Mathematical modeling and analysis of the electrohydraulic actuator with the throttle control

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Mathematical modeling and analysis of the electrohydraulic actuator with the throttle control

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Annotation
High demands to modern electrohydraulic actuators are placed. This applies to the static and dynamic characteristics of the drives, which is achieved by using different correcting devices (controllers). In the article analysis of the most effective regulator for an electro-hydraulic actuator is conducted during the comparison of its dynamic characteristics at introduction of various types of correcting devices: the introduction of state controller, the introduction of additional pressure feedback and a proportional controller. Block diagrams of the electrohydraulic actuator are constructed according to the corresponding mathematical models. The optimization of the control parameters was carried out to improve the static characteristics of the actuator.

Introduction.

High demands to modern electrohydraulic actuators are placed. This applies to the static and dynamic characteristics of the drives, which is achieved by using different correcting devices (controllers). In this case, the design parameters of the hydraulic drive are determined on the basis of energy, power and static characteristics [1]-[3]. To reduce the influence of external and parametric disturbances on the hydraulic drive, as well as to improve its dynamic performance, it is necessary to increase the quality factor of the electro-hydraulic actuator by increasing the gain of the proportional controller (P-controller) in a forward-path. The hydraulic drive is characterized by relatively low natural damping, and an increase in the quality factor in the presence on the hydraulic cylinder rod large inertial loads reduces the stability and dynamic quality of the drive [4]-[7]. One of the controllers that can solve this problem is the state controller, the principle of which is the introduction of additional state variable feedback.

Feedbacks on the drive state coordinates are entered into the control loop. The transmission coefficients of these feedbacks are adjusted so as to be able to achieve the required properties, dynamic and static characteristics of the electro-hydraulic actuator [8]-[12]. It should be noted that it is advisable to use state controllers only in hydraulic actuators with electrohydraulic amplifier, the natural frequencies of which are at least one and a half times higher than the natural frequency of a loaded hydraulic motor [13]-[16].

Negative speed feedback increases the natural frequency and reduces the relative damping of the hydraulic cylinder. The introduction of feedback on the speed and acceleration of the output link of the electro-hydraulic drive allows to set the parameters allows to set the parameters of the natural

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frequency and damping of the hydraulic motor independently of each other; therefore, it provides any speed-of-response behavior of the system with any gain in a forward-path [17]-[19].

In the articleanalysis of the most effective regulator for an electro-hydraulic actuator is conducted during the comparison of its dynamic characteristics at introduction of various types of correcting devices: the introduction of state controller, the introduction of additional pressure feedback and a proportional controller.

Mathematical model of electrohydraulic actuator.

Linear mathematical models can only be used for preliminary evaluation of the dynamic characteristics of real systems. In reality, there are nonlinearities that ambiguously affect the operation of the actuator. In particular, it is necessary to take into account the nonlinearity of the pressure loss/flow characteristics of the hydraulic amplifier:

$$Q_З = k'_з \cdot x_з \cdot \sqrt{\left| p_{пит} - p_{н} \cdot sign\left(x_з\right) \right|}\ , \tag{1}$$

where $k'_з = \mu_з \cdot \pi \cdot d_з \cdot k_{П} \cdot \sqrt{\dfrac{2}{\rho}}$,

$p_{н} = p_1 - p_2$ – the pressure difference in the hydraulic cylinder cavities;

$Q_З$ – flow through spool; $x_з$ – displacement of servovalve spool; $d_з$ – spool diameter.

Equation of motion of a loaded hydraulic cylinder:

$$m \cdot \frac{d^2}{dt^2} y + k_{тр} \cdot \frac{d}{dt} y = F_{ц} \cdot \left(p_1 - p_2\right) - P_{н}, \tag{2}$$

where y – displacement of hydraulic cylinder rod; $k_{тр}$ – friction coefficient; $F_{ц}$ – hydraulic cylinder piston area.

The pressure difference in the hydraulic cylinder cavities is found from the equation (2), which takes into account dependences on the force of viscous friction and external loading:

$$p_{н} = \frac{P_{н}}{F_{ц}} + \frac{m}{F_{ц}} \cdot \frac{d^2}{dt^2} y + \frac{k_{тр}}{F_{ц}} \cdot \frac{d}{dt} y. \tag{3}$$

To improve the static characteristics of the actuator (increase the static stiffness of the actuator), as well as to obtain a transient with the least oscillation, the optimization of the control parametersbased on the ITAE functionality (integral time of absolute error)was carried out. The basis of this functional is the integral of the product of the transient time t by the absolute run time error:

$$I = \int_0^{\infty} t \cdot \left| y_{зад} - y \right| dt,$$

where $y_{зад}$ – set position of a rod of a hydraulic cylinder.

The results of mathematical modeling.

According to the standard mathematical model of a linear system, a block diagram of an electro-hydraulic actuator was made in the program “ПКМВТУ” [20] with additional feedback on state variables (Fig. 1).

The optimization of the control parameters was carried out.The transient graphs on the position of the hydraulic cylinder rod was obtained (Fig. 2).

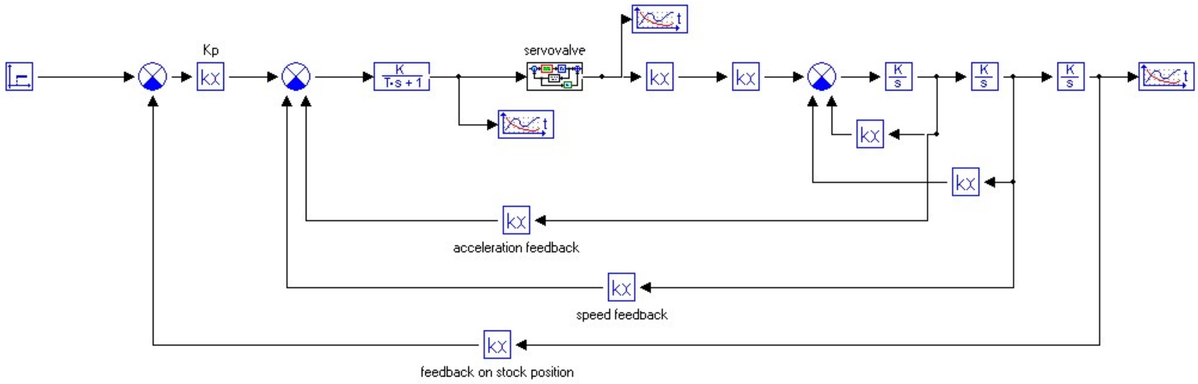

Fig. 1. Block diagram of an electro-hydraulic actuator with a state controller.

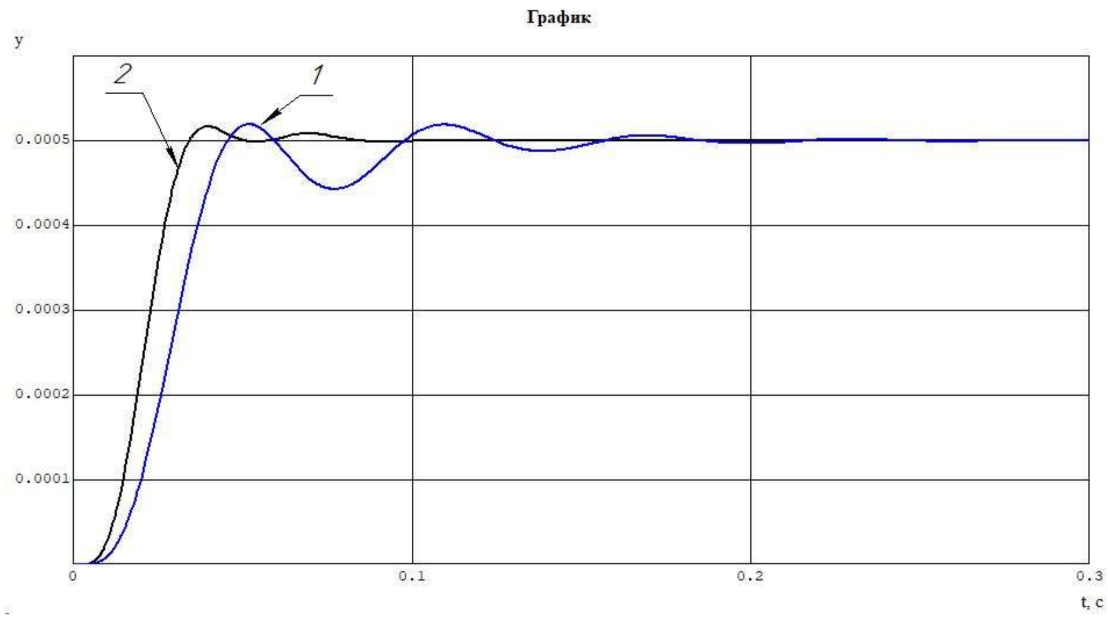

Fig. 2. Transient graphs of the electrohydraulic actuator.
1 – with a proportional controller; 2 – with state controller.

Indicators of the quality of transient processes are presented in table 1:
σ – run time error, %
$t_{п/п}$ – transition time, c

Table 1.

Correcting device	σ, %	$t_{п/п}$, c
proportional controller	4.12	0.115
state controller	3.35	0.042

According to the developed mathematical model, taking into account the non-linearity of the pressure loss/flow characteristic, a block diagram of the electrohydraulic drive was constructed, according to which, by optimization, the coefficients of the regulators were refined and the transients were calculated. Transient graphs with the introduction of different types of controllers (Fig. 3):

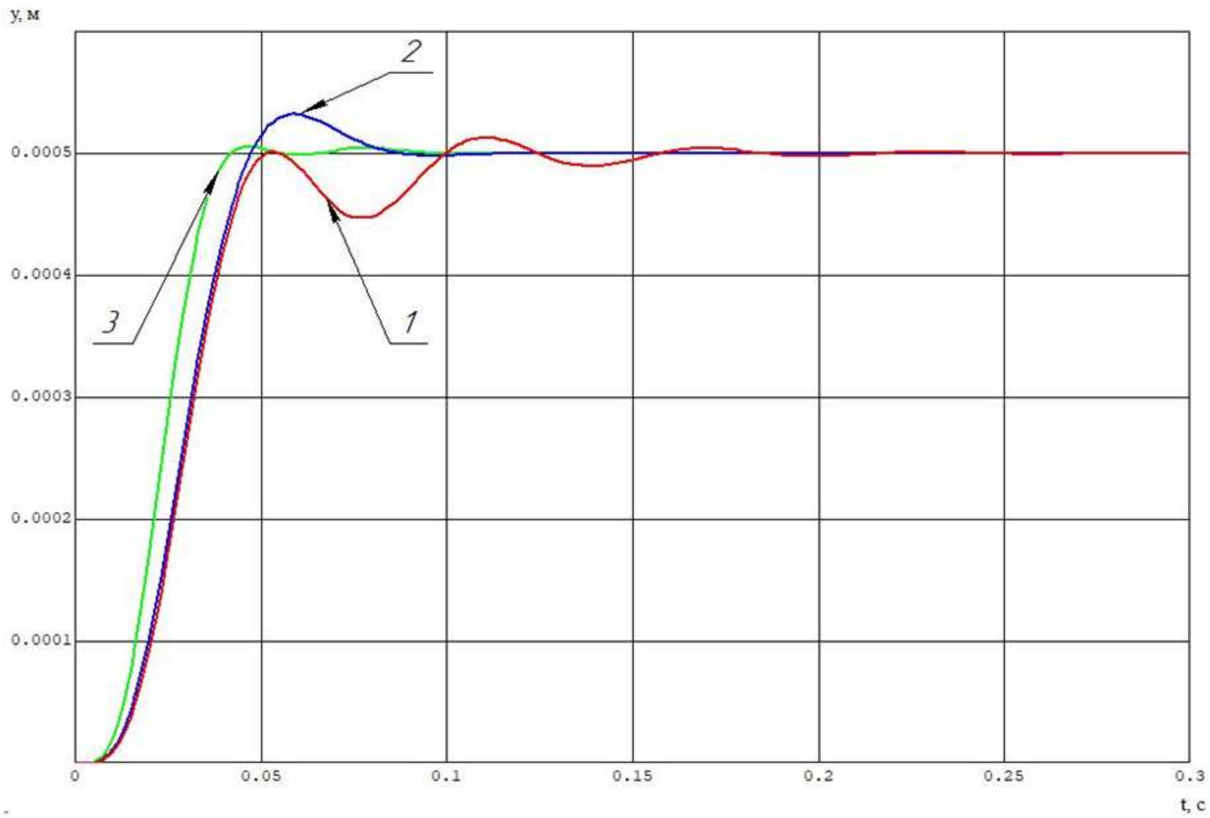

Fig. 3. Transient graphs of the electrohydraulic actuator with the introduction of different types of controllers.1 – with a proportional controller;2 – with additional pressure difference feedback; 3 – with state controller.

The results are presented in table 2:
k_p – control factor in a forward-path (proportional controller).

Table 2.

Correcting device	σ, %	$t_{п/п}$, c	k_p
proportional controller	2.46	0.094	1.3375
additional pressure difference feedback	6.39	0.072	1.6
state controller	1.05	0.038	3.0364

With the help of the ITAE functional, the most optimal values of feedback coefficients were found: for differential pressure - 2 * 10-8; for speed - 6.671 and for acceleration - 0.073.

Conclusion.
The dynamic characteristics of an electro-hydraulic actuator with three types of correcting devices are obtained: with a conventional proportional controller in a forward-path; with additional pressure difference feedback in the cavities of the hydraulic drive; with additional feedback on speed and acceleration (state controller).

The introduction of additional pressure difference feedback led to a significant reduction in transition time, to an increase in the stability of the system and to an increase in the quality factor, however the run time error also increased.

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The best controller for our actuator turned out to be a state controller. With the introduction of additional feedbacks on state variables, the best dynamic characteristics of the actuator were obtained: the transition time was significantly reduced, and the run time error became significantly less, the quality and stability of the system were increased. Using ITAE functionality for optimizing control parameters of an electrohydraulic actuator leads to an improvement in the dynamic and static characteristics, including by increasing the control factor in a forward-path.

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