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Analytical Analysis of a Pillar Crane for Handling of Sludge Pumps Breakdown

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Abstract: The article presents a technical description of a boom for handling sludge pumps. It is used in an object No. 900, a block V2 of the nuclear power plant in Jaslovské Bohunice. It is an object of a chemical water treatment plant belonging to the block V2. The boom is used at regular inspections of sludge pumps type 80 KD F150 9.5-A0-03 and for the needed handling with them during their operation. The boom of sludge pump designed for a load capacity of 120 kg was damaged during operation because the consequence of work the sludge pump was not considered during its design. This was causing a gradual accumulation of sludge around the suction openings of the pump. Therefore, the pump sometimes adhered to the bottom of the tank. In order to lift the pump thus adhered, it was subsequently necessary to apply approximately the four-times greater tensile force, for which the boom was no longer dimensioned. Therefore, it is important to optimize that state.

Keywords: pillar crane; handling; structural design; functional calculation; load capacity

1. Introduction

Man is said to be a sensible creature, but also comfortable. Comfort and the desire to make life easier are the qualities of people who have, for millennia, resulted in several inventions and innovations. Thanks to that, we haven't dragged loads on the ground for a long time, but we're using for example a wheelbarrow, we don't walk on stairs, but we use an elevator, and we don't heat food on a fire, but on a stove. The desire to make life easier in people has always been and will be. Although this desire has a huge impact on giving a person an idea or thought, it is not enough. In order to create something, one needs a dose of creativity, technical thinking and knowledge of the original state.

As we know them from books, inventions are often the result of a chance, an inspiration from observing nature, or an innovation of something existing. Inventions and a creative activity will always be in people, because in addition to being comfortable, a human is also very curious. And it is curiosity that leads people to discover and create something new, unknown. This applies in all directions and areas, including handling technology [1-5].

Among the basic means that are used in transport and handling technology belong cranes. A crane is generally a type of a machine used to handle a certain load in more axes.

Depending on the weight of the load and the requirements for its transfer, subsequently we divide the cranes into several types. The division of cranes can be executed on the basis of the overall shape:

- *bridge cranes,*
- *portal cranes,*

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- *semi-portal cranes,*
- *column cranes,*
- *tower cranes,*
- *cantilever cranes,*
- *cranes on a vehicle chassis and,*
- *floating and cable cranes.*

Depending on the type of power drive, following types are recoginzed:

- *electric,*
- *hydraulic,*
- *pneumatic,*
- *with internal combustion engine and,*
- *manual.*

Based on the type of movement are cranes:

- *stationary,*
- *moving,*
- *rotating,*
- *swimming cranes, and*
- *with combined movements.*

Further, the type of work divides cranes to:

- *workshop´s cranes and,*
- *construction cranes.*

Finally, based on places of the use can be used

- *port cranes and,*
- *railway cranes [6].*

Tower and pillar cranes (Fig. 1, Fig. 2) belong to the oldest types of cranes. The principle of these cranes consists in a movable (rotating) or a stationary column (tower) on which a fixed or adjustable jib is stored and the crane cat can move on it. By boom adjustment we mean raising and folding down the free end of the boom. From this point of view, it follows that mast and tower cranes can operate a full or a partial circular work surface, the diameter of which depends on the setting of the boom and the movement of the cat on the boom. In principle, we can divide column and tower cranes into:

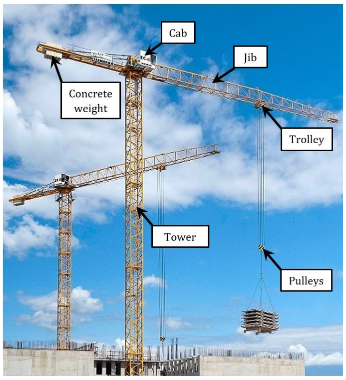

Figure 1: A tower crane with a non-rotating tower

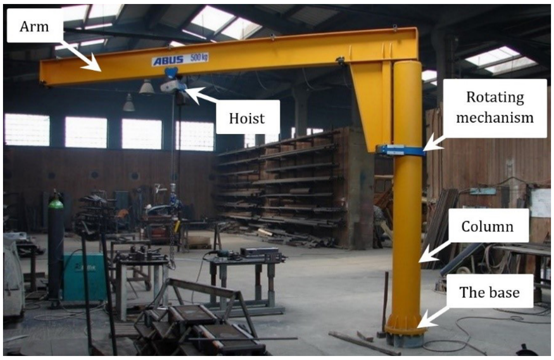

Figure 2: A pillar crane

a) Cranes with a rotating column, where they belong:

- *wall cranes,*
- *type of cranes "derrick",*
- *cranes with a high column which is housed in a rod tower structure,*

b) Cranes with a fixed column:

- *cranes with a low single column anchored at the base,*
- *cranes with a high lattice tower [7].*

A rotating jib is usually mounted on the column of a crane column. The boom can be in various versions, which also changes the area that the crane can operate. We can distinguish booms: horizontal or inclined. Inclined booms are usually without the possibility of changing the unload with a fixed pulley at the end of the boom. In most cases, the horizontal outriggers are designed so that it is possible to change the unloading most often with the help of a cat. For greater values, a counterweight (the balancing load) is also used [6, 7]. One of the possible design solutions of modern column cranes is similar to modern cantilever cranes. The difference is that the boom of column cranes, which in the case of the cantilever cranes is located on the wall, is fixed on the non-rotating column of the crane. The column can be either firmly anchored in the base (the most common solution) or anchored in a mobile chassis, which also serves as a counterweight. The column is usually steel, solid or hollow with different diameters. The construction of the boom most often consists of well-known I-beams, which are exceptional for their excellent strength characteristics, especially when bending. Thanks to the characteristic shape of the I-beams, it is possible to hang a movable hoist in its lower part. Another profile used for the construction of booms is the so-called KBK profile [8]. This profile is produced by cold rolling, which creates a characteristic branched shape with a cavity and a smooth surface. The profile has very good strength characteristics and low weight. In the case of KBK profiles used for a shorter operating distance, the inner part of the profile (cavity) is used to guide the trolley with a hoist, where the power cords are also guided together with the travel. For longer operating distances, the outer part of the profile is used. Furthermore, various special profiles designed based on specific requirements are used e.g. XM profiles, circular cross-section profiles, etc. [9]. The attachment of the boom is usually solved by means of a rolling bearing, which ensures easy handling during rotation. The rotation of the boom can then be either manual or electrically driven, e.g. by means of an electric motor and a screw gearbox.

2. Constructional Solution, Use of the Boom and Problems Related to its Use

The boom (Fig. 3 on the left) can, from a constructional and functional point of view, be included in the category of column cranes. The main parts of the structure consist mainly of available normalized profiles. The static part of the boom (console) consists of a plate which is firmly connected to the concrete bed by means of M16 steel dowels of the HILTI brand. The carrier is also welded to the plate, the tube TRø63.5x2.9 - 1250 mm, reinforced with four reinforcements made of sheet metal P5 welded to the side of the tube and to the plate. A flange is further welded to the upper part of the carrier. The rotating part consists of a bracket, TRø57x3.2 - 2145 mm, inserted into the carrier. The transverse clearance between the tubes is not additionally modified and therefore its value represents the difference between the inner diameter of the support and the outer diameter of the bracket, i.e. 1.3 mm.

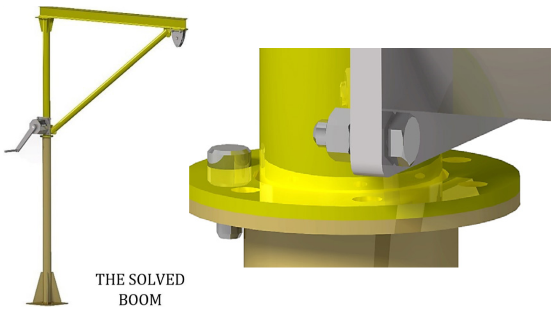

Figure 3: 3D CAD model of the original boom (left) and detail of the connection of the non-rotating carrier and the rotating bracket which are separated by flanges (right)

It is clear from the drawing documentation (Fig. 4) that the contact surfaces are in the vertical direction located between the bracket and the bottom plate and also between the flanges of the carrier and the bracket. There is no bearing between the contact surfaces of the carrier and the bracket, i.e. metal-to-metal friction occurs.

The I 80 profile is further welded to the bracket in the horizontal plane, reinforced with an oblique reinforcement TRø44.5x2.9 - 1457 mm welded between the bracket and the I-beams at an angle of 35˚ measured from the I-beams. A manual winding

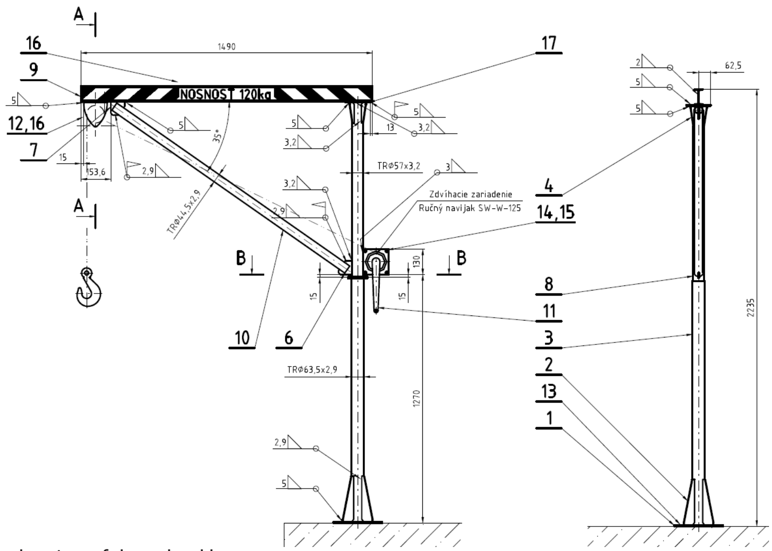

Figure 4: An assembly drawing of the solved boom

SW-W-125 – type device with a maximum load capacity of 125 kg is fixed to the console. A DSRB S 90x4-type pulley with a load capacity of 700 kg is fixed to the end part of I-beam. A rope with a diameter of 4 mm is used for the lift. The permissible load capacity of the structure is 120 kg.

During the use of the boom, it was found that the boom was damaged due to repeated, unwanted exceeding of the load capacity. The main reason was the fact that the design of the structure did not take into account the consequence of the work of the sludge pump, which was the gradual accumulation of sludge around the suction openings, which led to the attachment of the pump to the bottom of the tank. It was subsequently necessary to apply a higher tensile force to the pump attached in this way, for which the boom was no longer dimensioned. The weight of the pump itself is 42 kg, which represents a tensile force of F_1 = 412.02 N. The force required to pull the stuck pump out is measured to be higher than $F_1 \geq$ 1,700 N, which significantly exceeds the load capacity and eliminates the safe operation of the boom.

3. A Mathematical Description of a Function Between Weight of the Load and the Crank Control Force

A 2D calculation model (Fig. 5 right) was created from the 3D CAD model (Fig. 5 left). The input values of the calculation are the mass of the pump $m_č$ = 42 kg, the diameter of the drum of the manual winding device d_b = 40 mm, the crank arm r_k = 250 mm, the mechanical efficiency of the pin (slide bearing) $\eta_č$= 0.96 (-) [10], the mechanical efficiency of the rope drum η_b = 0.94 (-) [10], g = 9.81 m·s^{-2}.

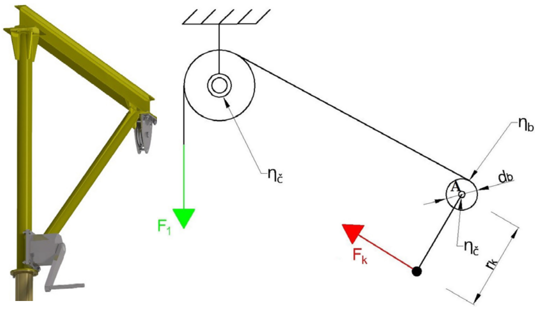

Figure 5: A 3D CAD model of the solved winding device (left) and schematic representation of the lifting mechanism with release (right)

The magnitude of the force in the rope F1 (Fig. 5 on the right) in the case of a pump not attached by the sludge is expressed from the equation (1):

$$F_1 = m_č \cdot g \tag{1}$$

By solving the equation (1), we get the value of F_1 = 412.02 N of the force in the rope. We calculate the force on the crank using the equations of equilibrium. From the equation of equilibrium, the moment equation to the centre of the crank pin is sufficient to calculate the force on the crank F_k (2):

$$\sum_i M_{iA} = 0 \Rightarrow F_k \cdot r_k - F_1 \cdot \frac{d_b}{2} = 0. \tag{2}$$

By solving the equation (2), we get for the manual force on the crank of F_k = 32.96 N. The calculation of the total efficiency of the mechanism η_c is performed using Fig. 5 on the right, where all structural nodes are shown in which we consider the mutual movement of kinematic pairs, i.e. friction. Then, the overall efficiency is calculated according to (3):

$$\eta_c = \eta_č \cdot \eta_č \cdot \eta_b \tag{3}$$

where $\eta_č$ is twice because in the solved system, two pins are (Fig. 5 on the right).

By solving the equation (3), we get for the total efficiency of the mechanism η_c = 0.87. The total crank force together with the mechanical losses F_{kc} will then be (4):

$$F_{kc} = \frac{F_k}{\eta_c}. \tag{4}$$

By solving the equation (4), we get the value of F_{kc} = 38.05 N. To lift the pump attached by the sludge, it was subsequently necessary to apply a tensile force approx. of F_1 = 1,700 N. The boom was no longer dimensioned for such a value. For the manual drive, it is possible to select the control force from the interval 120 N to 160 N. From equation (2), we get the value of 136 N without considering friction for the crank force from the pump. When the overall efficiency is considered, the crank force using relation (4) will have a value of 157 N. This value belongs to the interval considering the work and performance of the person operating the equipment. Optimization would take place if there was an objective function – in this problem only adaptation to the greater load is required. After analysing the problem from the point of view of safety it was determined that the new boom will be dimensioned up to a load capacity of 250 kg.

This boom will work with a view to increasing the comfort service with the electric swivel operator.

4. Conclusions

The article presented a technical description of the boom for handling sludge pumps. The boom of sludge pump designed for a load capacity of 120 kg was damaged during operation because the consequence of work the sludge pump was not considered during its design. The functional analytical calculation revealed that it would not be necessary to optimize the lifting mechanism, as it still meets the conditions for its implementation by manual lifting. It was further determined that the new boom will be dimensioned for a load capacity of up to 250 kg and that its rotation will be performed by an electric drive. This is the goal of ongoing research.

Acknowledgments

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References

1. Ju S.H., Kuo H.H., Yu S.W., Ni S.H. (2020). Investigation of vibration induced by moving cranes in high-tech factories. Journal of Low Frequency Noise Vibration and Active Control, 39, 1, 84-97.
2. Opala M., Korzeb J., Koziak S., Melnik R. (2021). Evaluation of stress and fatigue of a rail vehicle suspension component. Energies, 14, 12, 14 pages.
3. Koziak S., Chudzikiewicz A., Opala M., Melnik R. (2019). Virtual software testing and certification of railway vehicle from the point of view of their dynamics. 13th International Scientific Conference on Sustainable, Modern and Safe Transport, TRANSCOM 2019,
4. Blatnický M. (2015). Transport and handling machines: Solved tasks (In Slovak). 1st ed. Žilina: University of Žilina.
5. Hafid A., Salimi D., Ewitha, Nur S.H. (2019). Analysis and Design of Crane Beam of Experimental Power Plant Turbine Building. 1st Symposium of Emerging Nuclear Technology and Engineering Novelty, SENTEN 2018.
6. Remta F. et al. (1974). Cranes. Part I. (In Czech). Praha: SNTL.
7. Remta F. et al. (1975). Cranes. Part II. (In Czech). Praha: SNTL.
8. Column cranes (in Slovak), from http://www.kpk.sk/sk/stlp1.htm.
9. Technical Data KBK, from: http://www.demagcranes.de/files/content/sites/deutschland/files/PDF/Prospekte/Technische%20Daten%20KBK/TechnicalData_KBK_20297644_ENG.pdf.
10. Košábek, J. et al. (1990). Theory of transport and handling machines (In Slovak). Alfa Bratislava, Bratislava.