# IMPROVEMENT OF THE HYDRAULIC SERVODRIVE WITH JET TUBE

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In hydraulic actuators of mobile and stationary machines hydraulic servodrives with spool valves and with jet tubes are applied. The common fault of all spool valves is the danger of clogging of small positive allowances between mobile elements that result in a failure of the hydraulic drive. Hydraulic servodrives with a jet tube are insensitive to the pollution of operating fluid and with it they ensure a high reliability of operation.

Jet hydraulic boosters reduce inertia and friction of movements owing to their high speed operation and responsivity. The precision of operation of servodrives with jet hydraulic boosters is a little bit higher than at drives with one-aperture control valves but lower, than at the drives with four-aperture control valves. The maximum efficiency of hydraulic servodrives with fluidic amplifiers has an intermediate value between the maximum efficiencies of servodrives about one and four-aperture control valves, however the simplicity of construction and safety in operation in some cases make them more preferable to fluidic amplifiers [1].

Deficiency of hydraulic servodrives is that perturbations, for example, from forces of shearing and a friction, influence performances of drives. It is possible to lower or to completely remove this effect by introduction of an additional feedback on loading. Servodrives in which, except for the basic head circuit of regulating, there is still an additional circuit of perturbations effects, are systems of the combined regulation. Constructions of hydraulic servodrives of the combined regulation are already industrially applied [2].

In hydraulic servodrives with fluidic amplifiers it is possible to implement a feedback on loading. In Fig. 1 the constructive circuit of such drive is exemplified. Operating fluid is fed by the pump 1 of a reservoir 2 through the filter 3 and under fixed pressure is discharged under pressure in a jet tube 5. The value of the pressure is measured on the manometer 4 and determined by an adjustment of the pressure control valve 6, and at its full closing – pressure drops in a turnpike from the pump up to the force nozzle of a jet tube. The signal of control Y is fed on the feeler 8, timbered on a bar 9 which is rigidly connected to a jet tube. The axis 7 turns on a jet tube hingedly supported on the case 10 agencies of the drive which can be displaced on a timbered stock 15. The jet tube has an opportunity to turn at a small angle on both sides around an axis, perpendicular to a plane of the drawing. Reception nozzles 11 are established in the case on elastic diaphragms 12, which form together with the case controlling chambers 13 and 14. The spring 17 constantly holds down the feeler to any controlling device, for example, to the master cam.

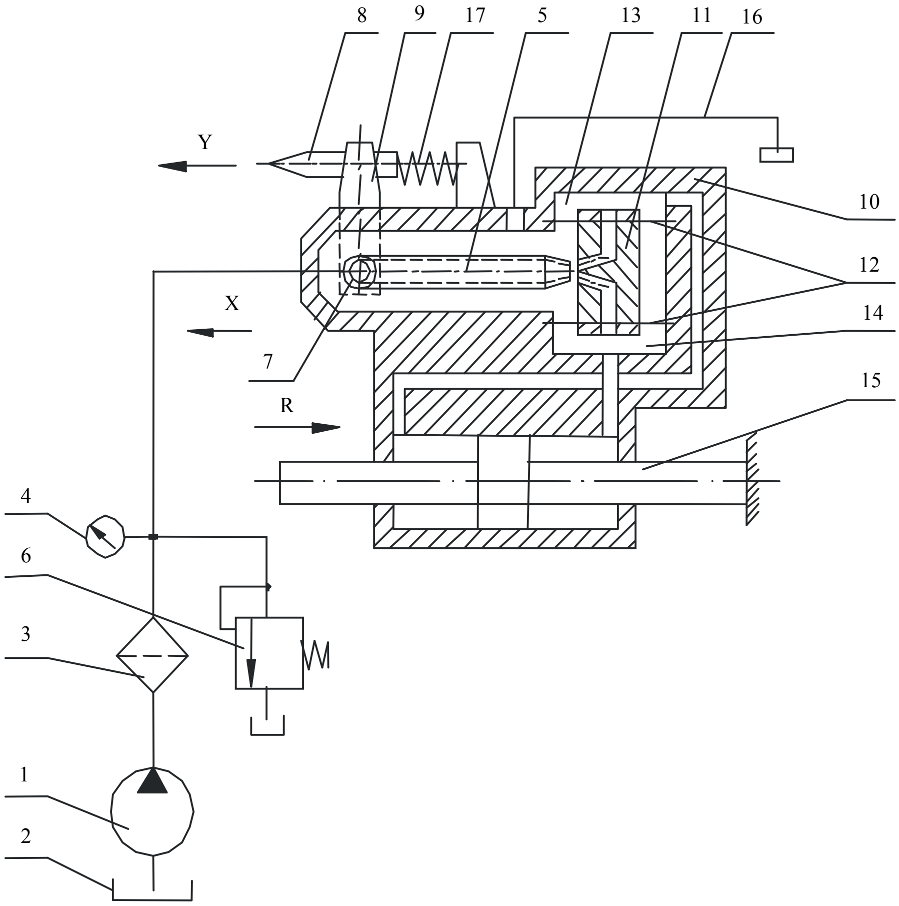


Fig. 1. The constructive circuit of a servodrive

The hydraulic servodrive works in the following way. The jet of the operating fluid outflowing from the force nozzle of a jet tube, has a defined amount of reserved kinetic energy. At a retardation of the fluid in the reception windows the kinetic energy passes into a potential energy of pressure. If the jet tube occupies an average position concerning the reception windows, the jet energy is uniformly arranged between the windows. Thus pressure values in controlling chambers and in cavities of an actuator appear equal. The turn of a jet tube occurs at an inequality of the controlling signal $Y$ and the coordinates of the operating mechanism.

The reception windows are connected to the cavities of an actuator in such a manner that a pressure differential originating at the turn of a jet tube, always has to be aimed to shift an agency in the direction of the controlling signal. At such migration the pivot axis of a jet tube, being propelled together with an operating mechanism, tends to return the tube to an average position concerning the reception windows. Due to this, in the drive, the rigid feedback at which the output coordinate of $X$ operating mechanism is compared to the value of the controlling signal $Y$ is carried out.

If loading $R$ is affixed to an agency (forces of shearing, friction, inertia of moving parts) for the compensation of an effect of loading, the reception windows will be displaced concerning the case. The magnitude of this displacement is directly proportional to the pressure differential in the cavities of an actuator (i.e. the value of loading) and inversely proportional to the rigidities of diaphragms. Therefore in the drive the additional feedback operating from the signal produced by the system is carried out at its loading. The feedback on loading redistributes the energy of the jet outflowing from the jet tube between the reception windows. The higher the value of loading, the greater the displacement of the reception windows and, accordingly, the higher the additional pressure differential, compensating the effect of loading. At the straightening sampling the rigidity of the diaphragm of the drive will be compensated on loading.

The engineering literature presents different approaches to mathematical exposition of the processes of interaction of a jet and streams in the reception windows. For the surveyed hydraulic servodrive it is convenient to use the technique which takes into account by means of Bernoulli's theorem the interconnection of speeds of secondary streams in the windows with the pressure of the fluid inside channels of the reception windows [3].

At the first stage the areas and overlapping of the windows of reception channels by the jet are determined geometrically (Fig. 2). The diameters of channels of the reception windows and the diameter of the nozzle of the jet tube are equal. Between the reception windows a connector, whose magnitude usually does not exceed 0.5 mm, is left.

It is possible to observe the diameter of the nozzle conterminous to an axis, as the sum of cuts included in it (the width of the connector, altitudes of segments and the hatched areas and displacement from a neutral position).

All the areas hatched in Fig. 2 will consist of two equal segments whose altitudes are determined by the expressions

$$h_1 = \frac{d_c}{2}\left[1 - \cos\left(\frac{\alpha_1}{2}\right)\right] \quad (1)$$

$$h_2 = \frac{d_c}{2}\left[1 - \cos\left(\frac{\alpha_1}{2}\right)\right] \tag{2}$$

where:

$d_c$ – diameter of the nozzle,

$\alpha_1$ and $\alpha_2$ – the corresponding central angles.

From expression (1) it is possible to find

$$\alpha_1 = 2\arccos\left(1 - \frac{2h_1}{d_c}\right) \tag{3}$$

Then

$$S_1 = \frac{\frac{d_c^2}{4}\left[\frac{\pi}{90^o} arc\cos\left(1 - \frac{2h_1}{d_c}\right) - 2\sin arc\cos\left(1 - \frac{2h_1}{d_c}\right)\cdot \cos arc\cos\left(1 - \frac{2h_1}{d_c}\right)\right]}{2} \tag{4}$$

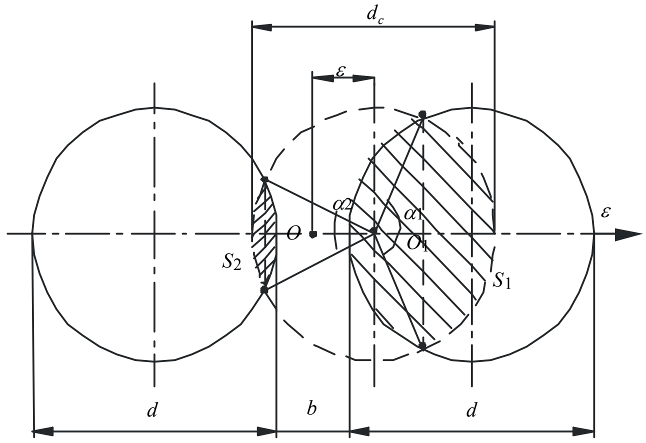


Fig. 2. The circuit of a zone of interacting of a jet with fluid streams in channels of a jet amplifying valve (cross-section)

Accepting for the base magnitude the full area of the circle with the diameter $d_c$ ($S_{max} = \pi d_c^2/4$), we obtain the relative value $\overline{S}_1$.

$$\overline{S}_1 = \frac{S_1}{S_{max}} = \frac{1}{180^o}\arccos\left(1 - \frac{2h_1}{d_c}\right) - \frac{1}{\pi}\sin\arccos\left(1 - \frac{2h_1}{d_c}\right)\cos\arccos\left(1 - \frac{2h_1}{d_c}\right) \tag{5}$$

The analogous value can be written down for $\overline{S}_2$.

It is possible to consider the diameter of the nozzle $d_c$, conterminous with axis $\varepsilon$, as the sum, including the cuts: width of a web $b$, altitude of segments $h_1$ and $h_2$ hatched areas $S_1$ and $S_2$, and also the displacement of a jet tube from neutral position $\varepsilon$.

For consequent calculations it is necessary to inject relative rates of the speed of an actuator $\overline{V} = V/V_{\max}$, pressures in take up channels of the windows $\overline{p}_1 = p_1/p_{1\max}$, $\overline{p}_2 = p_2/p_{2\max}$ and a tractive force $\overline{R} = R/R_{\max}$.

At the following stage the coefficients of restitutions of the pressure in the channels [3] are determined:

$$\overline{p}_1 = \left(\frac{\overline{S}_1 - \overline{V}}{1 - \overline{S}_1}\right)^2 \le 1 \tag{6}$$

$$\overline{p}_2 = \left(\frac{\overline{S}_2 - \overline{V}}{1 - \overline{S}_2}\right) \le 1 \tag{7}$$

The displacement of the cases of the take up windows under an operation of the pressure differential is

$$e = cS_{\mathrm{m}}\left(\overline{p}_1 - \overline{p}_2\right) \tag{8}$$

where:

$c$ – the rigidity of elastic diaphragms,
$S_{\mathrm{m}}$ – the area of diaphragms.

If the value $\overline{e} = e/e_{\max}$ is substituted in the equation (5) it is possible to define the change of the area under an operation of a pressure differential (analogously the new value $\overline{S}_2$ is determined). Then the new values are $\overline{p}_1$ and $\overline{p}_2$. The tractive force of an actuator is determined from the expression

$$\overline{R} = \overline{p}_1 - \overline{p}_2 - 2\zeta\overline{V}^2 \tag{9}$$

where:

$\zeta$ – factor of a liquid resistance of a hydroline between take up windows and a cavity of an actuator.

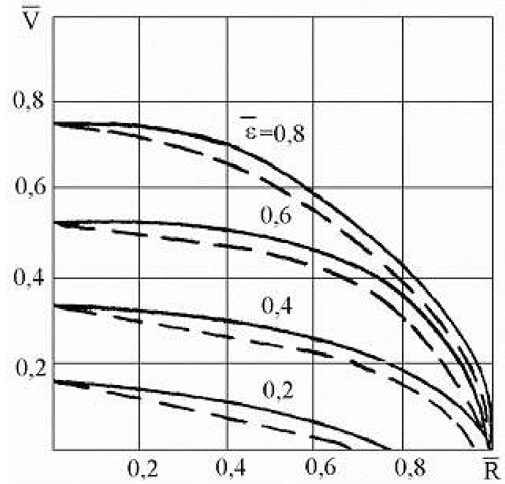


Fig. 3. A load characteristic of the servodrive

With the use of the expression (9) it is possible to build a load characteristic of an observed hydraulic drive (Fig. 3). Here analogous dependencies for the traditional circuit are reduced (dotted lines). Comparison of performances displays an increase in a the hydraulic rigidity of the drive at the introduction of a closed loop on loading. Introduction of a back coupling on loading in the jet tracking hydraulic drive has allowed to increase hydraulic rigidity, to lower a dead zone, to increase an efficiency of the drive. Such hydraulic drives can be applied in cutting machines, industrial robots and other machines. In addition to the analysis of the dynamics, it is necessary to test the stability saving of a tracking hydraulic drive.

## REFERENCES

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## SUMMARY

The construction of the hydraulic actuator with a jet tube in the capacity of a control element is considered. The feedback on loading that allows to increase hydraulic rigidity, decrease a dead zone of the hydraulic servo drive is implemented.