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RESEARCH ON THE INFLUENCE OF THE SPOOL WORKING EDGE SLOPE ON THE NONLINEARITIES OF THE PROPORTIONAL DIRECTIONAL CONTROL VALVE WITH ELECTROHYDRAULIC CONTROLLING

There had been developed the mathematical model and conducted researches on the characteristics of the proportional directional control valve with electrohydraulic controlling, namely, the dependence of the main spool position on the servo spool displacement, pressure drop across the main spool edge and on the slope angle of the main spool working edge.

As a result, the essential nonlinearities of the control system have been exposed both in static and dynamic operation modes.

These nonlinearities can be reduced by means of selecting appropriate values for the slope angle of the main spool working edge.

Keywords: *directional control valve, electrohydraulic controlling, mathematical model, non-linearity.*

Hydraulic drives with proportional electrohydraulic control are widely used in various mobile machines and automatic processing lines where it is necessary to provide precise positioning of actuators and operating mechanisms. Usage of hydraulic drives, controlled by the signal of programmable controllers with corresponding software, enables to increase considerably the productivity, to improve the performance quality of operations and to reduce unproductive power losses [1, 2, 3].

Directional control valves with electrohydraulic controlling system make the heart of such hydraulic drives. In the systems of such type the main spool displacement is caused by fluid flows, directed by servo spool.

Among the main characteristics of the control system are the dependences of the main spool position on the spool servovalve displacement and time [4].

The aim of this paper is to research the nonlinearities of the electrohydraulic directional control valve, that is, the dependences of the main spool position on the servo spool displacement, pressure drop ΔP across the main spool working edge and on the system design parameters [5, 6].

For conducting the researches there had been created the design model of the control system (Fig. 1), where the throttles 4, 5 determine the flow through the servo spool during its forward and backward movement (other designations of the design model you can find in [5, 6]).

Working port area, determined by the servo spool displacement, is calculated by the formula:

$$f_{31} = \mu \cdot \pi \cdot d_3 \cdot x \cdot \sin\alpha + f_0 , \qquad (1)$$

where x is servo spool displacement, α – slope angle of the main spool working edge (other designations you can find in [5, 6]).

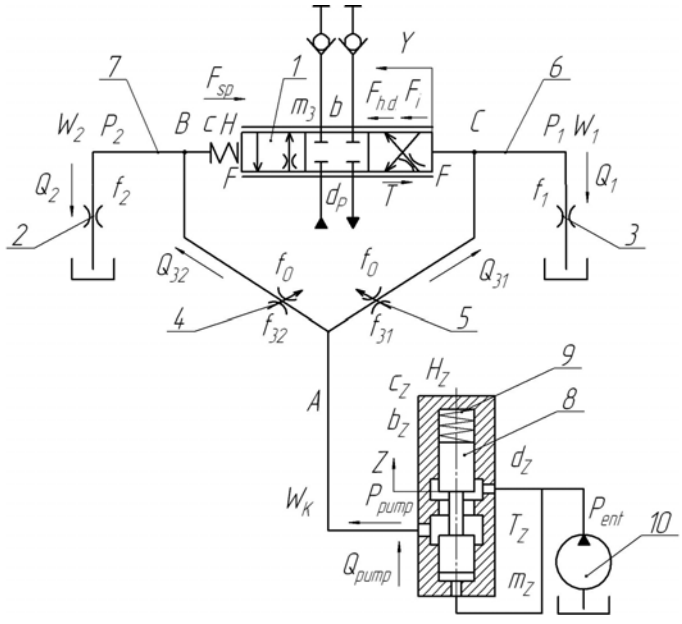

Fig. 1. Design model of the control system

The equations of the mathematical model, developed on the basis of the control system design model, are given by:

$$\mu\cdot\pi\cdot d_Z\cdot(z_0-z)\cdot\sin\beta_Z\cdot\sqrt{\frac{2\cdot|P_H-P_K|}{\rho}}=[\mu\cdot\pi\cdot d_3\cdot x\cdot\sin\alpha+f_0]\cdot\sqrt{\frac{2\cdot|P_K-P_1|}{\rho}}\cdot sign(P_K-P_1)+$$

$$+[-d_3\cdot\mu\cdot\pi\cdot x\cdot\sin\alpha+f_0]\cdot\sqrt{\frac{2\cdot|P_K-P_2|}{\rho}}\cdot sign(P_K-P_2)+\beta\cdot W_K\cdot\frac{dP_K}{dt},\qquad(2)$$

$$[\mu\cdot\pi\cdot d_3\cdot x\cdot\sin\alpha+f_0]\cdot\sqrt{\frac{2\cdot|P_K-P_1|}{\rho}}\cdot sign(P_K-P_1)=\mu\cdot f_1\cdot\sqrt{\frac{2\cdot P_1}{\rho}}+\beta\cdot W_1\cdot\frac{dP_1}{dt},\qquad(3)$$

$$[-d_3\cdot\mu\cdot\pi\cdot x\cdot\sin\alpha+f_0]\cdot\sqrt{\frac{2\cdot|P_K-P_2|}{\rho}}\cdot sign(P_K-P_2)=\mu\cdot f_2\cdot\sqrt{\frac{2\cdot P_2}{\rho}}+\beta\cdot W_2\cdot\frac{dP_2}{dt},\qquad(4)$$

$$m_3\frac{dV_y}{dt}=P_1\cdot F-P_2\cdot F-c\cdot(H+y)-b\,\frac{dy}{dt}-T\cdot sign\frac{dy}{dt}-$$

$$-d_3\cdot\mu\cdot\pi\cdot y\cdot\sqrt{\frac{2\cdot\Delta P}{\rho}}\cdot 0.324\cdot\sqrt{\Delta P}\,,\qquad(5)$$

$$m_Z\frac{dV_Z}{dt}=P_K\cdot\frac{\pi\cdot d_Z^2}{4}-c_Z\cdot(H_Z+z)-b_Z\frac{dz}{dt}-T_Z\cdot sign\frac{dz}{dt}$$

$$-d_Z\cdot\pi\cdot(z_0-z)\cdot\sin\beta_Z\cdot\sqrt{\frac{2\cdot(P_H-P_K)}{\rho}}\cdot 0.324\cdot\sqrt{(P_H-P_K)}\,.\qquad(6)$$

Mathematical model has been processed by MatLAB Simulink software package. Simulink is an interactive tool for modeling, simulation and analysis of dynamic systems. It is an application to the MATLAB package completely integrated with it [7].

The basic block-diagram for solving the differential equations set is presented in fig. 2.

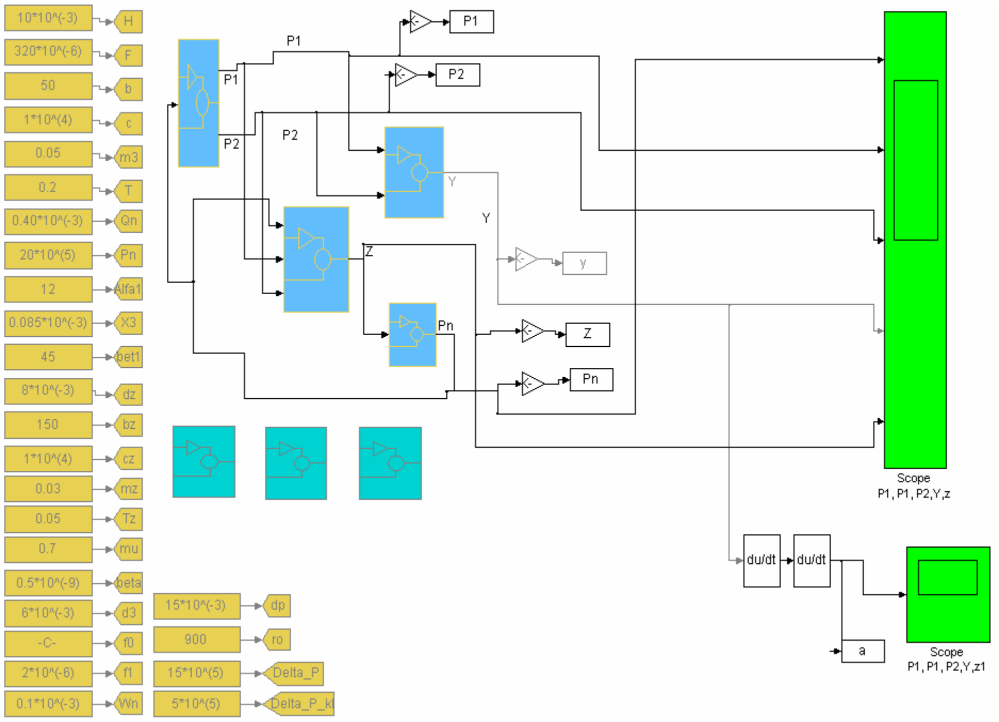

Fig. 2. Block-diagram for solving the equations set

Owing to the solution of the mathematical model, there had been researched the transient processes in the system, and the relationship curves have been obtained showing the dependence of the main spool working edge position on servo spool displacement, pressure drop ΔP across the main spool working edge and on the design parameters of the control system.

Curves in fig. 3 show the relationship between the position of the main spool working edge and servo spool displacement for different values of the pressure drop ΔP across the main spool.

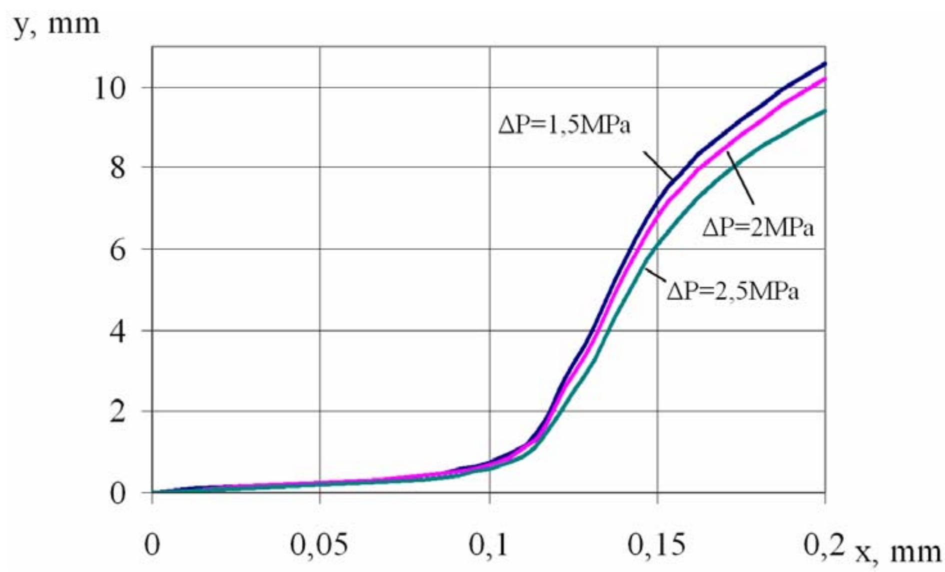

Fig. 3. Relationship between the position of the main spool working edge and servo spool displacement for different values of the pressure drop ΔP on the main spool

Analysis of the obtained relationships allows to make a conclusion about the nonlinear dependence of the control system output signal (position of the main spool 1 edge) on the input signal (servo spool displacement) in the static mode. Essential nonlinearity in the control system disturbs the proportional control of the main spool and reduces considerably the precision of its positioning.

Curves in fig. 4, 5 show the relationship between the position of the main spool working edge and time for minimal and maximal input signal x (servo spool displacement) and different values of the slope angle α of the main spool working edge.

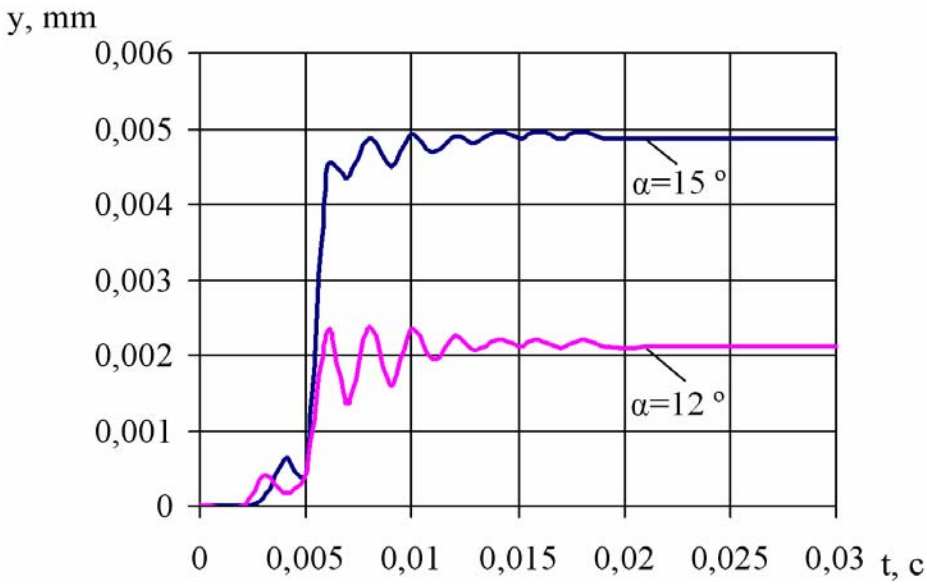

Fig. 4. Relationship between the displacement of the main spool edge and time for minimal displacement of the servo spool and different values of the working edge slope angle

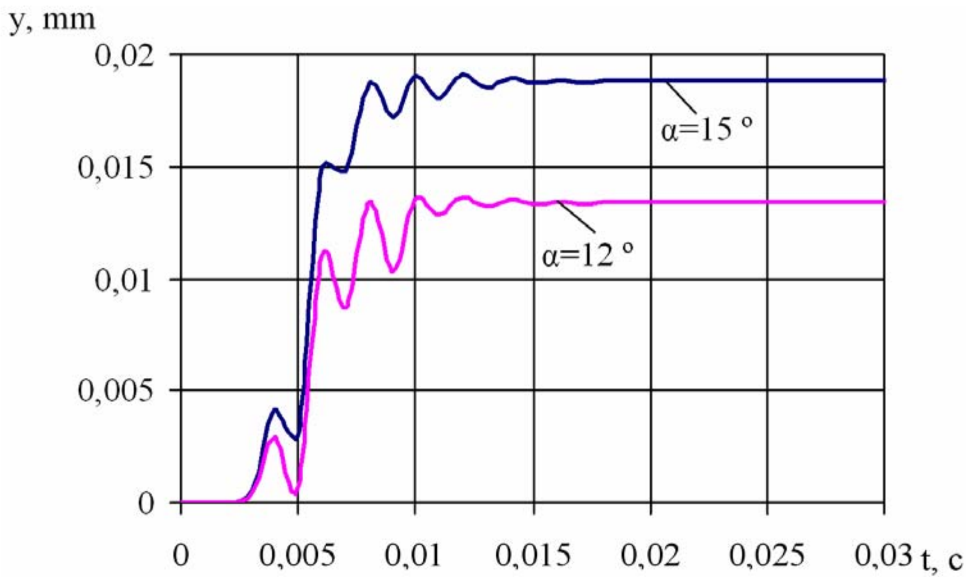

Fig. 5. Relationship between the displacement of the main spool edge and time for maximal displacement of servo spool and different values of the working edge slope angle

Analysis of the curves, presented in fig. 4, 5, allow to make a conclusion that the input signal value (servo spool displacement) has a considerable effect on the nature of the relationship between the displacement of the main spool edge and time. This is a strong evidence of a considerable nonlinearity of the control system in dynamic modes. By varying the slope angle α of the main spool working edge the nature of transient process can be changed.

The results of the researches enable to make a conclusion that in order to provide the control proportionality for the main spool of the directional control valve it is necessary to reduce the nonlinearity of the relationship between the input (servo spool displacement) and the output (position of the main spool edge 1) signals.

The required effect can be achieved by selecting corresponding values of the control system design parameters. Fig. 6 shows the influence of the slope angle α of the main spool working edge on the nature of the relationship between the input and output signals.

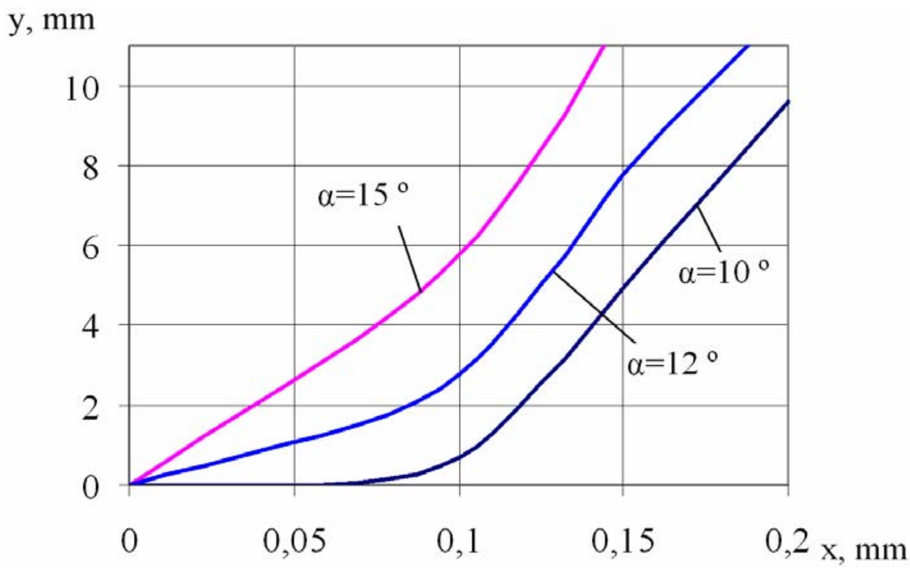

Fig. 6. Relationship between the position of the main spool working edge and servo spool displacement for different values of the slope angle α of the main spool working edge

Conclusion

The developed mathematical model and the researches conducted on the characteristics of the proportional directional control valve with electrohydraulic controlling have exposed essential nonlinearities in the control system that are observed both in static and dynamic operation modes.

These nonlinearities can be reduced by means of selecting the corresponding values for the slope angle of the main spool working edge.

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