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КОМПЛЕКСНАЯ ОЦЕНКА НАДЕЖНОСТИ ЗДАНИЙ, СООРУЖЕНИЙ И ТЕХНИЧЕСКИХ УСТРОЙСТВ ГОРНЫХ ПРЕДПРИЯТИЙ

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Аннотация: Приведена методология комплексной оценки надежности зданий и сооружений, технических устройств горных предприятий. Методология позволяет по первичным показателям, характеризующим техническое состояние производственных активов горных предприятий, проводить комплексную оценку надежности. На основании анализа нормативных документов и отчетных форм горных предприятий установлены показатели, характеризующие надежность. Большая часть показателей надежности относится к качественным характеристикам. Методом экспертных оценок выявлены наиболее значимые показатели: дефекты и повреждения, индекс износа, показатель режима работы и индекс критичности. Представлено обоснование методики оценки технической надежности зданий и сооружений, технических устройств на основе установленных зависимостей реализации отказов и аварийных ситуаций, связанных с показателями надежности. Предложенная методология поможет руководству горных предприятий осуществлять предиктивную аналитику, позволяющую организовывать управление производственными активами с наиболее рациональными капитальными вложениями при сохранении высокого уровня их надежности. Методология сводной отчетности о техническом состоянии основных фондов горных предприятий также включает в себя оценку степени технической надежности по промышленным активам.

Ключевые слова: надежность технических устройств, надежность зданий и сооружений, дефекты и повреждения, индекс износа, индекс критичности, коэффициент готовности.

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Comprehensive assessment of buildings, structures and technical devices reliability of mining enterprises

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Abstract: The article provides a methodology for a comprehensive assessment of the reliability of buildings, structures and technical devices of mining enterprises. The methodology allows carrying out a comprehensive reliability assessment based on primary indicators, characte rizing the technical condition of mining enterprises' production assets. Based on the analysis of regulatory documents and reporting forms of mining enterprises, indicators characterizing reliability have been established. Most of the reliability indicators relate to quality characteristics. By the method of expert assessments, the most significant indicators were identified: defects and damages, wear index, operating mode indicator and criticality index. The substantiation of the methodology for assessing the technical reliability of buildings, structures and technical devices based on the established dependencies of the implementation of failures and emergencies related to reliability indicators is presented. The proposed methodology will help the management of mining enterprises to carry out predictive analytics, which allows organizing the control of production assets with the most rational capital investments while maintaining a high level of reliability. The methodology of summary reporting on the technical condition of fixed assets of mining enterprises also includes an assessment of the degree of technical reliability of industrial assets.

Key words: reliability of technical devices, reliability of buildings and structures, defects and damages, wear index, criticality index, readiness coefficient.

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Introduction

The analysis of domestic and foreign experience in assessing the technical reliability of buildings, structures and technical devices of mining enterprises shows that currently there is no system of methodological documents that allows for a comprehensive analysis and assessment of technical reliability on an aggregate basis. The existing regulatory methodologies relate only to individual reliability indicators, use different criteria and do not allow for a comprehensive reliability assessment taking into account all reliability indicators [1—3]. The practical application of techniques that differ in their approaches makes it difficult to assess the reliability of the results obtained and make objective decisions to prevent failures and emergencies. Therefore, algorithmic support for calculations of technical reliability assessment should be based on the establishment of cause-and-effect relationships between the technical condition of buildings and structures, technical devices and ongoing measures to bring buildings, structures and technical devices into compliance [4, 5]. Based on the analysis of regulatory documents of mining enterprises, which include data on industrial asset management systems of companies, guidelines for managing the operational reliability of industrial assets, guidelines for managing maintenance and repairs and monitoring the operation of industrial assets, guidelines for assessing the criticality of industrial assets, guidelines for assessing the depreciation of industrial assets, as well as other internal standards and regulations of companies, analysis of universal reporting forms, identification reliability indicators [6—9], types of industrial assets and types of indicators (main or auxiliary) have been identified.

It should be noted that most reporting forms contain general information, inventory and factory numbers of technical devices, information on repair dates, responsible executors for repair and elimination of defects, as well as information on planned and preventive repairs and necessary material resources [10, 11]. In 30 per cent of the reporting forms, the information is repeated, in some forms the information presented is difficult to perceive and effectively analyze, contains many internal ciphers, which only confirms the relevance of developing a universal reporting form for assessing the technical reliability of buildings, structures and technical devices of mining enterprises.

From the currently provided reliability indicators for buildings and structures, it is necessary to identify the temperature profiles of soils for observation wells, the value of the depth of seasonal thawing, defects and damages, the nature of damage, data on the state of deformations and beacons [12—14], examination data and validity periods, the index of technical condition, wear, the regulatory frequency between major repairs, planned date of repair, duration of repair, etc. [15]. The following information is collected for technical devices: inventory and factory numbers, reliability data, failures, malfunctions, defects, etc. [16—18].

An analysis of the identified reliability indicators showed that about 18 per cents of reliability indicators are present in the reporting forms used by mining and processing companies. Most of the reliability indicators relate to the qualitative characteristics of reliability [19—21].

When developing a universal reporting form that allows collecting and processing information for further comprehensive assessment of the reliability of buildings, structures and technical devices, it is necessary to take into account the advantages and disadvantages of existing reporting forms. The universal reporting form should contain general information about the object of research, key reliability indicators

Table 1

Reliability indicators for buildings and structures
Показатели надежности для зданий и сооружений

No.	Reliability indicators	The value of the reliability indicator	Code	The coefficient of significance of the reliability indicator
1	Defects and damages	There are no defects or damages (the best option)	1	0,4
		Others	2	
		C	3	
		B	4	
		A (worst case scenario)	5	
2	Wear index	Less than 40% (the best option)	1	0,3
		40–80 %	2	
		More than 80% (worst case scenario)	3	
3	Indicator of the operating mode	Normal (the best option)	1	0,2
		Lowered	2	
		Unsatisfactory (worst case scenario)	3	
4	The criticality index	Low (the best option)	1	0,1
		Average	2	
		Very high and high (worst case scenario)	3	

that can be used to assess reliability in a timely manner, and secondary indicators [22, 23]. The information to be filled in in such a universal reporting form should be ranked by coal mines, mines, factories and other facilities for the convenience of conducting a comparative assessment between them. A universal reporting form will allow one to structure information on technical reliability and eliminate the "replication" of the same information on other forms of reporting. Thus, in the future, the reliability assessment will be more effective and organizational and technical solutions will be more operational.

The value of the integrated reliability indicator should also be recorded in a universal reporting form. Based on the value of the integrated reliability indicator, the degree of technical reliability should be established. It should be noted that when determining the degree of technical reliability and entering it into the form, an operational analysis of the existing state of technical reliability, as well as a retrospective analysis, is possible.

Methodology for assessing the technical reliability of buildings, structures and technical devices

The scientific significance of the conducted research lies in the substantiation of the structure and methodology for assessing the technical reliability of buildings, structures and technical devices based on the established dependencies of the implementation of failures and emergencies related to the reliability indicators presented in tables 1 and 2, which allows to prevent and minimize the consequences of failures and emergencies at mining enterprises.

The approach of obtaining normalizing coefficients characterizing the proportion (probability) of the most favorable situation, taken as a unit, is used as the basis for quantifying the reliability of buildings, structures and technical devices.

Table 2

Reliability indicators for technical devices
Показатели надежности для технических устройств

No.	Reliability indicators	The value of the reliability indicator	Code	The coefficient of significance of the reliability indicator
1	Readiness factor	1–0,99 (the best option)	1	0,4
		0,98–0,96	2	
		0,95–0,9	3	
		Less than 0,9 (worst case scenario)	4	
2	Wear index	Less than 40% (the best option)	1	0,3
		40–80%	2	
		More than 80% (worst case scenario)	3	
3	Indicator of the operating mode	Normal (the best option)	1	0,2
		Lowered	2	
		Unsatisfactory (worst case scenario)	3	
4	The criticality index	Low (the best option)	1	0,1
		Average	2	
		Very high and high (worst case scenario)	3	

When ranking indicators of reliability of buildings and structures, experts gave preference to indicators in the following order: defects and damage; wear index; operating mode indicator; criticality index.

The complex coefficient of reliability of buildings and structures is calculated using the formula:

$$K_{rsb} = \left(\varphi_d \cdot a_d + \varphi_w \cdot a_w + \right. \\ \left. + \varphi_{om} \cdot a_{om} + \varphi_{ci} \cdot a_{ci}\right) \cdot K_{0sb} \quad (1)$$

where φ_d — the coefficient of significance of the indicator "defects and damages"; a_d — the value of the indicator code "defects and damages"; φ_w — the coefficient of significance of the indicator "wear index";

Table 3

Values of the complex coefficient of reliability of buildings and structures
Значения комплексного коэффициента надежности зданий и сооружений

Code	K_{rsb}	Code	K_{rsb}	Code	K_{rsb}	Code	K_{rsb}	Code	K_{rsb}
1111	1,000	2111	0,80	3111	0,70	4111	0,60	5111	0,52
1112	0,98	2112	0,78	3112	0,68	4112	0,58	5112	0,50
1113	0,97	2113	0,77	3113	0,67	4113	0,57	5113	0,49
1121	0,95	2121	0,76	3121	0,65	4121	0,55	5121	0,47
1122	0,94	2122	0,74	3122	0,64	4122	0,54	5122	0,46
1123	0,92	2123	0,73	3123	0,62	4123	0,52	5123	0,44
1131	0,91	2131	0,72	3131	0,61	4131	0,51	5131	0,43
1132	0,89	2132	0,70	3132	0,59	4132	0,49	5132	0,41
1133	0,88	2133	0,69	3133	0,58	4133	0,48	5133	0,40
1211	0,86	2211	0,68	3211	0,56	4211	0,46	5211	0,38
1212	0,85	2212	0,67	3212	0,55	4212	0,45	5212	0,37
1213	0,83	2213	0,65	3213	0,53	4213	0,43	5213	0,35
1221	0,82	2221	0,64	3221	0,52	4221	0,42	5221	0,34
1222	0,80	2222	0,63	3222	0,50	4222	0,40	5222	0,32
1223	0,79	2223	0,61	3223	0,49	4223	0,39	5223	0,31
1231	0,77	2231	0,60	3231	0,47	4231	0,37	5231	0,29
1232	0,76	2232	0,59	3232	0,46	4232	0,36	5232	0,28
1233	0,74	2233	0,57	3233	0,44	4233	0,34	5233	0,26
1311	0,73	2311	0,56	3311	0,43	4311	0,33	5311	0,25
1312	0,71	2312	0,55	3312	0,41	4312	0,31	5312	0,23
1313	0,70	2313	0,54	3313	0,40	4313	0,30	5313	0,22
1321	0,68	2321	0,52	3321	0,38	4321	0,28	5321	0,20
1322	0,67	2322	0,51	3322	0,37	4322	0,27	5322	0,19
1323	0,65	2323	0,50	3323	0,35	4323	0,25	5323	0,17
1331	0,64	2331	0,48	3331	0,34	4331	0,24	5331	0,16
1332	0,62	2332	0,47	3332	0,32	4332	0,22	5332	0,14
1333	0,60	2333	0,45	3333	0,30	4333	0,20	5333	0,12

a_w — the value of the indicator code "wear index"; φ_{om} — the coefficient of significance of the operating mode indicator; a_{om} — the value of the operating mode indicator code; φ_{ci} — the coefficient of significance of the criticality index; a_{ci} — the value of the criticality index code; K_{0sb} — the normalizing multiplier.

When ranking the reliability indicators of technical devices, experts preferred the indicator "availability coefficient", in second place — the wear index, in third place — the indicator of the operating mode, in fourth place — the index of criticality. The complex reliability coefficient of technical devices is calculated using the formula:

Table 4

Values of the complex reliability coefficient of technical devices
Значения комплексного коэффициента надежности технических устройств

Code	K_{rtd}	Code	K_{rtd}	Code	K_{rtd}	Code	K_{rtd}
1111	1,00	2111	0,83	3111	0,65	4111	0,50
1112	0,98	2112	0,81	3112	0,63	4112	0,48
1113	0,97	2113	0,79	3113	0,62	4113	0,47
1121	0,96	2121	0,78	3121	0,60	4121	0,45
1122	0,94	2122	0,76	3122	0,59	4122	0,44
1123	0,93	2123	0,75	3123	0,57	4123	0,42
1131	0,92	2131	0,73	3131	0,56	4131	0,41
1132	0,90	2132	0,71	3132	0,54	4132	0,39
1133	0,89	2133	0,70	3133	0,53	4133	0,38
1211	0,88	2211	0,68	3211	0,51	4211	0,36
1212	0,87	2212	0,67	3212	0,50	4212	0,35
1213	0,85	2213	0,65	3213	0,48	4213	0,33
1221	0,84	2221	0,63	3221	0,47	4221	0,32
1222	0,83	2222	0,61	3222	0,45	4222	0,30
1223	0,81	2223	0,59	3223	0,44	4223	0,29
1231	0,80	2231	0,58	3231	0,42	4231	0,27
1232	0,79	2232	0,56	3232	0,41	4232	0,26
1233	0,77	2233	0,55	3233	0,39	4233	0,24
1311	0,76	2311	0,53	3311	0,38	4311	0,23
1312	0,75	2312	0,51	3312	0,36	4312	0,21
1313	0,74	2313	0,50	3313	0,35	4313	0,20
1321	0,72	2321	0,48	3321	0,33	4321	0,18
1322	0,71	2322	0,47	3322	0,32	4322	0,17
1323	0,70	2323	0,45	3323	0,30	4323	0,15
1331	0,68	2331	0,43	3331	0,29	4331	0,14
1332	0,67	2332	0,42	3332	0,27	4332	0,13
1333	0,65	2333	0,40	3333	0,25	4333	0,12

Table 5

Assessment of the degree of technical reliability of buildings and structures, technical devices of industrial assets

Оценка степени технической надежности зданий и сооружений, технических устройств промышленных активов

Degree of technical reliability	K_r
Normal level	⩾ 0,85
Lowered level	Less than 0.85, but not less than 0.7
Unsatisfactory level	Less than 0,7, but not less than 0,5
Emergency	< 0,5

$$K_{rsb} = \left(\varphi_{rk} \cdot a_{rk} + \varphi_w \cdot a_w + \varphi_{om} \cdot a_{om} + \varphi_{ci} \cdot a_{ci}\right) \cdot K_{0td} \quad (2)$$

where φ_{rk} — the coefficient of significance of the indicator "readiness coefficient"; a_{rk} — the value of the indicator code "readiness factor"; K_{0td} — the normalizing multiplier.

The indicators of the complex reliability coefficient, depending on the established code of reliability indicators, are shown in tables 1 and 2. The values of the complex reliability coefficient are obtained by the method of expert assessments.

Further, for each value of the complex reliability coefficient code, the values of the complex reliability coefficient of buildings and structures, technical devices were obtained (tables 3 and 4).

Based on the results obtained, the degree of reliability of buildings, structures and technical devices is determined and decisions are made to prevent and minimize failures and emergencies (Table 5).

Comprehensive assessment of the technical reliability of buildings, structures and technical devices by production associations (production units)

The degree of technical reliability for buildings and structures, technical devices is determined in accordance with the presented methodology for assessing the integrated reliability indicator.

In table 6, for each production unit of the considered production association, information on buildings, structures and technical devices is entered in accordance with their inventory number. A comprehensive reliability indicator is determined as a result of obtaining a specific group of codes in accordance with the data in tables 3 and 4.

Further, based on the obtained ratio of the number and degrees of technical reliability, the degree of technical reliability of the production association (production units) is determined (table 7) by the larg-

Table 6

A form for presenting the results of assessing the degree of technical reliability of buildings and structures, technical devices for production units

Форма для представления результатов оценки степени технической надежности зданий и сооружений, технических устройств для производственных единиц

Production units	Inventory number of the technical device / building and structure	Comprehensive reliability indicator	The degree of technical reliability of a technical device / building and structure

Table 7

Assessment of the degree of technical reliability by production association (production units)

Оценка степени технической надежности по производственным объединениям (производственным единицам)

Degree of technical reliability	The number of buildings and structures / technical devices of the total number of buildings and structures / technical devices, %
Normal	⩾ 85%
Lowered	Less than 85%, but mot less than 70%
Unsatisfactory	Less than 70%, but not less than 50%
Emergency	< 50%

est number of buildings, and structures, technical devices from the total number of buildings, structures and technical devices in production units, which may be in a normal, lowered, unsatisfactory degree of reliability or in an emergency situation.

When determining the degree of technical reliability by production association (production units), it is necessary to take into account:

- if the number of per cents matches at different levels of technical reliability, then the worst case scenario is accepted;
- if there is at least one building (structure) or technical device with a degree of technical reliability “emergency”, then the level of reliability for production associations (production units) is assumed to be a degree lower than the degree of technical reliability that has received the maximum number of per cents;
- if the number of objects in an emergency condition is more than 25%, then the degree of technical reliability is accepted as emergency.

In the future, based on the systematization and processing of data on the technical reliability of buildings, structures and technical devices, it is possible to determine what level of reliability each production unit belongs to according to the considered production association (table 8).

In a similar way, the degree of technical reliability is determined by the total number of buildings and structures of production units and technical devices of production units for each production association.

Depending on the obtained value of the technical reliability coefficient and the level of reliability for production associations (production units), it is recommended that those responsible submit to the management of production associations (production units) an action plan to

Table 8

A form for presenting the results of assessing the degree of technical reliability of buildings, structures and technical devices for several production units

Форма для представления результатов оценки степени технической надежности зданий и сооружений, технических устройств для нескольких производственных единиц

Production units	**The degree of technical reliability of the technical devices of the production unit**	**The degree of technical reliability of buildings and structures of the production unit**

increase the level of reliability and deadlines for the implementation of measures.

Conclusion

The developed methodology for assessing the technical reliability of buildings, structures and technical devices of mining enterprises is based on a quantitative assessment of the wholeness of defects and damages, the criticality index and the wear index, the readiness coefficient, as well as the operating mode, the construction of a gradation of factors characterizing, based on expert analysis, the proportion (probability) of the most favorable situations taken as a unit.

The consistency of expert opinions was assessed using the concordance coefficient.

The use of an algorithm for making organizational and technical decisions to increase the level of reliability allows increasing the level of reliability from unsatisfactory to lowered and normal, which helps to prevent and minimize the consequences of failures and emergencies. The algorithm provides for the differentiation of measures to improve the reliability of buildings, structures and technical devices, depending on the degree of technical reliability.

The technique makes it possible to predict the state of technical reliability. As a result of the forecast, the situation is monitored in order to timely identify the alarming symptoms of possible implementations of failures and emergencies.

The methodology of consolidated reporting on the technical condition of fixed assets of mining enterprises also includes an assessment of the degree of technical reliability of industrial assets, an assessment of the degree of reliability of technical devices of industrial assets, buildings and structures of industrial assets. The methodology allows predictive analytics, i.e., based on the available information obtained using descriptive and diagnostic analytics methods, to predict how events will develop further.

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