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АНАЛІЗ ВТОМНОЇ МІЦНОСТІ ВУЗЛІВ ОПИРАННЯ БАГАТОКАНАТНИХ ШКІВІВ ТЕРТЯ РАМНОГО ШАХТНОГО КОПРА

Укісні шахтні копри є найвідповідальнішими спорудами шахтної поверхні. На поточний момент гірничодобувної галузі спостерігається збільшення глибини шахтних стволів до 1200... 1300 м, що призводить до збільшення висоти укісних копрів до 60–70 м, а також до зростання динамічних навантажень. У зв’язку з цим, для гарантування безпеки конструкцій шахтних копрів необхідне уточнення наявних інженерних методик розрахунку шахтних укісних копрів. У роботі наведено результати теоретичних, експериментальних досліджень авторів, а саме – математичне моделювання напружено-деформованого стану вузлів опирання напрямних шківів конструкцій рамних шахтних копрів. За математичного моделювання встановлено: закономірності розподілу місцевих напружень; характеристики динамічних напружень для перевірки втомної міцності підшківних конструкцій; оцінено ресурс вузлів обпирання напрямних шківів за втомною міцністю. Проаналізовано втомну міцність конструкцій рамного шахтного копра багатоканатною підйомної установки, зокрема, вузлів обпирання напрямних шківів. Аналіз проводився на розрахунковій моделі, що складається з плоских і просторових скінченних елементів реалізованої в середовищі програмного комплексу “Ansys Workbrench 14.0”. У результаті численних експериментів у підшківних рамах полушатрового копра отримані: закономірності розподілу місцевих напружень під опорними підшипниками напрямних шківів, встановлені параметри напруженого стану при зміні технологічних і конструктивних чинників; встановлені характерні області змінних напружень; виконаний аналіз напружено-деформованого стану за дії динамічних навантажень; визначені характеристики циклів динамічних напружень. За характеристиками циклів виконані перевірки втомної міцності за трьома методиками: СНиП II-23-81 * (п.9.2 *), ДБН В.2.6-163 (п. 1.11.2) і EN1993-1-9-2009 (п. 8). Загалом отримані результати є основою для вдосконалення інженерних методик розрахунку сталевих конструкцій шахтних укісних копрів.

Ключові слова: шахтний рамний укісний копер; підшківні конструкції; вузол опирання напрямного шківа; напружений стан; місцеві напруження, аналіз міцності.

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ANALYSIS OF THE FATIGUE STRENGTH OF RESTING NODES OF MULTIPLE-ROPE FRICTION PULLEYS OF A FRAMED SHAFT HEADGEAR

The paper comprises the results of the analysis of the fatigue strength of the framed shaft headgear structures, among them a multiple-rope hoisting plant, resting nodes of guide pulleys. The analysis was carried out on the design model consisting of flat and spatial finite elements within the software complex “Ansys Workbrench 14.0”. From the numerical experiments the typical ranges of alternating stresses were fixed in the sub-pulley frames of the semi-hipped headgear; the analysis of the stress-deformed state under dynamic loads was carried out; the behavior of the dynamic stress cycles was found out and on its base the fatigue strength was tested by three techniques: the Building Code II-23-81* (point 9.2*), the Building Code B.2.6-163 (point 1.11.2) and EN1993-1-9-2009 (point 8).

Key words: frame sloping shaft headgear, sub-pulley structures, guide pulley resting unit, strength analysis, stressed state, local stresses.

Statement of problem. Steel shaft headgears are welded structures taking over intensive concentrated dynamic loads because of hoisting rope tension [6]. A unique feature of the framed shaft headgear is the construction form of the elements of the sub-pulley frames, which are spatial sheet box-type structures, are not shafts conceptually. At the design idealization these construction elements approximate by the shaft finite elements, the static equivalents of dynamic loads caused by the hoisting rope tension were taken into account. So, this design does not allow diagnosing the zones of local stress distribution, the characteristics of the dynamic stress cycles which are necessary to test the fatigue strength. Thus, the normative engineering techniques of designing shaft headgears are not quite accurate and require improvement.

The earlier investigations. In [4] they carried out the numerical analysis of the stress-deformed state of the main bearing elements of the framed sloping shaft headgear with the help of two finite element design model in the form of the shaft and lamellar approximation of the elements, its main conclusions being the following: 1) the comparison of the design results of the main and reduced stresses of two design models (the shaft and lamellar approximation of the elements) did not reveal any significant discrepancies for the elements: the stay leg branches, the vertical tower bodies, the stay leg beams, the vertical tower beams; for the main beams of the stay leg and sub-pulley frames they revealed significant deviations 82-167 %; at the approximation of these structures by the shaft finite elements they obtained the qualitatively incorrect results; 2) the elevation of the reduced stresses in the sub-pulley structures on the lamellar design model over the analogous stresses on the shaft design model is due to the available zone of local stresses in the resting nodes of the guide pulley bearings.

In [5] there was carried out the analysis of the stress0deformed state of the guide pulley nodes resting on the sub-pulley structures. This analysis was carried out on the design model consisting of flat and spatial finite elements under static loading. They revealed the typical ranges of local stress distribution in the resting nodes of the guide pulleys. For the range of local stresses under the base of the supporting bearing; under the “abnormal” combination of loads the conditions of strength by the tangential and reduced stresses ($\sigma_{red}/1.15R_y\gamma_c = 1.1$; $\tau_{max.}/\ 0.58R_y\gamma_c = 1.1$) are not fulfilled.

In [4] and [5] they received the results under the equivalent static loading. Due to this the parameters of the dynamic stress cycles in the problems under consideration were not determined. Because of the pronounced dynamic character of the loads caused by hoisting rope tension [6] it is necessary to determine the characteristics of dynamic stresses in the sub-pulley structures to test their fatigue strength.

The investigation is concerned with the sub-pulley structures of the skip semi-hipped framed headgear under operating conditions.

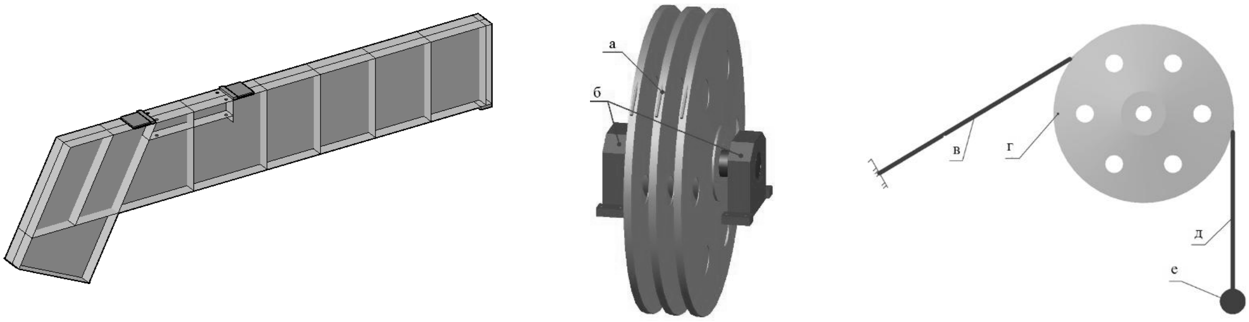
The sub-pulley structures of the framed sloping headgears are to support the guide pulleys. By the construction diagram the sub-pulley structures under consideration are a frame with slant legs. A girder and slant legs of the frame are made of the welded double tee. The guide pulley bearing rests on the frame upper chord. At the site of resting horizontal and vertical stiffening bars are provided for fixing bolts of the guide pulley supporting bearing.

The investigation techniques. The investigation of the stress-deformed state of the structures were pursued in three stages:

Stage 1. Modeling of the stress-deformed state of sub-pulley structures on the spatial design model approximated by the lamellar and volume finite elements within the software complex "Ansys Workbrench 14.0" [7].

On modeling the guide pulley node resting on the sub-pulley structures was considered as a mechanical system consisting of three subsystems.

Subsystem 1: a geometrically stable system of the construction elements of the sub-pulley frame and mounting hardware of the guide pulley supporting bearings (see Fig. 1, *a*).



a b c

Fig. 1. a – subsystem a – a sub-pulley frame; b – subsystem 2 – a guide pulley, supporting bearings; c – subsystem 3 – a boom hoisting cable, a guide pulley, a vertical branch of the hoisting cable, a vessel

The sub-pulley structures were considered as the attached ones with regard to the boundary conditions of the elastic interaction with the rest part of the structure. The interaction was modeled by fixing the sub-pulley frames with the help of the resilient flexing linkage which is equivalent to rigidity in the conjunction nodes of the sub-pulley structures, the main sloping beams and the pillar. The interaction of the base of the guide pulley supporting bearing and the stop frame and wedges was modeled by the "one-sided contact" in compression.

Subsystem 2: a guide pulley, a shaft, a guide pulley bearing were modeled by the volume finite elements in accordance with their geometry.

The pulley-shaft interaction was fulfilled in such a way that the pulley would have the kinematic degree of freedom corresponding to rotation in the supporting bearings (see Fig. 1, *b*).

Subsystem 3: "cable-hoisting vessels" – consisting of the following elements: a boom hoisting cable; a vertical branch of the hoist cable and a hoist vessel (see Fig. 1, *a*). Cables were modeled in the form of resilient members characterized by rigidity equivalent to the axial rigidity of hoisting cables. The mass of the hoisting vessel and the hoisting cable branch was considered as the reduced one at the end of the vertical resilient member.

Stage 2. Modeling of the dynamic behavior of the loads of the hoisting cable tension was carried out in the following way (see Fig. 2): the concentrated forces found out from [6] were attached to the concentrated reduced mass of the hoisting cable and vessel of the 3rd subsystem.

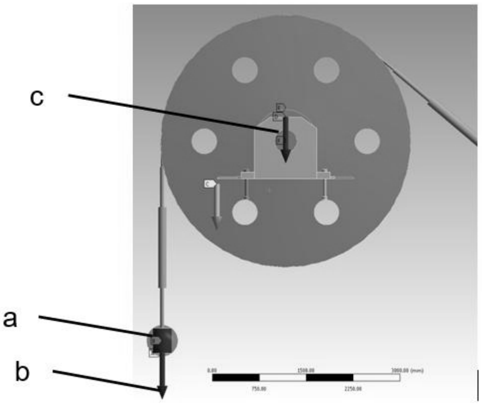


Fig. 2. The design scheme of the subsystem "pulley-cable-hoisting vessel": a – the reduced mass of the vessel and cable; b – the variable concentrated force which results from the vessel vibration; c – a proper weight of the sub-pulley structures and guide pulley

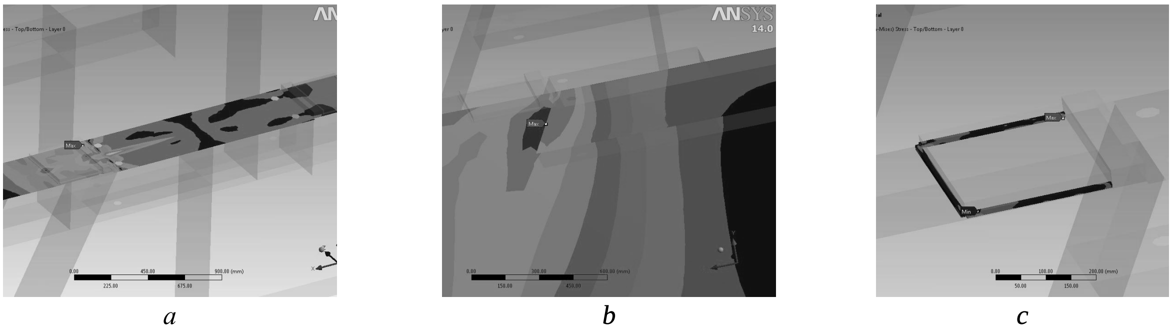
Stage 3. Fatigue strength testing. The analysis of the fatigue strength of the guide pulley resting nodes was carried out by three engineering techniques: the Building Code II-23-81* (point 9.2*), the Building Code B.2.6-163 (point 1.11.2) and EN1993-1-9-2009 (point 8).

Findings. The numerical modeling resulted in the parameters of the stress-deformed state of sub-pulley structures: principal stresses (σ_1, σ_2), reduced stresses (σ_{red}), normal stresses (σ_x, σ_y), and tangential stresses (τ_{xy}) with regard to the dynamic constituent of the hoisting cable tension load. The obtained results are given in Table 1.

Table 1

Node component	$\sigma_{max\,1}$, MPa	$\sigma_{max\,2}$ MPa	σ_{red} Mpa	$\sigma_{norm\,max}$, Mpa	$T_{max.}$ MPa	$\sigma_{max\,1}/\sigma_{max\,2}$	$\Sigma_{norm\,max}/R_y\gamma_c$	$\Sigma_{red}/1.15\,R_y\gamma_c$	$T_{max.}/0.58\,R_y\gamma_c$
Flange	-27.2	91.39	62.5	-59.9	32.8	-0.4	0.26	0.24	0.25
Wall	-66.9	0.001	58.56	-64.6	33.8	0.001	0.28	0.21	0.25
Weld joints of bearing block stop	-29.1	6.9	158.2	101.1	70.6	-0.24	0.43	0.59	0.52

The analysis of the stress-deformed state of the structures of the upper and bottom sub-pulley frames resulted in the following typical ranges of alternating stresses: "A1" is a flange of the resting node of the pulley bearing (under the frontend face of the pulley bearing); "A2" is a wall of the resting node of the pulley bearing (under the frontend face of the pulley bearing); "A3" are weld joints of the front block stop of the pulley bearing (see Fig. 3).



a *b* *c*

Fig. 3. The typical ranges of alternating stresses: a – "A1" is a flange of the resting node of the pulley bearing; b – "A2" is a wall of the resting node of the pulley bearing; c – "A3" are weld joints of the front block stop of the pulley bearing

Analysis of the typical ranges of alternating local stresses resulted in the following characteristics of the cycles: the maximum (σ_{max}, τ_{max}) and minimum normal and tangential stresses of a cycle (σ_{min}, τ_{min}); the coefficients of asymmetry of the cycle stresses $\rho = \sigma_{min}/\sigma_{max}$; the range of stresses of the cycle ($\sigma_{\text{т}}$, $\tau_{\text{т}}$) and the average stresses of the cycle (σ_a, τ_a).

On the base of the obtained characteristics of the cycles the fatigue strength was controlled with the help of three techniques (see Table 2).

Table 2

Type of fatigue strength control	Typical ranges of alternating stresses		
	A1	A2	A3
Building Code II-23-81* (point 9.2*)	is ***not*** met	is ***not*** met	is met
Building Code B.2.6-163 (point 1.11.2)	is ***not*** met	is ***not*** met	is ***not*** met
EN1993-1-9-2009 (point 8)	is ***not*** met	is ***not*** met	is ***not*** met

According to the given results for the pulley resting node of the multiple-rope hoisting plant the fatigue strength condition is not met, that paints to a necessity of taking into account the dynamic behavior of loads when designing sub-pulleys structures of the sloping shaft headgears.

Conclusions. The numerical experiment in the components of the guide pulley resting node resulted in the establishment of the character of the stress-deformed state under the static and dynamic components of the load of the hoisting cable tension. At the point of the supporting bearing attachment in the girder chord the investigation revealed a plane stress-deformed state ($\sigma_{max1}/\sigma_{max2}$ = -0.4). In the girder wall the stress-deformed state was close to the linear one ($\sigma_{max1}/\sigma_{max2}$ = -0.001).

The analysis of the stress-deformed state of the main components of the guide pulley resting nodes established the following typical ranges of the alternating stresses: “A1” – in the flange of the resting node of the pulley bearing (under the frontend face of the pulley bearing); “A2” in the wall of the resting node of the pulley bearing (under the frontend face of the pulley bearing); “A3” is a near-joint range of welded joints of the front block stop of the pulley bearing.

For the specified ranges we found out the behavior of the dynamic stress cycles (the maximum stresses of the cycle σ_{max}, the minimum stresses of the cycle σ_{min}, the average stresses of the cycle σ_{aver}, the amplitude of stresses of the cycle σ_a, the asymmetry parameter of the cycle of stresses) and tested the fatigue strength with the help of the techniques from [1, 2, 3] which showed that in the range of local stresses A1, A2, A3 the fatigue strength is not secured. Thus, the structural form of the resting nodes of the guide pulleys of the headgears equipped with the multiple-rope above-ground hoisting plants is not perfect and the components of these nodes are to be enhanced.

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