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Coordinate control of the proportional directional control valve

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Abstract

In this paper, we have considered the application areas of proportional directional control valves and current problems associated with them. It has been found that in existing hydraulic control valves with electromagnetic control (or control from a linear motor), the position of the spool is a function of the current flowing in the solenoid of the electromagnet, and also depends on disturbances, in particular, on changes in the random nature of the hydrodynamic force. In this regard, the relevance of replacing the power circuit of the mechanical system (spool – spring – electromagnet, with a geometric circuit – stepper motor – screw pair – spring – spool) is emphasized.

Keywords: Valve, hydraulic device, hydraulic proportional directional control valve;

1. Introduction

Hydraulic distributors are widely used in hydraulic systems to control the direction of flow and rate of throughput. The use of a proportional directional control valve (in comparison with a positional control valve) enables to obtain a number of functional advantages, such as: smooth control of flow and pressure through an electrical input signal, reducing energy consumption and simplifying the hydraulic circuit. The aim of this work is to identify existing problems in the management of proportional valve and justify the ideas to solve these problems.

2. Discussion

In [1], CFD was simulated and the influence of the profiling of the control edge on the magnitude of the hydrodynamic force was investigated. As a result, it was found that the profiling of the edge enables to reduce the angle of reaction force of the flow by seven degrees, in comparison with the non-profiled edge.

Later in [2], it was noted that because of too large flow forces, the use of single-stage directional control valves is impossible at high flow rates and pressure. The literature review revealed that a lot of work is done regarding the possibility of reducing the influence of the axial component of the hydrodynamic force. There is no doubt that this research gives positive results.

However, as it was noted in [3], all the proposed changes do not affect the strength of the transition process; therefore, they do not affect the time of its progress. In addition, in existing valves, there is a functional dependence of the position of the spool on the current in the solenoid.

To show the disadvantages of this dependency, we present the design scheme of the valve and the equations of its motion:

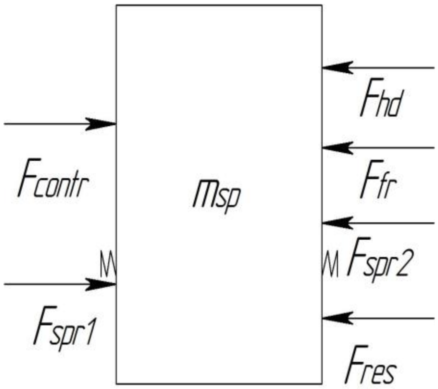

Fig. 1 Design scheme

$$m_{sp}\frac{d^2z}{dt^2} = F_{contr} + F_{spr1} - F_{spr2} - F_{fr} - F_{hd} - F_{res}$$

where m_{sp} is spool mass, z is spool movement, F_{contr} is control power, F_{spr1} *and* F_{spr2} are return spring forces, F_{fr} is spool friction force, F_{hd} is hydrodynamic force, F_{res} is resistance force, for example, from the side of the delay valve.

According to the presented scheme, the equilibrium position of the spool is ensured by equality to zero of the geometric sum of forces. If the balance is disturbed, the spool will move. Let us consider hydrodynamic forces. In the analysis of the facts presented in [1-4] we saw that the hydrodynamic force of the fluid flow has a significant effect on the stability of the spool in the proportional valve. This force is determined by the equation:

$$F_{hd} = \sqrt{\frac{1.28\gamma}{g\xi}} * \sqrt{\Delta p_w * Q},$$

where Δp_w is the pressure drop on the working window;
Q is the fluid flow rate.

In case of a rectangular shape of the working windows with zero overlap, the hydrodynamic force can be calculated by the following equation:

$$F_{hd} = c_{hd} * x$$

where c_{hd} is the stiffness of the hydrodynamic force of the fluid flowing through the spool windows.

The flow forces behave like a non-linear spring which rigidity varies depending on the pressure drop across the working window. In turn, the pressure drop is due to an external load, which value is random, in general. From the above, it follows that when the load changes, the balance of forces is violated and the position of the spool loses stability because it tends to occupy a new equilibrium position that is not identical to the given one.

In case of a closed system with a negative feedback on the position of the spool, the resulting mismatch will indeed be taken into account by the comparison device, and the signal going to the actuator will be corrected, but this will take time and will cause an oscillatory process. In addition, the presence of feedback will affect the cost.

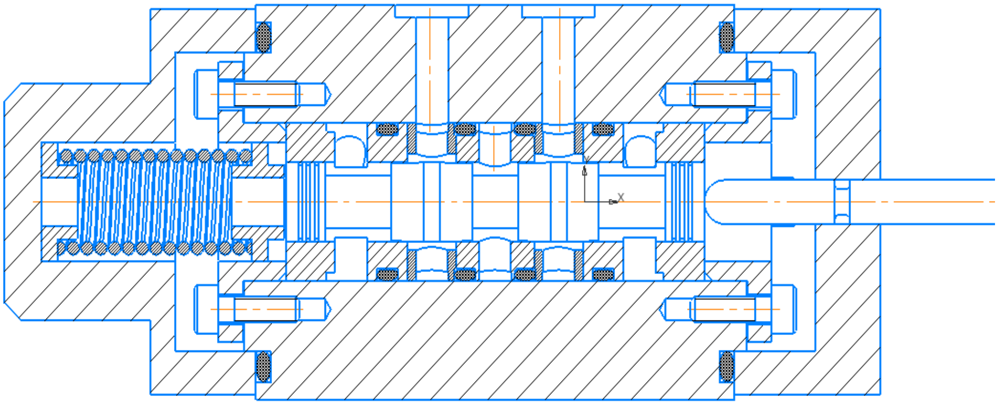

Fig. 2. Hydraulic proportional directional control valve

To reduce the influence of hydrodynamic force disturbances, the return springs must be rigid enough, but the spring force is a function of its deformation, thus during installing the springs along the ends of the spool, this force is equivalent to the linear displacement function of the spool. In extreme situations, this force is maximum.

We proposed to move away from the power circuit to the geometric one, whereby we came to the coordinate control. Instead of an electromagnet, we used a stepper motor and a ball screw. One end of the ball screw rested upon the butt end of the spool. The ball screw nut was free from slack.

The position of the spool in this case depends on the angle of rotation of the rotor and its constancy in the fluctuations of values of the resulting force is provided by the moment of holding the stepper motor and the force of pressing the spherical surface of the pusher against the spool end.

It is worth noting that the performance depends on the mass of the spool, stiffness of the spring and properties of the stepper motor. An important condition for the coordinate control is the constancy of the contact between the spool and the pusher.

This condition dictates the choice of such parameters as: spool mass and spring stiffness. In the end it can lead to a speed limit and impose its boundaries on the scope.

3. Conclusion

We noticed that the replacement of the power circuit of the mechanical system “spool - spring – electromagnet” with a geometric circuit “stepper motor - screw pair - spring – spool” enables to move away from the functional dependence of the position of the spool on the current strength of the electromagnet flowing in the solenoid, thereby advancing the constancy of performance and reducing the transition time. In addition, the use of a stepper motor instead of an electromagnet will increase the energy efficiency of the valve.

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