



The optimization of the flexibly suspended loads transport by microprocessor controlled overhead cranes

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Abstract

The optimization of the transport of the flexible suspended load for overhead cranes has been worked out. The solution of the problems connected with oscillation of the flexibly suspended load, positioning of the load, limitation of the bevel angle of the bridge, and friction of the wheel flanges and power regulation are presented in this paper. The problems have been solved by means of a microprocessor automatic and semiautomatic continual control of the speed of the travelling and traversing mechanisms, and constant power regulation for hoisting and lowering of the load. The system can be applied to the transport of the load in the transport area where the fixed obstacles are situated.

1 Introduction

The microprocessor control system for all of the mechanisms of the overhead crane has been built. It gives the possibility to position the load in every point of the three dimensional transport space. The system can co-operate with the board computer in the automatic working mode.

The hoisting winch contains the constant power regulation system and the position regulation system. The first, allows better use of the power of the electric motor and movement of the smaller at higher speed. The position control system allows delivery of the load to the chosen transport level.

The travelling and the traversing mechanism control systems demand that the control function must be worked out by the board computer and sent to the

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controller which is the main element of the control system. The control function is being delivered in the real time. The control system contains the continuously working speed and displacement regulators. They allow to transport the load to the chosen position. The shape of the control function gives the possibility to damp the load oscillations after the acceleration and braking phase. Additionally, the control system of the travelling mechanism enables to limit the bevel angle of the bridge over the duty motion. The computer chooses the proper horizontal way which can be realised by simultaneous work of the travelling and traversing mechanisms according to the transport level and obstacles connected with it. The optimization of the vertical and horizontal load transport has been worked out.

2 The Overhead Crane Control System

To confirm the optimum strategy of the load transport the microprocessor control system for the real overhead crane (load $Q = 50$ kN, span $L = 10$ m) has been built. The control system was used in the hoisting winch, in the traversing mechanism and in individual travelling mechanisms connected with the end carriages. All the mechanisms are driven by the asynchronous electric motors powered from the frequency converters. The work of each mechanism is organised by the microprocessor controller which realises all demanded functions of the control and regulation system. The main controller, called „master”, manages the work of all the controllers, lets communicate each other by „BITBUS” network and co-operates with the board computer in the automatic work mode. All the mechanisms can be controlled by the determined programs. The block scheme of the control system is shown in the fig. 1.

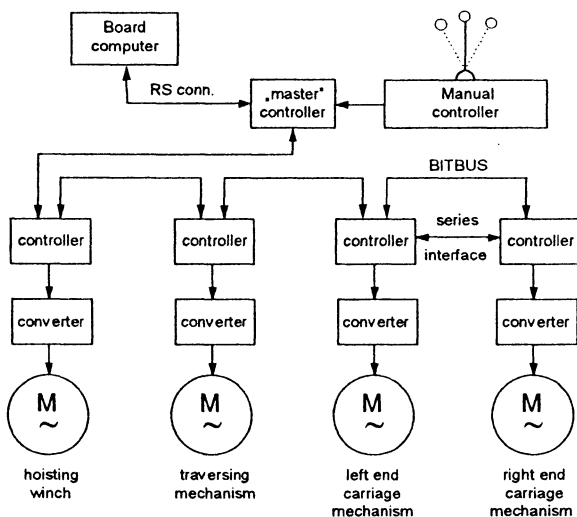


Figure 1. The block scheme of the control system.

3 The Optimization of the Vertical Load Transport

The following criteria have been taken for the optimization of the vertical load transport :

- the minimization of the dynamic loads during the acceleration and deceleration periods,
- the minimization of the hoisting and lowering time.

The following limitations have been taken into consideration:

- the adaptation of the system for the automatic suspension and disconnection of the load,
- the necessity of the measurement of the load mass,
- the necessity of the positioning of the load in its vertical motion.

3.1 The Idea of the Vertical Load Transport

Taking into consideration the criteria and limitations the idea of the duty cycle of the hoisting and lowering of the load and lifting sling has been thought out. It is presented in the fig. 2.

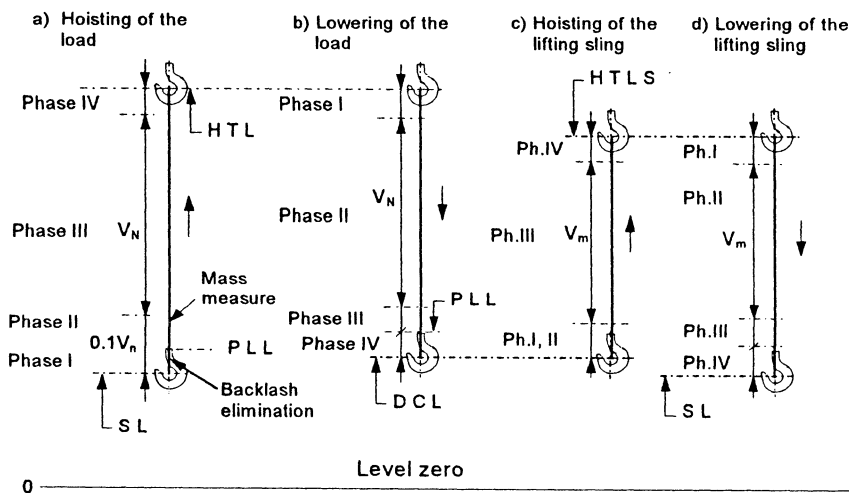


Figure. 2. The idea of the duty cycle of the hoisting and lowering.

The movement of the hoisting of the load (fig. 2a) begins from the level of the suspension of the load - SL. There are four phases of the motion. The time of the phase I can take 3-5 seconds. It depends on the lifting sling and kind of the load. During this phase at the beginning the lifting sling and next the load are hoisted with the low speed about 10% of the nominal hoisting speed value. The backlash elimination and tension of the constraints (ropes) partly take place. In the end of the phase I the load can be stopped on the positioning load level PLL. Almost at ones the II phase is begun. The load is accelerated to the low speed

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and at the end of the phase the load mass is measured. It allows the microprocessor of the controller to calculate the value of the maximum speed of the load for the basic hoisting during the phase III. The initial acceleration to the low speed and the acceleration to the basic speed by strained ropes allow to decrease the dynamic overloads. The hoisting speed is calculated by the constant power principle. This speed is softly reduced before the level of the horizontal transport of the load - HTL. It takes place in IV phase of the hoisting when the load reaches the area of the displacement regulation. It gives the possibility to position the load on the HTL level. The braking of the load is realised by the electric motor. The mechanical brakes are turned on after the stopping of the load. In this way the minimization of the dynamic forces during the braking and the proper accuracy of the load positioning have been achieved. The mechanical brakes discharge the electric motors and the frequency converters from the static load of the mechanism. The HTL level can be chosen automatically or manually.

The lowering of the load (fig. 2b) is realised in three or four phases. During the phase I the load is being lowered with the low speed (about 10% v_{nom}) and the load mass is measured like during the I phase of the hoisting. It is only necessary when the load mass has been changed after the hoisting (f.ex. for foundry cranes). When there is no possibility to change the load mass the system can begin the work with the high speed determined for III phase of the hoisting. Like for the hoisting the lowering speed is softly reduced during III phase before the load is stopped at the level PLL. After positioning the phase IV begins and the ropes are paid out by the small speed and after stopping the motion the disconnection of the lifting sling can be done

After the load positioning operation is finished the hoisting of the lifting sling is realised (fig. 2c) with the same procedure as during the hoisting of the load. The phase of the basic hoisting of the lifting sling is realised with the maximum speed. After the passing of the regulation displacement phase IV the lifting sling is stopped at the chosen level HTLS. To take out the next load the horizontal movement of the lifting sling is realised by the travelling and traversing mechanisms. After the stopping of the overhead crane at the chosen position the lifting sling is being lowered (fig. 2d). The procedure of this movement is similar to the lowering of the load. There are some situations the phase I can be eliminated and the lifting sling is being lowered with the maximum speed. After the passing of the III and IV phases the lifting sling is stopped at the suspension level SL and the system is ready to take out the next load.

Taking into consideration the criterion of the minimisation of the transport time the process of the basic hoisting of the load or lifting sling can be divided into two parts. The hoisting to the level HTL' where the horizontal movement is possible including the fixed obstacles. The hoisting of the load to the level of destination HTL which is being realised during the steady horizontal motion.

It is important to notice that the problem of the automatic connection between the load and the lifting sling should be solved for the automatic transport. Nowadays it is being realised for container gantry cranes. For the semiautomatic

control system the manual operations being done by a service are simplified because the levels of the suspension and disconnection of the load can be programmed. Of course, the manual choosing of these levels by the operator of the crane is possible as well.

3.2 The Control System of the Hoisting Winch

The scheme of the hoisting winch with the control system is shown in the fig. 3.

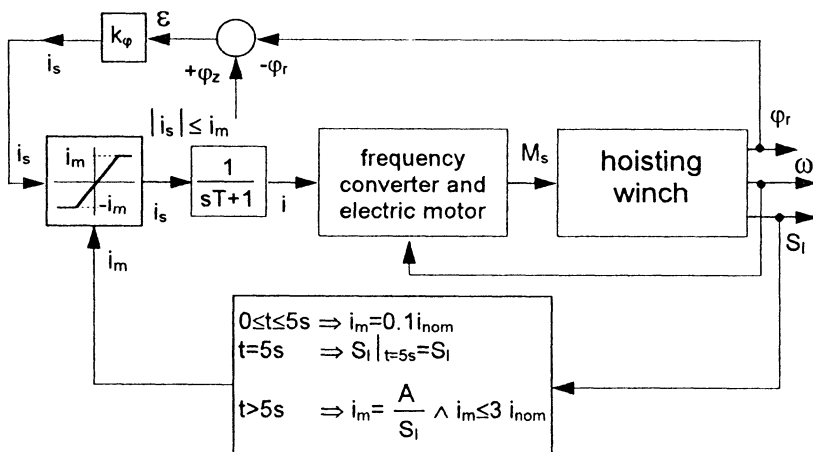


Figure 3. The scheme of the hoisting winch control system.

There are three regulation systems:

- the electric motor angular velocity regulation system,
- the constant power regulation system,
- the position regulation system.

The first one is realised by the frequency converter by using the impulse encoder fixed on the shaft of the electric motor which measures its real angular velocity ω in the feedback.

In the II phase of the motion the mass of the load is measured and the level of the maximum input signal i_m (proportional to the maximum speed of the load) is determined due to the power the mechanism can reach. The constant power regulation system is realised by the microprocessor controller.

The system is equipped with the load position regulation system as well. The absolute encoder connected with the shaft of the drum gives the electric signal of the feedback proportional to its real angular displacement φ_r which is compared to the signal proportional to the given angular displacement φ_z of the drum. The input control signal i_s is proportional to the difference ε between the angle φ_z and φ_r . Its value must not be greater than i_m determined by the power regulation system. The position regulation system is realised by the microprocessor controller.

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The dynamic changes of the input signal are limited by the first order inertial element realised by the microprocessor controller as well. It allows to limit the overloads in the spans of the mechanism in the acceleration and braking phase. The input signal for the system constant in the single duty motion is the given angular displacement φ_z . It can be received as a single value from the board computer.

3.3 The Tests of the Hoisting Winch

The dynamic model of the system has been worked out and described by the mathematical equations in the state space. In the fig. 4 the results of simulation tests of the hoisting winch duty cycle are presented. The runs of the control signals i and i_s , the force in ropes S_1 , the electric motor angular velocity ω and the difference ϵ for the load masses 1650 kg (plots „a”), 1200 kg (plots „b”) and 750 kg (plots „c”) are shown.

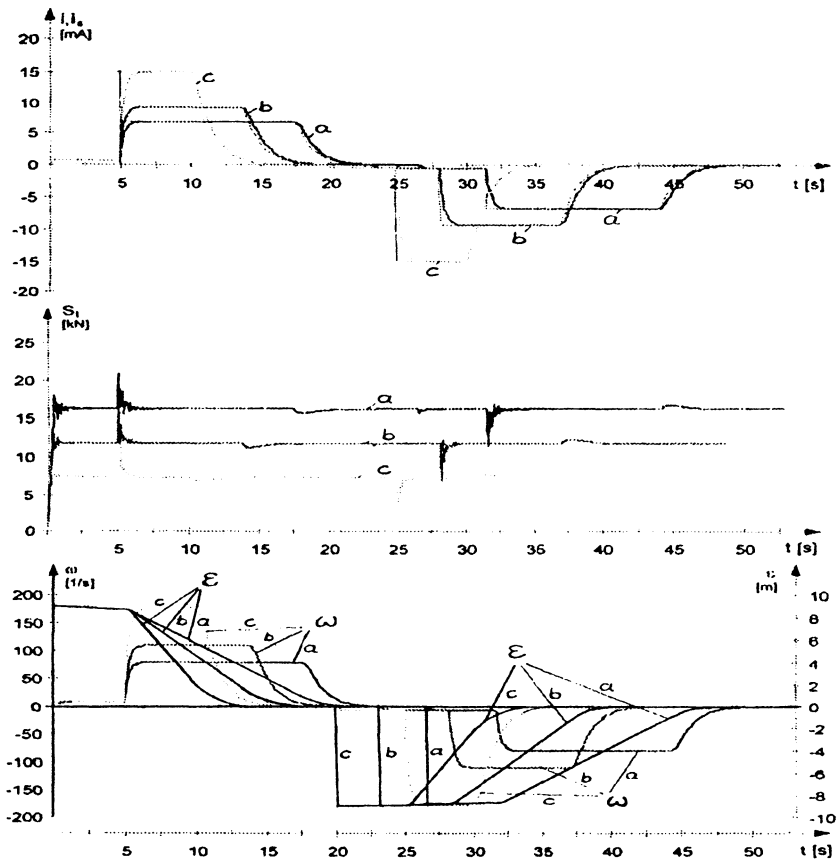


Figure 4. The simulation tests of the hoisting winch.

The experimental and simulation tests confirmed the high quality of the control system. The overloads are limited to 40% for the electric motor torque and to 20% for the force in the ropes. The load positioning accuracy is lower than a few millimetres.

4 The Optimization of the Horizontal Load Transport

The following criteria have been taken for the optimization of the horizontal load transport :

- the minimization of the horizontal transport time by choosing the proper way of the transport,
- the minimization of the dynamic forces and energy consumption by the minimization of the load oscillations after the acceleration and braking phases,
- the minimization of the bevel angle of the bridge and the flange friction of the wheels.

The following limitations have been taken into consideration:

- the digital system of the organisation of the horizontal transport levels,
- the limitation of the transport space by fixed obstacles,
- the limitation of the maximum acceleration and deceleration to avoid the wheels spin,
- the necessity of the load positioning accuracy during its horizontal motion.

4.1 The Idea of the Horizontal Load Transport

For the automatic and semiautomatic transport systems the co-ordinates of the points A, B, C... where the load is delivered or received are determined and introduced into the memory of the transport control system. These co-ordinates can be used by the manual control as well.

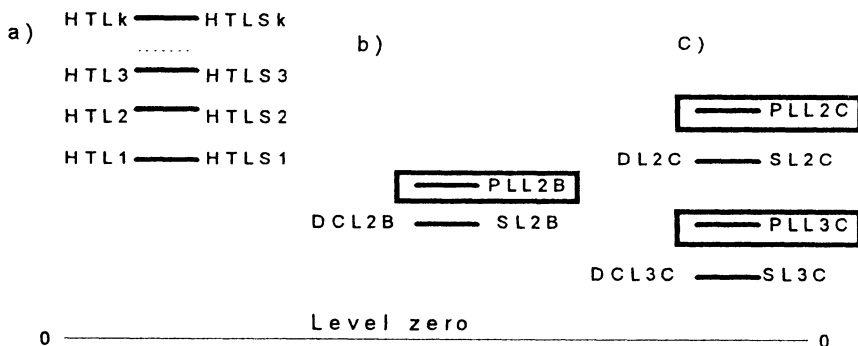


Figure 5. The levels of the load and lifting sling horizontal transport and the levels where the load is delivered or received (positioned) and its suspension and disconnection from the lifting sling.

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There are determined k levels of the horizontal transport of the load HTL and lifting sling HTLS (fig. 5a). The adequate transport level is chosen by the board computer for the determined load using the criterion of minimization of the transport time by the automatic or semiautomatic control system. There is the possibility to choose the appropriate level manually as well.

The determination of the levels of the load positioning, suspension and disconnection is connected with points of the load delivery A, B, C, ... and kinds of the loads 1, 2, 3, ... The combinations of these levels are shown in the fig. 5b,c.

If the initial and final points of the horizontal transport and the kind of the load are determined and introduced to the memory of the control system the board computer will analyse the situation and will choose the optimum way of the transport. By the analyse of the levels and ways of the horizontal load transport the criterion of minimization of the time operation was taken into consideration.

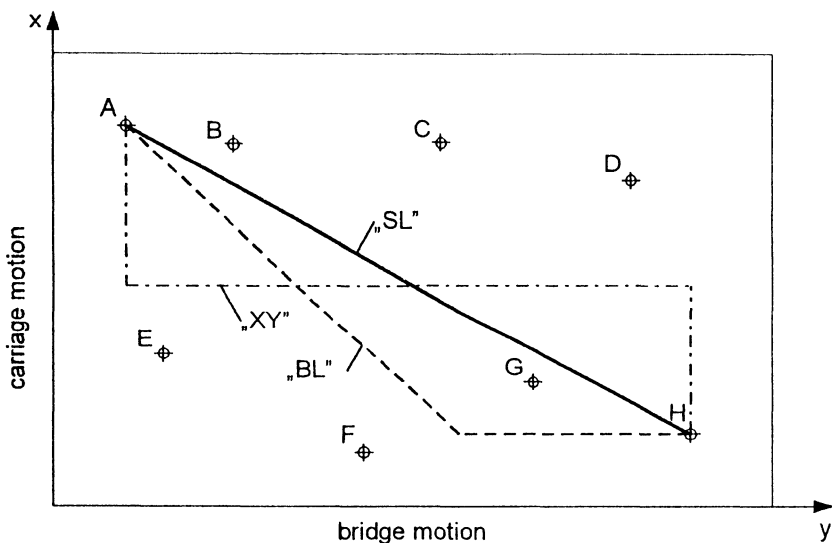


Figure 6. The map of the horizontal transport area.

In the fig. 6 the map of the horizontal transport area with the three possible ways of the horizontal transport „SL”, „BL” and „XY” are shown. The obstacles fixed in the transport space enable to choose one of the ways and levels of the load transport.

4.2 The Control System of the Traversing and Travelling Mechanisms

The control system of the traversing and each of the travelling mechanisms are different than the hoisting winch control system. It is caused that the speed of the carriage and the speed of each end carriage of the bridge must be still controlled to damp the load oscillations after the acceleration and braking

phase. The time run of the input control function U_s (proportional to the given speed of the carriage and end carriages) is worked out by the board computer, sent and stored to the microprocessor controller and delivered in the real time when the mechanism works in the automatic mode.

The scheme of the traversing and travelling mechanism control system is shown in the fig. 7.

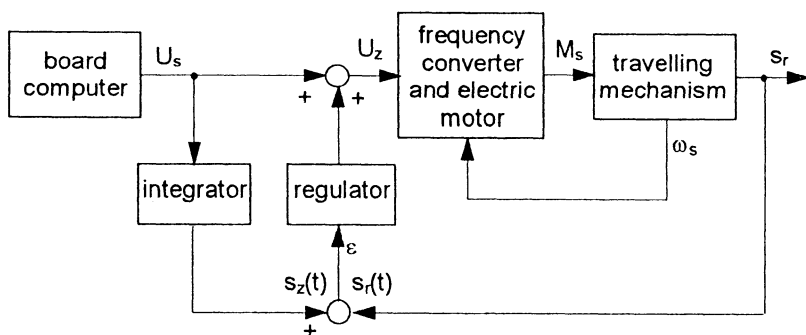


Figure 7. The block scheme of the traversing and travelling mechanism.

The control system contains the continuously working electric motor angular velocity regulator and displacement regulator. The first one is the same as in the hoisting winch. The displacement regulation system compares the real displacement of the carriage and end carriages s_r with their given displacement s_z got by the integration of the input control signal U_s . The difference ε between the displacements s_z and s_r amplified by the proportional regulator corrects the input signal before its sending to the frequency converter.

The worked out input control signal $U_s(t)$ sent to the control system gives the following possibilities:

- the damping of the load oscillations after the acceleration and braking phase achieved by the proper shape of the control function,
- the stopping of the load at the chosen position achieved by the calculated proper area under the time plot of the control function over the duty motion,
- the elimination of the bevel angle of the bridge by sending the same control function to the each end carriage travelling mechanism.

4.3 The Optimum Control Function

To determine the proper shape of the control function $U_s(t)$ during the acceleration and braking phase the optimization method of a gradient projection was used. The internal energy stored in the oscillating load at the end of the acceleration and braking phase was assumed as a optimization criterion.



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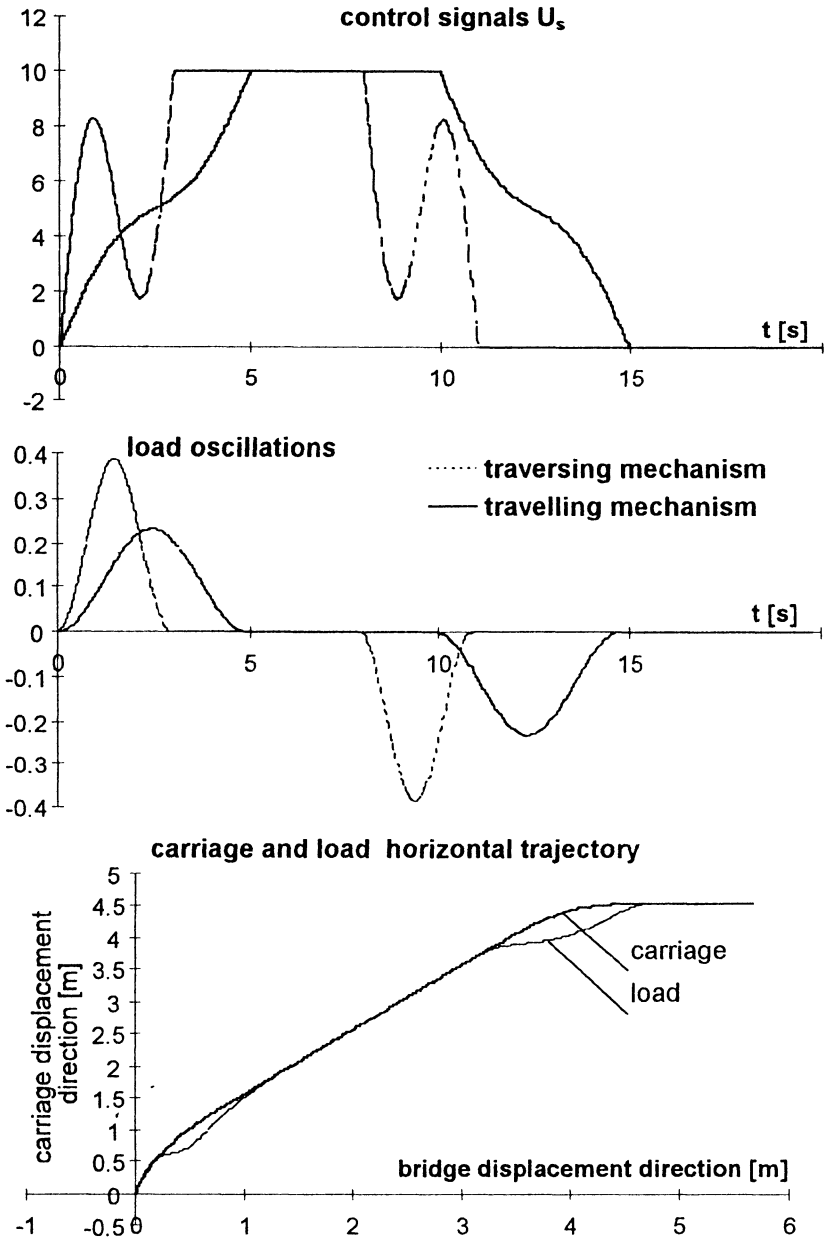


Figure 8. The simulation tests of the traversing and travelling mechanism.

The low value of the energy is in the correspondence with low load oscillations. The following models of the oscillating load were taken into consideration:

- the mathematical pendulum,
- the model with the plane motion of the load.

The space of permissible solutions was introduced due to the requirement that the solution should have a physical sense. It means the control signal U_i has to vary between 0 and U_{smax} and its increasing or decreasing must not be too fast to avoid the spins of the carriage and end carriages wheels.

The control function was transformed to a discrete form as a sequence of the impulses of amplitude U_{si} and duration dt . The optimization criterion was found as a function of them and its gradient was determined. The minimum of the optimization criterion was looked out in the direction opposite to the vector of the gradient. When this operation caused the getting out of the permissible space the gradient vector was projected on its border.

4.4 The Tests of the Traversing and Travelling Mechanisms

The dynamic model of the system was worked out and described by mathematical equations in the state space. The results of the simulation tests for simultaneous work of the traversing and travelling mechanisms are presented in the fig. 8. The runs of the control signals, the load oscillations in the both directions and the trajectory of the carriage and load in the horizontal plane are shown.

The experimental and simulation tests confirmed the high quality of the system. The load does not oscillate after the acceleration phase during the steady motion and after the braking phase. The load positioning accuracy is lower than 1 cm. The bevel angle of the bridge is reduced to zero in the first seconds of the motion.

5 Conclusion

Using the frequency converters and the microprocessor control for the drive systems of the overhead cranes the optimisation of the load transport can be done. By taking into consideration the criteria of the optimization and the limitations the following exploitation problems have been solved for the overhead cranes:

- the minimization of the load oscillations after the acceleration and braking phases,
- the minimization of the transport time by a choice of the proper transport way and by the power regulation in the hoisting winch, the minimization of the dynamic loads over the duty motion of the hoisting winch,
- the minimization of the bevel angle and flange friction of the wheels.

In this way the better transport quality has been reached for the flexibly suspended loads being transported by overhead cranes.



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