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OPTIMAL SERVICE TERM OF THE BRIDGE CRANES

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Abstract

The questions of the rational/optimal service term of the warehouse bridge cranes on the exploitation and projection stages are observed. The method of the residual crane resource's definition by the criterion of the specific reduced responses is suggested. On the stage of the crane projection, the forecasting of the warehouse cranes' resource in coordination with their constructive parameters is expedient. The existing task has main aspects: recognition of the residual crane resource and definition of the project crane resource. In course of time in the massive of the sample from the low carbon steel occur changes: grows firmness, equalize the internal tensions, little internal cracks "overgrow", sometimes the groups of little cracks create macrocracks. This are a diffusion action.
The definition of the rational constructive parameters is being carried out on the base of the work processes' mathematical modelling. On the base of modelling is defined the size of the residual deflection of the main beam that is formed during one work crane cycle considering the action of the main beams' free vibrations in the processes of start and braking considering the factor of the attenuation of those vibrations. In result of the modelling, we receive the microscopic size of the residual deflection, formed during one work cycle. On the base of the multisession modelling is noticed that the crane resource can be prolonged on 20-50%.

***Keywords**: bridge cranes, resource, modelling, constructive parameters*

1. Introduction

The warehouse bridge crane corresponds to the devices of the long-term usage. Its term is calculated by tenths of years. In the ideal variant the exhausting of the crane resource should be dated to the time of the warehouse building dismantle: it is approximately equal 50 years. Namely so is defined the nominal durability of the crane. Less is forbidden, more is not necessary.

The bridge crane should be certainly taken out of service by the exhausting of resource, particularly, – in case if the negative residual deflection of the main beams (or only one of them) exceeds the normative sizes.

Nevertheless, in limits of the resource the crane exploitation can be stopped, if the elimination of the defects (cracks) is economical inexpedient. Here are possible variants, among which it is necessary to choose an optimal variant. The size of the annual specific reduced expenses shall be confirmed as the optimality criterion on one ton of the processed load:

$$R_{educe} = 1/S_{tr}\left(C_{apit}/R_{epay} + W_{ear} + R_{epair} + W_{ages} + E_{nergy} + R_{est}\right), \quad (1)$$

where:

S_{tr} – annual goods traffic, provided by the crane, t/year,
R_{educe} – reduced annual expenses,
C_{apit} – capital responses, connected with the received delivery and the crane montage,
R_{epay} – recoupment term of the capital expenses, years,
W_{ear} – annual amortization expenses for the crane renovation,
R_{epair} – annual exploitation expenses for the middle, current repair and the technical service,
W_{ages} – annual expenses for the workers' wages,
E_{nergy} – annual energetic expenses,
R_{est} – other annual exploitation expenses.

The crane exploitation lasts tenths of years. For this time, unpredicted inflation slants powerfully the sizes of the expenses. Therefore, it is expediently to appreciate all expenses in the conditional monetary units, which appeal to the gold equivalent.

The existing task has two main aspects:

1) appreciation of the residual crane resource,
2) definition of the project crane resource

2. Appreciation of the residual crane resource

In the crane exploitation process it is possible to know the parameters of the metallic construction stage that by the plan must answer the question about the growth of the residual crane resource – in percent or time units. The market suggests the widest set of the diagnostic equipment:

- hardness measuring instruments,
- ultrasound devices for the revealing of the internal cracks,
- thickness indicators,
- device that realize the method of the acoustical emission, allowing to observe the acute (developing) cracks,
- devices for the definition of the metal magnetic field – coercitive forces.

We have: one sheet of the upper belt with width of 11 mm (project mean 12 mm) has the hardness HB 160, there are 10 internal cracks, from which 6 are developing, cut sample shows the impact strength 220 Joule/sm^2, coercive power 7.5 A/sm^2, the carbon content is 0.26%... It is necessary to answer the question about the percent of the residual resource. Certainly, there is no answer. Let us try to observe it from other side. On the Fig. 1 on the axe of abscess is put over the current time in years, on the axes of ordinates there are reduced expenses (curve 1) and the size of the residual deflection of the main beams (curve 2) in mm. The sizes of the expenses are taken by fact. The size of the residual deflection is measured periodically (for example, 1 time in a year) with help of the micrometrical pin-gage (Stihmass) as the difference of the current and past readout of the distances between the beam checkpoints and the ceiling construction. The received defectograms characterize:

a) the growth of the metallic construction repair expenses in course of time, when there is enough intensive growth of the deformation (residual deflection) of the main beams. The metallic construction is serious "ill". When the summary expenses reach the initial value, it is economically effectually to stop the crane exploitation,
b) the expenses grow intensively, but thus the forming of the residual reflection is very weak. It means that the lion share of the repair expenses falls on the end beams. It means that the main effort should be directed on the adjusting of the mechanical moving crane's wheel supports.

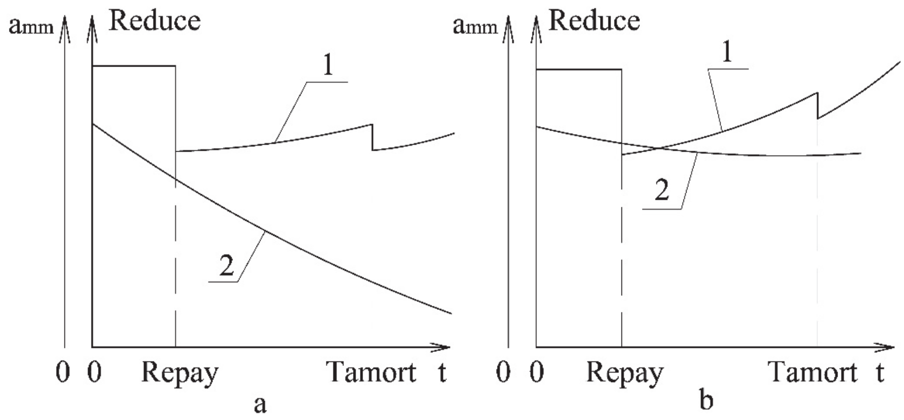

Fig. 1. Defectograms

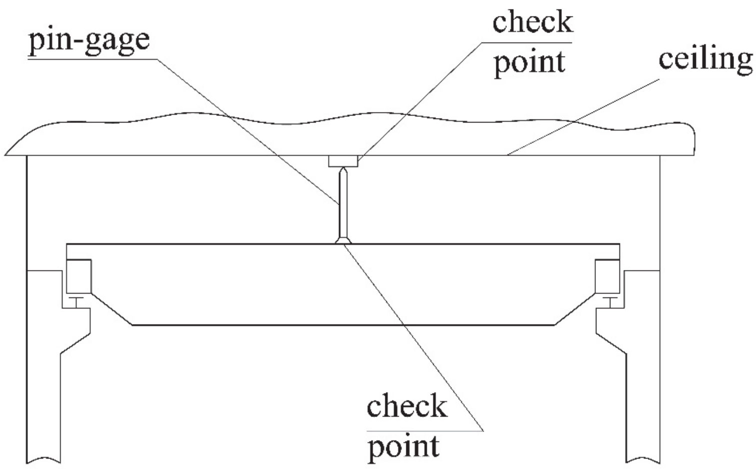

Fig. 2. Measuring of the residual deflection

Therefore, in exploitation crane stage there is a possibility of the diagnosing, and also the definition and the increasing of the residual resource. Concerning the residual resource, if is necessary the concrete size, this mean can be calculated very easily. During t_{years} of the monitoring the residual deflection of the left/right main beam was increased by a, mm. Considering that the limit residual deflection is equal [a], mm, and accepting the size of the building rise we shall find the rest time till the exhausting of the resource, having accepted the stock coefficient K_{stock}, we receive the residual resource:

$$T = k_{stoc} \frac{(2[a] - a)t}{a}, \text{ [years]}, \tag{2}$$

Thus, certainly, we proceed from the fact that namely the main crane beams as the main range define uniquely the exhausting of the resource. All other defects can be eliminated. In addition, if the elimination of the defects is very expensive, we should put the question about the crane elimination.

3. Definition of the warehouse crane's project resource

3.1. Engineering hypothesis of the main beams' maturing

If the welded crane bridge is established on the equal platform, there will be the typical phenomenon of the natural metal maturing. There is a process of the equalizing of the internal tensions. The active phase of the diffusion mass exchange will finish in some weeks.

This time is efficient to bang up primary the blameless welded construction: the difference of the diagonals will not be null, the misalignment of the base apertures will appear, and the angle of the bearing boxes' establishment in the plan can considerable exceed the limit of 0.0004 radians. However, the internal tensions will equalize.

If this bridge can be established on the crane way, thereby will be started the mechanism of the eternal diffusion mass streams, conditioned by the action of the constructive loads – from the own beam weight. The maturing expresses in the fact that the bridge will steady "sag" – the construction becomes old, and at last, it will destruct (maybe in 600 years). Moreover, by the presence of the mobile load, with the flexuous element, it will be much faster. This phenomenon is named creeping. The splash of interest, connected with the name of Saint-Venant, corresponded to the elements of the steam and gas turbines and to the equipment of steam lines. And only a little part of the works touches the "cold" beam creeping [1]. In addition, in the question the residual beam deflection forming we shall use not those four creeping theories that must save the turbines from the accidents, but the main positions of the adaptive metallurgy. The phenomena of the metal maturing appear very brightly in the low-carbon steel.

The activator of the material streams from corns (crystals) to the boundary zones between flakes is the difference of the material concentration, born by the fact that in the zones between flakes isn't provided the compact "packing" of the lattices volume cantered cube and by the fact that the real part of the materials (alloys) consists of the atoms of carbides, nitrides, sulfides. Otherwise, the concentration of the zone materials is less than in the crystal [2, 3]. The additive incentive factor of the parts' migration from the crystal to the periphery is a factor of the mechanical vibrations. It is known that by the high intensity of the vibrations (for example, owing to the heat) the atoms turn away from the units of the lattice.

Therefore, owing to the action of the loads, probably with the vibratory element, the crystals clear soon, avoiding from the admixtures and dislocations. In the same time, the zones between flakes append regularly quantitative. Nevertheless, because of the randomness the density of the zones between flakes stays less than by the crystal. It means that the cross-flow from a crystal to the zones between flakes keeps. It means that the lower, stretched belt of the beam becomes longer that cannot be said about the upper one. So the deflection of the main beam increases that does not contradict to the law of Hooke.

3.2. Mathematical modelling of the beams' diffusion maturing process

In course of time in the massive of the sample from the low carbon steel occur changes: grows firmness, equalize the internal tensions, little internal cracks "overgrow", sometimes the groups of little cracks create macrocracks. This is a diffusion action. The beam on two bearing supports, loaded lower than the limit of the proportionality, receives the residual deflection (creeping). It is also a diffusion that is expressed in the increasing of the geometrical length of the carrying elements (particularly, of the low belts of the beams). The sample under the action of the oscillatory loads much fewer than the limit of the proportionality destructs owing to the fatigue. It is also diffusion. Our mathematical model must describe the kinetic of the maturing process of the case bay metallic construction – contrary to the fact of the information absence about the constants in the expressions, which describe the diffusion process.

By the null load, we have the natural maturing. By the constant load, we have static exploitation maturing. The most important is the maturing of metal with the regard of the vibratory loads action.

According to the law of Fick the density of the particle flux:

$$I = -D\frac{\partial C}{\partial x}, \tag{3}$$

where:
x – coordinate in the stream direction,
C – concentration of the diffusing elements,
D – coefficient of the proportionality that depends on the temperature as a factor of the intensity of atomic vibrations in the system of the elastic electronic covers/levels (by high temperature the intensity of the vibrations is so big that it leads to the liquation of the metal).

The general diffusion stream (in time unit) that means the length increasing of the low bell):

$$Q = k_{pr} F_{osc} F_{str} , \tag{4}$$

where:
k_{pr} – coefficient of the proportionality,
F_{osc} – factor of the vibratory action that characterizes the influence of the vibrations intensity on the growth of the diffusion stream, it means, on the residual beam deformation,
F_{str} – the factor of the material concentration, defined by the size of the stretching loads that decrease the material concentration in the zone between the flakes, consequently, increase the concentration difference.

We operate with the size of the mass stream parameters, for example, Q. We do not know and we shall not know any time the size of these growths. We are interested with the proportional sizes: particularly, we are interested with the quickness of the beam deflection growth.

$$E_{miss} = k_{osc} Q , \tag{5}$$

where k_{osc} – proportionality coefficient.

The size F_{osc} is defined with the intensity of the atom vibrations in the system of the electronic covers, particularly, – in the result of the temperature action, vibrations. The intensity of the vibration is proportional to the square of the quickness (vibration quickness of the oscillations):

$$F_{osc} = \left(\frac{dx_{brd}}{dt} \frac{1}{V_{bas}} \right)^2 , \tag{6}$$

where:
x_{brd} – vertical generalized coordinate of the beam centre,
V_{bas} – basic size of the vibration quickness.

The difference of the material concentrations is proportional to the size of the stretched tensions, the increasing of which creates the rarefaction of the material of the zones between flakes:

$$F_{str} = k_{str} \, \sigma_{bend} , \tag{7}$$

where σ_{bend} – the size of the bending tensions, k_{str} – coefficient of the proportionality.

It is necessary to have results of the expert inspection of the bridge cranes' group, to which there is one necessary order: these cranes are episodically used – for example, it can be repair cranes or cranes, foreseen for the service of the definite equipping. By each of named cranes it is necessary to have following information: 1) calculative constructive load on the metallic construction σ_{bas}, Pa; 2) span L_{cr}, m; 3) period of the residual deflection forming T_{flex}; 4) size of the residual deflection f, mm.

On the base of the named information is used the averaged size

$$C_{flex} = \frac{f}{\sigma_{bas} \, L_{cr} \, T_{flex}}, \; \frac{mm}{Pa \; m \; month} . \tag{8}$$

So we define the size that is necessary for the approximately (there is not any other) appreciation of the diffusion processes' scales in static.

So, we can define for the definite observed crane with the case bay L_{cr} with the size of the bend tensions in the low belt σ_{bend} the size of the residual second deflection of the bridge in result of the diffusion factors' action, but without consideration of the diffusion processes' persistence factor:

$$E_{miss} = \frac{C_{flex}}{30 \cdot 24 \cdot 3600} \sigma_{bend}(t)\, L_{cr} \left(1 + \left(\frac{dx}{dt} \frac{1}{V_{bas}} \right)^2 \right). \tag{9}$$

Here C_{flex} is divided on the number of days in a month, the number of hour in a day, number of seconds in an hour.

Calculative tensions

$$\sigma_{bend} = \frac{C_{brd}\; x_{brd}\; L_{cr}}{4\, W_{brd}}, \tag{10}$$

where:

C_{brd} – bend rigidity of the observed crane's main beam (the effort is applied in the centre of the case bay),

x_{brd} – the generalized coordinate of the main beam movement in the vertical plane (current mean),

W_{brd} – profile resistance moment in the middle part of the main beam.

The process persistence can be described by the model "aperiodic link". Then the phenomenon of the emission diffusion stream forming is described in form:

$$E_{miss}(t) = T_{inert} \frac{dR_{emiss}}{dt} + R_{emiss}, \tag{11}$$

where :

R_{emiss} – speed of the residual deflection forming of the main beam with consideration of the persistence factor,

T_{inert} – time constant that characterizes the persistence grade of the diffusion streams.

Size T_{inert} is not known. It can be defined by the empirical method of the real processes' comparison with those processes that were received by the modelling. This size can be scientifically defined after that, when on the bridge cranes will be established loggers. In addition, while the probable (not more) size T_{inert} can be accepted in limits T_{inert} = 10-30 s.

Mathematical model, based on engineering kinetic hypothesis of the residual deflection forming, can be led to the model (9), (11) and:

$$R_{est} = 10^5 \int R_{emiss}(t)dt, \tag{12}$$

where R_{est} – current mean of the main beams residual deflection.

This model should be embedded into the mathematical model of the crane's working cycle.

3.3. Mathematical modelling of the load lifting work cycle

On the base of modelling is defined the size of the residual deflection of the main beam that is formed during one work crane cycle considering the action of the main beams' free vibrations in the processes of start and braking considering the factor of the attenuation of those vibrations. In result of the modelling, we receive the microscopic size of the residual deflection, formed during one work cycle. Having multiplied the received deflection size on the unique size, fixed for all variants of the work cycles modelling (for example, 100000), we receive the size of the residual deflection Rest in the end of the exploitation construction's maturing term. Varying different crane parameters, we define the influence of the named parameters on the crane resource, remembering that the model should be improved. The mathematic model of the crane metallic construction's maturing process is an ensemble of the elastic-viscous main mass dynamic model of the crane's transitional processes (start – constant movement – braking) and the process of the crane beams' negative residual deflection. On the Fig. 3 is shown the dynamic scheme of the system "drive of the lifting mechanism – load – carrying beams".

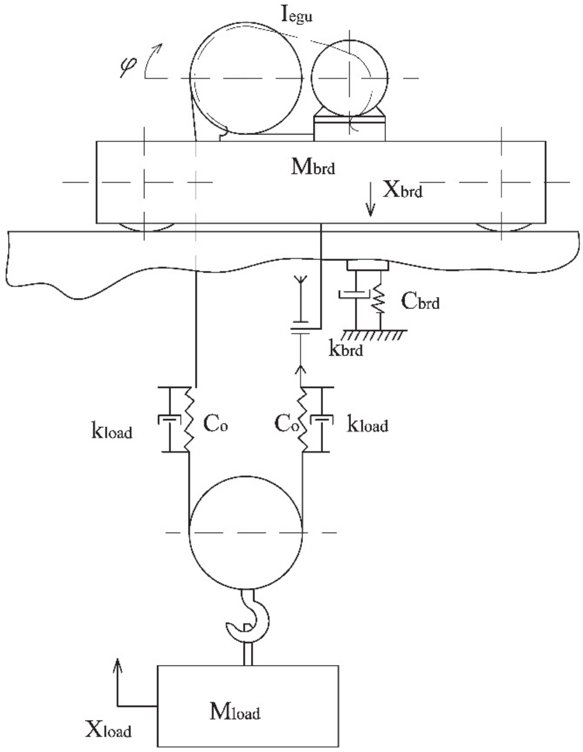

Fig. 3. Dynamical model of the lifting mechanism: φ, x_{brd}, x_{load} are taken as generalized coordinates: angular movement of the rope drum of the lifting mechanism; deflection of the main beam's middle point; linear load movement; I_{equ} – driven to the drum mass of the rising mechanism's rotation parts; M_{brd}, M_{load} – equivalent (considering the Relay principle) mass of the main beams with the additive mass of the load cart and the load mass; R_{drm} – radius of the rope drum; C_{brd}, K_{brd} – coefficient of toughness and coefficient of the equivalent of the main beams' viscous friction – as elastic-viscous connections

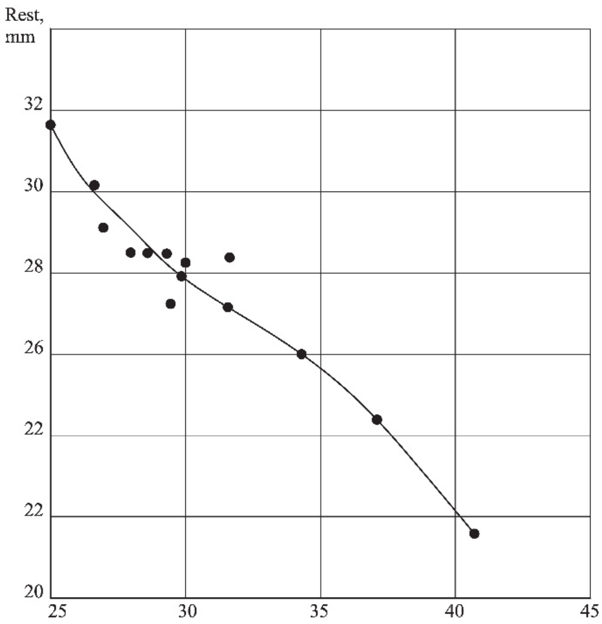

Fig. 4. Dependence of the negative residual deflection on 100000 operations from the constructive module $\omega = \sqrt{(C_{brd} – M_{brd})}$, received on the base of the multisession modelling

The system movement is described by the differential equations:

$$I_{equ}\frac{d^2\varphi}{dt^2}=\Big[i_{red}\,i_{pol}\big(M_{eng}G_{eng}-M_{brk}G_{brk}\big)-D_{drm}\,u\,i_{red}\,C_{cab}\big(R_{drm}\,\varphi-x_{load}-x_{brd}\big)+$$
$$-R_{drm}\,u\,i_{pol}\,K_{load}\left(R_{drm}\frac{d\varphi}{dt}-\frac{dx_{load}}{dt}-\frac{dx_{brd}}{dt}\right)\Big]G_{drv}, \quad (13)$$

$$M_{brd}\frac{d^2x_{load}}{dt^2}=\Big[-9.81M_{load}+C_{cab}\,u\,i_{pol}\big(R_{drm}\,\varphi-x_{load}-x_{brd}\big)+$$
$$+K_{load}\,i_{pol}\,u\left(R_{drm}\frac{d\varphi}{dt}-\frac{dx_{load}}{dt}-\frac{dx_{brd}}{dt}\right)\Big]G_{load}, \quad (14)$$

$$M_{brd}\frac{d^2x_{brd}}{dt^2}=9.81\,M_{brd}-C_{brd}x_{brd}-k_{brd}\frac{dx_{brd}}{dt}+$$
$$+C_{cab}\,u\,i_{pol}\big(R_{drm}\,\varphi-x_{load}-x_{brd}\big)-u\,i_{pol}\,K_{load}\left(R_{drm}\frac{d\varphi}{dt}-\frac{dx_{load}}{dt}-\frac{dx_{brd}}{dt}\right), \quad (15)$$

where:

- M_{eng}, M_{brk} – rotation electromagnetic motor's moment and applied to the rope drum rotation moment of the rising mechanism's brake,
- i_{red} – transmitting number of the redactor,
- i_{pol} – pulley ratio,
- u – number of the branches that wind on the drum,
- K_{load} – coefficient of the equivalent viscous friction of the elastic-viscous main beams' connection,
- C_{cab} – toughness of one drum branch,
- G_{eng}, G_{brk} – discrete operations of the motor and brake switching on and switching off,
- G_{drv} – discrete operator that allows to model the case when the brake is switched on ($M \neq 0$), thus the rope drum is immobile,
- G_{load} – discrete operator that allows in the modelling process to consider situations when the system is loaded by the load's weight only after passing of the central split (in the rope and the transmission) – particularly, in the case of lifting "with pickup", also that fact that the load movement in the process of lifting can begin only after the fact as the power of the viscous tension in the rope branches will increase the load weight.

On the base of the multisession mathematical modelling of the warehouse crane's resource exhausting process is defined, the dependence of the resource from the constructive parameters of the main beams (Fig. 4). Particularly is noticed the increasing of the resource with the increasing of the free vibrations' frequency of the bridge construction.

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