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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ
«ХАЛЫҚ» ЖҚ

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ИЗВЕСТИЯ

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APPLYING ELEMENTS OF A TOTAL EQUIPMENT CARE STRATEGY TO ANALYZE THE OPERATION OF MINING MACHINERY

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Abstract. The Total Productive Maintenance (TPM) strategy includes a group of actions and activities to keep machines up and running free of breakdowns by striving to limit the number of machine failures, unscheduled shutdowns, deficiencies and unscheduled maintenance. These actions are aimed at increasing the efficiency of using the company's existing devices and machines. A very important element of this strategy is the connection of technical activities with changes in their perception by employees. While the fundamental goal of implementing this strategy is to increase the economic efficiency of the enterprise. Growing competition and the need to reduce production costs lead to the fact that mining enterprises are forced to implement this strategy. The article presents examples of using the OEE model to quantify selected mining devices. The OEE model

is a quantitative tool for the TPM strategy and can be the basis for further work related to its implementation. OEE is the product of three components, including the availability and performance of the machine under study, and the quality of the resulting product. The results of a study on the effectiveness of utilizing a set of mining machinery within the longwall system, the primary component of coal mining operations, are detailed in the article. The machinery set under examination consists of a longwall miner, a reinforced face conveyor, and a crusher. In terms of reliability, the analyzed machinery set forms a system with a serial structure. The study relied on data collected by an industrial automation system implemented in mining operations, ensuring high reliability and full temporal synchronization of the data. The insights derived from the study are meant to be applied towards reducing breakdowns and failures, minimizing unplanned downtimes, enhancing productivity, and elevating the quality of products.

Keywords: mining, machines, diagnostics and testing of machines, efficiency of use

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ТАУ-КЕН МАШИНАЛАРЫНЫҢ ЖҰМЫСЫН ТАЛДАУ ҮШІН ЖАЛПЫҒА БІРДЕЙ ЖАБДЫҚҚА КҮТІМ ЖАСАУ СТРАТЕГИЯСЫНЫҢ ЭЛЕМЕНТТЕРІН ҚОЛДАНУ

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Аннотация. Total Productive Maintenance (TPM) стратегиясы ақаулар санын, жоспардан тыс тоқтауларды, кемшіліктерді және машиналарға жоспардан тыс техникалық қызмет көрсетуді шектеу ниетімен машиналарды ақаусыз және ақаусыз ұстау бойынша іс-шаралар мен әрекеттер тобын қамтиды. Бұл әрекеттер компанияда бар құрылғылар мен машиналарды пайдалану тиімділігін арттыруға бағытталған. Бұл стратегияның өте маңызды элементі техникалық қызмет пен қызметкерлердің қабылдауындағы өзгерістер арасындағы байланыс болып табылады. Бұл стратегияны жүзеге асырудың негізгі мақсаты кәсіпорынның экономикалық тиімділігін арттыру болып табылады. Бәсекелестіктің күшеюі және өндіріс шығындарын азайту қажеттілігі тау-кен өндіруші кәсіпорындардың да осы стратегияны жүзеге асыруға мәжбүр болуына әкеледі. Мақалада таңдалған тау құрылғыларын сандық бағалау үшін OEE моделін пайдалану мысалдары берілген. OEE моделі TPM стратегиясының сандық құралы болып табылады және оны жүзеге асыруға байланысты одан әрі жұмыс үшін негіз бола алады. OEE индикаторы үш құрамдас бөліктің өнімі болып табылады, оның ішінде зерттелетін машинаның қолжетімділігі мен өнімділігі, сондай-ақ алынған өнімнің сапасы. Мақалада көмір өндірудің технологиялық желісінің бірінші және маңызды буыны болып табылатын лаваның құрамына кіретін тау-кен машиналары кешенін пайдалану тиімділігін талдау нәтижелері берілген. Талданатын машиналар кешеніне лава комбайны, арматураланған ұңғыма конвейері және ұсақтағыш кірді. Сенімділік тұрғысынан талданатын машиналар кешені сериялық құрылыммен сипатталатын жүйе болып табылады. Талдау шахталарда қолданылатын өнеркәсіптік автоматтандыру жүйесімен жазылған деректер негізінде жүргізілді. Деректерді жинаудың бұл әдісі олардың жоғары сенімділігін және толық уақытты синхрондауды қамтамасыз етті. Зерттеулер мен талдаулардың нәтижелері бұзылуларды, ақауларды және жоспардан тыс тоқтап қалуды азайту, өнімділікті арттыру және өнім сапасын жақсарту үшін пайдаланылуы керек.

Түйін сөздер: тау-кен өнеркәсібі, машиналар, машиналарды диагностикалау және сынау, пайдалану тиімділігі

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ПРИМЕНЕНИЕ ЭЛЕМЕНТОВ СТРАТЕГИИ ВСЕОБЩЕГО УХОДА ЗА ОБОРУДОВАНИЕМ ДЛЯ АНАЛИЗА РАБОТЫ ГОРНЫХ МАШИН

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Аннотация. Стратегия Total Productive Maintenance (TPM) включает в себя группу мероприятий и действий по поддержанию машин в безотказном состоянии и без поломок благодаря стремлению ограничить количество отказов, незапланированных остановок, недостатков и незапланированного обслуживания машин. Эти действия направлены на повышение эффективности использования имеющихся в компании устройств и машин. Очень важным элементом этой стратегии является связь технических мероприятий с изменениями в их восприятии сотрудниками. В то время как, основополагающей целью внедрения этой стратегии является повышение экономической эффективности предприятия. Растущая конкуренция и необходимость снижения издержек производства приводит к тому, что и горнодобывающие предприятия вынуждены внедрять эту стратегию. В статье

представлены примеры использования модели OEE для количественной оценки выбранных горных устройств. Модель OEE является количественным инструментом стратегии TPM и может быть основой для дальнейших работ, связанных с ее внедрением. Показатель OEE является продуктом трех составляющих, включающих доступность и производительность исследуемой машины, а также качество получаемого продукта. В статье представлены результаты анализа эффективности использования комплекса горных машин, входящих в состав лавы, которая является первым и наиболее важным звеном в технологической линии добычи угля. В состав анализируемого комплекса машин вошли комбайн лавы, армированный забойный конвейер и дробилка. С точки зрения надежности, анализируемый комплекс машин представляет собой систему, характеризующуюся серийной структурой. Анализ проводился на основе данных, регистрируемых системой промышленной автоматизации, используемой в шахтах. Такой способ сбора данных обеспечил их высокую достоверность и полную временную синхронизацию. Выводы, сделанные в результате проведенных исследований и анализов, должны быть использованы для снижения количества поломок, отказов и незапланированных простоев, увеличения производительности и повышения качества продукции.

Ключевые слова: горная промышленность, машины, диагностика и испытание машин, эффективность использования.

Introduction. Greater competition in the global energy market forces raw material producers to take actions aimed at reducing the cost of production. One of the areas where there are large reserves related to this issue is the efficiency of utilisation of own machinery and equipment.

In coal mining operations, in order to optimise the use of machines, it is necessary to take actions that help to select machines according to the operating conditions and keep them in good condition. To assess the effectiveness of these actions, it is justified to use elements of the Total Productive Maintenance (TPM) strategy. The main objective of this strategy, is to improve the efficiency of equipment utilisation and change the perception of this problem by workers.

Total Productive Maintenance strategy comprises a group of activities and actions aimed at keeping machines in a fault-free and breakdown-free state through the tendency to limit machine failures, unplanned stoppages, deficiencies and unplanned maintenance (Balovtsev, et al., 2024; Gendler, et al., 2016; Gridina, et al., 2022; Karlina, et al., 2023).

These actions are designed to increase the efficiency of utilisation of the devices and machines available in the company. A very important element of this strategy is to link technical actions to changes in employee perception of them. While the fundamental objective of implementing this strategy is to increase the economic efficiency of the company (Kondrat'ev, et al., 2022; Evdokimov, et al., 2024).

Increasing competition and the need to reduce the cost of production leads to the

fact that mining companies are also forced to implement this strategy (Kondrat'ev, et al., 2016).

The article discusses ways to improve the efficiency of equipment utilisation in the mining industry. It highlights the concept of Total Productive Maintenance (TPM), which is a comprehensive approach to maintenance, and highlights the main principles and benefits of its application. The application of this strategy helps to improve equipment performance and longevity by reducing the probability of failures, losses, downtime, accidents, malfunctions, errors and damage. It is particularly important to increase awareness and responsibility among those involved in the operation of these devices (Gridina, et al., 2023; Gridina, et al., 2022; Rodionov, et al., 2022).

The paper provides examples of the use of Overall Equipment Effectiveness (OEE), a system for analysing overall equipment performance designed to monitor and improve production efficiency for the evaluation of selected mining machines. The OEE model is a quantitative tool for TPM strategy and can be the basis for further work related to its implementation (Kondratiev, et al., 2022).

The OEE score is the product of three components, which include the availability and performance of the equipment under study, and the quality of the resulting product.

The article presents the results of analysing the efficiency of using the complex of mining machines that make up the longwall face, which is the first and most important link in the technological line of coal mining.

The analysed set of machines consisted of a shearer with a face, a conveyor with an armoured face and a crusher (Skopintseva, et al., 2021; Teplyakova, et al., 2022; Zhukov, et al., 2022). From the reliability point of view, the analysed set of machines is a system that is characterised by a serial structure.

The analyses were based on data recorded by the industrial automation system used in the mines. This method of data collection ensured high reliability and full temporal synchronisation. The findings from the research and analysis should be used to reduce breakdowns, failures and unplanned downtime, improve productivity and product quality (Balovtsev, et al., 2024; Bosikov, et al., 2022; Kubrin, et al., 2022).

Characteristics of TPM strategy. The TPM principle emphasises not only the maintenance of optimal equipment condition, but also the development of human resources potential. The key idea of TPM is to involve every employee of the company in the process of maintaining equipment in good condition to ensure uninterrupted production. The benefits of TPM are manifested through the elimination of losses and defects, contributing to increased productivity and efficiency of production activities (Korshak, et al., 2019; Korshak, et al., 2020; Palyanitsina, et al., 2021).

The goal of the TPM strategy includes proactive fault prevention, aimed at avoiding possible failures and defects associated with losses. The essence of the TPM concept is to broadly penetrate the perceptions of all employees who, in the

course of their activities, seek preventive measures to avoid unforeseen situations and achieve the "three zeros" standard:

- no accidents;
- no damage and no failures;
- minimising downtime.

The idea of "three zeros" within TPM, although illusory, is a key incentive for continuous improvement. Production management actions within TPM aim to prevent contingencies and ensure an ideal state devoid of distortions and errors. The TPM approach seeks to eliminate 16 types of production losses, openness to preventive measures and regular replacement of worn parts to prevent failures and downtime. Focused on maintaining quality, TPM contributes to product quality and customer satisfaction (Korshak, et al., 2023; Kusimova, et al., 2023; Pshenin, et al., 2023).

An important aspect of TPM implementation is teamwork, changing the traditional division of labour into those responsible for maintenance and production. All employees must actively participate in the care of the equipment to ensure the highest productivity. By implementing the TPM concept, production efficiency is achieved through collective problem solving and a shared sense of responsibility. According to Nakajima, the fundamentals of TPM include maximising equipment utilisation, maintenance system, departmental co-operation, active participation of all employees and encouraging autonomous work by operators (Zhikharev, et al., 2023).

TPM strives for efficient utilisation of equipment and improvement of the company's performance. The implementation of this strategy requires organisational and technical measures, starting with an analysis of the current state and ending with an evaluation of the results after the changes have been implemented.

Characteristics of the OEE model. One tool for quantifying the baseline condition as well as for subsequently evaluating changes is the Overall Equipment Effectiveness (OEE) model. The application of this model provides an overall performance measure that is the product of three individual measures, including availability, productivity, and quality. The OEE value describes, as a percentage, the possibility of achieving an efficiency specific to a particular machine or set of machines. Through a certain value, it is possible to determine the level of utilisation of the potential of the equipment under study and find areas that need improvement (Rodionov, et al., 2023).

OEE can be calculated for an entire production line (set of machines) to identify the areas where the greatest losses occur. This approach allows the causes of losses to be identified and eliminated. Whereas in the case of a set of machines working individually, the OEE value can identify the machine that is characterised by the lowest efficiency. The performance of such machines should be analysed in more depth to determine the reasons for this negative condition.

In practice, it is considered that the ideal world class percentage level for the

three partial OEE indicators should be: in the case of accessibility, 90 per cent, performance, 95 per cent, and quality, 99 per cent. Based on these values, the OEE value should be around 85 %. It is assumed that 85 % is the ideal result that companies applying the Total Equipment Effectiveness model should strive for.

The overall equipment efficiency model analyses three areas including availability and performance of machines or devices, and product quality. For each domain, a coefficient value is determined. OEE is the product of the three calculated components (Khalikov, et al., 2023).

Figure 1 shows the relationships between total time, planned time, working time, working time, net working time, fully productive time and major machine maintenance losses (Sorokova, et al., 2023).

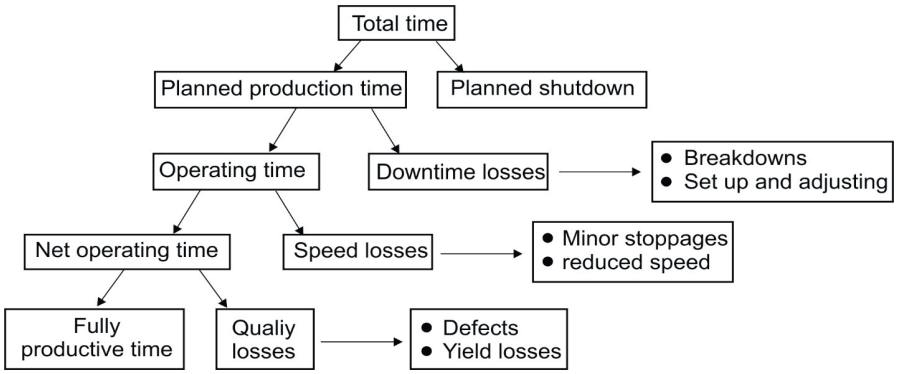

Fig. 1 - The relationship between time and the main losses in the process of servicing machines

Results and Discussion. Using the OEE model to analyse the performance of mining machinery. Mining equipment used in underground coal mining operations operates under very demanding conditions. In particular, shearers and scraper conveyors are directly involved in the extraction and transport of mined material from the face. These machines with roof bracing and crushers constitute mechanised longwall face complexes (Fig. 3). The purpose of these complexes is to ensure safe and efficient coal mining. Due to the high cost of these machines and their vital importance in the coal mining process line, companies are keen to maximise their use. This is as much about availability and productivity as it is about the quality of the coal being mined (Shtang, et al., 2021).

In this case, the set of machines that make up the mechanised face complex was analysed.

The set of machines analysed included a long bench harvester, an armoured conveyor and a crusher.

The analyses were based on data recorded by the industrial automation system used in the mines.

This method of data acquisition ensured high reliability and full time synchronisation.

The basis of the analysis was the determination of the accessibility of the tested machines. Underground observations and expert interviews clearly showed that the availability of the tested machines has the greatest influence on the efficiency of their utilisation. Therefore, data from the industrial automation system was used to determine the availability of the machines under study. This data made it possible to determine the duration of the recorded parameters. Figure 2 shows an example of the operating time of a combine harvester and the current consumed by its feed motors. On the contrary, Figure 3 shows the running time of the current consumed by the conveyor motors of the armoured face conveyor (in the face) and the cruiser.

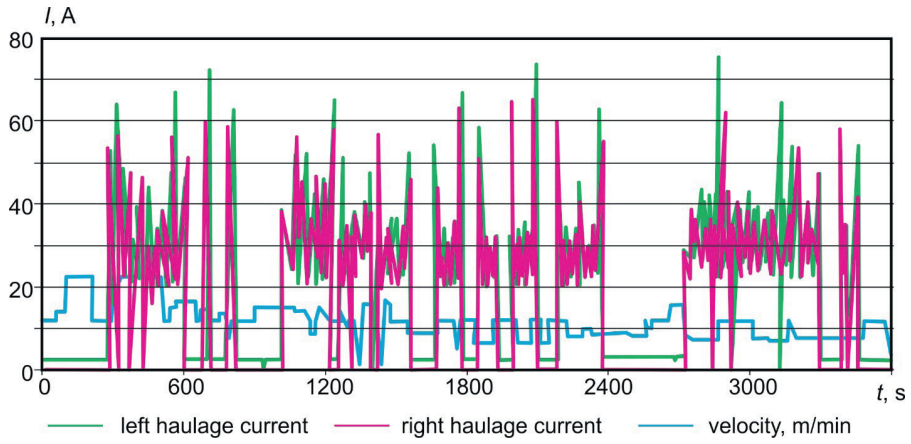

Fig. 2 - Time diagrams of the speed of movement of the combine and the current consumed by its feed motors

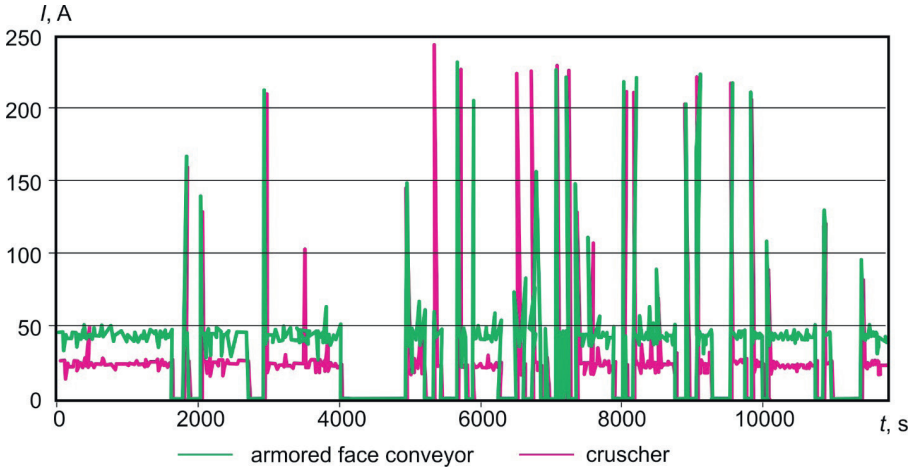

Fig. 3 - Timing diagrams of the current consumed by the motors of the conveyor with an armoured surface and the crusher

The performance of individual machines was determined based on estimated mining volumes in individual shifts related to their nominal capacity, which was determined for a particular longwall face. The quality indicator was established on the basis of information obtained from the preparation plant concerning the range of coal extracted and the gangue content of the ore (Konyukhov, et al., 2023). These data were determined as averages over a ten-year measurement period.

The data thus obtained became the basis for determining the average of partial OEE and machine set rates over twenty-five work shifts (Figure 4).

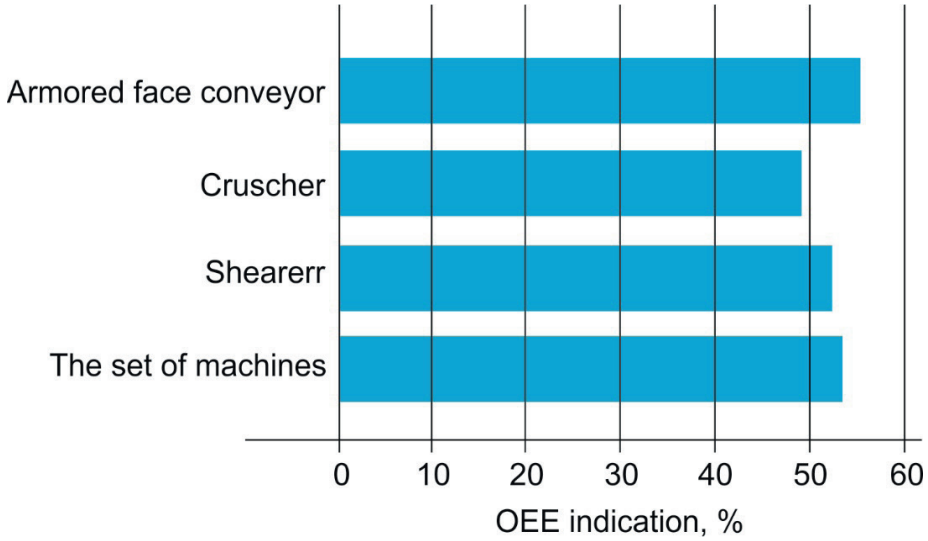

Fig. 4 - Efficiency values for tested machines over 25 work shifts

Conclusions. The main problem of the underground coal mining industry is the inefficient use of mining machinery. The machines that are currently used in the mining industry are very expensive, so it is necessary to take measures to maximise their use.

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

Certain OEE values for each machine and for the whole machine set clearly indicate that they are at a low level. It would therefore seem necessary for the relevant departments of the mine to take action to improve the values of these factors. The values given for these factors, especially when compared to the values for machines operating in other industries, are unsatisfactory. It may therefore be assumed that there is much room for improvement in the mining industry, mainly through appropriate labour organisation.

When assessing the degree of utilisation of mining equipment, the specifics of

mining operations must also be taken into account. There are many random factors in this process that are difficult to foresee in such an operation. These can have a negative impact on the efficiency of mining equipment. In particular, this applies to all sorts of hazards and the dynamic impact of rock. Despite these challenges, it is worthwhile to carry out such analyses in order to optimise the entire mining process

The results obtained should be an important source of information for the mine maintenance services and improvement measures should be taken based on them. Creating the conditions to maximise the utilisation of machines and at the same time keeping them in good technical condition should be a priority for maintenance services in coal mines. The results presented in this paper should be seen as one step in an extensive research process that aims to fully analyse machine utilisation in the mining industry.

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