Research Article

ASSESSING THE NEED FOR ROPE REPLACEMENT IN CRANE LIFTING EQUIPMENT AFTER CHANGE OF CRANE OPERATIONAL PARAMETERS

Jozef Kuľka[1], Martin Mantič[1], Melichar Kopas[1], Eva Faltinová[1]

[1] Technical University of Košice, Faculty of Mechanical Engineering, Department of Constructional, Automotive and Transport Engineering, Letná č. 9, 04022 Košice, Slovakia, e-mail: jozef.kulka@tuke.sk, martin.mantic@tuke.sk, melichar.kopas@tuke.sk, eva.faltinova@tuke.sk

ABSTRACT

This article describes a specific analysis and evaluation process of a foundry crane installed in a steel mill. The main task was to analyse the possibility of increasing the lifting speed of the crane in order to improve the efficiency of the production process. The condition of the steel supporting structure of the given foundry crane was assessed by means of the performed experimental measurements and calculations. The present article describes the special experimental/analytical methodology for the evaluation of the crane steel construction and lifting and travelling mechanisms. Furthermore, the required modifications of the individual crane construction parts are explained.

Keywords: foundry bridge crane, dynamic response of construction, residual durability.

INTRODUCTION

With respect to the challenges of the economy, it is presently necessary to deal with problems tied to raising the technical level of the existing machines and equipment by reconstruction with a view to enhancing particular performance parameters while sparing materials, and maintaining or increasing their functional and operational reliability.

The increasing application of computers to the process of solving the issues that arise in technical practice does not eclipse the significance of a technical experiment. Comprehensive input, including experiments, is gaining importance not only in the computer aided designing of mechanical systems, but also in the field of system testing and identification. Intensifying further technical capacity of heavy load-bearing steel structures depends mostly on the ability to predict residual service life. Predicting the residual life for the existing load-bearing structures is a serious technical, engineering, and scientific challenge. The nature of factors that affect the service life is twofold. Firstly, there are structural characteristics, structural materials, size, shape, structure construction, technological factors (surface treatment, notches, welds), and joints. On the other hand, there are service characteristics, such as structural loading, environmental factors (corrosion, high or low temperatures, radiation) and, to a considerable degree, the human factor (equipment operation).

In this spirit, an expert evaluation of the steel structure featured in Figure 1 was carried out on a foundry crane (250t / 63t / 12.5t – 26.4m). The assessment required taking relevant measurements carrying out checks and inspections of the crane to evaluate its technical condition, in preparation for the subsequent reconstruction aimed at increasing the working speed of the main lift from the current 5.3 m/min to 8 m/min. The steel structure of the crane was inspected for material loss caused by corrosion, and a series of tensometric measurements were taken to reflect the current technical condition of particular load-bearing parts of the crane and the crab structure (250t) after 26 years of service. By using the experimental-analytical approach, we established the crane's residual life, which in turn determined how valuable the lift's reconstruction would be.
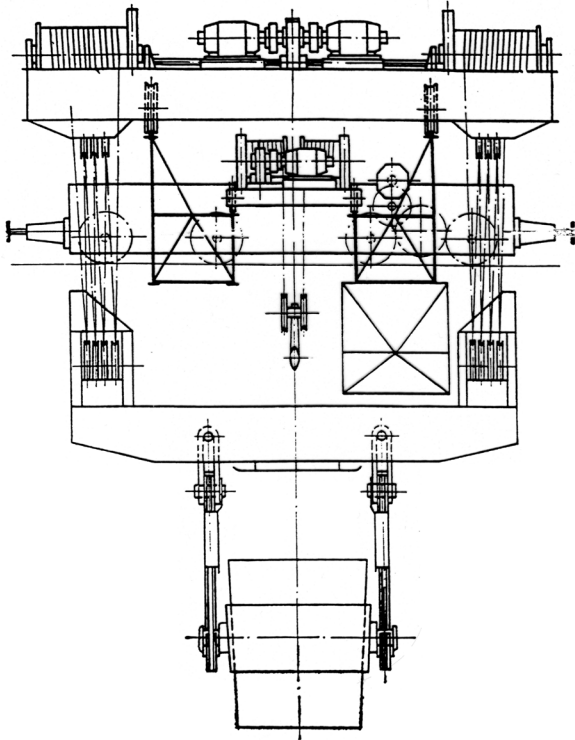
Fig. 1. Foundry 4-girder crane

EVALUATING THE CONDITION OF THE CRANE'S STRUCTURAL STEEL MATERIAL

This task involved random selection of points where the measurements of the individual steel plates were taken by an ultrasound thickness gauge. The measurements established that there had been no material loss in previous years. The inspection of the crane structure revealed that the welds were intact and there was no bulging.

The results of the calculations performed on the load-bearing steel structure and the crab frame of the foundry crane (Fig.1) together with the concurrent visual inspection allowed us to establish the application points for the tensometric sensors. The methodology for experimental determination of deformation, and consequently the stress, was proposed.

Dynamic response of the steel structure

A customized measurement of the experimental dynamic lift coefficient was designed to determine whether the foundry crane steel structure had the capability to withstand the planned lift speed increase from 5.3 m/min to 8 m/min. The calculated dynamic lift coefficient, as defined by the Slovak Technical Standard (STN) STN 27

0103 [6], is 1.331 at 5.3 m/min for the main lift and 1.352 at 8 m/min for the auxiliary lift. The individual development of this sensor measurement established that the lift coefficient did not exceed 1.2 in any of them. With the speed increasing to 8 m/min, the calculated lift coefficient for the main lift would be 1.352, and therefore the actual one would be 1.22 (acquired by extrapolating the linear dependence for the structural deformation in the elastic area). This value does not affect the dynamic characteristics of the steel structure, nor its consequent forces.

The measured relative strain values were used to calculate the normal tension values in the measurement points. This mode simulated three real work cycles, hence, approximately fifteen measurements represented the actual 24-hour operation of the foundry crane (3 shifts).

This overview of changes considers all dynamic and inertial effects caused by skewing as the crab moves. The nominal loading, based on its own weight, is established as the effect of distributed loads as well as single loads. The girder of the main 250-ton lift (including the platform, thermal protection, and electrical wiring): $q_I =$ c. 27 kNm^{-1}; The cross section module related to bend axis (static crane calculation and drawing documentation): $W_y = 135.058 \times 10^6$ mm^3; Bending moment in the centre of the girder based on its own weight: $M_q = 2300$ kNm which corresponds to the stress of approximately 16 MPa.

The stress changes presented in the graph in Fig. 2 signify the elevated values of normal stress in the upper flange of approximately 79 MPa. It follows that the overall stress will not exceed 100MPa.
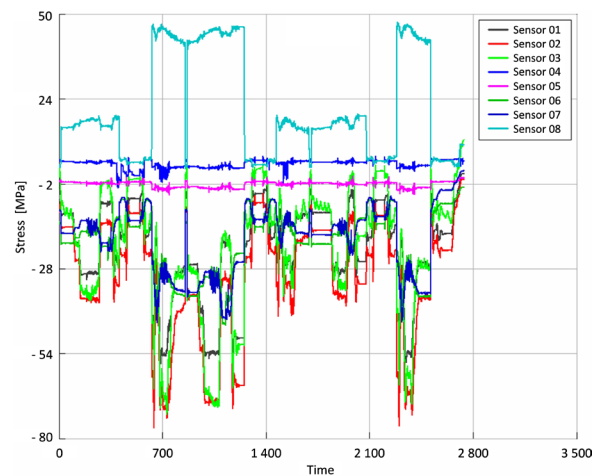

Fig. 2. Measured relative strain changes expressed as dynamic stress per work cycle

Residual durability of the crane girders

The foundry crane 250t-63/12.5t-26.4 m had already been in operation at the time of measurement for 26 years. The projected durability of the given kind of crane may be from 200,000 to 2,000,000 of operational cycles during the whole technical life of the crane, according to the technical standard STN 27 0103. Attachment No. II to the standard in question categorises this foundry crane into the operational group J6 and the determined stress spectrum is S3. Thus the applicable number of the technical life cycles, specified in Table 13 in the STN 27 0103, is $N_2 = 200\ 000 \div 600\ 000$. According to the crane operator the number of foundry ladles handled daily (during 24 hours)is approx. 45, hence the total number of working cycles in the technical life to date is: 300 days x 45 foundry ladles x 26 years = 351 000 cycles. This concludes that the current stage of the operational life of the given crane is near the middle of its technical durability range. This hypothesis was also verified by a calculation performed using the experimentally obtained results and methods according to the "Eurocode 3: Design of steel structures. Part 1-9: Fatigue" and STN 27 0103.

The kind of the crane loading cycle is almost a vanishing loading cycle, as shown in Fig. 2 and according to the STN 27 0103; consequently the stress amplitude value, which is used for the calculation of durability, can be determined as $R_{fat,t(0)}$ = 106 MPa and therefore such amplitudes, which are less or equal to the value 106 MPa, will not affect the crane durability. The fatigue strength can be calculated for the nominal stress values at the constant amplitude level according to the "Eurocode 3: Design of steel structures. Part 1-9: Fatigue" [2] as follows:

$$\Delta\sigma_R^m\ N_R = \Delta\sigma_C^m\ 2\times10^6$$

with

$$m = 3\ \ for\ \ N \le 5\times10^6 \tag{1}$$

The durability calculated from the equation (1) is:

$$N_R = 2\cdot10^6\ [106\ /\ 79]^3 = 4\ 831\ 325\ \text{cycles} \tag{2}$$

The performed evaluation of the crane durability appears to suggest that the actual technical status of the machine in question is characterised by a sufficient reserve of fatigue durability at a given operational mode, as the current fatigue rate of the crane is fewer than 10% of the projected value. Therefore, based on the aforementioned,

we may conclude that increasing the lifting speed of the given crane with regard to the residual durability of the crane construction is feasible. However, it is recommended that the verification of the technical status and functionality of the lifting mechanism be assessed.

Technical status and functionality of the crane lifting mechanism

The whole crane construction and the driving mechanisms were recalculated according to the Paragraph No.III, part "c" of the STN 27 0103. The performed calculations confirmed the potential of the existing crane construction for the modification of crane parameters. It was, however, unnecessary to recalculate the driving mechanisms of the crane crab for the auxiliary lift 63/12.5t, because this crane crab is not applied during transport and handling of the foundry ladles. The auxiliary crane crab is used as the so-called foundry crane crab. The auxiliary hook of the pulley block with the lifting capacity of 63 t enables titling of the foundry ladle especially during slag discharge.

The 250 t traverse with two lamellar hooks hangs on 20 cross-sections of the steel wire rope with the diameter of 40 mm. The 250t lift is equipped with a weighing system, which also serves as the overload protection device.

There is originally applied the steel wire rope Seal STN 02 4342.41 with the wire strength value 1570 MPa and with the nominal loading capacity F_0 = 1007 kN.

The daily working cycle consists of 45 cycles in 24 hours. According to the STN 27 0101 (Cranes. Design of crane steel constructions) [13] and the STN 27 0103 this crane is categorised into the lifting class H4, the type of operation is D1, the stress spectrum is S3 and the operational group is J6. The minimal value of the crane rope safety coefficient must amount to k = 5.0, and in the analysed case of the specified number of the working cycles the stress level in the rope should not exceed the value 320 MPa at a given strength level of the rope wires. The maximal static tension force in one cross-section of the rope for the load 250t, including the foundry traverse with the lamellar hooks (32 600 kg), is calculated as follows:

$$F_1 = (250\cdot10^3\cdot9.81 + 32.6\cdot10^3\cdot9.81)/20 = \\ = 138.615\ \text{kN} \tag{3}$$

The required rope cross-section is:

$$A \ge 138.615\text{x}10^3/320 = 433\ \text{mm}^2 \tag{4}$$

The cross-section of the rope with the diameter 40 mm (construction Seal) is 641.45 mm².

The calculated value of the dynamic lifting coefficient is 1.331 for the main lift with the lifting speed 5.3 m.min⁻¹. In this case the tension force acting on one rope cross-section will be:

$$F_{1d} = 138.615 \cdot 1.331 = 184.5 \text{ kN} \qquad (5)$$

The rope safety coefficient will be:

$$k_{1d} = F_0 / F_{1d} = 1007 / 184.5 \text{ kN} = 5.45 \qquad (6)$$

If the lifting speed is increased up to 8 m/min, the calculated lifting coefficient of the main lift will amount to 1.352 and the tension force in one rope cross-section will increase to the value:

$$F_{2d} = 138.615 \text{x } 1.352 = 187.4 \text{ kN} \qquad (7)$$

The rope safety value in this case is:

$$k_{2d} = F_0 / F_{2d} = (1007/187.4) \text{ kN} = 5.37 \qquad (8)$$

From the point of view of ensuring sufficient rope safety it is not even necessary to change the original rope with diameter 40 mm and rope strength 1570 MPa at the lifting speed increase to 8 m/min.

At the time of crane design other standards were in force. The previous rope calculation was done according to a currently effective standard, but within harmonization of the European standards, where new scientific knowledge and practical experience from a design of steel structures are applied, we will provide also rope calculation according to the standard ISO 4301/1 (Cranes and lifting appliances. Classification) [4] and ISO 4308/1 (Cranes. Selection of wire ropes. Part 1: General) [5]. Several authors [3, 7, 10, 11], engaged in problems of steel rope stress, their damage in operation, in experimental and simulation verification for different types of ropes and lay types, prove that rope under stress requires special attention. The stress states resulting from different kinds of loading [3] are often not included in calculations according to standards [1]. The comprehensive characteristics of steel wire rope should include the factors of: rope surface quality as well as the heat treatment [8].

The purpose of the structure analysis is to resolve whether the designed crane will be able to attain a projected lifetime at the considered operating conditions. The basic parameter of the classification is a certain number of cycles expected during crane lifetime. The number of working cycles to is 300 days x 45 foundry ladles x 26 years i.e. 351 000 cycles. According to [4] the mentioned number of cycles corresponds to U_5 class of crane usage.

The second parameter of classification is the loading state, with a corresponding value of the loading coefficient $K_p = 1.00$. This coefficient and class of crane usage represents the value A7 of group classification of a crane as a whole.

According to the technical standards the mechanism is considered as operating only when loaded. Here, the corresponding mechanism usage class is T_5, and the loading state of the mechanism expressed by the coefficient of loading spectrum $K_m = 1.0$ and the final classification of stroke mechanism M7.

The value of the rope selection coefficient is C = 0.125 and the minimal value of the rope safety coefficient is $Z_p = 7.1$ in the classification M7 of lifting mechanisms according to [5]. The minimal value of the rope diameter is given as:

$$d = C \cdot \sqrt{S} \qquad (9)$$

where S is the maximal loading of the rope expressed in Newton unit. Using the maximal loading value of one rope cross-section F_1 obtained from the previous calculation it is possible to determine the minimal rope diameter value:

$$d = 0.125 \cdot \sqrt{138615} = 46.5 \ mm \qquad (10)$$

According to the catalogue of the steel wire ropes the maximal possible rope diameter of the Seal construction is only 40 mm. The nearest category of the rope with the similar strength characteristics is a rope with 210 wires, Warrington type rope. The diameter of this rope is d = 47.5 mm and the nominal rope loading capacity is $F_0 = 1344$ kN. The rope safety in this modified situation is:

$$Z_{p1} = F_0 / F_1 = 1344/138.615 = 9.7 \qquad (11)$$

i.e. the sufficient level of the rope safety reserve is reached.

If the lifting speed is increased from 5.3 up to 8 m/min, the rope safety will be:

$$Z_{p2} = F_0 / F_{2d} = 1344 / 187.4 = 7.17 \qquad (12)$$

which means that the given rope is suitable in this case as well.

The lifting mechanism is equipped with the rope drum of a double arrangement. For this reason a double force in the rope is acting on the drum and the required power output of the lifting mechanism with the increased lifting speed 8 m/min (0.133m/s) is:

$$P = \frac{2 \cdot F_1 \text{ x } v}{\eta} = \frac{2 \cdot 138615 \cdot 0.133}{0.8} = 46 \ 205 \ W \qquad (13)$$

The lifting mechanism consists of two electromotors with the power output 160 kW, i.e. the power output reserve is sufficient also for the increased lifting speed. In this case it is not necessary to perform any modifications in the lifting mechanisms [9], however, the rope drum has to be replaced due to the application of the rope of higher diameter.

CONCLUSIONS

The specific analysis and evaluation of the supporting steel structure of the given foundry crane and its mechanisms (lifting and travelling mechanism) verified the capability of the tested crane to continue in current operation after increasing the lifting speed from 5.3 m/min up to 8 m/min. The reduction of material in the crane steel construction after 26 years of operation was not recorded. The dynamic response of the supporting steel structure to the required increasing of the lifting speed is in compliance with current technical standards, as well as the residual durability, which is a decisive factor in confirming the suitability of the crane to the projected change of the its parameters. The only problem is the application of the lifting ropes, which would have to be replaced with higher-diameter ropes, to comply with the current technical standard. It is necessary to keep or to increase the functional and operational reliability as well as safety of the applied technical equipment after reconstruction, which in the presented case was performed in order to improve specific parameters, efficiency and technical level of the existing machines and machinery.

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