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TRIBOLOGY ASPECTS OF PROACTIVE MAINTENANCE APPROACH

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Abstract: *There is an increasing need for improved methods of maintenance in order to enable improvement in efficiency, availability, reliability and prolonged lifetime of production and other technical systems. Changing focus of maintenance activities from corrective to preventive ones became main trend in previous period which resulted in much wider appearance of advanced maintenance methods like Condition Based Maintenance and introduction of new ones like Proactive Maintenance. The paper deals with the role of tribology in the large and complex scope of maintenance engineering and the different tribology-aspects related to implementation of proactive maintenance approach.*

Keywords: *tribology, failures, proactive maintenance, condition based maintenance*

1. INTRODUCTION

Tribology development as a scientific discipline causes major changes in thinking and strategic approach to the maintenance problem of technical systems for different purposes [1], [2], [3]. One result of this trend is the introduction a proactive approach of maintenance in the industrial practice.

The term proactivity and generally proactive approach and philosophy have their clear position and role in the broadest area of technical systems maintenance, no matter that concept has not yet been adopted and standardized.

Despite some terminological ambiguity and lack of support in the technical standards related to the term of proactivity, the most of the world's leading scientists and experts in this field agrees with the structure of the basic elements of a proactive approach [4]. In this sense, three elements (modules) of proactive maintenance approach are defined [5], [6]:

- monitoring,
- diagnostics and
- prognostic.

To these elements, or modules are typically joined by a fourth, related to making appropriate decisions.

2. FAILURES IN TECHNICAL SYSTEMS

Failure represents key term which is necessary for understanding the very essence and function of maintenance in modern manufacturing and business systems. Conducted investigation and researches showed that failure intensity curves could be very random and independent of time line. For analysis of failure modes that are not time-specific, besides the time factor, parameters of components or systems condition are also included.

In fact, even when they are not a function of time most failure modes generate certain kinds of signals and information that could be used to monitor the failure. Illustration of such behavior represent so-called "P-F" curve [7] (Figure 1.)

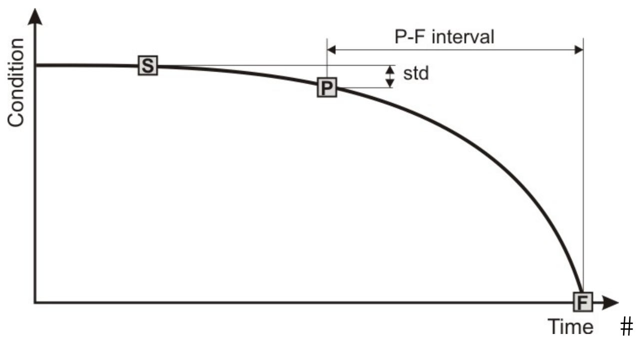

Figure 1. P-F curve

"P-F" curve defines behavior of components or systems from the moment the first symptoms to the failure. This curve has shown great importance in the theory of maintenance and is often used as a starting point for defining the various hypotheses [8], [9]. The analysis of this relatively simple but very important and illustrative diagram can be defined important **c**onclusions and directions for further reflection:

1) Point "S" represents the moment when failure is practically. It is a point that defines the moment in which the projected relations and parameters within components or systems are disturbed to such an extent that further exploitation leads to degradation of states and the outcome of the failure.

From the point of maintenance needs identification of the position of this point on the timeline is very important and identification of the preconditions for its occurrence.

2) The largest number of failures does not occur suddenly, at the time, but has the trend to develop over time and manifests itself first through the various symptoms and finally in its full, functional form. This time delay is defined as the axis interval between points "S" and "F", which allows maintenance personal to take appropriate actions in order to prevent functional failures and all consequences from it arise. The existence of larger or smaller intervals between points "S" and "F" represents basis for the definition and development of various methods, techniques and concepts of maintenance based on condition monitoring of the system or components.

Maintenance activities that are conduct aimed at preventing the progression of degradation of the system or components to point "F" or to extend interval between points "S" and "F" to its maximum.

3) Through the standard maintenance activities precise position of point "S" could not be defined, it may be only a result of modeling or approximation. Therefore, in practical terms point "P" is used that defines time at which we can identify the beginning of failure. This point represents value of condition degradation (condition parameter defining system state) which is measurable by techniques and methods at our disposal (human senses, instruments, measuring equipment).

4) It is very important that point "P" should be located as close as possible to the point "S", which means that identification of potential failures should be performed as soon as its is initialized. In this sense, there are two important factors.

First factor is interval in which condition monitoring, measurements and tests should be performed, because they define the time points where identification of point "P" is possible. There is obvious advantage of continuous monitoring over to measurements at discrete intervals, but it implies much higher costs as is the shortening of the interval between two measurements and increase their number in a given time interval.

Another factor is the minimum value of condition parameter change (in Figure 1 labelled with "std") that could be identified. Application of modern diagnostic methods and precision sensors and instruments leads to early identification of point "P". Also, the methods of measured values processing, understanding of the observed phenomena are of great importance for timely and correct diagnostic and location of point "P".

5) One failure mode can have many symptoms and parameters whose value changes defining point "P". In this sense, for each failure modality it is important to define a number of potential diagnostic parameters and to determine functional dependence system condition in relation to the diagnostic parameters values that define the point "P". Each parameter defines its own point "P" but particularly significant is ones with point "P" closest to the point "S", or those with longest "P-F" the interval.

Since one parameter is often not sufficient to provide a true picture of system condition, and that the error in the process of measuring and testing are always possible, monitoring multiple parameters, or multi-parameter analysis and defining point "P" being imposed as recommended solution.

6) Determination of "P-F" interval length and function of diagnostic parameters change in this interval is problem of primary importance for the maintenance function. Precise time location determination of point "F", or prognosis of "P-F" curve shapes and characteristics is one of the main factors for adequate planning and definition of maintenance activities.

7) Finally, the question that is sort of pushing the boundaries is a problem point "S" origin and in particular, the conditions and phenomena that preceded it. Is it possible to determine or predict the time of point "S" initialization and what are the parameters, symptoms and signs that could help us? If it is possible to determine pre-conditions for initialization of point "S", then it is certainly possible to prolong its origin or even completely eliminate possibility that it occurs, thus all practical dilemmas described above lose their meaning and maintenance function get quite new dimension, shape and significance.

3. PROACTIVE MAINTENANCE AS NEW MAINTENANCE APPROACH

Basic industry standard in the field of maintenance define two basic types of maintenance: Corrective Maintenance (Breakdown Maintenance) and Preventive Maintenance [10]. As part of Preventive Maintenance standard recognizes two methods: Time Based Maintenance (Predeterminated Maintenance) and Condition Based Maintenance (Predictive Maintenance) for total of three standardized maintenance methods.

If we take pre-defined "P-F" curve as a parameter for comparation differences in the approaches of these three models could be clearly observed.

Corrective Maintenance is a reactive approach to failure and it accepts failure as inevitable. This maintenance method has virtually no activity before point "F" and when it occurs (when functional failure occurs) then various activities are performed in order to return system or components condition to state as close as possible to one before failure. The aim is certainly that this level should fully corresponding to point "S" but often this is not quite possible because the occurrence of functional failure leaves some irreversible or long lasting effects.

Preventive Maintenance approach, as the name suggests, is based on principles of prevention activities that are conducted before point "F" in order to prevent, predict or delay its occurrence.

Time Based Maintenance involves the implementation of preventive activities in pre-determinated periods and intervals. Based on experience, technical recommendations, requires of specific technical system and the desired level of reliability, periodic activities are planned and defined in order to restore condition of components or systems to its initial values. These activities are conducted in the interval between points "P" and "F" or "S" and "F". Appropriateness and effect of activities could be significantly decreased as the term of its implementation is closer to the point "S".

Condition Based Maintenance method based itsapproach on the identification of system condition and implementation of relevant activities. It is fully based on previous analysis of "P-F" curves (early defining point "P", forecasting of timeline for point" F", analyzes the modalities of creation point "P"or" S ", the maximum extension of "P-F" interva, etc).

Condition Based Maintenance focuses on methods for monitoring and diagnosis of system condition through measurement of diagnostic parameters whose values are representative of the current state of the system and any disorders. These parameters are divided into direct ones, which include all physical valuess related to opperation processes in system (pressure, flow, force, speed ...) and indirect which primarily include vibration, temperature and wear products.

At the present level of technological development can be said that the method of preventive maintenance according to the state occupied an important place in industrial practice, but room for further improvement and expansion of influence is still huge. This method managed to overcome the gap between theory and practice and to find a real foothold in the minds of technical staff and the general policy of management of business systems, but there is still a significant difference in the expectations and needs of business systems and real, measurable results that can be identified in its implementation [11].

3.1 Proactive Maintenance

The question is should be division on three standardized maintenance methods accepted as final or there is a space for some expansion? Some 20 years ago in a particular engineering literature and magazines that deal with practical aspects of maintenance appeared new term - Proactive Maintenance. In previous period considerable number of different analysis and interpretation of proactivity were published but, up to date, this term is definitely not standardized nor its final place in the theory and technology of maintenance is specified. .

Authors and theorists of the concept of Proactive Maintenance departs their analysis from definition of Preventive Maintenance according to the state under which it is aimed at detecting the early symptoms of failure, or accept it as a possible state of the technical system. On the other hand, Proactive Maintenance is a series of activities and measures aimed at defining, monitoring and elimination of causes of failure.

Proactive Maintenance set its goal that failures or disruptions in the functioning of a component or the whole system does not come, or to provide such conditions of exploitation, which will ideally be an unlimited lifetime guarantee for technical system. According to this interpretation there is a lot of justification which supprot idea that Proactive Maintenance shoul be recognized as a new, independent maintenance method, which falls into the category of preventive and at the same hierarchical level as Time Based Maintenance and Condition Based Maintenance.

An additional argument for this interpretation could be found in previously conducted analysis of "P-F" curve, especially at last of seven conclusions.

Accordin to previous definition Proactive Maintenance put focus of its activities on point "S". Temporal coordinates of points "S" represents the boundary between the Proactive Maintenance and Condition Based Maintenance. All activities that belong to Proactive Maintenance are timely located in period before point "S", while first Condition Based Maintenance activities are related to early detection of point "P".

Another form of recognition of place and role of Proactive Maintenance is based on the views of Condition Based Maintenance through the prism of its broader definition, which established system condtion as basis for any decision and implementation of maintenance activities. According to this interpretation, Proactive Maintenance is assumed as modification and improvement, or a variation of methods of Condition Based Maintenance [5].

An additional argument to this interpretation is that the concept of Proactive Maintenance does not bring any new methods and tools and all methods used in Proactive Maintenance of well-known and already applied in Condition Based Maintenance. Proactive concept just pointing out the importance of certain methods and place them in the foreground. Analysis of numerous diagnostic parameters used in Condition Based Maintenance and their division into those with proactive and those with preventive diagnostic potential, are performed, while certainly there are parameters that can be helpful to use both approaches.

Both interpretations presented have clear grounds and arguments so it is very ungrateful to make definitive conclusions that would be an accepted and others rejected. Regardless of where it ranked, the concept of proactive maintenance represents a new and refreshing theory, which has been confirmed in practice. Bearing in mind the above mentioned facts, it is technically the most correct to use term proactive approach in maintenance, without prejudice to the decision of whether it is a completely new method of or part and modification of Condition Based Maintenance.

4. TRIBOLOGY AND PROACTIVE MAINTENANCE APPROACH

Tribology’s contribution to traditional maintenance strategies and methods could be examined in relation to the essential needs of detecting and diagnosing faults before failure occurs. Consequently, it tempts the question as to what tribology can contribute to establishing appropriate prognostic techniques for determining the remaining useful life of failing technical system [12].

In this context, failure could be assumed not only as deterioration in terms of system functionality but also in terms of a reduction in product quality to a level that is unacceptable to the customer.

Through the decades results of tribology investigations and technical development have been used as valuable contribution to maintenance theory and practice. On the basis on focus movement form corrective to preventive measures considerable attention has been given to channelling the fruits of tribological research through improved design methods and manufacture of tribological components and systems that have found application in everyday practice. This has led to marked improvements in the performance and reliability of technical systems [12].

Ways in which tribology contributes to the maintenance activity are shown on Table 1.

Table 1. Tribological inputs to the maintenance activities [12]

Maintenance activity	Tribological input
Corrective Maintenance	Failure examination and diagnosis Designed-out solution
Time Based Maintenance	Lubricant/additive properties Material properties and treatments Surface finish and damage inspection, including internal endoscope surfaces examination
Condition Based Maintenanc	Oil and wear debris analysis Vibration analysis and acoustic emission Preventive diagnostic parameters measurement and monitoring (displacement, temperature measurement)
Proactive Maintenance	Oil analysis (proactive paremeters) Root cause analysis Prediction of remaining wear life

As earlier mentioned Condition Based Maintenance could be assumed as corner stone of present advanced maintenance activities. Area of condition monitoring and diagnostic engineering today is an advanced and highly developed field of engineering and multi-technological task, which includes development and application of sophisticated systems to measure changes in performance, data collection, signal processing, diagnostics, prognostics and maintenance engineering, as shown in Figure 2. Tribology as science and technology is fully involved in definition and analysis of failure mechanisms, diagnostic, analysis and prognostic of processes.

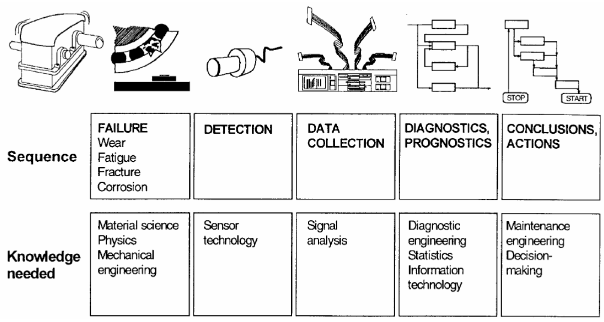

Figure 2. Tribology in Condition Based Maintenance [13]

There is absolutely no doubt that vibration monitoring has enjoyed a far greater presence as the technique of choice for Condition Based Maintenance than any other available (including thermography and oil analysis for instance). There are a number of reasons for this, but one of the main reasons is that oil has always been perceived as a cheap commodity within the maintenance budget by comparison to parts of rotating equipment. A cost justification for predictive maintenance on critical machinery invariably highlights the bearing condition as the main indices to potential system failure, as well as the bearing being a relatively higher cost item to replace. By comparison, the lubricant and industrial oils is a cheap, easily replaced commodity.

Other, very important factor is development of wide range of portable, low – cost instruments for basic vibration measurement together with computerised systems or data collector diagnostic systems with large number of various functions for FFT, CPB, SPM and other complex analysis of vibration signals. All those instruments are capable for real time, on-site and on-line measurements and analysis, while on the other hand analysis of oil and lubricant samples relied on the commercial laboratory services.

Introduction of Proactive Maintenance approach caused significant changes in a way that maintenance experts and technicians think and talk about oil analysis. Corresponding with results that focused oil contamination as major cause of failures in various technical system with oils, importance of oil analysis and related proactive diagnostic parameters become extremely important.

At this time there is no doubt that group of activities named as oil analysis are primary technique of choice for Proactive Maintenance approach. Great numbers of studies and investigations, with illustrative laboratory proofs and field confirmations, have mutual conclusion that oil contamination and corresponding tribological processes are clearly the most common and serious failure culprit.

Wear of components in technical systems with oils should be viewed in two ways:

- development of tribological processes in the system is the most dangerous consequence of contamination of oil and necessarily leads to a change of surface condition and the geometry of the vital parts of components, leaks, reduce efficiency, breakdowns and system failures in the final stage and
- wear parts of components comes to the intensive generating of solid particles, which are a structure much more dangerous to the system of other mechanical particles (dust, fibers, parts of the sealing material).

Bearing in mind previously presented data on significant negative impact of oil contamination on the function, reliability and length of the exploitation period of each technical system with oils, first step in Proactive Maintenance is the implementation of rigorous contamination control programs for lubrication fluids, hydraulic fluids, coolants, air, and fuels.

Contamination control program combines preventive and proactive measures and consists of three basic steps.

The first step is to determine the limits of an allowed contamination levels oils. The limits that we are defining refer to the basic proactive parameters - the concentration of solid particles, the presence of water, oil viscosity and degradation of hydraulic oils. Correctly determining the limits of an allowed contamination levels of hydraulic oils is of great importance for the successful implementation of the program, if the limits set too low (stringent requirements for cleanliness of oil objectively necessary) can lead to increased costs in the following steps. While too high placed limits (requirements for the oil cleanness are not on sufficient level) can disable contamination control program to give the expected results.

The second step in the contamination control program include implementation of a series of activities and measures aimed at reducing levels of contamination to previously defined limits levels and eliminate sources of contamination. This step involves not only the measures relating to oil purification, improved filtration systems and redesign of the hydraulic system in order to eliminate contamination. In addition, this step involves numerous other technical and organizational measures to ensure the proper implementation of routine daily activities in the phases of operation and maintenance of hydraulic systems in order to protect against penetration of any form of contamination.

The third step in the contamination control program includes regular and ongoing activities aimed at monitoring and maintaining the achieved level of contamination. These activities represent the most important part of proactive maintenance, because they provide filtering effectiveness feedback, condition of hydraulic components and oil, the intensity of tribology processes and provide informations that allow proper and timely response and implementation of appropriate measures.

Finaly another asspect of tribology contribution to Proactive Maintenance should be also mentioned. As stated before Proactive Maintenance approach place focus of its activities in on investigation of possibilities for determination of pre-conditions for initialization of point "S" (Fig. 1.) to prolong its origin or even completely eliminate possibility that it occurs. This is very complex and difficult engineering task related with use of numerous sophisticated tools and methods.

For better understanding of mechanisms, functions and methods for failure initialization in components and systems, during exploitation, importance and contribution of tribology is irreplaceable.

In tribology today, it is trend to go to smaller and smaller sizes in the investigation of friction and wear phenomena. In nanotribology, scales are coming down to the very basic dimensions of physical elements such as atoms and molecules. Emerging new technologies opened the possibility to study friction and wear phenomena on a molecular scale [12]. This trend opens quite new and promising directions for advanced failure root cause analysis.

5. CONCLUSION

At today's level of technical development, knowing the rigorous demands of the market in terms of strong economic and general business fluctuations, the proactive approach in defining of maintenance strategy is an essential element. Proactive Maintenance should include all activities aimed at anticipating changes and exploitation characteristics of technical systems.

Innovation of proactive approach is been based on the prediction of degradation and exploitation characteristics of the technical system through the process of prognostics. Prognostics process in a proactive approach aims at early detection of failure causes. Contribution of tribology to those efforts could be examined as very important on several levels and aspects. Oil analysis is recognized as primary tool for proactive maintenance for numerous technical systems.

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