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IMPACT SIGMOIDAL CARGO MOVEMENT PATHS ON THE EFFICIENCY OF BRIDGE CRANES

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ABSTRACT

The article dwells upon the results of study influence of movements time at traversing single obstacle arcwise with suppression of load's oscillation on the indices of assessing working process of a bridge crane. Simulation of movements was implemented using an imitating model with proportional-integral-differential control. The required trajectories of load transfer were set using sigmoid functions.

Keywords: bridge crane, PID regulator, sigmoidal

1 INTRODUCTION

The characteristic problems for the bridge crane (BC) with flexible suspension are uncontrolled load oscillations at movement, which significantly reduce the accuracy and performance of implementing works. Optimization of the trajectory of transferring point of load suspension located on the baggage cart (trolley) BC, i.e. optimization of the process controlling the bridge and cart's drive mechanisms is one of the perspective ways to solve this problem [1, 2]. There was proposed to use proportional-integral-differential (PID) control independently by two controlled coordinates of the bridge and baggage cart [3].

2 PROBLEM SOLUTION

According to the proposed functional diagram (Fig. 1), with using packet burst SimMechanics Second Generation of the system MATLAB, Simulink model of the BC mechanical system with PID-control was developed. Simulink-model allows us to study the bridge crane's operating modes on the engineering stage [4, 5, 6, 7, 8].
The conducted studies have shown that using sigmoid functions for setting required time dependencies of the horizontal coordinates of a cargo at traversing (load bypass) single obstacle, can significantly reduce, and in some cases even eliminate high-frequency oscillations of coordinates of load and suspension.

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In addition, there are removed the oscillations of velocities and accelerations of the suspension point in comparison with other methods of setting required trajectory of load movement (for example, using trigonometric sinusoidal time or coordinate functions or using consistent integration of graded jerk's functions). Also, there is a reduction of the absolute values of acceleration of the suspension point, they become comparable (i.e. values of the same order) with accelerations of load at the required ideal sigmoidal trajectory.
A series of computational experiments on a simulation model was conducted for study BC dynamic system's performance with PID regulators. As an example, which has wide practical application, there was modeled load bypass of a single obstacle of a "wall" type on a levelled trajectory assigned by horizontal coordinates X_0, Z_0 space in a fixed Cartesian system $O_0X_0Y_0Z_0$ by sigmoid (logistic) time functions of the form [9]

$$X_{TP}(t,a,c) = l_x \big/ \left(1 + e^{-a\cdot(t-c)}\right); \qquad (1)$$

$$Z_{TR}(t,a_1,c_1,a_2,c_2) = (s_x \cdot k_{sx}) \big/ \left(\left(1+e^{-a_1\cdot(t-c_1)}\right)\cdot\left(1+e^{-a_2\cdot(t-c_2)}\right)\right), \qquad (2)$$

where t - time; X_{TR}, Z_{TR} - the required coordinates of cargo in the horizontal plane at time moment t; a, c, a_1, c_1, a_2, c_2 - parameters of sigmoidal functions; l_x - the length of the displacement along the axis X_0 between starting and ending points of the required load trajectory (this points have zero coordinate $Z = 0$); s_x - value of maximum arc's displacement of the required trajectory of load along the axis Z_0 (laterally to avoid obstacles); k_{sx} - the correction coefficient of maximum value of the lateral displacement

$$k_{sx} = \left(1+e^{-a_1\cdot(c-c_1)}\right)\cdot\left(1+e^{-a_2\cdot(c-c_2)}\right). \tag{3}$$

Function (2) is the product of two sigmoid functions of the type (1) - increasing and decreasing with different time of inflection's points. The parameters c, c_1, c_2 set the time of inflection's points of sigmoid functions, and parameters a, a_1, a_2 - the rate of change (the rate of growth or decline is determined by the sign) of functions.

During a series of considered experiments, there was varied the conditional time of moving suspension point of the load T_P, which, according to the results of the research, is entered in the limits T_P = 1,33333 T_{GR}, where T_{GR} - conditional time of the load's movement.

By-turn, at using threshold value of the sigmoid function P = 0,999, at achievement of which a given load's movement was considered complete, the parameters of the sigmoid function (1) were determined by:

$$a = \ln(1/P-1)/(-T_{GR}/2);\ c = 2\cdot T_{GR}/2, \tag{4}$$

where $T_{GR} = 0{,}75\cdot T_P$.

Parameters sigmoid function (2) were determined by:

$$a_1=a;\ a_2=-a;\ c_1=c-k_{ud}\cdot T_{GR};\ c_2=c+k_{ud}\cdot T_{GR}, \tag{5}$$

where k_{ud} = 0,15 - accepted coefficient of relative distance from each other of two multiplied (2) simple sigmoid functions.

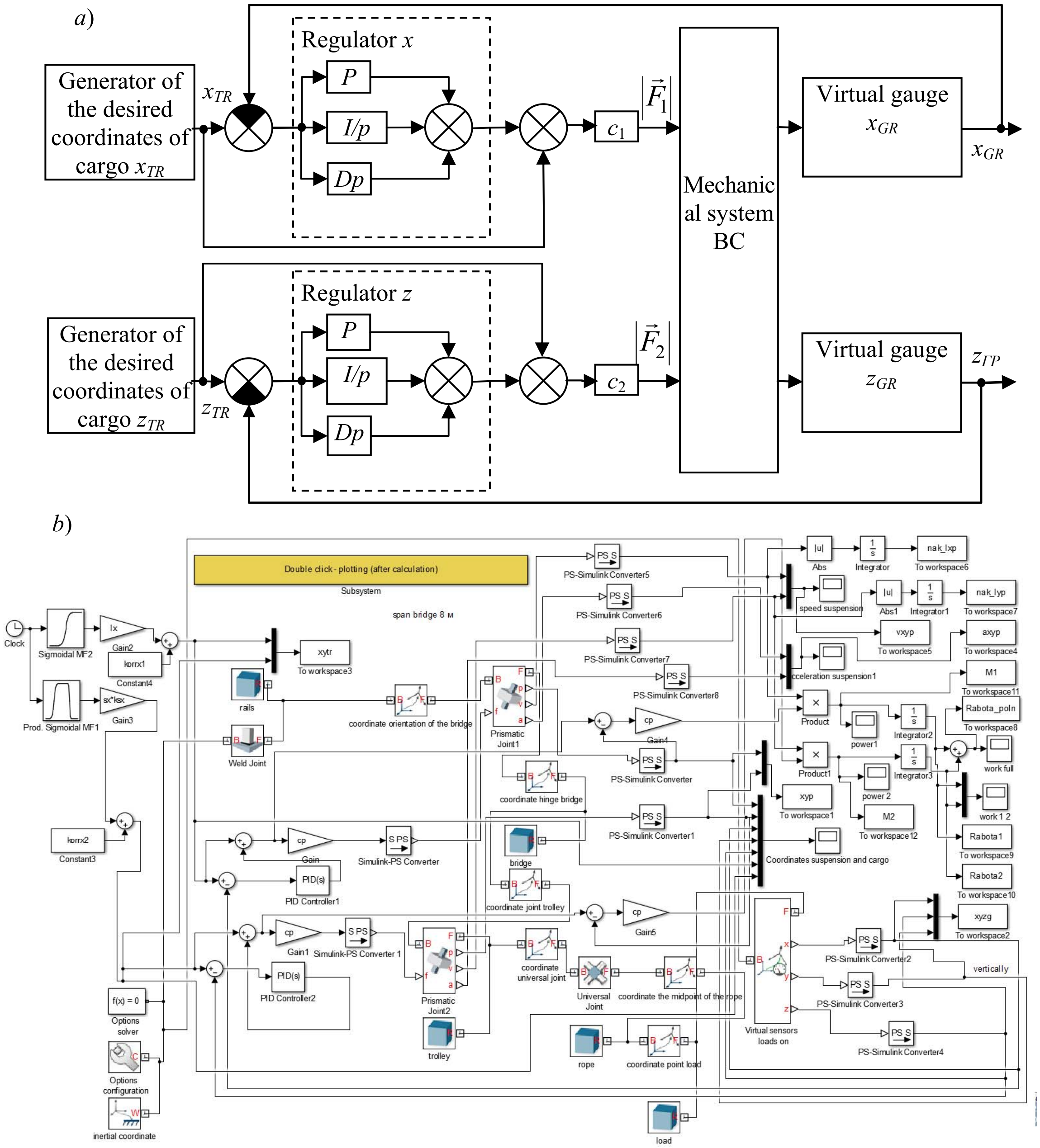

Figure 1 Functional diagram of connections for building model of mechanical subsystems of the bridge crane with PID-controller (a) and its corresponding model in the notations SimMechanics Second Generation and Simulink (b).

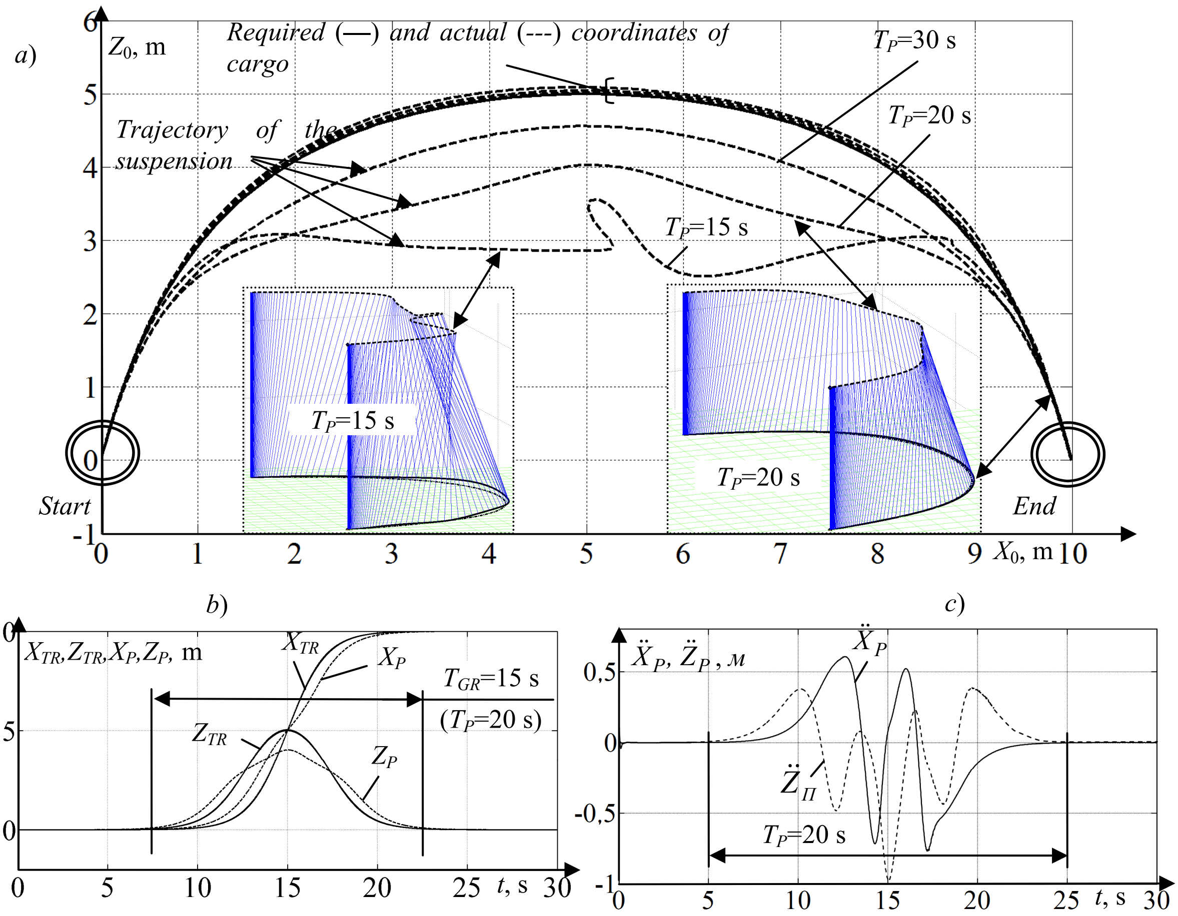

Figure 2 Diagrams of Cartesian coordinates of the load center's point and the suspension point (a, b) and acceleration of the suspension point (c) at realization of traversing single obstacle with the use of PID-control (example).

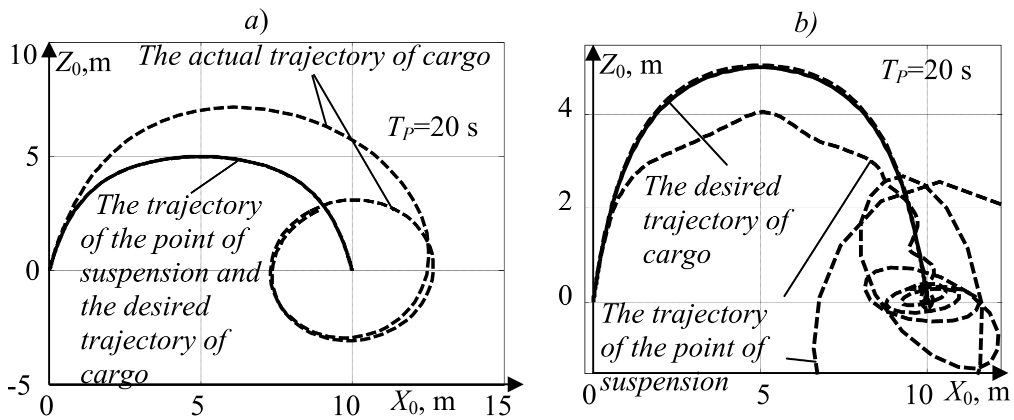

Figure 3 The examples of diagrams of Cartesian coordinates of the load's center point and the suspension point in the absence of correction of load's deviations (a) and proportional control (b).

Coordinate and time dependences of the synthesized, with the use of PID-regulators, coordinates of the load suspension's point (baggage cart) X_P, Z_P required X_{TR}, Z_{TR}, and actual X_{GR}, Z_{GR} coordinates of the load, and the time dependence of the acceleration of the suspension point are shown in the Fig. 2, as an example, for the conventional time for movement of cargo suspension point T_P = 15, 20 and 30 s.

The proportional, integral and differential coefficients of PID-regulators of controlling drives of the cart and bridge's movement in this task were possessed the values: P = 20; I = 5; D = 5.

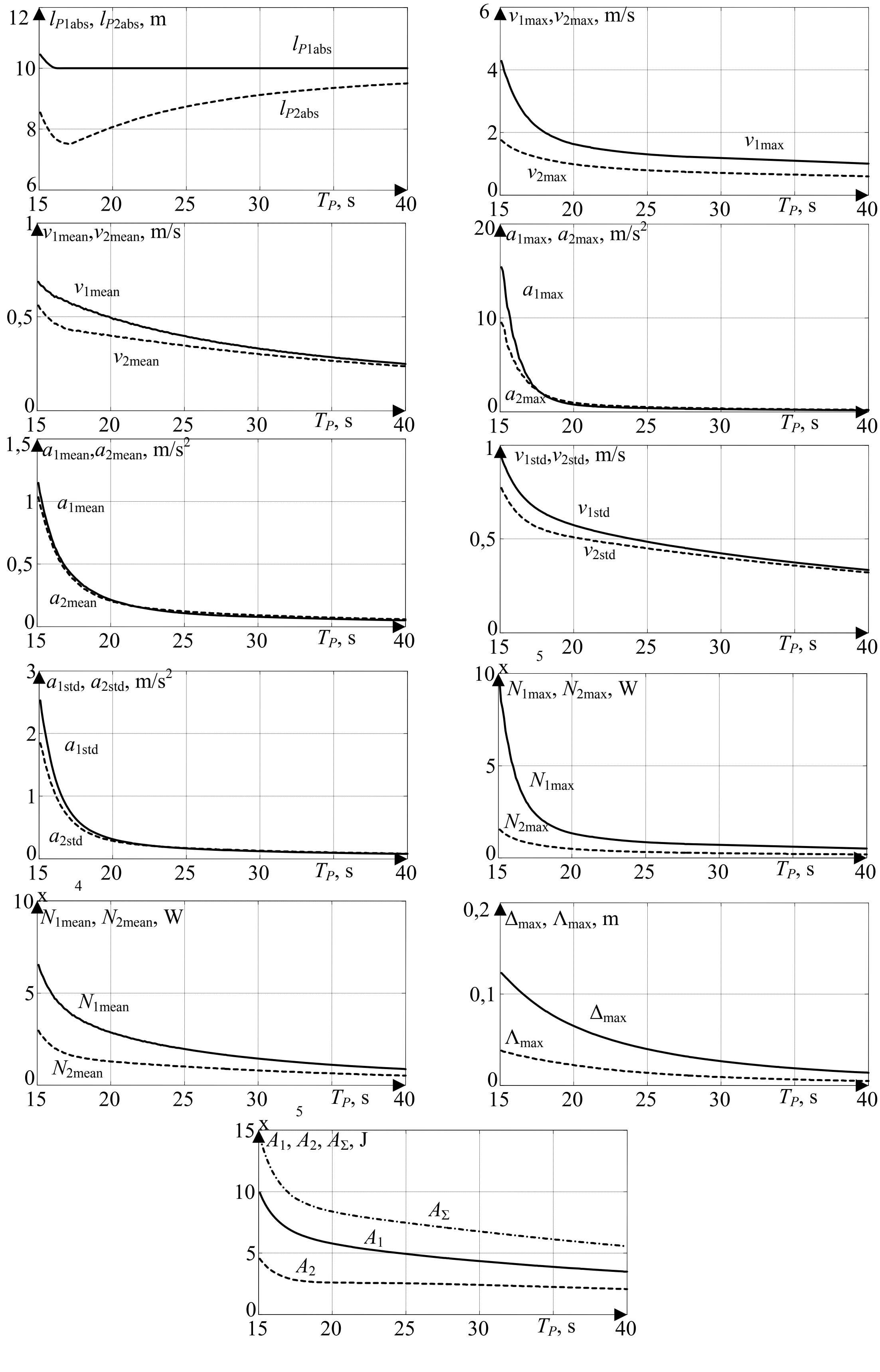

Figure 4 Performance of evaluation of the operation overhead crane depending on the travel time suspension point of cargo TA (example).

On the Fig. 3 for the illustration of the working efficiency and effectiveness of using the PID-regulators of controlling drives of the bridge and BC cart's movement, there are presented diagrams of Cartesian coordinates of the load's center and the point of suspension for a specified trajectory of the load movement, that shown in Fig. 2 with $T_P = 20$, with the values of the regulators' coefficients $P = 0$; $I = 0$; $D = 0$ (Fig. 3, and corresponds to the absence of correcting load deviations, i.e. drives move the point of suspension along the required trajectory of load movement) and $P = 20$; $I = 0$; $D = 0$ (Fig. 3*b*, proportional regulation). In the absence of corrective influences, the load, after a soft stop of the suspension point, begins to oscillate around the end point of equilibrium. At proportional regulation the specified trajectory of the load's movement is realized sufficiently precisely, but at approaching the end point the process becomes unstable and the suspension's point begins to oscillate with increasing amplitude around the end point of equilibrium.

The other parameters of the working process have the following values: the load cable length 12 m; the magnitude of the required movement of the load along the axis O_0X_0 - 10 m; the magnitude of lateral displacement for obstacles' bypass along the axis O_0Y_0 - 5 m; the mass of the bridge - 3500 kg; the mass of the baggage cart - 1250 kg; load weight - 100 kg; the presented coefficients of decrement by the angular coordinates of deviations of the load cable from the vertical in two mutually perpendicular planes - 100 N·m·s/rad.

The total time of the suspension's movement was varied from 15 to 40 s with interval of 0,1 s.

The working process of the bridge crane can be assessed by various parameters. On the Fig. 4, as an example, there are presented some of them, obtained during the described series of computational experiments: the absolute movements of the bridge and baggage cart correspondingly (at the realization of the specified trajectory) l_{P1abs}, l_{P2abs}, m; the maximum velocities of the bridge and baggage cart's movements v_{1max}, v_{2max}, m/s; the average velocities of the bridge and baggage cart's movements v_{1mean}, v_{2mean}, m/s; the maximum accelerations of the bridge and baggage cart's movements a_{1max}, a_{2max}, m/s^2; the average accelerations of the bridge and baggage cart's movements a_{1mean}, a_{2mean}, m/s^2; the standard deviations of the speeds of the bridge and baggage cart's movements v_{1std}, v_{2std}, m/s; the standard deviations of the accelerations of the bridge and baggage cart's movements a_{1std}, a_{2std}, m/s^2; the maximum instantaneous values of powers, spent by the bridge and baggage cart's drives N_{1max}, N_{2max}, W; the average values of powers, spent by the bridge and baggage cart's drives N_{1mean}, N_{2mean}, W; the maximum absolute error of the trajectory's realization $\Delta_{\max}$; the average absolute error of realization of the trajectory $\Lambda_{\max}$, m; the work, implemented by the drive of the bridge A_1, J; the work, implemented by the drive of the baggage cart A_2, J; the total work of the drives A_Σ, J.

The virtual measuring sensors, embedded in blocks of mechanical joints SimMechanics Second Generation, measuring movements and velocities by the degrees of joints' freedom were used during the working process for measuring and calculating the values of the above parameters.

The developed model allows solving the problems of the BC dynamics, analysis and synthesis of structural and technological parameters of the BC and their control systems. There is possible the study of large movements of the links. The results of the conducted studies lead to a conclusion that realization of the leveled trajectory of the movement of a certain type's load without high-frequency oscillations (rocking) of both the load and the suspension's point is possible at relatively low values of accelerations, developed by the suspension's point.

3 CONCLUSION

Analysis of the obtained dependences allows us to conclude that increasing the specified time of movement for the same test trajectory enables to reduce the requirements to the bridge and baggage cart's drives in terms of maximum and average values of velocities, accelerations, powers, works fulfilled by the drives, during simultaneous increasing the accuracy of load's movements.

Thus, the requirement to increase of the BC's operating efficiency (decreasing movements' time) is associated with the need of applying more powerful and fast-acting drives, increasing energy consumption and decreasing movements' accuracy.

The receiving of the mentioned dependences for an arbitrary specified trajectory creates the possibility to optimize the BC's working process by the criteria of accuracy, efficiency and energy consumption, including multi-criterion optimization taking into account various limitations.

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