the monitoring of the wear and the leakage from a hydraulic cylinder. The data that must be monitored could not be measured directly but has to be calculated by using a model of the cylinder.

**Requirement:** Determine the quantity of the internal leakage by utilization of the measurements of the hydraulic cylinder.

**Abstract Description:** With a model of the hydraulic cylinder its behavior should be simulated (figure 7). By measuring the input and output signals that are available at standard applications a changing of the normal state should be monitored and an alarm for leakage and for wear should be generated.

**Figure 7: Servo valve with hydraulic cylinder [2]**

**Monitoring function:** With the program Matlab Simulink the model of the hydraulic cylinder and an algorithm, which uses real measurements and the model data, were implemented. This algorithm estimates the nominal flow of the servo valve in normal operation condition. Hence, the driftwise fault of control spool edge erosion will be observed, which is crucial for the hydraulic system behavior. In such case, the nominal flow estimate will rise over time. Furthermore, the algorithm will also estimate the leakage of the cylinder. The quality of the estimation is influenced by the pressure difference (higher difference means best result) and the unknown control spool offset (figure 8).

**Figure 8: Leakage estimate for some strips at one HGC (between A- and B-side caused by worn cylinder seal)**

The performance of this flow and leakage estimation was at first verified by using historic measurement data of cylinders with known operation conditions, in especially normal and fault (leakage) conditions. In these scenarios the algorithm was able to detect and to quantify an internal leakage of faulty cylinders. This algorithm was converted into a graphical function block for the evaluation system using automated code generation techniques based on Matlab/Simulink. The function block was implemented into the online condition monitoring system and tested in real time operation. Figure 9 shows a picture of the cylinder with monitoring of the KPIs and status lights as an example. This monitoring function was also tested with historic data of normal and faulty operation conditions to ensure a safe detection of abnormal behavior. This procedure provides also an easy way to fit the model and the monitoring function parameters to obtain an improved robust performance.

**Figure 9: Monitoring of leakage and wear at a hydraulic cylinder**

**Benefit of a flexible monitoring**

The example shows that there are many possibilities to monitor the plant besides the standard CMS functions like vibration monitoring, oil analysis or others that could be implemented in a flexible monitoring system. For the roller tables a blocking could be predicted and with the machine-to-machine-interface a complete information package would show all necessary details for the maintenance team. The example of the hydraulic cylinders shows that also complex functions or simulations could be turned into monitoring functions. Here direct measurement of internal leakage that is very expensive and needs
new cylinders was turned into a pure software solution.

Conclusion
A flexible monitoring system, like the IT4Metals CMS from Primetals Technologies, offers the possibility to turn the knowledge from the maintenance team and the operators into monitoring functions that would give alarms and best information for a predictive maintenance.

Abbreviations
CMS – Condition Monitoring System
PLC – Programmable Logic Controller
PCMS – Programmable Condition Monitoring System
CAE – Computer Aided Engineering
OPC - OLE (object linking and embedding) for Process Control
OPC UA – OPC Unified Architecture
PDA – Process Data Analyzer

References