Advanced methodology of assessment of technical state of overhead type cranes

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S u m m a r y . Methodology of assessment of technical state of metal structures as well as determination of the time of further safe operation of climbing cranes based on the use of generalized (complex) parameter which characterizes the technical state of metal structure of cranes has been considered in the article.
K e y w o r d s . Methodology, climbing crane, technical state, generalized parameter, desirability function.

INTRODUCTION

It is well known that the resource of climbing cranes is determined by the level of technical state (TS) of its metal structure. From a number of studies [12, 13, 18] it is known that TS of cranes metal structure is characterized by numerous parameters. There is large number of parameters which characterize TS of cranes. This makes it difficult to get a comprehensive assessment of TS of climbing cranes. It is possible to reduce the number of parameters (up to one) using the desirability function of Harrington [10] which allows to get one complex (generalized) parameters from some parameters. The concept of such approach and methodology of assessment of the TS of climbing cranes are given in studies [1, 2].

Approbation of the methodology of assessment of TS of metal structure of climbing cranes given in the scientific work [2] and analysis of recent publications on the subject of studies [5, 8, 20, 21] require modernization of the methodology offered before.

MATERIALS AND METHODS

In our opinion objective approaches of assessment of TS of metal structure of climbing cranes are concepts of methods described in the studies [13, 18]. According to the offered concept a criteria approach must be taken as the main approach while assessing TS of climbing cranes. In the course of this approach the quantitative assessment is determined by index or a group of indexes calculated or obtained from the measurements and compared with the admissible value.

The methods given in the studies [13, 18] deserve much attention. They include the fact that the author offers to use the multi-criteria approach to the assessment of the TS recommending compare current parameter values with its admissible values.

According to the information from the source [11] expert examination of climbing cranes is made abroad. But the task of expert surveys is formulated in a different way. A typical formulation of the task of expert survey is given in the introduction to the International Standard ISO 12482-1 [14]. It is noted that cranes cannot operate uncertain time. They must be operated within the limits specified by the manufacturer. The terms of expert examinations are specified by the manufacturer.

Recently the method of assessment of TS of metal structure and forecasting of residual resource of the crane on the basis of non-destructive check (coercive force, coefficient of variation of hardness, metal magnetic memory) has been widely spread [9, 19]. However, it has a number of significant shortcomings that limits possibility of their use to solve the set tasks, for example, while determining the damage of the unit of metal structure the tension value at which this unit was operated is not taken into consideration and there are no means that allow to use dependences obtained for laboratory samples to solve the tasks on assessment of residual life of metal structure of crane [8], difficulties of assessment of operational integrity of metal structure of cranes with different thicknesses of the elements [5] .

Thus, summing up the considered approaches of assessment of TS of cranes we can come to conclusion that there is not a single science-based method at present.

Assessment of TS of climbing cranes is held according to the normative document [17]. The scope of work includes even examination that has non-destructive check of metal structure of cranes. However, the values of parameters of TS of metal structure of cranes obtained on the indicated methodology remain discrete that does not provide a complete picture of TS and the risks of further operation of the crane.

RESULTS, DISCUSSION

To suggest a modernized methodology of assessment of TS of metal structure of climbing cranes on the example of the overhead type crane that is based on the use of generalized (complex) parameter subject to the latest trends in the field.

As an object of research the overhead type cranes have been chosen as the most common type of climbing cranes the number of which exceeds 50 % of the total number of cranes in Ukraine.

Considering that the number of parameters that characterize the TS of metal structures of overhead type cranes is large; in our opinion the main ones are:

- value of the normal stresses in the metal,
- value of the horizontal inertial load that makes influence on the metal structure of the crane,
- general and local residual deformation of the crane's metal structure,
- mechanical and corrosion damage of the metal structure's elements,
- mechanical properties and chemical composition of materials of the crane metal structure,
- the value of the elastic deflection of the main beams of the crane bridge under load , etc.

Knowing the current values of parameters of TS and the principles of their change, we can estimate the time of their marginal state.

When solving tasks with several variables (parameters) we offer to use a so-called desirability function as a versatility indicator [10].

The desirability d_i means one or another desirable parameter level. At a special scale (Fig.) the value d_i can vary from 0 to 1. The scale is as follows:

d = 1,00 - the maximum possible parameter value,

d = 1,00 - 0,80 - maximum and admissible parameter value,

d = 0,80 - 0,60 - admissible and good parameter value,

d = 0,60 - 0,37 – admissible and satisfactory parameter value

d = 0,37 - 0 – poor parameter value.

Values of d on the scale of desirability can be displaced up and down depending on specific situations.

The idea of using desirability function as a complex parameter of crane's TS is that the value of each parameter of TS (y_i), the number of which can be large, is converted into the appropriate particular desirability (d_i); thereafter the so-called generalized desirability function (D) forms that is a geometric mean of desirability of separate parameters of the TS :

$$D = \sqrt[g]{d_1 \cdot d_2 \ldots \cdot d_g}, \quad (1)$$

where: g is the number of selected technical parameters of technical state of the crane.

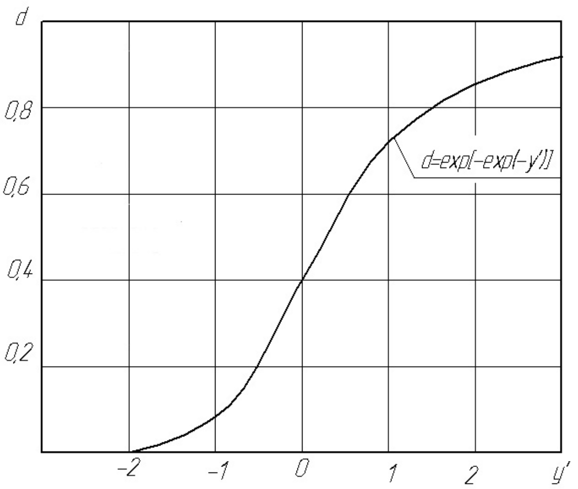

Fig. Chart of desirability function for one-sided constraint parameters

As a result the generalized desirability function turns to be the only parameter to assess the technical state instead of many ones.

The values of particular functions (parameters) of desirability d_1, d_2, d_3 are received by means of converting measured values of chosen parameters of the technical state into non-dimensional quantity on the formula (2):

$$d_i = e^{-(e^{-y_i'})}, \quad (2)$$

where: y_i' is a certain non-dimensional quantity related (often linearly) with the response y_i,

$$y_i' = a_0^* + a_1^* y_i. \quad (3)$$

The coefficients a_0^* and a_1^* are determined by setting the two values of the response function y_i corresponding to the basic (limiting) values of particular desirability function d_i.

Formula (2) can be applied when the parameter has got a one-sided constraint.

If these are two-sided constrains for parameter, notably, they are given as $y_{min} \leq y \leq y_{max}$ so then it is convenient to set the desirability function as follows:

$$d_i = e^{-\left(\left|y_i'\right|\right)^n}, \quad (4)$$

where: n is a positive number,

$$y_i' = \frac{2y_i - (y_{max} + y_{min})}{y_{max} - y_{min}}. \quad (5)$$

The exponent n can be calculated if to set the value d to the parameter y (preferably in the range 0,6 <d <0,9), calculate the counterpart $|y'|$ referring to (5) and thereafter use the formula:

$$n = \frac{\ln \ln \frac{1}{d}}{\ln |y'|}. \quad (6)$$

Choosing different values n, it is possible to set different desirability curvature of a curve. This allows to take into account the particular importance of separate parameters of TS: for them n will be of greater importance and a small change of parameter near the limiting ranges will correspond to the rapid change of desirability.

The generalized parameter D of TS of cranes allows to take the examined crane to one or another group of its TS. The resulting value of the generalized parameter D of TS is to determine the safety factor K_s, which is rated by the formula:

$$K_s = \frac{1}{\kappa_a \cdot \kappa_c \cdot \kappa_m} \cdot D, \qquad (7)$$

where: κ_a – coefficient of crane's "age", κ_c – coefficient of the operating conditions, κ_m – coefficient of operating mode.

It should be noted that the number of coefficients can be increased according to the characteristics and special operating conditions as well as allocation of crane. Safety factor $K_б$ can be used to determine the time of further safe operation of crane which is determined on the formula according to [20]:

$$T = T_p \cdot K_s, \qquad (8)$$

where: T_p – the rated resource of the crane according to its operating mode and passport data, K_s – coefficient of the carne's safety.

On the basis of analysis of a priori information out of numerous parameters that characterize the TS of metal structures of overhead type crane we have adopted:

σ – normal stress in the main supporting girders of a crane, MPa,

HB – Brinell hardness of the metal from which metal structure of crane is made, MPa,

f – residual deflection of the middle part of the main beams of the crane bridge mm.

We take into consideration these parameters as they characterize the TS of the crane's metal structure in the best way. Let us examine their characteristics in details.

Normal stresses in metal.

Cranes that are in operation for a long time may decrease in size of the cross-section of bearing elements due to the impact of various environmental factors. Therefore, it is necessary to check the calculations on the strength and stiffness of metal structures subject to the actual thickness of the metal structures elements.

In the practice of crane building two methods of calculating metal structures are applied:

- calculation on the method of allowable stresses based on the coefficient of safety factor established by practice; in this case the calculation is made either at the equivalent and maximum loads or at the basic and additional loads,

- calculation according to the method of limiting states that is based on statistical study of the actual load of structures in the field.

When calculating crane bridges on the allowable tension on the basic and basic plus additional loads two kinds of loads are considered:

- main (vertical) loads subject to dynamic coefficients,

- basic loads subject to dynamic coefficients and additional (horizontal) loads which are calculated without dynamic coefficients.

The dynamic coefficient of influence of the main loads on the crane metal structure is taken by the generalized dynamic coefficients [3 , 4]. Two dynamic coefficients are given:

Ψg - dynamic coefficient for the weight of crane components taken depending on the speed of movement of the crane:

when: $V_к < 1$ m/s $\Psi_g = 1{,}0$, at $V_к = 1$-2 m/s $\Psi_g = 1{,}1$, at $V_к > 2$ m/s $\Psi_g = 1{,}2$,

Ψ_Q - dynamic coefficient for cargo taken depending on the mode of operation of the crane: $\Psi_Q = 1{,}1$, $\Psi_Q = 1{,}2$, $\Psi_Q = 1{,}3$, respectively for light, medium and heavy operating regime of cranes.

Allowable tensions when calculating crane metal structures on the basis of load are usually denoted as $[\sigma]_I$, and when calculating basic and additional loads they are denoted as $[\sigma]_{II}$. When defining $[\sigma]_I$ safety factors are in the range 1.5-1.7, and for $[\sigma]_{II}$ safety factors are 1,33-1,4.

Hardness of the metal HB from which metal structure of the crane is made. The quality of steel is one of the main factors that determine the duration of operation of metal structures of cranes. The quality of steel is characterized by index of mechanical properties of steel such as conventional yield strength $\sigma_{0,2}$, ultimate stress limit $\sigma_в$, percent elongation δ, narrowing ψ, and toughness KCV. In the process of long-term operation of cranes the values of mechanical properties of steel can change. They can be determined indirectly while testing the hardness of metal.

Ultimate stress limit $\sigma_в$ and hardness HB are related to each other:

$$\sigma_в = к \cdot HB \quad (9)$$

where: HB is measure of the Brinell hardness, k is the coefficient of the steel type (k = 0.33 - 0.36).

The table for re-calculation of HB and $\sigma_в$ is given in State Standard 227671-77 [6].

Conventional ultimate strength $\sigma_{0,2}$ on the HB values (for hardness HB ≥ 1500 MPa) can be determined from the formula:

$$\sigma_{0,2} = 0,367 \cdot HB - 240, \quad (10)$$

and for the hardness of HB <1500 MPa from the formula

$$\sigma_{0,2} = 0,2 \cdot HB. \quad (11)$$

It should also be noted that the hardness of metal and the coercive force have quite good correlation [8]. This allows to refuse to measure coercive force while assessing TS of cranes metal structure having given preference to measuring the hardness of HB as a less costly method.

The deflection f of the main beams of the crane's bridge.

One of the main parameters that characterize the state of stress and operation life of the cranes is the deflection of the main beams of the bridges [7, 16]. At the time of cranes loading elastic vibrational deflections appear; they disappear after removal of the load and thereafter the beams come to their primary position. In the process of long-term operation of cranes residual deflection that exceeds the permissible norm appears in the bridge. It means that it is dangerous to use the crane at its nominal capacity.

Residual deflection can occur in welded and riveted (to a lesser extent) structures of beams after the first load. The second loading that does not exceed the level of the first one does not lead to the formation of residual deflection. As regards welded beams, residual deflection occurs from the beginning of load. Depending on the level of the stress state the residual deflection can be 1/1200 of the span (at a maximum stress 175 MPa). In this case the further work of the beam goes well.

Thus, the camber of longitudinal girders reduces significantly after the first load. With the further operation of the crane residual deflection will increase. Studies have shown that the crane can be operated without any restrictions if there is residual (negative) deflection f <0,0022 L (L - crane span). When deflections are 0,0022 L <f <0,0035 L there must be control over the development of residual deflection, namely, leveling at least once in four months. Residual deflection f=0,0035 L is the maximum, so that is why operation of the crane with such a residual deflection is not allowed.

The need to determine the residual deflection of the main beams is caused by the fact that during long-term operation of the overhead type cranes at recursive short-time mode the residual deflections of the main beams arise as a result of plastic deformations in the material of the structure. The maximum residual deflection of the main beams is regulated by the limiting state of metal structure of the crane and by the working joint welds on the basis of yield strength and safety factor of the structure material. If the tension in the welds exceeds the yield strength so then cracks can occur in the most loaded parts of the metal structure. Although the formation of cracks in the welds of local significance does not break the firmness of the whole structure, but they can be a focus of destruction so the work of the crane must be stopped until the strength of metal structure is restored [15].

The example of calculation of the generalized parameter D of TS for the bridge hook crane of general-purpose with the span L=18 m.

Creation of the desirability scale.

Conversion of the values of each of the above mentioned parameters into the corresponding desirability d_i is made by means of desirability scale the diagram of which is shown in Figure. To convert parameters of TS of crane the marks have been mapped on the scale of desirability for representative value of the parameters σ, HB, f. In this case, the following considerations have been taken. The lower bound "satisfactory" includes: for normal stresses σ - the maximum value [σ]≤160 MPa (for the steel grade St 3); for hardness of HB metal (steel CT3) - the maximum value of hardness [HB]≤1430 MPa, for the residual deflection of the main beams of the bridge f - the maximum value for the crane, for example, with a span L=18 m, equal to 1/700 L ≤ 26 mm.

The high bound "very good" includes:

for σ value is equal to triple reduction of stresses,

for HB value is equal to one of the possible values of hardness in the range of its variation,

for f value is equal approximately to triple decrease in deflection.

Having converted parameters into the particular desirability in accordance with formulas (2, 3) the following formulas have been received d1, d2, d3:

$$d_1 = \exp[-\exp(-(4{,}3177 + (-0{,}0269)\cdot \sigma))], \quad (12)$$

$$d_1 = \exp[-\exp(-(4{,}3177 + (-0{,}0269)\cdot HB))], \quad (13)$$

$$d_1 = \exp[-\exp(-(4{,}3177 + (-0{,}0269)\cdot f))]. \quad (14)$$

Calculation of the generalized parameter of TS. After conversion of parameter values of TS into the corresponding desirabilities we unite them into a generalized desirability D, which is the geometric mean of particular desirabilities d1, d2, d3:

$$D = \sqrt[3]{d_1 \cdot d_2 \cdot d_3}\ . \quad (15)$$

The program has been developed in order to automate the calculation of the coefficients a_0 and a_1 as well as calculation of the particular desirability d1, d2, d3 and the generalized desirability D.

Analysis of the results of calculations for the particular case chosen by us shows that if the measured values of parameters of TS are equal:

- the stress in the metal structure is 160 MPa,

- the hardness of the bridge crane metal is 1200 MPa,

- the residual deflection of the main beam of the bridge crane is 20 mm,

so, their particular desirability functions d are respectively equal:

$d_1 = 0{,}3700$; $d_2 = 0{,}8158$; $d_3 = 0{,}6906$.

Generalized parameter of the technical state will be equal:

$$D = \sqrt[3]{d_1 \cdot d_2 \cdot d_3} = 0{,}5932,$$

that corresponds to a satisfactory evaluation of TS of metal structure of the crane on a scale of desirability.

CONCLUSIONS

Advanced methodology of assessment of TS of metal structures of climbing cranes allows to:

1. Get an objective assessment of the TS of metal structure of climbing cranes due to the generalized (complex) parameter,
2. Apply the generalized (complex) parameter of the TS of metal structures of cranes when calculating the safety factor,
3. Calculate the further safe operation life of the crane subject to the safety factor.

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МОДЕРНИЗИРОВАННАЯ МЕТОДИКА ОЦЕНКИ ТЕХНИЧЕСКОГО СОСТОЯНИЯ КРАНОВ МОСТОВОГО ТИПА

Григорий Бойко

Аннотация. В статье приведена методика оценки технического состояния металлоконструкций и определения сроков дальнейшей безопасной эксплуатации грузоподъёмных кранов, базирующаяся на применении обобщённого (комплексного) параметра, характеризующего техническое состояние металлоконструкций кранов.

Ключевые слова. Методика, грузоподъёмный кран, техническое состояние, обобщённый параметр, функция желательности.