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THE ACTUATOR BASED ON THE ELASTIC FLUID DOSING

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ABSTRACT

Possibility of positioning of output joint of the hydraulic drive by dosing fluid into working chamber based on fluid elasticity and compressibility was considered. It is proposed to install an additional valve in the pressure and / or drain lines to perform elastic-hydraulic dispenser, that includes main direction valve and pipe inner volume. According to the results of simulation, the limits of changes in the portions of fluid were determined, also as dependencies on the pressure, load, pipe inner volume and properties of the fluid. A simplified hydraulic diagram with elastic fluid dosage was developed.

INTRODUCTION

Increasing of hydraulic automation systems corresponds to combination of traditional hydrodrive advantages with flexible control algorithm. Low-cost control systems based on using of PLCs and sensors allow to wide and simplify hydraulic drives implementation [1–4]. The most of advantages and disadvantages of hydraulic are outcome of fluid features and hydraulic control devices [1, 5, 6]. For example, compressibility of liquids is low, but there are still existing fluctuations of hydraulic rigidity. But it can be used with flexible pipe deformation to create dispenser using to make dose feeding into working chamber of actuator, providing little displacement. Mechanism of the dispenser based on periodical switching directional valves to fill pipe inner volume with fluid under pressure, housing it and released into aa working chamber. Knowing initial pressure, compressibility, elastic deformations, pressure drops and loads, it allows to find out values of displacements to increase positioning precision, without feedback. Additionally, feedback can be used to ensure precision of control and to negate influence of environment.

EXPOSITION

The main aim is to ensure possibility of elastic fluid dosing in hydraulic systems and to find out the most of dependencies among fluid and system parameters.

The diagram, that represents dosing mechanism, is shown at Fig.1. It consists of three directional valves, pipe inner volume, end switcher. The piston is moving to position, controlled by limit switch on regular mode. After signal of limit switch the actuator mode shifts on dosing mode. And actuator displacement depends on fluid quantity, was feed to chamber by number of same pulses.

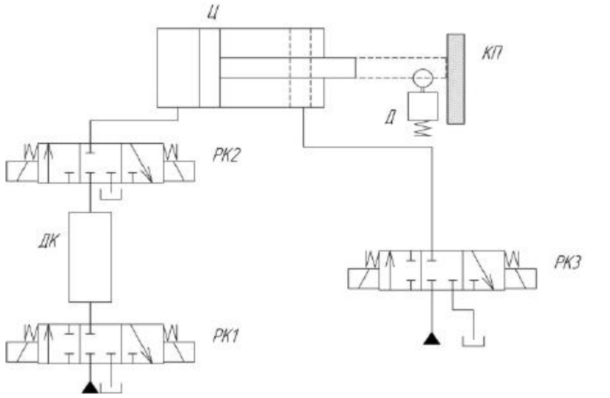

Fig. 1. Diagram of the actuator positioning (Ц – cylinder, РК1, РК2, РК3 – direction valves, ДК – dispenser volume, Д – end switch, КП – extraction limit)

The diagram provides positioning of the piston in region between limit switch and extraction limit. In some cases, it is need of different extraction value, but its range is little – few millimeters. For example, stamping or marking machines, positioning cutting or other type tool, which operate on series of detail with different height.

At the begining, to perform calculating of dosing mechanism were taken assumptions: fluid temperature is constant; gauge pressure, without load, in a retraction chamber is null; pipe between piston chamber and direction valve is absolutely rigid; no leakages; piston velocity doesn't affect on dose quantities.

As input data for calculation, parameters were taken: input pressure; external load; cylinder sizes; inner volume in valves; features of fluid; dispenser size.

The dispenser was calculated according to Fig.2. Also, simplified equations to find out extraction quantity were

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performed [7]:

$$y_\partial = y_m \cdot n_y + \Delta y_\partial ;$$

$$y_m = F_0 \cdot l_0 / (\sigma_\partial \cdot q_\partial), \qquad (1)$$

herein y_∂ – piston position; y_m – theoretical displacement per dosing tact; n_y – number of tacts; Δy_∂ – positioning deviation; F_0 та l_0 – area and displacement of dosing piston; q_∂ – efficient piston area; σ_∂ – coefficient of piston area difference.

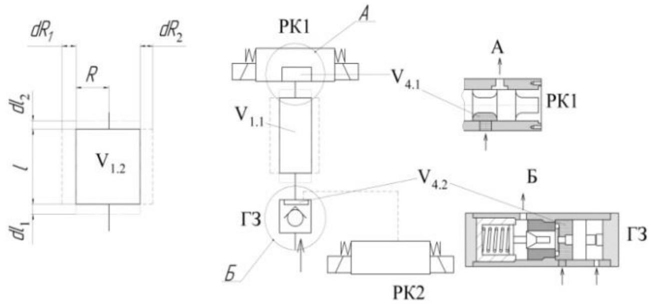

Fig. 2. Calculating diagram of dispenser: V_{11} – dosing chamber, А, Б – shut-off devices, РК1 – main directional valve, РК2 – feeding valve of the dosing chamber, V_{41} та V_{42} – valves inner volume

Evaluation of the displacement deviance includes fluid elasticity and chambers rigidity, pressure and external load:

$$p_c = \frac{p_n}{\sigma_\partial} - \frac{H_c}{\sigma_\partial \cdot q_\partial \cdot \eta_{\partial м}};$$

$$\Delta y_{\partial 1} = \frac{p_c - p_{am}}{\sigma_\partial \cdot q_\partial} \cdot \left(\frac{V_{ж}}{E_{ж}} + \frac{V_y}{E_y} \right) + \frac{V_{am}}{\sigma_\partial \cdot q_\partial} \cdot \left[1 - \left(\frac{p_{am}}{p_c} \right)^{\frac{1}{n}} \right]; \qquad (2)$$

$$\Delta y_{\partial 2} = \frac{p_c - p_{am}}{p_{ном} - p_{am}} + \frac{Q_{уном} \cdot t_{поз}}{\sigma_\partial \cdot q_\partial};$$

$$\Delta y_\partial = \Delta y_{\partial 1} + \Delta y_{\partial 2}$$

herein p_n та p_c – pressure in retraction and piston chambers; H_c – external static load; $\eta_{\partial м}$ – mechanical efficiency coefficient; p_a – atmospheric pressure height; $V_{ж}$, V_y, V_{am} – compression/extension values of fluid, housing, air; $E_{ж}$ – fluid elasticity module; E_y – averaged quantity of housing elasticity module; n – polytrophic coefficient; $p_{ном}$ – nominal fluid pressure; q_∂ – nominal leakages; t – positioning time.

Deformation of dosing chamber is defined as [8]:

$$dl = \frac{\omega(x)}{R},$$

herein $\omega(x)$ – radial displacement of casing.

Calculations were mad for solid metal pipes and high-pressure hoses

Displacement value per single pulse of dispenser:

$$\Delta h = \frac{dV_3}{S}; \; S = 0.25 \cdot \pi \cdot d_1^2 \qquad (3)$$

herein S – piston area; dV_3 – absolute increment of volume in piston chamber.

Displacement value by k – number of pulses:

$$\Delta h = \frac{dV_3}{S}; \; h = \Delta h \cdot k \qquad (4)$$

Equation (4) is using to find out number of pulses, that is needed to provide fixed displacement.

Simulation, using dependencies (2) – (4), to find out displacement, taking into account system parameters, was made. As fluid was used oil - АМГ-10, elasticity module = 130400 N/cm^2 [6]. Hydraulic line parameters were chosen according to standard.

The 1st simulation series were made to find out influence on displacement by length of dosing chamber (Fig. 3). Lengths were taken in range 2.5 … 9 meters. Pipe diameters were taken, according to standard, 6, 8, 10 and 12 mm. Supply pressure height were taken in range 30 … 60 bar. Elasticity module of pipes = 200000 MPa. Pipe thickness was: 2 mm for diameters 6 and 8 mm; 2.25 mm for diameters 10 and 12 mm.

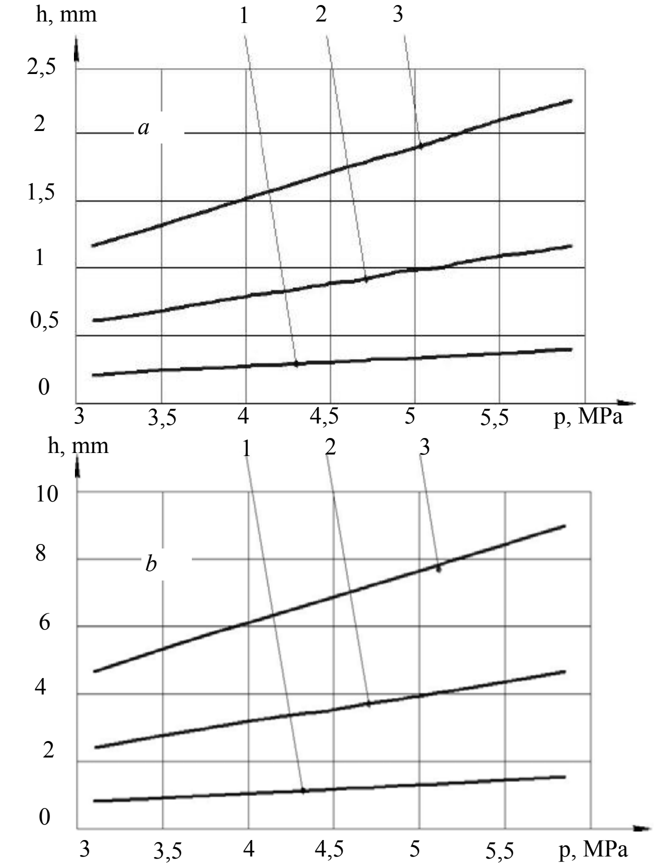

Figure 3. Piston displacement per pulse on pressure height: diameters 8 mm(a) and 12 mm (b); length: 1 – 2,5 m, 2 – 5 m, 3 – 7,5 m

It is clear, that as bigger volume of dispenser, as bigger displacement, in case of constant pressure height. Obtained dependencies have liner characteristics, that simplified its implementation to define rational dispenser parameters.

According to obtained data, displacements per pulse were recalculated (Table 1).

Hence, the influence of supply pressure and external load on displacement were studied. External load was taken as pressure in retraction chamber (Fig. 2). Cylinder diameter was taken as 30 mm, and piton rod diameter as 16 mm.

Table. 1. Piston displacements per pulse: d – dispenser inner diameter, l – dispenser length

d, mm	l=2,5m recalc. Δh for d				l=7,0m recalc. Δh for d			
	6	8	10	12	6	8	10	12
6	0,4	*0,33*	*0,39*	*0,45*	2,4	*2,31*	*2,34*	*2,31*
8	*0,71*	0,6	*0,63*	*0,8*	*4,3*	4,1	*4,16*	*4,08*
10	*1,1*	*0,94*	1,1	*1,25*	*6,5*	*6,64*	6,5	*6,38*
12	*1,6*	*1,35*	*1,58*	1,8	*9,6*	*9,22*	*9,36*	9,2

Simulation didn't include influence of dynamic processes of cylinder acting. However, dispenser parameters have influence on cylinder dynamic too. They were been considered by pressure propulsion in dosing chamber due to density changes and pipe deformation:

$$\Delta m = \Delta V_3(\rho + \Delta\rho) = l \cdot \Delta S_k(\rho + \Delta\rho),$$

herein $\Delta\rho$ – density change due to pressure, ΔS_k – chamber deformation, taking into account diameter and density changes.

Also, average deformation force was defined as:

$$F_m = 0,5 \cdot \Delta p \cdot S_k,$$

herein S_k – cross-section area of dispenser.

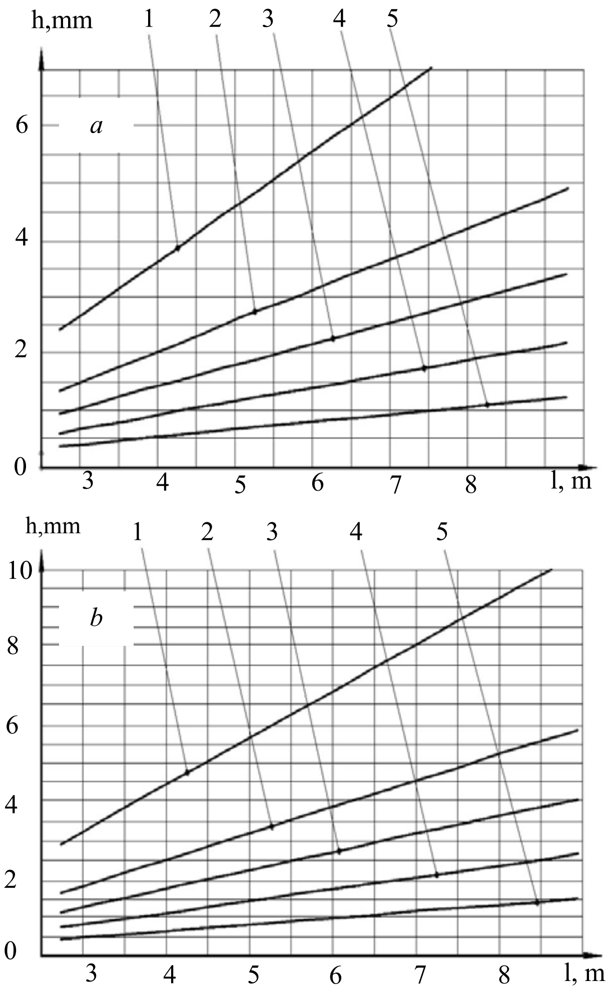

Figure 4. Definition of dispenser parameters by displacement step h without load at pressure 50 bar (a) and 60 bar (b): 1 – 16mm, 2 – 12mm, 3 – 10mm, 4 – 8mm, 5 – 6mm

Hence, simulation series, taking into account external load, were made (Fig.5). Obtained data allow to provide correlation between external load and supply pressure, insuring fixed displacement step (Table 2).

Approximation of step value is represented for dispenser: 16 mm diameter and 2,5 m length.

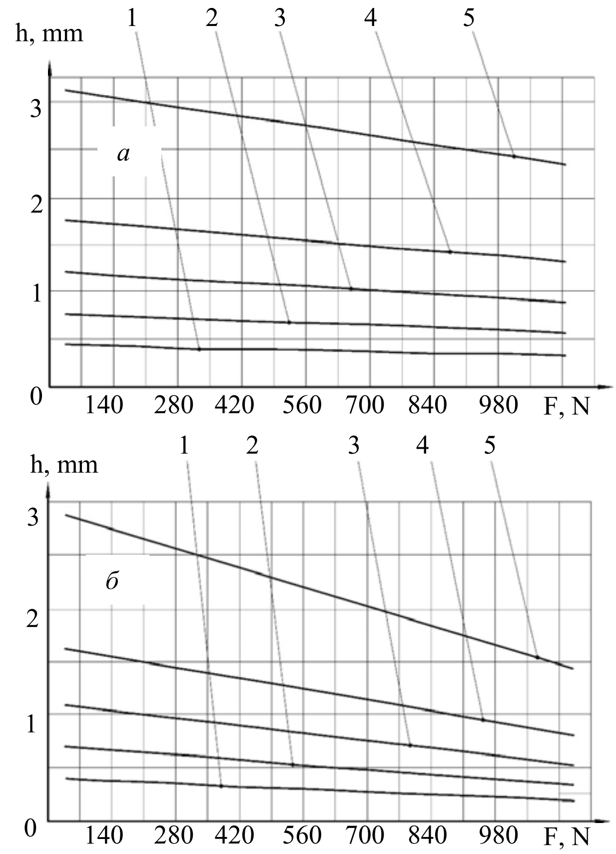

Figure 5. Correcting diagrams of displacement step recalculation: dispenser length 2,5 m (a) and 5,0 m (b) and diameters 1 – 6 mm, 2 – 8 mm, 3 – 10 mm, 4 – 12 mm, 5 – 16 mm

Table 2. Correlation between supply pressure and load to ensure fixed step

Supply pressure $p_{ж}$, bar			
60	50	40	30
Definition of step value Δh including load value by $p_{н}$			
$0,17 \cdot p_{н} + 2,86$	$-0,265 \cdot p_{н} + 2,61$	$-0,185 \cdot p_{н} + 1,93$	$-0,2 \cdot p_{н} + 1,456$
Approximation			
$\Delta h_m = -0,205 \cdot p_{н} + 0,4899 \cdot p_{пит} + 0,9875$			

Approximation should be used in control system to define numbers of pulse for dispenser in non-static conditions. Time of correction process in model is less 0.002 sec, that provide good swiftness for control circuit. Additionally, as feedback must be used pressure sensor, instead feedback by displacement. Controlling system will consist of tranceduser of feedback signal, controller and etalon simulation, with current parameters of system [4,9,10].

CONCLUSION

It is shown that the connecting pipelines of a hydraulic cylinder can be used, as dispenser in pressure line of actuator, to provide precision positioning of piston via controlled propulsions into piston chamber.

Were carried out dependencies between design parameters of dispenser and system features. The algorithm of control, based on propulsions and recalculations, were proposed for using in control curcuit without feedback of piston displacement.

Obtained data, via simulations and experiments, represented for using in approximation recalculation in dynamic conditions.

It is proposed using of pressure sensor, as feedback signal, additionally to simulation, to ensure high-precision of positioning.

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