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COMPLEXITY OF CALCULATING THE HARBOR QUAYSIDE LOADING EQUIPMENT EFFICIENCY

SAŽETAK

KOMPLEKSNOST PRORAČUNA UČINKA LUČKIH OBALNIH PREKRCAJNIH SREDSTAVA

Prekrcajni učinak lučkih obalnih i mobilnih dizalica ima dominantan utjecaj na vrijeme koje brod provede na pristanu. Zato se dimenzioniranje obalnog prekrcajnog postrojenja vrši upravo na temelju hipotetskog proizvodnog učinka ili stvarnog prekrcajnog kapaciteta lučkih obalnih i/ili mobilnih dizalica.

Pri utvrđivanju teoretskog prosječnog učinka pretpostavlja se da su svi varijabilni čimbenici sadržani u položaju polazne točke putanje kuke dizalice, položaju polupraznog broda, srednjem nivou mora i udaljenosti središnjice broda od krajnje točke putanje kuke na kopnenoj strani.

Razvijenom analitičkom metodom za izračunavanje vremenskog trajanja putanje radnog ciklusa, autor istražuje mogućnosti ispravnijeg vrednovanja učinka lučkih obalnih i mobilnih dizalica.

Primjenjena metoda zasniva se na pretpostavljenim uvjetima i empirijski određenim čimbenicima koji definiraju pojedine parametre puta materijalne točke zahvatnog sredstva sa svrhom iznalaženja nužnih pojednostavljenja pri proračunu učinka lučkih prekrcajnih sredstava.

1. INTRODUCTORY CONSIDERATIONS

The efficiency of loading, transport, i.e. transfer of cargo in harbor transportation depend on the flow and method of handling the goods, and can be analytically determined and evaluated by applying the appropriate mathematical procedures. In order to calculate the optimal efficiency of the harbor loading equipment, first the technical and technological characteristics need to be defined, which provide the highest possible transport and economic output of the harbor. These characteristics are parameters of single types of quayside and mobile cranes, and depend on the complexity of the applied operating procedure in which they are used.

Since the loading equipment efficiency depends on numerous influencing factors (lifting capacity of the loading equipment, the amount of transported cargo, speed, loading frequency, etc.), and stressing the space and time component, it is necessary to take into consideration the functional relationship between the ship, loading equipment and the land vehicle.

2. COMPLEXITY OF CALCULATING THE EFFICIENCY AS THE BASIS FOR EVALUATING LOADING EQUIPMENT

Planning of technical equipment, and especially of loading possibilities, plays a significant role in the development of any harbor. Loading possibilities are mainly determined by the number and capacity of the loading equipment (quayside and/or mobile cranes), and by the degree of their adaptability to goods of various structures that are involved in the loading process.

However, a greater capacity of the loading equipment does not necessarily mean a greater efficiency. On the contrary, in many harbors there is a disproportion between the loading capacity and the actual efficiency. Such an approach to harbors is explained by the need for "surplus" capacity, justified in situations where an increase and versatility of loading operations may be expected. For all the other situations in which there is a disproportion between the available capacity and actual efficiency, the interdependence of single influencing factors needs to be studied, in order to make a better use of the existing capacities and correct decisions in the future regarding purchase of new loading equipment.

Various influencing factors result primarily from the operation of the quay, i.e. its production efficiency depending on: loading equipment capacity, size and characteristics of the ship, technological downtimes, working hours, type of goods, delays in the operating process, external effects, and delays beyond the operating process.

By applying analytical methods, and depending on the values of certain considered influencing factors, the actual average and exploitation efficiency of quayside loading equipment can be roughly determined. It is necessary to know the exploitability level of the loading equipment capacity η, whose value (η≤1) depends on a range of corrective factors.

The so defined cargo handling efficiency of a crane is determined by its technical and exploitation features, and also by the organization of work and operating conditions, with the exploitability of the crane's positive features and the overall operating time playing a decisive role.

However, because of the difficulties that are certain to arise while determining the level of loading equipment exploitability, it is necessary to supplement the calculation of harbor crane efficiency by an adequate method based on physical values, primarily changes in the components regarding space and time.

Thereby it is necessary to distinguish the two concepts: "efficiency" and "capacity" of the cargo handling equipment or devices. Often the question is asked, what in fact is the capacity of a crane, and some consider this to be its lifting capacity. However, the concept "crane capacity", whose effects are realized by the speed of performing complex movements of its material structure, cannot be expressed by the static concept such as "lifting capacity", since its capacity is expressed, i.e. realized by the optimal exploitability of its lifting capacity in a time unit. Therefore, one may say that the crane capacity is a dynamic concept, including apart from the lifting capacity, also the technical and exploitation parameters, and in the first place operating speeds of single components of the crane system.

Cargo handling capacity of the crane is, therefore, its ability to handle a certain amount of goods in a time unit, with its more or less perfect technological structure, and under given conditions and appropriate organization of operation. Time units can be an hour, a working shift, a day, a month, a year, etc.

Since the crane cargo handling capacity is affected by technical and organization factors, it is necessary to differentiate between the technical and the actual cargo handling capacity.

Technical capacity is the numerically determined amount of goods (cargo) of certain properties, that can be handled in a period of one hour, day, month or year, with certain relations of geometrical values between the crane and the ship, and under the condition that the work is performed continuously at nominal speeds and accelerations, using the highest allowed lifting capacity, the medium sized cargo in the ship and mean water level, and the shortest path of the gripping device between the ship's center line and the end point on the quay.

Since the actual performance of the crane is lower than its technical loading capacity, and assumes depending on the operating conditions various values, its average values are known as the actual loading capacity.

Apart from technical features of the crane, its actual loading capacity takes into consideration also other influencing factors, which as environment reality most often reduce the possibility for a single crane of a special purpose to be technically perfect. The operating conditions also play a certain role, and they include: the arrangement of auxiliary facilities, operating surfaces, warehouses, railway tracks, roads, type of cargo handling devices, type of cargo, its physical and technical features (form, granulometric composition, homogeneity, density, etc.), various standstills, the operators' skills etc. The actual loading capacity of a crane is by measurement defined amount of goods in tons, pieces or cubic meters, that can be handled (transferred) within a period of one hour, one shift, a day, a month or a year, under concrete working conditions.

The difference between the technical and actual cargo handling capacity of a crane is represented by the surplus or loose capacity, which is necessary because of the lack of uniformity in transport and the instability within the cargo handling system itself.

Unlike the concept of "capacity", where the amount of goods (expressed in kN, tons, m^3 or pieces) that has to be handled within a certain interval is "assumed" or calculated mathematically, the concept of "efficiency" is related to the realized values of a certain handling equipment or system.

Therefore, when talking about cargo handling capacity, this means in fact the technical possibilities, and when talking about efficiency, it means the feasible values.

This needs to be emphasized in order to clearly differentiate between these two concepts which are sometimes even in professional literature insufficiently determined. Terminologically, these two concepts are often mixed up so that when speaking of the possible efficiency, capacity is meant, or when speaking of the achieved capacity, it should be called by its real name, i.e. efficiency.

The loading efficiency of the quayside cargo handling equipment can be defined analytically. This requires knowledge of the crane cycle times based on the defining of assumed parameters of the path between a certain point in the ship and a certain point on the quayside, as well as the mean masses of the handled cargo.

It is, therefore, necessary to determine the starting and the end points connected by appropriate path - trajectory. This trajectory presents the shortest connection between these two points. In the actual process of unloading this is often not so, due to various barriers on the path between the starting and end points that need to be avoided

Regarding the geometrical trajectory form of the elementary material flows, the cargo handling equipment can be studied according to features of the appropriate elementary flow, although a certain means can serve more than one elementary flow.

In calculating the cargo handling efficiency of the harbor quayside and mobile cranes, the mean trajectory of the material point of the gripping device (crane hook) is taken into consideration, although these cranes are classified as mobile transport devices since they realize more than one different trajectories within a certain range with different starting and end points.

Under the specific harbor conditions, there are numerous distances for transferring cargo from a point or towards a point. For a certain straight line and distance, the cargo handling efficiency is as follows:

$$Q_h = m_s \cdot n_c \text{ (t/h)} \qquad (1)$$

where:

Q_h - efficiency of cargo transport for one loading device (t/h)

m_s - average mass (amount) of cargo handled in one operating cycle (t)

n_c - number of cycles of one cargo handling device per hour (h^{-1})

The average mass of cargo (m_s) can be expressed as the mean value of all the individual cargoes (m_i) that are transferred within a period of one hour. It follows from the relation:

$$m_s = \frac{m_1 + m_2 + \ldots + m_n}{n_c} = \frac{\sum_{i=1}^{n} m_i}{n_c}, \text{(t)} \qquad (2)$$

In order to determine the theoretical number of cycles, it is necessary to determine the average path of the material point of the crane hook, i.e. cargo being handled (Figure 1), based on the assumed relations of geometrical values between the quayside crane and the ship.

The figure shows that a crane operating cycle consists of a range of time values needed to perform single

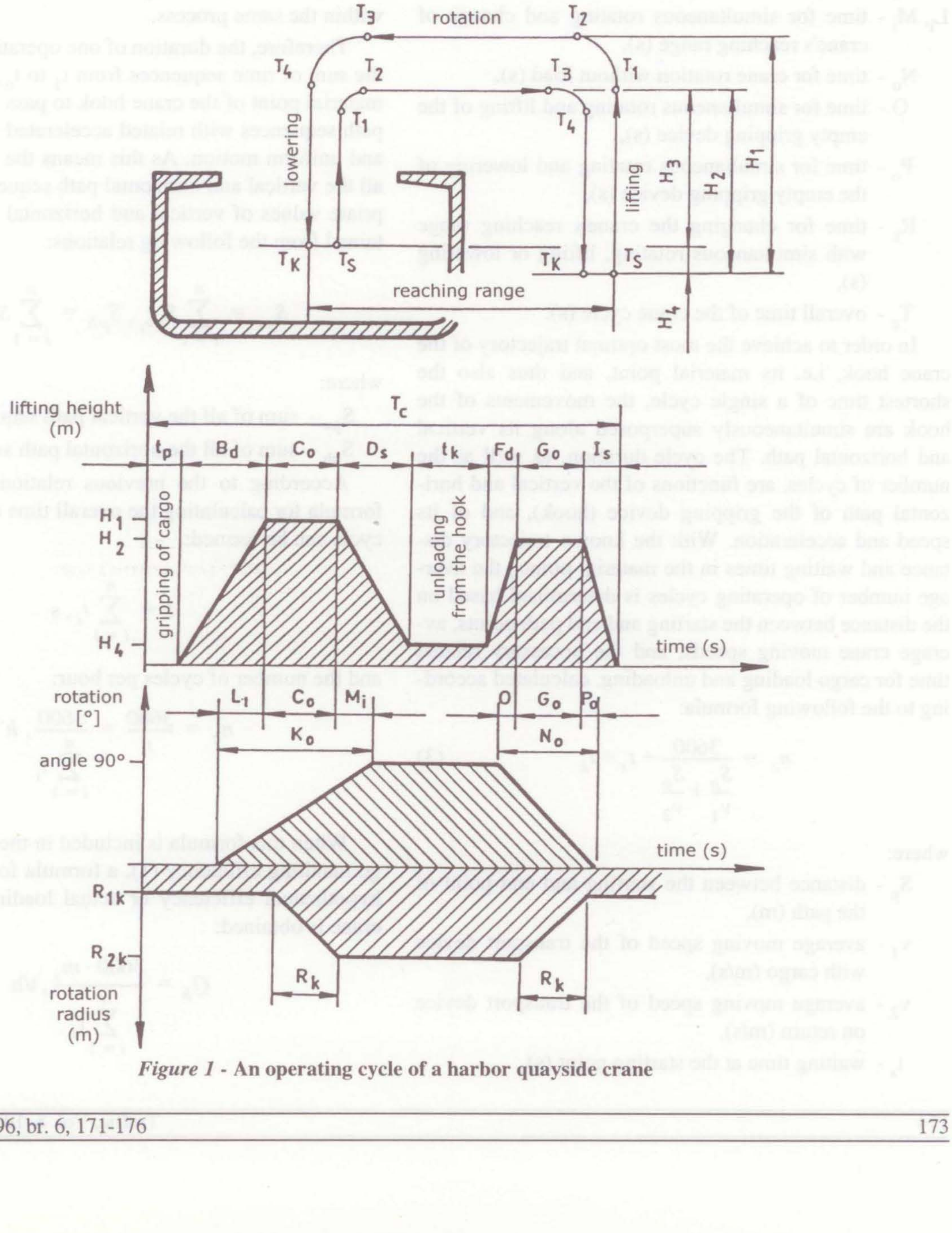

Figure 1 - **An operating cycle of a harbor quayside crane**

operations, marked by letter symbols, and having the following meaning:

t_p - time required to grip the cargo (s)

B_d - time for lifting the cargo of crane's nominal lifting capacity (s)

C_o - time for crane rotation carrying the cargo (without performing other operations) (s),

D_s - time for lowering the cargo of nominal lifting capacity (s)

t_k - time required to unload cargo from the gripping device (s),

F_d - time for lifting the empty gripping device (hook), (s)

G_o - time for rotation of an unloaded crane (without performing other operations), (s)

I_s - time for lowering the empty gripping device (s)

K_o - total time for crane rotation at 5° inclination (s)

L_i, M_i - time for simultaneous rotating and change of crane's reaching range (s),

N_o - time for crane rotation without load (s),

O - time for simultaneous rotating and lifting of the empty gripping device (s),

P_o - time for simultaneous rotating and lowering of the empty gripping device (s),

R_k - time for changing the crane's reaching range with simultaneous rotating, lifting or lowering (s),

T_c - overall time of the crane cycle (s).

In order to achieve the most optimal trajectory of the crane hook, i.e. its material point, and thus also the shortest time of a single cycle, the movements of the hook are simultaneously superposed along its vertical and horizontal path. The cycle duration, as well as the number of cycles, are functions of the vertical and horizontal path of the gripping device (hook), and of its speed and acceleration. With the known trajectory distance and waiting times in the material points, the average number of operating cycles is determined based on the distance between the starting and end path points, average crane moving speeds, and the necessary related time for cargo loading and unloading, calculated according to the following formula:

$$n_c = \frac{3600}{\frac{S_p}{v_1} + \frac{S_p}{v_2}} + t_s + t_k \qquad (3)$$

where:

S_p - distance between the starting and end point of the path (m),

v_1 - average moving speed of the transport device with cargo (m/s),

v_2 - average moving speed of the transport device on return (m/s),

t_s - waiting time at the starting point (s),

t_k - waiting time at the end point (s).

Since it is difficult to influence the times needed to grip and dispose of the cargo, which mainly depend on variable factors, such as type of goods, type of the gripping device, arrangement of cargo in the ship and on the vehicle, way of handling the cargo, need to place the goods on pallets, used harbor tools, organization of operation, workers' skills etc., the analyses are often directed towards the related machine times of the quayside cranes. However, here again relations regarding space have to be taken into consideration, which means the distances and rotation angles of the crane for the assumed working conditions ("full" - carrying the load or "empty" sequence of the crane cycle).

The operating cycle of the crane consists of a range of sequences with times needed to perform single movements as well as single isolated operations and movements, so that these operations can be differentiated within the same process.

Therefore, the duration of one operating cycle will be the sum of time sequences from t_1 to t_n, required by the material point of the crane hook to pass a certain sum of path sequences with related accelerated or slowed down and uniform motion. As this means the sum of times of all the vertical and horizontal path sequences, the appropriate values of vertical and horizontal path can be obtained from the following relations:

$$S_{pv} = \sum_{i=1}^{n} S_{pv_i}, \; S_{ph} = \sum_{i=1}^{n} S_{ph_i}, \text{ m} \qquad (4)$$

where:

S_{pv} - sum of all the vertical path sequences

S_{ph} - sum of all the horizontal path sequences

According to the previous relations the following formula for calculating the overall time of one operating cycle can be formed:

$$t = \sum_{i=1}^{n} t_i, \text{ s} \qquad (5)$$

and the number of cycles per hour:

$$n_c = \frac{3600}{t} = \frac{3600}{\sum_{i=1}^{n} t_i}, \; h^{-1} \qquad (6)$$

When this formula is included in the relation for cargo handling efficiency (1), a formula for calculating the hypothetical efficiency or actual loading capacity of a crane is obtained:

$$Q_h = \frac{3600 \cdot m_s}{\sum_{i=1}^{n} t_i}, \text{ t/h} \qquad (7)$$

When determining the cargo handling efficiency of a quayside crane, it is assumed that all the variable factors of the geometrical relation between the ship and the crane are included in the position of the starting point and the trajectory of the crane hook, which is defined by three parameters. These are: the position of the ship cargo hatchway, mean cargo level in the ship and the distance of the ship's center line to the end point of the hook trajectory on the quayside.

The applied method for calculating the cargo handling efficiency of the quayside crane is based on the assumed conditions and empirically determined factors that define single trajectory parameters of the material point of the crane hook. However, apart from the parameters that are defined by numerical values of geometrical relations between the quayside crane and the ship, the calculation must also include the values of other depending factors that affect single sequences of the hook trajectory between its starting and end points.

During unloading of a ship, due to the reduction of load, and because of the tides, the upper edge of the ship hatchway changes constantly, the same happening to the starting point of the hook trajectory. A similar, but reverse process occurs during loading of cargo into the ship. This causes constant change in the hook material point trajectory within the closed trajectory system. The change in the hook trajectory during unloading or loading is also significantly influenced by the size and position of cargo hanging off the hook, since its height affects the starting and end point of the material point trajectory in cargo handling. The trajectory can also be changed due to the swinging of cargo, especially in the case of those cranes that are not fitted with automatic speed adjustment of the device for the change of the reaching range. To illustrate this, figure 2 shows a simulation of a rigid crane system with double reaching range, with cargo hanging on a rope, and the driving mechanism for change of reaching range which has: a) non-automatic, b) automatic drive. By improved automation and regulation of this drive, especially at higher speeds of the gripper top at close range and sudden braking, the swinging of cargo and the change in its trajectory are avoided.

Positioning of cargo in the ship as well as on the land vehicle, primarily its height, also significantly affect the change of trajectory during cargo handling operations. Four factors have the greatest influence, and these are: type of the ship, type of the land transport vehicle, properties of the goods, and quayside crane design.

The type of ship here means the construction differences, especially regarding the design of the ship superstructure and storage space, their height (depth), hatch width, volume, accessibility, etc.

The type of land transport vehicles can affect the gripping device trajectory change, and thus also the crane efficiency, both negatively if the goods are not easily accessible as is the case with covered wagons, and positively, when the goods are easily accessible as in trailers or flat wagons. The physical properties of goods are important regarding the usage of space in the ship storage and the land transport vehicles, which is often reflected also on the change of crane hook material point trajectory change.

The properties of the goods affect the crane efficiency in a positive sense if the goods are unvaried, easy to handle, of high density, etc., or in a negative sense, if the goods are varied, uneven, bulky, etc., which renders them difficult for handling and prolongs the crane operating cycle.

More goods delivered on pallets will also reduce the cycle duration and increase the cargo handling efficiency. All these influencing parameters show the complexity of calculating the cargo handling efficiency of the quayside and mobile cranes. This complexity is caused by the inner functioning structure of the transport system on one hand, and external specific relations of the system and its environment, on the other. To define the optimal efficiency of the harbor quayside and mobile

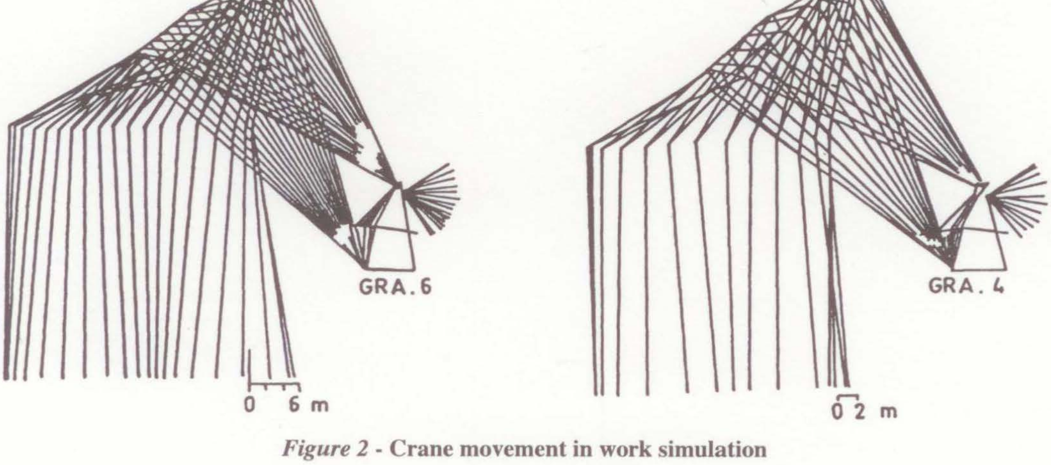

Figure 2 **- Crane movement in work simulation**

cranes, the optimal trajectory parameters and the operating speeds and accelerations need to be determined in advance, thus defining the limitations of the time function regarding movement of the gripping device and cargo, resulting in maximum values during the harbor cargo handling process.

CONCLUSION

The efficiency of harbor quayside and mobile cranes depends on a great number of factors which affect its realization with various intensity.

Since efficiency is a function of mass throughput and number of operating cycles, special importance is paid to correct estimate of the crane operating cycle duration. Defining the fixed points on the gripping device trajectory represents the basic prerequisites for the calculation, which makes specific features of variable factors, characteristics of the material circulation. By using the basic physical quantities, the obtained relations enable necessary simplifications in calculating the efficiency of harbor cargo handling devices.

SUMMARY

The loading efficiency of harbor quayside and mobile cranes affects significantly the time duration a ship has to spend at a quay. Therefore, the dimensions of the quayside loading equipment have to be determined precisely on the basis of hypothetical production efficiency or the actual loading capacity of the harbor quayside and/or mobile cranes.

When determining the theoretical average efficiency it is supposed that all the variable factors are contained within the position of the starting point of the crane hook path, the position of a half-loaded ship, mean sea level, and the distance of the ship center-line from the end point of the hook path at the quayside.

The author studies the possibilities to perform a more correct evaluation of efficiency of harbor quayside and mobile cranes, using the developed analytical method for calculating the time duration of the operating cycle trajectory.

The applied method is based on the assumed conditions and empirically determined factors that define single parameters in the path of the gripping device material point in order to find out the necessary simplifications in calculating the efficiency of harbor loading equipment.

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