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Choice of Correcting Link for Electrohydraulic Servo Drive of Technological Equipment

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Abstract. The issue of choosing a correcting link for improving the quality of regulation of electrohydraulic servo drive of technological equipment is considered. The analysis of the methods for correcting the dynamic characteristics of the electrohydraulic servo drives with throttle regulation is performed. For drives built on the basis of standard modules, it is shown the expediency of the serial installation in the circuit of the electrohydraulic amplifier of the correcting link—the real proportional-differentiating controller. The parameters of adjustment of the correcting link are considered to be the time constant and the transfer coefficient of the regulator are considered, as well as the time constant characterizing the inertia of the link. To select the optimal values for the adjustment parameters of the correcting link of the electrohydraulic servo drive of technological equipment, it is recommended to conduct studies in the Simulink environment of the MATLAB application package. Here is provided an example of investigation of the influence of the adjustment parameters of the correcting link on the dynamic characteristics of the electrohydraulic servo drive with throttle regulation. A block diagram for simulation of transient processes in the Simulink environment is presented. The features of the choice of the recommended values of the adjustment parameters of the correcting link of the electrohydraulic servo drives of the technological equipment for the mechanical processing of materials are noted. The transfer function of the electrohydraulic servo drive with the correcting link is obtained.

Keywords: Dynamic characteristics · Throttle regulation · Structural scheme · Transfer functions · Block diagram · Transient process · Adjustment parameters

1 Introduction

Modern technological equipment, in particular, equipment for mechanical processing of materials, makes high demands on the quality indicators for the regulation of automatic drives, namely, their system performance and the nature of the transient process [1–6].

The desire to achieve high accuracy by increasing the gain of the open loop of the drive (i.e., its quality factor) gives rise to unacceptable oscillation of the drive in the transient process. In this regard, there is a need to change the parameters or structure of the drive. In order to provide the required margin of stability, it is possible to evaluate

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the possibility of changing the structure of the elements and devices of the drive-in order to reduce the time constants of the corresponding dynamic links.

Essential alteration of the drive units is not always possible, and sometimes it does not give the desired result (if the inertia load on the drive is large, and the frictional forces in the actuator are negligible). Therefore, the way out of the predicament is found by using additional correcting devices [7–11].

2 Literature Review

The design of the correcting devices is different, and together they can be divided into two large groups: hydromechanical and electrical [12, 13]. It is clear that for including such elements in the structure of the system it is necessary that it has connections with physical quantities corresponding to them in nature.

For the electrohydraulic servo drive (EHSD) with throttle regulation [14], the following hydromechanical correction methods [12, 15–17] can be used:

1. Introduction of fluid leakage between the cavities of the hydraulic cylinder.
2. Providing additional feedback by using the elasticity of the hydraulic cylinder support.
3. Connecting the damper to the spool of the electrohydraulic amplifier.
4. Inclusion of additional feedbacks that generate signals from derivatives of pressure in the cavities of the hydraulic cylinder or by derivatives from the displacement of its stock.

When correcting the EHSD with throttle regulation by electrical and electronic devices [12, 18–20], various auxiliary circuits should be used, which are composed of elements with capacitance, inductance and active resistance. Connections from such elements allow obtaining dynamic links with characteristics that are close to the characteristics of the first and second-order forcing links, or real differentiating links [21, 22]. Electrical and electronic correcting devices can be connected in series to the control circuit of the electromechanical transducer of the electrohydraulic amplifier and can also be used to organize additional feedback circuits in the main drive circuit that generate signals from the time derivatives of single variables.

The purpose of this work is to justify the choice of the most effective standard correction link for the EHSD of technological equipment, as well as the development of a technique for selecting the optimum adjustment parameters of the correcting link.

3 Research Methodology

To carry out further research, we use the EHSD scheme presented in the authors' paper [14] and shown in Fig. 1.

The settlement scheme indicates: HC—hydraulic cylinders; EHA—electrohydraulic amplifier, including electromechanical transducer (EMT) and the hydraulic amplifier (HA); the FB—feedback gauge, EB—electronic block. The following main

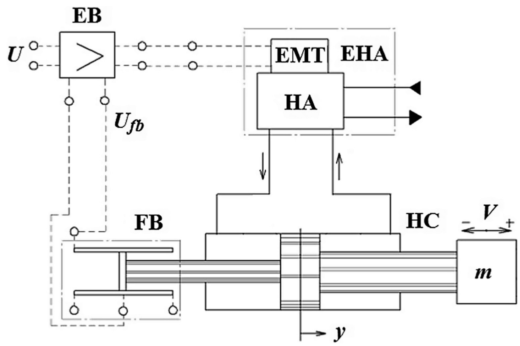

Fig. 1. The settlement scheme of the EHSD.

variables of the EHSD are marked on the scheme: U—input (control) voltage; U_{fb}—FB voltage; y, V—displacement and speed of the piston.

For deviations of variables, the authors obtained [14] a linear mathematical model, according to which the transmission of the control signal can be represented by the structural scheme shown in Fig. 2.

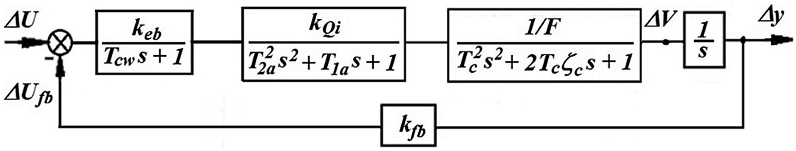

Fig. 2. The structural scheme of the control signal transfer.

The following drive parameters are indicated in the structural scheme: k_{eb}—transfer coefficient of EB; T_{cw}—time constant of control winding; k_{Qi}—EHA gain coefficient by flow rate; T_{2a}, T_{1a}—time constants of EHA; F—effective area of HC; T_c—hydromechanical time constant of HC; ζ_c—coefficient of relative damping of HC; k_{fb}—transfer coefficient of FB.

The method for estimating the parameters of the EHSD is described in detail in [4, 12, 14, 23, 24].

Let's consider the above methods of the EHSD correction.

With regard to the introduction of a leakage between the cavities of the hydraulic cylinder, here is necessary to note the following. It is known that with increasing leakage in the hydraulic motor, the oscillation of the servo drive decreases. At the same time, constant increased leakage reduces the following accuracy in the steady-state operating mode of the servo drive. Therefore, in the EHSD with throttling regulation, a correcting device operating on the principle of dynamic fluid leakages should be used. It creates fluid leaks during the transient process and stops them in the steady-state of operation.

Also note the feature of including additional feedbacks. Since one of the main tasks in choosing a correcting device is to reduce the oscillation, that is, to increase the stability margin of the EHSD while maintaining an acceptable speed following error, then additional feedback should not react to the steady-state drive speed. Its negative signal must be proportional to the second derivative of the displacement of the output link, i.e. its acceleration. Only in this the drive oscillation case can decrease.

Correction methods based on the use of electrical and electronic devices are simple enough to implement. They are especially useful in cases where it is necessary to correct the characteristics of the manufactured drive or drive assembled from the finished modules. Such devices can be installed both in the forward path of the control loop and in the main feedback FB. However, electrical and electronic devices do not always provide the required reliability of the drive, and, in addition, they can cause interference that distorts the control signals generated in the drive circuit. The noted shortcomings of electrical and electronic correcting devices are less evident when using hydromechanical correcting devices. But since hydromechanical correcting devices are usually organically associated with the design of the electrohydraulic amplifier EHA or hydraulic cylinder HC, therefore their application should be provided in advance when creating the drive.

Proceeding from the foregoing, it is convenient to use electric and electronic correcting devices to correct the dynamic properties of the EHSD with throttle regulation of technological equipment for mechanical processing of materials. As a correcting link, it is recommended to install the proportional differential controller in the circuit of the electromechanical transducer EMT of the electrohydraulic amplifier EHA. The transfer function of an ideal proportional-differential controller is calculated as

$$W_c^*(s) = Ts + k, \tag{1}$$

where

T Time constant of the correcting link;

k Transfer coefficient of the correcting link.

Since it is impossible to realize an ideal proportional-differentiating link, for the real correcting link we will consider the following transfer function

$$W_c = \frac{Ts + k}{T_{in}s + 1}, \tag{2}$$

where

T_{in} Time constant characterizing the inertia of the correcting link.

The installation of the correcting link in the EHSD with throttle regulation is represented in the structural scheme shown in Fig. 3.

It is convenient to investigate the dynamic characteristics of the EHSD when selecting the optimum values for the adjustment parameters of the correcting link in the MATLAB software package, using the structural scheme of the drive in the Simulink

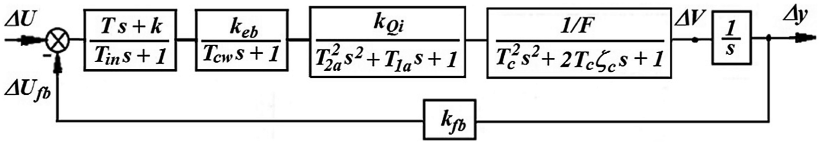

Fig. 3. The installation of the correcting link in the EHSD.

environment [25–27]. A block diagram for modeling the dynamic characteristics of the EHSD under consideration with a correcting link in the Simulink environment is shown in Fig. 4.

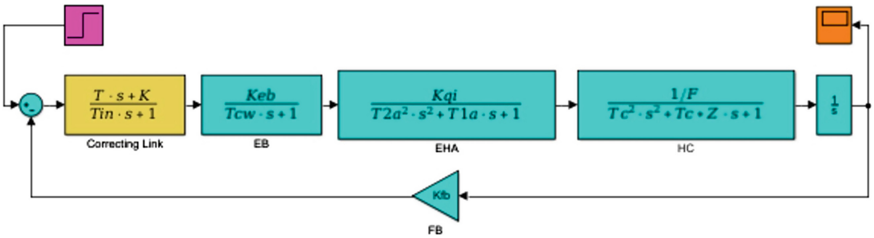

Fig. 4. Block diagram for modeling the dynamic characteristics of the EHSD with the correcting link in the Simulink environment of the MATLAB package.

It's necessary to note that the accepted designations of the parameters of the linear model of the EHSD on the block diagram in accordance with the capabilities of the built-in editor MATLAB practically coincide with those adopted earlier and do not require additional comments. The simulation results show that the inertia of the correcting link has no effect provided that the time constant characterizing its inertia is much less (by more than an order of magnitude) than the minimum time constant of the EHSD links

$$T_{in} \ll T_{\min}. \tag{3}$$

The modern element base of electrical and electronic correcting devices [28–30] allows realizing the condition (3) for the drives of technological equipment. In cases where condition (3) is not feasible, the inertia of the correcting link not only significantly affects the duration of the transient process, but also changes its character.

4 Results

We will give an example of the investigation of the influence of the adjustment parameters of the correcting link on the dynamic characteristics of the EHSD with throttle regulation for the drive parameters considered in [14]: T_{cw} = 0.01 s;

T_{2a} = 1.27×10^{-3} s; T_{1a} = 1.17 × 10^{-3} s; T_c = 2.62 × 10^{-3} s; ζ_c = 0.25; k_{eb} = 1754 Ω^{-1}; k_{Qi} = 5.16 × 10^{-4} m^3/(s A); F = 9.15 × 10^{-3} m^2; k_{fb} = 108 V/m. Transient processes are considered at a jump of the control voltage ΔU = 27 V, which corresponds to the steady displacement of the piston by Δy = 0.25 m.

In Fig. 5 shows the influence of the transfer coefficient k of the correcting link on the transient process with the time constant T = 0. As can be seen, an increase in the value of k leads to an increase in the oscillation of the system. The nature of the influence on the transient process of the time constant T of the correcting link at the value of the transfer coefficient k = 6 is shown in Fig. 6. The quantity T also appreciably determines the type of the transient process.

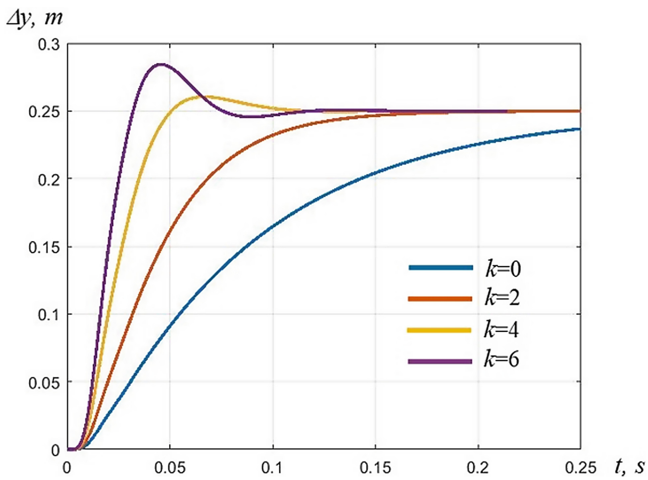

Fig. 5. The influence on the transient process of the transfer coefficient k of the correcting link at the value of the time constant T = 0.

The results of the simulation convincingly show that the proportional-differential controller allows effectively correcting the dynamic characteristics of the EHSD with throttle regulation, in particular the nature of the transient process and its duration. Thus, for the example considered, the change in the value of the time constant T in the range 0.01 … 0.6 s and the transfer coefficient k in the range 1 … 6 makes it possible to achieve an aperiodic, monotonic and oscillatory character of the transient process, and also significantly improve the drive response time. For example, with k = 6 and T = 0.04 s, the servo drive response speed increases by 7 times.

Also, it is important to note the following. When choosing the optimal adjustment parameters of the correcting link, it is necessary to take into account that in a number of cases the features of the technological designation of the equipment exclude the overshoot of the displacement of the working element or the change in the sign of its speed [4, 12, 13], in particular, in equipment for machining materials. Therefore, the

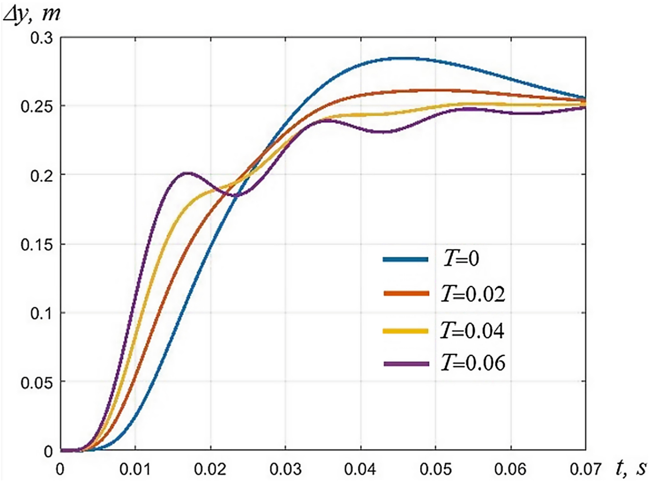

Fig. 6. The influence on the transient process of the time constant *T* of the correcting link at the value of the transfer coefficient $k = 6$.

recommended values of the adjustment parameters of the correcting link may not provide the optimal response time of the EHSD but should be determined by a complex quality control criterion.

A complex analysis of the dynamic characteristics of the EHSD technological equipment with a correcting link can be carried out according to the transfer function, which, according to Fig. 3 assuming $T_{in} \approx 0$ in correspondence with condition (3) is given by

$$W(s) = \frac{\Delta y(s)}{\Delta U(s)} = \frac{k_{yu}(Ts + k)}{a_6 s^6 + a_5 s^5 + a_4 s^4 + a_3 s^3 + a_2 s^2 + a_1 s + a_0}, \quad (4)$$

where

$$k_{yu} = 1/k_{fb}; \quad a_0 = k; \quad a_1 = T + \frac{1}{D_{EHSD}}; \quad D_{EHSD} = k_{eb} k_{Qi} k_{fb}/F;$$
$$a_2 = \frac{T_{cw} + T_{1a} + 2T_c\zeta_c}{D_{EHSD}}; \quad a_3 = \frac{T_{cw}T_{1a} + 2T_c\zeta_c T_{cw} + T_{2a}^2 + 2T_c\zeta_c T_{1a} + T_c^2}{D_{EHSD}};$$
$$a_4 = \frac{T_{2a}^2 T_{cw} + 2T_c\zeta_c T_{cw} T_{1a} + T_c^2 T_{cw} + 2T_c\zeta_c T_{2a}^2 + T_{1a} T_c^2}{D_{EHSD}}; \qquad \bar{x}, \bar{w}$$
$$a_5 = \frac{2T_{2a}^2 T_c \zeta_c T_{cw} + T_c^2 T_{cw} T_{1a} + T_{2a}^2 T_c^2}{D_{EHSD}}; \quad a_6 = \frac{T_{2a}^2 T_c^2 T_{cw}}{D_{EHSD}}.$$

In these expressions, k_{yu}—transfer coefficient of the EHSD by the control signal; D_{EHSD}—drive quality factor (open-loop gain).

5 Conclusions

Thus, the issue of choosing a correcting link for improving the quality for EHSD of technological equipment is considered. The analysis of the methods for correcting the dynamic characteristics of the EHSD with throttle regulation is performed. The expediency of the serial installation in the circuit of the electrohydraulic amplifier of the correcting link—the real proportional-differentiating controller is shown for drives built on the basis of standard modules. The parameters of adjustment of the correcting link are considered to be the time constant and the transfer coefficient of the regulator, as well as the time constant characterizing the inertia of the link.

To select the optimal values for the adjustment parameters of the correcting unit of the EHSD of technological equipment, it is recommended to conduct studies in the Simulink environment of the MATLAB application package.

Here is provided an example of investigation of the influence of the adjustment parameters of the correcting link on the dynamic characteristics of the EHSP with throttle regulation is. The possibility of achieving the required quality of the transition process, as well as a significant increase of the servo drive response speed is shown. A block diagram for simulation of transients in the Simulink environment is presented. The features of the choice of the recommended values of the adjustment parameters of the correcting link of the EHSD of the technological equipment for the mechanical processing of materials are noted.

The transfer function of the EHSD with a correcting link is obtained.

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