Improving stability of self-propelled jib cranes

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Abstract The article describes the developed and proposed to use device of outriggers, which provides an additional anchor force during operation of the crane on soil bases, that increases the holding torque of the crane. In the proposed external outrigger of the lifting machine, a screw which is screwed into the ground, and which has a conical tip and an angle of elevation of the helical surface less than the angle of friction of this surface against the soil, serves as a base plate. Upon that, the outrigger is equipped with an auger rotation drive, which, together with the feed drive, is screwed into the ground without chip separation. A calculation example shows that such outriggers can increase load stability, therefore, the lifting capacity or working radius of the crane can increase by 1.79 times and even more opposed to when the crane is working on conventional outriggers.

1. Introduction

Self-propelled jib cranes are among the most common machines used in the construction and installation works, due to their ability to move freely around the construction area. Such machines are also widely used to mechanize production processes in almost all industries. Among self-propelled jib cranes, predominantly automobile and pneumatic wheel cranes are equipped with external (optional) outriggers. When installed on outriggers near the crane, the support contour increases and its stability also increases, which allows for safely lifting heavier loads. The support contour is a contour formed by horizontal projections of straight lines, connecting the vertical axes of the crane supporting elements (of wheels or outriggers). Here it can be noted that the platform on which the crane is installed will usually have a slope relative to a perfectly horizontal plane and will not geometrically coincide with the reference contour. In modern self-propelled jib cranes, various outrigger device schemes (retractable, rotary, folding) are used, in which the outrigger support plates are pressed to the ground surface (soil) by means of mainly hydraulic cylinders and a hydraulic drive system. Outriggers are mounted on the running frame of the crane, as a result of which they unload the axles and pneumatic wheels of the machine when working with loads. To the greatest extent this effect is achieved when the crane is completely hung out on the outriggers, when the wheels get off from the ground surface. In the conditions of a construction or assembly site, self-propelled jib cranes often have to work on soil foundations of various load-bearing capacities. Moreover, cases of capsizing or accident of cranes as a result of loss of their cargo stability when lifting loads due to insufficient bearing capacity of soil bases are not uncommon. Therefore, according to the safety measures developed in Russia for self-propelled jib cranes, they must be installed and moved on soil bases, the bearing capacity of which is 0.3 ... 0.9 MPa, depending on the type and capacity of the crane. The bearing capacity of the soil must be determined before installing a crane on it. If the resistibility of the soil base is insufficient for the operation of the crane on it, the soil must be...
compacted or underlying devices must be used on it. When using underlying devices in the form of shields or plates, it is recommended to pour sand, gravel, and gravel with a layer of 5 ... 10 cm in order to avoid being crushed in loose or waterlogged soil. When installing the crane on a soil base, its angle of inclination, which is equal to the sum of the angles of inclination of the platform and draft caused by uneven deformation of the soil under the crane, should not exceed the values indicated in the crane passport. All of the above leads to complication of production processes and to increase of cost of work during which self-propelled jib cranes working on soil bases are used, therefore, there is a need to develop outrigger devices that increase the cargo stability of cranes.

2. Stability analysis of cranes operating on outriggers

A feature of jib cranes is the lifting and moving of cargo in an area that extends beyond the support contour of the crane. The external forces impacting the crane create a tilting moment relative to one of the edges of the support contour (tipping ribs), and the crane's own weight creates a holding moment, respectively. The stability of the crane in working condition with exposed outriggers can be estimated by one of the load stability factors $k_1$, defined as the ratio of the holding moment ($M_1$) created by the weight of the crane without taking into account the additional loads and the slope of the platform on which the crane is installed, to the overturning moment created lifted load ($M_2$).

$$k_1 = \frac{M_1}{M_2} = \frac{G a}{Q b} \geq 1.5,$$

where $G$ is the weight of the crane;

$a$ is the distance from the projection point onto the horizontal plane of the coordinate of the center of gravity of the crane to the tipping rib;

$Q$ is the weight of the load being lifted;

$b$ is the distance from the tipping rib to the vertical axis of hoisting.

More precisely, the degree of stability of the crane in working condition is determined by the coefficient of cargo stability, calculated taking into account the additional loads (inertial, centrifugal forces, wind load and others) and the slope of the platform on which the crane is installed, that is, taking into account factors that reduce the holding torque from tipping over of the crane towards cargo.

If we evaluate the effectiveness of the outriggers by calculating the crane's load stability on the supports and without them, we can conclude that the crane stability in the process of lifting the load is provided only by its own weight and the dimensions of the support contour, affecting the position of the tipping rib. The outriggers of modern cranes are designed in such a way that, when lifting a load, the main part of the work to ensure the stability of the crane is done by the outriggers set in the direction of the lifted load, and they also make a tipping rib.

The outriggers placed in the opposite direction from the load being lifted practically do not participate in this work. Obviously, the stability of the crane would be higher if the outriggers set in the direction of the load to be lifted were pressed less into the ground when lifting the load, thereby providing a smaller inclination of the platform on which the crane is installed. Also, the stability of the crane could increase if the outriggers set in the opposite direction from the load being lifted would also actively participate in ensuring the stability of the crane, working as an effective soil anchors, creating an anchor force holding the crane and an additional holding moment that prevents the crane from tilting and tipping over.

3. The device of outriggers, providing increased stability for the crane

It should be noted that among the published inventions and utility models related to outriggers of machines, there are devices that are a helical anchor immersed in the ground by communicating translational and rotational motion to it [1, 2]. The helical anchor in this case is executed as a rod with one or two turns of the helical surface. In this work, we propose a device for the outrigger of a lifting machine for the case of
work on soil foundations with low bearing capacity, in which a conical tip screw screwed into the ground and the angle of elevation of the screw surface is smaller than the angle of friction of this surface on the ground can be used as the base plate of the outrigger support. In this case, the outrigger is equipped with an auger rotation drive, which, together with the feed drive, ensures its screwing into the ground without chip separation. With this screwing, the screw should work in the ground not as a screw anchor immersed in the soil loosened by its lower blades, but as, for example, as a self-tapping screw screwed into wood. At the same time, to ensure the movement (feed) of the screw, corresponding to its rotation and screwing, and not drilling, the parameters of the rotation and feed drives should be interconnected by the ratio:

\[ V = n L, \]

where \( V \) is the feed rate of the screw; \( n \) is the screw rotation speed; \( L \) is the pitch of the screw surface of the screw.

In the proposed device, the supporting surface (the lower plane of the screw surface of the screw) of the outrigger will provide a more effective support on the ground than conventional outriggers of cranes and will have a large total area of support. Such an outrigger, set in the opposite direction from the load to be lifted, interacting with the soil with the upper plane of the screw surface of the screw, can create a significant holding force that prevents the machine from tipping over. Outrigger device is shown in figure 1.

![Figure 1. The device of the outrigger of the lifting machine, where: 1 – outrigger; 2 – feed drive; 3 – rotation drive; 4 – screw screwed into the ground.](image)

Comparing the proposed outrigger with the outriggers that are already installed on cranes and are currently being used, and other hoisting machines, it can be noted that the outrigger in the form of a screwed screw, which is, as it were, a support plate for the currently used external support devices, the support will not occur on the ground, but on the buried, more dense layers of soil, characterized by a greater bearing capacity [3]. In this case, the support on the ground of one support will occur not by the area of one support plate, but by the area of all turns of the screw immersed in the ground, from which the total area of support can be very significant. The use of a screw with an angle of elevation of its screw surface less than the angle of friction of this surface against the ground will ensure that the screw is not twisted out of the soil if the drive mechanism for rotating the screw is not braked when pulling the screw out of the ground from the roll of the machine. This also ensures good grip of the screw with the ground. To achieve significant bearing capacity of the screw working as an anchor, the depth of its screwing it into the ground, if one is using the recommendations [4], should be 5 ... 6 diameters of the screw blade. It is also obvious that the screw which is screwed into the soil to the indicated depth will provide significant resistance to the inclination of its axle. By installing a crane for working on
outriggers with the help of auger movement drives in the horizontal position of its frame, we can assume that the slope factor of the platform on which the crane is installed will lose its value. At the same time, the geological and geodetic conditions of the site on which the crane is installed can lead to unequal screwing depths of screw outriggers. The proposed outrigger, having a significant holding or anchor force, preventing the rollover of the machine, will significantly increase the load stability of the lifting machine, working on soils with low bearing capacity and this, in particular, will serve to prevent accidents. Such outriggers can be considered as a kind of prefabricated anchor foundations on which the crane is installed during its operation. In cases of operation of the machine with the proposed outriggers on solid foundations that do not allow screw screw to be screwed into the ground, as well as on durable coatings, the proposed supports can be installed on them without screwing and work as usual, resting on the surface of the solid foundation (coating) through a metal gasket which is in such cases put under the tip of the screw.

4. Evaluation of the effectiveness of the proposed outriggers

Let us evaluate the stability of a crane working on the proposed outriggers creating a holding anchor force with a load stability coefficient of $k_{1A}$ using a specific example. The assessment will also be carried out simplified as in the calculation of $k_1$ according to formula (1), calculating the holding moment $M_1$ in the numerator of the formula without taking into account additional loads and the slope of the platform on which the crane is installed. In this case, we take into account only the additional holding force $F_A$, which creates an additional holding moment, for each of the two supports set in the opposite direction from the load being lifted. The factor of providing the proposed outriggers exposed in the direction of the load to be lifted, support occurring not on the ground, but on the buried, denser layers of the soil, as well as the fact that the support on the ground will occur over the area of all turns of the screw immersed in the ground, and not over the area of one base plate, due to the uncertainty of the specific geological conditions of the crane and to simplify the estimated calculations will not be taken into account.

The scheme for calculating the coefficient $k_{1A}$ is shown in figure 2.

![Figure 2. Scheme of a jib crane on outriggers and loads for calculating cargo stability.](image)

Then the formula for calculating $k_{1A}$ will be written as:

$$k_{1A} = \frac{M_1}{M_2} = \frac{(G K_o/2 + 2F_A K_o)Q}{b} \geq 1.5,$$

where $G$ is the weight of the crane;
$K_o$ is the distance between the outriggers;
$F_A$ is the anchor force created by the outrigger;
$Q$ is the weight of the load being lifted;
$b$ is the distance from the tipping rib to the vertical axle of the load.
We will carry out a calculated assessment for the KS-55715 “Galichanin” crane by calculating $k_1A$, respectively, according to formula (2) for the specified crane, as if working on the proposed outriggers, and $k_1$ calculations according to formula (1) for the crane working on its outriggers pylons. Calculations are carried out for the case of lifting the load from the side as shown in figure 2. According to the reference data, this crane with a jib of 21.7 m is characterized by: a lifting capacity of 7 tons at a working radius (distance from the axle of rotation of the turning part to the vertical axle of the hook suspension) 6 m, and a lifting capacity of 1 t at a working radius of 18 m; the size of the support contour formed by the outriggers along the axle of the chassis ($B_o$) and across the axle; of the chassis of the crane ($K_o$), respectively 4.6 and 5.6 m; weight of the crane is 22.8 tons. To estimate the values of $F_A$ in the formula (3), we use the graphic dependences of the anchor force created by screw anchors in [4] in Figure 13 on the diameter of the anchor blade and the type of soil. Having taken the immersion depth of the bearing (lower) anchor blade in soil of 1 m, the blade diameter of 200 mm and the type of soil with low bearing capacity (soft foul clay), we determine the bearing capacity of one screw anchor – 45 kN or about 4.5 tf.

As a result of calculations of $k_{1A}$ according to the formula (2) and $k_1$ according to the formula (1) for the crane lifting capacity of 7 tons and a working radius of 6 m, the coefficients $k_{1A}$ and $k_1$ are obtained; they are, respectively, 5.1 and 2.85. For the crane lifting capacity of 1 t and the working radius of 18 m, the values of the coefficients $k_{1A}$ and $k_1$ are obtained, and they are, respectively, 7.52 and 4.2. The ratios of the coefficient $k_{1A}$ to $k_1$ for the indicated different values of lifting capacity and the working radius are the same, equal to 1.79.

5. Conclusions
The estimated calculations indicate a very significant increase in the cargo stability of cranes operating on soil foundations with low bearing capacity, if the proposed outriggers are used on them. An increase in the cargo stability coefficient of the crane by 1.79 times also means that with the same value of the cargo stability coefficient as when the crane was working on its outriggers, and when the proposed outriggers were used, it is possible to increase the crane's carrying capacity on the working radiuses indicated in the example. Also, when the crane is working on the proposed supports, an increase in working radiuses is possible at the same load capacities. This will provide the jib crane with great opportunities for installation and lifting works. It can also be noted that when using the proposed outriggers, there is no need for such expensive and time-consuming measures as compaction of the soil or coating of soft soils with shields and slabs. A patent was obtained for the proposed device [5].

Based on the foregoing, it is possible to recommend the general requirements for the devices of the outriggers of cranes or other lifting machines working on soil bases: the outriggers should transfer the load from the weight of the machines with the load not to the ground's surface, but to the buried layers of soil and work at the same time as the soil anchors.

References
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