Application of Elements of TPM Strategy for Operation Analysis of Mining Machine

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Abstract. Total Productive Maintenance (TPM) strategy includes group of activities and actions in order to maintenance machines in failure-free state and without breakdowns thanks to tending limitation of failures, non-planned shutdowns, lacks and non-planned service of machines. These actions are ordered to increase effectiveness of utilization of possessed devices and machines in company. Very significant element of this strategy is connection of technical actions with changes in their perception by employees. Whereas fundamental aim of introduction this strategy is improvement of economic efficiency of enterprise. Increasing competition and necessity of reduction of production costs causes that also mining enterprises are forced to introduce this strategy. In the paper examples of use of OEE model for quantitative evaluation of selected mining devices were presented. OEE model is quantitative tool of TPM strategy and can be the base for further works connected with its introduction. OEE indicator is the product of three components which include availability and performance of the studied machine and the quality of the obtained product. The paper presents the results of the effectiveness analysis of the use of a set of mining machines included in the longwall system, which is the first and most important link in the technological line of coal production. The set of analyzed machines included the longwall shearer, armored face conveyor and cruscher. From a reliability point of view, the analyzed set of machines is a system that is characterized by the serial structure. The analysis was based on data recorded by the industrial automation system used in the mines. This method of data acquisition ensured their high credibility and a full time synchronization. Conclusions from the research and analyses should be used to reduce breakdowns, failures and unplanned downtime, increase performance and improve production quality.

1. Introduction

Big competition in the global energy market forces producers of raw materials to take actions in order to reduce production costs. One of the areas in which there are large reserves associated with this issue is the effectiveness of the use of owned machinery and equipment. In the Polish mining industry, which over the last several years has been restructured, similar actions also have been taken in order to reduce production costs and improve the economic efficiency.

In mining enterprises that extract coal, in order to optimize the use of machines, it is necessary to take actions that contribute to appropriate machine selection for the operating conditions and keep them in good condition. To evaluate the effectiveness of these actions, it is justified to use elements of the Total Productive Maintenance strategy (TPM). The main task of this strategy, which is enacted by
to the managers of mining companies, is to increase the effectiveness of the use of equipment and to change the perception of this problem on the part of workers [1, 2].

Total Productive Maintenance (TPM) strategy includes group of activities and actions in order to maintenance machines in failure-free state and without breakdowns thanks to tending limitation of failures, non-planned shutdowns, lacks and non-planned service of machines.

These actions are ordered to increase effectiveness of utilization of possessed devices and machines in company. Very significant element of this strategy is connection of technical actions with changes in their perception by employees. Whereas fundamental aim of introduction this strategy is improvement of economic efficiency of enterprise [3, 4, 5, 6, 7].

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The article presents issues concerning the effective use of equipment in the mining company. It discusses the concept of Total Productive Maintenance (TPM), which is a complex approach to the maintenance process, with its basics and the benefits resulting from its use. Using this strategy improves the efficiency in the use of devices and their durability by reducing failures, wastes, downtime, accidents, disruptions, errors and damages. In this process it is also very important to increase awareness and responsibility of employees who operate these devices.

In the paper examples of use of OEE model for quantitative evaluation of selected mining devices were presented. OEE model is quantitative tool of TPM strategy and can be the base for further works connected with its introduction.

OEE indicator is the product of three components which include availability and performance of the studied machine and the quality of the obtained product.

The paper presents the results of the effectiveness analysis of the use of a set of mining machines included in the longwall system, which is the first and most important link in the technological line of coal production.

The set of analyzed machines included the longwall shearer, armored face conveyor and cruscher. From a reliability point of view, the analyzed set of machines is a system that is characterized by the serial structure.

The analysis was based on data recorded by the industrial automation system used in the mines. This method of data acquisition ensured their high credibility and a full time synchronization. Conclusions from the research and analyses should be used to reduce breakdowns, failures and unplanned downtime, increase performance and improve production quality.

2. Characteristics of the TPM Strategy

The Total Productive Maintenance (TPM) is a method of maintenance management in the production enterprises, assuming a comprehensive approach and based on organizational and management techniques. The main aim of this strategy is to provide and increase the availability and reliability of machines in all stages of the production process.

The TPM concept is primarily focused on maintaining a high level of machine parks, but it also refers to the human resources. TPM involves all the employees of the company in the maintenance of equipment in failure-free and faultless conditions and in the maintenance of continuity of production. This is done mainly by eliminating losses and deficiencies [4, 6].

The purpose of the TPM strategy is prevention, understood as taking action in maintenance in order to avoid possible failures and defects, and inseparably associated with losses. It is assumed that the concept of TPM must be taken by all employees who while performing entrusted actions aim to eliminate unintended events and achieve what are called "three zeros" [1, 4, 7]:

- zero accidents,
- zero damage and failure,
- zero downtime.
The mentioned zero values are more theoretical; however, they are very important points of reference in the pursuit of continuous improvement. Assumed exploitation actions in TPM should be mainly aimed at preventing unintended events.

Striving for the ideal state, assuming zero distortion and zero errors, the employees learn how to identify and eliminate losses. Effectively implementing the concept of TPM avoids the 16 types of losses that may occur in manufacturing processes [5].

TPM assumes taking preventive actions due to the fact that only regularly maintained and serviced machines can be optimally used. In order to provide more effective prevention of failures and downtime, maintenance standards should be applied and the wearing parts should be replaced on a regular basis. The high quality of the machine translates into increased quality of the product which is aimed at meeting the needs and expectations of customers. Maintaining the quality must become a task of every employee who is obliged to know the machine well and be responsible for the products [1, 4].

One of very important factors affecting TPM in the organization is teamwork which actively involves all employees. It should change the previous division of labor on people or departments engaging in the production, repairing or retooling of the machines. According to the basics of TPM every employee should be and feel responsible for the maintenance of the machinery in the best possible condition.

It can be assumed that the benefits of implementing TPM concept refer to two aspects: human and machine. The effectiveness of the entire production process increases due to teamwork, jointly made decisions and a great sense of responsibility for work and operating machines.

According to Nakajima [6], TPM is based on five basic assumptions, which include:
- maximizing the overall effectiveness of use of equipment,
- implementation of the maintenance system, which includes preservation, corrective and preventive actions,
- combination and cooperation of various departments (engineering, maintenance, operation) as a part of TPM implementation,
- active involvement of each employee, both at the level of management and operators,
- promoting autonomous activities, which assume that the operators at their machines perform actions such as cleaning, caring of tidiness, inspections, maintenance, minor repairs, which will help avoid errors, downtime and mistakes in the future.

The aim of TPM is primarily to increase the effectiveness of the use of equipment that is owned by the company.

Actions in TPM implementation are therefore associated with implementation of organizational and technical changes in the company. To implement them effectively, it is necessary to analyze the input state. In addition, after a period of assumptions and applying TPM actions, the effectiveness of implemented changes should be assessed.

### 3. Characteristics of the OEE Model

One of the tools for quantitative evaluation of the input state as well as for the subsequent evaluation of the changes is the Overall Equipment Effectiveness (OEE) model. The application of this model allows the determination of the overall effectiveness indicator which is the product of three partial indicators including availability, performance and quality. The OEE value describes in percentage the possibility to achieve effectiveness that characterizes a particular machine or set of machines. Through the determined value, the level of use of the studied equipment potential can be defined and the areas that need improvement can be located [1, 5, 8].

OEE indicator can be calculated for the entire production line (a set of machines) to identify the areas that generate the biggest losses. This approach allows the identification and elimination of the causes of losses. Whereas, in case of a set of machines working individually the OEE value make it possible to indicate a machine that is characterized by the lowest effectiveness. The work of such machines should be subjected to deeper analysis to determine the reasons causing such a negative state.
In practice, it is assumed that the ideal world-class percentage level of the three partial indicators of OEE should be: in the case of the availability - 90%, performance - 95% and quality - 99%. The assumption of these values makes that the OEE value should be about 85%. It is assumed that 85% is an ideal result which should be the aim for the companies that apply the Overall Equipment Effectiveness model [3].

The Overall Equipment Effectiveness model analyzes three areas which include availability and performance of the machines or devices and product quality. The value of coefficient for each of the areas has been determined. OEE is the product of the three calculated components [2, 3, 8]. Figure 1 shows the relations between total time, planned time, operating time, net operating time, fully productive time and main losses in the process of maintaining the machines [8].

**Figure 1.** The relations between time and the main losses in the process of maintaining the machines [8]

4. Results and discussions. Using the OEE Model for mining machine work analysis

Mining machinery used in underground coal mining work faces very difficult conditions. In particular, the shearer and scraper conveyors are directly involved in the mining and transporting of excavated material from the longwall. These machines with roof support and crushers are mechanized longwall systems (Figure 3). The purpose of these complexes is to ensure the safe and efficient exploitation of coal. Due to the high cost of these machines and vital meaning in the technological line of exploitation of carbon, the companies seek to maximize the use of these machines. This applies to both the availability and performance as well as the quality of excavated coal [2].

In the present case, a set of machines included in the mechanized longwall complex was analysed. The set of analyzed machines included the longwall shearer, armored face conveyor and crus cher.

The analysis was based on data recorded by the industrial automation system used in the mines. This method of data acquisition ensured their high credibility and a full time synchronization. The basis of the analysis was to determine the availability of tested machines. Underground observations and expert interviews have clearly indicated that the availability of the examined machines has the greatest impact on the efficiency of their use. Therefore, the data obtained from the industrial automation system were used to determine the availability’s indicators of the tested machines. These data have allowed the determination of the duration of the recorded parameters. Figure 2 shows an example of the timing of a shearer and the current consumed by its feed motors. In contrast, Figure 3 shows the timing of the current drawn by the motors of the armored face conveyor (in longwall) and the crus cher.
Figure 2. Time courses of the velocity of the shearer movement and the current consumed by its feed motors

Figure 3. Time courses of the current drawn by the motors of the armoured face conveyor and the crusher

Performance of individual machines was determined based on the estimated values of the amount of extraction in particular shifts, related to their nominal performance that was determined for the concrete longwall. Quality indicator was set on the basis of information obtained from the processing plant related to the assortment of excavated coal and gangue content in the ore. These data were determined as the mean values of the decade measuring period.
Data designated this way became the basis for determining the average value of the partial OEE indicators and indicators of the set of machines for twenty-five work shifts (Figure 4).

![Figure 4](image)

**Figure 4.** Values of efficiency indicators for the tested machines for the 25 working shifts

5. Conclusions

A major problem of the underground coal mining industry in Poland is the ineffective use of mining machinery. The machines, which are currently used in mining, are very expensive and as a result it is necessary to take measures to maximize use.

The analysis of using the OEE model to evaluate the efficiency of use of mining equipment that is presented in the paper should be an important source of information for mine maintenance services to improve the use of these machines.

The determined values of the OEE indicator for each machine and for the entire set of machines clearly indicate that they are at a low level. Therefore, it seems necessary for the appropriate mine services to take actions in order to improve the value of these indicators. The designated values of these factors, especially in comparison with the values for machines working in other industries are unsatisfactory. Therefore, it can be assumed that in the mining industry, there are plenty of reserves to improve - mainly through the appropriate organization of work.

In assessing the utilization of mining machinery, we must also take into account the specificity of mining production. In this process there are many random factors that are difficult to predict during such exploitation. They can adversely affect the efficiency of mining machinery. In particular, it concerns all types of hazards and the dynamic impact of the rock. Despite these difficulties, it seems reasonable to carry out such analyzes in order to optimize the entire mining process.

The results should be an important source of information for maintenance services in the mine and on this basis, actions should be taken to improve the situation. Creating conditions for maximum machine use and simultaneously, keeping them in appropriate technical conditions should be a priority for maintenance services in the coal mines. The results presented in this paper should be regarded as one of the stages of a broad research process, which aimed to make a full analysis of the use of machinery in the mining industry.
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