https://doi.org/10.33271/nvngu/2022-3/082

Yu. H. Sahirov,
orcid.org/0000-0002-8854-0639,
K. V. Tkachuk,
orcid.org/0000-0002-0309-1644,
V. V. Suglobov,
orcid.org/0000-0003-1743-0894

Pryazovskyi State Technical University, Mariupol, Ukraine,
e-mail: ev13tk@gmail.com

IMPACT OF STRESS CONCENTRATION ON RELIABILITY OF METAL STRUCTURE ELEMENTS OF GANTRY CRANES

Purpose. Analyzing the stress distribution in the metal structure of the gantry crane under the cyclic operation mode and identifying stress concentrators in the crane column to assess the survivability of the machine.

Methodology. In order to achieve the objective, the methods employed included analytical calculation method, finite element method, as well as differential and integral calculus methods. To study the state of the metal structure of the gantry crane, namely the column, the program Solid Works and its application Simulation were used.

Findings. Using the CAD/CAE-system, the loaded condition of the metal structure of the gantry crane was modeled and the maximum working loads were determined, and a calculated scheme of their operation was constructed. The method is presented for calculation of survivability of load-bearing elements of the crane taking into account coefficients of intensity and concentration of stresses which allow defining speed of growth of cracks in dangerous stress zones of a metal structure.

Originality. The existing methods for designing crane metal structures gained their traction. The integrated technique for assessing crane reliability has been suggested for the first time. This technique is focused on estimating the survivability of components elements. For the first time solid-state models of the crane and its column have been developed; the analysis of the stress-strain state of the column was performed, maximum stresses were determined, stress concentration points in the metal structure of the column were identified and recommendations for improvement of stress zones were presented.

Practical value. The presented method for assessing the reliability of metal structures of gantry cranes can be implemented in the practice of design organizations for the development, design of new gantry cranes and modernization of existing ones. The obtained results provide an opportunity to assess the accumulated damage in the elements of the metal structure, to predict the development of defects to a critical size, as well as to decide on the further operability of a gantry crane.

Keywords: *gantry crane, metal structure, load, reliability, defect, stress*

Introduction. In Ukraine, there is an urgent matter of operating weight-lifting equipment including gantry cranes whose standard operation life exceeds their operational limit by 3–4 times [1] but those cranes are in a working condition. A decision on excessive exploitation may be taken upon service reliability analysis and residual life evaluation of the steel structures, which identify future operability of the crane. Service reliability is the most significant parameter of weight-lifting equipment quality; it is a capability of the gantry crane to maintain all its characteristics and parameters within the stipulated limits ensuring the fulfillment of all the necessary functions under certain operational conditions.

When studying gantry cranes from the point of view of service reliability, special attention needs to be paid to load-bearing elements of the metal structures that are capable of gradual failures, the occurrence of unacceptable damage, metal degradation under the influence of cyclic loads. There is a necessity to create methods that will give an opportunity to simulate such deterioration and analyze the impact of long-lasting operation on the reliability of crane structures [2]. Among the defects of the metal structure, the most dangerous is the fatigue failure, which is concentrated in the zones of concentration of stresses of the elements [3]. They occur and develop for several years in the course of their operation. Fatigue failure is characterized by two stages: the stage of formation of cracks and damage and the stage of development of defects to a critical size. It is important to secure load models that take into account all stress concentrators [4]. Therefore, as for gantry cranes, it is important to assess the accumulated damage, the impact of stress concentrators on the reliability of the metal elements and on the performance of the crane as a whole. Recently, a concept has been spread of operating cranes based on admissible damage to structure where defects develop for a long period of time allowing timely revealing and removal of such defects. Such a concept regards the criterion of survivability with its main conditions for assessment being the data on stress distribution, duration and regularity of load, the length of defect areas and the properties of the material. In order to assess those parameters, stress-strain state in the components of crane metal structures is analyzed.

Thus, maintaining the efficiency and reliability of gantry cranes during long-term operation becomes possible through the development of new methods for calculating metal structures, which is an actual task of mechanical engineering.

Literature review. It is known that operation of gantry cranes is influenced by intensive cyclic load, which leads to development of local plastic deformations in stress concentration areas [5, 6]. Such deformations cause low-cycle destructions, boosting multi-cycle destruction and an irregular stressed condition [7]. Due to the complexity of the analysis of the stress-strain state, the authors of [8, 9] systematized the equations that relate the theoretical and effective stress concentration coefficients. The paper by [10] Kozhemiaka determined that the description and modeling of the survivability of metal structures is possible with the help of probability models within mathematical reliability. The methods for studying the service life and reliability of metal structures are identified, the main provisions for the analysis of the stress-strain state are indicated by Hubskyi [11], Moskvicheva [12]. Today this is possible due to the use of discrete calculation methods based on the theory of elasticity. These methods include the finite element method, the finite difference method, and the boundary integral equation method. However, the most common is the finite element method. The idea of this method is that any continuous quantity is approximated by a discrete model that is built on a set of continuous functions. Unlike classical methods, such calculation gives the chance to receive as close rational parameters of a metal structure as possible [13, 14]. The finite element method allows solving the problem of the strained body mechanics, destruction mechanics of carrying and lifting equipment constructions [15, 16]. The author of this article in the papers [17, 18] developed a method for designing rational metal structures according on the criteria of even stress distribution using CAD/CAE-system.

However, there are no methods for analyzing the impact of stress concentrators on the reliability of crane metal structure elements.

Unsolved aspects of problem. The finite element programs created in Ukraine do not have developed modules that enable one to assess load-bearing elements taking into account the criterion of survivability, including stress intensity coefficients, stress concentration coefficients. The criterion of survivability characterizes the change in load on the path of crack growth. The development of methods for designing metal structures is the numerical modeling of the survivability of load-bearing elements in the event of damage and a detailed analysis of the stress-strain state of the object. Therefore, it is important to identify the nature of stress concentration impact on the reliability of the components with the help of calculating the survivability of problematic areas of the metal structure.

Purpose. The objective of the research is to analyze the load distribution in the metal structure of the gantry crane under cyclic mode of operation and determine in the stress-strain state of the stress concentrators of the crane elements to assess the reliability and survivability of the machine as a whole.

In order to achieve this goal, the authors solved the following tasks: determination of the stress-strain state of the elements of the metal structure on the example of a gantry crane column; analysis of operating loads; calculation of survivability taking into account the coefficients of intensity and stress concentration.

Methods. To perform theoretical research aimed at improving the stress-strain state of the structural elements of gantry cranes, a calculated scheme of forces that occur at maximum working loads (Fig. 1). It is known that the reliability of the calculation largely depends on the choice of the scheme of action of loads, their level and places of concentration of loads.

Construction of the schematic design of forces at the maximum working loadings. Using dynamic and mathematical models of the boom system of the gantry crane [19], a dynamic analysis of the acting forces and their combinations under the working load of the crane was conducted.

These loads include G – weight of the cargo; W – external wind pressure force; F_α, F_β – forces from the weight of the load when the ropes deviate from the vertical; F_{IBOOM}, F_{IJIB}, F_{IPEN} – forces of inertia during the movement of the boom device; F_{Itan}, $F_{ItanJIB}$, $F_{ITanPEN}$ – tangential forces of inertia when turning the boom device; F_1 – forces of inertia of the elements acting on a rack pinion.

The schematic design is an idealized object, which does not take into account insignificant, in terms of impact on the

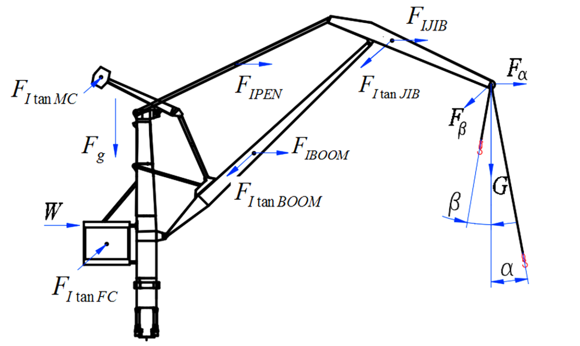

Fig. 1. The schematic design of forces acting on the metal structure of the gantry crane

stress-strain state, parts of the structure. The calculations are aimed at determining the nature of the load distribution, which will be further assessed by the reliability of the crane. The W-force from the wind pressure on the boom system is found by the formula

$$W = q \cdot k \cdot c \cdot n \cdot b \cdot L_{BOOM} \cdot \sin\gamma,$$

where q is dynamic wind pressure for operating condition (q = = 250 Pa); k is the coefficient taking the change in wind pressure over altitude into account; c is the coefficient of aerodynamic force, taking the shape of the structure into account; n = 1 is the overload coefficient; b is the average width of the windward area of the metal structure; L_{BOOM} is boom length; γ is the angle of the boom.

The forces F_α, F_β from the weight of the load when the deviation of the ropes are equal

$$F_\alpha = \frac{Q \cdot g \cdot \frac{\delta y}{\delta\alpha}}{\frac{\delta L}{\delta\alpha}},$$

where Q is the load capacity; $\frac{\delta y}{\delta\alpha}$ is the operator of the transmission of the first order of the vertical coordinates of the load in the plane of oscillation of the boom; $\frac{\delta L}{\delta\alpha}$ is the operator of the length of the working part of the rack of the mechanism of change of departure of an boom at each moment of time.

$$F_\beta = \frac{Q \cdot g \cdot \frac{\delta y}{\delta\beta}}{\frac{\delta L}{\delta\beta}},$$

where $\frac{\delta y}{\delta\beta}$ is first-order motion transmission operator vertical load coordinates perpendicular to the boom swing plane; $\frac{\delta L}{\delta\beta}$ is the operator of the length of the working part of the rack pinion of the mechanism for changing the departure of the boom relative to the angle of deflection of the ropes.

The forces of inertia during the movement of the boom device have the form

$$F_{IBOOM} = J_1 \cdot \alpha,$$

where J_1 is the moment of inertia of the boom; α is generalized coordinate of the system.

$$F_{IJIB} = \frac{m_2 \cdot y_2 \cdot \frac{\delta y}{\delta\alpha} + J_2 \frac{\delta\varphi_2}{\delta\alpha} \cdot \ddot{\varphi}_2}{\frac{\delta L}{\delta\alpha}},$$

where m_2 is trunk mass; y_2 is the vertical coordinate of the center of the trunk; J_2 is the moment of inertia of the trunk; $\ddot{\varphi}_2$ is angular acceleration of the trunk; $\frac{\delta\varphi_2}{\delta\alpha}$ is first-order motion transmission operator for the trunk.

$$F_{IPEN} = \frac{J_3 \dfrac{\delta\varphi_3}{\delta\alpha} \cdot \ddot{\varphi}_2}{\dfrac{\delta L}{\delta\alpha}},$$

where J_3 is the moment of inertia of the crane rods; $\ddot{\varphi}_2$ is angular acceleration of the crane rods; $\frac{\delta\varphi_3}{\delta\alpha}$ is first-order motion transmission operator for crane rods.

The tangential forces of inertia when turning the crane are determined by the formula

$$F_{ItanBOOM} = \frac{m_1 \cdot \pi \cdot y_1 \cdot n}{30 \cdot t_R};$$

$$F_{ItanJIB} = \frac{m_2 \cdot \pi \cdot y_2 \cdot n}{30 \cdot t_R};$$

$$F_{ItanPEN} = \frac{m_3 \cdot \pi \cdot y_3 \cdot n}{30 \cdot t_R},$$

where m_1, m_2, m_3 are weight of a boom, trunk, crane rods accordingly; y_1, y_2, y_3 are vertical coordinates of the boom, trunk, crane rods, respectively; n is frequency rotational motion; t_R is acceleration time of the turning mechanism.

One of the most loaded parts of the boom system is the rack pinion of the drive mechanism. The force in the rack pinion is created by the forces and moments of inertia of the links

$$F_{IBOOM} = J_1 \ddot{\varphi}_1 \frac{i}{R_d} + \frac{J_1 \cdot \ddot{\alpha} + m_2 \cdot y_2 \cdot \dfrac{\delta y}{\delta\alpha} + m_2 \cdot x_2 \cdot \dfrac{\delta x_2}{\delta\alpha} + J_2 \dfrac{\delta\varphi_2}{\delta\alpha} \cdot \ddot{\varphi}_2}{\dfrac{\delta L}{\delta\alpha}} + \frac{J_3 \dfrac{\delta\varphi_3}{\delta\alpha} \cdot \ddot{\varphi}_2 + J_4 \dfrac{\delta\varphi_4}{\delta\alpha} \cdot \ddot{\varphi}_4 + m_1 \ddot{y}_1 \cdot \dfrac{\delta y_1}{\delta\alpha} + m_4 \ddot{x} \dfrac{\delta x}{\delta\alpha}}{\dfrac{\delta L}{\delta\alpha}},$$

where $\ddot{\varphi}_1, \ddot{\varphi}_2, \ddot{\varphi}_3, \ddot{\varphi}_4$ are angular acceleration of the rotor of the electric motor, trunk, crane rods, counterweight; $\ddot{y}_2, \ddot{y}_1$ are vertical acceleration according to the center of mass of the trunk and cargo; $\ddot{x}_2, \ddot{x}_1$ are horizontal acceleration according to the center of mass of the trunk and cargo; i is the velocity ratio of the departure change mechanism; R_d is the radius of the pitch diameter of the spiral drive of the mechanism of change distance from the center to column; L_2 is the working part of the rack pinion.

Construction of a three-dimensional (*3D*) *model of a gantry crane.* Rod models of finite elements are not suitable for the analysis of the stress-strain state of local sections of structures that have stress concentrators. Plate models of finite elements are time consuming and require fragmentation, i.e. the construction of models of high detail. The most successful model of finite elements is a three-dimensional (3D) model of a gantry crane, which is implemented using the software Solid Works (Fig. 2).

Constructing a three-dimensional (3D) model allows obtaining plots of equivalent voltage distribution in the metal structure of the gantry crane. This allows identifying the busiest areas. Thus, the most stress zones of metal structure are the zones of attachment of the mechanism of change in departure, rocker arm counterweight, overarm, crane supports and areas on the crane column.

Method for calculating the survivability of the load-bearing elements of the crane. Theoretical approaches to the calculations of survivability allow estimating the intervals of crack growth and its progress from a significant size to a critical state.

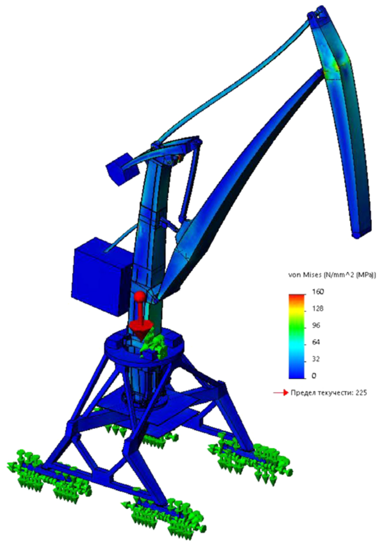

Fig. 2. Diagrams of the distribution of equivalent stress in the metal structure of the crane

Evaluation of the reliability of gantry cranes by the criterion of survivability takes into account various parameters of the reloading process.

Models for calculating survivability are based on the Paris-Elber equation [12, 20], which allows determining the growth rate of cracks

$$v = \frac{dl}{dN} = c \cdot (\Delta K_{eff})^n, \quad (1)$$

where l is crack length; N is the quantity of load cycles; c, n are empirical parameters of the position of cracks; ΔK_{eff} is effective (in terms of crack growth) amplitude of the stress intensity factor

$$\Delta K_{eff} = \begin{cases} \Delta K_{fc}, & K_{min} > 0 \\ \Delta K_{max}, & K_{min} \le 0 \end{cases}, \quad (2)$$

where $\Delta K_{fc} = K_{max} - K_{min}$ is double amplitude of the stress intensity factor; K_{max}, K_{min} are the maximum and minimum values of the stress intensity factor in the load cycle; K_{fc} is the stress intensity factor

$$K_{fc} = \sigma \sqrt{\pi \cdot a} \cdot F, \quad (3)$$

where σ is normal tensile stress acting on the area of crack growth; a is the estimated size of the crack; F is a function that takes into account the size of the geometric region of crack growth.

Given (1–3), we obtain the formula for calculating the survivability in the form of the number of load cycles, which changes the nature of the crack from the initial size a_o to critical a_k

$$N = \frac{1}{C} \cdot \int_{a_o}^{a_k} \left(\Delta\sigma \cdot \sqrt{\pi \cdot a} \cdot F \right)^{-n} da.$$

In [20] it is recommended to use the following for calculations of survivability for steel St-38-b2 – $c = 5.97 \cdot 10^{-11}$, $n = 2.25$; for steel St-3 – $c = 4.23 \cdot 10^{-11}$, $n = 3.05$.

Using the stress concentration factor K_σ, residual stresses are determined

$$\sigma_o = \frac{\sigma_T}{K_\sigma} - \sigma_n,$$

where σ_T is yield strength; σ_n is normal stress.

In [11], it is recommended to take the value of the stress concentration factor for steel St-3 – $K_\sigma = 2.095$, for steel St-38-b2 – $K_\sigma = 1.7$.

Thus, the assessment of the reliability and survivability of the gantry crane elements is carried out by calculating the loaded areas, taking into account the coefficients of concentration and stress intensity.

Results. The input material for assessing the reliability of metal structures of the gantry crane are the results of modern static calculation, which allows identifying the most dangerous zones in terms of damage accumulation. This calculation is performed from the action of vertical and horizontal forces using a CAD/CAE-system (Fig. 3).

To find the most vulnerable part of the metal structure, which determines its reliability, a qualitative analysis of the stress-strain state of the load-bearing system. These studies were conducted on the basis of finite element models.

In this paper, the authors analyze in detail the load and the impact of stress concentration on the reliability of the elements on the example of a gantry crane column as one of the most dangerous zones of metal structure. The model of the column is made using the original drawings of the manufacturer (Fig. 4).

The main load-bearing elements of the metal structure are realized in the model, a grid of finite elements is formed (Fig. 5).

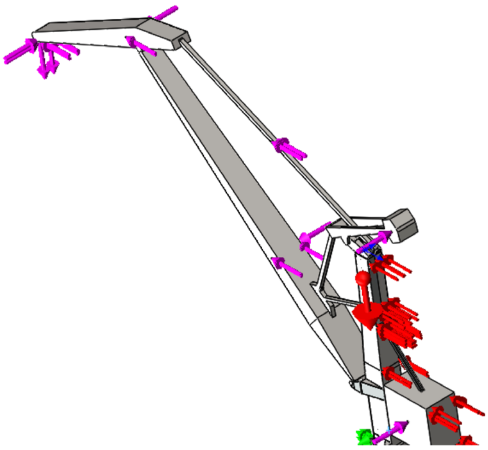

Fig. 3. The crane model under the action of vertical and horizontal forces

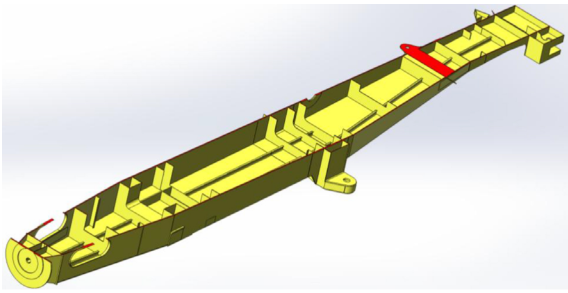

Fig. 4. The three-dimensional model (3D) of a column with a section

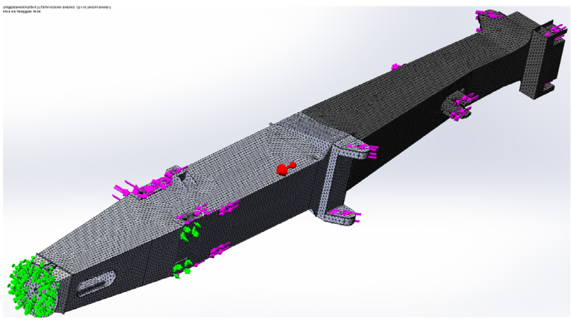

Fig. 5. Grid of finite elements of the gantry crane column

As a result of simulation of the stress-strain state of the column, stress values were obtained (Fig. 6).

In order to determine the areas of concentration of maximum stresses that can be a source of cracks and fractures, the ISO constraint was applied and plots of equivalent stresses in the model were obtained (Fig. 7).

110 MPa is accepted as the minimum value of stresses. The analysis of the diagrams showed that the most loaded zones-concentrators are the attachment points of the rocker arm hinge of the movable counterweight, the attachment point of the boom departure change mechanism, the attachment of the support rollers and the turning mechanism.

Analysis of the documentation on the inspection of the gantry crane column showed that in this element there are through cracks in the attachment points of the support rollers, cracks in the attachment points of the boom to the column and in the stiffeners, which corresponds to the stress concentration areas detected during modeling.

For the identified areas of stress concentration of the crane column, the following improvements in the metal structure are recommended: in the places of attachment of the support rollers, it is proposed to install pads for local stress reduction; to make additional diaphragms and scarves at the points of attachment of the boom to the column and stiffeners which allow ensuring uniform distribution.

The authors proposed a comprehensive method for assessing the operational reliability of sections of metal structures, where cracks are formed, which consists of two stages: load assessment with stress calculations and calculation of survivability depending on the operating time of the gantry crane. In

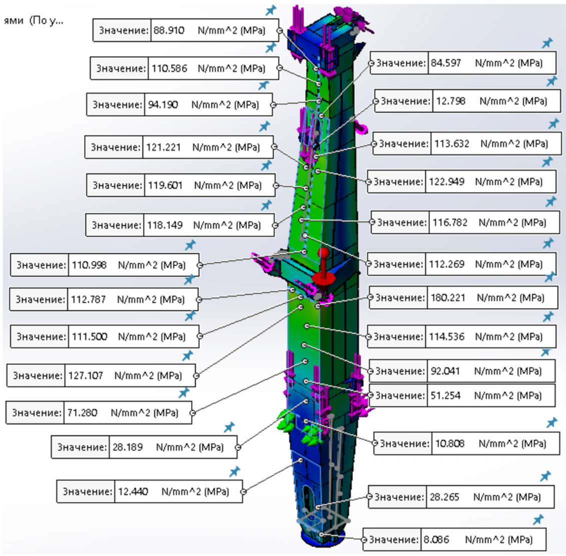

Fig. 6. Values of stresses at crane loading

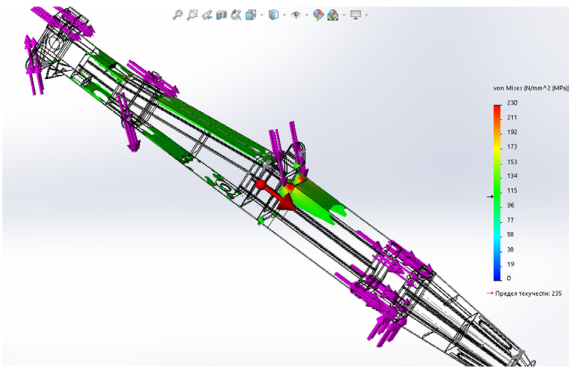

Fig. 7. Loaded sections of the gantry crane column using the “ISO Restriction” tool

this regard, the accounting of operational parameters (weight cargo, weight boom, working speeds of crane mechanisms, load during reloading, cycle time, etc.) was performed at all stages of the crane and the reliability of the metal structure by the criterion of survivability was considered.

Tables 1, 2 present the values of the critical dimensions of the crack length for a certain period of operation, thereby determining the survivability of stress zones of the metal elements. Numerical data is obtained due to the criterion of cyclic loading, intensity coefficients and stress concentration.

Among the considered variants of stress zones, the metal structure of the portal crane constantly working with the grab equipment has the worst survivability. Thus, for the area of attachment of the boom to the column, the beginning of the critical growth of the crack from 5 mm begins with 58 shifts.

Table 1

Survivability of stress zones of the boom system, equipped with grab equipment

Crane service, life *N*, number of shifts	The length of the crack along the area of attachment of the boom to the column, *l*, m	The crack length of the stiffeners of the upper boom belt,, *l*, m	The length of the crack at the point of attachment of the rod with the rotating part of the crane, *l*, m
10	0.001	0.0015	0.015
13	0.0014	0.0025	0.002
22	0.002	0.004	0.005-critical length
46	0.004	0.005-critical length	0.01
58	0.005-critical length	0.02	0.015
62	0.01	0.05	0.02
74	0.015	0.1	0.025

Table 2

Survivability of stress zones of the boom system, equipped with hook equipment

Crane service life, *N*, number of shifts	The length of the crack along the area of attachment of the boom to the column *l*, m	The crack length of the stiffeners of the upper boom belt, *l*, m	The length of the crack at the point of attachment of the rod with the rotating part of the crane, *l*, m
20	0.0014	0.0015	0.002
37	0.0015	0.0025	0.003
40	0.002	0.003	0.004
48	0.0025	0.004	0.0045
60	0.003	0.045	0.005-critical length
65	0.0034	0.005-critical length	0.01
71	0.0036	0.01	0.04
80	0.004	0.02	0.05
91	0.0045	0.05	0.04
122	0.005-critical length	0.1	0.05

For the stiffeners of the upper boom belt, the beginning of the critical growth of the crack from 5 mm begins with 46 shifts. At the point of attachment of the rod with the rotating part of the crane cracks begin to develop with 22 shifts.

As for the mode of operation with hook equipment, the onset of crack growth varies from 60 to 122 changes in operation depending on the area of the metal structure.

The analysis of survivability showed that in the conditions of occurrence of cracks of the noncritical size in stress zones of elements of a metalwork it is necessary to transfer from a grab mode of work to hook in order to weaken loadings.

Conclusions. As a result of the work, the complex technique for estimating reliability of cranes which is focused on calculation of survivability of elements was offered. The authors simulated the loaded state of the metal structure of the gantry crane, analyzed the influence of stress concentration on the reliability of the elements on the example of the gantry crane column as one of the most stress affected zones of the metal structure. The analysis of the stress-strain condition of the column was performed, the maximum stresses were determined, the places of stress concentration in the metal structure of the column were identified and recommendations for the improvement of dangerous areas are presented.

The results obtained provide an opportunity to assess the accumulated damage in the elements of the metal structure, to predict the development of defects to a critical size and to determine the ability of the gantry crane for further operation.

References.

1. Nesterov, A.A. (2016). Technique for replacement of swivel joints of boom systems of portal cranes without dismantling units and systems. *Hoisting and conveying equipment*, *3*(51), 94-103. Retrieved from https://ptt-journals.net/wp-content/uploads/2016/12/Pidtt-2016-3-12.pdf.

2. Pustovoi, V.M., & Reshchenko, I.O. (2012). Modeling of operational degradation of steels of cargo seaport structures in laboratory conditions. *Fizyko-khimichna mekhanika materialiv*, (5), 7-14.

3. Hryhorov, O.V., & Hubskyi, I.O. (2012). Influence of the movement mechanism of the bridge crane on a metalwork resource. *Visnyk KhNADU*, (57), 296-299.

4. Severyn, V.O. (2018). Modeling of random loads on the construction of frame-type buildings. *Zbirnyk naukovykh prats Ukrainskoho Derzhavnoho Universytetu Zaliznychnoho Transportu*, (179), 83-92. https://doi.org/10.18664/1994-7852.179.2018.147754.

5. Nemchuk, O.O., & Krechkovska, H.V. (2019). Fractographic Substantiation of the Loss of Resistance to Brittle Fracture of Steel after Operation in the Marine Gantry Crane Elements. *Metallofiz. Noveishie Tekhnol.*, *41*(6), 825-836. https://doi.org/10.15407/mfint.41.06.0825.

6. Nemchuk, O.O., & Nesterov, O.A. (2020). In-Service Brittle Fracture Resistance Degradation of Steel in a Ship-to-Shore Portal Crane. *Strength of Materials*, *52*, 275-280. https://doi.org/10.1007/s11223-020-00175-w.

7. Martovytskyi, L.M., Sochava, A.I., & Hlushko, V.I. (2016). Critical condition of crane metal structures. *Hoisting and conveying equipment*, *2*(50), 17-24. Retrieved from https://ptt-journals.net/wp-content/uploads/2016/12/Pidtt-2016-2-4.pdf.

8. Yevgrafov, V.S., Tsedin, I.K., Melnikov, B.E., Sherstnev, V.A., & Mochalov, M.A. (2014). Calculation of damage to elements of metal structures with stress concentrators under high-cycle fatigue. *Construction of Unique Buildings and Structures*, *4*(19), 128-138. https://doi.org/10.18720/CUBS.19.11.

9. Moskvichev, V.V., & Chaban, E.A. (2018). Bearing capacity of crane beams in normal and emergency operating conditions. *Sovremennie tehnologii. Systemnui analiz. Modelirovanie*, *2*(58), 8-18. https://doi.org/10.26731/1813-9108.2018.2(58).8-18.

10. Kozhemiaka, S.V., & Krupenchenko, A.V. (2017). Assessment of the stress-strain state of steel crane beams, taking into account defects and damage. *Vestnyk Donbasskoi Natsionalnoi Akademii Stroitelstva I Arhitekturi*, *6*(128), 58-63.

11. Hubskyi, S.O. (2018). Research into the stress-strain state of the metal structure of the lifting mechanism stand. *Visnyk NTU* "KhPI", *6*, 50-54.

12. Mockvichova, L.F., & Chernyakova, N.A. (2020). Studies on strength, service life and reliability of crane metal structures: review and results. *SibFU Journal. Engineering & Technologies*, *13*(8), 933-955. https://doi.org/10.17516/1999-494X-0147.

13. Ivanenko, O. I., Shcherbak, O. V., & Hnatenko, H. O. (2018). Improving the method for calculation and design of the main beam of the bridge crane. *Hoisting and conveying equipment*, *3*(59), 86-92. Retrieved from https://ptt-journals.net/wp-content/uploads/2018/12/pidtt-2018-3-11.pdf.
14. Talalay, B. A. (2010). Determination of rational geometric shapes of metal structures of working equipment of construction machines based on the analysis of their strength properties. *Modern Industrial and Civil Construction*, *6*(3), 159-168.
15. Orobei, V. F., Nemchuk, O. O., Lymarenko, O. M., & Romanov, O. A. (2020). Determination of stresses and strains of the bearing system of the portal-type mooring container reloader by numerical methods. *Visnyk Odeskoho Natsionalnoho Morskoho Universytetu*, (61), 140-153. https://doi.org/10.32684/2412-5288-2019-2-15-36-40.
16. Romanov, O. A., & Lumarenko, O. M. (2019). Study on the stress-strain state of the mooring container reloader by numerical method. *Collection of scientific works of Odesa State Academy of Technical Regulation and Quality*, *2*(15), 36-40. https://doi.org/10.32684/2412-5288-2019-2-15-36-40.
17. Sahirov, Y. H., & Suglobov, V. V. (2019). Load modeling and stress-strain analysis of crane portal elements. *Science and Transport Progress. Bulletin of Dnipropetrovsk National University of Railway Transport*, *3*(81), 110-120. https://doi.org/10.15802/stp2019/171311.
18. Artiukh, V., Mazur, V., Sahirov, Y., & Kapustina, N. (2020). Protection of Metallurgical Machines from Breakdowns at Iron and Steel Works. In Popovic, Z., Manakov, A., & Breskich, V. (Eds.). *VIII International Scientific Siberian Transport Forum. TransSiberia 2019. Advances in Intelligent Systems and Computing*, *1115*. Cham: Springer. https://doi.org/10.1007/978-3-030-37916-2_94.
19. Suglobov, V. V., & Tkachuk, K. V. (2017). Determination of design parameters of articulated boom systems of portal cranes. *Science and Transport Progress. Bulletin of Dnipropetrovsk National University of Railway Transport*, *1*(67), 157-167. https://doi.org/10.15802/stp2017/92618.
20. Hubskyi, S. O. (2014). Study on stress-strain state of metal structures of bridge cranes with different structures of the movement mechanism. *The Bulletin of the National Technical University "Kharkiv Polytechnic Institute"*, *42*, 65-74.

Вплив концентрації напружень на надійність елементів металоконструкції портальних кранів

Ю. Г. Сагіров, К. В. Ткачук, В. В. Суглобов

Державний вищий навчальний заклад «Приазовський державний технічний університет», м. Маріуполь, Україна, e-mail: ev13tk@gmail.com

Мета. Аналіз розподілу напружень у металоконструкції портального крана в умовах циклічного режиму роботи та визначення концентраторів напружень у колоні крана для оцінки живучості машини.

Методика. Для досягнення поставленої мети використано метод аналітичних розрахунків, метод скінченних елементів, метод диференціального та інтегрального числення. Для дослідження стану металоконструкції портального крана, а саме – колони, була використана програма Solid Works та її додаток Simulation.

Результати. Із використанням CAD/CAE-системи було змодельовано навантажений стан металоконструкції портального крана й визначені максимальні робочі навантаження, побудована розрахункова схема їх дії. Представлена методика розрахунку живучості несучих елементів крана з урахуванням коефіцієнтів інтенсивності й концентрації напружень, що дозволяють визначити швидкість росту тріщин у небезпечних ділянках металоконструкції.

Наукова новизна. Отримали подальший розвиток існуючі методи проектування кранових металоконструкцій. Уперше запропонована комплексна методика оцінки надійності кранів, що орієнтована на розрахунок живучості елементів. Уперше розроблені твердотільні моделі крана та його колони, виконано аналіз напружено-деформованого стану колони, визначені максимальні напруження, виявлені місця концентрації напружень у металоконструкції колони та представлені рекомендації з удосконалення небезпечних ділянок.

Практична значимість. Представлена методика оцінки надійності металоконструкцій портальних кранів може бути впроваджена у практику проектно-конструкторських організацій для розробок, проектування нових і модернізації існуючих портальних кранів. Отримані результати надають можливість виконувати оцінку накопичених ушкоджень в елементах металоконструкції, прогнозувати розвиток дефектів до критичного розміру й визначити здатність портального крана до подальшої експлуатації.

Ключові слова: *портальний кран, металоконструкція, навантаженість, надійність, дефект, напруження*

The manuscript was submitted 18.05.21.