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Improving the Safety of Operation of Overhead Cranes with Welded Modular Construction Based on the Analysis of Their Accidents

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Abstract

Introduction. The article presents an analysis of the destruction of welds that occurred during the operation of modular overhead cranes. Measures are proposed to prevent the occurrence of such defects in the future, reduce the likelihood of accidents and improve the safety of operation of overhead cranes with a welded modular construction. The relevance of the work is due to the fact that in the Russian Federation approximately 65 % of the lifting cranes registered with Rostechnadzor have fulfilled the standard service life.

The work objective is to improve the safety of operation of modular overhead cranes and the reliability of their welded metal structures. Achieving the objectives of the work, based on the analysis of the destruction of metal structures of overhead cranes, a diagnostic map of welded joints of metal structures of end beams with modules of travelling wheels of overhead cranes was compiled. The use of the proposed diagnostic card in a production environment will significantly improve the quality of diagnostics of welded joints.

Materials and Methods. Investigations of accidents of load-bearing metal structures of cranes by methods of technical diagnostics of destruction of welds that occurred during the operation of overhead cranes of modular design have been carried out. This made it possible to develop a number of measures to prevent accidents of overhead cranes initiated by the destruction of their welded modular structures.

Results. Based on the analysis of accidents, a diagnostic map of destructing welded joints of metal structures of end beams with modules of travelling wheels of an overhead crane has been compiled. The use of the proposed diagnostic card will increase the reliability of welded metal structures and improve the quality of diagnostics of welded joints in production conditions.

Discussion and Conclusions. As a result of the analysis of structural failures of modular overhead cranes, a number of measures are proposed to prevent the formation of such defects, the occurrence of accidents due to them, and to improve the safety of operation of overhead cranes.

Keywords: overhead lifting crane with welded modular construction, safety, accident.

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Introduction. Currently, overhead cranes with welded modular construction get widespread use in the Russian Federation. They are widely used in technological processes at various manufacturing facilities, which determines the degree of mechanization of loading and unloading operations, affects the costs of products and other technical and economic indicators of production.

At the moment, in the Russian Federation, approximately 65 % of lifting cranes registered with Rostechnadzor have fulfilled their standard service life [1]. The operation of overhead cranes that have worked out their service life is often accompanied by accidents with cases of industrial injuries and significant material damage. In accordance with Federal Law No. 116[1] the category of hazardous production facilities includes facilities where cranes are used, and the Federal Norms and Rules[2], regulate the expert examination of industrial safety of cranes.

With the introduction of Technical Regulations TR CU 010/2011 "On the Safety of Machinery and Equipment"[3], TR CU 011/2011 "Elevator Safety"[4], TR CU 018/2011 "On the Safety of Wheeled Vehicles"[5] the term "lifting crane safety" can be considered as "design safety" at all stages of the life cycle: design, manufacture and operation. Design safety violation can lead to an accident of the lifting structure. The issues of ensuring the strength of crane metal structures are considered in works [2–6], and from the standpoint of crane safety as a complex technical system in work [7].

The work objective is to improve the safety of operation of modular overhead cranes and the reliability of their welded metal structures. Based on the analysis of the destruction of metal structures of overhead cranes, a diagnostic assessment checklist of welded joints of metal structures of end beams with modules of running wheels of overhead cranes has been compiled. The use of the proposed diagnostic assessment checklist in production conditions will significantly improve the quality of diagnostics of welded joints.

Materials and Methods. Analysis of the operation of overhead cranes by technical diagnostics methods [8] shows that in recent years accidents have repeatedly occurred on such cranes initiated by the destruction of their welded modular structures. Moreover, such accidents occurred on overhead cranes with a welded modular structure, which worked for less than a quarter of their service life specified by the manufacturer[6]. Let us analyze the causes of accidents of overhead cranes with welded modular construction. The analysis of structural failures of modular overhead cranes will allow us to propose a number of measures to prevent the formation of such defects, the occurrence of accidents due to them, as well as to improve safety of operation of overhead cranes.

Results. The service life of lifting machines is regulated by state standards, technical specifications and other regulatory documents. Each crane has a certain service life specified in its technical data sheet. As a rule, the service life of a crane is determined by the service life of its load-bearing metal structures.

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[1] Federal Law No. 116-FZ of 21.07.1997 (as amended on June 11, 2021) "On Industrial Safety of Hazardous Production Facilities". Available from: http://www.consultant.ru/document/cons_doc_LAW_15234 (accessed 03.08.2022). (In Russ.).

[2] Federal Norms and Rules in the field of industrial safety "Safety rules for hazardous production facilities where lifting facilities are used". Available from: https://sudact.ru/law/prikaz-rostekhnadzora-ot-26112020-n-461-ob/federalnye-normy-i-pravila-v/ (accessed 03.08.2022). (In Russ.).

[3] TR CU 010/2011 Technical Regulation of the Customs Union "On the Safety of Machinery and Equipment". Available from: https://docs.cntd.ru/document/902307904 (accessed 10.08.2022). (In Russ.).

[4] TR CU 011/2011 Technical Regulation of the Customs Union "Elevator Safety". Available from: https://docs.cntd.ru/document/902307835 (accessed 11.08.2022). (In Russ.).

[5] TR CU 018/2011 Technical Regulation of the Customs Union "On the Safety of Wheeled Vehicles". Available from: https://sudact.ru/law/reshenie-komissii-tamozhennogo-soiuza-ot-09122011-n_19/tr-ts-0182011/ (accessed 11.08.2022). (In Russ.).

[6] GOST 33709.1-2015 Cranes. Vocabulary. Part 1. General. Available from: https://docs.cntd.ru/document/1200135709?marker=7D20K3 (accessed 13.08.2022). (In Russ.).

For example, the reliability requirements according to GOST 27584-88[7] set the parameters for indoor overhead cranes not less than the values given in Table 1

Table 1

Indicator of service life and reliability for overhead cranes

Indicator of service life and reliability for overhead cranes	Norm for mode groups			
	1K, 2K	3K	4K, 5K	6K, 7K
Service life, years, minimum	30	25	25	20
Time between failures, cycles, minimum	11000			
Established no-failure operating time, cycles, minimum	32000		40000	64000
Established time between overhauls, cycles, minimum	30000	150000	190000	230000

Thus, for a crane of the 6K, 7K mode group with 1.5 shift work per day and the number of cycles of 5 per hour, the established no-failure operating time will be 64000/300×12×5=3.5 years.

The load-bearing metal structure of the double-girder overhead crane, shown in Fig. 1, consists of two span beams, along which a cargo trolley with a lifting mechanism moves, and two end beams with a crane mounting on them.

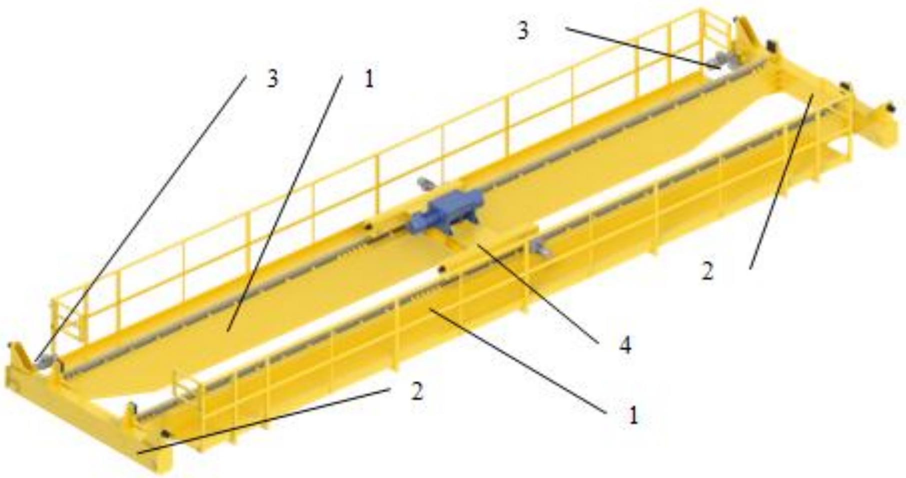


Fig. 1. General view of the metal structure of a double-girder overhead crane:
1 — span beams; 2 — end beams; 3 — crane mounting; 4 — cargo trolley

The typical metal structure of the end beam of a double-girder overhead crane, shown in Fig. 2, consists of belts (upper and lower), vertical walls and diaphragms placed inside the beam. As a rule, the vertical walls of the beams are made of a single sheet.

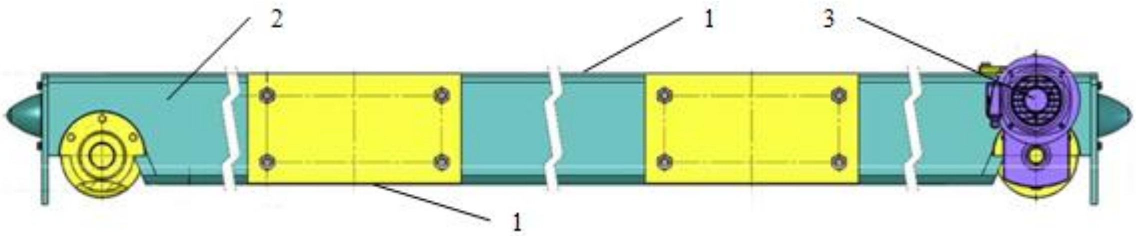


Fig. 2. General view of a typical metal structure of the end beam of a double-girder overhead crane: 1 — upper and lower belt; 2 — vertical walls; 3 — crane mounting

[7] GOST 27584-88 Electric overhead travelling cranes and gantry cranes. General specifications. Available from: https://docs.cntd.ru/document/1200004626 (accessed 19.08.2022). (In Russ.).

To install the undercarriage of a double-girder overhead crane, axle boxes with running wheels are attached to the end beams shown in Fig. 3.

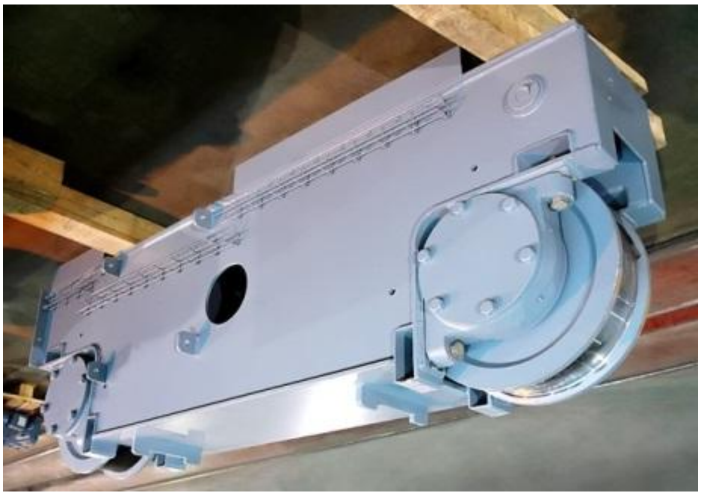


Fig. 3. Attachment of axle boxes with running wheels to the end beams of a double-girder overhead crane (photo by the authors)

Recently, modular designs of end beams with bolted (Fig. 4) or welded (Fig. 5) flange connections have become widespread.

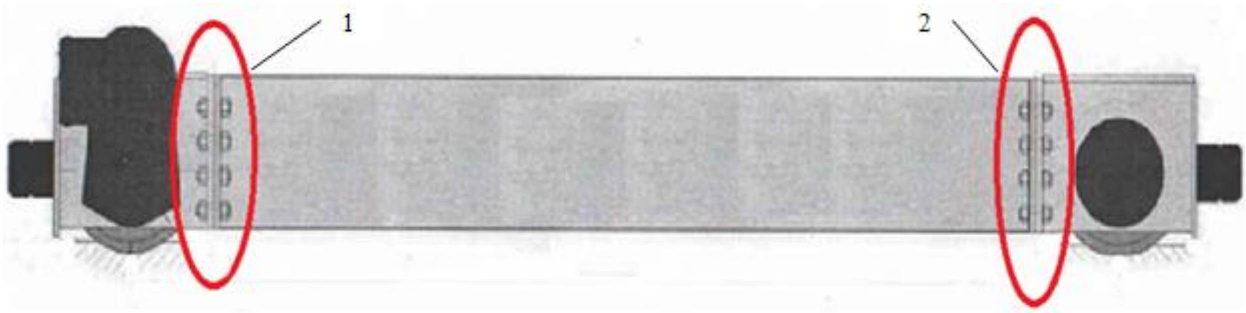


Fig. 4. Modular design of the end beam with bolted flange connection: 1 — flange connection of the drive wheel module; 2 — flange connection of the loose wheel module

Modular design makes it possible to reduce the dimensions of the end beams of the crane during its transportation to the installation site, but requires higher qualifications of specialists who install the crane in production conditions, especially modular construction with welded flange connection.

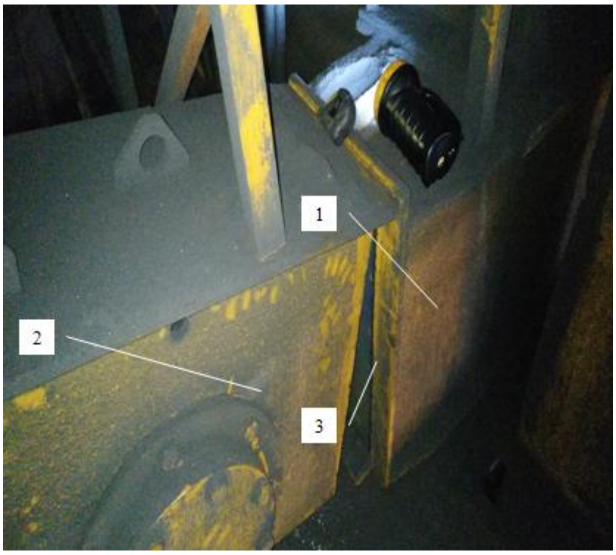
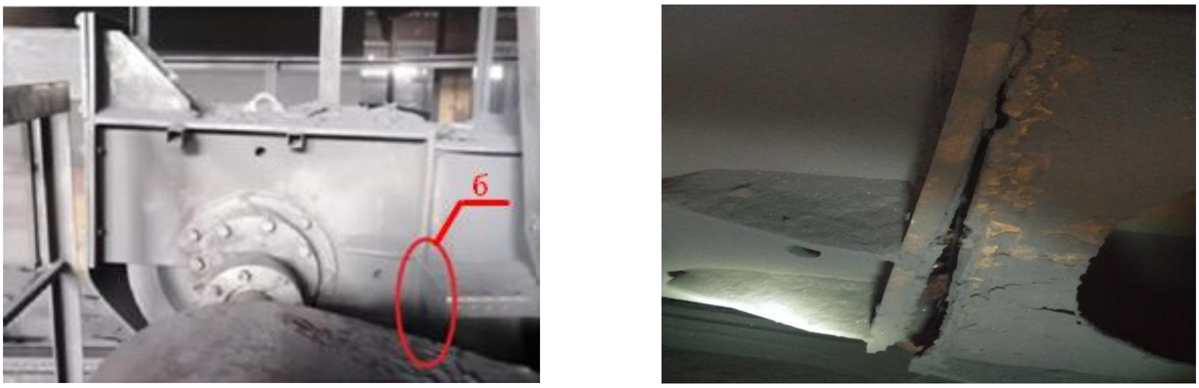


Fig. 5. Modular design of the end beam with a welded flange connection (photo by the authors): 1 — metal structure of the end beam; 2 — running wheel module; 3 — destroyed welded flange connection

The presence of a flange connection complicates the design of the end beam. In practice, there are accidents of overhead cranes caused by the destruction of the welded flange connection, shown in Fig. 6, of the undercarriage wheel module, both drive and loose, with an end beam.



a) *b)*

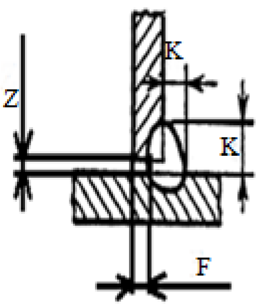
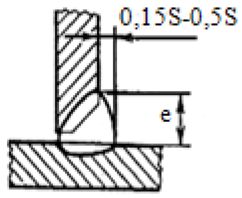
Fig. 6. Destruction of the welded joint of the drive wheel module with the end beam (photo by the authors): *a* — drive wheel module; *b* — destruction of the welded flange connection

The analysis of the causes of destruction of flange connection welds illustrated in Fig. 7, modular structures of overhead cranes allows us to prevent the appearance of such defects in the future, to increase the reliability of welded metal structures, to work out methods of diagnostics of welded joints in production conditions.

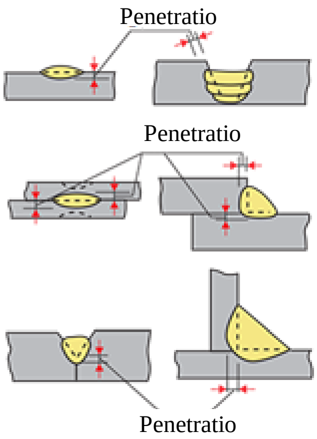
Based on the results of the survey using non–destructive testing methods [9–17], a diagnostic assessment checklist of welded joints of metal structures of end beams with modules of running wheels of an overhead crane with a lifting capacity of 10 tons was compiled, shown in Table 2.

Table 2

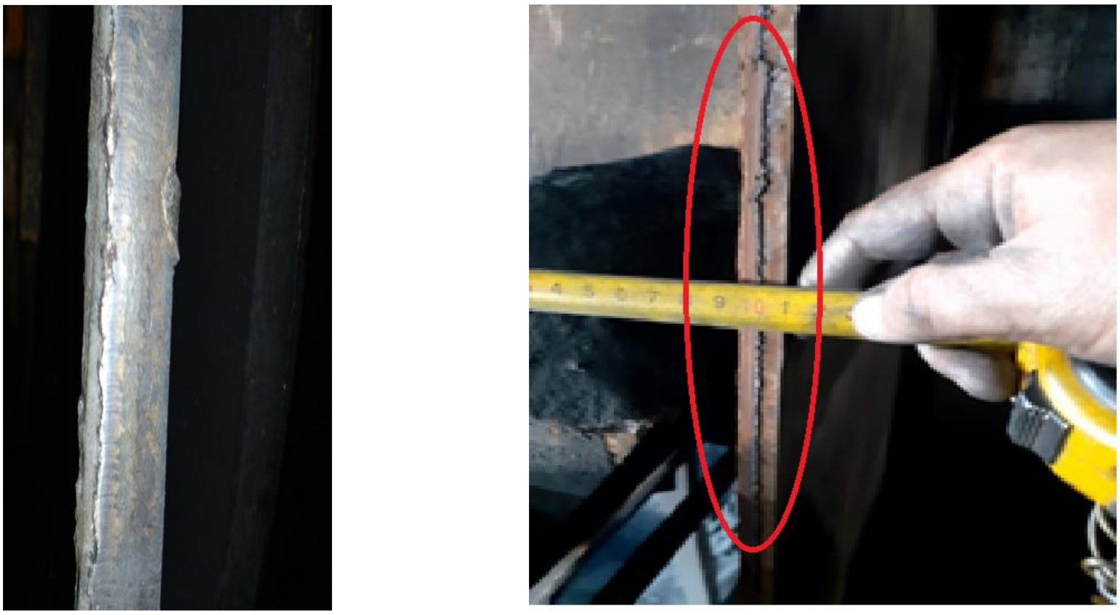
Diagnostic assessment checklist of welded joints of metal structures of end beams with modules of running wheels of an overhead crane with a lifting capacity of 10 tons

Parameter	Legend	Actual value	Recommended value
Welded joint design		T1 according to GOST 14771-76[8] – one-sided without edge preparation with constructive incomplete penetration	T6 according to GOST 14771-76 – with edge preparation 
Thickness of the metal to be welded, mm	S	10	10
Weld leg, mm, mm	K	K = 0.4s + 2 = 6	10 – 12
Gap between the metal to be welded, mm	Z	≈ 0	0 – 1.5

[8] GOST 14771-76 Gas-shielded arc welding. Welded joints. Main types, design elements and dimensions. Available from: https://docs.cntd.ru/document/1200004932 (accessed 25.08.2022). (In Russ.).

Parameter	Legend	Actual value	Recommended value
Penetration depth, mm	 H	≈ 0	1.5 – 2
Estimated height of the corner weld, mm	P	4.2	9
Estimated cross-sectional area of the weld, mm^2	F	18–20	50–70
Weld shape coefficient	$K_ф$	1.5	1.8
Calculated bearing capacity of the weld metal, kN/cm^2	$\frac{N}{\beta_f k_f l_w R_{wf} \gamma_c} \leq 1$	Estimated load-bearing capacity of 45% of the design one	Estimated load-bearing capacity of 100% of the design one

The connection unit of the undercarriage wheel module should be attributed to a heavy-loaded structure that receives loads from the crane's own weight, depends on the position of the cargo trolley in the crane span and the weight of the load lifted, receives dynamic loads from the state of the crane runway. The coefficient of shocks during the movement of the crane reaches a value of K = 1.3–1.4, and the horizontal component of the wheel pressure is R = 0.5 N, which should be taken into account when calculating the strength and durability of the structure.



a) *b)*

Fig. 7. The destroyed welded joint of the side wall of the end beam with the flange of the undercarriage wheel module (photo by the authors): *a* — penetration depth of the destroyed weld is close to zero; *b* — wall of the end beam with the destroyed weld

Discussion and Conclusion. The study presented above, in terms of improving safety of operation of modular overhead cranes and the reliability of their welded metal structures, shows that:

1. The structural safety of the modular end beam is reduced at the design stage by introducing an additional welded flange connection. The traditional design in the form of a continuous beam is more reliable in operation and has a longer service life.

2. At the manufacturing stage of the end beam, due to the unproven technological process of welding parameters, its structural safety was reduced to 45% of the required bearing capacity, which subsequently led to the complete destruction of the welded joint.

3. One-sided corner welds in the T-joints of metalwork elements should be used in structures of normal and reduced importance level according to GOST 27751-2014[9] classification. They should not be used in assemblies experiencing dynamic loads.

4. The purpose of the angle weld leg depending on the thickness according to formula K = 0.4s + 2 is acceptable for welded joints of general engineering products. For assemblies of crane metal structures that receive dynamic loads, the weld leg should be designed taking into account all possible combinations of loads.

5. The value of the weld strength coefficient φ is determined by the welding method and the weld design, which reduces its bearing capacity. For example, for a T-weld T1 with structural incomplete penetration φ = 0.65, for a welded seam T6 with full welding φ = 0.9–1.0.

6. Diagnostics of welded joints using visual and measuring control allows you to determine only surface defects, geometric parameters of the weld and their deviations. The thickness of the weld and the size of the structural incomplete penetration can be determined by ultrasonic testing using direct or inclined transducers.

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Claimed contributorship

A. A. Korotkiy — academic advising, analysis of the research results, correction of the research results. A. N. Pavlenko — formulation of the basic concept, goals and results of the study, preparation of the text. E. A. Panfilova — revision of the text, preparation of the research results. D. N. Simonov — non-destructive testing, calculations, formulation of the research results.

Conflict of interest statement

The authors do not have any conflict of interest.

All authors have read and approved the final manuscript.