Features of calculation of steel structures of bridge cranes at variable loads

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Abstract. The article deals with the calculation of metal bridge cranes operating under the influence of variable loads. Requirements to static and dynamic characteristics of mechanisms of load-lifting cranes are caused by specifics of work, features of a design and operating conditions of the cranes working at variable loadings. Thus, it is proposed to perform calculations of parts of crane mechanisms for endurance, operating under non-stationary variable load, based on the principle of linear summation of damage, allowing the calculation from the point of view of the load equivalent to the entire range of operating loads.

1 Introduction

In almost all sectors of the economy are widespread metal structures due to their characteristics [1-4]. Sozдание effective metal designs are based on a comprehensive consideration of the requirements of exploitation reliability and durability, fabrication and installation, which leads to the need of knowledge of work load, the correct choice of structural forms, use of standardized and harmonized solutions and relevant calculations to create designs [5-7].

Currently, most calculations of metal bridge cranes are performed by the method of allowable stresses under certain load combinations [8. 9]. Such as distributed load from self weight of the bridge structure of a crane, point loads from the cargo truck with the load located at mid-spans, concentrated load from a cargo truck with load located at the end of the beam or in dangerous cross-section, i.e. the transition section of the bridge beams from high to low [10].

The sections of the main beams of bridge cranes are mainly used box section in the form of a rectangular parallelepiped, so it is necessary to ensure the allowable values of the moments of resistance of the rectangular section at different ratios of the size of the belts and walls [11, 12].

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2 Formulation of the problem

Metal structures of bridge cranes are characterized by unsteady loads with varying values of stress amplitudes and asymmetry of the operating cycle [10, 13, 14]. To study the actual loading of bridge cranes in typical operating conditions requires continuous recording of their stress state, which is very laborious. Therefore, evaluation of loading elements of metal structures of bridge cranes get statistical processing of the results obtained [15-18] in the research process, modifying the individual components of the total loading of metallic elements: the force of gravity of a lifted load, the swing angle of the load, the magnitude of the departure of the alternating current, weather loads, followed by summation according to the laws of probability theory [19]. This approach to the study of structural elements is incomparably less time-consuming than a comprehensive study of loading in typical operating conditions. However, the determination of the probabilistic characteristics of individual random loads is also relatively time-consuming, and therefore the calculation method for load combinations has been widely used in crane construction [11].

3 Theory

When calculating the structural elements of a bridge crane under unsteady loads, it is necessary to know both the law of changes in stress in time and the effect of this law of changes in stress on fatigue resistance. However, for most elements of metal structures of bridge cranes there are no experimental data on the values of fatigue resistance at non-stationary loads acting on the calculated element. Therefore, the fatigue resistance values experimentally determined under the conditions of stationary loads are used in the calculations, taking into account the influence of changes in overload stresses from the non-stationary loading mode on their endurance limits.

Then the summation of fatigue damage from the action of overload stresses at a constant coefficient of asymmetry of the cycle in the case of a step change in the stress amplitudes can be represented by a linear dependence [15]

$$\sum_1^{i_0} \frac{n_i}{N_i} = a, \quad (1)$$

where n_i - the number of cycles of repetition of stresses σ_i ; N_i - fatigue life, i.e. the number of cycles of repetition of stresses required for failure from fatigue under stress σ_i ; σ_i/i_0 - the number of steps of change in the amplitude of stresses; a - the value characterizing the properties of the metal in connection with the mode of stress change. Load stages with stress amplitude below the endurance limit do not give a share in the sum of damage, because for them the number of cycles N_i on the fatigue curve is infinite and the partial damage is zero. It is obvious that with a sufficiently large number of steps to change the amplitude of the stress i_0 step diagram can be replaced by a continuous distribution with any degree of accuracy. The linearity of the dependence (1) is determined by the fact that the amount of damage increases uniformly, and for each cycle is $1/N_i$.

A lot of works are devoted to the issues of accumulation of fatigue damages under non-stationary load regimes. However, studies were usually carried out on small samples of processed materials used in the manufacture of machine parts. In comparison with them, the

work of metal structures of cranes at variable voltages has a number of features such as a significant ductility of structural steels, the nature of the impact of loads. In addition, such structures are made of metal with a preserved rolled surface and have stress concentrators in the form of welds. Therefore, the use of the results obtained in the study of typical samples of machine parts to determine the endurance of welded metal structures requires mandatory experimental confirmation.

4 Results

In the works [5, 11, 20] it is proposed to take into account the accumulation of fatigue damage under non-stationary loading regimes with the help of a linear law, taking the value $a=1$, in [1] the work of welded metal structures under non-stationary loading regimes was additionally subjected to a detailed experimental study.

Thus, the fatigue tests carried out under the most unfavorable two-stage loading confirm that in welded metal structures damages accumulate almost linearly and the law of their accumulation can be expressed in the form - $\sum n_i / N_i = a$. Adopting the sum of relative longevity $a=1$ contributes to the error allowed for engineering calculations, and in most cases gives a margin for fatigue resistance. In addition, it should be noted that the calculation formula for determining the reduced stress value is under the sign of the radical index of the degree of the fatigue curve $m = 3 \div 8$. Therefore, even with the highest value obtained experimentally on welded samples $a=1,5$, for example. $\sqrt[6]{1,5} \approx 1,07$, that is, it differs by less than 10%, overestimating the fatigue resistance in the calculation. Then for welded metal structures expression (1) will take the form

$$\sum_{i=1}^{i_0} \frac{n_i}{N_i} = 1 \quad (2)$$

The effect of stress overload on the fatigue limit is considered for two-stage loading, which corresponds to the division of the load combinations on the first and second design cases [21-23], i.e., given the gravity of the crane components, the gravity load, horizontal forces of inertia of the crane, the angle of deflection of the load from vertical and find out the influence on the endurance limit σ_{rk} stress overload, i.e., voltages greater than σ_{rk} . As applied to the two-stage loading at overload stresses σ_n and σ_k by condition (2) the expression is obtained

$$\frac{n_n}{N_n} + \frac{n_k}{N_k} = 1 \quad (3)$$

Applying the logarithm operation to expression (3), we obtain

$$\lg N_k - \lg n_k = \lg N_n - \lg(N_n - n_n) \quad (4)$$

Then for samples of the metal bridge crane received the influence of variable loads occur handling stress with PP cycles, secondary fatigue curve is constructed in logarithmic coordinates [24], is parallel to the primary fatigue curve obtained at stationary regime of loading (Fig. 1) [10].

Fig. 1. Graphs of the fatigue dependences: a) with voltages in the place of fatigue crack development $\leq \sigma_r$, 1 - samples in the initial state, 2 - samples after overload and σ_n in an amount n_n cycles'; b) at stresses at the site of fatigue crack development $> \sigma_r$, 3 - samples in the initial state, 4 - samples after static stress overload a , 5 - samples after the overload voltage and σ_n in an amount n_n cycles'; b) at stresses at the site of fatigue crack development $\leq \sigma_r$ at cycle asymmetry coefficient $r - 6$ и 7 , 8 - samples with a coefficient of cycle asymmetry r after overloading the voltage and σ_n in an amount n_n cycles at the stress ratio r

The equations of the primary and secondary fatigue curves can be written as:

$$\sigma_n^m N_n = \sigma_{rk}^m N_\sigma, \quad (5)$$

$$\sigma_n^m (N_n - n_n) = \sigma_{rk}^m N_\sigma, \quad (6)$$

then from (5) and (6) we get

$$\sigma_{rk}^* = \sigma_{rk} \sqrt[1 - \frac{n_n}{N_n}]{1 - \frac{n_n}{N_n}}. \quad (7)$$

From the expression of the primary fatigue curve

$$N_n = \frac{\sigma_{rk}^m N_\sigma}{\sigma_n^m}. \quad (8)$$

Substituting the value of N_n from (8) to (7), we obtain a reduced endurance limit as a result of cyclic stress overload σ_n in an amount n_n cycles equal to

$$\sigma_{rk}^* = \sigma_{rk} \sqrt[1 - \left(\frac{\sigma_n}{\sigma_{rk}}\right)^m]{1 - \left(\frac{\sigma_n}{\sigma_{rk}}\right)^m} \frac{n_n}{N_\sigma} = \sigma_{rk} \sqrt[1 - A^m B]{1 - A^m B} = \varphi_n \sigma_{rk}, \quad (9)$$

where $A = \sigma_n / \sigma_{rk}$ - the relative magnitude of the overload; $B = n_n / N_\sigma$ - the relative duration of the overload; φ_n - coefficient of reduction of endurance limit.

Then, if the metal structures experience overload stresses repeatedly over the entire period of loading cycles, then

$$\sigma_{rk}^* = \sigma_{rk} \sqrt[1 - \sum_{i=1}^i \left(\frac{\sigma_i}{\sigma_{rk}}\right)^m]{1 - \sum_{i=1}^i \left(\frac{\sigma_i}{\sigma_{rk}}\right)^m} \frac{n_i}{N_\sigma} = \sigma_{rk} \sqrt[1 - \sum_{i=1}^i A_i^m B_i]{1 - \sum_{i=1}^i A_i^m B_i}. \quad (10)$$

5 Summary and conclusions

Thus, in the case where $A^m B \geq 1$ or $\sum_1^{i_0} A_i^m B_i \geq 1$ there will be a destruction of the integrity of metal structures. At the site of the fatigue crack, the amount of residual stresses and stresses from the external load exceeds the yield strength of the metal material and as a result of the action of variable loads, the residual stresses are reduced.

During cyclic overloading of structures stresses σ_n in an amount n_n the secondary fatigue curve (Fig. 1b) will be parallel to the primary curve, but with a changed value of residual stresses.

Then the value of the reduced endurance limit can be determined by the formula:

$$\sigma_{rk}^{**} = \sigma_{rk}' m' \sqrt[1 - \left(\frac{\sigma_n}{\sigma_{rk}'} \right)^m]{\frac{n_n}{N_\sigma}}, \quad (11)$$

the law of accumulation of fatigue failure of metal structures of the crane can be expressed by linear dependence

$$\sum_1^{i_0} \frac{n_i}{N_i} = 1, \quad (12)$$

where N_i - durability of elements of metal structures with the changed value of residual stresses [25].

Thus, the operating loads and stresses arising in the structural elements of the bridge crane, in most cases, are random functions of time, and the characteristics of the fatigue resistance of the structure (service life, endurance limit) are random variables that are characterized by significant dispersion, so the refined methods of calculating fatigue strength are based on probability theory and mathematical statistics.

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