The Use of Predictive Maintenance in the Production Processes

Aneta NAPIERAJ[1)]

[1)] dr inż., AGH w Krakowie, email: aneta.napieraj@agh.edu.pl

http://doi.org/10.29227/IM-2019-01-55

Submission date: *11-07-2018* | Review date: *02-05-2019*

Abstract

Failures are a problem for every company that causes the plant to stop working and thus incur losses. It is therefore obvious that companies want to eliminate unplanned downtime in the production process. In the wake of the still increasing demands in terms of productivity and safety requirements, cost reduction, the industry is forced to seek the optimum between economic requirements and an acceptable level of risk in terms of security. Modern factories equipped with computerized processes and extensive diagnostic tools often do not use all the information that is collected from the hardware level. It happens that some of the relationships between events are often overlooked or neglected.

The article presents an approach to increasing machine reliability through predictive data analysis. The assumptions of the predictive and preventive maintenance methods are presented. The threats and possibilities offered by this methodology implemented in the production process are presented.

Keywords: prediction, predictive maintenance, preventive maintenance

Introduction

Until the 40s of the twentieth century, the approach to the failure was based on the reactive approach, or principle: "broke down, so we fix." The approach began to change during World War II, when the reliability of more and more complicated technical devices often decided about life or death. Smoothly began to undergo planned repairs, inspections and parts replacement. However, this solution also had some drawbacks. Among other things, it brought a high cost of maintenance, as the part that was in very good condition was often replaced. In particular, the aviation industry, as well as today, in the 1960s, analyzed the costs of maintaining the fleet of aircraft. With the arrival of the Boeing 747 with advanced technology, the Reliability Centered Maintenance (RCM) (Rausand 1998) method was developed, based largely on a predictive approach analyzing the condition of machines (called Condition Based Maintenance). Due to the rapid development of electronics, it became possible to more and more accurately analyze the parameters of machines and devices. On the other hand, the increasing share of electronics in machines caused that in addition to the traditional "bathtub" distribution of damage, several new ones appeared. Currently, the industry standard is vibroacoustic measurements, oil analyzes, and thermographic measurements of machines, electrical cabinets and substations. Various types of real-time measurements are also becoming more and more widely disseminated. Also thanks to the advances in technology, the sensor market has expanded its offer by testing many physical quantities, and at the same time the cost of a single sensor has dropped several dozen times (Piesik 2015). All this meant that modern production lines are equipped with hundreds and sometimes thousands of sensors that collect data on an ongoing basis and monitor the state and course of the production process.

It should be noted that research into the production process was carried out already in the second half of the nineteenth century, when the American engineer F.W. Taylor was the first to face the problem of production processes. He proposed the use of methods and techniques helpful in solving the problems of preparation and implementation of production by preparing the production process itself, eliminating unnecessary activities in the production process and establishing work standards. Further interest in the scientific sphere of production contributed to the foundations of the organization of production and the merit of the methods developed is attributed to: - L. and F. Gilbreth - methods of measuring working time, - H.L. Gantt - methods of planning and control of the production process, - H. Emerson - formulation of twelve principles of performance. This article, however, addresses the issue of failure in the production process and is devoted to the predictive approach to the analysis of the process in order to maintain its failure-free operation.

The concept of predictive maintenance and preventive maintenance

Prediction is rational, scientific anticipation of future events such as states of machines or industrial processes. It is a choice, within a given system, of the most likely way of changing the states of objects in the coming period, where the basis for this choice is the current course of this phenomenon and the current state of the system. Its aim is to reduce the risk in the decision-making process.

We base our prediction on the regularities that characterize the projected phenomenon or occur between it and other phenomena. Such existence of regularities, which are the result of mutual connections between various phenomena, is the ontological basis of forecasting, and their knowledge is the gnoseological basis. These can be regularities in the development of the forecasted phenomenon or causal relationships, similarities in development, symptomatic relationships between the predicted phenomenon and other phenomena.

Therefore, we can predict that:

- the event will occur because it occurred in the past,
- the event will occur because it is indicated by the frequency of its occurrence,
- the event will occur because it is strongly related to another event that occurred (Dittman 2016).

Among the many solutions recently, two approaches dominate - methods of machine maintenance: dependent on the state of the machine predictive maintenance/predictive testing and inspection (PdM/PTI) and proactive reliability centered maintenance (RCM). The basic assumption of predictive maintenance is to undertake preventive actions in the phase of deterioration of machine or process parameters, in order to prevent dangerous failures and associated downtime.

Predictive maintenance tools include: performance monitoring, non-invasive testing techniques and visual inspection. Within the scope of available methods, it is possible to use pattern recognition, trend analysis and correlation, statistical data analysis, and monitoring of alarm thresholds.

Implementation of online monitoring in relation to all machines is pointless (despite a marked improvement in safety and quality of work), and also results in a significant increase in investment outlays. In the case of the predictive maintenance method, it is important to conduct a criticality analysis, leading to the isolation of three groups of machines: critical, relevant and general application.

The classification can be made in terms of different criteria (Table 1) and depends to a large extent on the decisions of the maintenance services, diagnostics and management of the specific plant. Despite the strictly defined criteria, the assignment can lead to different results.

Critical equipment and machines whose failure affects the security of the industrial plant - machines important in the production process, failure of which results in a significant reduction in productivity,

- power units that cannot be duplicated or have high power output,

- machines with a high cost of purchase, maintenance and long-term renovation or repair,

- machines whose damage is caused by slight disturbances in the work process,

- machines for improving efficiency or improving the quality of production.

Essential equipment and machines whose failure may cause disturbance of the plant's safety and a significant reduction in the efficiency of the department or part of the production process:

- machines in which redundant units may or may not exist,

- the ability to start (after repair), which can affect the parameters of the production process,

- high power drive units and revolutions operating in an intermittent cycle,

- machines using a time-based exploitation model,

- machines with average cost and repair time,

- machines whose damage occurs as a result of progressive time (no sudden failures).

Equipment and general purpose machines whose failure does not affect the safety of the industrial plant - devices or machines not classified for a critical collection,

- duplicated or on-demand machines,

- machines with a low cost and short repair time (the risk of a subsequent failure after repair determined as minimal).

Prediction in technical systems makes sense if a favorable benefit-to-investment ratio is achieved. With reference to the presented classification and separate groups of machines:

- critical - online monitoring of parameters affecting the loss of quality and safety is required,
- significant - periodic measurements with trend analysis are recommended,
- general use - it is possible to implement periodic measurements, however, in many cases, it is sufficient to adopt a preventive method of operation (with scheduling repairs).

Predictive maitenance is one of the maintenance strategies based on the optimal use of machines. It is based on predicting the states of objects in the future and taking appropriate corrective, conservation and preventive actions in a timely manner. It is possible thanks to continuous monitoring of their technical condition and constant monitoring of the desired parameters.

Prediction allows to determine future states of objects thanks to continuous measurement (also in real time), analysis of current and historical states and estimation of future values. As a result, it is possible to optimally plan maintenance, overhaul, replacement and other work that minimizes the number of failures and allows you to achieve longer periods between failures. By taking action at the best of times, this method turns out to be more effective in preventing and removing failures than the preventive maintenance method (Levitt 2003).

The predictive maintenance strategy uses the CBM approach, that is, the exploitation of machines based on the technical condition. It is usually carried out on machinery and objects belonging to the high criticality group, because its use is demanding and for devices characterized by low production criticality would be unprofitable.

The effectiveness of the predictive maintenance model is closely dependent on the knowledge required at the stages (Birolini 2017):

1) planning the physical structure of the model - machine classification, selection of method for obtaining process data, identification of key parameters and determining the effectiveness of the tools used (including approximate payback period, cost of using tools, employee training, etc.),

2) implementation - proper configuration of the system with the condition of obtaining resistance to interference, determination of the diagnostic path and period of measurements,

3) use - knowledge and experience to determine the approximate time to failure and inference about possible causes, locations and the extent of failure or damage.

The advantages of implementing the predictive maintenance method include:

- reduction of failure costs and minimization of total downtime,

Tab. 1. Criteria for the division of machines enabling the identification of the measurement method and the variant of the implemented method of operation

Tab. 1. Kryteria podziału maszyn umożliwiające identyfikację sposobu pomiaru oraz odmiany wdrożonej metody eksploatacji

Machinery	Classification criteria
Critical equipment and machines whose failure affects the security of the industrial plant	- machines important in the production process, failure of which results in a significant reduction in productivity, - power units that cannot be duplicated or have high power output, - machines with a high cost of purchase, maintenance and long-term renovation or repair, - machines whose damage is caused by slight disturbances in the work process, - machines for improving efficiency or improving the quality of production.
Essential equipment and machines whose failure may cause disturbance of the plant's safety and a significant reduction in the efficiency of the department or part of the production process	- machines in which redundant units may or may not exist, - the ability to start (after repair), which can affect the parameters of the production process, - high power drive units and revolutions operating in an intermittent cycle, - machines using a time-based exploitation model, - machines with average cost and repair time, - machines whose damage occurs as a result of progressive time (no sudden failures).
Equipment and general purpose machines whose failure does not affect the safety of the industrial plant	- devices or machines not classified for a critical collection, - duplicated or on-demand machines, - machines with a low cost and short repair time (the risk of a subsequent failure after repair determined as minimal).

- the possibility of observation of current machine operation parameters and analysis of their condition,
- improvement of work safety and increase of production quality,
- no need to use complicated statistical models of machine reliability, in favor of the use of known diagnostic methods (based on standards) or relations between diagnostic signals,
- reducing the impact and elimination of secondary damage (i.e. resulting from the harmful effect of vibrations, elevated temperatures, enlargement of the looseness of damaged elements), which directly affects the extension of the machine's operating time,
- reducing the time needed for repair (registering a drop in the quality of work below the acceptable threshold, with the simultaneous location of the damage, allows you to order parts and prepare tools for the repair), developing procedures or actions to prevent further deterioration (including automatic safety devices).

An obstacle in the implementation of predictive maintenance is the costs associated with the need to use an advanced monitoring system, purchase of analyzers and continuous improvement of staff qualifications.

As determinants of the correct implementation of predictive maintenance, generally accepted indicators can be used, in the form of:

- OEE (Overall Equipment Efectiveness) Total Equipment Efficiency - implementation of predictive maintenance should cause a clear increase in the rate,
- MTBF (Mean Time Between Failure) Mean Time Failure-Free - increase the ratio while reducing the Mean Time To Repair (MTTR) Mean Time of Failure Removal.

In the case of OEE, using predictive maintenance techniques, it is possible to limit the loss of availability (failure and regulation), increase the use (stop times) and quality (gains, scrap, need for corrections). Other components of losses (conversion, idle time, start-up and machine shutdown) are included in the domain of management methods and adopted technology.

Tools, techniques and indicators of the predictive maintenance exploitation model

The basic tools used in the implementation of predictive maintenance strategies include primarily:

- monitoring performance and its parameters,
- non-interventional tests,
- visual observation,
- automatic state monitoring,
- IT systems supporting maintenance (CMMS systems).

Prediction in maintenance is also strongly related to the already mentioned basic performance indicators, i.e. OEE indicator and MTBF indicator, by means of which equipment performance and availability are measured. For a plant, they have a value that verifies whether the prediction is being carried out correctly (increase in the value of indicators), or whether it is necessary to re-plan/optimize the adopted strategy.

The main danger and distortion of the machine-dependent exploitation model is incorrect understanding of the possibilities hidden in predictive maintenance methods and tools.

Exceeding the set alarm threshold informing e.g. about the bearing's wear and making a decision on its replacement is the most correct procedure. At this point, however, a trap appears. Avoiding it requires checking the period between successive exchanges. It is worth observing groups of similar machines and periods of wear of individual components. Too frequent bearing replacement in one case can be caused by, for example, unbalance or other factors shortening the service life of a bearing node.

Monitoring the variability of parameters allows to define alarm thresholds. After exceeding the defined values, preventive or corrective actions are required.

One of the most popular methods of predictive maintenance is vibration diagnostics, most often used to assess the condition of machine bearings and drives. An important barrier to other methods is the still low level of knowledge and the high cost of implementing specialist tools.

Parameter monitoring is the basic element used to reduce the operating costs of technical systems. For drives:

- electrical - available methods focus on vibration diagnostics, monitoring of electrical parameters, state of brakes and lubricants,
- pneumatic and hydraulic - failure prevention can be carried out by scheduled inspections (replacement of filters, seals, hydraulic fluids), leak detection and the state of the working medium.

In many production plants, there is a disturbed exchange of information between departments and even groups of employees responsible for handling specific machines in one department. The implementation of the predictive maintenance model in such conditions will certainly not bring the expected results.

Diagnostics of machines and production systems must be supported by advanced equipment (not always of a closed structure, i.e. without the possibility of expansion) and the experience of employees.

If the team implementing the model of predictive maintenance is characterized by high knowledge of machines, an attempt can be made to build a diagnostic system based on online monitoring and diagnostic rules defined by maintenance services. The advantage of such a solution is the possibility of using universal tools that can be configured and freely expanded (as needed), according to the current user's requirements. In the development of a system for obtaining process data, attention should be paid to (Nash 2016):

– requirements related to architecture of the considered system of devices and machines:

• centralized - the possibility of using local data visualization in the form of HMI panels and diagnostic procedures stored in the PLC,

• distributed - using SCADA systems, IO modules and industrial networks bus,

– measurement sensors - the choice of process sensors should take into account the nature and type of the measured quantity (temperature, pressure, flow, displacement, presence, etc.), equipment with network interfaces, accuracy, measurement method, the need for calibration and purchase of additional equipment,

– accessibility to measured parameters - point (lights, displays, signaling towers) or decentralized (using industrial networks).

Documentation in the process of building a predictive model

Building a predictive maintenance model is a complex task that includes the need to include information contained in the documentation. The collection of basic elements includes documentation:

- technical and operational - including: specification of technical parameters, drawings (executive and assembly), lists (of normal and special equipment), diagrams (body, kinematic, electric and pneumatic), instructions (use, operation, maintenance and lubrication, health and safety), recommended manufacturer's repair norms, lists (spare and spare parts),
- operation history - including the history of the machine's operation and current records of operating notes of maintenance staff,
- the scope and expected values of monitored variables - sometimes deviating from norms.

A common case in industrial practice is exceeding the permissible thresholds defined by standards (e.g. ISO 10816 and ISO 7919 groups of standards), and yet the machines are not subject to rapid wear. The occurrence of such a state of affairs forces the necessity of a deeper analysis. The source of error is that in many cases the condition of newly installed machines is treated as a reference point for further evaluation. If all requirements (assembly, configuration and operation) are met, you can use the current work parameters of new machines as reference values. Irregularities can appear in every element (improper machine installation, power parameters, loose mechanical connections, inaccuracies etc.). It is therefore important to keep in mind three basic groups of errors related to the stages of construction, assembly and pre-operation.

Implementation of predictive maintenance

The implementation of the predictive maintenance system includes the following steps:

1) identification of needs - defining the current failure rate and the course of work of objects (e.g. on the basis of indicators), the number and range of variability of parameters uniquely identifying the state of the analyzed object,

2) an analysis of the reasonableness of implementation - taking into account the criticality of machines and the assessment of alternative methods projecting directly on the possibility of improving the safety, quality and productivity of production,

3) execution of statements (equipment, procedures, requirements) and determination of implementation costs - the decision stage in which the assumptions may change,

4) implementation - the stage requires defining the course of proceedings allowing the implementation of equipment and equipment, with the simultaneous possibility of a periodic decrease in the quality or performance of machines or entire lines,

5) assessment and correction - control of performance and effects, allowing identification of weak points of applied solutions and their removal.

The implementation of a comprehensive predictive diagnosis program requires close cooperation of maintenance services, managerial staff and machine operators. Many industry experts pay particular attention to the latter, as it is line workers and operators that in practice implement production and diagnostics management procedures at the lowest level of factory structures. In order to improve the operation of the system, it is also recommended to develop procedures for dealing with specific machine failures.

Summary

The implementation of the predictive maintenance model is possible in three mutually complementary variants:

- surveillance of trends - a diagnosis based on the basis of exceeding defined alarm thresholds, which necessitates the need to perform measurements at fixed time intervals and periodic control with non-invasive methods,
- qualitative measurements - a diagnosis based on the operator's knowledge, and the frequency of measurement depends on a visual assessment of the deterioration of the machine's operating parameters,
- quantitative measurements - based on the CM (Condition Monitoring) method, including the registration of online parameters, their archiving and analysis.

The progressive automation of industrial processes and the development of IT technologies are a determinant of the predominance of diagnostic systems operating on common historical databases (offering access to multiple users with different levels of authority). The presented forecasts indicate the importance of an additional criterion, which is the possibility of adapting the existing model of machine maintenance to new requirements and its extension, without the need to replace all diagnostic and monitoring equipment.

Scientific work carried out at the Faculty of Mining and Geoengineering of the AGH University of Science and Technology Stanisława Staszica under the contract number 16.16.100.215

Literatura – References

1. Birolini A., (2017), Reliability engineering : theory and practice. Springer-Verlag GmbH, Berlin
2. Dittman P., (2016) Prognozowanie w zarządzaniu sprzedażą i finansami przedsiębiorstwa, Oficyna a Wolters Kluwer business, Warszawa
3. Levitt J., (2003) Complete Guide to Preventive and Predictive Maintenance. Industrial Press, New York
4. Nash F.R., (2016), Reliability assessments: concepts, models and case studies. CRC Press Taylor & Francis Group.
5. Rausand M., (1998) Reliability centered maintenance. Reliability Engineering and System Safety, Vol. 60
6. Inżynieria i utrzymanie ruchu (2015) Predykcyjne utrzymanie ruchu <https://www.queris.pl/baza-wiedzy/predykcyjne-utrzymanie-ruchu/> [dostęp 15/02/2019]
7. Piesik J., (2015) Zastosowanie narzędzi statystycznych do poprawy niezawodności i bezpieczeństwa maszyn poprzez predykcję awarii oraz poprawę pokrycia diagnostycznego maszyn <https://media.statsoft.pl/pdf/czytelnia/zastosowanie_narzedzi_statystycznych_do_poprawy_niezawodnosci.pdf> [dostęp 10/03/2019]

Wykorzystanie predictive maitenance w procesie produkcyjnym

Awarie to problem każdego przedsiębiorstwa powodujący zatrzymanie pracy zakładu a przez to ponoszenie strat. Oczywistym zatem jest, że firmy chcą eliminować nieprzewidziane przestoje w procesie produkcji. W następstwie rosnących wciąż wymagań w zakresie produktywności i wymagań bezpieczeństwa, redukcji kosztów, przemysł zmuszony jest do poszukiwania optimum pomiędzy wymaganiami ekonomicznymi i akceptowalnym poziomem ryzyka w zakresie bezpieczeństwa. Nowoczesne fabryki wyposażone w skomputeryzowane procesy i rozbudowane narzędzia diagnostyczne często nie wykorzystują wszystkich informacji, które są zbierane z poziomu sprzętowego. Zdarza się, że niektóre z relacji pomiędzy zdarzeniami są często pomijane lub zaniedbywane. W artykule przedstawiono podejście do zwiększenia niezawodności maszyn poprzez predykcyjną analizę danych. Zaprezentowano założenia metodyki predictive i preventive maintenance. Przedstawiono zagrożenia i możliwości jakie daje ta metodyka zaimplementowana w procesie produkcyjnym.

Praca naukowa realizowana na Wydziale Górnictwa i Geoinżynierii Akademii Górniczo-Hutniczej im. Stanisława Staszica w ramach umowy numer 16.16.100.215

Słowa kluczowe: predykcja, predykcyjne utrzymanie ruchu, prewencyjne utrzymanie ruchu