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К ВОПРОСУ ОЦЕНКИ НАДЕЖНОСТИ ТЕХНИЧЕСКИХ УСТРОЙСТВ НА ГОРНЫХ ПРЕДПРИЯТИЯХ

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Аннотация: Для контроля текущей ситуации, предупреждения отказов и аварийных ситуаций путем своевременного проведения мероприятий по обеспечению безопасности технических устройств важно проводить оценку их надежности. Представленный методологический подход основан на получении единого комплексного показателя, позволяющего установить степень надежности оборудования и оценить его техническое состояние в режиме реального времени, а также учесть критичность его отказа для основных направлений деятельности предприятия. Предлагается собираемые предприятиями показатели подразделить на три группы: идентификационные, предназначенные для идентификации объекта, оперативные, позволяющие получить текущую информацию и учесть иные аспекты влияния, не связанные с системными воздействиями, и системные, отражающие способность системы непрерывно выполнять свои функции с учетом состояния технического устройства и уровня влияния его отказа на критически важные направления деятельности предприятия. В качестве системных показателей надежности технических устройств предлагается использовать коэффициент технической готовности, индекс износа и индекс критичности. Данные показатели необходимо собирать в единую информационную базу, используя для удобства унифицированный формуляр, позволяющий оперативно осуществлять сбор и структурирование информации и исключать ее дублирование. Применение такого подхода позволит на основе выявления ключевых показателей надежности осуществлять прогнозирование состояния надежности технических устройств, а также поможет оперативно принимать организационно-технические решения, направленные на повышение надежности, предотвращение и минимизацию последствий отказов и аварийных ситуаций.

Ключевые слова: надежность, оценка надежности, технические устройства, безопасность технических устройств, системные показатели, информационная база, отказ, авария, горные предприятия.

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On the issue of assessing the reliability of technical devices at mining enterprises

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Abstract: In order to control the current situation, prevent failures and emergencies by taking timely measures to ensure the safety of technical devices it is important to assess their reliability. The presented methodological approach to assessing the reliability of technical devices condition is based on obtaining a single comprehensive indicator that allows determining the degree of reliability of equipment and assess its condition in real time, as well as take into account the criticality of its failure for the main activities of the enterprise. It is proposed to divide the indicators collected by enterprises into three groups, First is identification. The second – operational, allowing to obtain current information and to consider other aspects of the impact not related to systemic impacts. The third one is system, reflecting the ability of the system to perform continuously its functions, taking into account the state of the technical device and the level of impact of its failure on critical areas of the enterprise. It is proposed to use the technical readiness coefficient, the wear index and the criticality index as system indicators of the reliability of technical devices. These indicators should be collected into a single information base, using a unified form for convenience, which allows one to quickly collect and structure information, eliminate its duplication and analyze and evaluate the reliability of technical devices. The use of such an approach will allow, based on the identification of key reliability indicators, to predict the state of reliability of technical devices, and will also help to make organizational and technical decisions aimed at improving reliability, preventing and minimizing the consequences of failures and emergencies.

Key words: reliability, reliability assessment, technical devices, safety of technical devices, system indicators, information base, failure, accident, mining enterprises.

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Introduction

Mining enterprises are currently undergoing reconstruction and technical re-equipment, obsolete technical devices are being replaced, new technologies and equipment are being introduced, implying minimal human participation in the production process, as well as monitoring systems that collect, transmit and visualize data on the operation of technical devices. In addition, there has been a tendency to replace worn-out and outdated mining equipment of foreign production with Russian analogues.

At the same time, there remains a large number of fixed assets operated after the expiration of the use period. Basically, these are large-sized permanently installed equipment operating from the moment of opening of the enterprise until its closure, maintained in good condition by upgrading control and parameter control systems (main ventilation fan installations, lifting installations, etc.). Figure 1 shows mining equipment operated according to Rostechnadzor after the expiration of the period of use (in percent).

Since insufficient financing remains a serious problem, the replacement of technical devices at mining and processing enterprises does not always occur quickly and in a time, which makes it difficult to ensure their safe operation. The repeatedly extended service life of mining equipment, the imperfection of the design of technical devices and malfunctions caused by the lack of timely repairs and technical inspections of mining transport and technical devices, lead, as the statistics of

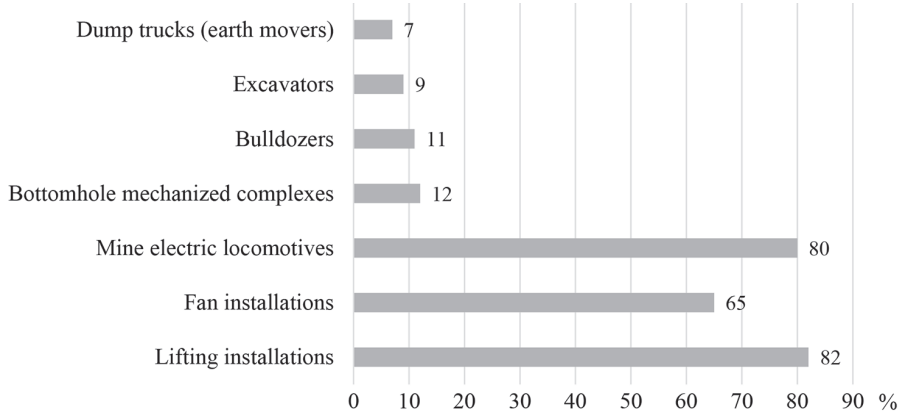

Fig. 1. Percentage of mining equipment operated after the expiration of the use period (Rostechnadzor data)
Рис. 1. Процент оборудования горной отрасли, эксплуатируемого по истечении срока использования (данные Ростехнадзора)

Rostechnadzor for 2020 — 2021 show, to a significant number of fatal injuries.

In this regard, it is important to assess the reliability of technical devices, focusing on which it is possible to quickly and in time develop the necessary measures to ensure safety [1, 2]. Understanding the existing problems and the severity of their consequences, the management of mining and processing enterprises is also interested in such an assessment.

Domestic and foreign experience in assessing the reliability of technical devices at mining enterprises shows that today there is no single methodological approach that allows for a comprehensive analysis and assessment of the reliability of technical devices [3 — 5]. The available methods consider individual reliability indicators and are based on the use of various criteria [6, 7]. The application in practice of various methods, differing in their approaches, does not allow for a comprehensive assessment of the reliability of technical devices and hinders the assessment of the reliability of the results obtained, as well as makes it difficult to make timely and objective decisions to prevent failures and emergencies.

It becomes urgent to develop a methodological approach to assessing the reliability of the technical condition of technical devices, based on obtaining a single comprehensive indicator that allows establishing the degree of reliability, monitor the current situation to prevent failures and emergencies. At the same time, it is especially important to choose such reliability indicators that allow assessing the condition of a technical device in real time and taking into account the criticality of its failure for the main activities of the enterprise [8 — 10].

Methodological approach to assessing the reliability of technical devices

According to State standard 27.301-95, reliability calculation refers to the procedure for determining the values of reliability indicators of a technical device using methods based on their calculation from reference data and data on the reliability of analog objects, as well as data on the properties of materials and other information available at the time of calculation.

The following methods of reliability assessment have found the greatest application in the mining industry [11 — 13]: computational, analytical, statistical, structural, expert, state function method, critical path method and simulation method [14, 15].

To assess the reliability of technical devices, it is necessary to determine the indicators identifying the objects under study, establish the nomenclature and the required values of reliability indicators, choose a calculation method adequate to the features of the objects, calculate the values of the necessary indicators and analyze the results obtained in order to make subsequent decisions. At the same time, it is necessary to create information and analytical support, which is one of the most important elements of the procedure for analyzing the level of reliability and technical safety.

The information database should consist of indicators set, regulatory and methodological documentation. At the same time, the information collected at the enterprise should be supplemented with data from other sources, for example, statistical information on the probability, frequency and intensity of failures. The use of such data by mining enterprises will allow for a priori and predictive assessments of the state of safety [16, 17]. It is important to form a database of reliability and safety indicators of technical devices not only within individual production units, but also for the enterprise as a whole.

The use of various types of monitoring in the process of forming information flows will allow systematically collecting and processing information necessary for the formation of an information database and subsequent management [18, 19]. The data obtained as a result of monitoring link the key subjects of management and therefore are the most important feedback tool [20, 21]. Timely and prompt identification of critical changes and making adjustments to the information base will improve the management process.

In the theory of reliability, such indicators as reliability, durability, maintainability and persistence are distinguished. In addition, there are complex reliability indicators — readiness coefficient, operational readiness coefficient, technical utilization coefficient, planned application coefficient, efficiency conservation coefficient, etc. [22].

Currently, mining and processing enterprises collect and analyze a large number of qualitative and quantitative indicators characterizing the technical condition and reliability of technical devices [23—25]. The number of indicators is in the hundreds, this is due, among other things, to the fact that a significant share of them falls on indicators describing equipment, its location, belonging to a specific division and the specifics of its accounting at the enterprise. In addition, the frequency and form of collecting indicators may differ in different branches and divisions of the enterprise. Some indicators assume an automatic system of their collection, others are recorded by employees in manual mode, which has a significant impact on the uncertainty of the result.

For large companies, a serious problem is the exchange of information between the parent organization and branches in terms of the speed and volume of incoming information, a different set of indicators for specific equipment, duplication of information in reporting forms, as well as the need for subsequent processing of this data. Such a large array of data is difficult for management to analyze and perceive, which is especially critical in conditions of lack of time and the need for rapid management decision-making [26—28]. In this regard, it is important to obtain a comprehensive reliability indicator that would allow visualizing the state of technical devices, seeing weaknesses in time, helping management to make the necessary decisions in a timely manner and correctly redistribute financial resources [29, 30].

The use of this indicator can become the basis for creating an effective system for predicting changes in the state of technical devices and serve as a key tool for

minimizing equipment downtime, increasing its service life and reducing the cost of its maintenance [31 – 33].

To assess the reliability of the technical condition of technical devices, it is proposed to use a methodological approach based on the use of a system of indicators. In such a system of indicators three groups can be distinguished:

- identification indicators;
- operational indicators;
- system indicators.

Identification indicators help to determine the location and characteristics of a specific technical device. Identification information can be obtained from design, technological, operational and repair documentation. Such indicators include: the name of the technical device, its code, status, factory, garage or inventory number, technical place, type, class, model / brand, manufacturer, etc. At large mining enterprises, as a rule, there is a wide variety of indicators identifying technical devices. At the same time, these indicators are often not consistent not only in the company as a whole, but also between its individual divisions. In this regard, the unification of these indicators throughout the company becomes an important task.

Operational indicators allow to get current information and make it possible to take into account other aspects of the impact on technical devices that are not related to systemic impacts. The main idea of the assessment is to determine the relative deviation of the main operating parameters of technical devices.

System indicators reflect the ability of the system to continuously perform its functions, taking into account the state of the technical device and the level of impact of its failure on critical areas of the enterprise.

The choice of reliability indicators is carried out taking into account the specifics of the functioning of a particular object. Reliability indicators should be simple and understandable, easily calculated and, if possible, verifiable. In addition, there should not be many such indicators, since a large number of them confuses and complicates the analysis. It should be limited to two or three indicators.

System indicators of reliability of technical devices

In large companies, the following key indicators are usually collected and determined to assess reliability:

- readiness factor (characterizes the readiness of a technical device for operation);
- average time between failures (characterizes uptime);
- the share of unplanned downtime in the total number of downtime due to a technical malfunction;
- average time between repairs (characterizes the continuity of the technical device between scheduled, unplanned and urgent repairs);
- wear index (loss of its properties by a technical device during use due to physical aging);
- total maintenance and repair costs (allows to track the economic component of repairs);
- unit maintenance and repair costs (allows to estimate the economic component of repairs, taking into account production volumes and operating time of the technical device);
- average time to restore equipment operability (characterizes the average recovery time after failure);
- criticality index (takes into account the impact of failure of a technical device on possible production losses, labor protection, industrial safety and the environment);
- equipment utilization factor (shows the degree of use of the technical device);
- actual equipment performance (allows to evaluate the effectiveness of the organi-

zation of production, maintenance and repairs).

Of the listed indicators, the readiness coefficient, the wear index and the criticality index are of the greatest interest from the point of view of reliability and safety. The remaining indicators reflect the effectiveness of the use of technical devices in time and cost terms, therefore, they are auxiliary in order to assess reliability.

Thus, it is proposed to use the availability coefficient, the wear index and the criticality index as system indicators of the reliability of technical devices. The characteristics of these indicators and the methods of their determination are given in Table.

The system indicators listed in the table, together with identification and operational indicators, can serve as a basis for determining a comprehensive indicator of the reliability of a technical device, on the basis of which it is possible to establish the degree of reliability and monitor the current situation in order to timely identify alarming symptoms of possible implementations of failures [34] and emergencies.

All these indicators should be collected into a single information base [35, 36], using a unified form for the convenience of collecting and analyzing information flows. Such a form will allow collecting information flows from different branches and divisions of the enterprise in a single format, avoiding a shortage or, conversely, duplication of data, and, consequently, will facilitate the perception, visualization and analysis of information. When collecting indicators, it is advisable to use the reporting already available at enterprises, which will help reduce the burden on per-

System reliability indicators of technical devices and methods of their determination
Системные показатели надежности технических устройств и способы их определения

The name of the indicator	**Characteristic of the indicator**	**Method of determination**
Readiness factor KR	The probability of finding a technical device in working condition at any time (not including planned periods during which the use of a technical device for its intended purpose is not provided)	The indicator is calculated using the formula: where TCF is the calendar fund of the time of the technical device, hour; TUR is the time of unplanned repairs (unplanned repair downtime), hour. As a rule, the frequency of calculation of the readiness coefficient is a year, a quarter or a month, and if it is necessary to calculate for several years, the coefficient is calculated as the arithmetic mean over the years.
Wear index KI	The percentage of deterioration of mechanical, physical, functional and other properties of the technical device in relation to the new one.	This indicator can be determined by various methods, for example, the observation method, the effective age method, the method of restoring a technical device after repair, the method of deterioration of the main parameter, etc. In the case of determining the wear index of a technical device by different methods, the worst (highest) index value should be selected.
Criticality Index KK	Category of technical device by criticality rank (1 — very high criticality rank, 2 — high rank, 3 — medium rank, 4 — low rank).	Criticality can be determined by the impact of failure of a technical device on: labor protection and industrial safety, negative impact on the environment, loss (need for replacement) of a technical device, impacts associated with production losses. The determination of the criticality index is based on a point-rating approach and expert assessments. When determining by different methods (expert or calculated), one should focus on the worst (smallest) value of the indicator.

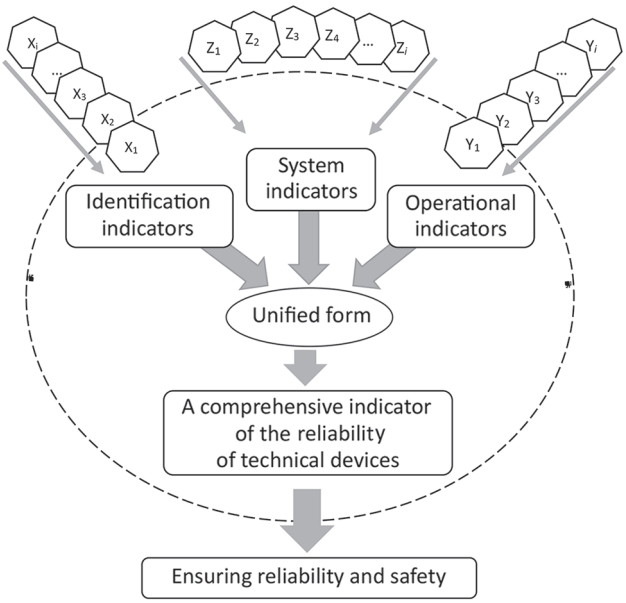

Fig. 2. The process of ensuring the reliability and safety of technical devices: X_i, Y_i, Z_i — input parameters of identification, operational and system indicators

Рис. 2. Процесс обеспечения надежности и безопасности технических устройств: X_i, Y_i, Z_i — входные параметры идентификационных, оперативных и системных показателей

sonnel and simplify the application of this methodology.

It should be noted that when establishing the degree of reliability and entering it into the form, both an operational analysis of the existing state of reliability of technical devices and a retrospective one are possible.

The process of ensuring the reliability and safety of technical devices is shown in Figure 2. It is assumed that, focusing on the value of a comprehensive safety indicator, determined on the basis of a system of indicators, it will be possible to develop targeted preventive measures to improve the reliability and safety of technical devices. The application of such a methodological approach to assessing the reliability of technical devices will help mining and processing enterprises to obtain significant benefits, since it will allow timely prevention of equipment failures, increase the level of safety and increase productivity [37].

Conclusion

Today, mining enterprises collect and analyze a large number of reliability indicators, which makes it difficult for management to perceive and analyze information, and, therefore, can not only increase the time for making management decisions, but also lead to incorrect decisions.

Assessing the reliability of technical devices at mining and processing enterprises is an urgent, but not an easy task, which does not have a unified methodological approach that allows analyzing and making decisions on improving the reliability and safety of technical devices based on a single integrated indicator.

In the proposed methodological approach the indicators, collected by enterprises, necessary for the subsequent determination of a comprehensive indicator of the reliability of technical devices and reliability assessment, are divided into three groups: indicators identifying the objects under study, indicators that allow obtain-

ing current information, and indicators reflecting the ability of the system to continuously perform its functions, taking into account the state of the technical device and the level of impact of its failure on critical areas of the company's activity.

There should not be many indicators, but they should be simple and understandable. It is proposed to use the technical readiness coefficient, the wear index and the criticality index as system indicators of the reliability of technical devices. It is convenient to collect indicators from different branches and divisions of the enterprise into a single information base using a unified form.

Taking into account the identified key reliability indicators of technical devices and their significance, the value of a comprehensive reliability indicator is determined, on the basis of which operational organizational and technical decisions are made aimed at improving the reliability of technical devices, preventing and minimizing the consequences of failures and emergencies.

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