

# The Parameter's Study of the Optimal Location of the Tower Crane Parking Place

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**Abstract**— The work is devoted to the study of the parameter influence on the relative position tower crane and the panel warehouse on the construction site. Due to the nonlinearity and trigonometricity of the equations obtained, they are solved numerically using a specially compiled computer program. The goal is to find how the minimum time of cargo movement from the warehouse to the installation site changes as the distance between them increases. It is necessary to find out the dependence (with minimum time of cargo movement) of the distance from the tower crane stand to the shortest line between the warehouse and the installation site on the speed ratio of the crane truck and the rotation of the crane boom. It is interesting to define how the minimum time of cargo movement varies depending on the speed ratio and crane boom. And finally we should know what the dependence - minimum time / distance - is between the parking of the tower crane and the warehouse. The results show that the first step is to minimize the distance between the warehouse and the installation site. The second conclusion relates to the mutual arrangement of the crane, the warehouse and the place of installation. It is necessary that they are isosceles, and even an equilateral triangle is better. Finally, there is the most appropriate relation of the selected geometry between the speeds of the trolley and the boom. And in some cases minimizing the time of cargo delivery is ensured by only one movement - the rotation of the boom.

**Keywords**— building structures; tower crane; load movement path; optimal control; dependency study.

## I. INTRODUCTION

Modern construction technologies are characterized by the following main trends: an increase in the number of floors and the size of buildings, an increase in structural spans, the use of large-sized elements, an increase in the volume and rate of construction. This leads to a sharp increase in the volume of lifting work, the need to increase the mass and speed of goods

movement, so the leading link on the construction site, of course, is a tower crane, as the main and most expensive mechanism provides, among other things, multithreading technology. The mechanization of hoisting, handling, and warehousing operations is overwhelmingly carried out with the help of various types of cranes. The efficiency and quality of work performed in construction largely depend on the effectiveness of crane work.

The organization of the crane work is closely connected with the general organization of construction and installation work at the construction site. Depending on the specific conditions determined by the nature of the structure, the project of organization of the technological process, a crane can only be used for installation work, for example, only lifting and transport and installation operations. In addition, the crane can participate in the loading and unloading operations, as well as supplying materials during the period of finishing works when the building is under roof.

During the shift, the crane delivers relatively few loads, their flow is many times less than that with masonry or installation. For each cycle the crane lifts a portion of materials that make up a small part of its load capacity by weight. Therefore, the cost of 1 ton of lifted load is greatly increased compared with intense operation.

The organization of the tower crane work should contribute to the greatest part of its performance and the implementation of safety regulations. Currently, the construction of residential and civilian buildings is mainly carried out according to the so-called two-gripping system, in which each building is divided into two sections - the seizure.

Depending on the accepted organization of work, tower cranes can enter into operation from the beginning of the construction of foundations and basement walls or from the moment when the above-ground part of the building is installed and remains until the completion of the roof installation. The

operating mode of cranes is closely related to the number of work shifts at the site of bricklayers and installers. With one-shift work, bricklayers work in 1-2 shifts, with two shifts - in 2-3 shifts

The performance of a tower crane is determined by the amount of cargo (building materials, parts and structures) that the crane can lift or mount per unit of time (hour, shift, day). The performance of a tower crane depends on a number of constants and variables.

The constant values include the working dimensions of the crane, speed, carrying capacity, as well as the method of changing the boom reach, the location of the cab on the tower and the control panel inside the cab itself, the method of moving the crane along small radius curves, etc.

Variables are: the type of cargo (piece, packaged, long, large size); qualification of the driver, scaffold workers, installers, the signalman; the nature of the operations performed by the crane (lifting and handling, installation, loading and unloading); the design and shape of the building being erected, the front of work, the placement of warehouses, the organization of the crane's work - linking its work with the work of elevators, loaders, motorcycles and other related machines and mechanisms; sequence of operations; composition of operations.

The combination of these values in specific production conditions determines the mode of operation of the crane, i.e., the degree of its use in terms of power and time.

The mode of crane operation depends on the completeness of the use of structural quantities - carrying capacity, speed, combining movements, movement along curved sections of the path. The mode of crane operation in time to shift depends on the time of useful work and interruptions in work. The use of a crane for a longer period depends on the number of shifts per day, the duration of interruptions due to meteorological conditions (frost, heavy rains, etc.), on the supply of construction materials, structures, electricity, on the supply of cranes with spare parts, lubricants and wiping materials, on the duration of scheduled maintenance, assembly, dismantling and transport operations, on the time the crane was at the facility.

To reduce machine cycle time, the driver must move loads along the shortest path. It should be remembered that an excessive lifting of the load over the structures and workers makes the hook path much longer, since the loaded and empty hook rises and falls four times over each working place during each cycle. This is especially noticeable during the construction of the first floors of the building. Therefore, in the process of moving over the building, the load must be raised above floor platform to a height of no more than 2-3 meters on average, which ensures safe movement of it over the working and protruding parts - window frames, elevators, chutes, etc. With a high qualification of the driver and good visibility of workplaces, the lifting height above the structures can be 0.2–0.5 m.

The distance of movement of the crane, trolley and angle of rotation of the boom with the load depends on the method of suspension of the load; on the configuration of the building and installation site of the crane, on the layout of the goods in the on-site warehouse, on the size of the grab being serviced by the crane. Depending on the specific working conditions and speeds of individual movements of the crane, the driver must

choose the most rational schemes for the supply of goods by the crane, ensuring the shortest machine cycle time.

A significant reserve of increasing the productivity of the crane is to reduce machine cycle time by the greatest possible combination of movements and minimizing idle, shunting movements of the crane. Work with a combination of movements mainly depends on the experience of the driver, as well as on a number of external conditions: the location of the crane near the building, the placement of materials in the warehouse, the design of the crane itself. Under normal operating conditions of the crane, as a rule, it is possible to combine any two operations.

It is not recommended to combine the movements of boom rotation and lowering the hook over the scaffolds, as in this case it is difficult to calculate the trajectory of the load that moves along the curve, as a result of which it can touch the structures.

Reduction of idle runs of a crane depends largely on the correct placement of materials in the warehouse and on the clarity of the work of the transport and installation wizard or the signalman. The work should be organized in such a way that for several cycles in a row one must deliver a homogeneous load — only containers, only a mixture, or only prefabricated parts. As a result, the driver, starting from the second cycle, will be able to outline the shortest path for moving the load and most fully combine operations. In addition, the time spent on replacing lifting devices and on shunting crane movement from one group of goods to another, located on an on-site warehouse, will decrease. The signaler or the master should also, if possible, place on the object the loads delivered over several cycles within relatively short distances.

Improving the performance of a tower crane can be achieved by improving its use of capacity. This is achieved in several ways, for example, by the fullest loading at a given boom angle when lifting wall materials, packing up partitions and window shields, enlarging architectural details and containerizing small elements [1].

Currently, cranes in most cases continue to be used unsatisfactorily, especially in the production of basic installation works. The coefficient of intra-shift use of tower cranes is 60–65%, of which no more than 40–45% of their working time is occupied by the crane during installation. On loading, cranes are used for 40-50%. Heavy and expensive cranes are often “idle because of organizational deficiencies and malfunctions, or they are distracted by loading and unloading and warehousing operations that can be performed with the help of other, lighter, cheaper and mobile machines. A characteristic drawback in the organization of work may be the installation of an excessive number of tower cranes at an industrial building under construction, the wrong choice of the necessary type of crane, the overlook of architectural, planning and design solutions of buildings under construction, as well as local conditions for organizing a construction site, deviations from technical conditions on the construction and maintenance of crane tracks.

The main proposals and recommendations that contribute to a significant improvement in the use of cranes, both in time and in performance, are as follows.

1) It is necessary to significantly improve the organization of delivery and warehousing of prefabricated products in the on-site warehouses, placing the stacks in the area of the erection

crane in order to ensure free access for scaffold workers and reduce the duration of the assembly cycle.

2) In building projects to achieve the optimal ratio of prefabricated elements in quantity and in weight, it is rational to assign the maximum weight and number of products with the best use of cranes in terms of capacity.

3) When developing the layout of residential neighborhoods and arrays, it is necessary to strive (not to the detriment of the quality of the design) rational use of tower cranes in the conditions of continuous construction [2].

At the construction site when using the technologies of panel housing construction, the leading machine is a tower crane [3-5], therefore it is necessary to organize the work so that a simple crane is minimal. To achieve this goal, the relevant criteria were considered in [6] and the corresponding tasks were set, some of which were solved [7]. Let us consider the task of minimizing the time of delivery of panels from the warehouse to the place of installation.

Most studies of the movement of cargo by lifting mechanisms for various purposes are aimed at developing ways to control crane installations, ensuring maximum speed of the process of moving cargo under the condition of fulfilling the production task, as well as safety rules and technical operation, and teaching these methods to crane operators. It should be noted that the performance of the lifting work is influenced by many factors, one of which is the choice of the trajectory of the cargo movement.

## II. THEORY

The study of the effectiveness of the cargo movement in the configuration space of the mechanical subsystem of a jib crane has already been set [8-10]. At the same time, the solution of the optimization problem is based on the criterion of minimum energy consumption and the development of methods for optimal control of crane installations in order to minimize the deviation of the load ropes from the vertical in the process of moving the cargo, as well as combining the movements of several mechanisms in time in terms of optimal dynamic process indicators.

Without diminishing the merits of such approach, we consider here another criterion related to minimizing the time of cargo delivery to the installation area.

The first obvious consideration is that the shortest trajectory of cargo delivery lies in the vertical plane passing through the warehouse and place of installation. However, in order to ensure the position of the trajectory of the cargo movement in this plane, a crane-robot is necessary with the combination of several strictly time-coordinated movements, and therefore with computer-controlled drives. Another limitation adopted in normal construction practice is to ensure safe work practices, including limiting the simultaneous execution of crane operations [11, 12] (turning with lifting cargo, moving crane truck with lifting cargo, and finally turning with simultaneous lifting cargo). From this it follows that it is possible to separate the movements and taking the vertical ascent into the independently carried out, optimize the trajectory only in the horizontal plane. Since it is desirable to exclude simultaneous movements, we accept a scheme of two movements: rotation of the boom and the final load adjustment using the movement of the crane truck. We accept further the following layout of the

construction site [13] and the location of the crane on it, shown in Figure 1.

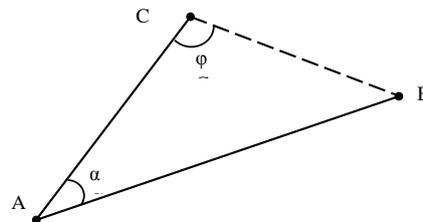


Fig. 1. Scheme of the layout of the construction site and the location of the crane

Point A here reflects the position of the warehouse of panels, point B - the place of installation, finally at point C - the tower crane is located, respectively, the AC - the departure of its boom. In this notation, we can formulate the following minimized criterion:

$$t = \min_{\alpha} \left\{ \frac{\varphi}{\omega} + \frac{|BC-AC|}{V} \right\}. \quad (1)$$

Here  $\omega$  is the angular velocity of rotation of the crane,  $V$  is the speed of movement of the crane truck.

The first term in the formula (1) reflects the time of boom rotation, the second - the time of movement of the trolley. Moreover, in the latter case, the direction of movement of the trolley is not important, therefore the absolute value of the distance traveled by the trolley is taken in the numerator of the second term.

Applying the sine, the theorem can be written:

$$\frac{AB}{\sin \varphi} = \frac{\sqrt{AC^2 + AB^2 - 2 AC AB \cos \alpha}}{\sin \alpha}. \quad (2)$$

From here you can express the angle  $\varphi$ . Substituting then the resulting expression in (1) we have:

$$t = \frac{\arcsin \frac{AB \sin \alpha}{\sqrt{AC^2 + AB^2 - 2 AC AB \cos \alpha}}}{\omega} + \frac{|\sqrt{AC^2 + AB^2 - 2 AC AB \cos \alpha} - AC|}{V}. \quad (3)$$

To achieve the minimum time value, it is necessary to differentiate this expression by  $\alpha$  [11,12], and equating the resulting expression to zero, we obtain an equation for  $\alpha$ :

$$V(AB \cos \alpha (AC^2 + AB^2 - 2 AC AB \cos \alpha) - AB^2 AC \sin^2 \alpha) + \omega(AC^2 + AB^2 - 2 AC AB \cos \alpha - AB^2 \sin^2 \alpha) AC AB \sin \alpha = 0 \quad (4)$$

## III. DATA AND METHOD

As follows from the theory, the resulting equation (4) is nonlinear and trigonometric. To solve it for different values of the input parameters, a computer program has been developed that uses the Newton method to find the roots.

The data used for the numerical calculation are summarized in table 1.

TABLE I. DATA FOR CALCULATIONS

Parameters	V	$\omega$	AB	AC
Dimension	m/sec	rad / sec	m	m
Fixed value	0.42	0.063	20	15
Change range	0.1-0.5	0.1-0.087	1-50	10-30

Computer simulation was intended to reveal how the minimum time for moving a load is related to the parameters reflected in the table.

First of all, the goal was to find out how the minimum time of cargo movement from the warehouse to the place of installation changes as the distance between them increases. At the same time, in the formula (4), the distance *AB* changed in steps of 1 m and recorded: the linear speed of the crane truck, the angular speed of the crane boom, the distance from the crane parking to the warehouse. The minimum time was calculated by the formula (3).

Second, it is necessary to answer the question: what is the relationship (with the minimum movement time of the load) the distance from the tower crane parking place to the shortest line between the warehouse and the installation site (*AB*) on the speed ratio of the crane truck and the rotation of the crane boom. At the same time, the speed of the trolley increased with a step of 0.03 m/s, the angular velocity of the boom decreased with a step of 0.001 rad/s, and the fixed values took the distance between the warehouse and the installation site and between the warehouse and the parking of the crane.

Third, it was found out: how the minimum time of movement of cargo varies depending on the speed ratio of the trolley and crane boom. Linear speed and angular change in the same way as in the previous case, the distance between the warehouse and the crane stand, as well as the distance between the warehouse and the place of installation was fixed.

Finally, in the fourth study, it was necessary to identify the dependence of the minimum time on the distance between the parking of the tower crane and the warehouse, which changed in 1-meter increments. The linear speed of the trolley and the angular velocity of the boom, as well as the distance from the warehouse to the parking of the crane and installation sites were assumed to be permanent.

In all studies, the ranges of changes in the changing parameters, as well as the values of the recorded parameters, were taken from Table 1.

IV. RESULTS AND DISCUSSION

Figure 2 shows the dependence of the minimum time of movement of cargo from the warehouse to the installation site on the distance between the crane and the warehouse. In general, there is a prorational increase in time with distance from the warehouse. There is a distinct minimum in the middle of the graph (*AC* = 17 m). It is due to the fact that the cargo is delivered only by turning the boom (the *ABC* triangle is isosceles), and there is no movement of the trolley.

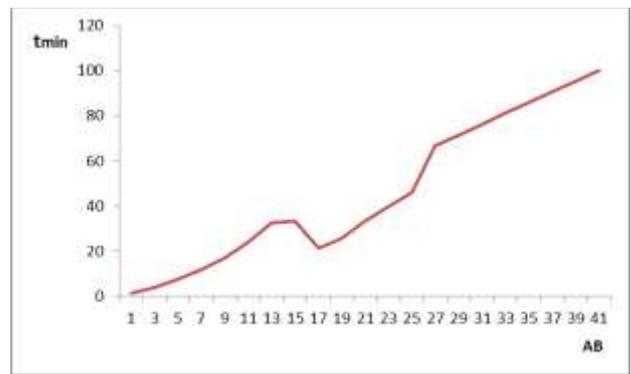


Fig. 2. Dependence of the minimum time on the distance between the warehouse and the installation site

Figure 3 shows the dependence of the distance from the crane to the straight line *AB* on the ratio of the linear speed of the trolley to the angular velocity of the boom. At first, this distance increases proportionally with a decrease in the ratio, at the end of the range the graph goes to “saturation” - the distance remains equal to 15 m, that is, the distance of the *AC*, while the angle  $\alpha = 90^\circ$ .

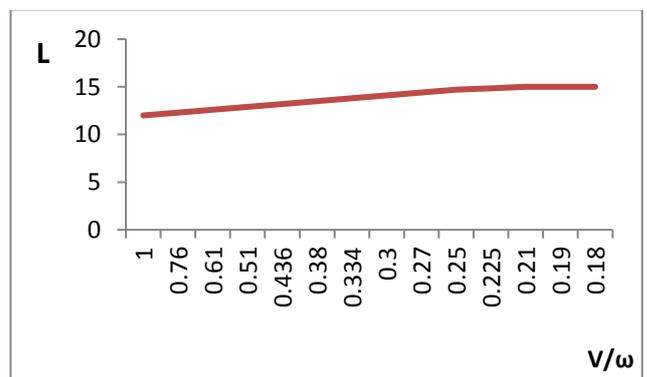


Fig. 3. Dependence of the optimum position of the crane with respect to the line *AB* on the ratio of the speeds of the boom and the trolley

Figure 4 shows the dependence of the minimum time on the ratio of the speed of the trolley and the rotation of the boom. The minimum time is observed at a ratio of 0.61, that is, with this ratio of speeds, the most successful configuration is an isosceles triangle *ABC*.

Finally, figure 5 shows the dependence of the minimum time on the distance of the crane parking area from the warehouse. At the same time, we see that the minimum is observed at a distance of 17 m. The maximum shows that the *ABC* triangle became equilateral, and then time gradually decreases with distance from the warehouse, as the angle  $\phi$  decreases, and therefore the duration of the angular rotation of the boom does.

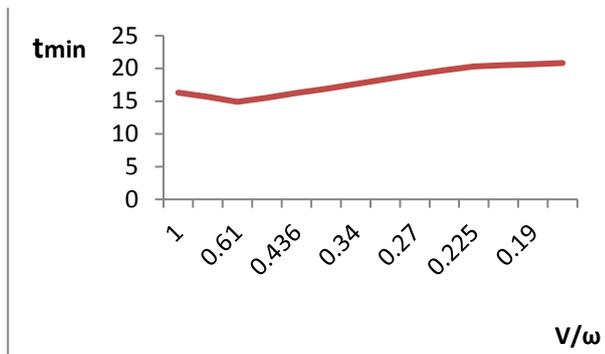


Fig. 4. Dependence of the minimum time on the ratio of the speeds of movement of the boom and bogie

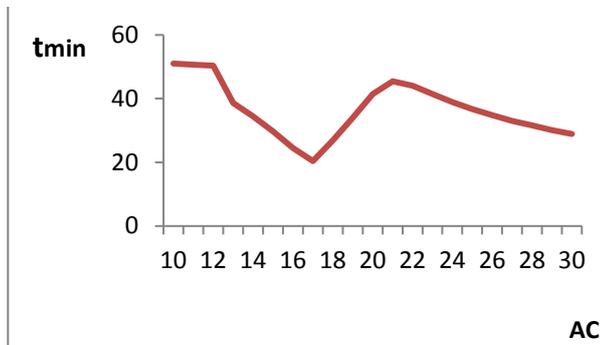


Fig. 5. Dependence of the minimum time on luffing

The study allows us to give the following practical recommendations on the choice of the parking place of the crane. The first dependence suggests shortening the distance between the warehouse and the installation site, the second and third dependences show the superiority of the isosceles of the *ABC* triangle and the choice of the ratio between the speed of the boom rotation car at 0.61.

## V. CONCLUSION

Thus, the study of the parameters of the optimal location of the parking places of the tower crane shows the presence of certain features in the process of achieving a common goal - minimizing the time of movement of cargo. First of all, it refers to the mutual arrangement of the crane, the warehouse and the place of installation, it is necessary that they form an isosceles, and even an equilateral triangle is better. On the other hand, there is a ratio between the speeds of movement of the rotation

boom and the crane boom which is the most suitable for the chosen geometry. In this study it is equal to 0.61.

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