Determination of vertical pressures on running wheels of freight trolleys of bridge type cranes

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Abstract. The problematic issues of the design of the bridge-type trolley crane, connected with ensuring uniform load distribution between the running wheels, are considered. The shortcomings of the existing methods of calculation of reference pressures are described. The results of the analytical calculation of the pressure of the support wheels are compared with the results of the numerical solution of this problem for various schemes of trolley supporting frames. Conclusions are given on the applicability of various methods for calculating vertical pressures, depending on the type of metal structures used in the trolley.

1. Introduction
One of the main tasks to be solved during the design of a truck of a bridge type crane is to ensure a uniform distribution of vertical pressures to the running wheels from the weight of the transported load and the weight of the own elements of the trolley. With significantly different loads, uneven wear of the rolling surface of the wheels is observed, which can lead to a skewing of the trolley at the moment of movement, jamming of the truck and increased wear of the flanges [1].

In the general case, the pressure difference between the heaviest wheel and the wheel with the minimum load should be 10-15% [2]. A similar distribution of pressures is obtained by successively adjusting the dimensions and the base of the trolley, as well as by placing individual units of the trolley mechanisms and upper blocks of the cable pulley block on the entered coordinate plane, thereby approximating the desired pressure values to the required values

2. Method description
Within the framework of the adopted design sequence of cargo trolleys according to the adopted determination of vertical pressures, the following should be obtained:
- detailed scheme for placing mehanisms on the frame;
- overall dimensions of the trolley;
- arrangement of load-bearing elements of the frame scheme, getting vertical loads (the position of vertical sheets, curved profiles, etc.);
- position of the centers of gravity of the truck elements in the empty state and when working with a nominal load [2];

Thus, the procedure for determining vertical pressures is the central stage in the formation of the overall design of the freight trolley.

The established procedure for determining pressures has the following drawbacks:
- the position of the mass centers of all individual elements (reducers, electric motors, etc.) is determined on the basis of general recommendations. In this case, the position of the mass centers of the elements may differ somewhat from the generally accepted points, depending on the design, which introduces a certain degree of inaccuracy in subsequent calculations;
- in the course of determining vertical pressures, the exact value of the metal structure mass and the position of its mass center are unknown, which is connected with the initial uncertainty of its configuration; the trolley is assumed to be conditionally symmetric with respect to the central geometric axes of coordinates with the center of mass coinciding with the center of the indicated coordinate system; this circumstance also negatively affects the accuracy of the calculations; after determining the configuration and weight of the trolley, the values of the vertical reference pressures can be refined, which increases the laboriousness of the calculation and the total time allotted for the design of the trolley;
- in the existing method, the pressure on the wheel is determined based on the position of the common center of gravity of the installed elements. This does not take into account the effect of the design of the trolley support frames on the distribution of loads between the running wheels.

The drawbacks described in the first two paragraphs can be eliminated by the use in the design process of automated systems in which the mass-dimensional characteristics of the elements are determined with high accuracy for each individual case, as well as the introduction of frame trolleys with a universal layout scheme [3]. The position of the gravity center and the main load-bearing elements that perceive external forces in such trolleys are known in advance and remain constant throughout the design process.

The purpose of the research is to find a technique for determining vertical pressures on the trolley wheels, which allows the most accurate determination of the value of vertical pressures, taking into account all the attendant factors.

The task of determining the vertical pressures on four travel wheels is externally once statically indeterminate. Thus, the exact solution of the problem is very difficult and almost impossible. For its analytical solution, two main hypotheses are used: about a hinged and absolutely rigid frame [4, 5].

According to the theory of the hinged frame, its individual elements are connected together hingedly, while inaccuracies in manufacturing, the elastic properties of the rope and the base do not affect the distribution of pressures on the running wheels, but the arrangement of the elements inside the hinge frame is of great importance. According to this, the support reactions of individual wheels are determined from the expressions (Fig. 1) [5, 6]:

$$P_{1,3} = \frac{Q}{4}\left(1 \mp \frac{b_Q}{B}\right)\left(1 \pm \frac{a_Q}{A}\right);$$

$$P_{2,4} = \frac{Q}{4}\left(1 \mp \frac{b_Q}{B}\right)\left(1 \mp \frac{a_Q}{A}\right);$$

where A and B – track and base of the cart, are respectively, aQ and bQ are the distance from the point of all masses resultant location Q to the intersection point of the reference contour diagonals, which characterizes the most advantageous position of the resultant, accompanied by the same load on all running wheels.

When applying the rigid frame theory, its construction is regarded as an absolutely rigid body, up to loading resting on all four points. In this case, the value of the reference pressures is determined by the expressions [5]:

$$P_{1,3} = \frac{Q}{4}\left(1 \mp \frac{b_Q}{B} \pm \frac{a_Q}{A}\right)$$

$$P_{2,4} = \frac{Q}{4}\left(1 \mp \frac{b_Q}{B} \mp \frac{a_Q}{A}\right);$$

To find the most accurate method for determining vertical pressures, based on the presented theories, calculations were made of the distribution of forces between the running wheels of different construction vehicles: with a universal layout scheme and a frame made of longitudinal and transverse closed beams (Fig. 1). In this case, the effect of the mechanisms on the frame of the trolley was determined with the help of efforts at the reference points of the individual elements (electric motors, reducers, etc.) whose coordinates, unlike the coordinates of the centers of gravity of the elements, are absolutely accurately known from the arrangement diagrams of the mechanisms. Static loads are applied at the reference points and, if necessary, dynamic loads are obtained during the dynamic analysis of the corresponding types of cranes [7, 8]. Within each of the theories, the calculation of the reference pressures was made from the resultant of all external forces, as well as from each force separately, followed by the summation of the found components. The results of these analytical solutions were compared with the values of the reference pressures determined by numerical modeling of trolleys using the finite element method. The material of the construction is specified in the form of a linearly elastic isotropic model with characteristics of carbonaceous quality steels. To avoid artificial overstating of the frame rigidity, when imposing restrictions, recommendations given in [9] were taken into account. So a rigid embedding was imposed on neither of the supports of the trolley (No. 2 of Figure 2, Figure 3), the displacement of two adjacent points (No. 1.3 of Figure 2, Figure 3) was limited vertically and along one of the horizontal axes, the displacement of the point , diagonally opposite to the rigid seal (No. 4 of Figure 2, Figure 3) were limited only in the vertical direction. The above-mentioned limitations were imposed on the interface plane of the metal frame of the trolley frames with truck bxes and wheel modules.
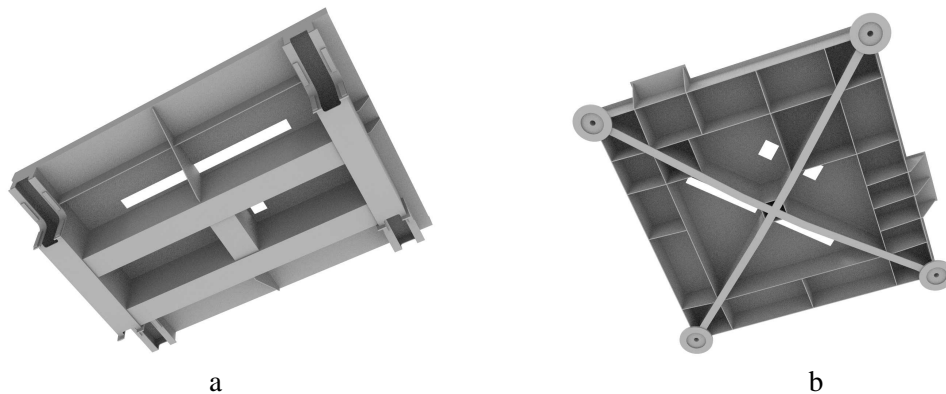

a   b

Figure 1. Structures of load-bearing frames of cargo trolleys of the bridge type crane: a - a construction consisting of longitudinal and transverse beams of box type; b - construction with a universal layout and main diagonal support elements.

Fig. 2, 3 show the loading schemes of the corresponding frames of the cargo trolleys by external forces transmitted from the installed hoisting mechanism with a load capacity of 10 tons. The mass of the elements of the movement mechanisms is small and the forces of their weight can be neglected, as in the case of the use of rotary motion engines, and in the case of linear traction motors [10]. At points A and B, the trolley is influenced by the forces from the weight of the load, the drum, the reducer; at point C, a force is exerted from the upper hook suspension blocks, point D is acted on by the free-standing bearing support of the drum, and at points E and F - the forces from the weight of the motor. In the universal layout scheme trolley (Fig. 1 b, Fig. 2), the lifting mechanism is located diagonally across the trolley over one of the main bearing elements, the upper blocks are also located on the main

bearing element perpendicular to the first. This arrangement of the trolley is one of the most rational in the case of using a universal layout scheme, while the trolley and the base of the trolley are equal and are 2000 mm. The trolley and base of the trolley with a beam support frame (Figure 1a, Fig.3) are 2000 mm and 1254 mm respectively.
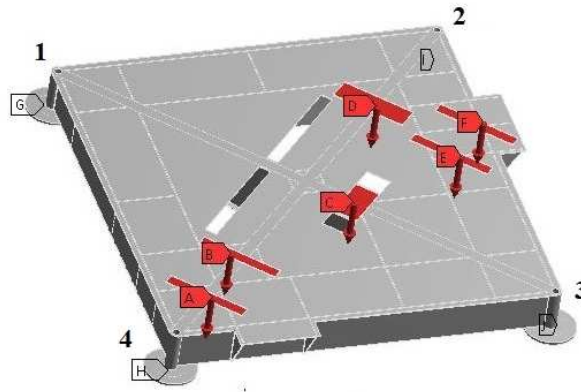

Figure 2. The scheme of loading of a carriage with a universal layout scheme by external forces.
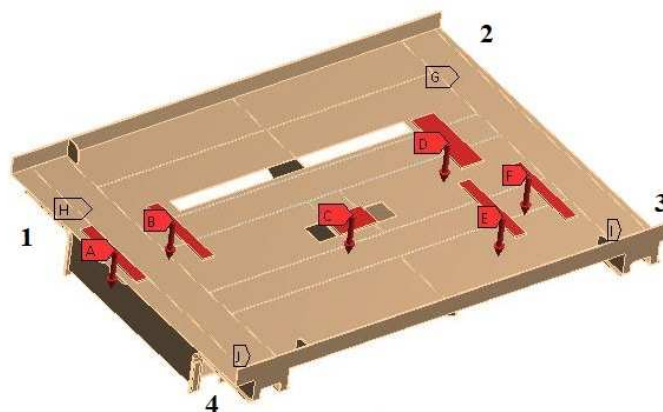

Figure 3. The scheme of loading of a trolley with a bearing frame made of box girders by external forces.

The results of calculating the reference pressures for a trolley with a universal layout are shown in Fig. 4. Here, as well as in the following diagrams, the graphs correspond to: a - the results of numerical simulation of reference pressures; b - the results of determining the reference pressures from the resultant of all forces in the theory of a rigid frame; c - the results of determining the reference pressures from individual forces on the theory of a rigid frame; d - the results of determining the reference pressures from the resultant of all forces in the theory of the hinged frame; e - the results of determining the reference pressures from individual forces in the theory of a hinged frame. It is noteworthy that the values closest to the results of numerical simulation (Fig. 4, a) are shown by calculations carried out from individual forces based on the hinged frame hypothesis (Fig. 4, e). The most loaded are the supports located at the ends of the diagonal with the installed lifting mechanism (Fig. 2, supports 2, 4).

The study showed that a similar distribution of reference pressures is also characteristic of larger trolleys with a similar arrangement of the lifting mechanism and upper blocks. The results obtained in the remaining three calculated cases (Figures 4, b, c, d) are close to each other in terms of the magnitude of certain pressures, but their distribution between the supports does not coincide with the pattern of numerical simulation.
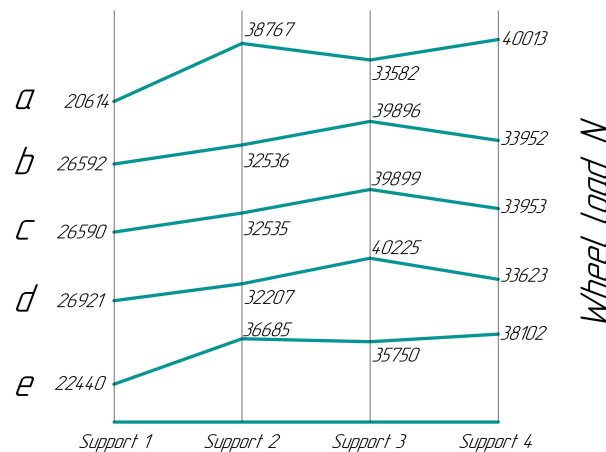
Figure 4. The diagram of the distribution of vertical bearing pressures of the trolley with a universal layout scheme.

The results of calculations of the vertical bearing pressures of a trolley with a supporting frame made of box girders are shown in Fig. 5. It is seen that the results of all four calculated cases (Figures 5, b, c, d, e) coincide with the results of numerical simulation (Fig.5, a) with sufficient accuracy both in magnitude and in the general patterns of distribution between supports .
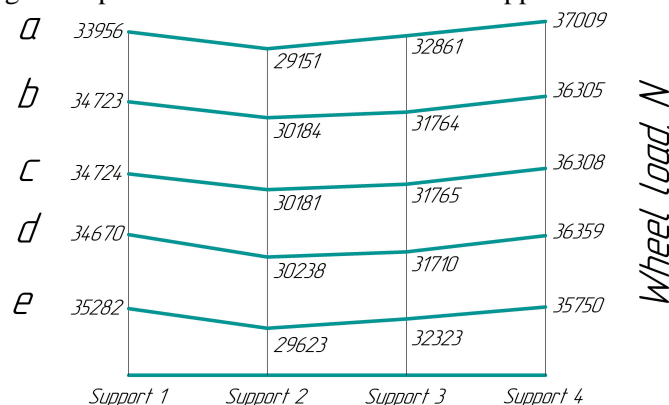

Figure 5. The diagram of the distribution of vertical support pressures of a trolley with a supporting frame made of box girders.

According to the described method, an analysis was also made of the distribution of vertical pressures on the running wheels for another design of the trolley with a universal layout scheme. Within the framework of this scheme, the lifting mechanism is installed perpendicular to the direction of the trolley movement and is supported by auxiliary chord elements that connect the main carrier diagonals and transmit the perceived forces to them. The trolley loading was carried out in the same way as described above. The trolley payload is 25 tons, the track and base are 3800 and 3000 mm respectively.

The obtained diagram of the distribution of vertical reference pressures is shown in Fig. 6. As in the case of a frame made of beam elements, the values of the vertical support reactions and their distribution between the supports are close in all the four calculated cases (Figures 6, b, c, d, e) to the results of numerical simulation (Figure 6, a).
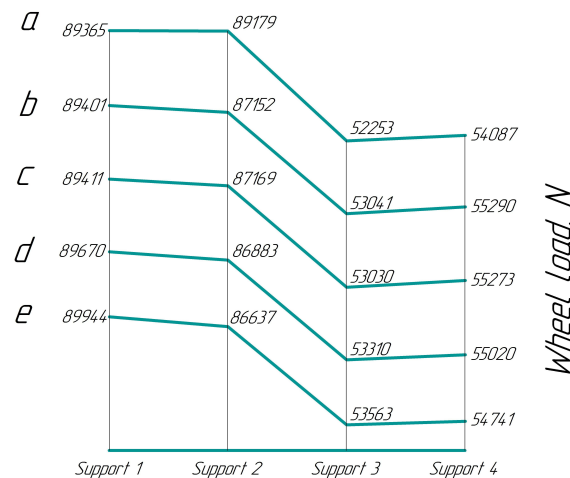
Figure 6. The diagram of distribution of the vertical bearing pressures of the trolley with the universal layout scheme with the arrangement of the lifting mechanism perpendicular to the direction of movement of the trolley

3. Conclusion

The above-mentioned calculations allow us to draw the following conclusions:

- In the case when the main part of the load is transmitted directly to the load-bearing elements located diagonally of the frame of the load carriage through the most stressed points (the locations of the drum supports and the upper blocks of the cable pulley block), the calculation must be made separately from the driving wheels for the most accurate determination of the vertical pressures on the running wheels each acting force with the subsequent summation of the found components on the basis of the hypothesis of a hinged frame.
- If the points with the maximum acting forces are equidistant from the main carrier diagonals and the forces on them are transmitted through the auxiliary elements, and also in the case of using the frame of their longitudinal and transverse box section beams, all the considered calculation methods give a fairly accurate result and can be used to determine vertical pressures.

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