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Tribotronics Facilitates e-maintenance Implementation

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ABSTRACT

Our modern society depends to a great extent on the functionality and efficiency of all the mechanical machinery that we see around us and use every day. All these machines involve numerous tribological contacts. A contact between two surfaces that are in motion relative to each other will result in friction and wear.

A constant trend towards more compact mechanical systems with higher power densities requires them to operate in increasingly severe conditions, which heavily influence tribological contacts. They, in turn, affect machine efficiency and impose a limit on machine reliability and service life.

Present tribological systems are passive, i.e. their performance cannot be tuned on-line. The purpose of tribotronics is to control so-called loss outputs in a tribo-mechanical system: friction, wear, vibration, etc. Such a system includes sensors, a control unit and actuators. A tribotronic system is thus autonomous and self-adjusting. This allows for on-line tuning of the tribological components for the best performance.

This paper illustrates how tribotronic systems can facilitate e-maintenance and thus provide foundation for the best maintenance decisions.

Keywords: active tribology, e-maintenance, condition monitoring

1. INTRODUCTION

For too long maintenance has been considered as a minor element of strategic thinking by senior managers and yet for many companies the cost of maintenance will be around 40-60 % of the total production costs when direct and indirect costs of maintenance are taken into account. In addition to these high costs of maintenance, about 30 % of accidents and fatalities have been identified as happening during the maintenance or related to maintenance.

However, the image of the maintenance function within industrial organization has been undergoing transformation since the last two-three decades. The importance of maintenance to company profitability and safety is becoming more apparent to the top managers. Maintenance, that once was considered (if at all) as a "necessary evil" and often ignored, is now receiving attention to cope with an ever increasing demand on reliability, availability, flexibility and controllability of industrial systems. The driving force behind this change in management thinking is the introduction of sophisticated, complex and automatic systems and processes, stringent quality specification from the customers, tough competition and lower profit margins from the ventures. The increased complexity of operations and automation has put severe demand on decision making in real time to avoid unplanned stoppages and to increase the effectiveness of maintenance function. The focus has shifted from Fail-and-Fix (FAF) to Predict-and-Prevent (PAP).

Managing information is critical to increase the maintenance effectiveness (Parida anfd Kumar, 2004, Parida et al 2004). The need of information for maintenance effectiveness needs no emphasis, as collaboration and integration are the prime requirements amongst all stakeholders. Maintenance effectiveness depends on the key personnel's taking correct decisions. The results and values of these much-needed decisions depend on quality, timeliness, accuracy and completeness of information on which they are based. The information and data collection would need that only the relevant and useful data are collected through the sampling and performance indicators, stored and analysed for effective decision making as per priority and its importance. Management of all these aspects and varieties of information demands effective information management involving and integrating all stakeholders, so as to achieve the desired maintenance effectiveness. With development and emergence of intelligent e-maintenance in the manufacturing and process industry, the maintenance information system convert the field data into useful information, so that decisions to achieve maintenance optimization can be made on-line and/or remotely through wireless means.

However, an identification of a deviation from the normal performance state may not be sufficient, as it often affects the industrial competitiveness negatively. It is also necessary to initiate actions to prevent and reduce the deviations. This necessitates a holistic maintenance strategy and supporting tools that are adaptive and dynamic to meet the challenges. However, information is identified as key for development of dynamic maintenance and operation strategy in the context of software intensive complex technical systems. For this purpose information must be passed on to right stakeholders, in right context and in right time. This involves processing and aggregation of data from various processes, subsystems, and components for use at different maintenance echelons so that reliability and availability performance can be assured for complex technical systems.. Reliability and maintenance is a major issue and concern for securing functionality of complex technical systems ensuring excellence in performance (and high production capacity) throughout their whole lifecycle. However, availability performance and efficiency of these complex systems are not satisfactory. One reason for this is insufficient reliability performance of the components and units of these systems which are equipped with varieties of electronics and software. Another reason is long lifecycle often leading to co-existence of different generations and versions of items in a complex configuration, which leads to many interface problems affecting performance and even functionality and availability.

The insufficient availability performance of any technical system or item causes disturbances in the customers' value-chain process and often results in losses and customer dissatisfaction. This has brought a paradigm shift in management philosophy of support suppliers moving from a traditional business model selling goods and services to providing solutions and guaranteeing the performance at agreed cost with enhanced control over all the logistics chain (Karim et al, 2009) Some of the issues and concerns arising during application of Performance Based Logistics and Performance Based Contracting can be addressed through implementation of e-maintenance solutions in the business value chain.

2. CURRENT TRENDS AND SOLUTIONS

2.1 E-Maintenance

E-Maintenance solutions can provide services that enable extracting information from the huge amount of data being collected using sensors and other means, regarding the impending problems and Remaining Useful Life (RUL) of items etc., FIGURE 1.

In general the operation and maintenance data generated by complex technical systems and their enabling systems are in large volume, therefore methodologies and technologies for data analysis provide a great potential to make these systems robust, reliable and cost-competitive fulfilling the expected availability performance goals.

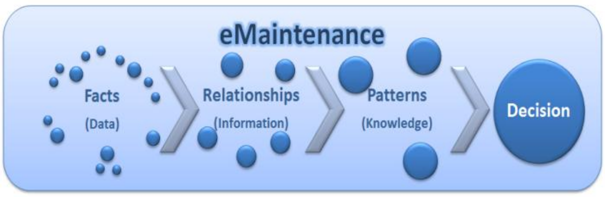

FIGURE 1. From data to decision (Adapted from Karim et al. 2009)

Most of the complex technical systems currently deployed in industry are instrumented to operate and collect data and information at various levels (low level sensor data integrated with high level ERP etc). The large amount of data and information collected at sensor level is refined and processed to extract value at higher level through various aggregation models, methods, algorithms. Presently many pattern recognition techniques are being employed, tested and further developed to fulfill the need of value extraction from the data. One of the main issue being the estimation of the RUL of technical systems, or estimation of best time interval for opportunistic maintenance, considering the current status of enabling systems and hence the total business risk.

The important challenges in this regard are:

- developing methodologies, technologies and tools that will facilitate easy and continuous extraction of valuable information from the data collected;
- recognizing and localizing the major causes for poor availability performance of complex system leading to increased LSC;
- developing novel active approaches expanding the possibilities of traditional passive maintenance methodologies.

One of the most promising data processing techniques is Support Vector Machine, which is still in evolution even though it is finding major application in medical sciences-(Nobel, 2006), been applied to modelling of RUL.

2.2 Support Vector Machine

The theoretical foundation of Support Vector Machine (SVM), named statistical learning theory, has multidisciplinary origin which covers statistics, optimization methods, functional analysis, etc. The philosophy of SVM is in decision making based on both the "history", including "current status", and the "future" instead of the "history" solely.

Classical mathematical methods such as regression models, Neural Networks, are essentially to make the decision based on "the history and historical data" to "the future decision". The critical factor, future information concerning load, variations in operating environments, changed demand both regulatory and economic during model development, is neglected [Vapnik 1992].

SVM uses one framework named Structural Risk Minimization (SRM) to implement the above mentioned philosophy [Vapnik, 1992]. The performance of SVM has been proven outstanding by a numerous researches [Widodo, A. and B.S. Yang, 2007, Chen , 2007]. From the maintenance point of view, the SVM is less sensitive and less dependent on data. And SVM is more adaptive to variations and the new operating condition and demand. These advantages guarantee that the maintenance model based on SVM will be more reliable than traditional models based on mathematical theories using computer algorithms.

Another distinct advantage of SVM is in using of a "kernel" method [Fuqing and Kumar, 2011 Fuqing et al, 2010). By using this method, especially for condition based maintenance, the data classification can be improved by a transformation from lower to higher dimension. In the higher dimension, the inherent failure or incipient failure will be more identifiable. Moreover, by using "kernel", some high dimension data can be dealt with effectively and efficiently, whereas some classical models are infeasible or inaccurate to address such problem. SVM is thus a powerful pattern recognition technique, which can be used for automatic failure diagnosis and prognosis. There are however, as with all techniques, some limitations [Fuqing and Kumar, 2010], which can be addressed by implementing an active approach to monitoring conditions in tribomechanical systems.

2.3 Machine Wear

Wear is responsible for shortened machine service life, machine failure and enormous loss due to interrupted production. Friction leads to energy loss and thus adversely affects machine efficiency. In Sweden total losses due to friction and wear account for 5% of BNP.

In order to cope with the ever increasing rate of technological progress, improved maintenance techniques and, more importantly, pioneering approaches and solutions to the design and operation of tribological contacts in various types of machinery must be found. Present tribological contacts are passive, i.e. their performance cannot be tuned on-line. Geometry, material and oil properties are all pre-determined so that a system is sensitive to any increase in severity of operating conditions. There is then a question of what can be done to promote improved safety, performance and reliability of tribological contacts and consequently the whole machinery. The key issue is to employ active tribology or tribotronics.

3. TRIBOTRONICS

The term tribotronics applies to the integration of tribology and electronics [Glavatskih and Höglund, 2008, Sherrington and Glavatskikh, 2008]. The main principle of tribotronics is to use additional so-called "loss outputs". These outputs are friction, wear, vibration, etc. The purpose of tribotronics is to control these loss outputs and through doing so, to considerably improve the performance, efficiency and reliability of tribological units and therefore, of the entire machinery. Electronic control offers the potential for tribological systems to be operated at a dramatically higher level of performance. The definition of tribotronics resembles that for a mechatronic system, but there are essential differences. A mechatronic system uses only information from inputs and functional or useful outputs of a mechanical system to control its operation. The functional outputs include rotational speed, torque, load etc. A tribotronic system includes four central components interacting as shown in FIGURE 2.

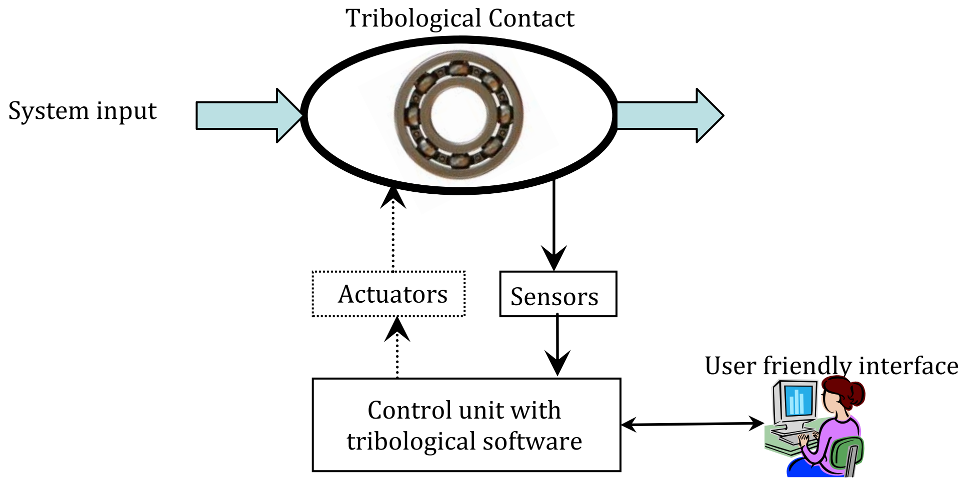

FIGURE 2. Tribotronic system and its elements.

The conditions of a tribological system are monitored by sensors that provide information on temperature, pressure, friction, vibration, oil properties such as total acid number or additive depletion, and other parameters of interest. The signals from these sensors are processed and transmitted to the control unit. In the computational or decision making part, software based on tribological algorithms for tribological optimization determines the required action, which is then implemented by actuators. Such a system is thus autonomous and self-adjusting. This allows for real time or near real time, tuning of the tribological system for the best performance.

A strategic step is then to integrate tribotronic systems and e-maintenance.

4. INTEGRATION OF TRIBOTRONICS INTO E-MAINTENANCE

The concept of tribotronics forms the basis for development of e-maintenance solutions. Current challenges within e-maintenance, such as integration of different types of data and generation of decision support advices on demand, can efficiently be addressed by including tribotronic components in the e-maintenance systems. Such an approach will also facilitate easy and continuous extraction of valuable information from the data collected as well as recognition and localization of the major causes for poor availability performance of complex systems.

The control unit, FIGURE 2, communicates with e-maintenance framework, which has all the information relevant to business process (e.g. market demand, stock status, loss rate, type of customers, etc), and produces “advices“for the actuators. Accordingly, actuators adjust the system to deliver the function in line with the advices.

Tribotronic systems facilitates e-maintenance in terms of improved

- quality of data collected due to the use of more efficient tribological algorithms;
- timeliness due to on-line monitoring
- information on dynamic remaining useful life of a system/component
- data transfer efficiency; decision making process is partly shifted to the tribotronic systems so that data volume transferred to the main monitoring center is significantly decreased reducing the risk for net overloading

- accuracy of the operation and maintenance data;
- completeness of information; no more large volumes of non relevant data stored
- benchmarking of system performance to business processes
- feedback; it is now possible to enhance machine efficiency and slow down a developing problem
- safety margins; this gives companies an increased competitive strength as machine operation can now be pushed to the limit
- operation efficiency and reduce maintenance costs

5. SOME EXAMPLES

We give two examples of how tribotronics facilitates e-maintenance. The first example is related to wind power industry while in the second example we consider mining/transport industry. In both examples tribotronic systems include rolling element bearings.

There is currently a trend towards increasing the power output from wind power installations. The drive to design ever larger wind turbines creates a number of engineering challenges while simultaneously offering an excellent opportunity to develop novel tribo-mechanical components with in-built actuating capabilities as well as e-maintenance solutions.

The most critical tribo-mechanical components in the modern wind turbine are the gear boxes and rolling element bearings. There are, however, various wind turbine designs without gear boxes. At the same time the bearings will always be used as long there are moving parts. Hence, we discuss, as an example, integration of rolling element bearing based tribotronic systems and e-maintenance.

Damage due to electrical current in rolling element bearings in wind turbines is not uncommon. There is constant generation of electrostatic charge on rotating parts due to their interaction with air. Current passes through the lubricant films, which are less than 1 μm in thickness, and leads to erosive pitting of the contact surface. These pits lead to increased noise and vibration (loss outputs). If they continue to grow in size it potentially leads to bearing malfunction. To implement a tribotronic system to address this issue we can use an existing technique, vibration monitoring, to detect the development of pits. Alternatively, the bearing could be electrically insulated to measure current passing through the contact. In the latter case sensitivity for detecting bearing damage is much higher. If adverse current or vibration is detected, an actuation could be applied. This could be achieved by activation, or supply, of special lubricant additives that build dielectric tribo-films restricting the formation of pits on the steel surfaces. Such a system would increase reliability, prolong bearing service life and facilitate e-maintenance.

Another scenario is a bearing on the axle box of a wagon transporting iron ore from Kiruna to Narvik. If the bearing develops a problem the common practice is to stop the train. Sensors mounted on bearings can communicate with an enterprise resource planning system of a mining company, get information about front end customers and the likelihood of losses associated with train not reaching the destination within a given time. Also it gets information about the support and maintenance organization, location of train, estimate of repair time, etc. All this information is processed within the framework of e-maintenance and advices like "don't stop the train, just reduce the speed from 90 km per hour to 30 km per hour" or/and "operate the train to the next station" where help will be available. A more efficient strategy to manage the safe journey instead of reducing the speed of trains or stopping them is to slow down the process of developing a problem in the bearing. The actuator in the bearing system initiates mechano-chemical actions to restore the performance of the bearing so that train could run at 90 km per hour. This approach enhances system efficiency and simplifies the decision making process.

In this example, the communication of bearing performance status to control unit vis a vis expected performance, and linkage to ERP to assess the risk and subsequent definition of tasks for actuator to compensate for the developing problem is a good example of how tribotronics can facilitate e-maintenance framework.

6. CONCLUSION

An approach to integrate tribotronic solutions and e-maintenance in complex industrial systems has been described in this paper. The concept of tribotronics is explained. Current challenges in e-maintenance have been considered and addressed through the use of the tribotronic solutions.

It has been shown that tribotronic systems facilitate e-maintenance in complex industrial applications where reliability and extended service life are primarily factors. Such integration also improves information logistics. The assets are managed in a much more efficient way reducing the revenue loss (no standstills) and increasing the company competitive strength.

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