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COMPARATIVE RESEARCH OF THE VARIANTS OF THE FIRST CASCADE OF PROPORTIONAL ELECTRO HYDRAULIC DISTRIBUTOR

There had been suggested the two variants of the first cascade of the distributor: on the base of valve and spool-type distributive elements. There had been developed the mathematical models of the variants of the first cascade and conducted the comparative research of their characteristics. On the base of the comparative transient processes and static characteristics there had been stated the advantage of the first cascade with the valve distributive element.

Key words: *electro hydraulic distributor, first cascade, mathematical model, speed of operation, hysteresis.*

Introduction

The modern mobile machines tend to transfer to the hydraulic drives (HD) on the base of proportional electro hydraulic distributor. The operative loads of such machines are determined by the high working pressures in HD, therefore they need the operation of significant flows [1, 2].

Such conditions are the main factor for the manufacturing of the construction of electro hydraulic distributors of several cascades, which allows to shift the spool even during the significant working flows, using the proportional electric magnets with small armature stroke ($2 \cdot 10^{-3}$ m – $4 \cdot 10^{-3}$ m) and tractive force up to 100 H [1, 3].

Static and dynamic characteristics of electro hydraulic distributors greatly depend on the first cascade and on quality of its operation [1, 3, 4].

The main variants of the constructions of the first cascade differ by the type of shut-off-and-regulating element: «flapper-nozzle», land pipe, valve-type, spool-type etc. [1 – 5].

Objective

In the HD of mobile machines the distributors with the first cascade on the base of valve and spool-type distributive elements are most widely spread [1 – 6]. The objective of the paper is the research and comparison of the characteristics of the two suggested variants of the first cascade of proportional electro hydraulic distributors for the above mobile machines.

The design model of the first cascade of proportional electro hydraulic distributor on the base of the valve distributing element is presented in fig. 1 [7].

Its main elements are the delivery line 1, drain line 2, the spool of the second cascade 3, supported by the spring4, valve of the first cascade 5 with proportional electric magnet 6 etc. [7]. The stream, delivered to the feeding lines of the first cascade passes through the flow-regulating valve 7 and is divided into two streams, one of which goes to the valve of the first cascade 5 and through the flow-regulating valve f_3 to the drain (Q_{s1}), and the second goes through the flow-regulating valve 8 and acts on the end of the spool of the second cascade 3 (Q_1). The value of the opening of the working window of the first cascade is proportional to the shift of the valve 9, which is controlled by the proportional electric magnet 6. Regulating the conductivity of the working window of the first cascade 5 allows to change the value of the stream Q_1 proportionally, and, consequently, the value of the shift of the spool in the second cascade 3.

The design model of the suggested first cascade of proportional electro hydraulic distributor on the base of spool distributive element is presented on fig. 1 [8]. Its main elements are the delivery line 1, drain line 2, the spool of the second cascade 3, supported by the spring 4, as well as servo element 5.

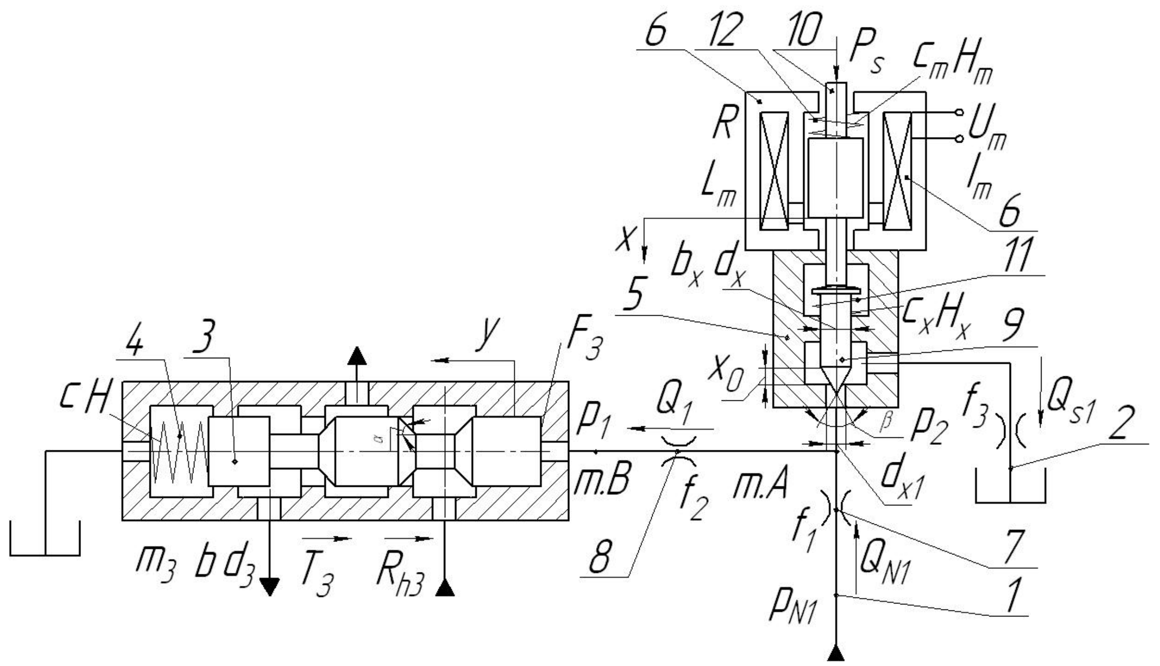

Fig. 1. The design model of the first cascade of proportional electro hydraulic distributor on the base of the valve distributing element

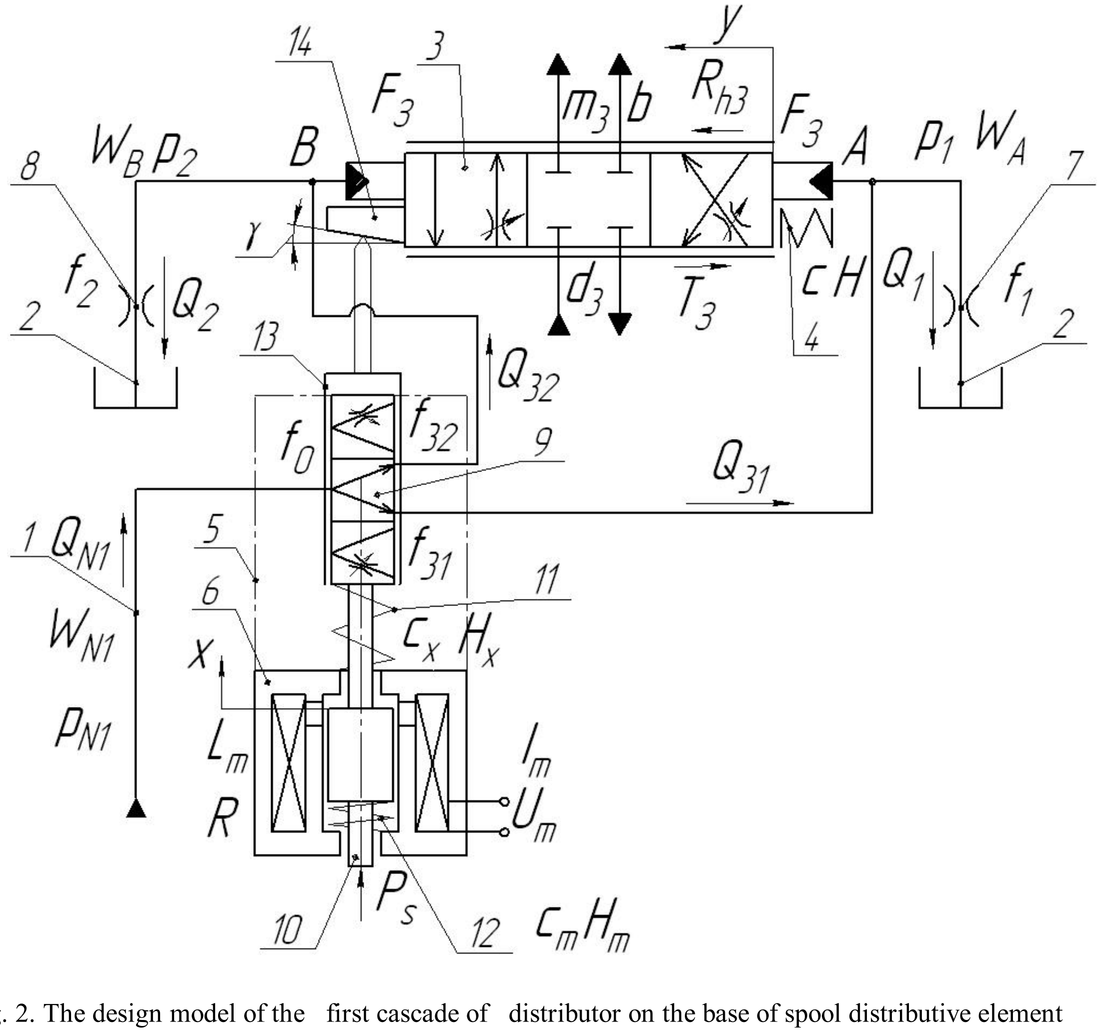

Fig. 2. The design model of the first cascade of distributor on the base of spool distributive element

Servo element 5 contain the spool of the first cascade 9 with spring 11 and moving cylinder 3. This cascade operates as follows: the signal from the electric magnet 6 moves the stock 10, which, driven by the magnetomotive force, shifts the spool of the first cascade 9, changing the values of the opening of the working windows. This also causes the correlations between the values of the pressures p1 and p2, the influence of which moves the spool of the second cascade 3 in the direction of smaller pressure proportionally to the value of the signal, supplied from the magnet.

The peculiarity of this first cascade is the availability if the feedback sensor (FS), manufactured as target sleeve14 with angle of deflection γ, placed on the spool of the second cascade 3. Contacting the top of the cylinder13, which, moving, regulates the squares of the opening of the working windows in servo elements 5, the cone 14 performs the tracing function, correcting the values of the streams Q31 and Q32, depending on the move of the spool of the second cascade 3 (fig. 2).

For the research and comparison of the considered variants of the first cascade there had been built their mathematical models (1) (2), solved in MatLab Simuliuk [7 – 9].

$$
\begin{cases}
\dfrac{di}{dt} = \dfrac{1}{T_L}\left(\dfrac{U_y - K_E \cdot \dfrac{dx}{dt}}{R} - i\right); \\[2ex]
P_S = K_{Fi} \cdot i; \\[2ex]
m_x \dfrac{d^2x}{dt^2} = P_S - p_2 \cdot F_x - c_x \cdot (H_x + x) - c_m \cdot (H_m + x) - b_x \dfrac{dx}{dt} - T_x \cdot \operatorname{sgn} \dfrac{dx}{dt}; \\[2ex]
m_3 \dfrac{dV_y}{dt} = p_1 \cdot F_3 - c \cdot (H + y) - b \dfrac{dy}{dt} - T \cdot \operatorname{sgn} \dfrac{dy}{dt} - R_{h3}; \\[2ex]
\mu \cdot f_2 \cdot \sqrt{\dfrac{2 \cdot |p_2 - p_1|}{\rho}} \cdot \operatorname{sgn}(p_2 - p_1) = F_3 \cdot \dfrac{dy}{dt} + \beta \cdot W_B \cdot \dfrac{dp_1}{dt}; \\[2ex]
\mu \cdot f_1 \cdot \sqrt{\dfrac{2 \cdot |p_{N1} - p_2|}{\rho}} \cdot \operatorname{sgn}(p_{N1} - p_2) = \mu \cdot f_2 \cdot \sqrt{\dfrac{2 \cdot |p_2 - p_1|}{\rho}} \cdot \operatorname{sgn}(p_2 - p_1) + \\[2ex]
+ \mu \cdot \left[\dfrac{\pi}{2} \cdot ((x_0 - x) \cdot \sin\beta_1 + 2 \cdot d_{S1}) \cdot (x_0 - x) \cdot \sin\dfrac{\beta}{2}\right] \cdot \sqrt{\dfrac{2 \cdot p_2}{\rho}} + \beta \cdot W_A \cdot \dfrac{dp_2}{dt}.
\end{cases}
\tag{1}
$$

$$
\begin{cases}
\dfrac{di}{dt} = \dfrac{1}{T_L}\left(\dfrac{U_y - K_E \cdot \dfrac{dx}{dt}}{R} - i\right); \\
P_S = K_{Fi} \cdot i; \\
m_x \dfrac{d^2x}{dt^2} = P_S - p_2 \cdot F_x - c_x \cdot (H_x + x) - c_m \cdot (H_m + x) - b_x \dfrac{dx}{dt} - T_x \cdot \operatorname{sgn} \dfrac{dx}{dt}; \\
Q_{N1} = \mu \cdot [\pi \cdot d_X \cdot (x - y \cdot tg\gamma) \cdot \sin\alpha + f_0] \cdot \sqrt{\dfrac{2 \cdot |p_{N1} - p_1|}{\rho}} \cdot \operatorname{sgn}(p_{N1} - p_1) + \beta \cdot W_N \cdot \dfrac{dp_{N1}}{dt} + \\
+ \mu \cdot [-d_X \cdot \pi \cdot (x - y \cdot tg\gamma) \cdot \sin\alpha + f_0] \cdot \sqrt{\dfrac{2 \cdot |p_{N1} - p_2|}{\rho}} \cdot \operatorname{sgn}(p_{N1} - p_2); \\
\mu \cdot [\pi \cdot d_X \cdot (x - y \cdot tg\gamma) \cdot \sin\alpha + f_0] \cdot \sqrt{\dfrac{2 \cdot |p_{N1} - p_1|}{\rho}} \cdot \operatorname{sgn}(p_{N1} - p_1) = \mu \cdot f_1 \cdot \sqrt{\dfrac{2 \cdot p_1}{\rho}} + \beta \cdot W_A \cdot \dfrac{dp_1}{dt}; \\
\mu \cdot [-d_X \cdot \pi \cdot (x - y \cdot tg\gamma) \cdot \sin\alpha + f_0] \cdot \sqrt{\dfrac{2 \cdot |p_{N1} - p_2|}{\rho}} \cdot \operatorname{sgn}(p_{N1} - p_2) = \mu \cdot f_2 \cdot \sqrt{\dfrac{2 \cdot p_2}{\rho}} + \beta \cdot W_B \cdot \dfrac{dp_2}{dt}; \\
m_3 \dfrac{dV_y}{dt} = p_1 \cdot F - p_2 \cdot F - c \cdot (H + y) - b\dfrac{dy}{dt} - T \cdot \operatorname{sgn} \dfrac{dy}{dt}.
\end{cases}
\tag{2}
$$

Mathematical models are composed with the following main tolerances and simplifications: The value of pressure in hydroline feeding the first cascade was accepted as stable [1, 5]; There had been considered the lumped parameters; wave process had not been considered [1, 5]; discharge coefficient through the flow-regulating valve as well as spool elements were accepted as constant; the volumes of hydraulic lines during the transient process did not change; Pressure loss in hydraulic lines were not considered; flexibility coefficient of the working fluid was considered as the value, independent of pressure.

Mathematical models designate:

U_m – magnitude of control stress; p_{N1} – pressure in the supply line ; p_1 – pressure of control over the spool in the second cascade (fig. 1); p_2 – pressure, made by the valve of the first cascade 9 (for fig. 1, for fig. 2 p_1 and p_2 – pressure of control over the spool of the second cascade 3); K_E – back emf factor; L_m – inductivity of coils of electric magnet; R – active resistance of electromagnetic coils ; I_m– control current; P_s – push force of electric magnet; K_{Fi} – factor, which considers the dependence of the pushing force of electric magnet on the control current intensity; f_0 – the square of the initial opening of the working windows of servo element 5; f_1, f_2 – squares of the working windows of flow-regulating valves 7 and 8 (further for the variant of the first cascade on the base of valve distributive element , for convenience, we will use f_2 and a factor of correlation of squares of flow-regulating valve elements $k_f = \dfrac{f_1}{f_2} \geq 1$); W_A and W_B – volume of fluid in points A and B; W_N – volume of fluid in the supply line (fig. 2); F – square of the spool end 5; F_X – square of the element of the first cascade 9, influenced by the fluid pressure ; c, c_x, c_m – spring force 4, 11, 12; H, H_x, H_m – initial compression of spring; 4, 11, 12; m_3, m_X – spool mass 3 and valve (of spool) 9; b,

b_X – factor of viscous friction of spool 3 and valve (of spool 9; d_3, d_X, d_{X1} – spool diameter 3, valve (of spool) 9 and the input channel of the valve of the first cascade 5; y and Vy – coordinate of location and speed of the spool 3; x and Vx – – coordinate of location and speed of the valve 9; x0 – initial– coordinate of location of the valve (of spool) 9; T3, TX – force of friction, which influence the spool 3 and valve (spool) 9; α – deflection angle of the distributing edge of the valve 3; ρ – dencity of hydraulic liquid; μ – discharge coefficient; β – coefficient, which considers the sum total deformation of hydraulic liquid and rubber-metallic arms.

Peculiar attention during the research was paid to the characteristics of shift of the spool of the second cascade, which will control over the main flows in the distributor, namely: smoothness of movement, absence of fluctuations, hysteresis range, which may worsen the quality of HD working body movement.

On the base of the results of mathematical simulation it had been determined that the movement of the spool of the second cascade y(t) for the variant of the first cascade on the base of the valve distributive element is followed by the fluctuations with small amplitude (fig. 3), the move of the spool of the second cascade y(t) under the control by the second variant of the first cascade is followed by the fluctuations of higher amplitude (fig. 4). The hysteresis range of the characteristics *y(u)* for the variant of the first cascade on the base of valve distributive element makes up – 5,7% (fig. 5), which is somewhat smaller in comparison with the other variant – 9,5% (fig. 6).

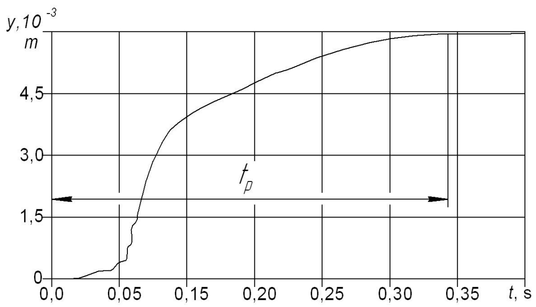

Fig. 3. Dependence *y(t)* of the first cascade on the base of valve distributing element

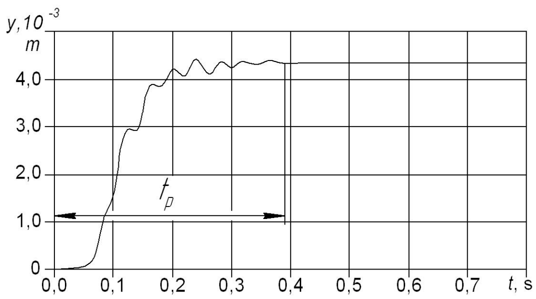

Fig. 4. . Dependence *y(t)* of the first cascade on the base of spool distributing element

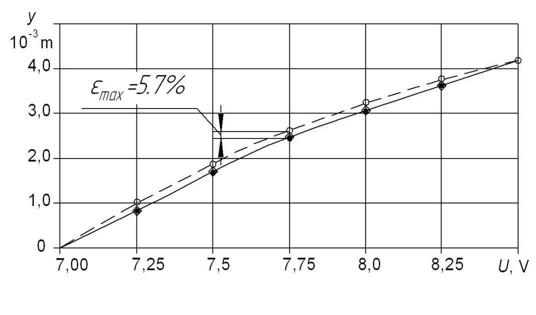

Fig. 5. Dependence of coordinate of spool move of the second cascade y on voltage on the electric magnet y(u) for the first cascade on the base of valve distributing element (main line – fore stroke, dashed – backward stroke)

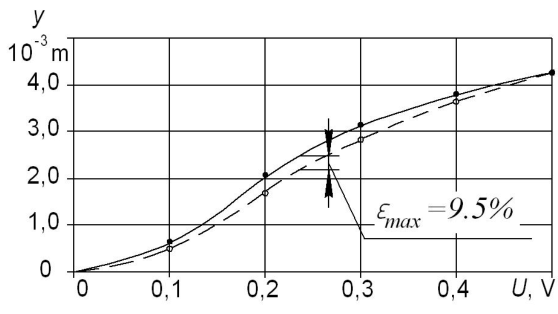

Fig. 6. Dependence of coordinate of spool move of the second cascade on voltage on the electric magnet *y(u)* for the first cascade on the base of spool distributing element (main line – fore stroke, dashed – backward stroke)

It is possible to achieve the improvement of the characteristics y(t) for both variants of the first cascade due to the efficient choice of constructional parameters or optimization , which is presented in [1, 7, 8] (fig. 7) in details.

On the base of comparison of transitional processes in the first cascade with efficient constructional parameters it is possible to conclude that the first cascade on the base of valve distributive element (fig. 2, 8) had better dynamic characteristics (more low oscillation and regulation time), lower hysteresis of the dependence y(u) – 5,7% and better responding speed – 0,22 s (determined by the transitional processes of move of the spool of the second cascade for both variants (fig. 7)).

This variant is accepted as the basic for the creation of the proportional electro hydraulic distributor with independent control of flows.

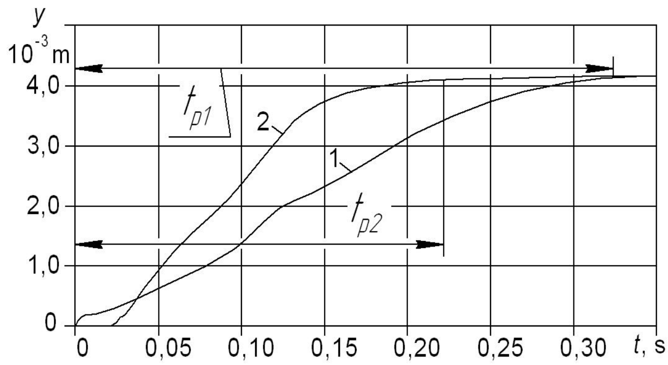

Fig. 7. Dependence of move of the spool of the second cascade on time: 1 – variant of the first cascade on the base of spool distributive element, 2 – variant of the first cascade on the base of valve distributive element

Conclusions

There had been suggested the two variants of the first cascade of the distributor (on the base of valve and spool distributive elements).

There had been developed the mathematical models of the variants of the first cascade and conducted the comparative research of their characteristics, in the result of which there had been chosen the first cascade of the distribution on the base of valve distributing element, since this variant is more fast-acting (regulating time t_r = 0,22 s), has lower hysteresis y(u) – 5,7% and improved dynamic characteristics (lower oscillation of the dependence y(t)).

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