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CONTROL SYSTEM, DEVELOPED FOR SUSPENSION OF LOAD STABILIZING PLATFORM IN HOISTING CRANE

Abstract: The given paper offers a parametrically low sensible system of selectively coordinative control over multi channel suspension of hoisting crane's stabilization platform. It belongs to a class of more fast-acting systems of series-parallel action. The synthesis of its selectively switched on regulators is based on the method of Synthesis of nonlinear stabilizations systems with sliding modes in the circuits of dithering location.

Keywords: Control system, stabilizing platform, hoisting crane.

1. INTRODUCTION

Massive urban development makes it necessary to use hoisting cranes with high mobility due to the limited working area of transported loads. That's why it becomes a matter of special interest to stabilize the path of transported load. And particularly important issue is to stabilize the movement of crane's gripper. To solve this task we usually apply a special stabilization platform. Structurally such platform is a steel frame shaped as equilateral triangular, to the bottom of which we usually attach pincers or magnetic pad grippers for transported load. Angles of this frame (corners of triangle A, B and C) are fixed from above to analogous upper frame by six steel cables (two for each corner) (fig. 1). Upper frame in its turn is horizontally fixed to the arm of jib crane, trolley of overhead or turret slewing crane. Herewith two autonomous electro actuators of the suspension of two closest corners in stabilization platform are assembled in each corner of the upper frame D, G and H.

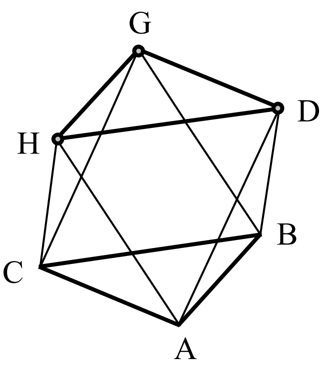

Fig. 1

The most widely spread devices to stabilize different kinds of platforms are systems of automatic control over load position with subordinate regulation of speed and current in direct-current motor, which are powered by thyristor converters [2]. Objects of such systems as a rule are multi channel. Special methods are developed to synthesize the systems of coordinated control over multi channel objects [3, 4]. However, selective control over electro actuators in suspension is necessary to adjust multi channel suspension of stabilization platform in hoisting crane. The matter is that funicular forces change when stabilization platform deviates from the prescribed path. To set the platform back to its basic position it is necessary to stretch out the loaded cables until funicular force in stray cables exceeds a certain threshold value F_0. One of the variants of selective coordination of multi channel suspension in stabilization platform, which is realized according to the principle of subordinate regulation, was offered in [5]. However systems with such regulation principle, i.e. follow systems, demand properly adjusted nonlinear position regulator [2] to achieve the optimal length of monotonous transition process according to controlled output value. However even such regulator can't guarantee the required quality of transient processes, as load and inertia moment of electro actuator in a hoisting crane's suspension are variables because of the changing weight of transported load.

The given paper offers a parametrically low sensible system of coordinative control over multi channel suspension of hoisting crane's stabilization platform. It belongs to a class of more fast-acting systems of series-parallel action. The synthesis of its selectively switched on regulators is based on the method described in [6].

2. MATHEMATICAL DESCRIPTION OF CONTROL OBJECT

Fig. 1 shows, that the system of automatic control contains parametrical feedback. Due to this feedback the system acquires low sensitivity to parametric ditherings in its straight chain. Regulators of speed and cable slackening length are plugged with their outputs into the inputs of selective logical elements min and max. That's why synthesis of these regulators can be realized autonomously from each other.

As control object we assume a direct current motor of autonomous actuation together with thyristor converter and sensors of controlled values. Such control object is described with a system of known equations [2]:

$$\left.\begin{aligned} R(1+\mu_1 p)(1+Tp)u_i &= C_{CS}(I_a u-(1+\mu_1 p)C_E \Phi_0 \omega); \\ J(mg)(1+\mu_2 p)pu_\omega &= C_{SS}C_M \Phi_0 i - C_{SS}M_H; \\ pu_l = C_{lS}K_P\omega; \quad u_F &= C_{fS}F, \end{aligned}\right\} \tag{1}$$

in which R, T – active resistance and response time of motor's anchor chain; C_E, C_M – constant indices; $J(mg)$ – equivalent moment of motor and load inertia, which is the function of transported load mass; I_a, μ_1 – amplification index and equivalent response time of thyristor converter; i, ω – current and motor speed; Φ_0 – magnetic flow, Φ_0 = const; M_H – moment of load resistance; C_{cs}, C_{ss}, C_{ls}, C_{fs} - transfer constants of current, speed, cable slackening length and funicular force sensors; μ_2 – response time of speed sensor filter; u_i, u_ω, u_l, u_F – output signals of the same sensors; u – input signal of thyristor converter.

3. SINTHESIS OF CURRENT REGULATOR

Control object of this regulator is described by the first equation of system (1). The current component, brought about by counteractive EMF $E=C_E\Phi_0\,\omega$ will be assumed as immeasurable perturbation action, while we neglect the fast time constant μ_1 of thyristor converter during structural synthesis. Response time μ_1 will be taken into account in the process of parametric synthesis. In this case the equation of analyzed control object is simplified:

$$(1+Tp)u_i = (C_{CS}/R)I_a u \tag{2}$$

We choose the required equation, which describes the movement of current control loop:

$$(1+\tau_{11}p)u_i = u_{im}$$

Proceeding from this equation, we can find the required laws of variations in output signal of current sensor and its derivative:

$$\dot{u}_i^T = \frac{1}{\tau_{11}}(u_{im}-u_i); \quad u_i^T = \frac{1}{\tau_{11}p}(u_{im}-u_i) \tag{3}$$

If we insert formula (3) into equation (2), we can find the law of variations for control action:

$$u = \frac{R(1+Tp)}{C_{CS}I_a\tau_{11}p}(u_{im}-u_i) \tag{4}$$

in which the value of variable τ_{11} can be calculated through the fast time constant of thyristor converter, proceeding from the conditions of optimization the current control loop according to module [2], i.e.

$$\tau_{11}=2\mu_1. \tag{5}$$

4. SYNTHESIS OF SPEED LIMIT REGULATOR

In the process of optimization the work of current control loop in accordance with the formulae (4) and (5), we can approximate it through relaxation circuit, described by equation [2]:

$$[1+(1+\mu_1 p)\tau_{11} p]i \approx (1+\tau_{11} p)i = C_{CS}^{-1} u_{i3} \qquad (6)$$

On the basis of equations (1) and (6) we can write down an equation for control object of speed regulation circuit:

$$(1+\mu_2 p)(1+\tau_{11} p) p u_\omega = J^{-1}(mg)\left[K C_{SS} C_M \Phi_0 C_{CS}^{-1} u_{i3} - C_{SS}(1+\tau_{11} p) M_H \right]$$

Speed component, brought about by load resistance moment $M_{H,}$ will be assumed as immeasurable perturbation action, and fast time constants μ_1 and τ_{11} are neglected. In this case the equation, which describes the control object of speed regulation circuit is simplified, i.e.

$$p u_\omega = J^{-1}(mg) C_{SS} C_M \Phi_0 C_{CS}^{-1} u_{i3} \qquad (7)$$

We choose the required equation, which describes the movement of speed regulation circuit:

$$(1+\tau_{21} p) u_\omega = u_{\omega m}.$$

Proceeding from this equation, we can find the required law of variations for the derivative of output signal in speed sensor:

$$\dot{u}_\omega^T = \frac{1}{\tau_{21}}(u_{\omega m} - u_\omega) \qquad (8)$$

Inserting this formula into equation (7) we find the required law of variations for current preset signal:

$$u_{i3}^* = \frac{J_0 \hat{\Delta} J(t) K_{ДТ}}{K_{ДС} \tau_{21} C_M \Phi_0}(u_{\omega m} - u_\omega) \qquad (9)$$

in which J_0 is the basic value of inertia moment, and $J\ (mg) \approx J_0 \Delta\hat{J}(t)$.

We introduce parametrically stabilizing feedback [6] into speed regulation circuit to form the multiplicative component $\Delta\hat{J}(t)$ of the equation (9). The feedback contains original computational device (CD), presented by a local tracing system which calculates the reverse amplification constant for section of a straight chain in the synthesized system:

$$\Delta\hat{J}(t) = \frac{1}{\sigma}\int_0^t Sign\left\{\left|\frac{K_{ДС} C_M \Phi_0 \mu_2 p u_{i3}^*}{J_0 K_{ДТ}[1+(1+\mu_1 p)\tau_{11} p](1+\mu_2 p)^3}\right| - \Delta\hat{J}(t)\left|\frac{\mu_2 p^2 u_\omega}{(1+\mu_2 p)^2}\right|\right\} dt + \Delta\hat{J}(0) \qquad (10)$$

in which $\Delta\hat{J}(0) = 1$, $\sigma = 2\tau_{11.}$

The value of variable τ_{11}can be calculated through the response time τ_{11} and μ_1 proceeding from the conditions of optimization the current control loop according to module:

$$\tau_{21} = 2(\tau_{11} + \mu_2) \qquad (11)$$

5. SYNTHESIS OF REGULATOR, WHICH ADJUSTS THE LENGTH OF EASING OUT THE CABLE

Proceeding from formulae (1) and (6) we can write down an equation for control object of the circuit, which regulates the length of easing out the cable, i.e.

$$(1+\tau_{11}p)p^2u_l = J^{-1}(mg)\left\{C_{lS}K_PC_M\Phi_0KC_{CS}^{-1}u_{i3} - C_{lS}K_P(1+\tau_{11}p)M_H\right\} \quad (12)$$

Output signal component, brought about by load resistance moment M_l, will be once more considered immeasurable perturbation action, and we neglect fast time constant τ_{11}. Then the equation, which describes the control object of analyzed regulation circuit is simplified, i.e

$$p^2u_l = J^{-1}(mg)C_{lS}K_PC_M\Phi_0C_{CS}^{-1}u_{i3} \quad (13)$$

We choose the required equation to describe the movement of circuit, which regulates the length of easing out the cable:

$$(1+\tau_{31}p+\tau_{32}p^2)u_l = u_{l3}$$

Proceeding from this equation, we can find the required law of variations for the second derivative of output signal of the regulator, which adjusts the length of easing out the cable:

$$\ddot{u}_l^T = \frac{1}{\tau_{32}}[u_{l3} - (1+\tau_{31}p)u_l] \quad (14)$$

If we insert this formula into the equation (13) we find the required law of variations of current assignment signal, which can be written down in the following way if we take into account its feasibility:

$$u_{i3}^* = \frac{J_0\Delta\hat{J}(t)C_{CS}}{C_{lS}K_P\tau_{32}C_M\Phi_0}\left\{\frac{1}{1+\mu_2p}u_{l3} - \frac{1+\tau_{31}p}{1+\mu_2p}u_l\right\} \quad (15)$$

The same parametrically stabilizing feedback (10) was applied to form the multiplicative component $\Delta\hat{J}(t)$ of law (15), which describes the circuit, that regulates the length of easing out the cable.

We can calculate the values of variables τ_{31} and τ_{32}, if we solve the task and find the conditional extremum of the functional[6]:

$$\left.\begin{aligned} I = \int_0^\infty [u_{l3}(t) - u_l(t)]dt, \quad u_{l3}(t) = 1(t), \quad u_l(0) = 0 \\ |A(j\omega)| \geq 1, \quad 0 \leq \omega \leq \infty, \end{aligned}\right\} \quad (16)$$

where A(*jw*) is Michaelmas frequency function of the circuit, which regulates the length of easing out the cable in accordance with time response τ_{11}.

If we solve task (16) as a result we get [6]:

$$\tau_{31} = 4\tau_{11}; \quad \tau_{32} = 8\tau_{11}^2. \quad (17)$$

Regulators, which adjust speed and length of easing out the cable operate selectively. That's why in required laws of variations (9) and (15) we single out common cofactor from the selective logical element min (max), i.e.

$$u_{i3}^{*} = \frac{J_0 \Delta \hat{J}(t) K_{ДТ}}{C_M \Phi_0} \min\left\{ \frac{(u_{\omega m} - u_{\omega})}{K_{ДС}\tau_{21}},\ \frac{1}{K_{ДД} K_P \tau_{32}} \left(\frac{u_{im}}{1 + \mu_2 p} - \frac{(1 + \tau_{31} p) u_i}{1 + \mu_2 p} \right) \right\}$$

in which $\Delta\hat{J}(t)$ is described by formula (10).

6. SYNTHESIS OF LOAD LIFTING HEIGHT REGULATOR

This device is a regulator of averaged movement during load lifting/dropping. As a regulated variable we assume the minimal current height of all the three angles of stabilization platform.
While adjusting the circuits, which regulate the length of easing out the cables, in accordance with equations (15) and (17), the regulator can be approximated through the relaxation circuit, described by equation: $(1 + \tau_{31} p) u_l = u_{l3}$.
The control object of the circuit, which regulates the height of load lifting, is also described by analogous equation, i.e.

$$(1 + \tau_{31} p)(u_z - u_h) = u_{l3} \qquad (18)$$

, in which $u_h = u_z - u_l$.

It is reasonable to present the required equation, which describes the movement of this regulation circuit, in the following form: $(1 + \tau_{41} p)(u_{h3} - u_h) = 0$
Proceeding from this equation we can find the required law of variations for the output signal of the analyzed regulation circuit:

$$u_h^T = \frac{1}{\tau_{41} p}[(1 + \tau_{41} p) u_{h3} - u_h] \qquad (19)$$

If we insert this formula into equation (18) and neglect fast time constant τ_{31}, we find the required law of variations for assignment signal of circuits, which regulate the length of easing out the cable:

$$u_{l3}^{*} = \frac{1}{\tau_{41} p}(u_z - u_l - u_{h3}) - u_{h3} + u_z \qquad (20)$$

Proceeding from conditions of optimization the current control loop according to module, we can calculate the value of variable τ_{41} through response time τ_{31}:

$$\tau_{41} = 2\tau_{31} \qquad (21)$$

7. SYNTHESIS OF WORK ALGORITHM FOR COODINATIVE SIGNALS GENERATOR

The components Δu_{li} $(i=1, 2, \ldots, 6)$ of coordinative signals vector Δu_l are calculated through logical processing the output signals of funicular force sensors u_{Fi}, i.e.

$$\Delta u_l = \begin{cases} \alpha\,[1-1(t-t_1)]\,e^{(t_1-t)/\tau}\int\limits_0^{t_1} t\,dt, \ \ \textit{если} \ \ c_i(t)=\begin{cases}1 \ \ \textit{при} \ \ 0\le t\le t_1;\\ 0 \ \ \textit{при} \ \ t>t_1;\end{cases} \\ 0, \ \ \ \textit{если} \ \ c_i(t)=0, \ \ \ (i=\overline{1,\ 6}), \end{cases}$$

in wich

$$c_i(t)=\begin{cases} y_2y_4y_6+\begin{cases} y_5(y_2+y_6)+\begin{cases} y_3(y_4+y_6) \ \textit{при} \ i=1;\\ y_1(y_2+y_4) \ \textit{при} \ i=3;\end{cases}\\ y_3(y_4+y_6)+y_1(y_2+y_4) \ \ \textit{при} \ \ i=5;\end{cases}\\ y_1y_3y_5+\begin{cases} y_6(y_3+y_5)+\begin{cases} y_4(y_1+y_3) \ \textit{при} \ i=2;\\ y_2(y_1+y_5) \ \textit{при} \ i=4;\end{cases}\\ y_4(y_1+y_3)+y_2(y_1+y_5) \ \ \textit{при} \ \ i=6,\end{cases}\end{cases}$$

$y_i(t)=\begin{cases}1 \ \ \textit{при} \ \ u_{Fi}\le u_{F0}\\ 0 \ \ \textit{при} \ \ u_{Fi}>u_{F0}\end{cases}$ $(i=\overline{1,\ 6})$, α – the maximum allowable acceleration of load lifting/lowering according to exploitation conditions; y_iy_j are connected through the operation of logical multiplication, $y_iy_j = y_i \wedge y_j$ and y_i+y_j connected through the operation of logical addition,

$$y_i + y_j = y_i \vee y_j$$

8. CONCLUSIONS

A parametrically low sensible system of selectively coordinative control over multi channel suspension of hoisting crane's stabilization platform guarantees the required quality of transient processes although the load and inertia moment of electro actuator in a hoisting crane's suspension are variable because of the changing weight of transported load.

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