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TECHNICAL DIAGNOSTICS IN INDUSTRIAL SYSTEMS - THE BASIS OF PREVENTIVE MAINTENANCE

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Abstract *The application of technical diagnostic methods, along with the use of modern and computer-supported technical equipment for system monitoring, is the basis of the concept of condition-based maintenance. Based on the monitoring of certain elements of a system or by monitoring the processes that define the state of a system, it is possible to predict the behavior of a system in the future and the emergence of conditions for the occurrence of unwanted failure states, and undertake certain preventive or corrective activities that ensure the optimal operation of a system in changing environmental conditions. The paper provides an example of the application of technical diagnostics within the framework of maintenance in an industrial production system and a discussion of the character of subsequent corrective maintenance activities that are a consequence of the obtained diagnostic results. The results of the application of technical diagnostics in the production industrial system are of great importance both for maintenance personnel (planning of maintenance activities) and for technological personnel (monitoring of process parameters).*

Key words: *Maintenance, Technical diagnostics, Condition based maintenance, Industrial system*

1. INTRODUCTION

Ensuring a high level of readiness of production industrial systems to fulfill the designed function is a basic prerequisite for their sustainability on the increasingly demanding world market. Maintenance, as an integral part of production systems, with its way of organization and degree of effectiveness of work processes, has a significant role in ensuring optimal working conditions related to the projected technical capacities of the equipment. The requirements of a high level of reliability of industrial systems with continuous production processes impose the need to implement the concept of condition based maintenance, which has the possibility of ensuring the continuity of the production process. The basis of the introduction and application of the condition based maintenance concept is the procurement and use of standard and special (dedicated) systems for

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technical diagnostics. The global trend in the development of technical systems imposes the need to apply modern diagnostic systems for process control in production, and without them it will be almost impossible for many technical solutions to ensure the accomplishment of planned production and business goals.

2. MAINTENANCE – BASIC TERMS

The emergence of the concept of maintenance is associated with the beginning of the use of tools (means) for work by man, at the moment of damage to the means, which either reduced its function or completely prevented its use due to failure. Failure means the loss of an asset's working capacity or the impossibility of achieving the desired level of quality during its use. Maintenance gained wider importance after the first industrial revolution, when the tools for work became more complicated, the first machines appeared, and failure states that could only be overcome by the specific knowledge of workers engaged in solving problems in their work became a reality.

There are numerous definitions that describe the concept of maintenance. According to [1] and [2], maintenance is a combination of all technical administrative and management activities during the life cycle of parts intended to maintain or restore the state of a system in which the required function can be provided. Maintenance today implies a systemic approach and certainly does not refer to a series of random events with an uncertain outcome. The EN 13306:2001 standard defines maintenance as a combination of all technical, administrative and management activities during the life cycle of parts intended to maintain or restore the state of a system in which the required function can be provided, [3]. To put it simply, to maintain means to conduct supervision and control over a certain asset while undertaking certain activities in the sense of ensuring the execution of its designed function in prescribed (optimal) conditions.

As an integral part of production industrial systems, maintenance can be conducted in different ways, which at the same time determines the concept of maintenance. The selection of the maintenance concept is primarily influenced by the nature of the technological processes within the production, projected conditions of reliability, safety and quality, available capacities (own maintenance or engagement of specialized external support), level of education of the maintenance staff, etc.

Positive industrial practice applies the following maintenance concepts:

- preventive maintenance,
- corrective maintenance,
- reliability based maintenance (RBM),
- condition based maintenance (CBS),
- totally productive maintenance (TPM),
- logistic maintenance,
- self-maintenance,
- maintenance “without maintenance” and others.

Certainly, the financial possibility of a business system has a dominant influence when it comes to the source of the appropriate concept of maintenance.

The current rapid development of technical systems within industrial production systems has conditioned the intensive application of the condition based maintenance concept, which consists of the activities of monitoring, analysis and comparison of quantities that describe the working condition of elements or the complete system, along with giving forecasts about the behavior of condition parameters in the future. Condition Based Maintenance (CBM), or as it can also be found in the literature as Predictive Maintenance (PdM), is defined as the result of the behavior of the equipment/s lines before complete failure, while proactive maintenance may require redesign and/or modification of the adopted maintenance procedure, wherever it is necessary. Condition based maintenance represents a combination of preventive and proactive strategies [4].

3. Tecnical diagnostics

The basis of the application of the condition based maintenance concept is the application of technical diagnostic methods. According to [5], technical diagnostics is the science of recognizing the state of a technical system. By monitoring and analyzing the size of the condition, the occurrence of malfunctions can be predicted. By eliminating the factors of possible system failure, the efficiency and reliability of the system increases.

In order to be able to continuously or periodically (according to the request) monitor the working characteristics of the observed system, it is necessary to often invest significant financial resources in modern diagnostic devices as well as in the education of the maintenance personnel who use this equipment. If we are dealing with industrial systems with high reliability requirements, such as thermal energy plants, aviation industry, shipbuilding, process industry and the like, the level of investment in diagnostic systems is certainly justified multiple times in relation to the amount of downtime costs that may arise in the event that there is no possibility for process monitoring and control.

The choice of the method and type of monitoring of the state variables that determine the behavior of a system over time depends on the nature of the technical-technological system and the presence of some of the measurable physical variables during the production process, such as vibrations, temperature, noise, pressure, etc. The diagnostic process consists of registering, measuring and comparing the obtained values of the monitored parameters with the limit (allowed) values previously defined. If the value of the monitored parameter goes beyond the limit values, the diagnostic system reacts (alarms) and provides information about the potential disruption of the system state so that the management structures (individual or one of the autonomous systems) undertake certain activities (corrections) and prevent further disruption of the system state.

4. Application of technical diagnostics in industrial systems

Industrial practice shows that often the result of diagnostic measurement is the need for certain activities that return a system, which for some reason goes out of the optimal conditions in which it provides its projected function, to its original normal working state. A practical question arises: whether the observed deviation of a monitored operating condition parameter from the normal/optimal value, which the technical diagnostics system defines as a potentially dangerous condition for the further/future operation of the system, and the very activity to eliminate the observed problem by the maintenance department, have a character preventive or corrective maintenance. As an illustration of the indicated dilemma, an example from industrial practice will be cited - specifically in the case of technical diagnostics of drive electric motors, within the industrial plant for the production of hygienic paper from Banja Luka. The mentioned industrial system works in a continuous production process and there is a need for periodic or in some cases constant control of certain working positions of the paper machine, such as press bearings, drive and driven roller bearings, high-voltage (HV) motor bearings and the like, Fig. 1.

Fig. 1 HV electromotor in industrial plant

During regular diagnostic inspections of the state of vibrations of the drive electric motors of the technical system of the paper machine, on 21 March 2019, an increase in vibration amplitude was observed at the position of bearing L2, the high-voltage (HV) motor for driving fans for drying paper tape, compared to the previous, one-month measurement at the same position, Figs. 2, 3 and 4.

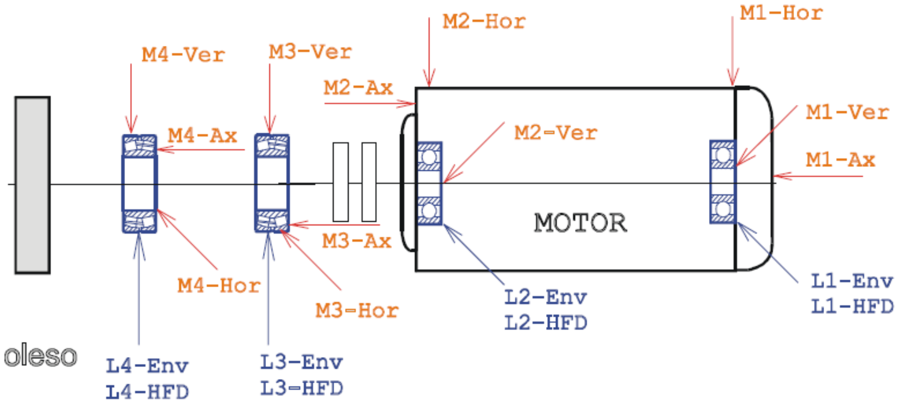

Fig. 2 Diagnostics measuring points on the system motor-coupling-fan

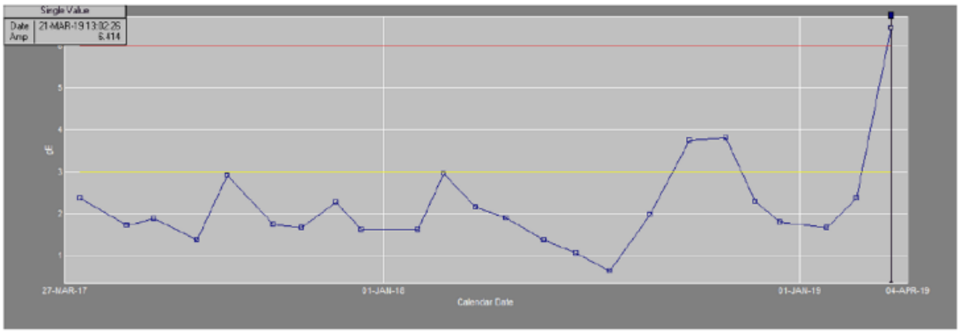

Fig. 3 Data measuring trend on the bearing L2 motor position with the Enveloping method

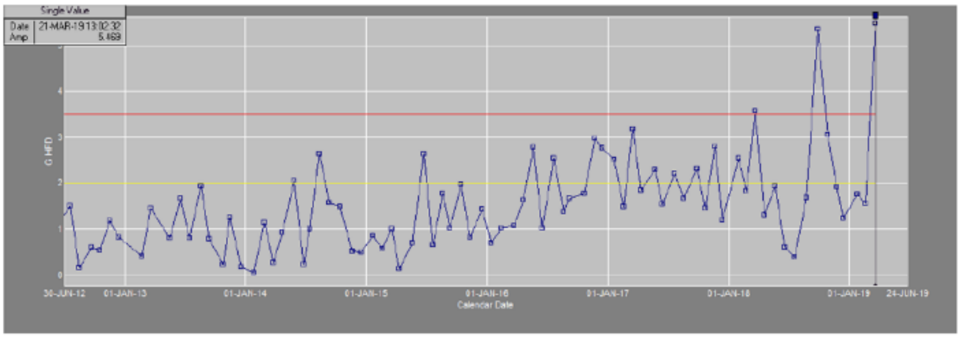

Fig. 4 Data measuring trend on the bearing L2 motor position with High-Frequency Detection (HFD method)

A significant increase in the value of the oscillation amplitude above the permissible limits for that type of plant indicated an imminent possible occurrence of catastrophic failure (possibility of breaking the bearing cage, cracking of the ring, etc.). Based on the results of the measurements, a short work meeting of the responsible maintenance and technology workers was held and a decision was made to stop the plant. The term of the planned stoppage is already defined for the beginning of the first shift of the following day, in order to carry out all organizational and logistical preparations for properly stopping the system and performing maintenance activities.

It should be emphasized that the working position of the mentioned electric motor is very specific and requires complex preparation and implementation of maintenance activities. The engine is located on a concrete base at an altitude of +6 meters from the level of the external road with a pre-made platform on the outside of the wall, adapted for its extraction in cases of necessity of its replacement, Fig. 5.

After preparation, the plant was stopped on 22 March 2019 and the engine with the problematic bearing was replaced with a spare engine in the working position. Replacing the engine from the mentioned working position is a complex maintenance activity because it involves hiring a truck crane, partially dismantling the wall (light partition panel), dismantling the coupling, careful centering, etc., Figs. 6 and 7.

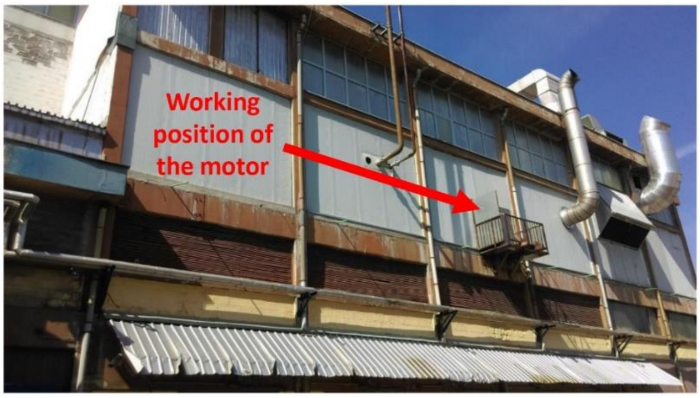

Fig. 5 Working position of the HV motor

Fig. 6 Logistics of maintenance activities

Fig. 7 Coupling replacement

In addition to the defined procedures, during the replacement the problem of non-uniformity of the dimensions of the stand and the dimensions of the spare motor appeared because the motors were not from the same manufacturer, which caused an additional modification (cutting the openings on the stand in relation to the openings on the supports of the spare electric motor), Fig. 8.

Fig. 8 Modification of the placement of the HV motor

All these activities led to the total stoppage of the paper machine plant of 10 hours. As an illustration, the impact of downtime on total production costs can be shown. If the hourly output of the paper machine plant is known to be 4.8 t/h, the total production loss (P_L) expressed in tons of paper produced is:

$$P_L = 4{,}8\,\frac{t}{h} \cdot 10h = 48\;t \tag{1}$$

Considering the wide production range, if we assume an average gross margin - GM of €340/ton of produced paper, the previously estimated loss of production due to a stoppage of 10 hours converted into monetary cost (M_C) would amount to:

$$M_C = GM \cdot P_L = 340\frac{€}{t} \cdot 48t = 16.320\ € \qquad (2)$$

This is only part of the costs related to production, since not all indirect costs are shown (services of external companies, loss of energy for maintaining the paper machine system in “warm” mode, etc.). It is clear that these are significant losses that are especially dominant in continuous production systems.

This loss of working time and loss of production should have been recorded in the production tracking system. The question arose: was the production stoppage the result of preventive or corrective maintenance?

It is evident that monitoring the state and control of the operating parameters of the technical assemblies of the plant in the production system is a form of preventive maintenance with the aim of maintaining a stable continuous production process. But it is also a fact that after noticing a potentially dangerous malfunction or a significant deviation of the monitored parameters from the nominal values for further work, it was decided to stop the entire plant. This shutdown, although planned, had the full character of corrective maintenance because the system was stopped due to the transition from the working state to the state of the system in failure, i.e., due to the appearance of a significant malfunction of a part of the production system. Even in the process of deciding on the exact date of the shutdown of the plant, a constructive debate developed regarding the nature of the future shutdown of production. The production sector rightly insisted that the future stoppage is defined as a maintenance stoppage due to a malfunction/failure of a part of the plant, while the maintenance sector explained that the mentioned stoppages are the result of planned monitoring of the condition of the system elements and a planned decision to stop the system preventively, eliminate the malfunction and avoid unplanned stoppages with catastrophic consequences. Both sides have real arguments. Nevertheless, the very nature and scientific definition of the term CBM as “a form of preventive maintenance with subsequent corrective activities that are defined and implemented after monitoring the performance or parameters of the state of the elements of the observed system” [3], justifies the activities that are the result of decisions on the basis of planned monitoring and analysis of system parameters, which are treated as preventive maintenance. Of course, the time (hours) of the resulting stoppage is recorded as time caused by maintenance, but the stoppage is the result of preventive, i.e., proactive maintenance that avoids cancellations with larger and significantly more severe emergency situations (longer downtimes, a greater number of damaged and connected parts, higher costs, possible injury to workers, endangerment of the working and living environment, etc.).

4. Conclusion

The traditional understanding of maintenance implied the performance of certain maintenance activities in the sense of returning the system from the state of failure to the state of operation after the failure occurs. Today, modern maintenance systems are designed primarily to prevent unwanted conditions that can impair work ability. The dominant goals of maintenance within modern industrial systems are ensuring the maximum level of equipment reliability, maximum effectiveness of production systems and ensuring the conditions of a safe and secure working environment for workers and equipment. Maintenance goals defined in this way can only be achieved with an appropriate maintenance strategy, which represents the highest goal of the company's policy and management. The accelerated development of technical systems and the intensive application of electronics as part of technical solutions and the complication of technological processes have led to the intensive application of the condition based maintenance concept, which enables and facilitates access and quality control of processes and conditions of certain sizes that characterize the operation and behavior of the system. By applying modern diagnostic systems, it is possible to define the current technical state of the system components and forecast (predict) the behavior of the system in the near or conditionally distant future. Modern systems for technical diagnostics are usually complex systems for which it is necessary to allocate significant financial investment funds, which is especially problematic from the point of view of business operations in problematic time periods, such as regional wars, COVID-19, natural disasters and the like. However, insufficient investment in maintenance most often leads to accelerated wear of equipment and to the creation of conditions for failure in a short time interval of exploitation.

Diagnostics and assessment of the condition of elements of technical systems is the most difficult and sensitive part of the maintenance process. It requires adequate equipment and the appropriate level of knowledge of individual maintenance workers, who, based on the collected information about the state of system components, should make decisions about preventive or proactive activities that need to be implemented in order to correct or completely eliminate observed deviations from the designed operating conditions of the equipment. Certainly, the information obtained by using the system for technical diagnostics is relevant and objective, and subjectivity is avoided in making executive decisions.

The result of the application of the system for technical diagnostics is the assessment of the current state and the undertaking of certain corrective actions if the parameters describing the current state of the monitored system have exceeded the previously defined limits. The essence of these corrective activities is in fact the prevention of the occurrence of far more unfavorable conditions in the nearer or longer period of time, which can cause more serious failure conditions (accidents, endangering the safety and health of workers, endangering the environment, etc.) and the occurrence of large unplanned maintenance costs. In this sense, the application of the condition based maintenance concept and the use of systems for technical diagnostics provides the possibility of a safer production process and the achievement of better production and business results, which is a condition for the survival of industrial production systems on the competitive market.

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