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Axial Piston Hydraulic Motor with Heightened Control Range

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Abstract

One of the main characteristics of hydrostatic drive based on axial piston hydraulic motor is a control range of rotating frequency of output shaft at rated load. This characteristic is defined by frictional forces stability in kinematic couplings and design features of this type of hydraulic motor. The article considers the structural scheme of the axial piston two-unit hydraulic motor with hydrostatic unloading of cylinder-piston coupling. Preliminary results of the hydraulic motor prototype testing designed according to this scheme are described.

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Keywords: hydraulic motor; hydrostatic drive; rotating frequency; control range; piston; cylinder

1. Introduction

One of the main tasks in the design of hydrostatic drive based on the axial piston hydraulic motor is to get a maximum control range of rotating frequency of the hydraulic motor output shaft which is defined as the ratio of the maximum to the minimum frequency at rated load on the shaft [1-4]. This ratio depending on the size of the hydraulic machines can reach up to 30-50 under load with a pressure of the 25-35 MPa. It is important that dead zone, i.e. minimum frequency will be as small as possible. Control range is mainly determined by the design type of axial piston hydraulic machines used as hydraulic motors [1, 2]. For example, axial piston hydraulic motors with tilted block have a maximum rotating frequency of 260s^{-1}, and minimum of 5s^{-1}. Axial piston hydraulic motors with tilted disc have these values of 250s^{-1} and 10s^{-1} respectively [2]. Obviously, the high values of the minimum rotating

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frequency increase the dead zone of this type of drive, thereby limiting the scope of their use. Such values of the minimum rotating frequency appear due to high values and instability of frictional forces acting at piston groups, distribution mechanisms, as well as some of the design features of this type of motors. Besides, these factors greatly increase the loss of value in the efficiency of the motor when operating at low rotating frequency. Developing designs of the axial piston hydraulic motors which have lower minimal rotating frequency can increase the control range [5, 6], thereby expanding the scope of usage for this type of drive. This can be done by reducing the loss in friction pairs of hydraulic motor or changing its design.

2. Proposed solution

In the article it is proposed a design solution of the problem of decreasing minimal rotating frequency. Figure 1 displays the design of the axial piston two-unit hydraulic motor with heightened control range which was developed in The Baltic State Technical University on the Applied Mechanics and Automation chair [7].

Axial piston hydraulic motor on fig. 1 has two cylinder blocks 1 and 2 mounted on bearings in the casing 3 at an angle to one another, and angular displacement of blocks synchronizer configured as a pair of bevel gears 4 mounted on the outside of each block. Cylinder blocks are supported in end control valves 5 and 6, channels of which communicate with external hydraulic lines 7 and 8. Pistons 9 of one of the blocks are connected by means of rigid curved rods 10. Moreover the link of rod 10 with the piston 11 is designed in the form of a ball joint 12. In the piston and rod there are channels 13, which connect cavities 14 of cylinders of both blocks.

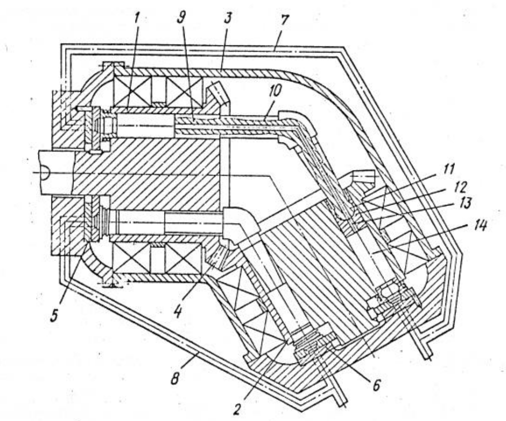

Fig. 1. Constructive scheme of the axial piston two-unit hydraulic motor.

Hydraulic motor operates as follows. In one of the hydraulic lines 7 or 8 hydraulic fluid is supplied under pressure. Getting into the cylinders 1 and 2 units, liquid, putting pressure on the underside of the pistons 9 and 11, creates axial forces of equal magnitude. In this case, the interaction between pistons and cylinders produces equal torques on blocks. Torque on the cylinder block 1 is taken by a drive shaft, and the torque from the engine block 2 is transmitted to the cylinder block 1 by a pair of gears 4. The design of connection between piston rods of one block and pistons of another block in the form of a ball joint allows the pistons to self-align inside of blocks, excluding the possibility of jamming of the piston and providing a uniform load distribution along the surface of the piston, creating a torque on the shaft. This design ensures the stability of the friction forces in the piston groups for all modes of operation of the hydraulic motor and reduces the value of the minimum rotating frequency at rated load. Nevertheless, the magnitude of frictional forces in the conjugation, and therefore loss, will have high values.

3. Design solution

One way to reduce the frictional forces (see fig. 2) in piston-cylinder coupling is to provide hydrostatic unloading of the coupling. For this purpose, the supporting surfaces of the pistons 1, 2 have symmetrically positioned inclined locked grooves “a”, fluidly connected with the subpiston cylinder cavity. Pin 3 holds the piston 2 from rotating about its axis, providing a constant parallel of grooves "a" of the pistons 1, 2. Supporting inclined surface “b” of the pistons is also a sealing surface. Hydrostatic pressure "q", is applied on the inclined surfaces of the pistons formed by the inclined grooves "a" and creates a force P_1 and P_2, which are mutually balanced.

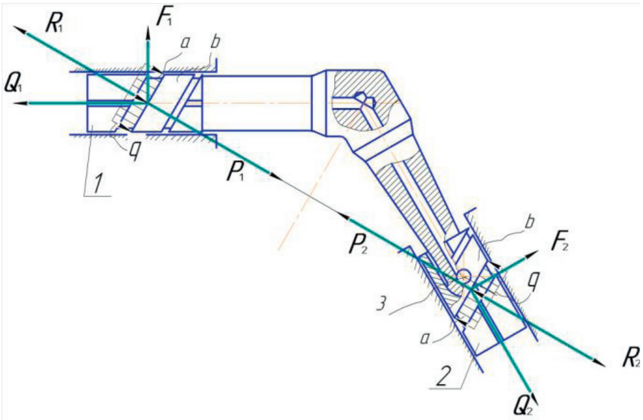

Fig. 2. Hydrostatic unloading of the piston-cylinder coupling.

Hydraulic reactions R_1 and R_2, equal to P_1 and P_2, exerted by the pistons on the cylinder, create axial forces Q_1, Q_2 and radial forces F_1 and F_2. Axial forces are perceived by hydraulic distributors of cylinder blocks. The radial hydraulic forces F_1 and F_2 act on the lateral surface of the cylinders and create a torque on the hydraulic motor shaft. Thus coupling piston-cylinder is hydrostatically unloaded and it becomes possible to virtually eliminate immediate contact of the piston surface and the cylinder, even at low speeds of their mutual displacement, which will greatly reduce the friction loss in this coupling.

4. Expected results

After the necessary strength calculations and design studies the prototype of the axial piston two-unit hydraulic motor was made with hydrostatic strain of piston-cylinder coupling of working volume $90\times10^{-6}m^3$/rev and nominal pressure 30MPa (see fig.3). Specifications of the hydraulic motor were determined by its operation as motor in closed-loop hydrostatic drive. Loading of hydraulic motor shaft was made by a special powder brake.

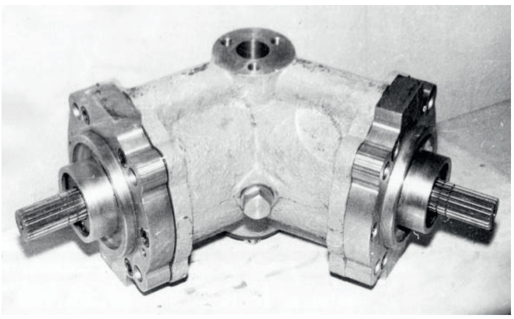

Fig. 3. The prototype of the axial piston two-unit hydraulic motor.

The testing of the hydraulic motor prototype showed the following preliminary results. The pressure drop in the lines at which the breakaway of hydraulic motor at no-load happens does not exceed 0,005MPa, indicating low loss in friction pairs. Minimum rotating frequency of hydraulic motor at a nominal pressure 30MPa did not exceed $0,1s^{-1}$. Nominal rotating frequency at rated load was $210s^{-1}$, which provides a control range of around 2000. Mechanical efficiency of hydraulic motor at nominal pressure was not lower than 0.97.

Conclusion

Analysis of hydrostatic drives based on the axial piston hydraulic machines showed that their control range can be increased by reducing the minimum rotating frequency of hydraulic motor shaft. Design solution of the problem was presented in this paper.

The main idea of design development of axial piston two-unit hydraulic motor was to provide hydrostatic unloading of the piston-cylinder coupling. Emphasis was made on production and testing the prototype of the hydraulic motor. The prototype provides the following results:

- A minimum rotating frequency at rated load of not more than $0,1s^{-1}$
- Control range of 2000
- High mechanical efficiency at rated load when operating at low rotating frequency

The logical next step would be endurance testing of the axial piston two-unit hydraulic motor prototype.

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