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ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ НАПРУЖЕНО-ДЕФОРМОВАНОГО СТАНУ ПІДШКІВНИХ КОНСТРУКЦІЙ ШАХТНИХ РАМНИХ УКІСНИХ КОПРІВ

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Анотація. У статті наведено результати теоретичних і експериментальних досліджень напружено-деформованого стану вузлів опирання направляючих шківів конструкцій рамних шахтних копрів. В результаті математичного моделювання та статистичного аналізу експериментальних даних встановлені: закономірності розподілу місцевих напружень; характеристики динамічних напружень для перевірки втомної міцності підшківної конструкції. Виконано порівняння результатів математичного моделювання та фізичних експериментів. Виконана оцінка ресурсу вузлів обпирання напрямних шківів по втомної міцності. У цілому отримані результати є основою для вдосконалення інженерних методик розрахунку сталевих конструкцій шахтних укісних копрів.

Ключові слова: шахтний рамний укісний копер, підшківні конструкції, вузол опирання направляючого шківа, метод тензометрирування, напружений стан, місцеві напруження, втомна міцність.

ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ НАПРЯЖЁННО-ДЕФОРМИРОВАННОГО СОСТОЯНИЯ ПОДШКИВНЫХ КОНСТРУКЦИЙ ШАХТНЫХ РАМНЫХ УКОСНЫХ КОПРОВ

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Аннотация. В статье приведены результаты теоретических и экспериментальных исследований напряжённо-деформированного состояния узлов опирания направляющих шкивов конструкций рамных шахтных копров. В результате математического моделирования и статистического анализа экспериментальных данных установлены: закономерности распределения местных напряжений; характеристики динамических напряжений для проверки усталостной прочности подшкивных конструкций. Выполнено сопоставление результатов математического моделирования и физических экспериментов. Произведена оценка ресурса узлов опирания направляющих шкивов по усталостной прочности. В целом полученные результаты являются основой для совершенствования инженерных методик расчета стальных конструкций шахтных укосных копров.

Ключевые слова: шахтный рамный укосный копёр, подшкивные конструкции, узел опирания направляющего шкива, метод тензометрирования, напряжённое состояние, местные напряжения, усталостная прочность.

EXPERIMENTAL RESEARCH OF THE MODE OF DEFORMATION OF SUB-PULLEY STRUCTURES OF SHAFT FRAME-TYPE SLOPING HEADGEAR

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Abstract. The paper is about the theoretical and experimental survey of the mode of deformation of the guide pulley resting joint of the shaft frame-type sloping headgears. As a result of the mathematical modeling and statistical analysis of the experimental data we have ascertained the mechanism of local stress distribution; the characteristics of the dynamic stresses for testing the sub-pulley structure fatigue stress. We have compared the results of the mathematical modeling and physical experiments and have estimated the resource of the sub-pulley resting joints by fatigue stress. By and large the obtained data provide a basis for the improvement of the engineering procedures of designing steel structures of shaft sloping headgears.

Keywords: shaft sloping headgear, sub-pulley structures, guide pulley resting joint, stressed state, local stresses.

Urgency

Shaft sloping headgears are the most important structures of a shaft area [4]. At present in Ukraine they design and put into operation new structures of the shaft hoisting units whose technical characteristics are many times higher than the known models. The deeper area the shafts (up to 1200…1300 m), the higher area the sloping headgears (up to 60…70 m) and the larger are the dynamic loads [4, 5]. So, to provide a high degree of safety of shaft headgear structures, it is necessary to define the existing engineering design procedures which would allow taking into account the following factors of their real operation: a) distribution of local stresses in the guide pulley resting joints; b) the vibration character of the hoisting rope loads [4]. The experimental survey of the mode of deformation of sub-pulley structures is urgent as they are in charge of the reliability of the theoretical statements of the engineering procedures of designing shaft headgear.

In [6, 7, 8] for some typical structural forms of the shaft frame-type sloping headgears there was taken the theoretical survey and mathematical modeling of the stressed state of the basic bearing structures. As a result, the structures of the frame-type sloping headgears were zoned by the type and character of stress distribution. It was found out that the engineering procedures of designing sub-pulley structures, in particular the guide pulley resting joints, need refinements most of all. In [9] the mathematical modeling made it possible to determine the mechanism of distribution of local stresses under the pillow blocks of the guide pulleys which greatly differ from the traditional ideas [10].

The purpose of this research is to experimentally check the following theoretical results given in [8, 9]: a) the type of the stress state in the range of the active local stresses in the sub-pulley structures; b) the position of the most stressed point in the resting joints of the sub-pulley structures; c) the conclusion on the limitless resource by the fatigue stress of sub-pulley structures.

To achieve this purpose the following experimental problems were solved: a) measurement of the parameters of the plane stress state of the guide pulley resting joints under different operational conditions of the hoisting units; b) measurement of the parameters of the dynamic stresses in the most stressed points; c) determination of the characteristics of the cycles of the dynamic stresses.

Two frame-type shaft headgears with different structural and technological features were taken as the objects of research: a) a frame-type semi-hipped cage headgear of height 36 m equipped with a drum hoist, БЦК-9/5×2.5, with the hoisting height 1242 m, lifting speed 7 m/sec (Fig. 1a, 1c); b) a combined frame-type cage headgear of height 40 m equipped with a multiple-rope hoist of the ground location МПМН 6.2x3, with the hoisting height 1253 m, lifting speed 8.5 m/sec (Fig. 1b, 1d).

So first, for the above objects there was made a mathematical modeling of the mode of deformation of the sub-pulley structures (Table 1, Fig. 2); the results of this modeling provide a basis for the comparison with the physical experiment results.

Experimental Technique

To measure stresses in the structures, the method of strain-gage testing was applied [2, 3, 5]. To measure stresses in the structures, strain gauges ПКБ-20-200 and КФ5Р4-15-200 were used. Three-element rosettes were bonded in each measurement point (Fig. 3).

The strain gauge readings were registered with the help of the interface «ОВЕН» which quantifies the measurement results. Stresses were measured at static and dynamic loads during two complete cycles of the hoisting unit operation. The

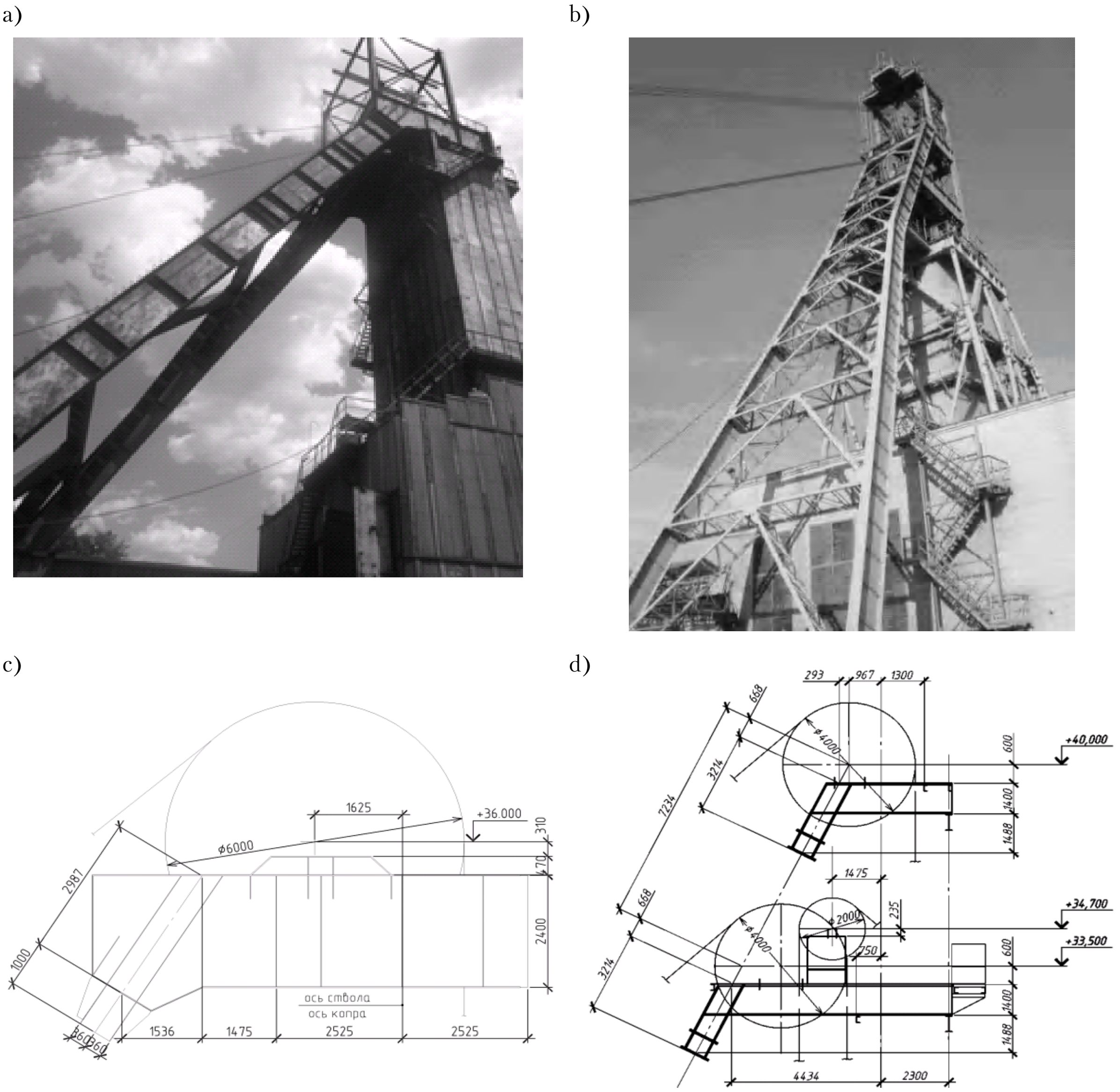

Figure 1. The general view of a semi-hipped cage headgear (a); a combined semi-hipped cage headgear (b); geometry of sub-pulley structures of a semi-hipped cage headgear (c); geometry of sub-pulley structures of a combined semi-hipped cage headgear (d).

Table 1. Results of the numerical simulation of the mode of deformation of the experimental objects

Headgear name	Values of $\sigma_{1,2}$ max in the pulley resting joints under operation loads (see Fig. 2)	
	σ_1 max, MPa	σ_2 max, MPa
Semi-hipped cage headgear	0,20	–22,8
Combined semi-hipped cage headgear	0,001	–71,1

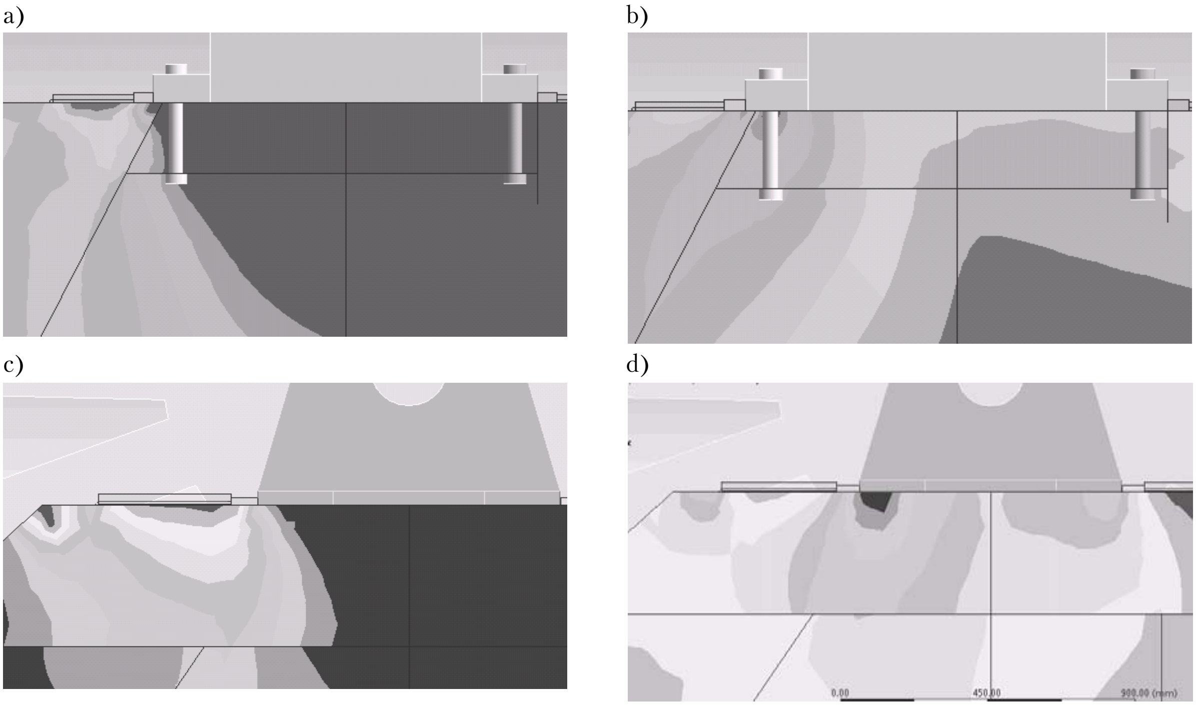

Figure 2. Iso-fields of principal stresses in a guide pulley resting joint: a) σ_1 for a combined semi-hipped cage headgear; b) σ_2 for a combined semi-hipped cage headgear; c) σ_1 for a semi-hipped cage headgear; d) σ_2 for a semi-hipped cage headgear.

general view of the measurement instrument layout on the sub-pulley structures is given in Fig. 4.

As a result of the experimental data processing according to [11] the principal stresses and orientation of their areas were determined.

In accordance with the laboratory test results the error of measuring linear stresses was not higher than 5 % at confidence coefficient 0.95. The characteristic of the measurement accuracy was done by the results of the independent trials with the use of the methods of the statistical processing of data [1, 2, 3].

The outcome of the experimental research

Correlation between the principal stress distribution diagrams resulting from the mathematical modeling and the experimental data are given in Fig. 5 and in Table 2.

The correlation between the design and experimental values of the principal stresses for a semi-hipped cage headgear (Table 2, Fig. 1a, 3a, 5a) showed the following: a) σ_1 measured in points 3–4; 6–12* coincide with the numerical simulation data; b) σ_1 measured in points 1; 2; 5 differ from the design values by 3–9 %; c) σ_2 measured in points 1–5 differ from the design values by 2.2–6.5 %; d) σ_2 measured in point 7 (the point of the maximum local stresses in zone «A» [6]) differs from the design values by 10.3 %; e) σ_2 measured in points 6; 8–12* differ from the design values by 4.5–34.2 % which is explained by the influence of the geometry imperfection in the guide pulley attachment point.

The correlation between the design and experimental values of the principal stresses for a combined semi-hipped cage headgear (Table 2, Fig. 1b, 1d, 3b, 5b) showed the following:

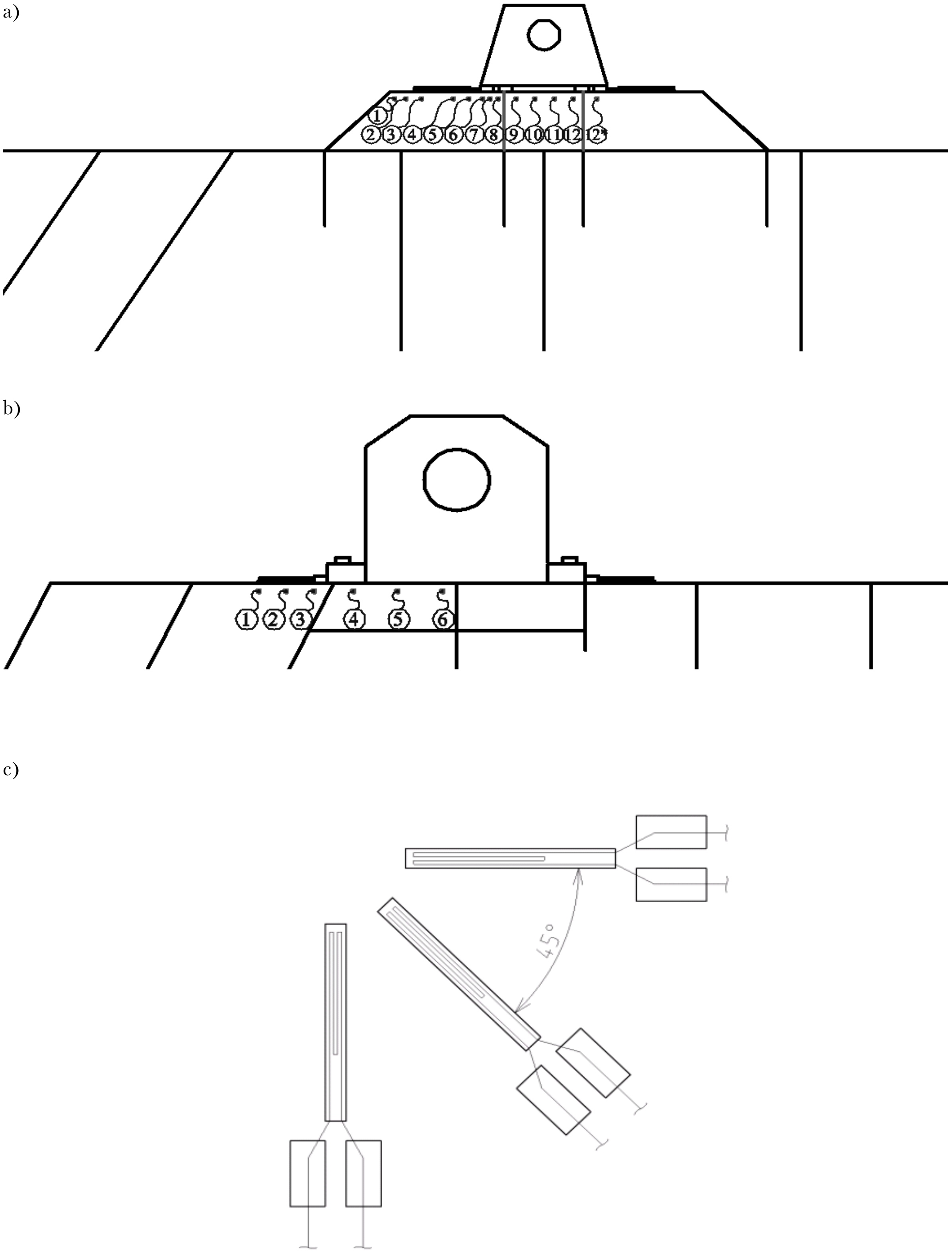

Figure 3. The layout of the rosette-type strain gages: a) for a semi-hipped cage headgear; b) for a combined semi-hipped cage headgear; c) the layout of three-element rosette bonding; 1-12*– the numbers of the stress measurement points.

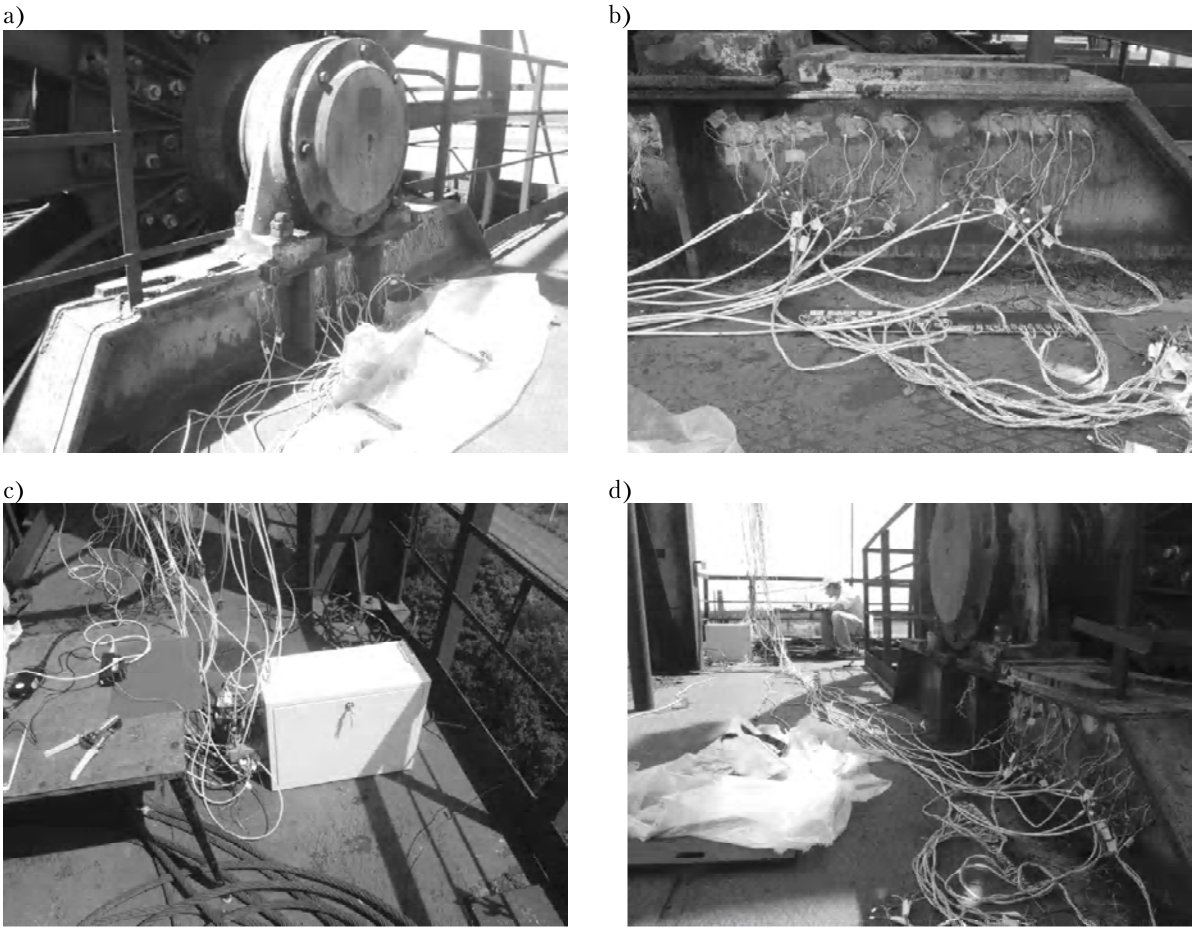

Figure 4. The general view of the measurement instrument layout on the sub-pulley structures: a) the general view of a guide pulley resting joint; b) the layout of the strain gauges; c) the testing equipment layout on the sub-pulley deck; d) the general view of the measurement equipment switching.

a) σ_1 measured in points 1–6 coincide with the numerical simulation data; b) σ_2 measured in points 1–3, 5 differ from the design values by 5–8 %; c) σ_2 measured in point 4 (the point of the maximum local stresses in zone «A» [6]) coincide with the numerical simulation data; d) σ_2 measured in point 6 differ from the design values by 29 % which is explained by the influence of the geometry imperfection in the guide pulley attachment point.

The experimental data being analyzed, there was determined the dimensionless parameter «σ_1 / σ_2» distribution which characterizes the kind of the stressed state in the guide pulley resting joints (Table 3).

The correlation between the theoretical [6, 7] and experimental data (Table 3, Fig. 1a, 1c, 3a, 5a) for a semi-hipped cage headgear gave the following: a) stress measurement points 1–6. 11–12* correspond to zone «B» with the plane stress state with σ_1 / σ_2 being in the range of 0.10–1.03; b) points 7–10 correspond to the uniaxial stress zone «A» with σ_1 / σ_2 being in the range of 0.01–0.04. The same results were obtained for a combined semi-hipped cage headgear (Table 3, Fig. 1b, 1d, 3b, 5b): a) stress measurement points 1–3 correspond to zone «B» with the plane stress state with σ_1 / σ_2 being in the range of 0.35–0.44; b) points 4–6 correspond to the uniaxial stress zone «A» with σ_1 / σ_2 being in the range of 0.02–0.04. Thus, the results of the numerical simulation of the stressed state of the guide pulley resting joints by the kind of the stressed state practically coincide with the results of the full-scale experiments.

The points with the largest tensile normal stresses were determined for the guide pulley resting joints; they are given in Fig. 6–7 [8, 11].

The design points shown in Fig. 6 were determined from the maximum values of the normal tensile stresses which make fatigue

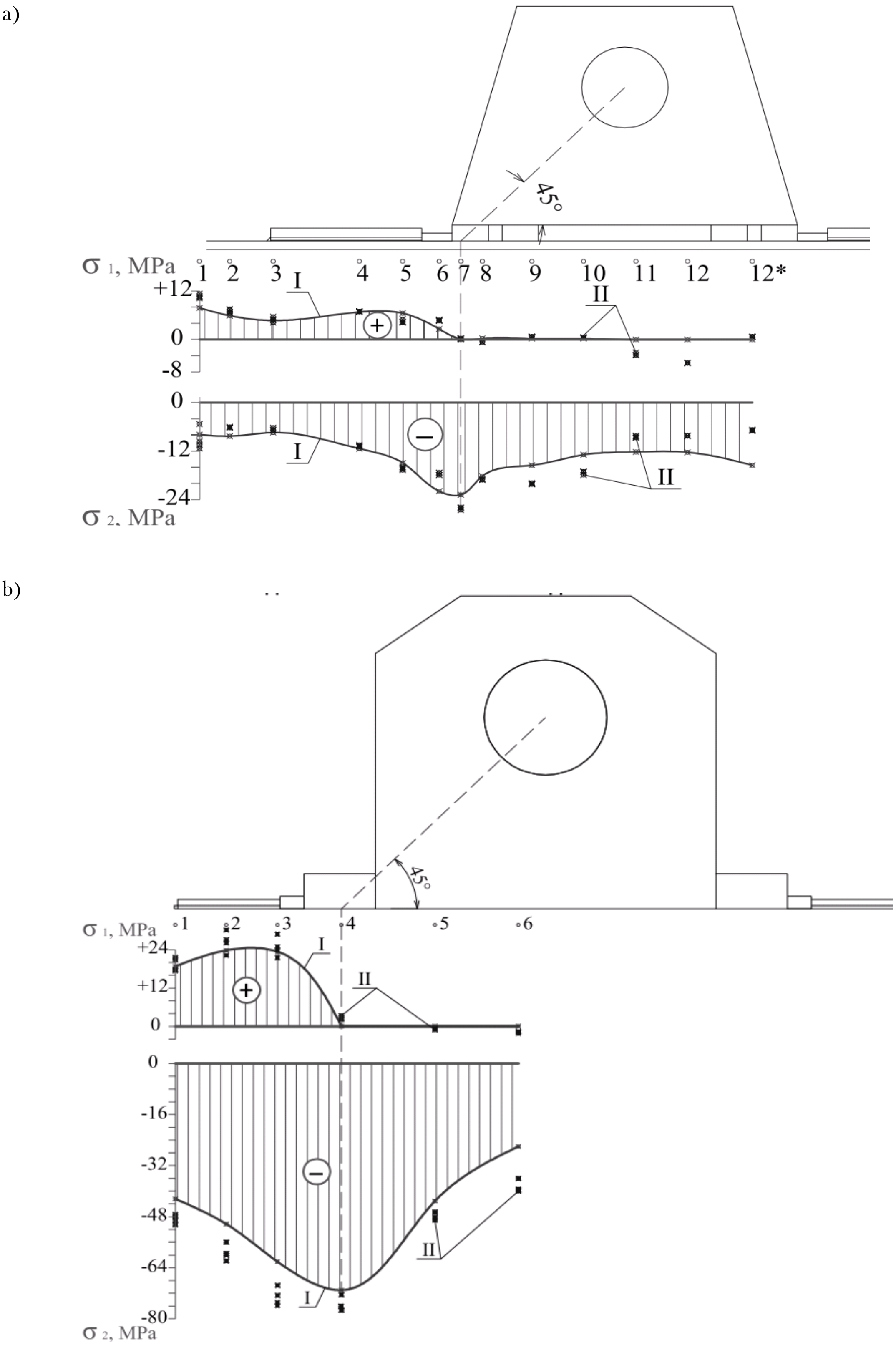

Figure 5. Correlation between the principal stress distribution diagrams in the guide pulley resting joints and the experimental data: a) for a semi-hipped cage headgear; b) for a combined semi-hipped cage headgear; I – theoretical principal stress distribution diagrams; II – experimental values of the stresses.

Table 2. Correlation between the design and experimental values of principal stresses in the guide pulley resting joints

Point num–ber	Design value σ_1. MPa	Mathematical expectation σ1. MPa		Derivation from experimental data	Design value σ_2. MPa	Mathematical expectation σ_2. MPa		Derivation from experimental data
		inf	subf			inf	subf	
Semi–hipped cage headgear								
1	8,8	9,10	9,91	3 %	–8,9	–9,45	–9,23	5,8 %
2	5,9	6,25	6,70	6 %	–8,3	–7,88	–6,88	5,0 %
3	4,7	4,18	4,78	0	–7,4	–7,02	–5,96	5,2 %
4	6,8	6,68	7,11	0	–11,4	–11,15	–10,25	2,2 %
5	5,5	4,64	5,01	9 %	–14,9	–16,95	–15,93	6,5 %
6	3,5	3,42	3,91	0	–21,9	–18,25	–16,74	16,7 %
7	0,16	0,16	0,18	0	–22,8	–26,99	–25,41	10,3 %
8	0,027	0,60	0,69	–	–18,2	–19,25	–19,05	4,5 %
9	0,027	0,69	0,72	–	–15,5	–20,30	–19,88	22,0 %
10	0,027	0,53	0,57	–	–12,9	–17,21	–16,94	23,9 %
11	0,0042	–3,74	–3,33	–	–12,3	–9,07	–7,988	26,3 %
12	0,0042	–5,80	–5,75	–	–12,3	–8,24	–8,18	33,0 %
12*	0,0042	0,670	0,72	–	–15,5	–10,200	–9,31	34,2 %
Combined semi–hipped cage headgear								
1	18,8	18,40	22,74	0	–42,4	–52,15	–45,15	6 %
2	23,8	23,58	32,09	0	–50,3	–64,89	–53,25	6 %
3	23,4	21,54	30,92	0	–62,1	–72,90	–67,83	8 %
4	0,001	1,88	2,90	–	–71,1	–80,49	–70,19	0
5	0,001	–1,19	–0,47	–	–43,1	–50,65	–45,29	5 %
6	0,001	–2,63	–1,13	–	–26,1	–41,69	–36,71	29 %

Table 3. The dimensionless parameter «σ_1 / σ_2» distribution in a guide pulley resting joint

Point number	σ_1/σ_2			Stressed state kind
	Trial 1	Trial 2	Trial 3	
Semi–hipped cage headgear				
1	–1,03	–1,00	–1,02	Plain mode of deformation
2	–0,86	–0,87	–0,91	
3	–0,71	–0,64	–0,73	
4	–0,64	–0,64	–0,66	
5	–0,30	–0,28	–0,30	
6	–0,21	–0,22	–0,20	
7	–0,01	–0,01	–0,01	Mode of deformation close to the linear one
8	–0,03	–0,03	–0,03	
9	–0,04	–0,04	–0,03	
10	–0,03	–0,03	–0,03	
11	0,42	0,41	0,42	Plain mode of deformation
12	0,70	0,70	0,70	
12*	–0,1	–0,07	–0,1	
Combined semi–hipped cage headgear				
1	–0,41	–0,41	–0,41	Plain mode of deformation
2	–0,43	–0,42	–0,44	
3	–0,35	–0,35	–0,35	
4	–0,03	–0,03	–0,03	Mode of deformation close to the linear one
5	0,02	0,02	0,02	
6	0,04	0,04	0,04	

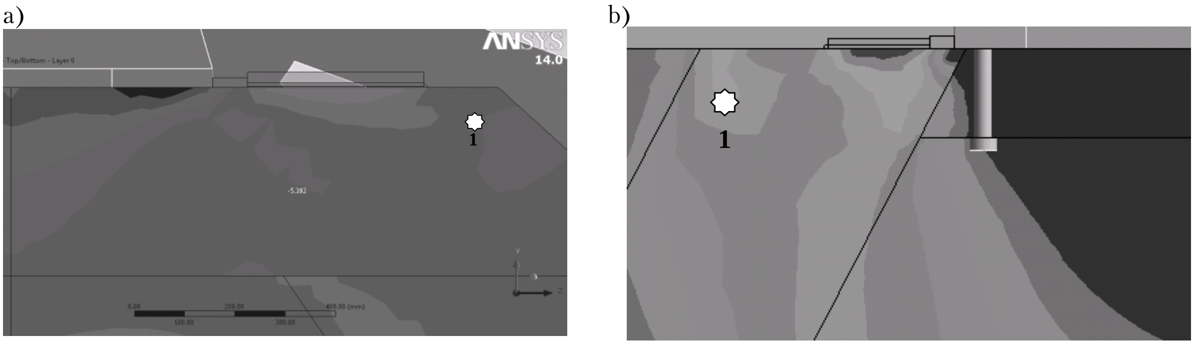

Figure 6. Points the largest tensile normal stresses (iso-fields of normal tensile stresses on the design model): a) for a semi-hipped cage headgear (see Fig. 1a, 1c, 3a); b) for a combined semi-hipped cage headgear (see Fig. 1b, 1d, 3b).

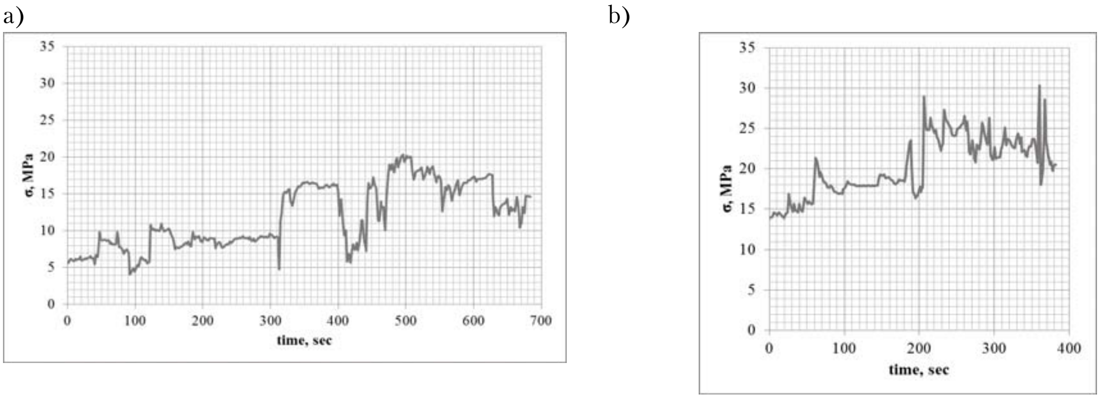

Figure 7. Diagrams of local stress changing in the design points of hoisting units during complete work cycles: a) for a semi-hipped cage headgear (see Fig. 6a); b) for a combined semi-hipped cage headgear (see Fig. 6b).

damaging possible. The diagrams of dynamic stresses in the design points for a complete work cycle of a hoisting unit are given in Fig. 7.

After the harmonic analysis of the diagrams of dynamic stresses there were determined the amplitude-frequency characteristics of the dynamic stresses and the histograms of the local stress range spectra were plotted as a function of frequency and according to the techniques given in [2, 3, 11]; the histograms are shown in Fig. 8.

The stress range being $\Delta\sigma$ = 16.24 MPa (Fig. 8a), $\Delta\sigma$ =16.43 MPa (Fig. 8b), then according to [11] fatigue stress is not limited.

Conclusions

1. The correlation between the design iso-fields of stresses in the guide pulley resting joints and experimental data disclosed a good convergence both in the kinds of the stressed state and in the location of the design points of the extreme value stresses and provided support for the theoretical conclusions in [6, 8, 9].
2. The discrepancy between the design and experimental values of stresses in the design points intended for controlling local and fatigue strength at confidence coefficient 0.95 is in the range of 5...10 % which suggests a good convergence with the theoretical results in [6, 8, 9].
3. The harmonic analysis of the dynamic stresses in the design points of the guide pulley resting joints showed their unlimited life in fatigue strength which provides support for the theoretical conclusions in [6, 8, 9].

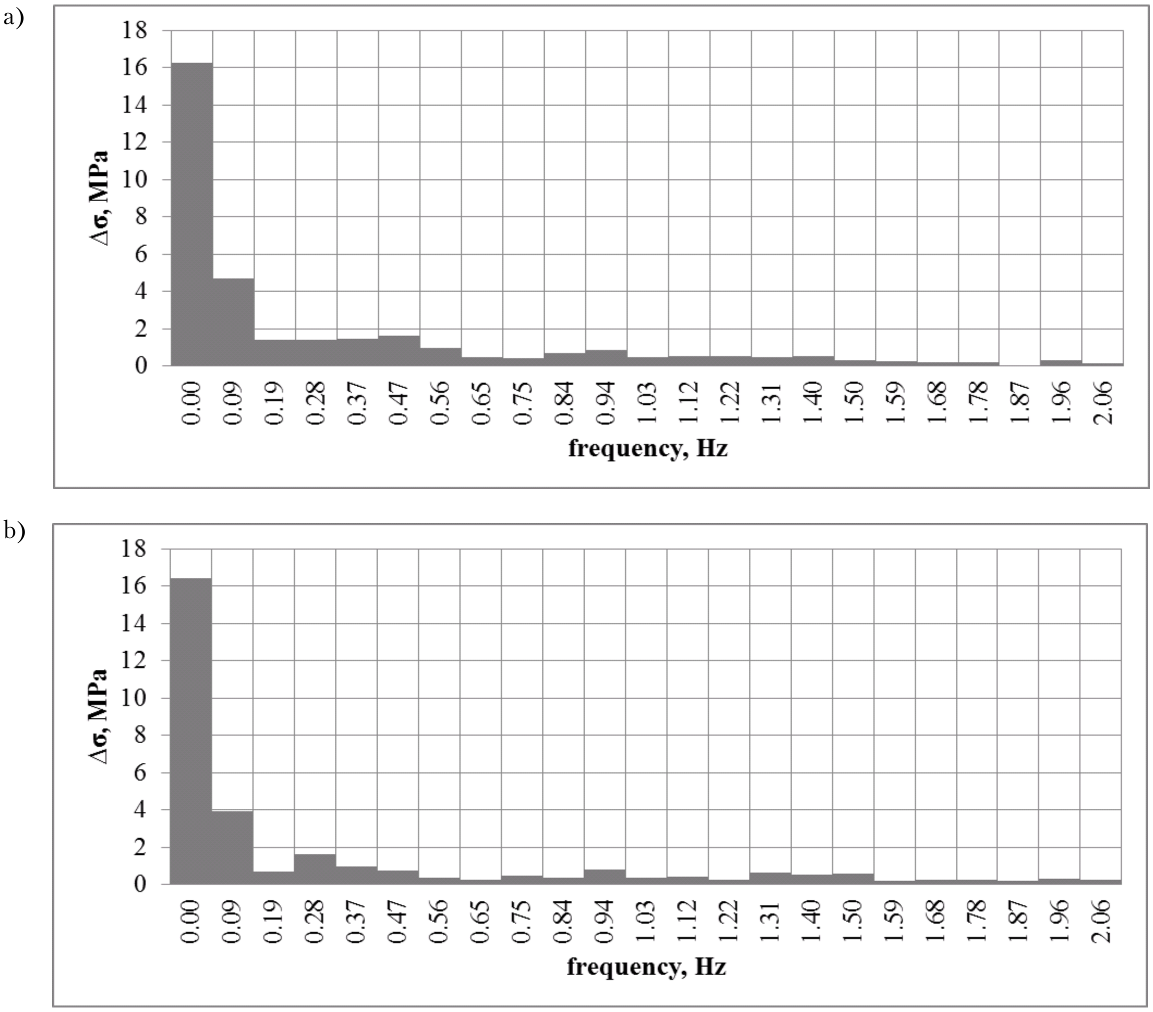

Figure 8. Amplitude-frequency characteristics of dynamic stresses in the design points of the guide pulley resting joints: a) for a semi-hipped cage headgear; b) for a combined semi-hipped cage headgear.

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