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Questions of safety of load-lifting cranes structural connections

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Introduction. The article presents an analysis of accidents of lifting cranes, the causes of which are the destruction of load-bearing structural connections during the designated service life, caused by structural and technological deficiencies, with operational loads not exceeding the passport specifications.

Problem Statement. The objective of the study is to analyze the causes of accidents of different types of lifting cranes and the features that connect these accidents.

Theoretical Part. A review of statistical data on accidents on lifting cranes has shown that the destruction of load-bearing structures occurs not only due to fatigue strength during long-term operation, but also due to insufficient bearing capacity of the hinge joints, violations of technological processes of structural elements welding in conditions not exceeding the passport specifications during the service life.

Conclusions. It is established that the destruction occurs in the design elements of metal structures associated with the crane mounting at a relatively high level of operating stresses and insignificant loading cycles, which indicates errors in the design and violations of welding processes during their manufacture.

Key words: lifting crane, structural element of a lifting crane, safety, accident.

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Introduction. According to the data of the Federal Service for Environmental, Technological and Nuclear Supervision, more than 200 thousand lifting cranes are currently registered in the territory of the Russian Federation, of which more than 64% have served the standard service life [1].

It is known that the operation of lifting cranes that have served the standard service life is more associated with accidents due to fatigue failures of load-bearing structures. More dangerous cases of accidents occur at facilities during the specified lifetime at loads not exceeding the passport specification, due to insufficient bearing capacity of hinge joint structures or insufficient strength of welded joints of structural elements.

Problem Statement. The analysis of the operation of lifting cranes shows that there are cases of accidents at the facilities that have not worked out even half of the standard service life specified by the manufacturer [2, 3]. Let us analyze the causes of accidents of different types of lifting cranes and determine the features that unite these accidents.

Theoretical Part. Let us consider the examples of accidents related to the destruction of design elements of lifting cranes.

Example No. 1. An accident on a bridge crane with a lifting capacity of 10/10 tons. The specified service life of the crane when operating in passport mode is 10 years, the warranty period of operation is 24 months, the operating time of the crane at the time of the accident is no more than A4 with a passport value of A7.

After a year of operation of the bridge crane, during the movement of the crane, when performing technological operations with an empty grab, the welded joints of the walls of the free wheel module with a vertical sheet of metal structure of the end beam were destroyed from the side of the feeding trolleys (Fig. 1). Repair and restoration was carried out. The operation was continued.

Fig. 1. Destruction of welds along the metal boundary of the fusion of the connection of the free wheel module with the vertical sheet of the end beam

A year later, there was a complete destruction of the two nodes during crane movement when performing technological operations:

— welded joints of the module walls of the free wheel with a vertical sheet of metal structure of the end beam from the control cab side, while the wheel module fell into the aisle (Fig. 2);

— welded joints of the elements of end beams (belts and walls) with a vertical sheet of the free wheel module from the feeding trolleys side, the module wheels stay on the track (Fig. 3).

Fig. 2. Complete destruction of welded joints along the metal boundary of the fusion of the walls of the free wheel module with the vertical sheet of the end beam from the side of the crane operator's cabin

Fig. 3. Complete destruction of welded joints along the metal boundary of the fusion of the walls of the free wheel module with the vertical sheet of the end beam from the side of the trolleys

All the above-mentioned destruction of welds occurred along the metal boundary of the fusion of the elements "module elements — vertical sheet" and "end beam elements — vertical sheet". The destruction of welds on the weld metal has not been recorded.

The establishment of the circumstances of the accidents showed that the operating mode and operating conditions of the crane did not exceed the passport values, and the condition of the crane tracks met the requirements of the FRR [4].

By checking the strength of the end beam of the crane using the integrated structural analysis system "STRUCTURE CAD", it was confirmed (Fig. 4) that the applied materials and metal thicknesses of the end beams correspond to its load capacity and operating loads [5].

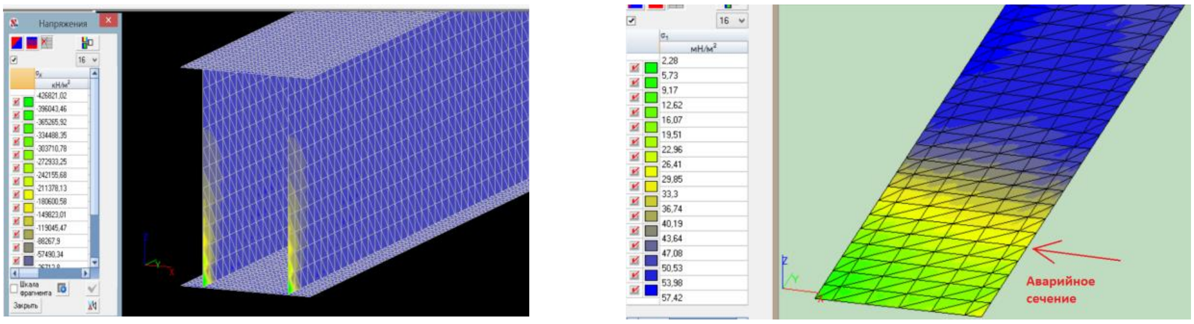

Fig. 4 Calculation model of the crane end beam

The investigation of the crane accident showed that the destruction of the end beams occurred due to insufficient structural strength (bearing capacity) of the welded joints of elements of the free wheels modules and elements of end beams with vertical sheet, namely:

— welded joints was performed without edge preparation, seam T1 GOST 14 771-76 [6], which does not match the type of the weld specified in the passport of the crane (T6 GOST 14771-76 with edge preparation);

— the actual leg, height and cross-sectional area of the destroyed welded joints made with a T1 type seam did not provide the necessary strength of the joints;

— the actual absence of a gap (less than 0.2 mm) between the welded elements of the joints (at an acceptable value of 1.5-2 mm) prevented high-quality penetration of the welded joint;

— the geometric parameters of the destroyed welding joints of the end beam elements did not meet the requirements of the design standards according to GOST 14 771-76 and RD 36-62-00 [7].

The cause of the accident should be considered a violation of welding technologies in the manufacture of the metal structure of the end beam of the bridge crane.

Example No. 2. The accident of a portal crane with a lifting capacity of 20 tons. The service life specified by the manufacturer when working in passport mode is 20 years or 50,000 hours.

During the operation of the portal crane, fatigue destruction of the two axes of the balance trolley attachment occurred.

At the time of the accident, the crane had the following operational parameters:

— the operating time of the crane of the service life — 25,000 hours;

— the mass of the overloaded material is 2.2 million tons;

— the number of work cycles is 220,000.

The analysis of the circumstances of the accidents showed that the working surfaces of all 16-running wheels have a characteristic wear of the rolling surface (Fig. 5) in the form of a "roll" with a height of 3-4 mm. The wheel flanges came into contact with the inside of the rail head due to the movement of the crane along curved sections of the track.

Fig. 5 Wear of the working surfaces of the running wheels

According to the results of the planned high-altitude alignment of the section of the rail track on which the accident occurred, a narrowing of the track above the permissible value was established.

The axles of wheeled trolleys are made of forged steel 40XFA GOST 4 543-71 [8]. 40XFA grade steel [9, 10] is alloyed, heat-treatable, has low weldability due to high crack sensitivity.

The destruction of the axles of wheeled trolleys occurred in the transition zone of the axis diameters from ∅ 150 mm to ∅ 230 mm. This section of the axis is characterized by an increased effective stress concentration coefficient at cyclic variable loads not lower than $K_\sigma = 2.5$ [11, 12]

Traces of corrosion were found on the surface of the axis fracture, which indicates the presence of an old crack with an area of about 50% of the area of the axis of the balancer. The fracture surfaces (Fig. 6, 7) have characteristic zones indicating fatigue failure of the metal resulting from the influence of alternating cyclic stresses (Fig.. 8) [12, 13]:

— 1 – zone of origin of the fatigue crack is located on the lateral surface of the axis in its most loaded part;

— 2 – fatigue crack development zone, has a smooth (lapped) surface;

— 3 – rupture area, has a coarse-grained fibrous structure of the surface, indicating the direction of destruction (Fig. 9).

Fig. 6. Fracture surfaces of axis No. 1

Fig. 7. Fracture surface of axis No. 2

Fig. 8. Fatigue failure with characteristic zones

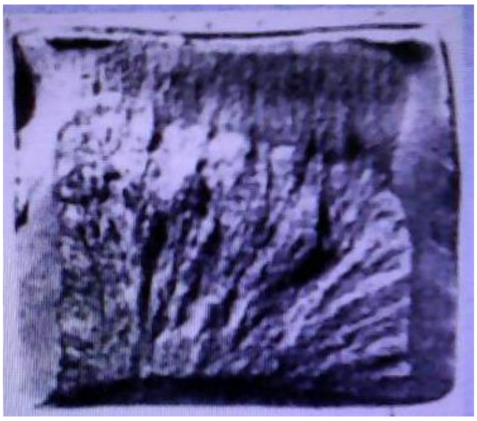

Fig. 9. Fibrous structure of the rupture area

The calculations performed using the integrated structural analysis system "STRUCTURE CAD" (Fig. 10) has showed that the combination of loads during crane operation on a curved section of the track is damaging and the condition of long-term strength is not met.

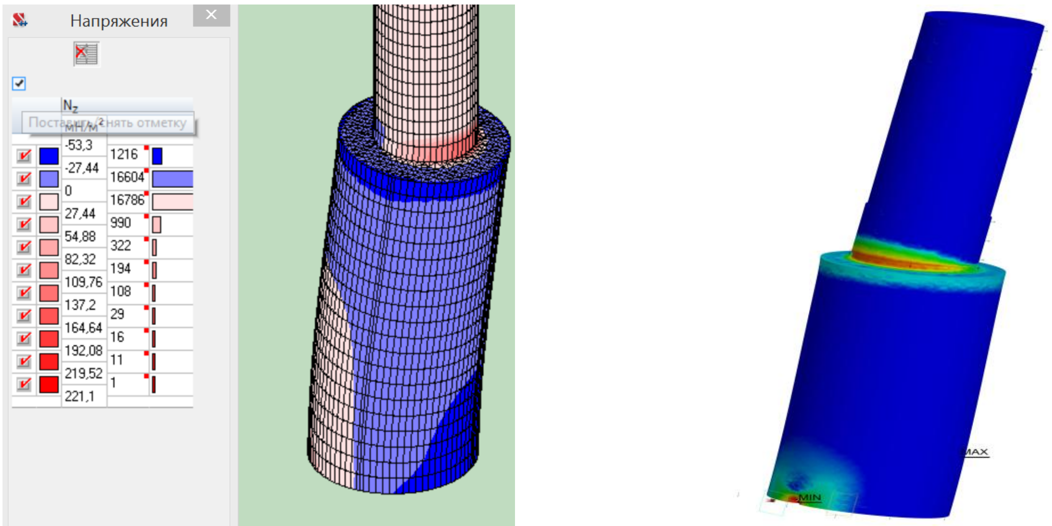

Fig. 10 Deformations and stresses in the axle of a wheeled trolley

The calculations performed on the static and fatigue strength of the axis of the balancing trolley has showed that:

1. Static loading, taking into account the weight of the grab with the load at the maximum reach in the section of the sharp transition of the diameter of the axle of the trolley, is not damaging, because the design voltage is significantly lower than the permissible one.

2. When operating the crane on a curved section of the rail track, the horizontal component of the force from the rotary part of the crane and the reaction from the interaction of the running wheel with the rail are transmitted to the crane gantry. The above combination of loads is damaging, which leads to the beginning and subsequent development of fatigue cracks in the dangerous section of the axes.

The cause of the accident and premature destruction of the axis of the balancing trolley is an error in the design of a complex-shaped product having a transition section with a high effective stress concentrator.

Conclusions. The accidents described above of lifting cranes that have not worked out even a half of the standard service life are united by the following features:

— the cranes belong to the classification group (mode) according to ISO 4301/1 – A7;

— destructions occur in the design elements of metal structures associated with the crane mounting that receive loads from the crane's own weight, moving loads and reactions from the crane rail;

— the stressed state is characterized by a relatively high level of operating stresses and the number of cycles less than $N = 10^5$.

References

1. Annual report on the activities of the Federal Service for Environmental, Technological and Nuclear Supervision in 2020. Available from: https://www.gosnadzor.ru/public/annual_reports/ (accessed: 13.01.2022). (In Russ.).

2. Federal Law No. 116-FZ of 21.07.1997 (as amended on June 11, 2021) On Industrial Safety of Hazardous Production Facilities. ConsultantPlus. Available from: http://www.consultant.ru/document/cons_doc_LAW_15234/ (accessed: 15.01.2022). (In Russ.).

3. GOST 33709.1-2015. Interstate standard. Cranes. Vocabulary. Part 1. General. Electronic Fund of Legal and Regulatory Documents. Available from: https://docs.cntd.ru/document/1200135709?marker=7D20K3 (accessed: 15.01.2022). (In Russ.).

4. Federal Rules and Regulations in the field of industrial safety "Safety rules for hazardous production facilities where lifting structures are used". Judicial and Regulatory Acts of the Russian Federation. Available from: https://sudact.ru/law/prikaz-rostekhnadzora-ot-26112020-n-461-ob/federalnye-normy-i-pravila-v/ (accessed: 16.01.2022). (In Russ.).

5. ScadSoft. Available from: https://scadsoft.com/products/scad (accessed 16.01.2022).

6. GOST 14 771-76 Gas-shielded arc welding. Welded joints. Main types, design elements and dimensions. Electronic Fund of Legal and Regulatory Documents. Available from: https://docs.cntd.ru/document/1200004932 (accessed: 17.01.2022). (In Russ.).

7. RD 36–62–00 Lifting equipment. General technical requirements. Electronic Fund of Legal and Regulatory Documents. Available from: https://docs.cntd.ru/document/1200022810 (accessed: 17.01.2022). (In Russ.).

8. GOST 4 543–71 Structural alloy steel bars. Specifications. Electronic Fund of Legal and Regulatory Documents. Available from: https://docs.cntd.ru/document/1200005485 (accessed 15.01.2022). (In Russ.).

9. Marochnik stali i splavov. Available from: http://splav-kharkov.com/z_mat_start.php?zname_id=3050 (accessed: 17.01.2022). (In Russ.).

10. Stal' 42CrMo4: kharakteristiki, rasshifrovka, khimicheskii sostav. Available from: https://metal.place/ru/wiki/42crmo4/ (accessed: 18.01.2022). (In Russ.).

11. Moskvichev V. V., Makhutov N. A., Shokin Yu. I. et al. Prikladnye zadachi konstruktsionnoy prochnosti i mekhaniki razrusheniya tekhnicheskikh system. Novosibirsk: Nauka, 2021. 796 p. 10.7868/978-5-02-038832-1 (In Russ.).

12. Smirnov A. N., Muravev V. V., Ababkov N. V. Razrushenie i diagnostika metallov. Moscow: Innovatsionnoe mashinostroenie; Kemerovo: Siberian Publishing Group, 2016. 479 p. (In Russ.).

13. Goritskiy V. M. Diagnostika metallov. Moscow: Metallurgizdat, 2004. 402 p. (In Russ.).

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Contribution of the authors:

A. A. Korotkiy — scientific supervision, analysis of the research results, correction of the conclusions; A. N. Pavlenko — formulation of the basic concept, goals and objectives of the study, preparation of the text; E. A. Panfilova — revision of the text, preparation of the conclusions; D. N. Simonov — calculations, formulation of the conclusions.