УДК 622.673.1

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INFLUENCE OF DYNAMIC PROCESSES IN MINE HOISTS ON SAFETY OF EXPLOITATION OF SHAFTS WITH BROKEN GEOMETRY

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ВПЛИВ ДИНАМІЧНИХ ПРОЦЕСІВ У ШАХТНИХ ПІДЙОМНИХ УСТАНОВКАХ НА БЕЗПЕКУ ЕКСПЛУАТАЦІЇ СТВОЛІВ З ПОРУШЕНОЮ ГЕОМЕТРІЄЮ

Purpose. The substantiation of diagnostics methodology for technical state of reinforcement in vertical shafts with broken geometry and renewal of the exploitation safety of mine winding plants.

Methodology. Relationship between parameters technical state of the system elements and parameters of exploitation safety of mine winding plants is established. Methods of instrumental measurement and calculation of the system diagnostics parameters are substantiated.

Findings. The methods of choosing maintenance and repair operations and correcting operating parameters of system elements, providing safe exploitation of mine winding plants in shafts with broken geometry in the specified technological modes, are grounded.

Originality. The article specifies the dependence of dynamic parameters which determine the risk of emergency danger on the parameters of the technical state of separate links of winding plant In the article on the base of complex research studies, regarding the structure of the mine winding plant as an iterative, multimass discrete-continual system with plural deviations of operating parameters from the legitimate project values. On the base of findings the methodology of the instrumental diagnostics of the system in the operating mode and the emergency braking mode, as well as methods of reducing emergency danger level while increasing the plant work intensity are grounded.

Practical value. The methods of apparatus control and determination of diagnostic parameters of winding plants under production conditions, methods of targeted choice of repair operations providing transition of plants from the potentially dangerous operating state into safe technical state are grounded.

Keywords: *mine winding plant, mine shaft, mine lifting vessel, diagnostics of mine shaft reinforcement, mine shaft reinforcement, dynamics of mine hoist plants*

Introduction. Nowadays technical condition of mine winding plants of Ukrainian and CIS mining enterprises have entered the stage when their further operation in the design modes either is not possible at all, or is a source of increasing emergency danger due to being deteriorated up to 50 %. Depth of the main rock shafts in Ukraine has already passed 1500 m level. However, due to the lack of sufficient funds for restoration and repair of the operative equipment they are operated within the reduced capacity, or within the increasing emergency danger. Such situation has resulted in the fact that in many cases shafts became a bottle neck in a transport chain of the mining enterprises.

During last decades there has been a sharp reduction of fund allocations for maintaining the working condition of the equipment. The underground part of hoisting complexes is exposed to severe wearing out and increasing damages under the influence of hostile mine environment, displacement of rocks, great dynamic loadings. Such a situation have resulted in decreasing mine productivity everywhere by 2–3 times with hoisting speeds reduced from 14 m/s designed to 5–7 m/s according to the criteria of emergency for technical condition of the equipment.

Due to the situation in the market of the mining enterprise production, recent years have seen a steady tendency of necessity of re-introducing design operating modes. However, fulfillment of these requirements is almost impossible because of huge capital expenditure on a complete recovery of the mine shafts hoisting equipment.

Under such conditions the way out of the situation described is to develop the methodology of the ruled transition of the hoisting equipment from the multidefective technical state, which allows operation at the lowered speeds only and requires permanent repairs to avoid emergences, to the operational condition which allows safe working in the design modes.

Statement of the problem. Mine winding plant is considered as being the multipart, multimass discrete and continual dynamic system. It has multiple deviations of working parameters from admissible design values at the stage of long-term operation under difficult geological and mining conditions.

Based on establishing relationship between the system operating and physical-and-mechanical parameters of separate links, it is necessary to determine the parameters which affect risks of emergencies during the hoisting, to prove methods of instrumental diagnostics of the system in every technologically possible mode and methods of calculating corrective action parameters which provide transfer of the system in a safe operating state.

The complex mathematical model describing the interconnected dynamic processes in the "hoisting machine – ropes – lifting vessels – roller directors – reinforcement" system which allows defining necessary dependences is described in the article [1].

Results of the research. Instrumental tests provide unbiased data on dynamic behaviour of the system "vessel – reinforcement" regarding the depth of a shaft. Tests are carried out during the series of diagnostic descent – load lifting in operating modes and in emergency braking mode in the set points of a shaft. Such tests are carried out according to the special scheme including a variation in speeds of the vessel movement and its loading combined with geometrical measurements of parameters of guide profiles. The equipment layout during the tests and the registered parameters are given in Fig. 1.

The diagnostics scheme for the system "vessel –reinforcement" with application of instrumental dynamic tests and deformation and strength calculations is given in Fig. 2. The particular feature of this method is

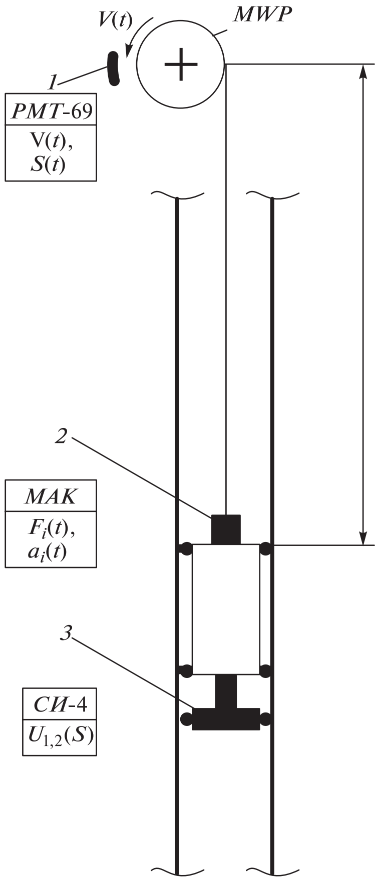
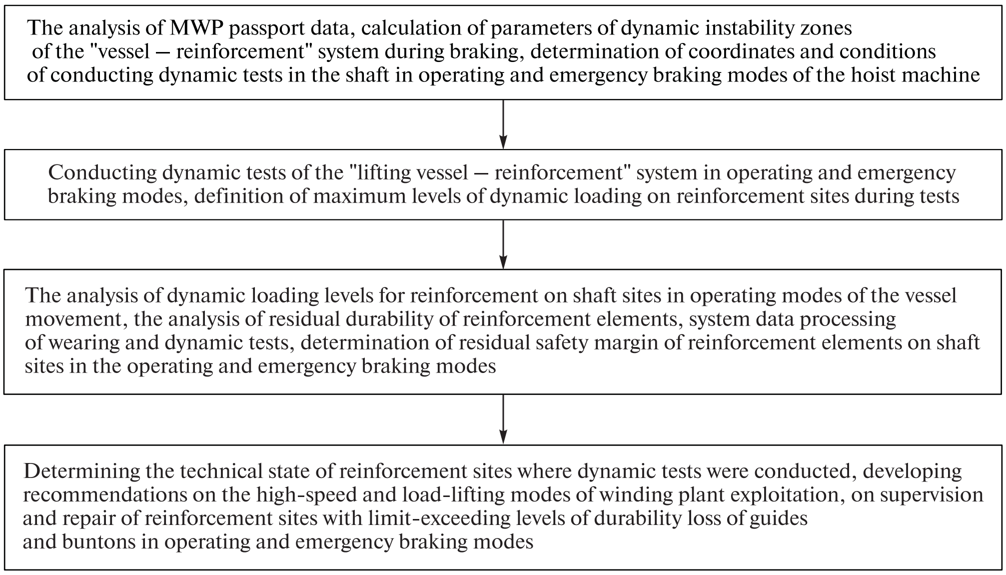


Fig. 1. The scheme of measuring dynamic and geometrical parameters of the system "hoisting machine – vessel – reinforcement":

1 – registration equipment of rotation parameters of hoisting machine drum (V(t) is rotation speed, S(t) is the coordinate of head vessel); 2 – registration equipment for dynamic parameters of interaction of vessel with guides ($F_i(t)$ is contact force in protective runner, $a_i(t)$ is vibroshock accelerations of protective runners); 3 –surveying equipment for measuring deviations of conductor profiles from vertical U1,2(S)



The analysis of MWP passport data, calculation of parameters of dynamic instability zones of the "vessel – reinforcement" system during braking, determination of coordinates and conditions of conducting dynamic tests in the shaft in operating and emergency braking modes of the hoist machine

Conducting dynamic tests of the "lifting vessel – reinforcement" system in operating and emergency braking modes, definition of maximum levels of dynamic loading on reinforcement sites during tests

The analysis of dynamic loading levels for reinforcement on shaft sites in operating modes of the vessel movement, the analysis of residual durability of reinforcement elements, system data processing of wearing and dynamic tests, determination of residual safety margin of reinforcement elements on shaft sites in the operating and emergency braking modes

Determining the technical state of reinforcement sites where dynamic tests were conducted, developing recommendations on the high-speed and load-lifting modes of winding plant exploitation, on supervision and repair of reinforcement sites with limit-exceeding levels of durability loss of guides and buntons in operating and emergency braking modes

Fig. 2. Scheme of diagnostics making of the system "lifting vessel – reinforcement"

that dynamic tests of the "lifting vessel – reinforcement" system are carried out on a series of operating cycles of vessel hoisting according to the special program and tests in the mode of emergency braking. The values of dynamic overload coefficients of reinforcement on each horizon are received as a result of data processing of the tests and are accepted as the main diagnostic parameters for assessment of technical condition of guides and buntons on the section with increased level of wearing.

The greatest dynamic loadings are experienced by reinforcement at activation of emergency braking of a hoisting machine on the section with the maximum speed movement, which can occur on a signal of any chain of hoist protection should there be any accident threat (real or false). Such activation can occur at any point of a shaft. In this regard, to obtain reliable data on behaviour of specific lifting vessel while interacting with reinforcement, it is expedient to conduct testing with instrumental measurements of dynamic parameters of lifting vessels and the drum of a hoisting machine on the sections located at control points of the top-end, middle and lower parts of a shaft. These experiments should be done during descent and raising of a vessel with various loadings and initial speed at the moment of braking.

The implementation of this method includes the following stages (Fig. 2): preliminary data processing (analysis of the mining winding plant (MWP) parameters, choice of the scheme and program of carrying out dynamic tests); carrying out dynamic tests of the "lifting vessel – reinforcement" system (tests in operating modes of the hoist machine work and at emergency braking); system mathematical processing of the dynamic tests results; development of conclusions and recommendations.

The main stage of the system diagnostic is carrying out its dynamic tests in an operating mode and at emergency braking.

During dynamic instrumental testing with the informative parameters, providing insight into the lifting vessel movement in the mode of braking, the following instant values registered within certain time appear: horizontal accelerations of the lifting vessel directors on its top and lower belts; vertical acceleration of the lifting vessel; angular frequency of rotation (rotation speed) of the hoist machine drum; signal of emergency braking activation; length of head rope at the braking moment (coordinate of the point of lifting vessel braking in a shaft); full tension of the head rope; time since the beginning of braking.

Amplitude values of dynamic parameters for the vast majority of lifting compartments of national mine shafts are within the following ranges: the linear horizontal accelerations of directors are 0–10 m/s^2; the linear vertical accelerations of directors are 0–5 m/s^2; contact loadings are 0–90 kN.

During the system processing, the results of dynamic measurements are combined with the data of surveying profiling of guides to establish correlative relationship between them regarding the shaft sections.

The stage of processing experimental data is as important and complicated as the stage of carrying out measurements.

The purpose of processing and analysing these measurements is to determine qualitative and quantitative differences of process of dynamic interaction of the vessel with reinforcement during braking from the same process when the vessel is passing the braking section at a constant speed in the operating mode. Quantitatively, these differences can be characterized by the dynamic overload coefficient.

The qualitative characteristic of the vessel and reinforcement interaction at braking results in a definition of the law of changes of the maximum amplitudes of dynamic parameters of horizontal fluctuations of the vessel in time. Emergency braking being activated, the nature of this parameter change is additionally defined during the oscillatory process, that is, whether it is decreasing, increasing, increasing-decreasing or continuous function in time and on which system parameters it depends on.

Tiered synchronization of the dynamic testing result, data on measuring deviations of guide profiles from a vertical, their parametrical analysis, data on measuring wearing out and calculating the bearing ability of guides and buntons enables to reveal the weakest elements in every cross-section of the reinforcement, as well as to establish the reasons for decrease in residual margins of safety of metalwork.

Parameters of the technical condition of the system are the maximum values of contact dynamic loadings in spans of guides in the front and side planes, defined as a result of a series of hardware dynamic tests. The main parameters of the operational safety of the "lifting vessel–reinforcement" system functioning are the residual margins of span safety of guides and buntons, calculated for each section of the reinforcement considering the actual wearing and the operating loadings.

Fig. 3 exemplifies the final safety chart which is developed for each element of the reinforcement design and shows a ratio between margins of safety of elements, its residual durability and the level of the actual loading for each section. The gaps on curves of permissible loadings correspond to durability loss caused by wearing out; the peaks on curves of the actual loadings correspond to the raised dynamic loadings due to irregularities of vertical position or other geometrical parameters of guide system of this vessel. The graphs reveal the actual safety margin for each specific element of the reinforcement within this hoist operating mode.

The diagram shows that in sections 53–63 and 150–172 bearing ability of the bunton is reduced due to the increasing wearing and design safety margin is less than the minimal admissible 1.0 on a fluidity limit. In sections 110–125 and 145–165 upsurge in contact loadings is caused by irregularity of vertical position of guides. However, in sections 110–125 this upsurge does not lead to decrease in safety margin below the

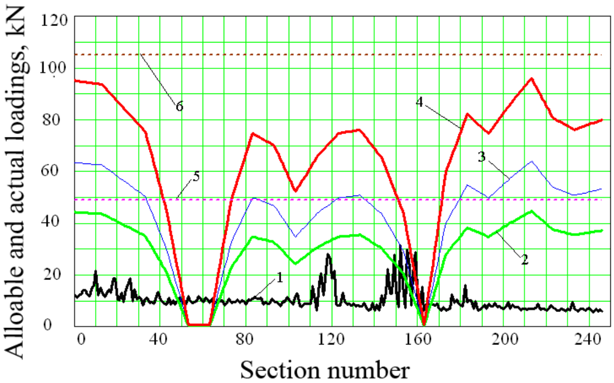


Fig. 3. Safety Chart for reinforcement loading of side bunton of counterbalance shaft compartment:

1 — actual maximum loadings for all cycles of dynamic tests; 2 — permissible loading with safety margin 2.15; 3 — permissible loading with safety margin 1.5; 4 — permissible loading with safety margin 1.0; 5 — permissible loading at margin of safety 2.15 for unworn bunton; 6 — permissible loading with safety margin 1.0 for unworn bunton

nominal rate 2.15, and in sections 157—172 it leads to decrease in safety margin below admissible 1.0 because of imposing of violations of guides profile in a section with raised wear of bunton. Therefore, in section 53—63 renovations of the bearing ability of the bunton by replacing its beams or hardening the existing design are required. And in section 150—172 both renovations of the bearing ability and flattening of guides after local profiling are necessary.

The "residual safety margin" parameter of elements of metal construction reinforcement under the influence of the actual operational loadings is the basic one, defining the degree of emergency of shaft operation. The value of safety margin equal 1.0 is the minimal admissible. It corresponds to equality of actual tension in the most loaded metal construction cross-section to the fluidity point of its material. Therefore, all the measures to ensure safe operations are aimed at its increasing up to the nominal size of 2.15, which corresponds to the actual tension lower than the endurance limit. With such safety margin in metal, no accumulation of fatigue damages occurs under the influence of cyclic sign-variable dynamic loadings from vessels [2]. This level can be achieved in several ways.

The most widespread way of safety margin increase is the reduction of hoisting speed on the fixed shaft section to decrease dynamic loadings to safe level with same guides profile and residual bearing ability of the reinforcement.

For winding plants with computer control systems, an effective way of loading decrease is application of the smoothed charts of drum rotation speed, minimized at jerk. Graphs of conventional and optimized charts of hoisting speed and graphs of contact loadings of reinforcement are shown in Fig. 4. It is illustrated that application of the smoothed chart of speed allows reducing nearly 40—50 % of contact loadings of reinforcement due to reduction of vertical jerk of the top ends of rope [3].

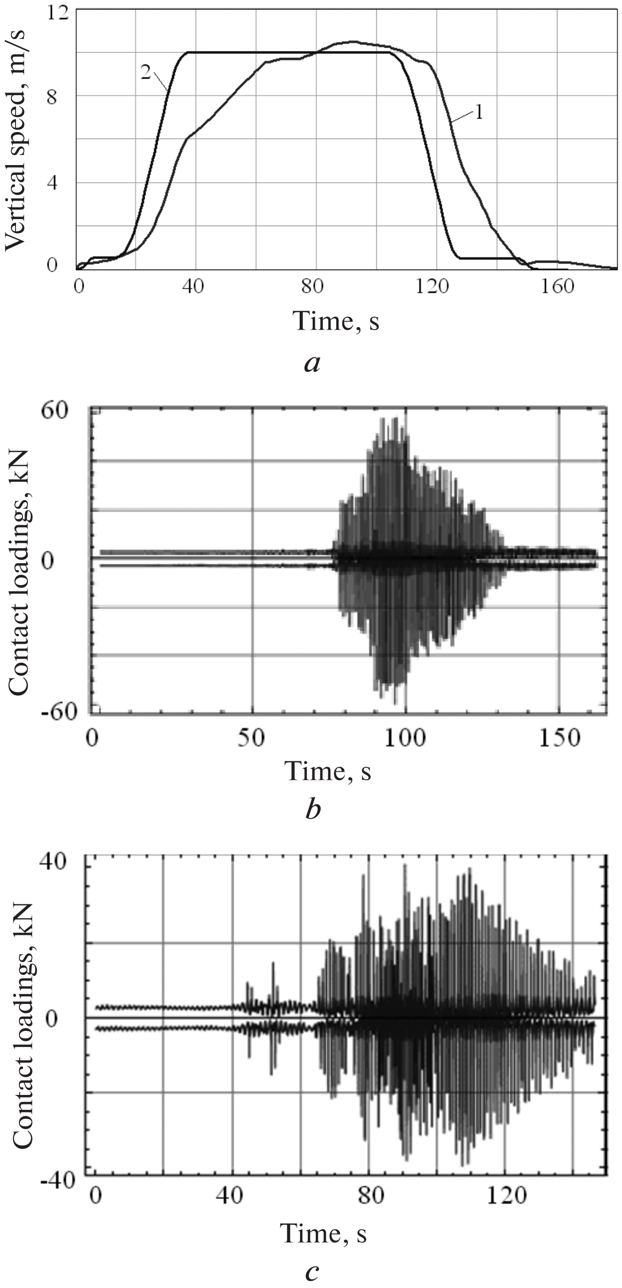


Fig. 4. Graphs of hoisting speed charts (a):

1 — conventional; 2 — optimized; graphs of contact loadings of reinforcement at conventional (b) and optimized (c) speed charts

Doing local profiling and straightening guides in sections with the most severe irregularities of vertical position is a more complicated way. Application of roller directors with advanced dissipative properties of dampers also contributes to improving dynamic situation. Replacement of worn-out beams of buntons and guides for the new ones is the most complicated way. Beams with the thickened walls are applied in some cases [4]. It results in need of additional dynamic calculations and correction of traditional measurements to control the residual strength of such beams during wearing out.

Graphs of dependence of the maximum contact loadings on the size of the profile smoothing coefficient are given in Fig. 5. The tests are conducted with various values of stiffness of the roller directors. It is shown that complex application of these measures allows reducing shock loadings on reinforcement significantly and to bring the "vessel–reinforcement" system out of abnormally dangerous technical condition without replacing metalwork [5].

Due to the the "vessel – reinforcement" systems upgrading at working safety, it becomes possible to increase the maximum operation hoisting speed in operating modes with a certain stock. Despite certain growth of contact loadings with increasing vertical speed, the balanced application of complex of actions and systematic instrumental control allows keeping the actual safety margins of metalwork at the level providing absence of spontaneous destructions and emergencies.

In case when one failed to avoid an accident in the shaft, the only choice is to apply autonomous mobile hoisting sets. The cage moves down to a shaft with the main vessel stuck to deliver people to the surface. Various conditions existing in shaft bottom space, the application of such sets in each case also demands special calculations to determine safe settings of control systems of the operating and emergency braking modes [4].

Conclusions.

1. As a result of the conducted research studies, the complex diagnostics method for dynamic condition of mine shafts reinforcement is substantiated. It includes instrumental dynamic testing of the "lifting vessel – reinforcement" systems in operating modes of the vessels moving and in the mode of emergency braking, complex mathematical data processing of dynamic measurements of the vessel moving, the chart of periphery speed of hoisting machine work, data on measuring wear of guides and buntons, data on instrumental measurements of deviations of guides profiles from the vertical.

2. The methodology of determining recovery measures on operational safety level of reinforcement is developed. Moreover, the methods of calculating correction of operating parameters of hoisting machine, profiles of guides and parameters of the roller directors of lifting vessels are developed. They allow reducing the level of dynamic loading of shaft and increasing the safe speed of hoist work and its productivity.

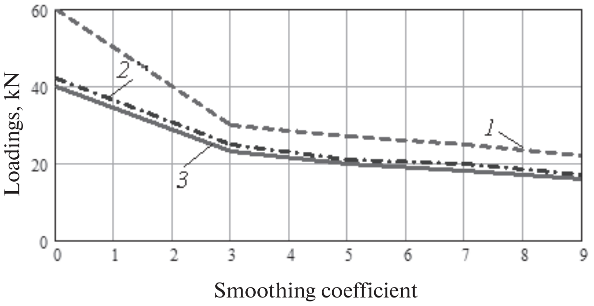


Fig. 5. Graphs of dependence of maximum contact loadings on the smoothing coefficient of a guide profile:

1 – 750 N/mm stiffness; 2 – 550 N/mm stiffness; 3 – 150 N/mm stiffness

The developed methods of diagnostics and recovery of level of operational safety of the "vessel – reinforcement" systems have been applied for over 15 years and shown successful performance practically in all the ore shafts with a straight reinforcement in Ukraine under the direction of bodies of Krivoy Rog mining territorial administration of the State Technical & Mining Inspectorate of Ukraine with its specialized Board of shaft statement analysis.

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Самуся С.В. Обоснование рациональных параметров и режимов эксплуатации аварийно-спасательных мобильных подъемных установок: автореф. дис. на соискан. научной степ. канд. техн. наук / С. В. Самуся // ІГТМ НАН України ім. Полякова – Днепропетровск, 2011. – 19 с.

Мета. Обгрунтовування методології діагностики технічного стану армування вертикальних стволів з порушеною геометрією та відновлення безпечного експлуатаційного стану шахтних підйомних комплексів.

Методика. Апаратурні вимірювання динамічних параметрів системи „посудина – армування“, параметрів зносу провідників і розстрілів, геометричних параметрів профілів провідників у шахтних стволах, математичне моделювання та аналіз динамічної взаємодії підйомних посудин з армуванням ствола з урахуванням даних апаратурних вимірювань.

Результати. Обґрунтовані методи вибору ремонтно-відновлювальних заходів і корекції робочих параметрів елементів системи, що забезпечують безаварійну експлуатацію підйомного комплексу у стволах з порушеною геометрією в заданих технологічних режимах.

Наукова новизна. У роботі на базі комплексних досліджень, що враховують структуру шахтної підйомної установки як багатоланкової, багатомасової дискретно-континуальної системи, яка має багато відхилень робочих параметрів від допустимих проектних значень, встановлена залежність динамічних параметрів, що визначають ризик аварійної небезпеки від параметрів технічного стану окремих ланок установки. На підставі одержаних результатів обґрунтована методологія апаратурної діагностики системи в робочих режимах і режимі запобіжного гальмування, а також методи зниження рівня аварійної небезпеки при підвищенні інтенсивності роботи установок.

Практична значимість. Обґрунтовані методики апаратурного контролю та визначення діагностичних параметрів установок у промислових умовах, методики адресного вибору ремонтних заходів, що забезпечують перехід підйомного комплексу з потенційно небезпечного експлуатаційного стану в безпечний технічний стан.

Ключові слова: *шахтна підйомна установка, шахтний ствол, шахтна підйомна посудина, діагностика армування шахтного ствола, армування шахтного ствола, динаміка шахтних підйомних установок*

Цель. Обоснование методологии диагностирования технического состояния армировки вертикальных стволов с нарушенной геометрией и восстановления безопасного эксплуатационного состояния шахтных подъемных комплексов.

Методика. Аппаратурные измерения динамических параметров системы „сосуд – армировка“, параметров износа проводников и расстрелов, геометрических параметров профилей проводников в шахтных стволах, математическое моделирование и анализ динамического взаимодействия подъемных сосудов с армировкой ствола с учетом данных аппаратурных измерений.

Результаты. Обоснованы методы выбора ремонтно-восстановительных мероприятий и коррекции рабочих параметров элементов системы, обеспечивающие безопасную эксплуатацию подъемного комплекса в стволах с нарушенной геометрией в заданных технологических режимах.

Научная новизна. В работе на базе комплексных исследований, учитывающих структуру шахтной подъемной установки как многозвеньевой, многомассовой дискретно-континуальной системы, имеющей множественные отклонения рабочих параметров от допустимых проектных значений, установлены зависимости динамических параметров, определяющих риск аварийной опасности от параметров технического состояния отдельных звеньев установки. На основании полученных результатов обоснована методология аппаратурного диагностирования системы в рабоих режимах и режиме предохранительного торможения, а также методы снижения уровня аварийной опасности при повышении интенсивности работы установок.

Практическая значимость. Обоснованы методики аппаратурного контроля и определения диагностических параметров установок в промышленных условиях, методики адресного выбора ремонтных мероприятий, обеспечивающих перевод подъемного комплекса из потенциально опасного эксплуатационного состояния в безопасное техническое состояние.

Ключевые слова: *шахтная подъемная установка, шахтный ствол, шахтный подъемный сосуд, диагностика армировки шахтного ствола, армировка шахтного ствола, динамика шахтных подъемных установок*

Рекомендовано до публікації докт. техн. наук К. С. Заболотним. Дата надходження рукопису 21.05.15.