A statistical model of operational impacts on the framework of the bridge crane

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Abstract. The technical regulations of the Customs Union demands implementation of the risk analysis of the bridge cranes operation at their design stage. The statistical model has been developed for performance of random calculations of risks, allowing us to model possible operational influences on the bridge crane metal structure in their various combination. The statistical model is practically actualized in the software product automated calculation of risks of failure occurrence of bridge cranes.

1. Introduction
Bridge cranes of general-purpose are one of the most widespread means of mechanization of cargo handling, transport, warehouse works in various types of productions and warehouse complexes [1]. According to clause 7 of article 4 of the Technical Regulations of the Customs Union TR CU 010/2011, when designing bridge cranes of general-purpose, it is necessary to develop the safety justification including risk analysis of the operation [2-5].

The resource of the bridge crane, its cost and operation safety depend to a greater degree on a metal construction. In its turn, the main and most responsible part of the metal construction of the bridge crane is a framework of the bridge (one or two main rails).

Thus, the designer has a serious task on how to develop such a metal construction of the crane that meets conditions of durability, rigidity, stability, fatigue resistance, possesses an optimum specific quantity of metal and corresponds to the required failure risk level. In the submitted paper, this issue is decided on the basis of statistical modelling of operational influences on the crane metal structure for the purpose of an estimation of failure risks of various variants of metal structures, thrashed out by the designer.

2. Materials and methods
For carrying out the analysis of failure risk of the bridge crane, it is necessary to have statistical data. They can be received in the full-scale tests of the designed crane or on the basis of supervision over similar machines. However, carrying out natural tests and collecting statistical data on the operation under conditions of the operating production are extremely expensive, and, in certain cases, it can be absolutely impracticable. Statistical modeling of the operation of the bridge crane of general-purpose, by means of which it is possible to obtain all necessary data on loading of its metal construction, can be the way out. These data can be transformed into quantitative and qualitative characteristics of reliability and, respectively, risks of failure [6].
To obtain this information, a method of statistical modeling has been used in the paper. Statistical modeling is the type of computer modeling allowing one to consider a random factor of the occurring process and to obtain statistical data on the modelled object.

For this purpose, it is necessary to have basic data about the modelled object. These basic data for the bridge crane of general-purpose are the loading capacity, parameters of driving mechanisms and an operating mode defining performance loadings.

3. Analysis of the failure risk of the bridge crane
Performance loadings for parts of the bridge crane are random variables. The adjustment of the starting and brake equipment as well as the qualification of the crane operator exert an essential influence on the distribution of performance loadings. For definition of the current efforts in parts of the bridge crane design by the method of statistical modeling, it is necessary to present this design in the form of the equations of the movement.

In figure 1, there is a control flow chart of an algorithm of steady-state modeling of loading of the bridge crane of general-purpose which considers dynamic components of loading.

Basic data for steady-state modeling of the operation of the bridge crane of general-purpose are: the crane loading capacity, the flight, the length of the serviced site of the shopfloor, the average height of load lifting, the base of the crane, speeds of executive mechanisms of the crane, the average time of strapping and unstrapping of freight, the weight of components of the crane, the modeling time.

The range of loadings of the bridge crane is set on the basis of an operating mode. The position of the cargo cart on the bridge of the crane during lifting and lowering of freight depends on the arrangement of the serviced equipment in the shopfloor, features of a production cycle, etc.

The analysis of the researches conducted by various authors allows drawing a conclusion that distribution of positions of the cargo cart during lifting and lowering of freight for each half of the bridge is close to symmetric normal distributions regarding one quarter and three quarters of flight.

Expressions for the definition of mathematical expectation $a$ and the error of the mean square of deviation $\sigma$ of the cargo cart position for the bridge crane of any flight $L_k$ will look as follows:

– for the left half of the bridge:

$$ a_i = 0.27 \cdot L_k \quad \sigma_i = 0.12 \cdot L_k ; $$

– for the right half of the bridge:

$$ a_j = 0.66 \cdot L_k \quad \sigma_j = 0.1 \cdot L_k . $$

Inquiry coordinates for the hoisting-and-transport operation by the crane are $x_1$, $y_1$, and unloading place coordinates $x_2$, $y_2$ are generated in each cycle of modeling. Thus, the values of these random variables are considered to be distributed according to the normal law.

After passing one cycle of modeling, final coordinates of inquiry are equated to initial ones and the cycle is repeated. The entire procedure will proceed until the counter timer is equal to preset value $t_{\text{mod}}$ (modeling time).

We will calculate the time of operations execution using the following formulas:

– movement from an initial point to an inquiry point:

$$ t_i = \max(\text{abs}(x_0 - x_1) / v_x, \text{abs}(y_0 - y_1) / v_y) , $$

where $x_0, y_0$ – coordinates of the initial position of the crane; $v_x$ – crane movement speed; $v_y$ – load carriage movement speed;
Figure 1. The control flow chart of the algorithm of statistical modeling of loading of the bridge crane.
- movement from an inquiry point to a final point:
\[ t_2 = \max (\abs{x_1 - x_2}/v_x, \abs{y_1 - y_2}/v_y); \]
- lifting and lowering of freight:
\[ t_3 = z_{av}/v; \]
where \( z_{av} \) – the average height of loads lifting; \( v \) – speed of lifting and lowering of freight;
- general time of performance of one running cycle is
\[ t_c = t_1 + t_2 + 2 \cdot t_3. \]

The quantity of the passable rail joints for one cycle is
\[
n_j = \left[ \abs{x_0/l_x - x_i/l_x} \right] + \left[ \abs{(x_0 + b_k)/l_x - x_i/l_x} \right] + \left[ \abs{x_i/l_x - x_2/l_x} \right] + \left[ \abs{(x_i + b_k)/l_x - x_2/l_x} \right],
\]
where \( l_x \) – the length of a rail of a crane runway.

This value in combination with the known location of the cargo cart on the crane bridge will allow calculating dynamic loadings when passing rail joints.

Determination of the size of loading in ropes is carried out taking into account the dynamics of the operation of the hoisting mechanism and loads occurring when passing rail joints.

The most dangerous tension can arise because of the possibility of the collapse of the section of the main beam, which can be determined by known dependencies during bending analysis of the main beam [7-10].

4. Conclusion
Thus, the developed statistical model of the crane operation allows one to model operational loading and to obtain data on the operating stresses in a metal construction of the crane bridge for the subsequent calculation of statistical data on the failure risk. This model is used for assessment of the failure risk of cranes with regard to accumulation of elasto-plastic damages in local zones of metal constructions [11]. Authors have enabled the practical realization of the presented statistical model in the software product that allowed automating the calculation of failure risks of bridge cranes.

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