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DETERMINING STRESSES IN THE METALLIC STRUCTURE OF AN OVERHEAD CRANE WHEN USING RUNNING WHEELS OF THE NEW DESIGN

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This paper proposes a method to experimentally study the stressed state of the metallic structure of an overhead crane when using running wheels of different designs. The study employed a functioning electric, supporting, double-girder overhead crane with a capacity of 5 tons and a run of 22.5 m. Strain gauges assembled in a semi-bridge circuit and connected to the analog-digital converter Zetlab210 (Russia) were used to determine the girder deformations at the time of hoisting and moving cargoes of different masses. The cargo was lifted and displaced under the same conditions, on the regular wheels of a cargo trolley and the wheels with an elastic rubber insert. The girder deformation diagrams were constructed. The subsequent recalculation produced the stressed state's dependences at each point of cargo movement when using both regular wheels and the wheels with an elastic rubber insert. Also established were the dependences and the duration of oscillations that occur over the cycle of cargo lifting and moving. The experimental study cycle included cargo lifting in the far-left position by a trolley, moving the cargo to the far-right position, and returning the trolley with the cargo to its original position.

It should be noted that the application of a new, modernized design of the running wheels of a cargo trolley with an elastic rubber insert effectively dampen the oscillations in the metallic structure of the crane.

The experimental study's results helped establish an 18 % reduction in stresses in the girder of the overhead crane, as well as a decrease in peak vibrations, by 20 seconds, at the same cycles of cargo hoisting and moving. In addition, using wheels with an elastic rubber insert reduces the period of oscillation damping at the end of the cycle of cargo movement, by at least 30 %

Keywords: strain-gauge testing, stresses, running wheel, elastic insert, overhead crane, cargo trolley

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1. Introduction

Overhead cranes are the most used cargo-hoisting machines in modern industries, which is why ensuring their reliable and uninterrupted operation is a relevant task.

The service life of an overhead crane depends to a greater extent on the durability of its metallic structure, which perceives significant variable loads. The cyclical operation of a cargo-lifting crane predetermines the loading processes that change rapidly not only over time but also in their magnitude. This necessitates a careful determination of all the force factors that occur during overhead crane operation, both static and dynamic.

The main loads that the metallic structure of an overhead crane is exposed to occur during cargo lifting and in the operation of the mechanisms that move the cargo trolley and bridge. The relevance of this study is associated with the possibility to reduce dynamic loads during the operation of the mechanisms that move an overhead crane.

2. Literature review and problem statement

The success of the industrial process is determined by the reliability of using overhead cranes at modern manufacturing and energy-generating enterprises [1–3].

However, in addition to advantages, overhead cranes have some drawbacks [4]. Structures under cranes perceive loads from other construction and technological structures leaning on them [5]. However, such a load transfer is permissible only in cases where it is designed by default.

Large volumes of metal are used to manufacture crane metallic structures [6]. Therefore, improving the structural shape of overhead cranes is one of the important tasks.

Currently, the structural forms of many crane metallic structures have changed significantly [7]. The search for ways to reduce the weight and cost of structures while improving their quality has led to the widespread implementation of sheet box structures instead of grid-type ones and, in the grid-type ones, to a significant increase in the closed tubular profiles [8].

Despite the improvement in the structural forms of crane metallic structures, the stresses that arise in them when hoisting, lowering, and moving cargo on the crane bridge by a cargo trolley [9, 10] lead to defects in the structure of the metal [11, 12]. These defects are found in the form of bends, microcracks, and cracks in the metallic structure of an overhead crane [13].

Work [14] considered the factors that lead to the emergence of skewing forces and the destruction of individual nodes in the metallic structures of overhead cranes such as the end beams and girders. Several methods of improving the operation of crane metallic structures have been proposed. Namely, the use of hydrodynamic and hydrostatic actuators in the mechanisms that move and rotate cranes. As well as supplementing metallic structures with new carbide-and-nitride-forming alloys of iron whose fluidity limit indicators are 4–5 times larger than those of St3. Implementation of the latest research in the field of laser technology at manufacturing plants. Introduction of high-strength bolts and electric rivets to connect the girders and end beams. It is also said that these methods could improve the operation of crane metallic structures. However, there is no comparison of peak stresses in the crane metallic structures when using certain methods.

Papers [15, 16] studied the finite-element model of a metallic structure of the overhead crane and performed the static analysis using a method of finite elements to determine the stress at a dangerous point of the metallic structure. The orthogonal design was applied to model the random values of stresses at a dangerous point. A new method was devised for accurate quantitative analysis and design of the metallic structure of an overhead crane. In addition, the authors argue that their method could significantly reduce the cost of designing an overhead crane; however, no precise information about reduced costs was given.

Work [17] proposes the structure of a multidisciplinary optimization of the overhead crane. The authors reported a study of the multidisciplinary technology of crane design. The optimal mathematical model of the crane was built to optimize its metallic structure. There is also a claim that the structure of the multidisciplinary optimization of the overhead crane using finite-element analysis and dynamic modeling could ensure the rigidity of the metallic structure, which would make it possible to withstand the stresses in it. Similarly, this multidisciplinary optimization structure improves the strength and other characteristics of the crane. The study results show that the optimization of the metallic structure could significantly reduce the overall mass of the crane. Decreasing the crane mass would save money for its fabrication. However, the experimental study was conducted only on a 3D model of an overhead crane. No research involving the overhead crane at any production facility under real conditions was undertaken.

The optimization of the metallic structure of the crane with a welded box section of the beam is considered in work [18]. The optimization of the metallic structure is carried out by resizing sections of the crane girder, as well as changing the position of a cargo trolley on the girder. This technique implies comparing available analytical results to the data acquired from an analytical software employing the finite-element method and simulation. The work focuses on the modification of the existing crane metallic structure. The dimensions of the transverse cross-section of the crane girder are reduced to minimize the use of the material in its manufacture, which reduces its cost. When devising the methodology of finite elements, the authors considered the shear stress, complete deformation, maximum principal stress, and minimal principal stress to optimize the project. The optimization includes changing the parameters of metallic structures such as the size and thickness of the plates. The modernized girder proved effective in terms of design technique and was confirmed to be cost-effective given its weight loss by 8.39 % compared to the existing structure. However, no other methods to optimize the crane metallic structure were considered.

The analytical calculation of the metallic structure of an overhead crane is reported in work [19]. The maximum bending and deflection stresses of the girder were determined. The authors also calculated the parameters and built a crane model employing software. The crane model was analyzed using a finite-element method. Only after testing the metallic structure of the crane using the software, its laboratory physical model was fabricated. And, according to the authors, further research would be carried out using that laboratory model.

Our analysis of the literary sources [1–19] has revealed a lack of data on reducing the dynamic loads during the operation of the mechanisms that move an overhead crane through the improved design of the running wheel.

3. The aim and objectives of the study

The aim of this study is to determine the stressed-strained state of the overhead crane girder when using running wheels with an elastic rubber insert on the cargo trolley, which makes it possible to significantly reduce dynamic loads.

To accomplish the aim, the following tasks have been set:

– to determine the stressed-strained state of the girder at the time of hoisting and moving cargoes of different masses on the regular and modernized running wheels of the cargo trolley of an overhead crane;

– to compare the results of experimental studies of using the regular and modernized running wheels of the cargo trolley of an overhead crane.

4. Materials and methods to study the stressed-strained state of the metallic structure of an overhead crane

During the research, we used the running wheel of the cargo trolley of an overhead crane of the modernized structure, specifically with an elastic rubber insert.

The overhead crane cargo trolley was first equipped with regular wheels, then they were replaced with the modernized wheels (with an elastic, rubber insert). The crane capacity was 5 tons; the run, 22.5 meters; the lifting height, 8 meters; the operation mode, 7K.

We registered occurring loads using electric strain gauges.

Strain-gauge testing of machines, mechanisms, assemblies, and technological equipment is necessary to assess the stressed-strained state of elements, parts, and units under the operational or special modes [20, 21].

Strain-gauge testing methods are based on studying and measuring deformations, which, in most cases, makes it possible to assess the stressed state [22]. Strain gauges are resistors whose resistance changes with a change in their linear dimensions under the influence of external factors [23, 24]. The operation of strain gauges is based on the phenomenon of a strain effect, whereby the resistance of conductors changes at their mechanical deformation.

There are wire, foil, and semiconductor strain gauges. The geometric dimensions of strain gauges of the first two types change when they are deformed. The main role in the generation of an electrical signal in the semiconductor strain gauges belongs to a change in their specific resistance under the influence of mechanical loading.

The sensitivity of both mechanical and semiconductor strain gauges is estimated by the gauge factor k determined from the tensoresistive effect:

$$k = 1 + 2\mu + \nu = (\Delta R/R)/(\Delta l/l), \qquad (1)$$

where:

– μ is the Poisson coefficient;

– v is the coefficient of change in the conductor specific resistance;

– ΔR is the increase in the conductor resistance;

– R is the conductor resistance;

– Δl is the gain (decrease or increase) of the conductor geometric parameters;

– l is the conductor length.

A wire strain gauge (Fig. 1) is a mesh made from wire with a diameter of 0.02–0.05 mm, glued to the base (lining) of thin paper or lacquer film.

Wire strain gauges are executed on the base, with the loop length l=5–30 mm. The gauge factor of wire strain gauges made from the constantan wire is k=2±0.2; rated operating current, I=0.3 mA; maximum deformation should not exceed 0.3 %.

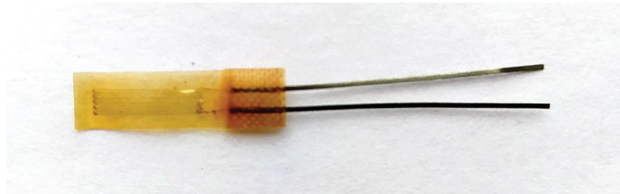


Fig. 1. Strain gauge with a wire sensing element

The wire strain gauges 2DCP–10–100B (Ukraine) were used in our experimental study.

Each strain gauge from among those selected is subject to inspection and verification. In addition, the resistance of strain gauges is measured to group them based on a minimum spread.

After marking the diagram of gluing the strain gauges (strain gauges are placed on the tested part in such a way that when deforming the latter, the strain gauge's mesh stretches or compresses), the surface of the part was heated to a temperature of 50–70 °C.

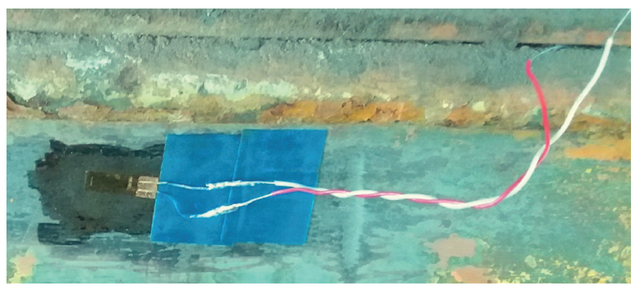


Fig. 2. Gluing strain gauges to the surface of the overhead crane girder

To glue the strain gauges (Fig. 2) to the surface of the part, we used the butyral phenolic adhesive BF-2 (Ukraine).

After checking the quality of gluing the strain gauges, we waterproofed them to protect against moisture, heat, and mechanical damage.

We also calibrated strain gauges; the calibration is carried out in combination with measuring equipment. The calibration process implies establishing a functional relation between the load, acting on a tested part, and the output signal from the equipment.

The outer wires of strain gauges were connected, with the help of terminal pads, to the wires in a semi-bridge circuit, which was connected to the analog-digital converter (ADC) ZetLab 210 (Fig. 3).

Data from the ADC are sent to the electronic computing machine (PC).

Calibration implied the lifting and gradual increasing of cargo weight from 0.0 kg to 3,500 kg, with a step of increasing the cargo of 500 kg.

The cargo weight was measured using the dynamometer DPU-10-2 (Ukraine).

When lifting cargo, the delay during each cycle was 60 seconds. When lowering cargo – 180 seconds.

Fig. 3. General view of measuring equipment: 1 — terminal pad; 2 — PC; 3 — ADC; 4 — semi-bridge connection scheme

The stresses in the crane bridge for signal 1:

$$e_0 = (E_v/2)\cdot k_d \cdot \varepsilon_v, \qquad (2)$$

where:

– e_0, the stress in the crane bridge (obtained experimentally);

– E_v, the power supply to the strain gauge bridge;

– k_d, the gauge factor;

– ε_v, the relative deformation.

Find the relative deformation:

$$\varepsilon_v = \frac{dl}{l} = \frac{\varepsilon_a}{l_d}, \qquad (3)$$

where:

– ε_a, the absolute deformation;

– l_d, the strain gauge length.

Absolute deformation is calculated from the following formula:

$$\varepsilon_a = \frac{2e_0}{E_y}\cdot k_d. \qquad (4)$$

5. Results of studying the stressed-strained state of the overhead crane girder

5. 1. Results of the experimental study of the stressed-strained state of the girder

The following initial data were used for further calculations:

– the length of the working surface (crane span), l_p=22,500 mm;

– the crane bridge manufacturing material, VMST3ps;

– the girder wall thickness, δ=6 mm;

– the duration of cargo lifting is 180 s, t_p=60 s;

– the duration of cargo lowering is 60 s, t_0=180 s;

– the strain gauge length, l_d=30 mm;

– the strain gauge bridge power, E_v=1.5 V;

– the gauge factor, k_d=2;

– the Poisson coefficient, υ=0.3;

– the stresses in the bridge of the crane (obtained experimentally, Fig. 4), – e_0, mV;

– the Young modulus, E=2.05·10^5 N/mm^2.

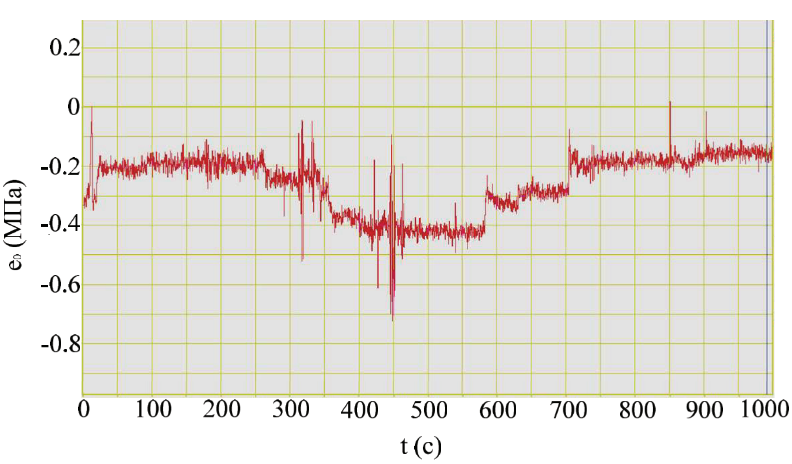


Fig. 4. Stresses in the crane bridge that were derived experimentally using the ADC Zetlab 210

Then the stress at a point (the strain gauge base) is equal to:

$$\sigma = E\cdot\varepsilon_v, \qquad (5)$$

where E is the Young modulus (of elasticity), for steel VM-ST3ps, E=2.1·10^5 N/mm^2.

To simplify the recalculations of the results, we shall highlight, at each stage of the experiment, the main points of the maximum and minimum, when lifting and lowering the cargo from 0.0 kg to 3,500 kg, in increments of 500 kg.

List the stresses obtained when the crane trolley moves without cargo and adopt the results as a reference point, Table 1.

Next, we measure the stresses in the girder at the point equidistant from the wheels of the cargo trolley of the overhead crane.

The Mathcad15 calculation software was employed to determine other strains and stresses (Fig. 5, 6).

Table 1

Summarized table of estimated physical quantities

Physical quantity	Estimated data
ε_a	0.1
l_k	750
ε_v	1.3·10^{-4}
σ	28

Based on the average values, when lifting and lowering the cargo, the crane bridge was exposed to the mechanical strains given in Table 2.

Based on the results of average strain values during the lifting and lowering of cargo, we shall build a calibration curve (Fig. 7).

The chart of strain gauge calibration shows that measuring and registering equipment and software makes it possible to build functional dependences between the load acting on the tested part and the output signal of the measuring and registering equipment in real time.

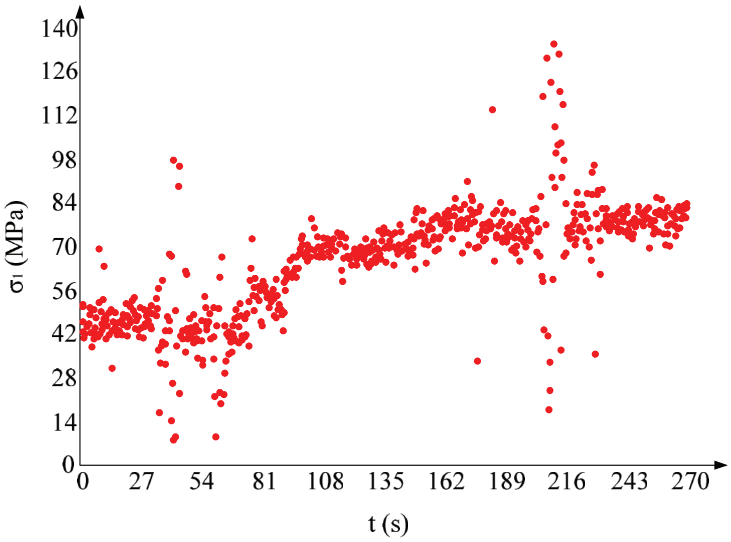


Fig. 5. Chart of stresses in the crane bridge during the lifting of cargo from 0.0 tons to 3.5 tons

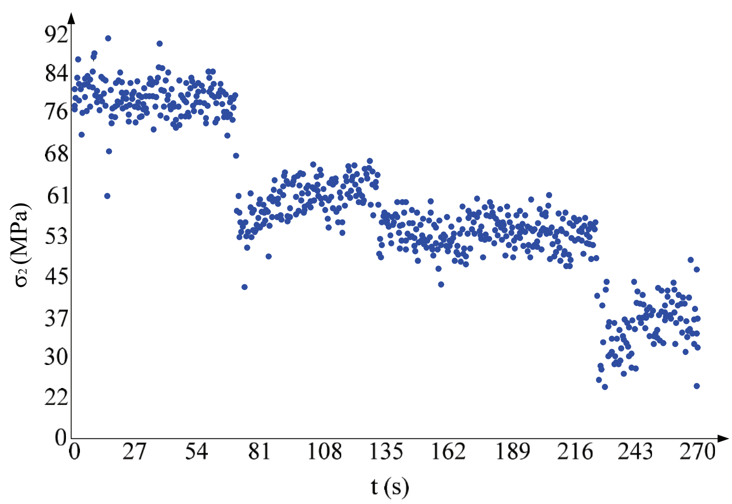


Fig. 6. Chart of stresses in the crane bridge during the lowering of cargo from 3.5 tons to 0.0 tons

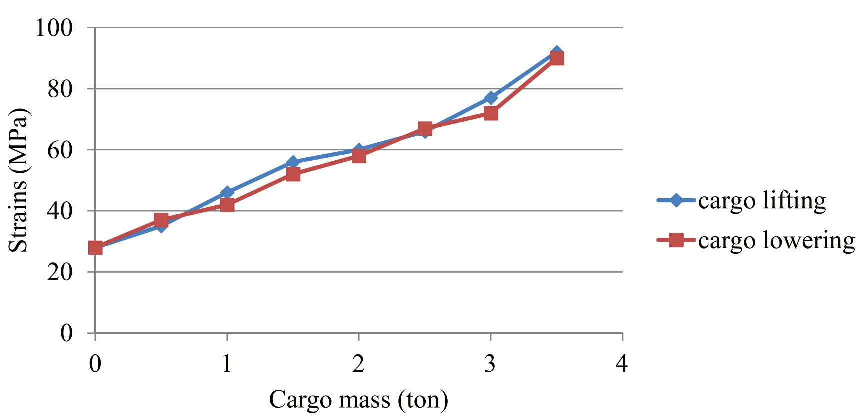


Fig. 7. Calibration curve

During the experimental study, we measured stresses in the girder of the overhead crane when the loaded trolley was moving from one edge of the girder to the other. The cargo weighing 500 kg, 800 kg, 1,800 kg was lifted with a cycle of movement of 3 times. Measurements were carried out in two variants:

1. The cargo trolley was equipped with an axle for regular running wheels.

2. The cargo trolley was equipped with an axle for the running wheels with an elastic rubber insert.

Table 2

Mechanical strains in the crane bridge during cargo lifting and lowering

Cargo mass (ton)	Strains during cargo lifting (MPa)	Strains during cargo lowering (MPa)
0	28	28
0.5	35	37
1	46	42
1.5	56	52
2	60	58
2.5	66	67
3	77	72
3.5	92	90

We built the charts of changes in the stresses recorded by strain sensors during the lifting and movement of cargo weighing 500 kg, under the influence of this cargo. When the cargo trolley was equipped with an axle for regular running wheels (Fig. 8, *a*). When the cargo trolley was equipped with an axle for running wheels with an elastic rubber insert (Fig. 8, *b*).

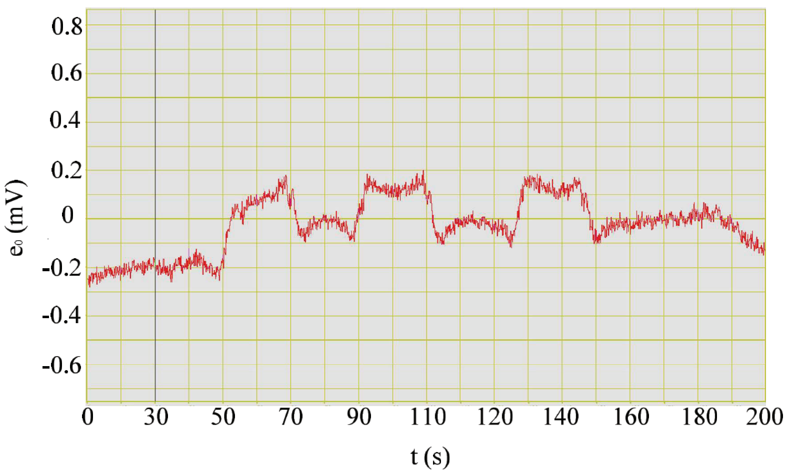
The acquired data on the stressed state in the girder of the overhead crane are converted from electrical stress signals (mV) to mechanical strains (MPa), using the already built calibration chart. Compare these data.

The procedure of data recalculation is identical to the one used in obtaining calibration data.

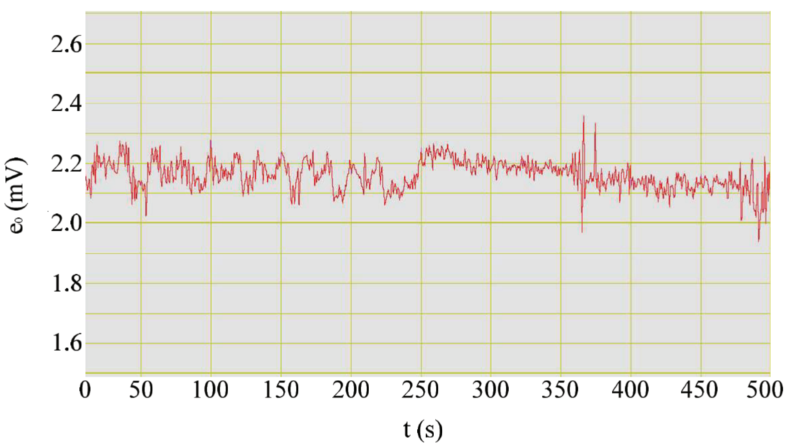
Fig. 9 shows the stresses that occur in the girder of the overhead crane when moving the cargo weighing 500 kg. The stresses that arise when using an axle with regular running wheels – σ_1. The stresses arising from the use of an axle with running wheels with an elastic rubber insert – σ_2.

The chart in Fig. 9 shows that the peak stresses σ_1 over the time of one cycle of movement of the loaded trolley from the extreme far-left to the extreme right position occur over a time of 1/2 of the trolley movement time. In addition, the chart (Fig. 9) demonstrates that the peak stresses σ_2 are much short-lived and less than σ_1 by the orders of time.

Peak stresses σ_2 are short-lived and quickly dampened due to the influence of the elastic rubber insert, which dampens the oscillations and reduces their propagation along the entire length of the girder of the overhead crane. It should also be noted that already during the movement of cargo weighing 500 kg, the elastic rubber insert in the wheels effectively dampens the oscillations of the girder. Thus, the elastic rubber insert reduces the transfer of oscillations to the mounting sites of the girder and the final, known place of stress concentrator and the site of defects.



a



b

Fig. 8. Strains in the girder of the overhead crane when lifting cargo weighing 500 kg: *a* — when the cargo trolley was equipped with an axle for regular running wheels; *b* — when the cargo trolley was equipped with an axle for running wheels with an elastic rubber insert

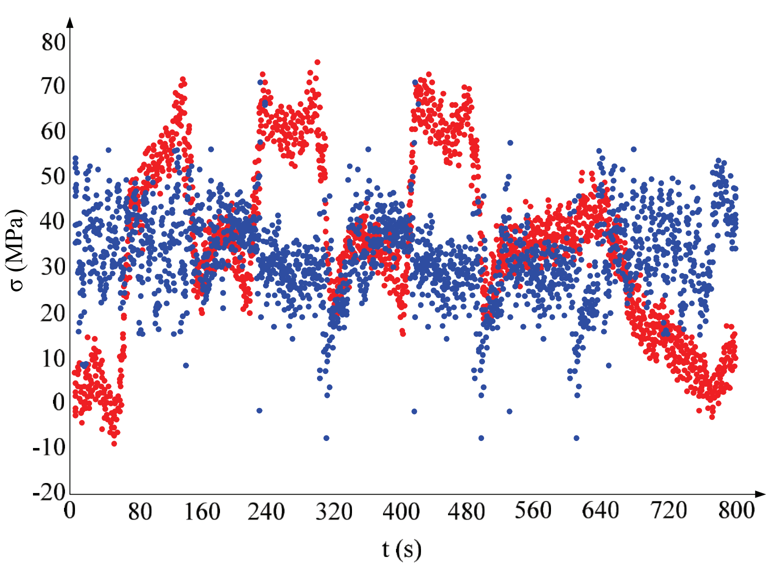


Fig. 9. Comparison of mechanical strains in the girder of the overhead crane when moving cargo weighing 500 kg: ● ● ● — σ_1; ● ● ● — σ_2

The elastic rubber insert in the wheels of the trolley axle reduces both the size and duration of oscillations, thereby reducing the work of the crane metallic structure during operation. When lifting and moving the cargo, the metallic structure of the crane performs the function of the resistance to forces that should not go beyond the zone of elastic deformations, which is briefly possible at resonant oscillations. The elastic rubber insert either significantly reduces the period of peak resonance oscillations or eliminates them altogether.

The intensity and duration of mechanical strains in the girder of the overhead crane change, when using regular running wheels and the wheels with an elastic rubber insert, in line with the tendency given in Table 3.

Table 3

Comparison of mechanical strains in the girder of the overhead crane when moving cargo weighing 500 kg

Cargo trolley position (cycle)	The nature of the load relative to the position studied	σ_1 (MPa)	σ_2 (MPa)
1	Starting point (no load)	0	0
2	Lifting the cargo in the far-left position of the trolley on the girder of the overhead crane	10	33
3	Moving the trolley with cargo to strain gauges (located in the middle of the run)	40	40
4	The trolley with cargo is in the middle of the run	63	50
5	Peak stresses	72	52
6	The cart with cargo is in the far-right position	38	20
The average value of stresses in the girder		37.1	32.5

The next stage of our experimental study is the lifting and movement of cargo weighing 800 kg, which is 16 % of the maximum permissible carrying capacity.

The lifting and moving cargo weighing 800 kg produced the charts of changes in the stresses recorded by strain sensors under the influence of this cargo. When the cargo trolley is equipped with an axle for regular running wheels (Fig. 10, *a*). When the cargo trolley is equipped with an axle for running wheels with an elastic rubber insert (Fig. 10, *b*).

The built charts of experimental data demonstrate a pattern of reducing the stress in the girder of the overhead crane (Fig. 11). The stresses that arise when using an axle with regular running wheels – σ_1. The stresses arising from the use of an axle with running wheels with an elastic rubber insert – σ_2.

However, the trend of reducing stresses is of a different nature.

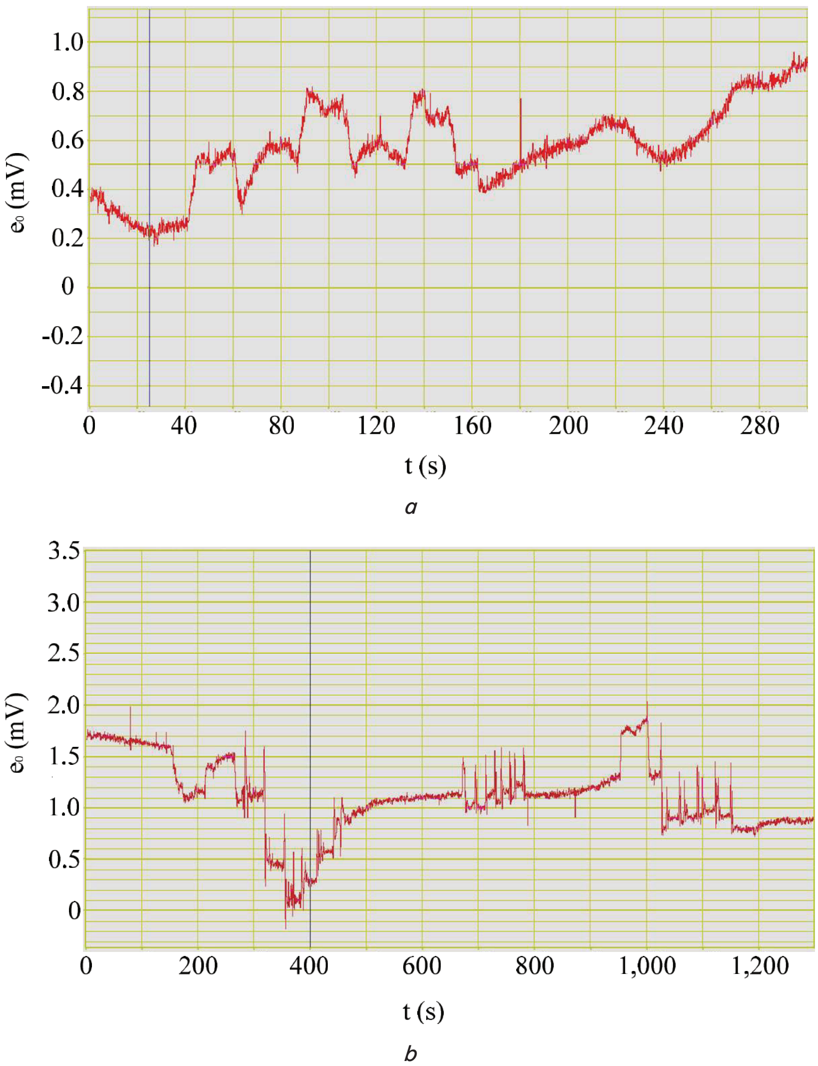


Fig. 10. Strains in the girder of the overhead crane when lifting cargo weighing 800 kg: *a* – when the cargo trolley is equipped with an axle for regular running wheels; *b* – when the cargo trolley is equipped with an axle for running wheels with an elastic rubber insert

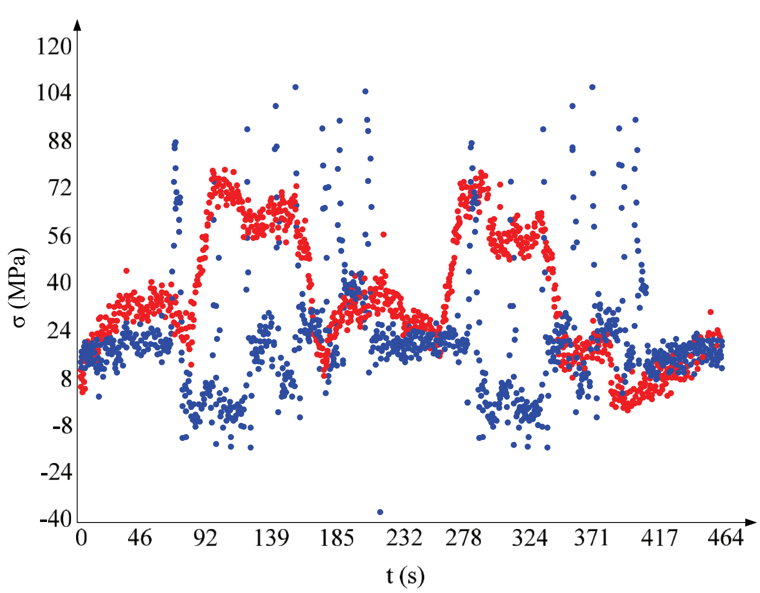


Fig. 11. Comparison of mechanical strains in the girder of the overhead crane when moving cargo weighing 800 kg: ● ● ● – σ_1; ● ● ● – σ_2

Similarly, there is a significant decrease in the duration of the peak, resonance stresses when the cargo trolley is equipped with an axle for running wheels with an elastic rubber insert. However, the magnitude of peak stresses at some points even exceeds the stresses when the cargo trolley is equipped with an axle for regular running wheels. However, the intensity and duration of mechanical strains in the girder of the overhead crane, when using an axle with running wheels with an elastic rubber insert, change in line with the trend given in Table 4.

Table 4

Comparison of mechanical strains in the girder of the overhead crane when moving cargo weighing 800 kg

Cargo trolley position (cycle)	The nature of the load relative to the position studied	σ_1 (MPa)	σ_2 (MPa)
1	Starting point (no load)	0	0
2	Lifting the cargo in the far-left position of the trolley on the girder of the overhead crane	24	20
3	Moving the trolley with cargo to strain gauges (located in the middle of the run)	40	28
4	The trolley with cargo is in the middle of the run	70	40
5	Peak stresses	90	82
6	The trolley with cargo is in the far-right position	42	28
The average value of stresses in the girder		44.3	38

The next stage of our experiment is the lifting and movement of cargo weighing 1,800 kg, which is 36 % of the maximum permissible cargo capacity.

The lifting and moving cargo weighing 1,800 kg produced the charts of changes in the stresses recorded by strain sensors under the influence of this cargo. When the cargo trolley is equipped with an axle for regular running wheels (Fig. 12, *a*). When the cargo trolley is equipped with an axle for running wheels with an elastic rubber insert (Fig. 12, *b*).

The built charts of the experimental stress distribution data, when hoisting cargo weighing 1,800 kg, demonstrate the steady and repeated pattern of reducing the averaged stresses throughout the entire experimental cycle (Fig. 13).

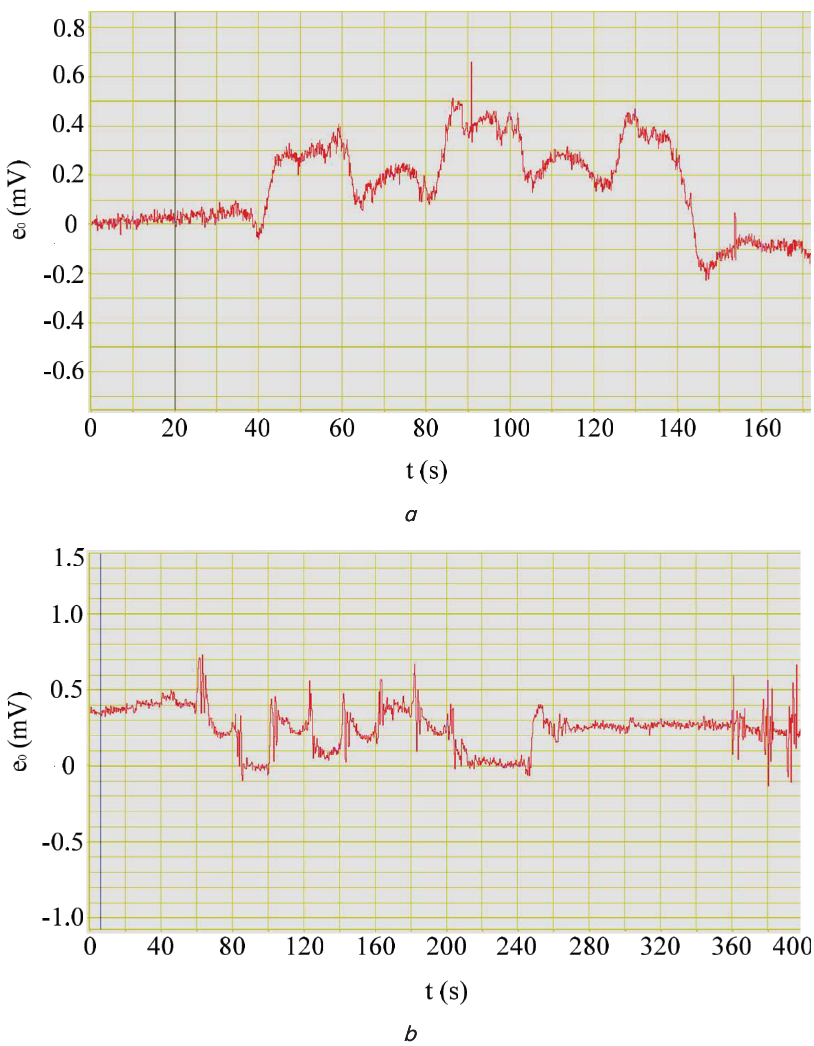


Fig. 12. Stresses in the girder of the overhead crane when lifting cargo weighing 1,800 kg: *a* — when the cargo trolley is equipped with an axle for regular running wheels; *b* — when the cargo trolley is equipped with an axle for running wheels with an elastic rubber insert

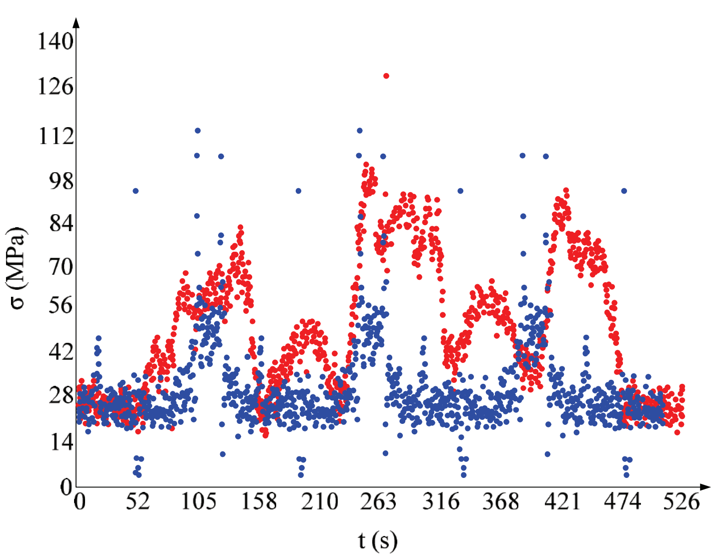


Fig. 13. Comparison of mechanical strains in the girder of the overhead crane when moving cargo weighing 1,800 kg: ● ● ● — σ_1; ● ● ● — σ_2

There is both a decrease in the amplitude of oscillations and the magnitude of peak stresses, as well as their duration over time. Processing the results, we define the patterns of stress distribution in different periods of passing the trolley with a load weighing 1,800 kg, across the girder of the overhead crane. The intensity and duration of mechanical strains in the girder of the overhead crane, when using an axle with running wheels with an elastic rubber insert, change in line with the trend given in Table 5.

Table 5

Comparison of mechanical strains in the girder of the overhead crane when moving cargo weighing 1,800 kg

Cargo trolley position (cycle)	The nature of the load relative to the position studied	σ_1 (MPa)	σ_2 (MPa)
1	Starting point (no load)	0	0
2	Lifting the cargo in the far-left position of the trolley on the girder of the overhead crane	24	28
3	Moving the trolley with cargo to strain gauges (located in the middle of the run)	56	42
4	The trolley with cargo is in the middle of the run	94	56
5	Peak stresses	105	112
6	The trolley with cargo is in the far-right position	42	28
The average value of stresses in the girder		53.5	44.3

When comparing the results of the experimental study, during the movement of cargo weighing 1,800 kg, we see a significant decrease in both stresses and oscillations when using wheels with an elastic rubber insert.

5. 2. The comparison of experimental data using running wheels of the regular and modernized design

The comparison of mechanical strains in the girder of the overhead crane when moving cargo weighing 500 kg shows a rapid dampening of peak stresses. We also observe that the peak stresses, when the cargo trolley is equipped with an axle for regular running wheels, are 72 MPa (Table 3). At the same time, under the same operating conditions σ_2, when the cargo trolley is equipped with an axle for running wheels with an elastic rubber insert, is 52 MPa, which is 30 % less (Table 3).

The reduction of stress in the girder of the overhead crane is due to the dampening of oscillations by the dampening elastic rubber insert and, as a consequence, the reduced effect of resonance. Under this effect, the

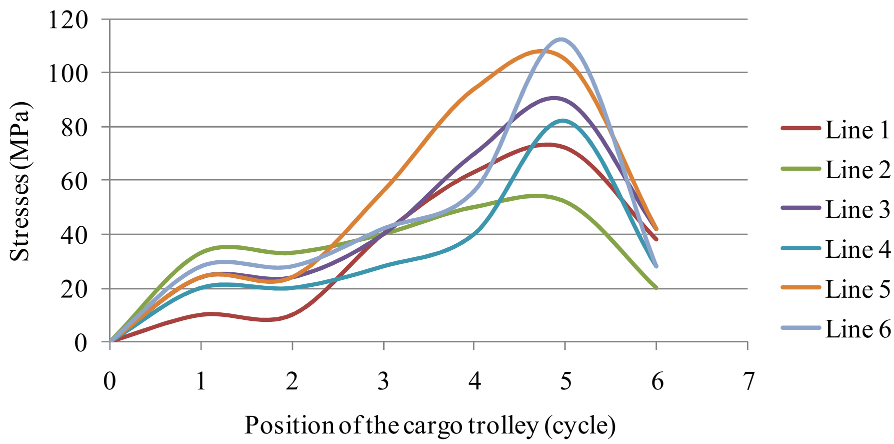


Fig. 14. The chart of dependence of the stressed state of the girder of the overhead crane on cargo weight: line 1 – the use of regular wheels, the weight of the cargo is 500 kg; line 2 – the use of wheels with an elastic rubber insert, the weight of the cargo is 500 kg; line 3 – the use of regular wheels, the weight of the cargo is 800 kg; line 4 – the use of wheels with an elastic rubber insert, the weight of the cargo is 800 kg; line 5 – the use of regular wheels, the weight of the cargo is 1,800 kg; line 6 – the use of wheels with an elastic rubber insert, the weight of the cargo is 1,800 kg

eigen frequencies of the bridge's oscillations coincide with oscillations that are transmitted during the movement of the trolley. In these cases, the elastic rubber insert makes it possible to effectively dampen the oscillations and significantly reduce peak stresses in the carrying metallic structure of the crane.

The average value of stresses when passing all cycles of lifting and moving cargo weighing 800 kg on the girder of the overhead crane for an axle with regular running wheels is 44.3 MPa (Table 4). For an axle with running wheels with an elastic rubber insert, it is 38 MPa (Table 4). There is also an 18 % reduction in stress when using an axle with running wheels with an elastic rubber insert. However, it should be noted that the reduction of stress for the axle with running wheels with an elastic rubber insert was not observed in all points of the studied position.

The magnitude of the peak stress values in the middle of the overhead crane run on the axle with running wheels with an elastic rubber insert was 90 MPa (Table 4). At the same time, on the axle with regular running wheels, the value of stresses was equal to 82 MPa (Table 4). It should also be noted that the peak stress on the axle with running wheels with an elastic rubber insert was registered 10 times with a period of 0.5 seconds (Fig. 10, *a*). On the axle with regular running wheels, the same period was continuous and lasted 65 seconds (Fig. 10, *b*). Such a long-term exposure to peak stresses significantly reduces the resource of crane metallic structure and entails rapid fatigue of the metal.

Based on the average stress values when using an axle with running wheels with an elastic rubber insert during the movement of cargo weighing 1,800 kg, the strain in the girder decreases by 18 % (Table 5). It should also be noted that there is a significant decrease in the duration of peak oscillations in the beam. They are, on average, 30 seconds for regular running wheels, and 10 seconds for wheels with an elastic rubber insert (Fig. 12).

After analyzing the data from the field experiment, we build a chart of the stressed state of the girder of the overhead crane depending on the weight of the cargo that is lifted and the position of the cargo trolley (Fig. 14).

The following positions (cycles) were considered: 1 – a cargo trolley in the far-right position without cargo; 2 – a cargo trolley in the far-right position with cargo; 3 – a cargo trolley with cargo begins to move to the central axis of the girder crossing; 4 – a cargo trolley is in the center of the axis of the girder crossing; 5 – the maximum, short-term peak indicators of the device or simulation; 6 – a cargo trolley with cargo moves to the far right position.

This chart illustrates the distribution of stresses in the central axis of the intersection of one of the two girders of the crane relative to 6 positions of the trolley with cargo.

There is also a tendency to reduce the oscillations and stresses of the girder when lifting cargoes of different masses, taking into consideration the use of wheels of different designs.

The proposed methodology for experimental studies of metallic structure stresses differs from those reported in the above works [14–19]. The impact of crane running wheels was considered previously only on the dynamic forces while our work investigates their effect on the static ones.

6. Discussion of results of studying stresses in the metallic structure of the overhead crane

As shown by Fig. 8, the maximum amplitude of stress fluctuations in the metallic structure of the girder is 0.4 mV when using regular wheels, and 0.2 mV when using wheels with rubber inserts.

When using regular running wheels, oscillations are sign-changeable, which has a rather negative effect on the girder material. When applying the upgraded running wheels, the elastic insert to the wheel is to a certain extent a shock absorber of vibrations and mitigates stresses.

These patterns are inherent in the operation of the crane with other cargoes (Fig. 10, 12), so one can consider the advantages of using the modernized design of the wheel, Fig. 14.

In the future, it would be expedient to conduct an experimental study using the running wheels of the modernized structure on the cargo trolley of the overhead crane with a carrying capacity exceeding 5 tons.

7. Conclusions

1. The stressed state of the girder when using running wheels of the new design (with an elastic rubber insert) decreases by 18 %. This is due to the elastic properties of the insert. This makes it possible to improve the durability of overhead crane girders.

2. The duration of peak oscillations when using running wheels of the new design is reduced by 30 %, which is also due to the elastic properties of the insert. This makes it possible to reduce the weight of the girders of the overhead crane by adopting smaller profiles.

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