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Dynamic loads during failure risk assessment of bridge crane structures

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Abstract. The paper presents the method of failure risk assessment associated with a bridge crane metal structure at the design stage. It also justifies the necessity of taking into account dynamic loads with regard to the operational cycle of a bridge crane during failure risk assessment of its metal structure.

1. Introduction

The operation risk analysis of a bridge crane encompasses search of all potential failures, collection of statistical data on their frequency and calculation of operation risk via the existing method [1].

In practice, approximately 40% of bridge crane failures occur due to fatigue damage of support metalworks. This type of failure leads to drastic consequences and entails huge financial and human losses.

Thus, the designer faces a serious task to develop a crane structure that satisfies the conditions of strength, rigidity, stability and fatigue resistance, has the best possible metal consumption and corresponds to the given level of failure risk.

2. Results and discussion

Operational loads applied to elements of a bridge crane structure represent random variables [2]. The adjustment of starting and braking units, as well as qualification of a crane operator exercise a significant influence on the distribution of operational loads.

The bridge crane is exposed to dynamic loads when there are changes in the speed of freight or metal structure traffic. They reach the upper-range value in case of unstable motion.

Modern control systems used for variable-frequency gears provide for a smooth start and stop of crane motors. In turn, this minimizes dynamic loads in cables and structures of a bridge crane. However, these systems are rather expensive, have lower maintainability and require highly qualified service staff.

As practice shows, relay-contactor systems are still relevant. The customers often require the manufacturer to build up bridge cranes with such control systems to ensure ease of maintenance, low cost and availability of spare parts at any plant. However, due to their imperfection, such systems fail to guarantee a smooth start in comparison with frequency regulation systems, which, in turn, increases dynamic loads.

When passing through irregular crane runways (gaps and steps of rail joints), substantial dynamic loads occur in cables and metal structures of bridge cranes. The study shows that the overload may reach 1.85 [3, 4]; therefore they shall be taken into account when designing a metal structure of a bridge crane.

Within one operating cycle of a crane, which includes load lifting, movement and delivery, its metal structure is subjected to several loading cycles (due to dynamic processes), and hence this process may be presented as the stress change chart (Fig. 1).

The design of bridge cranes shall consider the following two load combinations: 1a and 1b. The combination 1a is caused by loads arising from the gravity action of crane structures and lifted freight. Freight lifting leads to stress change cycles due to fluctuations of a crane bridge vertically, which is the reason of cables and main beams flexibility. The study shows that accounting of more than 2 … 4 oscillation periods is inadvisable. The combination 1b produces stress change cycles caused by crane movement (run-up, slowdown, passing through rail joints)[4].

The equation of load change within a cable can be presented as follows [5]:

$$F_l = A_1 \cdot e^{\lambda \cdot t} + e^{\alpha \cdot t}(A_2 \cos \omega t + B \sin \omega t) + F_i ,$$

where A_1, A_2, B – initial amplitudes of oscillations;

ω – bridge oscillation natural frequency;

F_i - load weight.

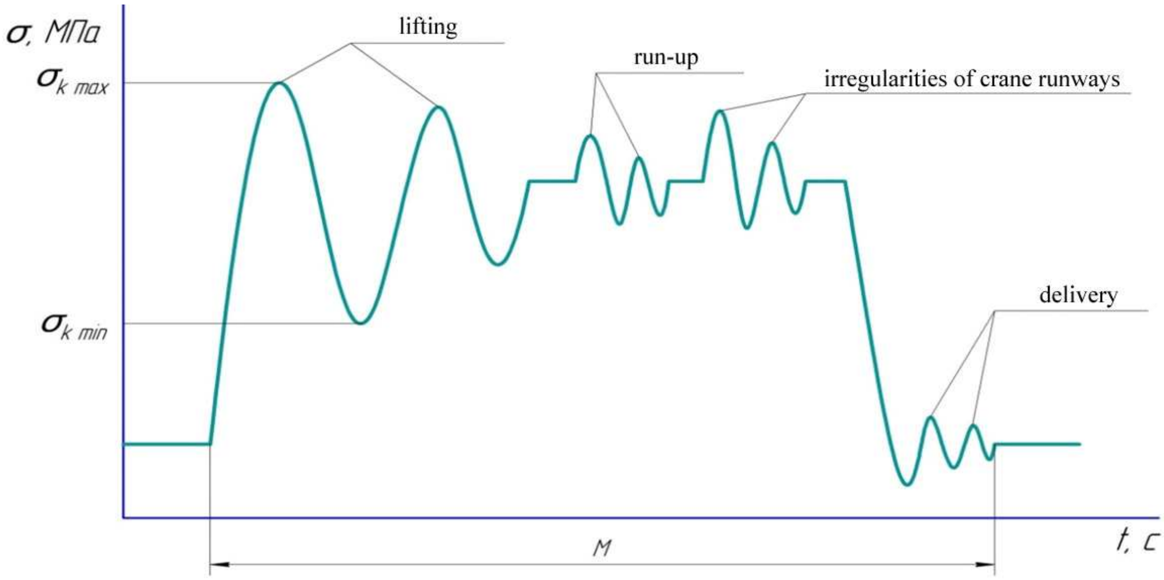

Figure 1. Stress change in bridge crane structure at operating cycle stages

This equation makes it possible to define maximum and minimum loads F_l in a cable, which are transferred to a metal structure through oscillations.

Depending on crab position, the stress in the main beam section can be determined according to the following formula:

$$\sigma_{i\ y} = \frac{\frac{G_b}{2} \cdot \left(\frac{1}{X_{i\ cs}} - \frac{X_{cs}}{L_b} \right) + \frac{(G_m + F_l)}{2} \cdot \frac{X_i}{L_b}}{W_x} ,$$

where G_b – main beam weight;

G_m – crab weight;

L_b – main beam length;

$X_{i\,cs}$ – main beam section coordinate;

X_i – crab position on a bridge during lifting;

W_x – main section modulus about the X-axis.

Equivalent maximum and minimum stresses in section per one crane operating cycle can be calculated as follows:

$$\sigma_{ei\frac{max}{min}} = \sigma_{max_i} \sqrt[m]{\sum_{i=1}^{i_0} \left(\frac{\sigma_{e-1ki}}{\sigma_{i\frac{max}{min}}} \right)^m \frac{n_i}{N_b}},$$

where σ_{max_i}, σ_{min_i} – maximum and minimum stresses per one operating cycle;

m – degree of fatigue curve;

n_i – number of stress change cycles σ_{e-1ki} applied to the basic number of cycles N_b per one crane operating cycle.

$$\sigma_{e-1ki} = \frac{1}{2 \cdot k \cdot n} \cdot \left[n(k+\psi_\sigma) \cdot \sigma_{max_i} - (k+\psi_\sigma) \cdot \sigma_{min_i} \right],$$

where k – reduced factor of stress concentration;

n – safety factor against potential decrease in stress ratio;

ψ_σ – sensitivity factor against stress cycle asymmetry.

A similar formula may be applied to calculate global equivalent stress transferred to the basic number of crane operating cycles within its operating time [6].

Below, there is the obtained global reverse stress:

$$\sigma_{e-1red} = \frac{\sigma_{e\,max} - \sigma_{e\,min}}{2} + \frac{\sigma_{e\,max} + \sigma_{e\,min}}{2} \psi_\sigma,$$

The failure risk assessment of a bridge crane structure can be made according to the following formula:

$$Q = 1 - 0{,}5 \cdot C \cdot \left[\Phi\left(\frac{\sigma_{-1kn}^{max} - \langle \sigma_{-1kn} \rangle}{\sqrt{2} \cdot \sigma_{\sigma_{-1kn}}} \right) - \Phi\left(\frac{\sigma_{e-1red} - \langle \sigma_{-1kn} \rangle}{\sqrt{2} \cdot \sigma_{\sigma_{-1kn}}} \right) \right],$$

where $\langle \sigma_{-1kn} \rangle$, $\sigma_{\sigma_{-1kn}}$, σ_{-1kn}^{max} – expectation value, root-mean-square deviation and the maximum fatigue endurance of the metal structure material, at N number of loading cycles, stress ratio R=1 and stress concentration factor (within section under consideration) – k;

$\left\langle \sigma_{-1kn} \right\rangle = \alpha \left\langle \sigma_{-1k} \right\rangle \sqrt[m]{\frac{N_b}{N}}$, σ_{e-1red} – equivalent reverse stress of bridge design;

$\left\langle \sigma_{-1k} \right\rangle$ – expectation value of crane material fatigue endurance corresponding to basic number of loadings cycles Nb at asymmetry coefficient R = 1 and stress factor k;

C – coefficient considering abbreviated Gaussian law.

The obtained failure rate of the main beam structure [7] serves one of the source data for failure risk analysis associated with the bridge crane at the design stage.

3. Conclusions

The proposed method provides for much-simplified risk assessment of the bridge crane operation at the design stage since it allows calculating the failure risk without expensive field tests of a metal structure.

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