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CALCULATION OF A MAST TYPE JIB CRANE FOR SLUDGE PUMPS HANDLING

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Abstract *This paper represents a continuation of the technical solution of the mast type jib crane for handling sludge pumps. It is situated and used in building no. 900, block V2 of Jaslovské Bohunice nuclear power plant. It accounts for an optimization of the original, damaged during operation, handling equipment with manual control of lift and rotation. Inasmuch as it was established that the lifting force still belongs to the recommended range of 120 N to 160 N for comfortable operation by one worker after the modifications made to the mast type jib crane, the overload of the equipment has a negligible effect on the lifting force on a crank. Due to the fact that in the original design there was a complete absence of bearings in the rotating mechanism, it is the solution to this problem that is on the subject of the paper. The difficulties with lifting the pumps from sludge ambient, which occurred during the use of the mast jib crane, was an inspiration to modifications of the original structure. As a solution, it is proposed to cancel the original construction of the carrier inserted into the support and replace it with a fixed mast on which the jib would rotate. In this way, it would potentially increase the load capacity and thus solve the problem of lifting pumps attached to the bottom of a tank. On the other hand, it is also attainable to amplify the range of action of this crane.*

Keywords *mast type jib crane, handling, structural design, functional calculation, load capacity*

1 INTRODUCTION

Transport is one of the basic branches of industry. In addition, it not only enters all stages of the production and consumption process, but is also a key condition for international trade. Material handling is directly linked to transport. In most cases, lifting machines and equipment are employed when handling the material. From time immemorial, these devices have been used to facilitate work, e.g. the first primitive prototypes were employed in the construction of Egyptian pyramids. Many years have passed since then and the lifting equipment has undergone extensive development until it has acquired the shape and parameters of today's equipment. Moreover, their operation significantly speeds up work and simplifies life of ordinary people. It is probably difficult to conceive the panorama of a growing modern city without cranes, which seem to have become an integral part of various constructions. It is more than certain that cranes will advance this work in the future and, thanks to constant innovation and modernization, will improve and make the crane as a symbol of development and progress (Blatnický, 2015; Košábek, J. et al., 1990; Remta, 1974).

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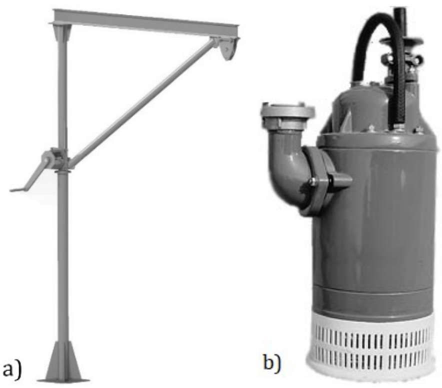

Fig. 1 Three-dimensional model of the original mast type jib crane a) and manipulated sludge pump type 80-KDU-15 b)

From constructional and functional point of view, the mast type jib crane depicted in Fig. 1a can be comprised in the category of jib cranes. The technical specifications of the original mast type jib crane have been put forward in the paper (Blatnický et al., 2022a). The mast is served for building no. 900, block V2 of Jaslovské Bohunice nuclear power plant. Inside this building a chemical water treatment plant belonging to block V2 is situated. The mast type of jib crane is exploited during regular inspections of sludge pumps type 80 KDFU150 9.5-A0-03 weighing 42 kg (Fig. 1b) and for the indispensable handling of them at their operation time. The mast type jib crane intended for handling sludge pump was designed for a load capacity of 120 kg (Blatnický et al., 2022b). However, mentioned crane was damaged in operation due to the fact that the consequence of the sludge pump action has not been taken into account in calculations at the time of its design. This means that during the operation of the sludge pump, there was a gradual accumulation of sludge around the suction nozzles of the pump, causing fix the pump to the bottom of the tank. It has been caused necessary to apply approximately four times more force in order to lift the pump. Unfortunately, aforementioned crane was not provided for such force value. Therefore, this paper attends to optimize the given state. In other words, it concentrates on an analytical dimensional calculation of an optimized design (the fixed mast on which the jib would rotate) with an implemented rotating device with electric drive. The modified mast type jib crane will be designed for a load capacity of 250 kg, considering the consequence of sludge pump action.

2 NEW DESIGN OF A MAST

At the beginning there was made a decision about design of the main support mast and how the jib should be connected to this mast. The main goal was therefore to solve the bearing of the rotating part and to ensure the smoothness and accuracy of operation with the least possible mechanical losses. After several considerations and suggestions, a schematic design of this joint has been reached (Fig. 2). Further calculations were carried out for the schematic design.

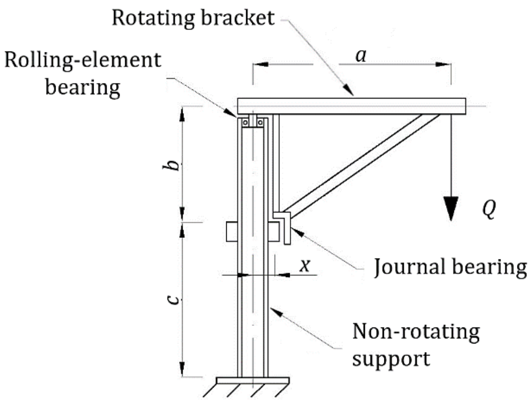

Fig. 2 Schematic design of the structure

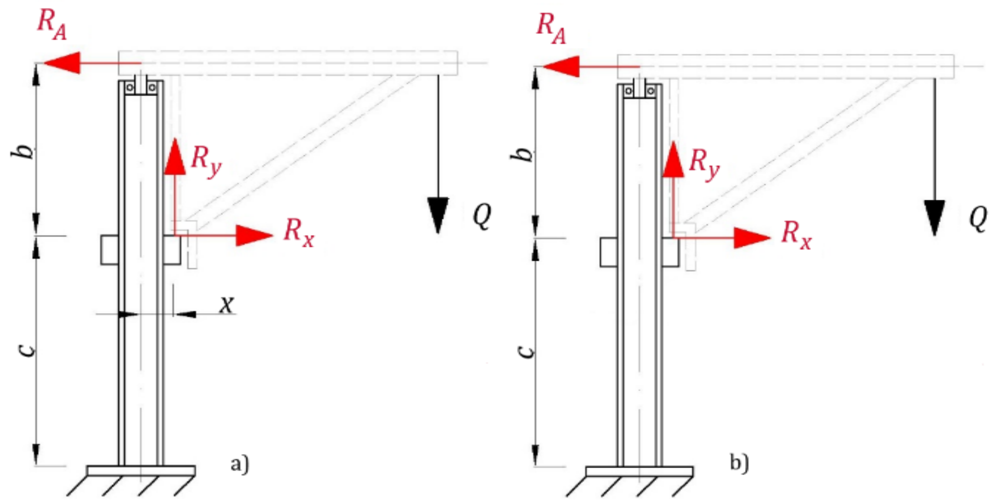

Fig. 3 Intended release of the crane mast with considered dimension *x* a) and ignored dimension *x* b)

For the dimensional design of the crane mast, which is stressed primarily by bending, it has been decisive to know the values of the reactions arising in the bearings. The forces R_A and R_x are substantial for calculating the value of the bending moment. Since the dimension *x* has not been known in the design yet (Fig. 3), this dimension has been temporarily neglected. The dimension *x* represents the distance of the forces of the journal bearing from the vertical mast axis. After designing the whole structure, the calculations were repeated and the above fact of eliminating the dimension *x* proved to be appropriate. The differences in forces values obtained as a result of calculations with and without *x* dimension took into account have been minimal. The depiction of the structure (Fig. 4) in the form of a strut-frame, with a neglected dimension *x*, has been used to calculate the reactions. The input quantities required for the calculation are as follows: length of crane jib a = 1.49 m, perpendicular distance of crane bonds b = 1.1 m, length dimension c = 1.2 m, weight of a load m_b = 250 kg, load force Q = 2452.5 N.

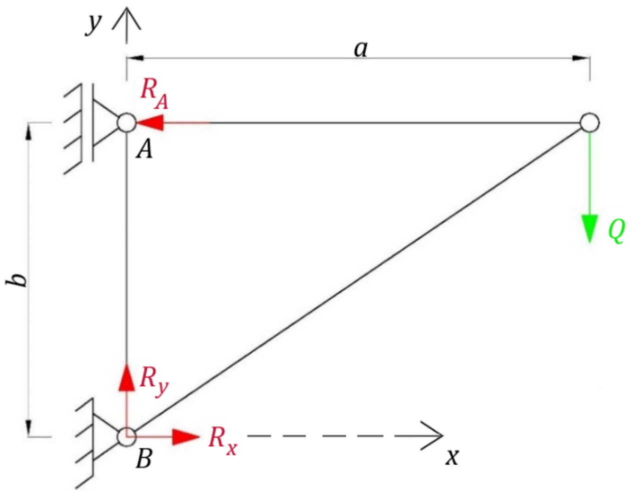

Fig. 4 Depiction of the jib in the form of a strut-frame

Static equilibrium equations (1), (2) and (3) has been formulated:

$$\sum F_{i_x} = 0, \Rightarrow R_x - R_A = 0, \tag{1}$$

$$\sum F_{i_y} = 0, \Rightarrow R_y - Q = 0, \tag{2}$$

$$\sum M_{i_B} = 0, \Rightarrow Q \cdot a - R_A \cdot b = 0. \tag{3}$$

The values R_A = 3322 N, R_x = 3322 N and $R_y = Q$ = 2452.5 N have been calculated by solving equations (1), (2) and (3). Subsequently, the bending moment has been calculated. This moment will strain the crane mast by means of the already detected reactions (Fig. 5, left). For the sake of greater clarity, a schema of a tilted crane mast in the form of a simple beam stressed by two bending forces has been exploited (Fig. 5, right).

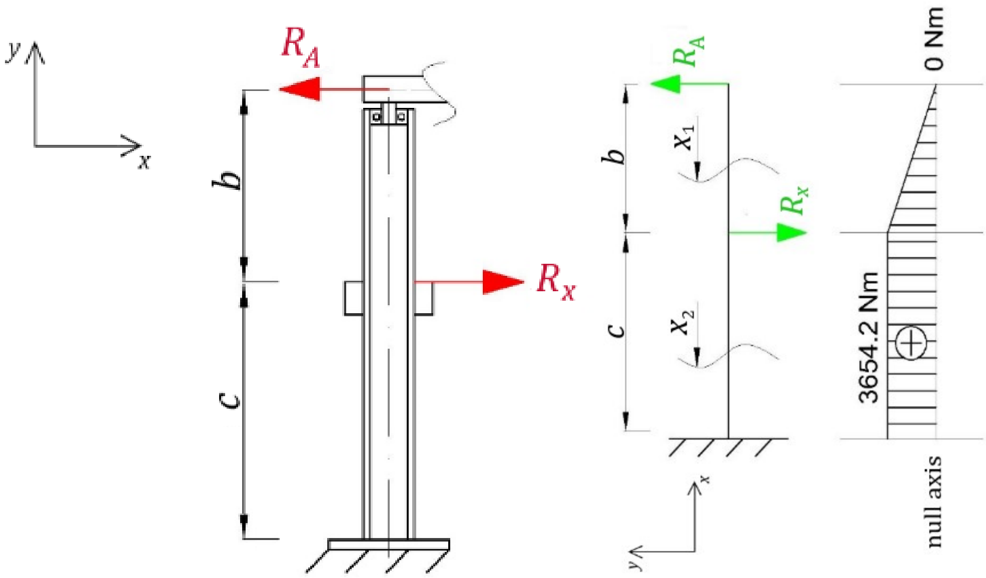

Fig. 5 Considered bending forces of the crane mast (left) and the diagram of the bending moment (right)

The boundary of the first cut has been selected in the interval according to (4). Then the bending moment for this interval has been calculated using equation (5):

$$x_1 \in \langle 0, b \rangle, \tag{4}$$

$$M_{b_1} = R_A \cdot x_1. \tag{5}$$

Substituting values into equation (5), the value of M_{b_1} is:

$$\begin{gathered} M_{b_1(x=0)} = R_A \cdot 0 = 0 \text{ N} \cdot \text{m}, \\ M_{b_1(x=b)} = R_A \cdot b = 3322 \cdot 1.1 = 3654.2 \text{ N} \cdot \text{m}. \end{gathered} \tag{6}$$

The boundary of the second cut has been selected in the interval (7). Then the bending moment for this interval has been calculated using equation (8):

$$x_2 \in \langle 0, c \rangle, \tag{7}$$

$$M_{b_2} = R_A \cdot (x_2 + b) - R_x \cdot x_2. \tag{8}$$

Substituting values into equation (8), the value of M_{b_2} is:

$$\begin{gathered} M_{b_2(x=0)} = 3322 \cdot (0 + 1.1) - 0 = 3654.2 \text{ N} \cdot \text{m}, \\ M_{b_2(x=c)} = 3322 \cdot (1.2 + 1.1) - (3322 \cdot 1.2) = 3654.2 \text{ N} \cdot \text{m}. \end{gathered} \tag{9}$$

From the calculations and depiction of bending moment diagram (Fig. 5, right) it can be asserted that the value of maximum bending moment, by which the crane mast is stressed, is $M_{b\max}$ = 3654.2 N·m.

3 ANALYTICAL DIMENSIONAL CALCULATION OF CRANE MAST

A standardized tube TRø70x14,2-2214 made of structural steel E 295 (Leinveber, 2021) has been selected for the production of the crane mast. The tube had to be checked for bending loads by the calculated bending moment $M_{b\max}$. The value of the permissible, vanishing, bending stress for the material S 235 is in the range σ_{bper} = 100 ÷ 150 MPa (Leinveber, 2021). Equation (10) has been used in order to determine a real bending stress σ_{breal}:

$$\sigma_{breal} = \frac{M_{bmax}}{W_b}, \tag{10}$$

where $M_{b\max}$ is maximum bending moment, W_b is section modulus to bending. The value of section modulus to bending for hollow circular cross-section is determined according to following formula (11):

$$W_b = \frac{\pi}{32} \cdot \frac{D^4 - d^4}{D}, \tag{11}$$

where D = 70 mm is outer diameter of tube, d = 41.6 mm is inner diameter of tube. After substituting the values to formula (11), the value of section modulus is:

$$W_b = \frac{\pi}{32} \cdot \frac{70^4 - 41.6^4}{70} = 29473.7 \text{ mm}^3. \tag{12}$$

Subsequently, substituting values into equation (10), the value of real bending stress σ_{breal} can be calculated as:

$$\sigma_{\mathrm{breal}} = \frac{3654200}{29473.7} = 123.98 \text{ MPa}. \tag{13}$$

The value σ_{breal} = 123.98 MPa is less than σ_{bper} = 150 MPa and for this reason the selected profile conclusively meets the condition of the maximum permissible bending stress. Furthermore, it has been essential to check the tube for the pressure load σ_{creal} caused by the calculated reaction R_y. According to equation (14), it has been first necessary to calculate the area of the circular hollow cross-section A_{ch}:

$$A_{ch} = \frac{\pi}{4} \cdot \left(D^2 - d^2\right). \tag{14}$$

After substituting values into (14), the value of A_{ch} is:

$$A_{ch} = \frac{\pi}{4} \cdot \left(70^2 - 41.6^2\right) = 2489.27 \text{ mm}^2. \tag{15}$$

Subsequently, the value of real compressive stress σ_{creal} caused by reaction R_y has been determined using formula (16) (Fig. 3a):

$$\sigma_{\text{creal}} = \frac{R_y}{A_{ch}},$$
$$\sigma_{\text{creal}} = \frac{2452.5}{2489.27} = 0.98 \text{ MPa}. \tag{16}$$

The value of the permissible, vanishing, compressive stress for the material E295 is in the interval σ_{cper} = 100 ÷ 130 MPa (Leinveber, 2021). Thus, the selected profile conclusively meets the condition of the maximum permissible compressive stress. Ultimately, it has been indispensable to calculate a real reduced stress σ_{redR} (17) and compare it with a permissible reduced stress σ_{redP} (19):

$$\sigma_{\text{redR}} = \sigma_{\text{breal}} + \sigma_{\text{creal}}, \tag{17}$$

where σ_{breal} is real bending stress, σ_{creal} is real compressive stress. Substituting values into (17), the value of real reduced stress σ_{redR} is calculated as:

$$\sigma_{\text{redR}} = 123.98 + 0.98 = 124.96 \text{ MPa}. \tag{18}$$

The permissible reduced stress σ_{redP} has been determined using equation (19), where the yield strength R_e for the material E295 is according to the tables R_e = 290 MPa and the safety factor k is selected 1.5 (-):

$$\sigma_{\text{redP}} = \frac{R_e}{k},$$
$$\sigma_{\text{redP}} = \frac{290}{1.5} = 190.33 \text{ MPa}. \tag{19}$$

After obtaining above values of real reduced stress σ_{redR} and permissible reduced stress σ_{redP}, these stresses can be compared (20), i.e. whether the condition of safety is met or in other words if the real reduced stress is lower than permissible reduced stress.

$$\sigma_{\text{redR}} \le \sigma_{\text{redP}},$$
$$124.96 \text{ MPa} \le 190.33 \text{ MPa}. \tag{20}$$

Due to the fact that real reduced stress σ_{redR} is less than the permissible reduced stress σ_{redP}, it can be asserted that the selected profile meets the safety condition (20).

4 CONCLUSIONS

The paper has been put forward the analytical calculation of the mast of the mast type jib crane for the handling of sludge pumps. The selected profile TRø70x14,2-2214 for the mast made of E295 material is appropriate for the mentioned mast type jib crane, as the determined real reduced stress of 124.96 MPa is less than the real permissible stress of 190.33 MPa. Thus, the safety condition has been met. Presented mast type jib crane for sludge pumps handling is designed for a load capacity of 250 kg. This is for the reason to prevent it from being damaged during operation, as it has happened to the current mast type jib crane with a 120 kg load capacity, where the consequence of sludge pump action was not considered. In other words, the quadruple force to lift the sludge pump weighing 42 kg was not taken into account. In the next steps, it will be required to solve a design of the bearing of the jib consisting of the upper rolling-element bearing and lower journal bearing. Moreover, it will be also essential to solve a design of an electric mechanism of the jib rotation. Provided that complete electrification will be performed, the designed crane could then be employed in a way of inspecting individual components of steam generators. In other words, it can be used as a remote-controlled, single purposed mast type jib crane for introducing manipulators served to check individual components of steam generators. These steam generators are classified in areas with a high level of radioactive radiation. Inasmuch as the crane is operated by workers, the level of radiation is acceptable and it is not required to take into account the degradation process of the crane material due to radiation. These intentions are on the subject of ongoing research.

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