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RESEARCH OF THE CONTOL SYSTEM OF THE PROPORTIONAL ELECTROHYDRAULIC DISTRIBUTOR

There had been developed the mathematical model and the research of the control system for the proportional electro hydraulic Distributor were conducted.

There had been conducted the simulating research of pressure distribution in the control system by COSMOS FLOWORKS software, on the basis of the research results there had been modernized the construction of the system, that allowed to increase the control pressure.

There had been determined the limits of values of design parameters of control system, which ensure stable operation of the distributor. On the base of research upon the mathematical model there had been specified the dependence of the operation response of the control valve in the second cascade of the directional control valve on flow characteristics of throttle elements in the first cascade and operation response of the valve in the first cascade.

There had been determined the aggregates of values in constructional parameters which ensure the maximum operation response in functioning of the valve in the first cascade and control valve in the second cascade of the directional control valve.

Key words: *directional control valve, control system, mathematical model, operation response, simulating research.*

Introduction

The modern mobile machines tend to switch over to the hydraulic drives on the base of proportional electro hydraulic directional control valves, which in majority of cases have some cascades, operating on the principle of electro hydraulic booster [1, 2].

Static and dynamic characteristics of electro hydraulic directional control valve greatly depend on the operation of the first cascade, which acts as a control system [3, 4].

The objective of the paper is to research the operation of the first cascade in the electro hydraulic proportional directional control valve on the base of valve stop- regulatory element.

Many papers study one and multi-cascade electro hydraulic units, [1 - 4] in particular, however, in our opinion, the issues, related to the influence of conductivity area of throttle elements in control system upon the characteristics of the directional control valve are paid less attention.

Fig. 1 presents the diagram of directional control valve [5, 6]. Its principal elements are: feed line 1, piston valve of the first cascade 2 with proportional electromagnet 3, the diagram also presents the valve of the second cascade 4 with the spring 5.

Control system operates as follow. With the absence of signal on coils 6 of electromagnet 3, the valve 7 is in the upper position under the action of the spring 8. The fluid from the feed line 1 passes through the throttle 9, the valve of first cascade and hydraulic line 10 to the drain, with $Q_{S1} \rightarrow Q_{N1}$, $Q_1 \rightarrow 0$. A piston valve of the second cascade 4, acted by spring is in the right position, since pressure p_1 of the control flow Q_1 is insufficient for its shift.

When a signal (voltage U_m) is applied to the proportional electromagnet 3, the rod 11, under the action of electromagnetic force and spring 12 is shifted down, pushing the valve 7, reducing the area of conductivity of the first cascade 2 and Q_{S1} flow and increasing the flow, which comes from the hydro line 1 through the throttle 13 to the face of the second cascade piston valve 4 - Q_1, which causes the increase in difference of pressure $p_2 - p_1$. The fluid under the pressure P1 acts upon the piston valve of the second cascade 4 and moves it to the left, proportionally to the control voltage U_m.

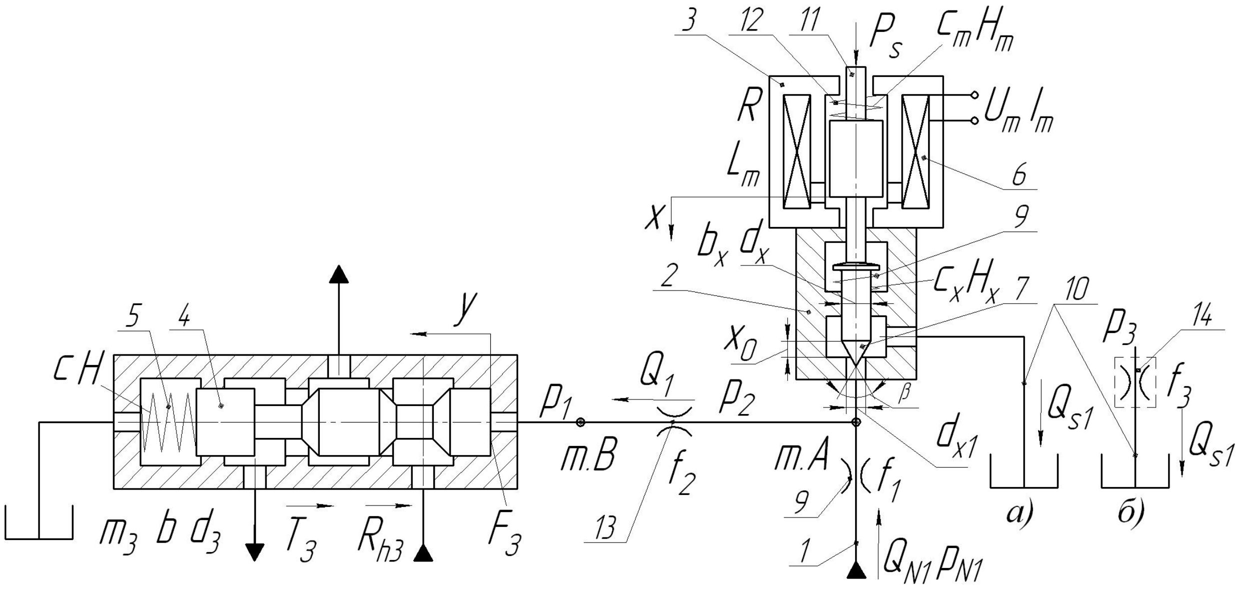

Fig.1 The diagram of the proportional electro hydraulic direction control valve

Prior to the mathematical simulation there had been conducted the simulation research of the first cascade by COSMOS FLOWORKS software [7, 8].

COSMOS FLOWORKS is based on the latest achievements in the hydrodynamics and allows to solve a broad range of problems: research of two-dimensional, three-dimensional, laminar and turbulent flows, incompressible flows and compressible fluid medium, stationary and non-stationary flows of multicomponent fluid media in channels or around the bodies, taking into account the gravity, wall roughness, etc.

During the calculations there had been used such constant values:

$K_{П.Е}$ = 0,15; L_m =20; R = 2.2 Ohm; K_{Fi} = 4,5; $d_3 = 16 \cdot 10^{-3}$ m; $d_x = 8 \cdot 10^{-3}$ m; $d_{x1} = 4 \cdot 10^{-3}$ m; $\beta = 0,5 \cdot 10^{-9}$ mm; ρ = 900 kg/m^3; $W_A = 0,1 \cdot 10^{-3}$ m^3; $W_B = 0,05 \cdot 10^{-3}$ m^3; μ = 0.7; $c = 7,831 \cdot 10^4$ H/m; $c_x = 0,67 \cdot 10^3$ H/m; $c_m = 0,3 \cdot 10^3$ H/m; $H = 2,3 \cdot 10^{-3}$ m; $H_x = 2,9 \cdot 10^{-3}$ m; $H_m = 2 \cdot 10^{-3}$ m.

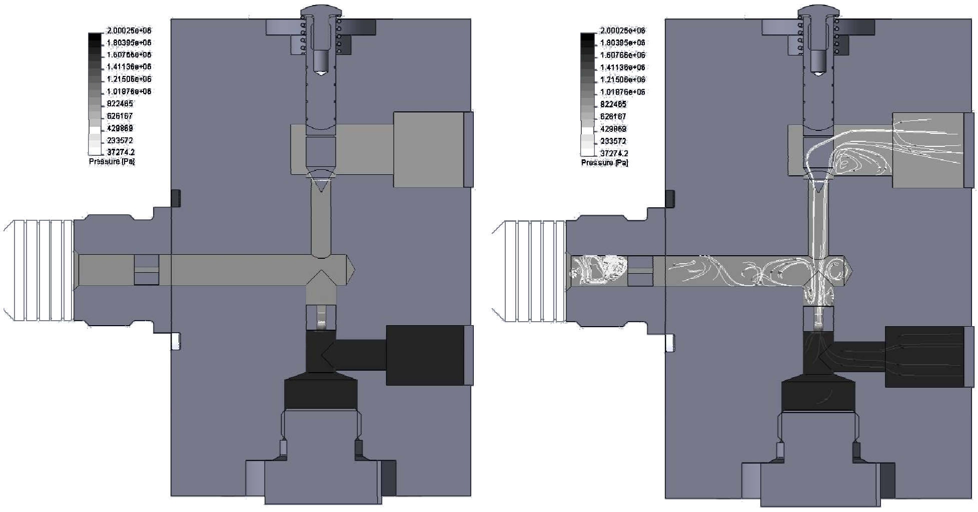

Fig. 2 Distribution of pressures in the first cascade of the directional control valve

The analysis of pressure distribution in the first cascade (Fig. 2), allows to make a conclusion that hydroline 10 connection to directly to the drain (Fig. 1, a), the pressure $p_1 \leq 0,2$ MPa (p_{N1} = 1,5 MPa, $x = 1,8 \cdot 10^{-3}$ m) is insufficient for shifting the piston valve of the second cascade (the pressure shift for the piston valve with the diameter of $20\cdot10^{-3}$ m is $p_1 \geq (c\cdot H+T_{sp})/F_3 \geq 0{,}6$ MPa).Achievement of pressure increase p_1 is possible due to pressure increase p_{N1} or increasing value of moving x of the valve 7 or decreasing pressure drop on the valve 7.

The increase in pressure p_{N1} requires the use of pumping station of higher capacity, which increases energy consumption. The increase in the movement of valve 7 reduces the control zone and will require more accurate movement of electromagnet rod.

Therefore, for the solution of the above problem, in the hydro line 12 there was placed the throttle 14 (Fig. 1, b), with the area f_3.. The expediency of this constructing solution is confirmed during the simulation (Fig. 3), since under the unchanged initial conditions there was achieved the increase in the pressure p_1 up to (0,50…0,65) MPa.

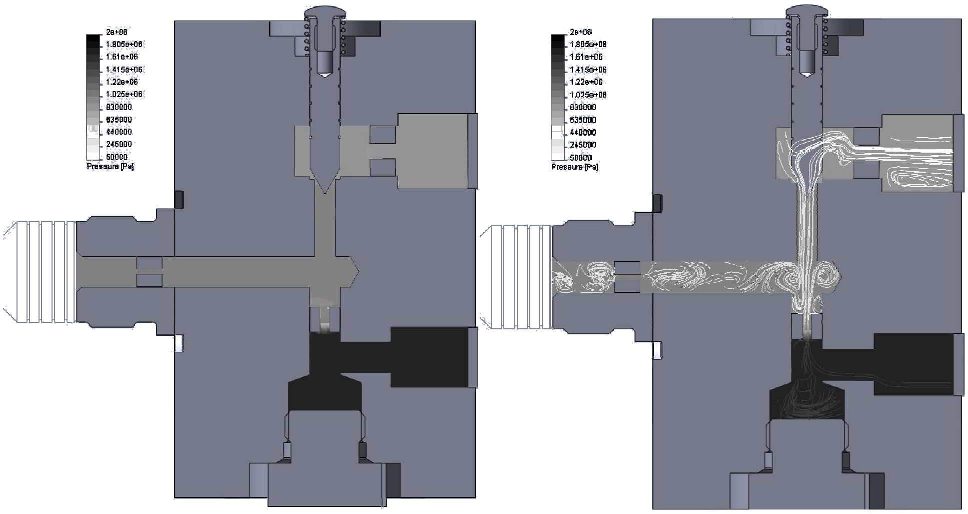

Fig.3 Distribution of pressures in the first cascade of the directional control valve during the installation of the additional throttle

For the research of the operation of directional control valve its mathematical model was created, that consists of equilibrium equations in electric circuit of the electromagnet (1), the equation of the magnetic force of the electromagnet (2), the equations of forces that act on the movable elements of the system (3, 4) and the equations of flow continuity (5 -7).

$$U_m = L_m \cdot \frac{di}{dt} + i\cdot R + K_{П.Е}\frac{dx}{dt}; \quad (1)$$

$$P_S = K_{Fi}\cdot i; \quad (2)$$

$$m_x\frac{d^2x}{dt^2} = P_S - p_2\cdot F_x - c_x\cdot(H_x+x) - c_m\cdot(H_m+x) - b_x\frac{dx}{dt} - T_x\cdot\mathrm{sgn}\frac{dx}{dt}; \quad (3)$$

$$m_3\frac{dV_y}{dt} = p_1\cdot F_3 - c\cdot(H+y) - b\,\frac{dy}{dt} - T_3\cdot\mathrm{sgn}\frac{dy}{dt} - R_{h3}; \quad (4)$$

$$\mu\cdot f_1\cdot\sqrt{\frac{2\cdot|p_{N1}-p_2|}{\rho}}\cdot\mathrm{sgn}(p_{N1}-p_2) = \mu\cdot f_2\cdot\sqrt{\frac{2\cdot|p_2-p_1|}{\rho}}\cdot\mathrm{sgn}(p_2-p_1) + \beta\cdot W_A\cdot\frac{dp_2}{dt} + \mu\cdot\left[\frac{\pi}{2}\cdot((x_0-x)\cdot\sin\alpha + 2\cdot d_{X1})\cdot(x_0-x)\cdot\sin\frac{\alpha}{2}\right]\cdot\sqrt{\frac{2\cdot|p_2-p_3|}{\rho}}\cdot\mathrm{sgn}(p_2-p_3); \quad (5)$$

$$\mu\cdot\left[\frac{\pi}{2}\cdot((x_0-x)\cdot\sin\alpha + 2\cdot d_{X1})\cdot(x_0-x)\cdot\sin\frac{V}{2}\right]\cdot\sqrt{\frac{2\cdot|p_2-p_3|}{\rho}}\cdot\mathrm{sgn}(p_2-p_3) = \mu\cdot f_3\cdot\sqrt{\frac{2\cdot p_3}{\rho}}; \quad (6)$$

$$\mu \cdot f_2 \cdot \sqrt{\frac{2 \cdot |p_2 - p_1|}{\rho}} \cdot \mathrm{sgn}(p_2 - p_1) = F_3 \cdot \frac{dy}{dt} + \beta \cdot W_B \cdot \frac{dp_1}{dt}. \qquad (7)$$

The equations of the mathematical model are composed with the following principle assumptions and simplifications: there had been considered the concentrated parameters ; the temperature of the working fluid was considered as constant; the wave processes had been not considered; the factors of flow through the throttle and the piston valve elements had been considered as constant; the loss of pressure in hydro lines had not been considered ; hydrodynamic force in the valve of the first cascade had not been considered ; the factor of compliance rate of the working fluid had been considered as an average value for the considered range of pressure change; the pressure value in feeding in hydro line of the first cascade had been considered as constant.

The mathematical model designates:

U_m – value of control voltage; p_{N1} – pressure on the output of a pump 1; p_1 – -control over the piston valve in the second cascade (Fig. 1); p_2 – pressure that is formed by the first cascade valve; 7; $K_{П.Е}$ – factor of anti- EDF; L_m – inductance of electro-magnet coils; R – electromagnet coil active resistance; I_m– value of control current; Ps – pushing force of electromagnet; K_{Fi}– factor, considering the dependence of pushing efforts of electromagnet on control current; f_1, f_2 – the squares of the operating windows of throttles 9 and 13 (hereinafter for convenience we will use f_2 and $k_f = \frac{f_1}{f_2} \geq 1$) ; W_A and W_B – volumes of fluid in points A and B; F – square of piston valve face 4; F_X – square of input channel of the valve in the first cascade 2; c, c_x, c_m – stiffness of the springs 5, 8, 12; H, H_x, H_m – initial compression of the springs 5, 8, 12; m_3, m_X – weight of the piston valve 4 and valve 7; b, b_X – factor of ductile friction of piston valve 4 and valve 7; d_3, d_X, d_{X1} diameters of the piston valve 4, valve 7 and input channel of the valve in the first cascade 2; y and V_y – coordinate of location and speed of piston valve 4; x and V_x –coordinate of location and speed of piston valve 7; x_0 – initial coordinate of position of the valve 7; T_3, T_X – friction force acting on the piston valve 4 and valve 7; R_{h3}– hydrodynamic force acting on the piston valve 4; α – slope angle of the piston valve operating edge 7; ρ – density of the working fluid; μ – factor of flow; β – factor considering the total deformation of silent sleeves.

The processing of mathematical model is done by MatLAB Simulink [9].

Mathematical model equation is solved for the following initial conditions:

$p_{N1}(0)$ = 1,5MPa, $p_1(0)$ = 1,2 MPa, $p_2(0)$ = 1,4 MPa, $p_3(0)$ = 1,0 MPa, $y(0)$ = 0 m, $x(0)$ =0 m.

The objective of the paper is to research the influence of conductivity of the throttle elements of the first cascade valve on the static and dynamic characteristics of the directional control valve, namely, on the stability, speed of movement of the valve in the first, and piston valve of the second cascade.

The research results showed that it is possible to achieve the stability of the direction control valve with the following values of construction parameters $k_f > 0{,}9$ and $f_2 > 0{,}6 \cdot 10^{-6}$ m^2. The increase in the diameter of the opening in the valve of first d_{X1}, cascade insignificantly increases the stability zone (Fig. 4 - shading is directed to the stability zone).

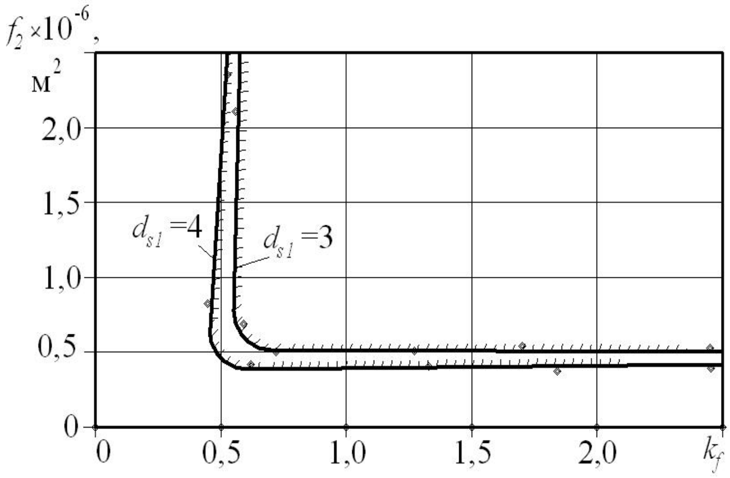

Fig.4 Dependence of the stability of directional control valve on the square of throttle window f_2 and factor k_f

For the two-cascade electro hydraulic directional control valve one of the main characteristics is operation response, especially for the elements of the first cascade, since the operation response of the second cascade as well as the speed of execution of all working operations of the whole drive depend on this parameter.

Fig.5 presents the graphs of dependences of operation response of elements in distribution control valve. The upper dependences (main lines) determine the operation response of the piston valve in the second cascade, the low(shading lines) – valve of the first cascade. Shading determines the limits in values of the constructional parameters with efficient characteristics of the system (the time of operation response of the piston valve in the second cascade $t_{sp}(y)$ has to exceed that of the valve in the first cascade $t_{sp}(x)$).

The aggregate of values $f_2 = 4{,}7\cdot10^{-6}$ m^2 when $k_f = 1$, $f_2 = 2{,}32\cdot10^{-6}$ m^2 when $k_f = 2$ and $f_2 = 1{,}3\cdot10^{-6}$ m^2 when $k_f = 3$ ensures maximum operation response for snapping into the action of the valve in the first cascade and piston valve in the second cascade of the (shaded zone).

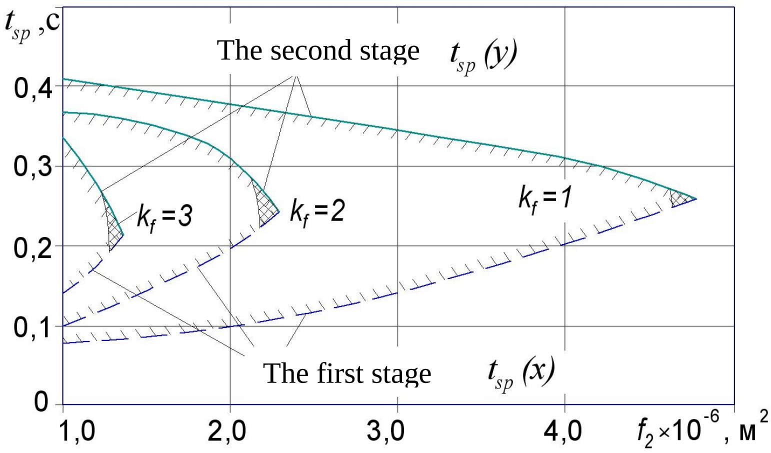

Fig.5 Influence of the throttle window area f_2 on the operation response of functioning of elements of directional control valve for different factors k_f

Conclusions

There had been researched the operation of electro hydraulic proportional direction control valve. There had been determined the limits of the constructional parameters of control system (the first cascade), which ensure the stable operation of the directional control valve: $k_f > 0{,}9$ and $f_2 > 0{,}6\cdot10^{-6}$ m^2.

On the base of the research on the mathematic model there had been specified the dependence of operation response of piston valve in the second cascade of the directional control valve upon the flow characteristics of throttle elements of the first cascade and operation response of the valve in the first cascade. The received data are used while the development of construction of proportional directional control valve.

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