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THE EXPERIENCE OF DYNAMIC APPARATUS CONTROL AND ESTIMATION OF EXPLOITATION SYSTEM SAFETY "VESSEL – REINFORCEMENT" OF VERTICAL MINING SHAFTS

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Key words: mine, shaft, reinforcement, diagnostic

Abstract:

Practical experience and theoretical results from Ukrainian mining operations addressing dynamic system control of «lifting vessel — reinforcement» in vertical shafts with the use of portable digital measuring stations.

1. Introduction

The mine winding plant (MWP) is an extensive, multiple-link, multi-oscillatory system with multiple degrees of freedom where links consist of a combination of assumed hard limits of operating parameters and stochastic variables with high variability. During operation their exists strong correlations between mutual influenced dynamic processes where non-localized heterogeneous links influence each other.

The operational state of each link is sufficiently characterized by a set of diagnostic parameters with normative values that are both deterministic and stochastic in nature. The functioning deterministic state of the MWP links must work in the projects dynamic operation dampening the presence of the undue fluctuations influencing the dynamics of other system links.

2. Estimation of exploitation system safety "vessel – reinforcement" of vertical mining shafts

In the presence of local defects, the dynamic isolation of processes is disrupted by separate links distributing energy such that stochastic processes appears in temporal concentration in motion in links or within pairs of contiguous links. Such energy pumping corresponds to unforeseen resonance activation in the system of different types: external, internal including parametrical, «beating», auto-oscillations, etc.

The most dangerous behaviors are resonances which are revealed upon actual operation of the mine hoist and attempts to compensate are taken into account in an operating project documents. An array of other resonance effects is camouflaged from attention and only revealed indirectly via disturbances in the chain of dynamic links and operations of individual links. These defects appear as unexpected energy due to accumulation of system effects from the total influence of insignificant defects in the functioning of links. Such effects are not studied and not reflected in a normative documentation on servicing, adjusting, and diagnosing tests on the MWP equipment. This is especially true in the MWP shaft equipment where conditions of:

- Intensive corrosive effects and mechanical wear are present.
- Reinforcement with minimal permissible errors on amplitudes of oscillations of lifting vessels (20—30 mm) as compared to their overall sizes (10—20 m) exist.
- Small deviations of guides from the vertical alignment (10 mm on contiguous tiers).
- Large contact loading in a pair «vessel — guide» exist.
- Transmissible on bunton and shaft's lining are present.

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The main MWP working element and concentrator are subject to influences from different links within the plant while lifting the vessel where the links attempt to provide a safe and stable hoisting motion.

Objective information measuring the technical parameters of MWP equipment operational states experiencing long-term exploitation, consist of special inspections of apparatuses during dynamic tests of hoisting during operating and test conditions with subsequent system analysis. In Ukraine, such measurements are conducted in accordance with positions of normative documents [1], [2] and involve complex constructions described in articles [3 — 6]. In a number of countries, dynamic control of the systems «vessel — reinforcement» is obligatory along with traditional surveyor observation of guides' shape. For example, in Poland, it is an act of Minister of National Economy 06.28.2002, that «… accordance with the schedule, set by the chief of operating management of mining enterprise, depending on local terms and load of lifting vessels, but not rarer than one time in 5 years, research of the technical state of shaft's linking and control measurement must be produced:

- geometry of shaft, its reinforcement and elements of equipment,
- straightforwardness of guides,
- real forces of influence of lifting vessels on the shaft's equipment.

Project tiers of reinforcement are designed to work with identical terms of loading and, at one level, resist loading from the side of lifting vessels and rock massif. During the first decade of exploitation, because of influence of aggressive environment, dynamic loading, moving of rock, and repair works there appears sharply heterogeneous changes on the depth of the shaft picture dispensing levels of bearing strength and reinforcement elements — guides & buntons.

As a result of data analysis, greater than one hundred and fifty (150) inspections and dynamic tests of systems «vessel— reinforcement » must be conducted on mine shafts to determine their technical state and operating security level. These tests are conducted by Diagnostic Laboratory of the mining hoist of IGTM in the name of N.S. Polyakov NAS of Ukraine, that states during the life cycle of shaft's functioning values of technical state parameters of elements of reinforcement get substantially heterogeneous character on its depth. They can be unlike on different areas of shaft in 5—10 times.

The level diagrams for remaining sections of guides and buntons, was derived on the basis of instrumental measuring during mine shaft inspection and can serve as illustration of this statement (see Fig. 1). An upper line shows a project level for new reinforcement (100 %), and continuous curves show its value varies on the numbers of tiers. The dotted line represents the level of loss of section 20 % where below it an object must be exposed to special inspections for estimation the operational technical state and security level of exploitation. As we see on the beams of the central buntom, there are anomalous areas of section loss up to 90 % in the top part of shaft at tiers № 60—50 (with the proper level of loss of load-carrying ability), while on average the section shaft loss consists of 50—60 %.

The picture is different for guides, where the first guide lost up to 40 % section in top part of shaft, and the second has an obvious local anomaly on the area of tiers № 270—280 with a loss 50 % of section at a general level of section's saving to 80 % in the shaft.

A similar process of homogeneity loss concerning properties takes place in the geometrical parameters of guide shapes which the lifting vessels move, thus geometrical heterogeneity concerning reinforcement on the depth of shaft appears.

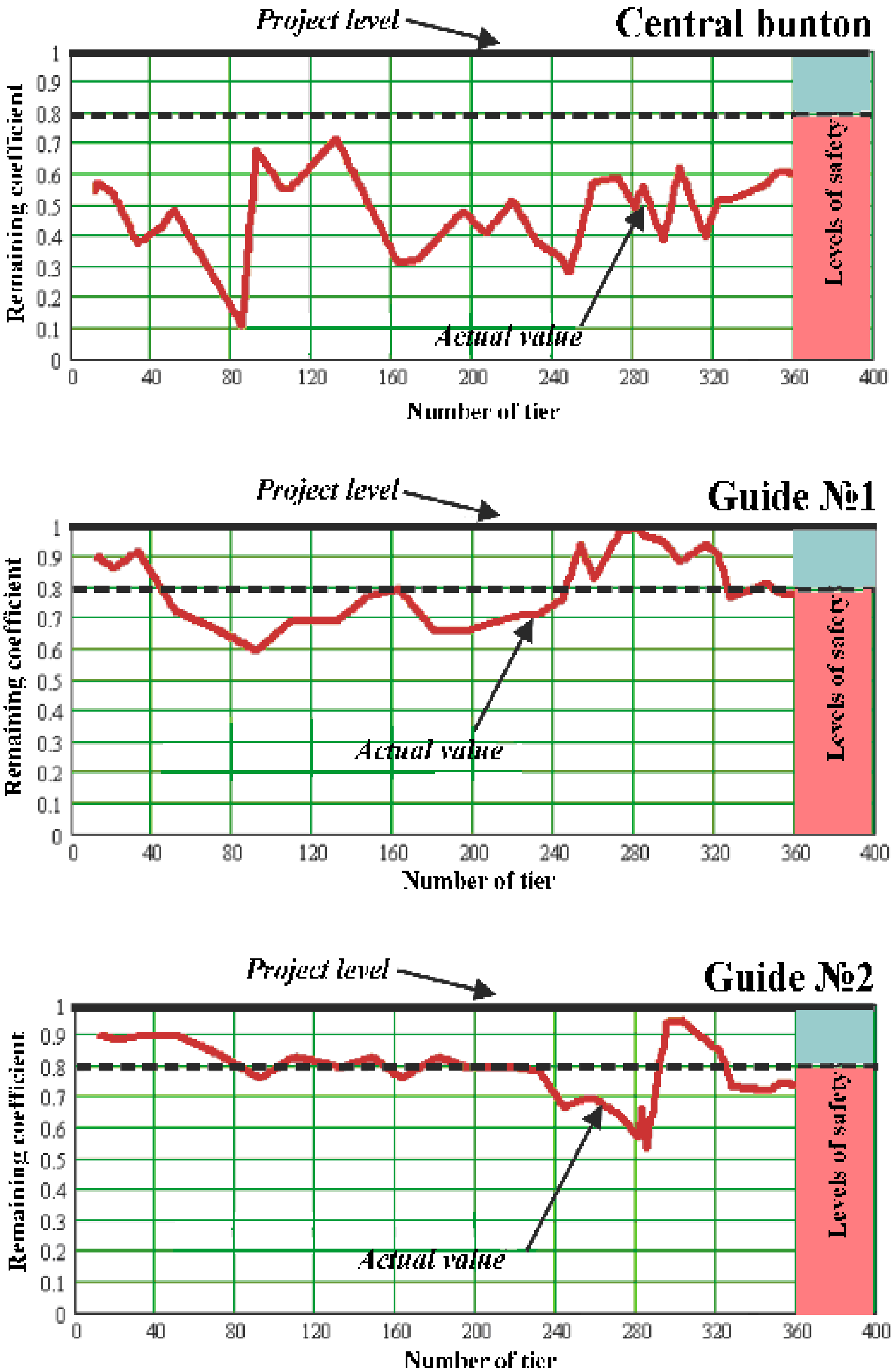

Fig. 1 *Diagram of levels of remaining section of reinforcement elements*

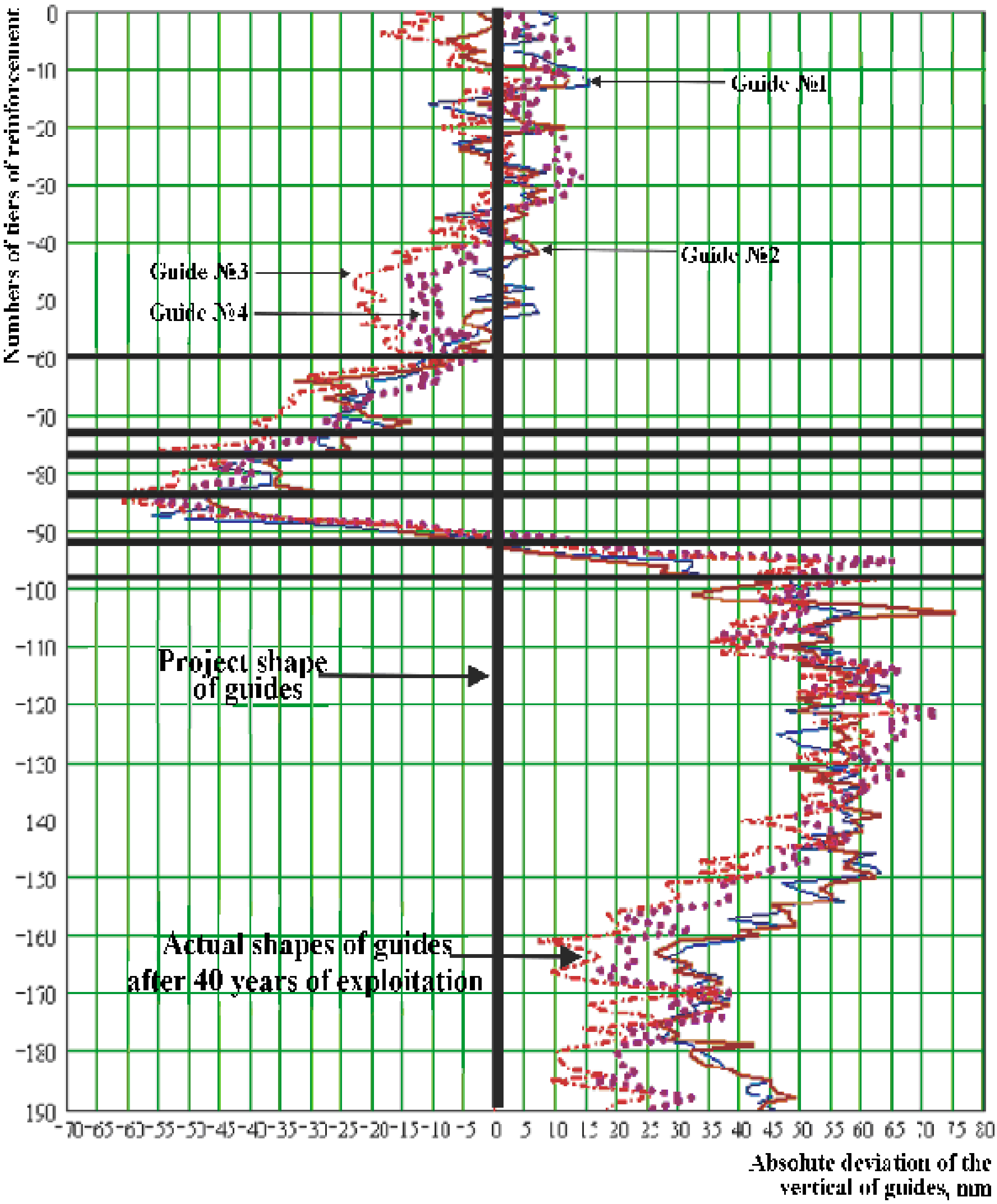

Fig. 2 *Diagram of rejections of guides from the vertical line of cage compartment in the area of the rock movement*

Fig. 2 shows the shape of guides in the cage compartment of shaft, where the area of rock movement shown. Between tiers № 70—150 one can observe geometrical anomalies of guide rejection from a vertical line. Clearly such areas of vessel cooperation will have unfavorable behavior especially in conditions of transition involving increased operating speed.

The mode of operations for the lifting machine is another type of heterogeneity on the depth of shaft. Fig. 3 demonstrates the speed of rotation for lifting machine in cage compartment as shown. There is deceleration of lifting vessel to 1 m/s according to the requirements of unified safety regulations on each working level. Thus the graphic below demonstrates differentiation of this diagram where differences are vertical accelerations of vessel lifting.

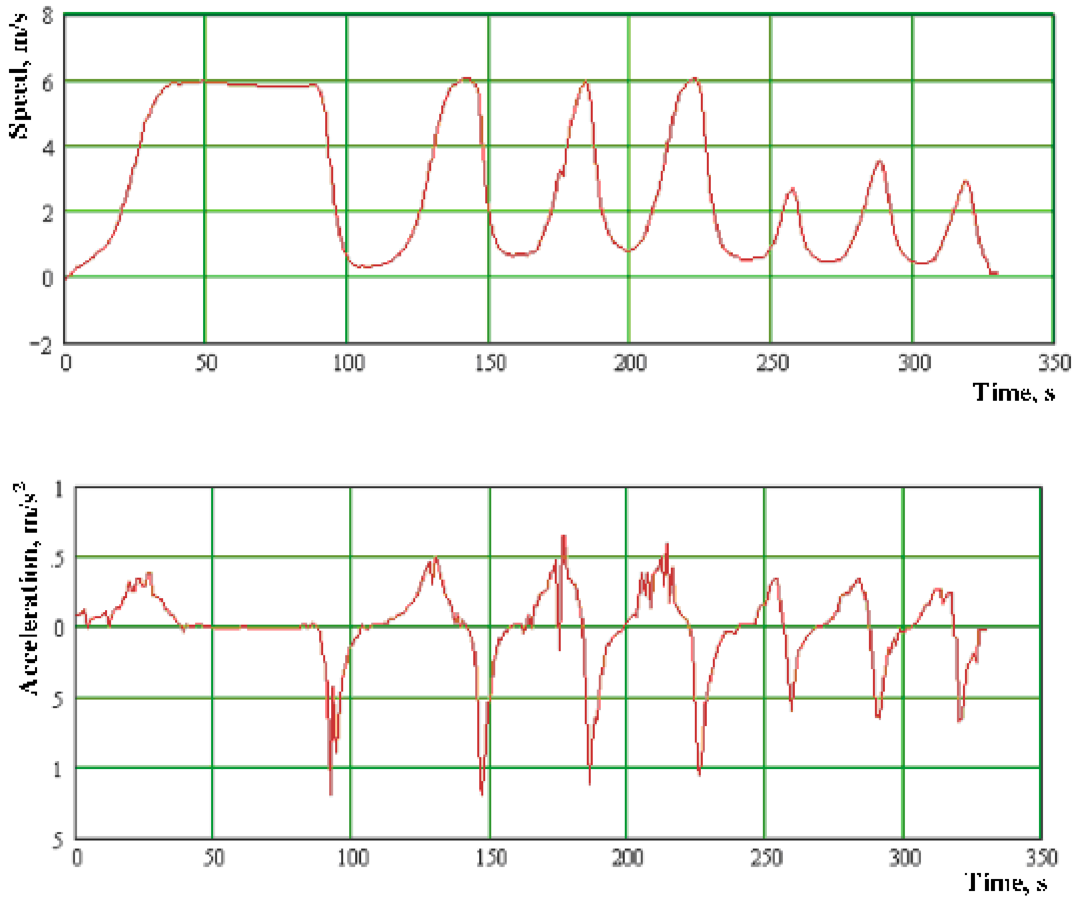

Fig. 3 *Diagram of circumferential speed and acceleration of drum of lifting machine in cage compartment of shaft*

Our research indicates that along points in the shaft, there exist sharp changes in the speed of vessel lifting especially with action covering the preventive brake. There are horizontal impacts of vessels on guides that are four — five times higher than during motion with constant speed, this is due to the excitation of vertical speed oscillations along a resilient rope. Repeating from cycle to cycle, they are instrumental in accumulation of tireless damages in guides and buntons, formation of cracks on the welds, weakening of attachment points of guides, slacking of buntons in the places of lining attachment [6].

All these heterogeneous anomalies which are simultaneously, permanently and slowly changing - affect the process of dynamic cooperation of vessel with reinforcement which it takes place on each tier area. Original dynamic heterogeneity of loading reinforcement on the depth of shaft with the middle level and areas of dynamic anomalies appears as a result of such imposition (see Fig. 4).

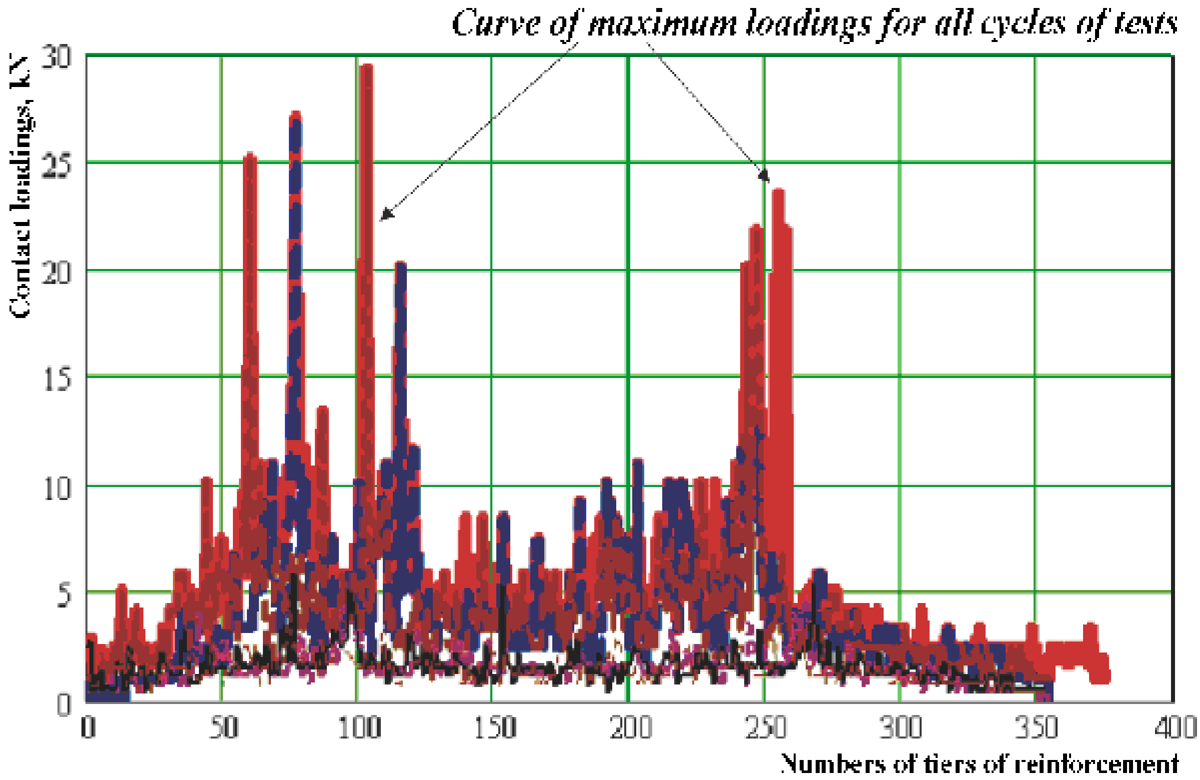

Fig. 4 *Diagrams of the dynamic loadings on guides during motion of lifting vessel*

The primary factor determining the technical state of shaft's reinforcement, is remaining assurance coefficients concerning elements (guides and buntons) which are defined on every tier. Destruction of any even along one tier, will inevitably result in a failure with drastic consequences.

Dynamic cooperation along vessels with reinforcement has an impact and cyclic causal character and this has been taken into consideration while estimating the technical guides and buntons states under effect during the actual operating loading cycles. It is necessary to adopt the minimal assurance coefficient (2.0) on the criterion to account for the accumulation of fatigue damages in metalware reinforcement. A combination of loading and remaining ruggedness for guides and buntons, provides an assurance coefficient (on the limited area of shaft) such that its technical state is considered safe. As assurance coefficient declines from 2.0 to 1.0 (on a local area or even on separate tiers) the state becomes potentially dangerous, requiring special supervision after appearance of fatigue cracks and another defects. Tiers (with an assurance coefficient less than 1.0) are considered on the limit of stretching strain, thus it is necessary to:

- considered them abnormal, dangerous and required immediate acceptance of measures or;
- decline of the contact loading (due to the decline of motion speed on an area) or on the renewal of ruggedness of the element of reinforcement .

There are three independent and basic processes affecting the remaining assurance coefficients concerning bearing elements of reinforcement:

1) wear of guides and buntons (corrosive and mechanical);
2) curvature of spatial shape of guides (under influencing of moving of rocks and violations at permanent repair of reinforcement, formation of ledges on the units of guides);
3) sharp change of altitude rate of lifting vessel.

Reinforcement wear causes a decline in the remaining load-carrying capability of its elements where the decline is due to the possible contact loading at the intended values of assurance coefficients. Curvature of guides' shape causes growth of the dynamic loading on the local areas of the shaft - on condition of absence of the resonance effect. Sharp changes in vessel altitude rater (emergency braking (EB), in particular) cause certain areas of instability along the shaft with growth in the horizontal dynamic loading on guides [6].

Indicated heterogeneities are the sources of potential danger during the long exploitation of lifting complexes.

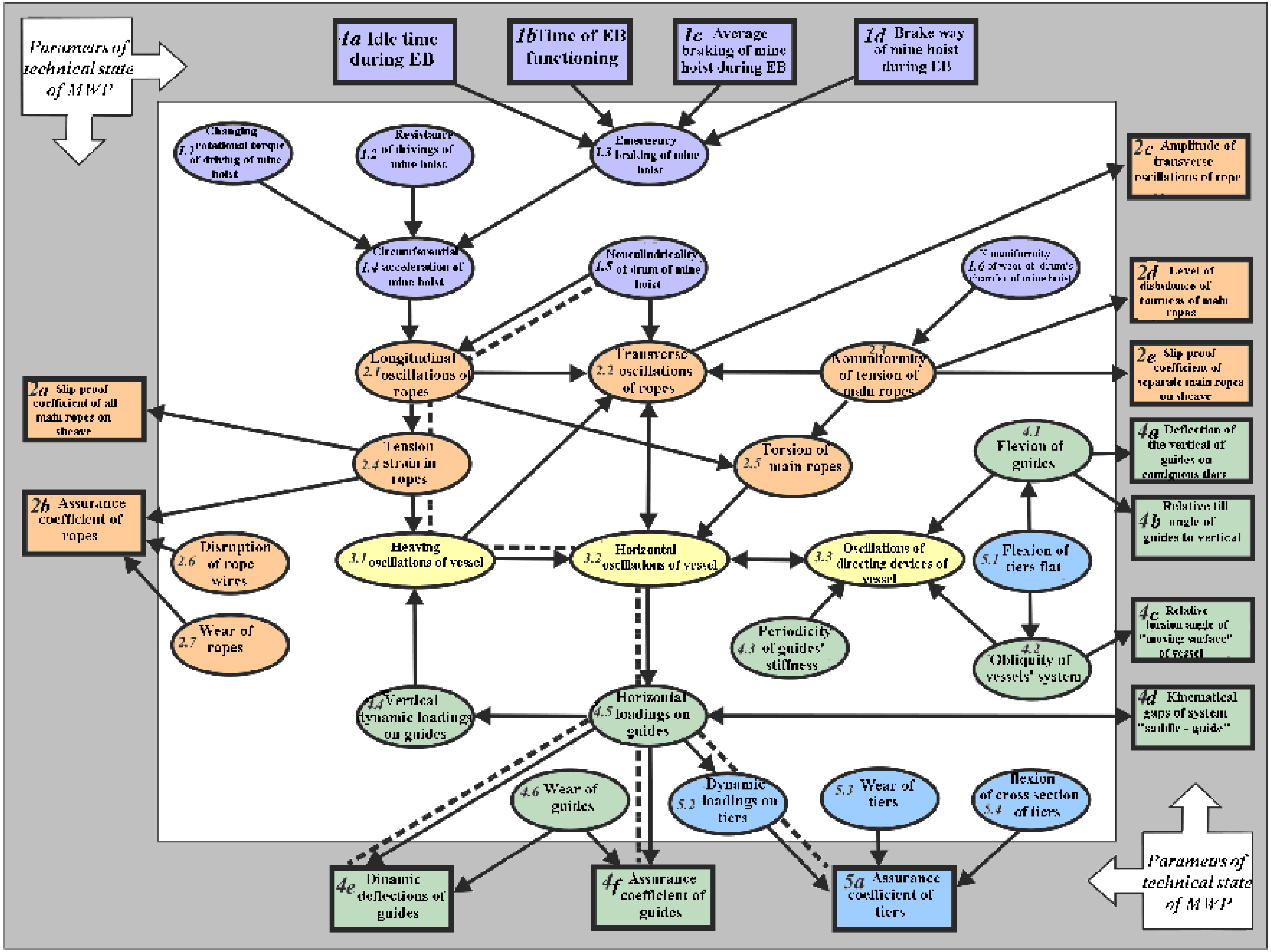

Fig. 5 *Graph of interconnection of dynamic characteristics and parameters of technical state of the MWP equipment with strong reinforcement of shaft*

Studying of the stochastic effects in the multiple-link system of MWP and exposure of the defective technical states, origin reasoning and terminology underlie the technology of management in the technical state of MWP during periods of long exploitation. For illustration of interconnection of dynamic characteristics and parameters of the technical state of MWP equipment we developed the base variant of the scaled-up graphic scheme (dynamic graph of the MWP), which describes power interconnection of mechanical processes between the links of the hoisting (see Fig. 5).

- Units of scheme (top of graph) represent dynamic processes and features of links.
- Communications (one — sided and two — sided arrows) describe the physical mechanisms of energy transmission (transmission only in one side or periodic exchange in both sides) between links (the systems of differential or integral-differential equations, described these effects, mathematically correspond to them).

Breaking the units of this scheme on smaller blocks, it is possible to build the detailed atlas of power interaction processes with any level of detail.

On this scheme we observe possible channels of energy transition and dynamic processes during at work in every link of MWP through the successive chain of communications between links. We also observe what sources can affect certain MWP parameters and in what way the influence can be added from a few sources and localized in a separate link, forcing parameters outside permissible limits.

Building the local chain of channels (of influence) on the graph using graph theory terminology (routes); it is possible to develop a mathematical models approximating connections between processes and properties of links bounded on the scheme and to define what channels & parameters of interaction are not studied or described yet in literature.

For example, the direct route of 3.1 → 3.2 is shown, describing the influence of vertical oscillations of lifting vessels on horizontal because of local dynamic process [6]. The «function of remaining kinematical gap» of the system “saddle — guide” is also entered, determined on the basis of experimental researches in every curtain weight lifting compartment (direct route 4.5 → 4d). Its use allows to forecast changing of parameters of technical state on the certain period of exploitation during implementation of diagnostic inspections.

As an example of application, the Figure 5 route depicting formulation of the problem is shown by the dotted line and described in works [7], [8]. It reveals an influence of disturbing of drum’s cylindricality of lifting machine on the parameters of the technical state of shaft reinforcement.

The model is built on the basis that the given graph allows one to trace and explore complex mechanisms through influencing dynamic characteristics of equipment elements on surface-based MWP where output parameters of underground shaft equipment due to the slow change (degradation) of links’ properties of the system during the long exploitation [9].

This is effective when task solving to build a proper route proper with the purpose of visualization its place & role in the general MWP dynamic process for convenience of analysis. Comparing the represented aggregation of parameters with the parameters rationed in an operating normative — technical document, it is possible to select, which have to be rationed for the increasing of safety of the MWP exploitation. This is especially true when taking into consideration degradation of equipment that has accumulated during its working lifetime.

As observed, the general process picture has a subdivided character where the local dynamic processes can have the sources of origin isolated from each other. Influence of sources can be passed through the chains of directly connected mechanical links, summed and, finally, affect the basic factors of the technical state and safety of work of all hoisting plant. Thus, lifting a vessel is a basic concentrator assuming and influencing all functional MWP links.

Ceteris Paribus – the main parameters determining the level of the dynamic loading on reinforcement are the parameters of shapes of the system of guides in weight lifting compartment. A system of differential mathematical data analysis concerning profiling was developed and allows one to effectively tie data of mine surveying guides with data of apparatus dynamic tests of the «vessel — reinforcement» systems. It determines (except for normative values of rejections on contiguous tiers and width of track) spatial geometrical parameters of shapes not only as separate guides but also as pairs belonging to one vessel which are the most probable casuses of origin in the promoted shock loading. This allows one to calculate parameters of correction for guides’ shapes, providing the required decline of the contact loading even at impossibility of return to the project level of verticality of their threads from moving of rocks or other technical reasons and to advance altitude rate to the necessary size while saving of possible loading level.

The «Diagrams of safety» developed are the graphic form of this system and presented with measurments and calculations (see Fig. 6), which are built for each element of reinforcement. They include the results of mathematical data processing for instrumental measuring of guides’ and buntons’ wear, apparatus measuring of the contact loading, stress-strain analyses of reinforcement [10].

Curves of maximum possible contact loading from the side of lifting vessel for the assurance coefficient of n=1, n=1.5, n=2 are built on diagrams for each guide or bunton using the numbers of tiers of reinforcement. They take account of the actual remaining thickness of given section of the given element and curves of the actual maximal contact loading got for all test passways of vessel in a shaft according to the program of dynamic tests [1].

Diagrams depict:

- areas of assurance values / coefficients for each certain element of reinforcement on every tier in the moment once inspection is exploited (emergency dangerous, potential dangerous, safe);
- because of technical reasons an element enters a negative area of safety according to the assurance coefficients. Appearance of areas of failures on the curves of possible loading is caused by the increased wear of the given element of reinforcement. Therefore, even at the moderate dynamic loading an element can be exploited in an under abnormal condition dangerous area. Appearance of splashes of the increased values of the actual operating loading is caused by the presence of large local disturbing of straightness of guides' shapes or ledges on their units.

Fig. 6 *The diagrams of safety for the lateral boxlike guide of strong reinforcement in skip compartments of mine shaft in lateral (a) and frontal (b) loadings*

From the analysis of diagrams we observe what technical measures are necessary in order to choose primary metrics and plan for translation of element exploitation in areas with high assurance coefficient values. The decline in the level of the contact loading on the set area of shaft (above all things) can be provided with decline of altitude rate of vessel on an area, or with correction of parameters of guides' shapes or ledges in units. The increase of level of the possible loading on element without a correction of shape and altitude rate of vessel is achieved by replacing or measures on strengthening of load-carrying capability construction.

Doing this work on the mines reveals that even in the hard technical conditions, the effective management by exploitation safety of shaft equipment and its maintenance is possible.

References:

[1] Диагностика состояния систем «крепь—массив» и «подъемный сосуд—жесткая армировка» шахтных стволов. Порядок и методика выполнения. Министерство промышленной политики Украины ГР 3—032—2004. Согласовано Госнадзорохрантруда Украины. ПБП „Экономика". Днепропетровск. 2004. —40с.

[2] Организация контроля безопасного состояния оборудования вертикальных стволов и подъемных установок шахт. СОУ—Н МПП 73.100—079:2007. Министерство промышленной политики Украины, 2007 —99с.

[3] Ильин С.Р., Гавруцкий А.Е. Повышение безопасности работы шахтных подъемов путем применения компьютерных технологий и средств электронного контроля за состоянием оборудования стволов в Приднепровском регионе // Геотехническая механика: Межвед. науч.— техн. сб. – 1998.,—Вып.6.— С. 169—173.

[4] Чередниченко О.Л., Ильин С.Р., Радченко В.К. Мониторинг безопасности эксплуатации шахтных стволов. — //Технополис, Днепропетровск. —2008. Вып. 12. – С. 30—31.

[5] Ильин С.Р., Трифанов Г.Д., Воробель С.В. Динамический контроль состояния армировки шахтных стволов.//Рудник будущего. Пермь. —2009. Вып. 5. С.130—132.

[6] Ильина И.С. Разработка и обоснование метода диагностирования состояния систем «подъемный сосуд — армировка» при предохранительном торможении. Автореф. канд. дисс. Днепропетровск. —2005. —16 с.

[7] Ильин С.Р. Диагностическая модель влияния нарушений цилиндричности канатоведущих шкивов на уровень динамического взаимодействия подъемных сосудов с армировкой шахтных стволов. — Геотехническая механика. Сб. науч. тр. ИГТМ НАН Украины. —Днепропетровск.—2000.—Вып.22. —С.118—121.

[8] Белобров В.И., Дзензерский В.А., Самуся В.И., Ильин С.Р. Динамика шахтных подъемных установок. Изд. Днепропетровского государственного университета. Днепропетровск —2000. —380 с.

[9] Ильин С.Р. Разработка и обоснование общей диагностической модели оборудования шахтных подъемных установок. Геотехническая механика. Сб. науч. тр. ИГТМ НАН Украины. —Днепропетровск.—2008.—Вып.76. —С.66—85.

[10] Ильин С.Р., Дворников В.И., Кърцелин Е.Р. Программный комплекс «Армировка шахтного ствола» // Сборник научных трудов национальной горной академии Украины. №13, том 3. Изд. "Навчальна книга" Днепропетровск. 2002. – С.40—43.

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