PROCESS OPTIMIZATION IN "SMART" COMPANIES THROUGH CONDITION MONITORING

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ABSTRACT

The objective of "Condition Monitoring" (CM) is to ensure smooth production operations. Traditional reactive and proactive CM processes are not enough. Horizontal and vertical IT integration form the basis for process optimization through predictive and prescriptive management. Digital concepts of industry 4.0 enable innovative business models and flexible business processes.

APPLICATION POTENTIAL OF CONDITION MONITORING

The desire for more resource-efficient processes arises in particular in connection with digital, disruptive technologies. In this context, both established and innovative methods are taken into account in corporate practice. A future-oriented approach is condition monitoring. CM is based on a regular collection of plant and machine data, by recording and analyzing various parameters such as vibration, temperature, quantity as well as wear and tear.

The simplest form of CM follows the reactive principle. The machine or plant can be used productively until a component becomes defective or damaged. In contrast to this, a proactive approach is based on the precautionary principle when wear parts are replaced as a preventive measure according to the manufacturer's instructions or the experience of a maintenance operator. This is to avoid unscheduled downtime, line stoppage and costs incurred from this.

For "smart" companies that rely on digital and networked manufacturing within the framework of Industry 4.0, there is ample room for improvement beyond reactive and proactive CM. The implementation can take place through real-time-based, predictive and possibly prescriptive IT solutions. An innovative process that combines an integrated and a flexible approach is able to eliminate limitations and problems of reactive and proactive CM, optimize resource efficiency and at the same time guarantee sufficient reliability. Based on this, additional design optimization can also be created in the associated processes and, if valuable, in the business models.

By using an advanced version of CM, certain operational activities in the environment of error detection, identification, diagnosis, process recovery/intervention, maintenance and error avoidance can be supported in the decision making process (Laakso et al. 2002) or can be taken over partially or completely autonomously. Algorithms implement the repetitive (routine) acquisition and evaluation in real-time. Furthermore, we are able to predict future IT conditions and different scenarios can be proposed. Management innovation, defined as the implementation of new state of the art management practice, process or technique, has an important role in the overall approach (Birkinshaw 2008). Such management envisions innovative business models where it can select optimal scenarios and more refined adjustment of the parameters in real-time to control the target processes with the resultant increased efficiency as well as improvement in the technical condition of the objects. On the level of strategic decisions, a higher diagnostic effectiveness can be achieved by means of "Smart Data" (Laakso et al. 2002). This is about planning, monitoring and controlling the life cycles in a factory that are associated with condition monitoring of production equipment and maintenance (Hoppe 2014).

In practice, the definition of optimum maintenance intervals proves to be extremely complex. However, this definition forms the basis for intensive coordination between planning, production and maintenance areas in the company. Suboptimal solutions inevitably lead to conflicts between the planning of production orders and the associated output on the one hand and the fixed maintenance intervals on the other. A synergy of the knowledge of workers, maintenance operators and the manufacturer's specifications is the central basis for improvement.

PROCESS-BASED CONDITION MONITORING

Traditional Condition Monitoring

Maintenance is often referred to as having a very short time frame to address actual issues or further optimizations, because of its reactive character. The

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technical analysis of the system´s condition is focused on interweaving empirical values in connection with selective point checks. Its decision is based on previous experiences in regards to the scheduled maintenance interval or the need for maintenance. If the optimum degree of wear is not precisely met, this usually results in avoidable maintenance or a short running time of the machine or plant. These are associated with more frequent downtimes, which in turn lead to a lower production output, production delays and related cost effects. Other environmental conditions such as heat or vibration can also lead to deviations from the optimally planned maintenance intervals.

The best possible time for maintenance is not precisely predictable and is based on the experience and assessment of a central maintenance department guided by known wear and tear schedule. In the positive case, this leads to a better learning process with a reactive diagnostic characteristic ("What just happened?"). This enables the worker to learn and expand his or her know-how. Experience acquired by the workers and maintenance staff over time cannot be easily transferred. Furthermore, in case of non-availability or withdrawal from the company, this know-how is lost, which makes condition monitoring problematic. If necessary, companies can use other sub-areas/plants or unconditionally follow the manufacturer's specifications for the corresponding maintenance interval.

The objective of systematic condition monitoring in a company is to relieve workers, maintenance staff and other departments involved (e.g. quality assurance, sales, purchasing and human resources management) and to exclude them as a possible source of error. Possibilities for optimization arise from an orientation to the ITIL approach within the area of service operations or to ISO/IEC 20000-1 within the "Resolution Processes". Here, a distinction is made between incident and problem management:

An "incident" describes an unplanned interruption or quality reduction or an event that could cause impairment in the future. Incident management is responsible for rectifying faults as quickly as possible and in the specified time. It manages all incidents throughout their entire lifecycle. The term "problem" represents the cause of one or more incidents. An associated process systematically takes preventive measures to avoid incidents or - if this is not possible - to keep incidents to a minimum.

In traditional condition monitoring, the company does not have any further indicators for the degree of wear and tear or expected known failures which may lead to complications in production. Furthermore, the unplanned downtime of a machine or plant can cause further damage to the objects. It is a complex task for companies to implement a methodology within this framework that brings them closer to the optimal degree of wear and tear. The integration of a vertical and horizontal IT landscape is helpful, in which information technology supports the affected parties.

Optimization through Increasing IT Support

In comparison to traditional condition monitoring with low networked IT systems and centered more on people, the manufacturers of machines and plants have equipped their products with additional sensors in recent years. A dynamic new development in regards to size, functionality and possible connection/networking can be detected. Standardization initiatives in the area of interfaces have significantly improved the ability to connect to Manufacturing Execution Systems (MES).

MES represent IT-based production control systems that manage production orders and production resources. They integrate additional modules such as quality and human resources management and can be connected to ERP or similar systems. Within the recent years, MES development has experienced a strong functional improvement by extending the integration of production-related areas. The company- and plant-specific configuration of MES components has also been extended. This development accompanied by digital technological innovations made it possible to have better use of CM functionalities such as remote access to machine controls and control surfaces (e. g. mirroring). The increased networking of production-related IT systems enables the company's own or external employees to proactively operate CM in real-time. In the context of plant order planning, it is possible to monitor the status of several machines with their respective production orders via a graphical user interface.

There is a wide range of optimization options available within the scope of production order planning. In the case of traditional CM, orders are often still calculated manually and visualized on a blackboard. Coordination between the planning, production and maintenance departments is typically limited. In the event of a constantly changing order situation, taking into account unforeseen maintenance tasks, this approach does not meet the requirements. As a consequence, the processing of production orders is delayed, production may stagnate and the overall effectiveness of the process may be affected by “informational insufficiencies”.

CM is able to support the integrated planning process and to facilitate optimization (Kletti et al. 2015). After production orders have been either generated manually or transferred by the leading ERP system, detailed planning of the production orders can be carried out. This usually takes place on a graphical user interfaces, which display all machines with the respective production orders over a selected period of time. The production order duration is automatically calculated in real-time on the basis of sensor data recorded within the respective machines. In addition, the planning department receives data on existing resource bottlenecks, tool locks, and so on. In

combination with the managed master data, optimized production operations management is possible to reduce throughput times, stock levels and setup times supported by the system. This enables determination of the completion date of the respective production order more precisely with increased capacity utilization while taking into account the necessary maintenance tasks.

System integration leads to stronger networking and more intense cooperation: For example, when the planning department reschedules production orders, they automatically receive a message in case of availability conflicts. This occurs for example, if the tool is blocked by maintenance within the intended period of time. If the related order has a higher priority, the planning department can immediately contact the maintenance department to postpone the maintenance at short notice. In the event of unforeseen repairs, the planning department is informed in real-time so that any necessary changes can be made immediately.

CM makes it possible to simultaneously plan, monitor and control the condition of numerous machines based on real-time data. Furthermore, the associated management activities are still strongly centered on people and roles. In addition, numerous parameters are monitored with regard to limit value over- or undershooting, but no (partially) automated optimization of the operating status is carried out. This is an important potential for the expansion of condition monitoring to a future-oriented CM.

Future-Oriented Design Potential

If conventional condition monitoring is based on descriptive analysis ("What happened?") and real-time diagnosis ("Why did it happen?"), an expanded understanding then allows the inclusion of predictive and prescriptive questions. Furthermore, the design of business rules to support real-time decisions is an important option for the optimized interaction between man and machine. This requires a high level of expertise in strategic planning and operational management of processes as well as a consistent and congruent allocation of responsibility. Depending on the complexity and scope of the project, certain areas can also be automated in this context.

Predictive analysis ("What will happen or what could happen?") is based on a suitable mathematical model in order to be able to make forward-looking predictions. Patterns and trends are generated from quantitative data sets using inductive statistical methods. The focus is on the analysis of the relationships between already known and predicted variables using past events. The result is then used for the forecast. Accordingly, the quality of the data analysis and the selection of the assumptions made have a direct impact on the accuracy and usefulness of a forecast.

Barriers to the use of predictive analyses are posed by the following circumstances, among others (Eckerson 2007):

- Content-related complexity: The development of realistic models typically proves to be a slow, iterative and labor-intensive process.
- Data quality: Incorrect or missing data is a key problem for real-time decisions.
- IT performance: Complex analytical queries and evaluations can adversely affect network and database performance. Interfaces between different IT systems may also play an important role.
- Total (transactional) costs: Direct and indirect costs must be taken into account, both in the personnel area and within IT.

Forecasts provide well-founded statements about events, conditions or developments in the future. This can take the form of a simulation with “What-If” or “How-to-achieve” questions, for example. Projections can be characterized by the fact that they are not based exclusively on historical data, but also on the use of subjective assessments.

The term “data mining” is closely linked to predictive analysis. This means the systematic application of descriptive methods or inductive test methods to a database in order to identify new patterns. Pattern recognition is primarily concerned with recognizing regularities, repetitions or similarities in a set of data.

On the other hand, prescriptive models or analyses ("What should happen?") aim to provide guidance for practical implementation by generating recommendations that change, suppress or steer predicted events in the desired direction. Such a model typically describes the following factors:

- A defined set of options for action and decision making
- A target or key performance indicators for measuring success
- A set of rules that defines which selection is allowed.

Corresponding models are suitable for real-time decisions, which characterize the analytical process (Panian 2009): The aim here is to analyze events that have occurred and to propose actions that will achieve the previously defined goal with the highest possible probability. Related interim and final results are systematically recorded and analyzed in order to improve future recommendations. On the IT side, "decision management" systems can be used for this purpose. One field of application in this area is business rules, which comprise a collection of if-then conditions. These will check the attributes for the respective values and execute corresponding actions if the conditions are fulfilled.

Machine learning can also be used in this context: The aim is to apply processes that enable IT systems to absorb and expand knowledge independently. The algorithms used learn from training data and test cases of the past in order to find correct hypotheses and thus transfer them to new data constellations. There is also the possibility of active learning, where the algorithm generates questions about correct output based on predefined input values. Machine learning is typically suitable for unknown, difficult to describe or difficult to calculate problems. An example of future-oriented condition monitoring based on digital networking is provided by the maintenance department, for example by remote monitoring and maintenance. In the context of Industry 4.0, "Internet of Things (IoT)" and the use of "Cyber-physical Systems (CPS)", maintenance and servicing are becoming increasingly important for the optimization of overall costs. Industry 4.0 addresses the individualization or hybridization of products as well as the integration of customers and business partners into business processes.

The future-oriented concept is moving away from failure and time-dependent maintenance to condition-based maintenance (CBM). In the event of malfunctions, this means that real-time rescheduling is necessary. The aim is to optimize the expenditure, material usage, service life and reliability of the overall system.

For prognostic maintenance, data on faults that have occurred in the past have to be systematically collected, analyzed and correlated with historical sensor readings and observed effects. On the IT side, several components are required for this.

- Integrated data in sufficient quality: Measuring equipment, monitoring and controlling systems must be consolidated to form an overall picture of the machine and plant performance as well as the logistic processes. This includes, among other things, order data, maintenance plans, standards and legal regulations as well as the availability of personnel and material resources.

- Automatic monitoring and event-based signals: The permanent real-time monitoring in combination with the evaluation of historical data indicates possible problem states or maintenance cases and triggers an alarm when thresholds are exceeded. The detection of defect patterns can be linked to the automatic creation and scheduling of a maintenance order or maintenance task.

- Web- and KPI-based dashboards, analysis tools and augmented reality: These serve as the basis for mobile and flexible human-machine interaction. Depending on the stakeholders, different cockpits or solutions have to be designed.

- Dynamic model development: The automatic recognition of error patterns and the derivation of associated tolerance intervals have to be checked over time and optimized when indicated.

The establishment of a future-oriented CM requires corresponding measures to optimize data, to connect and network technical components as well as to improve supporting analysis tools. This enables vertical IT integration, from the field level with CPS to management information systems. Furthermore, the organizational structure has to be redesigned in order to support the optimized business processes.

"SMART" CONDITION MONITORING MANAGEMENT

Companies that have successfully implemented approaches such as Lean Management and on their way to Industry 4.0 can extend their business processes with an IT-based CM and implement additional services from this. A central challenge is to actively monitor the "market of technical possibilities" and to evaluate both the technical and economic maturity of the respective services. SAP for example offers a rapid-deployment solution for condition-based maintenance (CBM) that enables companies to perform maintenance only when necessary with sophisticated intelligence (Lange 2014).

For "smart" factories, there is the opportunity to expand existing systems to use CM of technical components and processes with the help of IoT elements: There is an ongoing development in the field of sensor technology, in monitoring and controlling of actuators, in the automation of process sequences and in the processing and storage of processed data. This is accompanied by the development of decision support tools that are more user-friendly, and have far more powerful adaptable analytic capabilities which create numerous different and more efficient possibilities for process optimization. The technological feasibility is typically accompanied by an economically justifiable effort and the optimization potential makes a rapid payback period seem realistic (Kletti et al. 2015).

Digitalization offers application companies the opportunity to provide their own customers value-added services that in turn improve their work processes. The use of digital data eyeglasses optimizes the possibilities for remote support by maintenance experts in the event of a malfunction and, if necessary, reduces the costs of worldwide product support. Production-relevant containers, their condition and level can be monitored via real-time location systems and container sensors, which reduce the risk of production delays. For example, the monitoring of the historical, hourly and expected future condition of aircraft engines allows a "ground time"-optimal execution of engine maintenance considering the availability of parts, expertise and available time slots. Real-time monitoring of building elevators forms the basis for safe and economical operation. Automated remote diagnosis of household and office equipment opens up potential for the early detection of future malfunctions as well as automated procurement of spare

parts and consumables.

It is an open question whether this development will lead to a reduction or polarization of the associated jobs. The discussion of the consequences from digital transformation is ambivalent in various disciplines and areas. In principle, a higher degree of automation means, for example, that the possibility exists of further shifting the tasks from the workers to essential, quality assurance or monitoring work and, if necessary, of employing workers who have been trained on an ad hoc basis in a flexible manner. However, the new work profiles will tend to place higher demands on employees with an impact on the associated integrated business processes. An important question in this context is the future interaction between man and machine. In the sense of an optimized distribution and coordination, it is a question of who will assume which tasks and roles within human-machine interaction.

In the context of CM management, the authors believe that it is primarily about evolutionary changes. Regarding business practice, CM finds its limits if the technical possibilities and the services offered do not meet the expectations of effective and efficient process monitoring or decision support. In strategic CM, creative ideas for innovative business models are in demand, which can only be achieved by highly qualified and motivated participants. To this end, creative management practices and innovative business processes have to be developed. Targeted investments in advanced CM-enabling technology and functionalities can form the basis for placing value-added services, which support the relationships and interactivity of the CM solution.

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