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RISK-FORMING FACTORS AND PROCESSES AT THE STAGES OF THE LIFE CYCLE OF HOISTING EQUIPMENT IN THE MINE VERTICAL SHAFTS

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Abstract. In the article, the authors discuss a risk oriented approach to monitoring and control of technical condition of the shaft hoisting complexes, which assumes the transition from the reactive principle of control to proactive, that is, from compensation for damage to the prevention of industrial injuries and accidents in mine shafts. Risk-forming factors at the stages of the life cycle (design, construction and operation) of the hoisting plant in vertical shafts and mines were determined. Technological, technical and evolutionary groups of risk factors, which are external or internal in relation to the shaft and its equipment, are considered. Anomalous changes in the properties of hoisting plant are revealed, which are formed as a result of its long-term operation. These include geometric, kinematic, physical-mechanical, dynamic, power and deforming anomalies. The main processes that lead to risk of failures of mechanical devices in shaft hoisting plant and emergency hazardous situations are considered. The of risk factors are classified by criteria of time, controllability and material damage values. A schematic diagram was built for relationships between the risk-forming factors and unfavorable events in a shaft hoisting system, which reflects the effect of risk factors on the probability of adverse events in the hoisting system, which allows to determine the risks of these events. It is shown that the main parameters that characterize the degree of emergency hazard of the "conveyance – shaft framework" systems are the strength margin of each load-carrying element of the shaft framework and margin for the engagement between the rigid guides of cage and guides of the shaft. Methods for calculating risk indicators during the operation of the "cage – shaft framework" systems in complex mining conditions were developed. The directions of the risk oriented approach to the control of shaft hoisting systems during mining operations are determined, the main of which are the real-time automated control of equipment parameters and identifying of risk for the key parameters by periodic or continuous monitoring with using specialized expert systems.

Keywords: shaft hoisting, shaft, shaft conveyance, shaft framework, risk forming factors.

Introduction. In recent years, in many countries around the world, the main mechanism for solving problems of occupational and industrial safety is a system based on risk assessment and management. Currently, in the conditions of Ukrainian mining enterprises, the safety control of technical condition of hoisting complexes is carried out in a reactive mode. As a rule, assemblies which are completely outworn and are in critical technical condition for a long time are repaired. The risk-oriented approach involves the transition from the reactive principle of control to the proactive, from compensation for damage to the prevention of occupational injuries and accidents in mine shafts.

Life cycle of the shaft hoisting systems consists of the stages of design, construction and operation of the shaft hoisting plant [1 - 3]. The operation of shaft hoisting systems for a long time in difficult conditions in the presence of uncertainties is characterized by appropriate types of risks. The versatility of the concept of risk is explained by a variety of factors that characterize both the characteristics of a particular activity and the specific features of the uncertainty in which this activity is carried out. Such factors are called risk-forming, understanding them as the essence of the processes or phenomena that contribute to the emergence of a particular type of risk and determine its nature.

The purpose of this work is:

- to identify risk-forming factors and processes at the stages of the life cycle of a hoisting plant in vertical shafts of mines and quarries;

- to classify risk factors and to build a schematic diagram of their relationship;
- to develop methods for calculating risk indicators in the operation of "cage-shaft framework " systems in complex mining conditions;
- to define directions of the risk-oriented approach concerning control of shaft hoisting systems during conducting mining operations.

Methods. Safety of operation of mine shafts at their long operation depends on set of characteristic risk-forming factors. Operation of vertical shafts of mines in the conditions of technogenic shift and rock movement is a source of technological group of risk-forming factors. The specifics of the modern heavy-duty hoisting plant operation is a source of technical risk factors. Increasing intensity of operation of shaft hoisting systems, together with the existing level of degradation of its main equipment, is a source of evolutionary risk factors [4].

The technological group includes factors that are external to the shaft and its equipment. These factors determine the degree of risk of loss of rock stability around the shaft during its long-term operation. Thus, the shear factor of the rocks around the shaft leads to local curvatures of the shaft walls. This, when effecting the props and guides of rigid equipment, leads to their deformation and weakening of the shaft laying, which creates dangerous situations during the movement of cage. For shafts with rope guides, such deformations often lead to impossibility to keep the cage within safe gaps from the walls of the curved shaft.

The technical group includes internal risk factors in relation to the shaft and its equipment. This is a factor of reduced value of the residual thickness of the metal structures in the shaft framework - reinforcement, pipelines, stairways, detachment of branches, etc. Its manifestation is associated with the action of external factor of the watercourse, and with a number of technical parameters of heavy-duty cages. The internal technical factor is also the residual strength of the elements of the shaft equipment - guides, props, cage, main and balancing ropes. It is determined mainly by technical parameters of hoisting plant operation and the level of complex operating loads acting on each assembly of the system.

The evolutionary group of factors primarily includes the inflow of water in the shaft, which is a mining and geological external risk-forming factor. When interacting with the atmosphere of the shaft, the inflow creates an aggressive corrosive environment, which corrodes metal structure of the shaft framework. The intensity of wear and corrosion of the shaft elements depends on the factors due to the influence of which degradation processes - corrosion and mechanical wear of shaft framework, changes in the mass and design of the cage - occur at long-term operation of the shaft hoisting plant.

At the stage of designing of mine shafts, the risk-forming situation is that the parameters of the system "conveyance – shaft framework" and speed diagrams are determined based on the criteria of dynamic stability, which do not take into account the possibility of parametric resonance between the adjacent sectors. Due to this error, there is a risk of conveyance destruction at the start. But, even if the system was designed with a sufficient margin for stability, due to degradation processes in the shaft, it falls into the zone of unstable oscillations of the resonant type, which is a source of accidents. Therefore, the mines are forced to slow down hoisting rate to escape the resonant-dangerous zone, due to which the mine is unable to work in the design modes. If the mine shaft does not enter the dangerous resonant zone, it falls into the zone of strength breaking due to wear, which causes the risk of destruction of conveyances in the process of their movement because of criterion of strength breaking of the guides and buntons.

During the long-term work in difficult mining, technical and geological conditions the basic operational parameters of the system "cage – shaft framework" in terms of operating hoists exceed design restrictions by 2-3 times, and the area of working surface of the guide sectors under reconstruction is reduced by 30% -50%. In such conditions, the increased wear of the main elements of the hoisting system, in combination with the violation of design values and inconsistencies in the operating parameters, cause an uncontrolled risk for the hoisting complex to transit from technical condition to emergency state.

Another design risk-forming factor is that all spans of the shaft framework are designed to work under the same load conditions and resistance to load from the cages and rocks around the shaft. However, over time, due to the above external factors, a significantly heterogeneous picture of the load-bearing capacity distribution in the elements of the shaft framework is formed along the depth of the shaft.

At the stage of construction of mine shafts risk factors are defects made during installation of the shaft framework, which lead to high loads, wear of framework and the risk of accidents. The dynamic interaction in the system "conveyance – shaft framework" can be characterized as a process that largely depends on the risk of defects during the construction work when the system operates outside the main area of resonance. But, even if during the construction of the framework in a new mine shaft the accuracy of installation works is observed, then later, in the process of shaft operation, gaps are disturbed, strength of framework elements and reliability of their attachment decreases and design parameters are changed under the influence of various factors.

In Ukrainian shafts that have served for more than 50 years, the main internal risk-forming factors that most affect the safety of hoisting are [3, 4]:

- profile of the system of the conveyance guides;
- wear of guides and props;
- shape of the diagram of the circumferential speed of the hoisting plant in the operating mode, in particular the presence of a polychromic pulsation of the speed relative to a given diagram;
- deceleration parameters when safety brake activates;
- imbalance of rope tension caused by deviations of radii of gutters on multi-rope pulleys and drawing of ropes;
- skew of the conveyance caused by the deviation of the centre of mass of the load from the axis of the conveyance or the imbalance of the tension of the ropes.

These processes are the main sources of increasing the risk of accidents during intensive operation of the system "conveyance – shaft framework".

Due to the technological and technical features of the shaft hoisting plants, risk factors often act simultaneously. Their negative impact can be summed up at any moment of the conveyance movement or in any part of the shaft, and then there is a "cumulative effect". As a result, there may be a spontaneous failure of mechanical elements of the system - shaft framework, conveyance or rope. The root causes of such accidents are the regularity and duration of negative impacts on individual assemblies of mechanical equipment, which occur due to unfavourable combinations of geometric parameters with the peculiarities of the power equipment.

Risk-forming factors at the stage of operation of shaft hoisting plant. According to the project, all spans of the shaft framework are designed to work under the same load conditions and at the same level to withstand the load from the conveyance and rocks around the shaft. However, during the life cycle of the shaft, from the moment of its construction till the moment of closing, the characteristics of the shaft framework undergo significant changes. During several years of operation, due to the impact of aggressive environments, rock shifts, increased dynamic loads on the shaft framework, scheduled or emergency repairs and other external risk factors, abnormal changes of hoisting plant properties occur along the depth of the shaft.

The geometric anomaly of the shaft framework along the depth of the shaft is formed due to changes in geometric parameters of the profiles of the guides along which the conveyance move. This is characterized by the following parameters: local deviations of the guide from the vertical, angles of incidence of guides, angles of rotation of the surface of the pair of guides, kinematic gaps in the pair "shoe-guide" in the frontal plane (mashing, disengagement), kinematic gaps in the pair "shoe-guide" in the lateral plane (disengagement). The kinematic anomaly is caused by the consequences of "jerks" of the conveyance at the working speed, especially when the safety brake is activated, in which there are strong horizontal strike of the conveyance against the guides. Repeating from cycle to cycle, they contribute to the accumulation of fatigue damage in the guides and buntons, formation of cracks in the welds, weakening of the guide attachment, loosening of the props in the back part of their attachment. Physical-mechanical anomaly is caused by a decrease in the residual strength of the shaft framework elements – guides and props.

With time, these factors affect the process of dynamic interaction of the conveyance with the shaft framework in each its span. The result is a dynamic anomaly of the shaft framework load along the depth of the shaft, which is characterized by two parameters - contact loads on the guides and dynamic strength margin for the guides and buntons. The result of the superposition of geometric and dynamic anomalies is an anomaly in the distribution of residual strength margin in guides and buntons along the depth of the shaft under the action of actual operating loads at a specific speed and load of the conveyance (strength anomaly).

As a result of the action of all these factors there is a deformation anomaly of shaft framework, which is characterized by excessive deflections of its elements.

Defects of underground shaft framework refer to the type of risk-forming factors leading to the greatest technical and economic consequences at work of shaft hoisting plant. There is certain interdependence in the occurrence and development of defects in different assemblies of hoisting plant, which is due to the branching of the system, energy and kinematic interaction of dynamic processes in its various sections connected in a single power chain. This leads to the following risks in the assemblies of the hoisting plant:

- failure of the assembly, the functionality of which is restored by repairing or replacing its individual functional and structural elements;
- failure of the assembly, the functionality of which is restored by replacing the assembly itself.

At the stage of operation of the shaft hoisting system, two main types of risk-forming modes are determined by the time criterion:

- explicit modes at which there is a spontaneous and rapid development of destruction of mechanical equipment, which sometimes occurs during fractions of a second;
- hidden modes, which are associated with the gradual development of micro-disorders which are accumulated in the assemblies of the equipment. When the number and nature of such failures approach a critical level, there is a spontaneous destruction of the assembly, which switches the situation to the type of explicit modes.

Explicit modes are usually monitored automatically in real time by issuing a command for emergency braking. But at the same time, the most severe consequences leading to destruction occur as a result of the development of explicit modes, which are realized due to defects of the emergency brake - a decrease in speed and increase of braking torque parameters [5].

Hidden modes and the degree of their approach to the critical level are controlled by periodic inspections of equipment. If the time between two consecutive inspections exceeds the time for which the system will pass the critical level, this leads to the risk of unforeseen accidental destruction of the system. The transition from hidden to explicit mode means the risk of pre-failure state of the system. According to the severity of the consequences and the duration of their elimination, explicit modes prevail over hidden ones. However, the technical causes of accidents mainly lie in the plane of hidden modes.

According to the criterion of controllability, i.e. by possibility to intervene in the process at an early stage of its development, explicit modes are divided into automatically controlled and uncontrolled. Explicit controlled modes usually cause moderate consequences, and uncontrolled modes entail the most severe consequences. All hidden modes refer to the type of controlled by periodic monitoring followed by minor repairs or preventive repairs. Thus, the most severe damage is caused by explicit uncontrolled emergency modes, less severe damage – by explicit controlled mode, and hidden controlled emergency modes, which are early detected during operation, lead to only minor destruction of equipment parts.

Risk-forming factors in the operation of shaft hoisting plant by the criterion of the amount of material damage from the action of this factor:

a) risk factors that cause minimal damage:

- failures and errors in the electric drive system, at which it is necessary to carry out repair work in the electrical system;

- reduction of pressure in cylinders of safety brake and in a network of an air duct that leads to spontaneous braking of the plant;

b) risk factors that cause the moderate loss:

- overtravel of the cage, which leads to its strike against structural elements of the headframe and to the destruction of the conveyance;

- exceeding the normal speed by 15%, which leads to increased speed of the conveyance approach to the extreme position in the headframe or dib hole and the destruction of their structures and conveyance itself;

- the approach of the conveyance to the upper position at a speed more than 1,5 m/s, which causes increased dynamic loads on metal structures of the headframe and the conveyance at collision and their destruction;

- reverse motion of conveyance at a speed of less than 0,5 m/s, which leads to a collision of the conveyance with the shock absorbers and their local destruction;

- breaking of transmission between the shaft of the hoisting plant and the pulse sensors measuring the path and speed, which leads to exceeding the allowable speed of approach of the conveyance to one of the end positions and collision followed with destruction of safety devices;

- exceeding of allowable idling time and the operation of emergency brake, which causes the destruction of the catchers at the end points of the cage travel;

- dragging of the balancing rope loop by the conveyance due to wedging of the swivel and cross-section of branches;

c) risk factors that cause maximum damage:

- constant collision of the conveyance with the guides in one and the same section of the shaft in an intense vibroimpact mode with regular alternating dynamic loads, which leads to sudden destruction of the shaft framework and guides;

- sagging of the string and the overhang of the rope when the conveyance hangs, which leads to the destruction of the guides and framework of the shaft;

- slippage of the rope on the friction pulley when the conveyance is stuck in the guides, which causes the destruction of the guides and the conveyance;

- wear of the main and balancing ropes, which leads to their sudden destruction;

- corrosion and mechanical wear of guides and buntons, which leads to the loss of their cross-section and reduction of bearing capacity to the emergency level.

Thus, shaft hoisting plants are complex multi-sectional, high-speed electromechanical systems of great spatial length. All dynamic processes that occur during their work are interconnected and have the property of a strong relationship and cumulative increase in risk-forming phenomena in the systems " conveyance - shaft framework ". The cumulative effect significantly increases the risk of an emergency situation when the cages interact with the shaft guides in conditions of wear due to the long-term operation. The main sources of operational risks are the " conveyance – shaft framework " systems, which are located in the underground part of the hoisting complex and operate in an aggressive mine environment under significant vibroimpact loads. Destruction of the shaft framework during the operation of conveyance, which often leads to their breaking off and falling into the shaft, is the most severe of all types of accidents that occur in the shaft hoisting system.

Results and discussion. The risk of an adverse event in the shaft hoisting system due to the influence of risk-forming factors (RF) is determined by the formula:

$$R = P(x) \cdot D(x), \tag{1}$$

where: x is an adverse accident (A) or emergency events (EE) in the shaft hoisting system, *P (x)* is the probability of occurrence of this event depending on the influence of external (ERF) and/or internal (IRF) risk factors, *D (x)* - material damage from this event.

Risk is a two-dimensional characteristic of an event, so for its adequate assessment it is necessary to fulfil two groups of tasks for the shaft hoisting system: to determine a probability of specific emergency or accident-hazardous situation as a technical event or mode of shaft hoisting and to assess material damage from its occurrence.

The schematic diagram of the relationship between the risk factors and adverse events in the system of shaft hoisting is shown in Fig. 1.

This diagram illustrates the influence of risk factors (RF) on probability of adverse events (AE) occurrence in the shaft hoisting system, which allows to determine the risks (Rij) of such events by using formula (1). Adverse emergency events (EE) in the shaft hoisting system include the destruction of elements of hoisting plant – shaft framework, ropes, cages, etc. Adverse accident-hazardous events (EE) include failures of hoisting plant assemblies, the accumulation of which leads to the risk of accidents (A).

According to the scheme shown in Fig. 1, the following types of risks Rij should be assessed in the system of shaft hoisting system:

- risks R_{12} of transition of external risk-forming factors to internal ones;
- risks R_{13} and R_{23} of failures as dangerous events;
- risks of R_{14}, R_{24} and R_{34} of damage as accidents.

All anomalous changes are internal risk-forming factors at the stage of operation of the shaft hoisting plant, which cause the risk of reducing the bearing capacity of the elements of the shaft framework to an emergency level. And, as the cage consistently travels through all sections of the shaft, destruction of any bearing element of the shaft framework, disengagement of conveyance even in a short site (and other failures or accident-dangerous events, fig. 1) inevitably lead to serious accidents and great destructions (emergency events, Fig. 1).

The main parameters that characterize the degree of accident-hazardous systems " conveyance – shaft framework" are the strength margin of each of the load-bearing elements of the shaft framework and the margin for engagement between the rigid guides of conveyance and guides of the shaft.

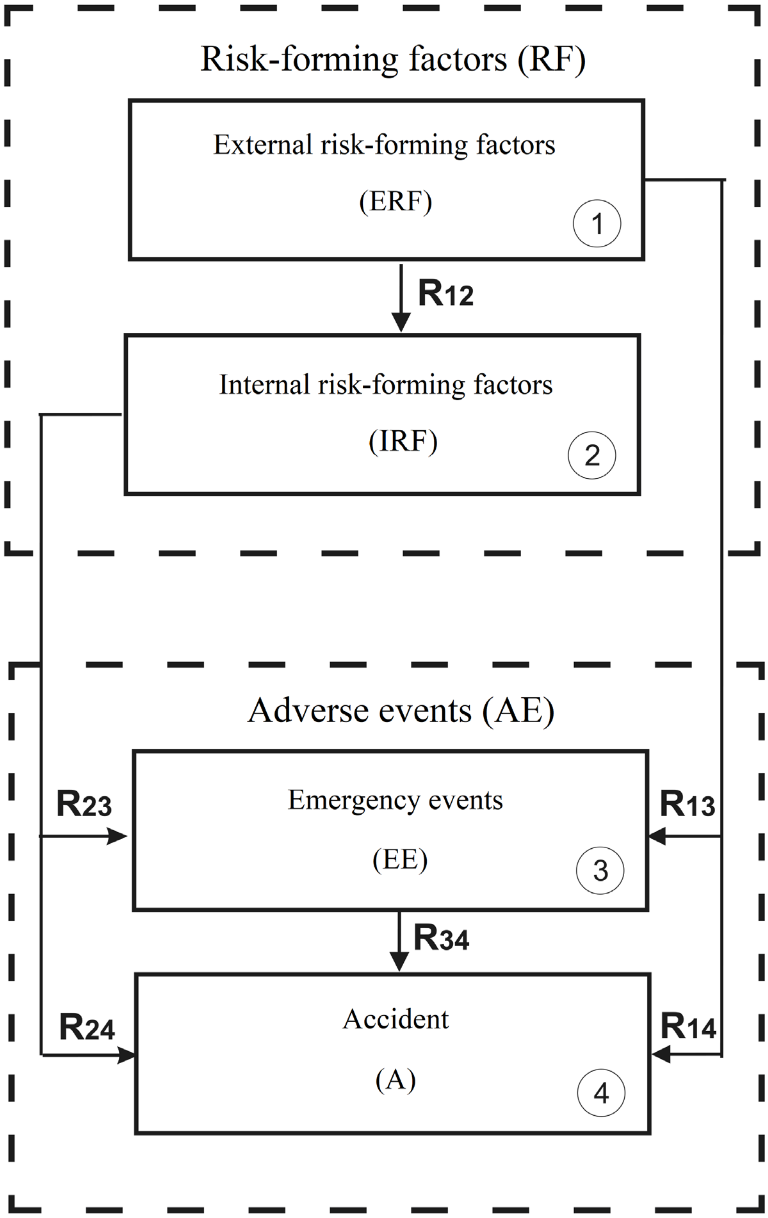


Figure 1 - Scheme of the relationship of risk factors and adverse events in the shaft hoisting system

The technical condition of each guide and prop in the shaft by their strength margin is divided into three levels:

- accident-hazardous level, at which the actual strength margin n_{fact} is less than the maximum allowable under the condition of destruction of $n_{авар}$;

- potentially dangerous level, at which the actual strength margin n_{fact} is greater than the maximum allowable under the condition of destruction of $n_{авар}$, but less than the limit of endurance under the action of alternating shock-dynamic loads n_{with};

- safe level, at which the actual strength margin n_{fact} is greater than the endurance limit under the action of alternating shock-dynamic loads n_{with}.

The risk parameter R_{pr} should vary from 0% (at $n_{fact} > n_{with}$) to 100% (at $n_{fact} < n_{av}$). Given the inversely proportional nature of the relationship between $R_{pr}(n_{fact})$ and strength margin, we obtain the following formula:

$$R_{pr}(n_{fact}) = \frac{n_{with} - n_{fact}}{n_{with} - n_{av}} \cdot 100\% \ , \tag{2}$$

where: n_{fact} - is actual strength margin; n_{av} - is maximum allowable strength margin under the condition of failure; n_{with} - is endurance limit under the action of alternating shock-dynamic loads.

Another risk factor for accidents during the conveyance movement is engagement of the conveyance guides with the guide system of the shaft section. For the conveyance – shaft framework systems with opposite guides, the conveyance may disengage without breaking the guide or the prop. For this, it is enough that the sum of the dynamic deflection of one of the guides and the static width of the track in the frontal plane of the guides becomes greater than the full width of the conveyance with the side edges of the slip shoes.

Similar to the strength margin, this process is characterized by the parameter "margin for engagement", which determines the degree of the side edges of the slide shoes overlapping the side faces of the guides of both rail and box types. If these parameters are equal, then the margin for engagement $nz_{av} = 0$, and the risk parameter of engagement $Rz_{av} = 100\%$. It is impossible to increase the degree of engagement by constructive increase of the shoe throat depth (height of shoe ribs) to more than a certain limit, which is set by the distance between the assemblies of the guide attachment to the bunton, which are protruded into the track guides of shoe edges.

For each specific design of the system "conveyance -shoes-assemblies of attachment-buntons" there is a maximum allowable value of mutual overlap of the guides of the shoes (depth of the throat of the shoes), which provides the value of the margin for engagement, at which the risk parameter $Rz_{with} = 0\%$. In this case, due to wear of the shoes and guides, the degree of engagement changes quickly enough during operation, as friction shoes are worn within 1-2 weeks at intensive hoisting.

Let’s find the relationship between the margin for engagement and the magnitude of the overlap of the edges of the shoes on the side surfaces of the guides. We introduce the dimensionless parameter "margin for engagement" nz_{fact} by the formula:

$$nz_{fact}(Z_{fact}) = \frac{Z_{fact} - Z_{av}}{Z_{with}}, \tag{3}$$

where: Z_{fact} - is maximum actual (in the process of dynamic interaction) overlap of the guide by the side edge of the slide shoe; Z_{av} - accident-hazardous (minimum allowable) overlap of the guide by the edge of the slide shoe; Z_{with} - safe (maximum allowable) overlap of the guide by the edge of the slide shoe.

When $Z_{fact} = Z_{av}$ we have:

$$nz_{fact}(Z_{av}) = nz_{av} = 0. \tag{4}$$

When $Z_{fact} = Z_{with}$ we have:

$$nz_{fact}(Z_{with}) = nz_{with} = \frac{Z_{with} - Z_{av}}{Z_{with}} \tag{5}$$

The risk parameter $RZ(nz_{fact})$ should vary from 0% (at $nz_{fact} = nz_{with}$) to 100% (at $nz_{fact} = nz_{with}$). Given the inversely proportional nature of the relationship between $RZ(nz_{fact})$ and the margin for engagement similar to (1) we obtain the following formula:

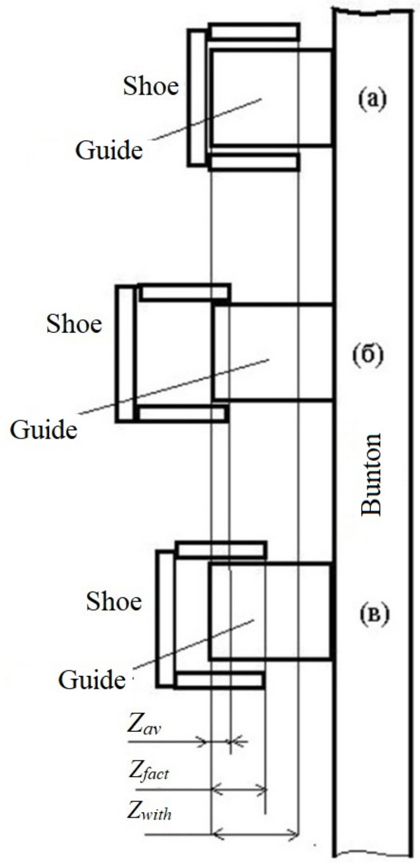
$$RZ(nz_{fact}) = \frac{nz_{with} - nz_{fact}}{nz_{with} - nz_{av}} \cdot 100\% \tag{6}$$

In this formula, the parameter nz_{with} is calculated by formula (5). The parameter Z_{with} is determined with taking into account the normalized gap between the edge of the shoe and the assembly of the guide attachment to the prop (or the prop itself, depending on the design of the attachment), the depth of the shoe throat. Parameter Z_{av} is determined with taking into account the frontal dynamic deflection of the guide, the static track width, the shape of the cross-section of the guide and the current lateral dynamic loads.

In fig. 2, a kinematic diagram of the system "shoe – guide - prop" is shown which illustrates the cases of completely safe engagement and incomplete emergency-dangerous engagement [3].

During the expert examination, the risk parameter R_{pr} should be determined by a special method for each of the guides and bearing props along the entire depth of the shaft under the action of operational dynamic loads from the conveyance. As there are several hundred spans of equipment in each shaft consisting of 5-7 beams of props and 8-12 adjacent spans of guides, this work assumes a significant amount of mine measurements, which are performed directly from the observation decks of conveyance for a long time by manual measuring devices.

As data of expert surveys show, the interval of change n_{fact} for individual elements of shaft framework usually lies in the range from 1.1 to 3.0 - 5.0 depending on the degree of wear of the shaft framework and the level of actual loads. Assuming that $n_{av} = 1.0$, and $n_{with} = 2.15$ we obtain a graph of dependence (Fig. 3).



a) - complete safe engagement; b) - incomplete emergency-dangerous gearing; c) - actual gearing

Figure 2 - Kinematic diagram of the system "shoe – guide - prop"

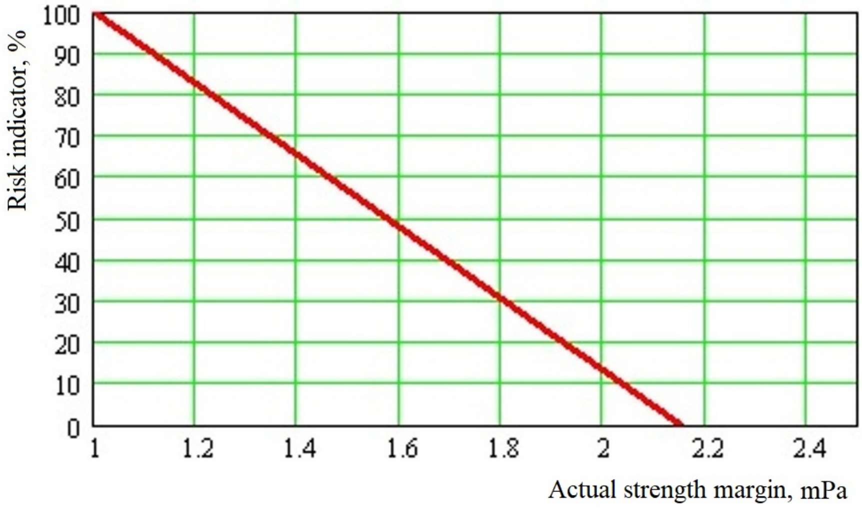


Figure 3 - Dependence of the risk indicator on the actual strength margin of the shaft framework element

The graph of function (6) is similar in shape to the graph in Fig. 2, however, the angle of its inclination will be determined by specific values of the parameters Z_{av} and Z_{with}, individual for each system "cage – shaft framework".

After determining risk indicators for each element of the shaft framework there is a problem of determining the generalized risk parameter $R_{pr,com}$ to each cargo compartment as a whole, depending on the distribution of values of R_{pr} parameters along the depth of the shaft and cross-section of its spans. While solving this problem, it is necessary to proceed from physical essence of the process of interaction of the cage with the shaft framework at its moving along the shaft.

Spans of the shaft framework with adjacent guide spans are a system of bearing and guiding elements sequentially installed along the depth of the shaft. The conveyance at each moment of time contacts by its slide guides with only one concrete cross-section of guides, being in continuous engagement with them. The destruction of at least one of the spans of any guide immediately disengages the conveyance and leads to the destruction of a large area of shaft framework due to a great reserve of kinetic energy during the conveyance descent or ascent, creates a shock load on the rope often leading to its break and conveyance fall into the shaft.

This means that the generalized risk indicator by the strength criterion for the cargo compartment as a whole should be determined by minimum value of all load-bearing elements for which the examination was conducted, as the destruction of any of them inevitably leads to an accident throughout the shaft.

Conclusions. The main directions of the risk-oriented approach to the control of shaft hoisting systems are the automated control of equipment parameters in real time and the identification of risks of key parameters according to data of periodic or continuous monitoring by using specialized expert systems.

When assessing the dynamic state of " conveyance – shaft framework " systems in modern conditions, it is necessary to apply a comprehensive approach, which, firstly, determines the presence or absence of dangerous processes of resonant excitation in the system, and secondly, determines the presence of risk factors contributing to uncontrolled accumulation of degradation disturbances in the main bearing elements of the equipment in pre-resonant modes. For this, in addition to the known methods of calculation by modelling, development of new methods and tools is required for determining and evaluating the qualitative and quantitative characteristics of dynamic loads on the shaft framework at continuous operation with focus on achievements of modern electronics and computer facilities for measuring and processing information in real time mode [6, 7].

At expert inspection of a shaft in modern conditions it is necessary not only to determine admissible speeds of conveyance at critical excitation in long sections of a shaft, but also to consider capability of shaft framework to resist shock dynamic load at actual wear during corresponding time of operation on separate spans of guides and props. The purpose of the application of these tools should be to obtain multi-statistical address information along the depth of the shaft in terms of level of dynamic tension of the guides and props in each of the spans of the shaft framework for a certain period of operation.

To determine the level of risks for the operation of shaft hoisting plant, it is necessary:

- to determine loss of cross-section of guides and props along the depth of the shaft by method of instrumental measurements, and, by the method of comparative analysis, to determine the rate of loss of cross-section of guides and props in sections of the shaft and to identify areas in the shaft with the maximum value of the rate of loss of cross-section;
- to perform statistical analysis of the smooth rotation of the drum of the hoisting plant by a series of cycles by the method of instrumental measurements and mathematical analysis, to identify excitation factors from the electric drive impacted on dynamic tension of supporting ropes, to determine their amplitude-frequency characteristics;
- to determine parameters of curvature of the guide profiles along the depth of the shaft on each span of the shaft framework by the method of instrumental measurements. To identify areas with violation of regulatory limits by the parameters of the curvature of the guides by the method of mathematical processing
- to determine parameters of smoothness of horizontal interaction of the conveyance with the guides of the shaft framework along the depth of the shaft by the method of instrumental measurements on a series of cage test passages at operating speed with its variations downwards to 5-6 m/s;
- to determine informative parameters that characterize the level of emergency risk of destruction of shaft framework and conveyance by the method of mathematical processing. For hoisting plants operating with a speed of 5 m/s and less, the estimated values of dynamic loads should be determined by the method of mathematical modelling;
- to perform the calculation of risk by the method of mathematical modelling for each of the informative parameters determined by the methods of instrumental measurements and mathematical processing.

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РИЗИКУТВОРЮЮЧІ ФАКТОРИ ТА ПРОЦЕСИ НА ЕТАПАХ ЖИТТЄВОГО ЦИКЛУ ПІДЙОМНИХ УСТАТКУВАНЬ ВЕРТИКАЛЬНИХ ШАХТНИХ СТОВБУРІВ

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Анотація. В статті розглянуті питання ризик-орієнтованого підходу щодо контролю та керування технічним станом обладнання шахтних підйомних комплексів, який передбачає перехід від реактивного принципу управління до проактивного, тобто від компенсації завданої шкоди до профілактики виробничого травматизму та аварій в шахтних стовбурах. Виявлено ризикутворюючі фактори на етапах життєвого циклу (проектування, будівництва та експлуатації) підйомних устаткувань вертикальних стовбурів шахт та рудників. Розглянуті технологічні, технічні та еволюційні групи факторів ризику, які є зовнішніми або внутрішніми по відношенню до стовбура і його обладнання. Виявлені аномальні зміни властивостей підйомного обладнання, які утворюються внаслідок тривалої експлуатації підйому. До них відносяться геометрична, кінематична, фізико-механічна, динамічна, міцністна та деформаційна аномалії. Розглянуті основні процеси, що призводять до ризиків виникнення збоїв в механічному обладнанні шахтних підйомних устаткувань та до аварійно небезпечних ситуацій. Проведено класифікацію факторів ризику за критеріями часу, керованості, величини матеріальних збитків. Розроблена принципова схема взаємозв'язку ризикутворюючих факторів і несприятливих подій в системі шахтного підйому, яка відображає вплив ризикутворюючих факторів на вірогідність несприятливих подій в системі шахтного підйому, що дозволяє визначати ризики виникнення таких подій. Показано, що основними параметрами, які характеризують ступінь аварійно небезпечних систем «підйомна посудина-армування» є запаси міцності кожного з несучих елементів армування в стовбурі та запаси по зачепленню між жорсткими напрямними підйомних посудин і провідниками. Розроблені методи розрахунку показників ризику при експлуатації систем «посудина – армування» в складних гірничотехнічних умовах. Визначено напрямки ризик-орієнтованого підходу щодо керування системами шахтного підйому під час ведення гірничих робіт, основні з яких полягають в автоматизованому контролі параметрів устаткувань в режимі реального часу та в ідентифікації ризиків ключових параметрів за даними періодичного або постійного моніторингу за допомогою спеціалізованих експертних систем.

Ключові слова: шахтний підйом, стовбури, посудина, армування, ризикутворюючі фактори.

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