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METHODOLOGY OF RESIDUAL RESOURCE ASSESSMENT IN THE METALLIC STRUCTURES OF LIFTING MACHINES

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Abstract. One of the key problems of particular companies that operate cargo lifting machines in Ukraine (previous affiliation of author – *Department of Handling Machinery and Mechanization of Reloading Work, Odessa National Maritime University, Ukraine*) as well as other post-Soviet countries is that the guaranteed-by-manufacturer period of their safe exploitation has ended. Further use should be subjected to qualified inspection of the metal construction and mechanism. This article focuses on the metal constructions as they are the basis of all cargo lifting machines. Up to now, there has been no common way to determine the degradation of metal constructions and predict their residual resource. The author suggests a methodology for resolving this problem.

Keywords: lifting machines; residual resource; finite element method; full-scale experiment; stresses; strain.

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Introduction

In spite of the aging fleet of overload equipment, which is particular to Ukraine (previous affiliation of author – *Department of Handling Machinery and Mechanization of Reloading Work, Odessa National Maritime University, Ukraine*) as well as the other post-Soviet countries, insufficient acquisition of new cranes is insufficient in all fields of activity. Conventional exit from the current situation for companies, which exploit this equipment are continuously using the lifting machines, which worked out their normal durability (NPAOP 0.00-1.01-07 2007). In this regard, the need arises for a reasonable assessment of the residual resources of the metallic structure (Kotel'nikov 2006). On the whole, a trouble-free exploitation of crane depends on the accuracy and rightness of this assessment. Up to now, the assessment of the residual resources boils down to the issue of the certificate from the owner of the cargo lifting machine to the organization. Performing the diagnostics of metallic structure about their life span, will be expressed in the technological cycles of the crane's work. The organization calculated residual resource according to the following dependence:

$$N_{res} = N_{pass} - N_{lif},$$

where: N_{res} is the crane's residual resource in technological cycles; N_{pass} is the crane's resource, according to the passport in technological cycles; and N_{lif} is the crane's life length in technological cycles for the entire period of exploitation.

There is difficulty in using this method because it requires accurate data about the quantity of handled cargo and the weight of every lifting. Subject to a common absence of the crane's registration devises and bad record keeping at companies, this method is almost impossible. Regardless of the importance factor, the crane's residual resource has to be built on stress cycles as opposed to the usage of technological cycles. Accounts of the residual resource based on the technological cycles of the crane's work can give false results, because at one technological cycle of the crane's work one or

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more stress cycles may act. Considering the complications described above, the following area of using this method for estimation of residual resource of crane's metal structure is limited.

Presently, there are two main solutions to this problem based on the application of nondestructive inspection technique. Application of the nondestructive inspection technique is based on the impact strength test of specimens. These metal specimens are taken from the most dangerous elements of the metal construction. This method has a number of considerable defects – weakening of dangerous assembly from repair welding, which is performed after cutting metals for specimens, necessary in creating the repair's technology of metal construction's element, after taking out the metal and unloading of this dangerous element before taking off a metal.

Statement of research problems and a technique for their decision

The defects that are stated above, initiated an active search for alternative diagnostic methods, which is based on the nondestructive inspection technique. The following process was used, applying diagnostic parameters such as the usage of hardness, coefficient of hardness variation, coercive force, metal's magnetic memory and acoustic emission. A research was carried out regarding the possibility of coercive force's application, for determining metal fatigue damage. They show an ability of using coercive force for solving problems of assessment in residual resource of metallic structure (Grigorov *et al.* 2008, 2011; Gubskiy, Grigorov 2010; Petryshynets *et al.* 2010; Shimamoto *et al.* 2008). Based on the results of these research methodological guidelines, which were approved by authorities '*Gosgorpromnadzor*', were created. However, based on the results of a new research, which was carried out previously, it was obvious that many statements were incorrect, demanded considerable improvement and further research.

The goal of this paper is to develop a methodology, which would be based on the assessment of metallic structure's residual resource of lifting machines, which could be used for decisive decision-making a reasonable amount of investment by means of modernization or reconstruction of the lifting machine.

Suggested methodology based on the dissertation work of Starykov (2011) is about how coercive force is changed according to the cycles of loading the crane metal construction and the stress witch could be taken into account as our studied element.

The list of steps in our methodology:

1) collection and analysis of documentation about manufacture exploitation, carrying out repairs, and modernizations, etc.;
2) detection of the most dangerous places in metal structure of the crane, which was investigated in our application of coercive force parameter (Starikov *et al.* 2011; Starikov, Nikiforov 2012);
3) creation of the crane's mathematic model and crane's calculation on cycle's strength for typical conditions of crane work were planned;
4) full-scale experimentation (with using of strain gauges) for identification of conformance of calculating scheme to the real conditions of crane's exploitation;
5) detection of conditions, possibility of further exploitation, and assessment of residual resource.

The first stage of methodology which was suggested assumes a collection and analysis of documentation which exist and this stage closely approximated from a similar stage in working methodologies to date.

The second stage is the inspection of the crane's metallic structure which is conducted with magnetic nondestructive technique of coercive force parameter. Application of this parameter enables us to determine dangerous elements of the crane according to increased magnitudes of coercive force. For the purposes of using coercive force in diagnostic of cranes, the special device was developed by Ukrainian company (Fig. 1). It allows performing nondestructive control without removing of paint (if the thickness of paint layers up to 1 mm) from the surface, which is diagnosed.

Obtained data for a coercive force measured in different elements of metal construction, which have different thickness of metal is presented. Thus, to compare these results with each other and the rejection value, they must be adjusted to the equivalent thickness of metal (8 mm). When the coercive force reaches its rejection value, it will mean that the metal of the crane element is in dangerous exploitation. The method of coercive force is new and developing it requires solution of current tasks, which can be without answers. Carrying out of works at this stage requires not only expert's basic training about nondestructive inspection technique, but also big engineering mental outlook, analytical thinking, and abilities for carrying out replicate experiments of investigation of the metal. The result of this work stage is finding of the most dangerous elements of crane and damage level of metal inside them (indication about metal's damage level). For example, author use the sketch of measuring of coercive force for the jib of gantry crane '*Sokol*' (Fig. 2).

Fig. 1. The device for coersive force measuring

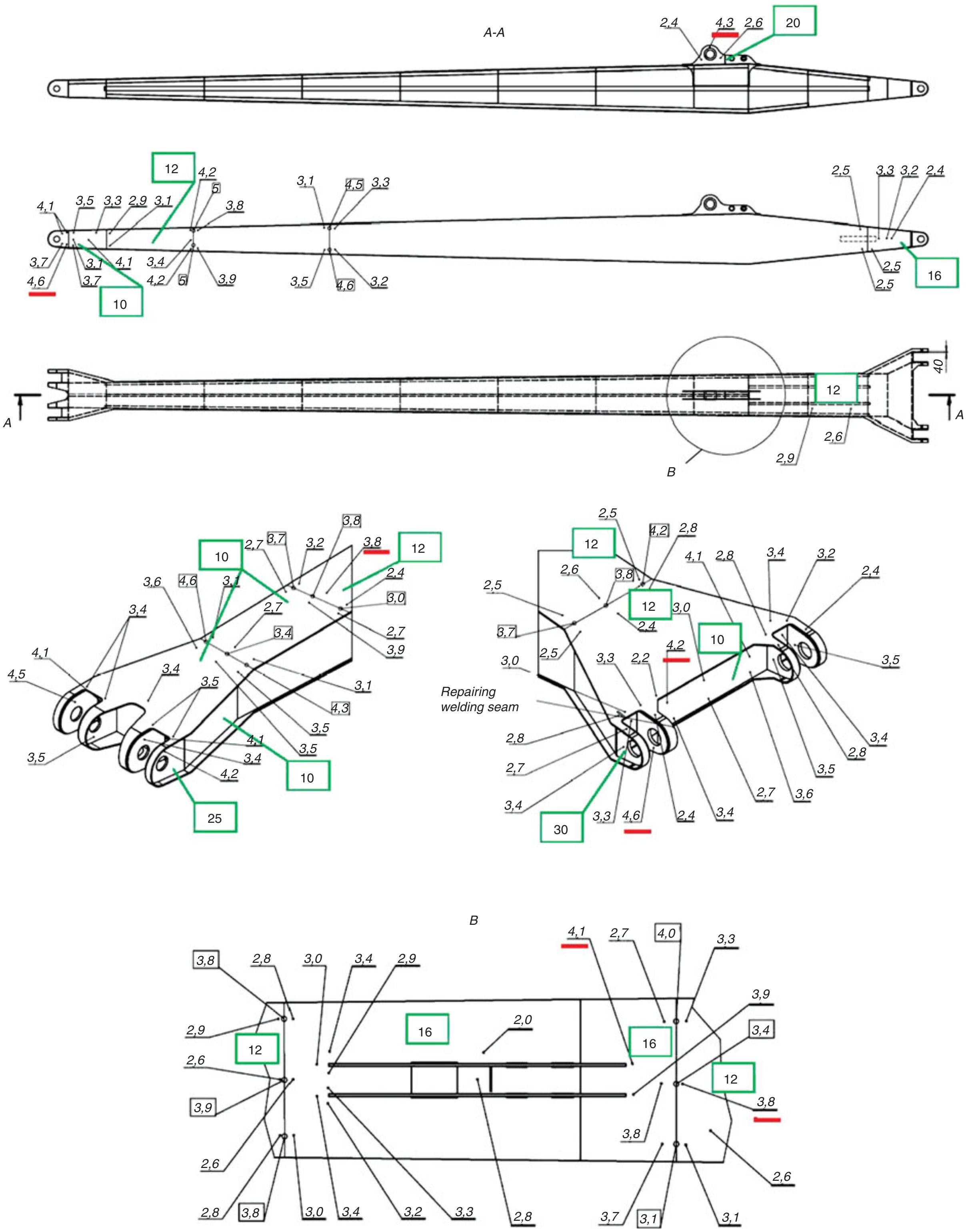

Fig. 2. Value of coercive force in the boom of portal crane

Corresponding thickness of elements, where coercive force was measured, indicated in green rectangular. Measured values of coercive force are shown in the callouts.

The very dangerous elements have the most values of coercive force and are underlined with red. The results of conversion of measured values to the equivalent values (for thickness 8 mm) are shown in the Table 1. By comparing between the converted value of coercive force and the limit value, using diagrams (MV 0.00-7.01-05 2005) the author obtained the level of fatigue damage accumulated in the metal construction for the period of its exploitation (in presents).

For determining the residual resource in cycles but not in percent, the author has to know the conditions and working cycle of the crane for its further analysis. From data collected, using calculation, the author obtained the cycle of stress variation during the crane's working cycle, which will appear in the most dangerous elements of crane's metallic structure (stages 3 and 4) (Voyiadjis, Kattan 2005). For example, the calculation of residual resource for Ship-to-Shore crane is presented. The basics for such calculations (typical cycles of crane's work) should be supplied by the customer, for which the author assigns the dependence of stress time. The result of the calculation of the marine console's metallic structure which is situated on the Ship-to-Shore crane using the finite element method was realized in the complex program ANSYS (Madenci, Guven 2005; Stolarsky *et al.* 2007), see Figs 3–8.

The calculation was done for the cases of loading, which were simulated by the cycle of crane work:

1) trolley with container is between root hinge of console and clamping hinge of console;
2) trolley with container is above the clamping hinge of console;
3) trolley with container is at the end of console.

Table 1. Results of control and detection of equivalent of coercive force, assessment of residual resource

Arrangement of the most dangerous elements of boom's metallic structure	Thickness of metal h, mm	Measured value of coercive force H_c, A/cm	Converted value of coercive force $H_{c(\text{new})}$, A/cm	State of metal	Residual resource, %
Sheet in the boom root area	10	4.2	4.5	Condition of controlled exploitation	22.0
In the area of joint between rack and boom	12	3.8	4.4	Critical condition of exploitation	23.0
In the area of joint between rack and boom	16	4.1	5.0		14.0
Lug of hinge of rack lashing	20	4.3	5.4		7.0
Lug of boom point	25	4.6	5.8		5.5
Lug of boom root	30	4.6	6.0		4.0

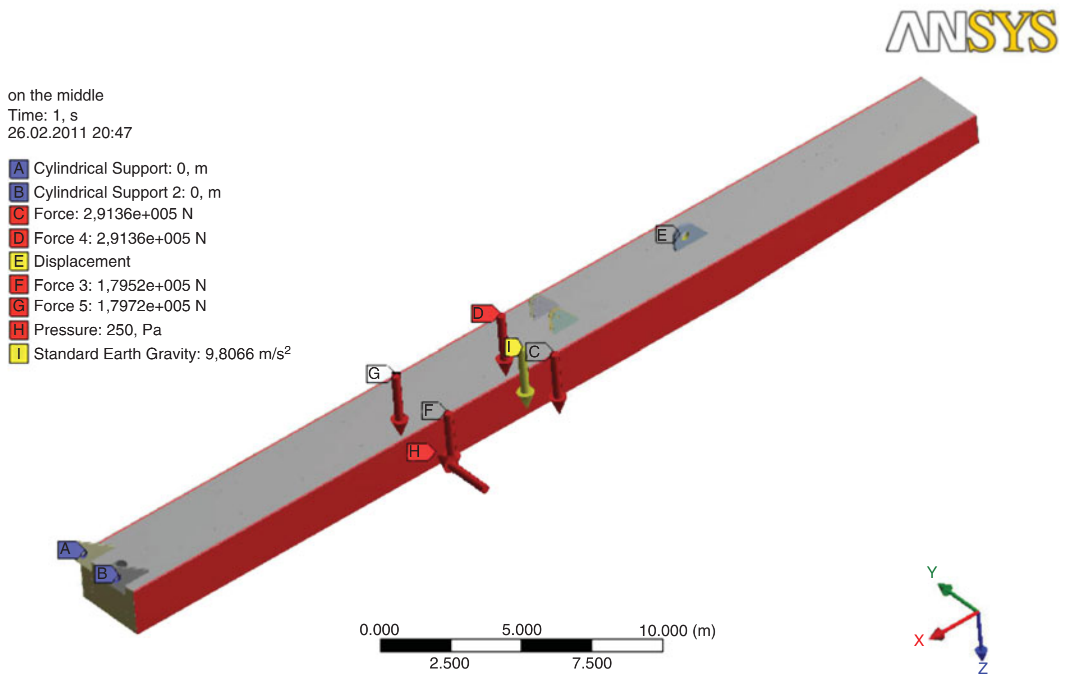

Fig. 3. Trolley with container is between root hinge of console and clamping hinge of console (boundary conditions)

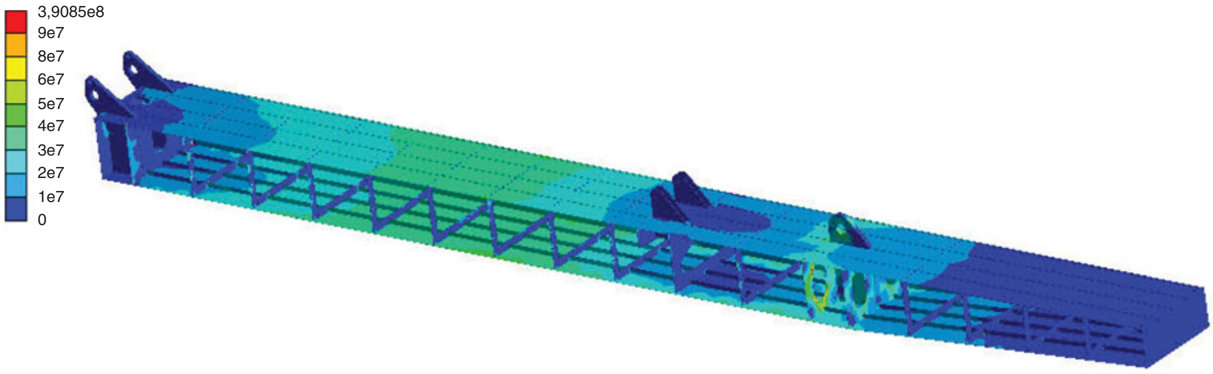

Fig. 4. Trolley with container is between root hinge of console and clamping hinge of console. Stress state of console (Von Misses, MPa)

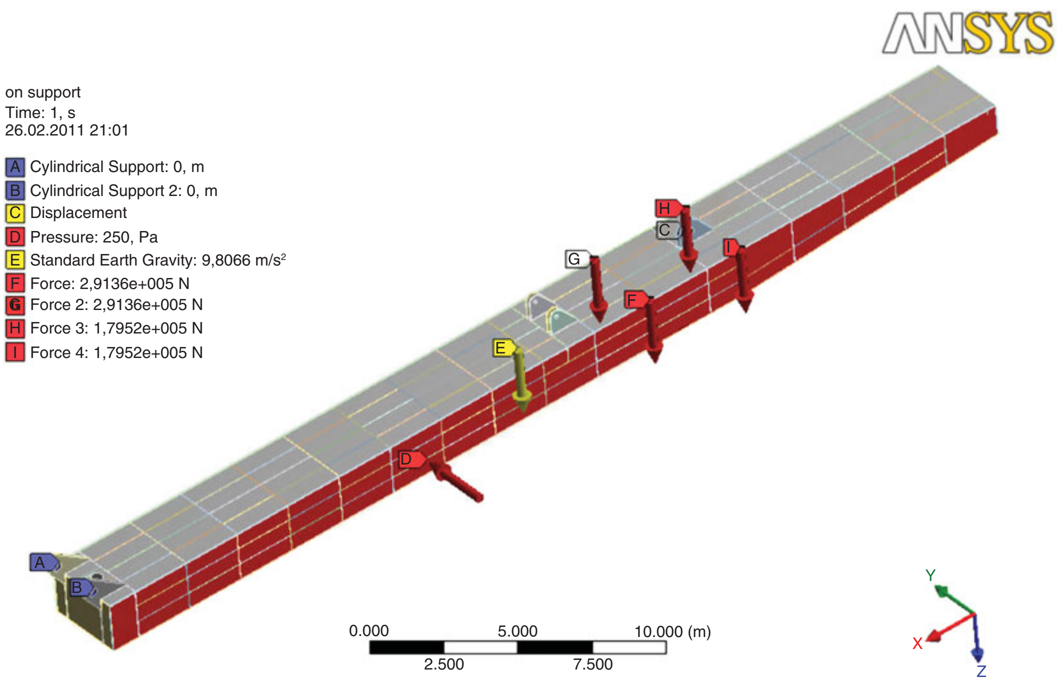

Fig. 5. Trolley with container is between root hinge of console and clamping hinge of console (boundary conditions)

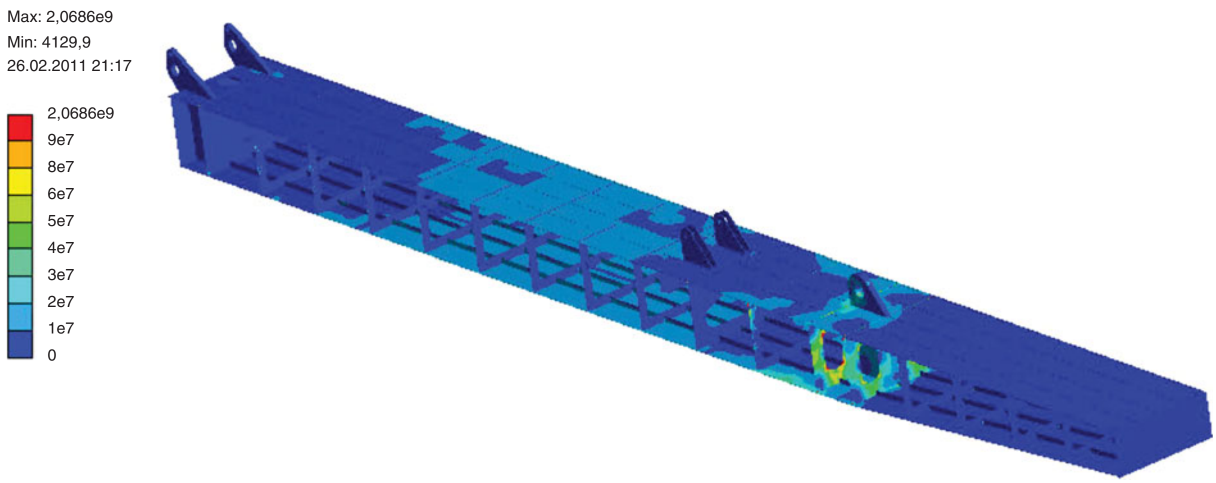

Fig. 6. Trolley with container is between root hinge of console and clamping hinge of console. Stress state of console (Von Misses, MPa)

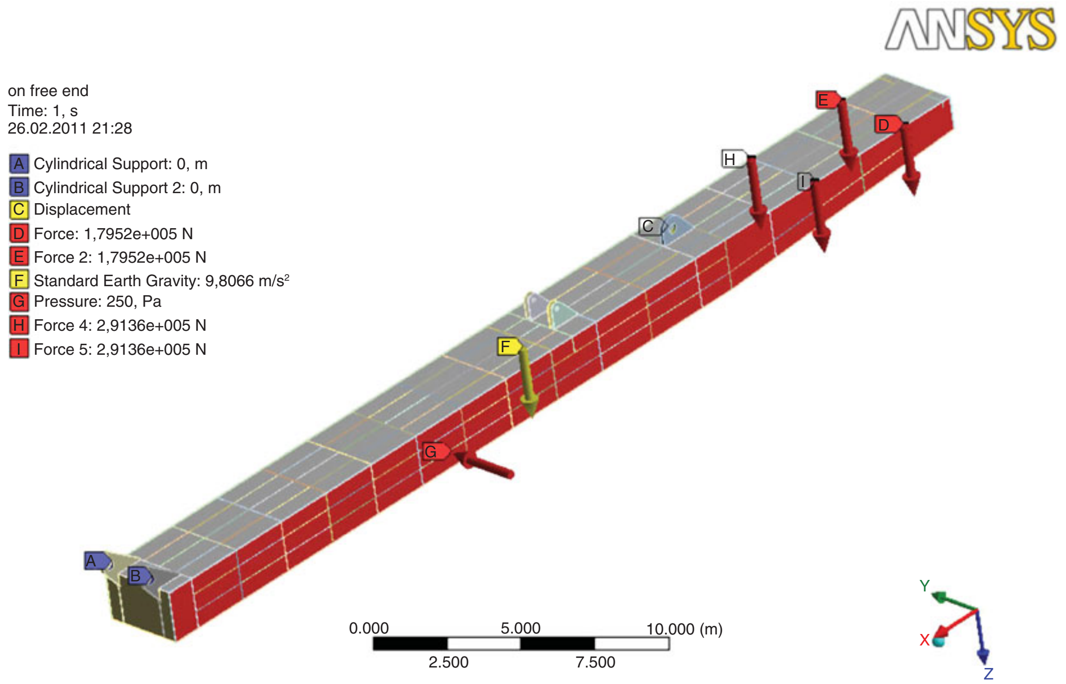

Fig. 7. Trolley with container is at the end of console (boundary conditions)

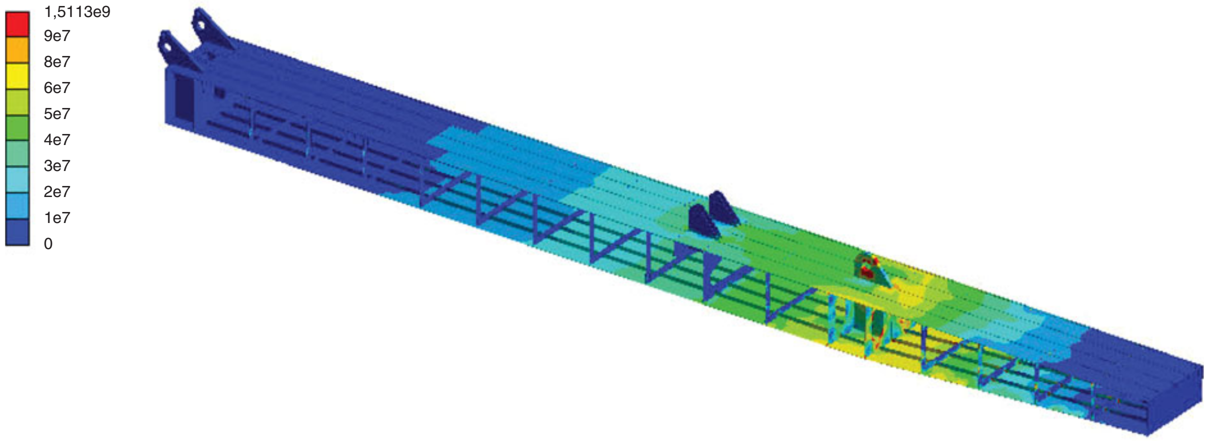

Fig. 8. Trolley with container is at the end of console. Stress state of console (Von Misses, MPa)

A check on the adequacy in calculations was performed using a full-scale experiment, which is in the majority of cases based on the use of strain gauges. For Ship-to-Shore crane console, dependence of Von Misses stress-time variation, which was obtained as result of calculations based on the main stresses, is shown in the Fig. 9:

$$\sigma_{\mathrm{MISSES}} = \frac{\sqrt{2}}{2} \times \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2},$$

where: σ_1, σ_2, σ_3 are main stresses.

The stress-time variation taken from strain gauges is shown in the Fig. 10.

It is difficult to do these stages because the calculation of metallic structures and organization of experiment, demand the deep engineering knowledge of special subjects, and the ability to analyze obtained result (Lee *et al.* 2004). As experience has shown, the execution of this part of work could not be done by majority of engineering staff. However, this work could be done by specialists of chief departments in universities, academies, by engineers with vast work experience, who specialized on durability and those who works in the construction bureaus. After analysis of stress variation depending on time author can agree that this stress does not accumulate fatigue damage into the most dangerous element of the crane. So in this case, if the Ship-to-Shore crane is working in such conditions, the fatigue will not be a key factor in breaking it down, so more attention should be paid to other processes – such as corrosion, etc.

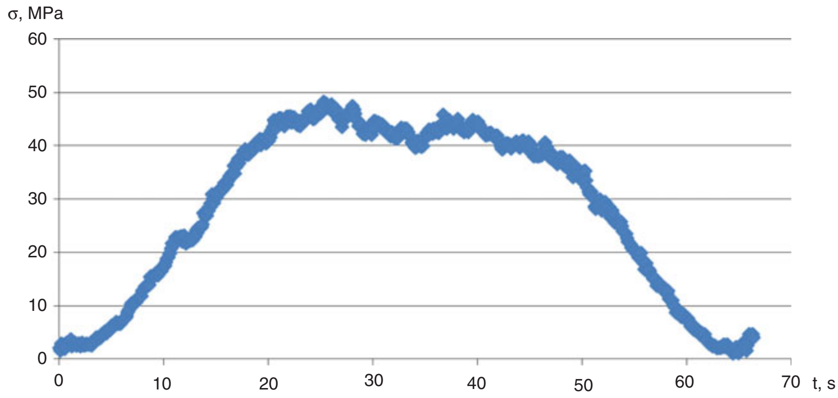

Fig. 9. Von Misses law of variation of equivalent stresses depending on time during the work cycle of a crane (experimentally)

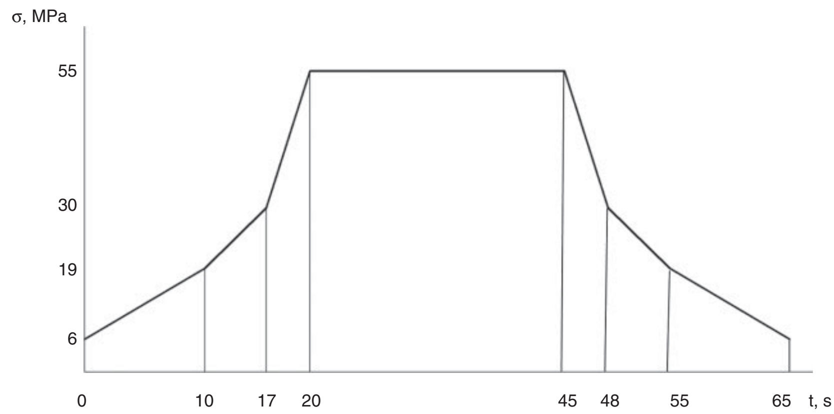

Fig. 10. Von Misses law of variation of equivalent stresses depending on time during the work cycle of a crane (calculation)

Resulting from investigations, a reasonable conclusion about the state of the crane's metallic structure, residual resource of it, necessity of its elements reinforce, its modernization, realization of repair or about crane's writing-off in time of economical inexpediency of the crane's reconstruction.

Conclusions

1) Methodology of the assessment of residual resource in metallic structures of lifting machines was proposed. This methodology is based on modernized method of nondestructive inspection according to coercive force's parameters, full-scale experiment with application of strain gauges, and modeling of stressed-deformed state in overload machine which was explored with using the method of final elements.
2) Our proposed methodology is more preferred, than methodology which was used till now (this methodology is based on using the breaking test with a cut out material for specimens from the most dangerous units of crane metallic structure).
3) Proposed methodology for cranes investigation and identification of their residual resource should be perform by special companies, that have personal with deep engineering grounding, knowledge in special areas (CAD, CAE, etc.) and abilities for analysis of result. As experience has shown, this area of work cannot be done by majority of the engineering staff.

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