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Analysis of non-spool throttle flow dividers for synchronous hydromechanical drives

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Abstract. Relevance and goals. Hydraulic drives of modern mobile machines and technological equipment are, as a rule, branched and multi-circuit. At the same time, there is often a need to ensure synchronous (coordinated) movement of two or more independent hydraulic motors. The analysis of the conducted studies has shown that throttle flow dividers are the most suitable for providing automatic control of hydraulic drives. The use of spool flow dividers in general-purpose hydraulic drives, especially if they work in harsh conditions with high dustiness of the environment is impractical. Materials and methods. The article provides an overview of existing designs of non-spool throttle flow dividers for synchronous hydromechanical drives, their design schemes and operating principle are given. A comparative analysis of the functions performed by them and the quality of work is carried out. Suggestions are given on the principles of selecting a particular design of the flow divider, depending on the operating conditions. Results. A scheme of a test bench for piston hydraulic cylinders with energy recovery is proposed. A mathematical model of the stand has been developed and an example of a preliminary calculation of its functioning is given. Conclusions. The conclusion is made about the design features that make it possible to ensure the synchronous operation of hydraulic drives with high accuracy at minimal cost.

1 Introduction

Hydraulic drives of modern mobile machines and technological equipment are, as a rule, branched and multi-circuit. At the same time, there is often a need to ensure synchronous (coordinated) movement of two or more independent hydraulic motors. So, for example, it is necessary to ensure simultaneous movement with equal speeds of two hydraulic cylinders for moving the reel of the harvester harvester in the vertical and horizontal planes. A similar task is also in the bending press, the punch, which is moved by two hydraulic cylinders located at a distance of more than three meters from each other, while its movement should be flat parallel. In the hydromechanical brush drive system of the airfield sweeper, it is necessary to synchronize the rotation of hydraulic motors that transmit torque to the brush shaft from its different sides.

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2 Material and research methods

Studies have shown [1] that it is advisable to solve such problems using throttle flow dividers (DP) and throttle flow dividers (DSP), which are designed to ensure synchronous (coordinated) movement of hydraulic motors regardless of the load on them. The throttle flow divider includes three main elements: a sensing element, a setting device and a shut-off and control element.

The flow dividers currently used both in our country and abroad use spool pairs as a shut-off and regulating element. The simplest example of such a divider is a flow divider of the G75-6 type, used in particular in technological equipment. These flow dividers have inherent disadvantages characteristic of all hydraulic devices with spool shut-off and regulating elements.

The manufacturing technology of precision spool pairs is very complex, it includes a large number of high-precision operations (grinding, honing, etc.), which increases their cost. When assembling spool pairs, such operations as fine-tuning or selective assembly are used, which makes them practically non-repairable, and this in turn increases their operational cost, in addition, they are very sensitive to the quality of the working fluid, to which very high requirements are imposed.

In connection with the above, the use of spool flow dividers in general-purpose hydraulic drives, especially if they work in harsh conditions with high dustiness of the environment, including in hydraulic drives of forging and stamping equipment, is impractical.

In recent years, attempts have been made in a number of countries around the world, including Russia, to create a design of a throttle flow divider that would contain a shut-off and control element different from the traditional one - a spool.

An example of such a design is a spring-type flow divider [1-5], the design scheme of which is shown in Figure 1.

The principle of operation of a spring-type flow divider is the same as that of a spool, but the role of a shut-off and regulating element here is performed by springs together with a flexible membrane element. In this design of the flow divider there are no movable precision pairs, which increases the reliability of operation. However, it also has a number of serious drawbacks:

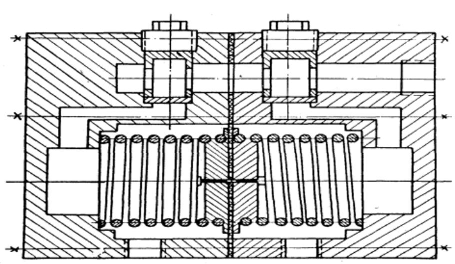

Fig. 1. Spring type throttle flow divider

- firstly, the role of adjustable hydraulic resistances here is performed by the inter-turn gaps of the spring, which imposes very strict requirements on the accuracy of their design dimensions;
- secondly, the stiffness of the springs and the membrane element significantly affect the accuracy of the divider;
- thirdly, a pressure drop corresponding to the pressure drop in synchronized hydraulic motors acts on the membrane element separating the output chambers, which significantly reduces the accuracy of the divider.

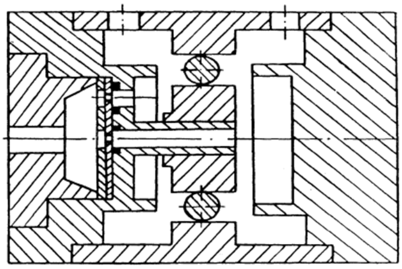

Fig. 2. Throttle flow divider with a regulator in the form of an elastic ring

Another way to avoid moving precision pairs in the flow divider is to use an elastic ring as a shut-off and regulating element [6-9]. Figure 2 shows the design diagram of such a flow divider. The principle of its operation is similar to the principle of the spool flow divider, and the functions of the spool here are performed by a movable elastic ring (for example, rubber).

The disadvantages of this design are that:

firstly, when moving the locking and regulating element, it is necessary to overcome the friction forces at the places of its contact with the housing, which significantly increases the synchronization error;

secondly, a pressure drop corresponding to the pressure drop in synchronized hydraulic motors acts on the sealing ring outside the throttling gap, which also worsens the quality of the divider.

In a number of DDP designs [10-16], elastic cylindrical shells are used as shut-off and regulating elements. An example of such a flow divider [17] is shown in Figure 3. The use of elastic shells in dividers made it possible to completely eliminate the need for the use of rubbing movable elements, but at the same time introduces its own specific disadvantages. So in the flow divider (see Fig. 3) there are different control conditions in the branches, which requires special adjustment of the sensitive elements (input chokes). This setting, in turn, depends on the flow rate of the liquid at the inlet to the divider and on the elastic properties of the shell itself.

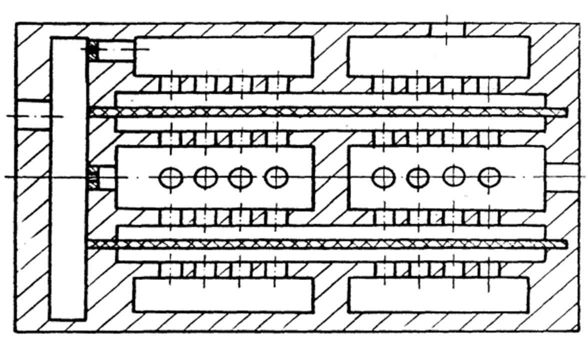

Fig. 3. Throttle flow divider with cylindrical membrane

The flow divider [18-20] is a non-interlocked throttle flow divider, the spring setpoint here is the elastic shell itself, which requires its manufacture with strictly defined elastic properties. This divider also involves the restructuring of sensitive elements when the flow rate changes through it. In addition, over time, the elastic properties of the shell material change, which again requires a corresponding adjustment of the sensitive elements.

The need to adjust the sensing elements when changing the fluid flow and elastic properties of the shell imposes significant restrictions on their use in mobile machines and technological equipment, the flow of working fluid in hydraulic systems which can vary widely during operation.

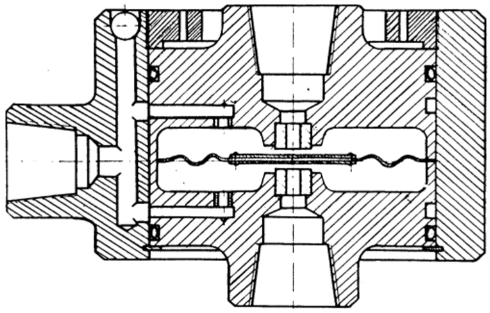

Fig. 4. Throttle flow divider with a regulator in the form of a flat membrane

Figure 4 shows the design of the throttle flow divider, in which the functions of the shut-off and control element are performed by a flexible diaphragm element with a rigid center in combination with adjustable hydraulic resistances of the flat valve type.

This divider has mechanically interlocked set points - the same membrane simultaneously participates in the control of variable resistances of both branches.

There are known designs of flow dividers using variable hydraulic resistances such as a flat valve with hydraulic locking [8], the scheme of such a flow divider is shown in Figure 5.

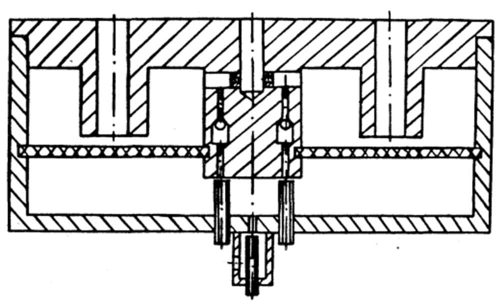

Fig. 5. Diaphragm type throttle flow divider with hydraulic locking

Here, to control the variable resistances of each branch, its own membrane elements are used, connected to each other hydraulically by means of a liquid enclosed in a closed volume.

There are completely no movable rubbing pairs, which significantly increases the reliability of their operation and eliminates the influence of the quality of the working fluid on the control process. However, the adjustable pressure drop in them, as in dividers manufactured according to the scheme shown in Figure 4, affects the shut-off and control element, causing an increased synchronization error.

The main disadvantage of membrane flow dividers with variable resistances of the flat valve type is that the pressure drop that occurs at the output resistances during operation of the divider affects the membrane element during regulation. This is the reason for their very unsatisfactory operation in the steady state.

Figure 6 shows a flow divider, in which the sensing element is made not in the form of permanent chokes, but in the form of variable resistances of the flat valve type, which makes it possible to compensate for the effect of an adjustable pressure drop on the shut-off and control element, which significantly improves operation in static mode, but leads to complication of its manufacture, since it requires the use of membrane elements with strictly specified elastic properties.

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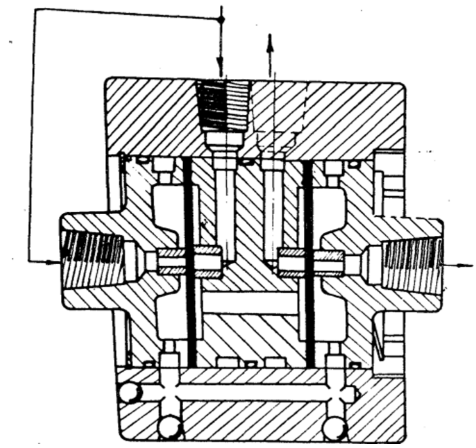

Fig. 6. Diaphragm type throttle flow divider with variable input resistances of the flat valve type

Another way to exclude the influence of an adjustable pressure drop on the executive control element is used in the design of the flow divider [20-22] shown in Figure 7.

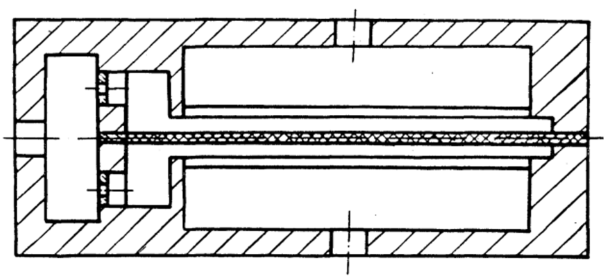

Fig. 7. Throttle flow divider of membrane type with outlet openings in the form of slits

Here, unlike the flow divider shown in Figure 4, the membrane element does not have a rigid center, and the outlet openings are made in the form of narrow slits. The hydraulic resistance of the outlet slots is controlled by partially overlapping them with a membrane element. At the same time, the adjustable pressure drop affects the part of the membrane element that lies on the gap and does not participate in regulation, and the absence of a rigid center makes the membrane element practically indifferent to small-scale movements.

The high accuracy of the described flow divider makes it very promising from the point of view of application in non-reversible synchronous hydraulic drives.

Another way to improve the accuracy of a diaphragm-type DP with variable hydraulic resistances of the flat valve type is to compensate for the effect of an adjustable pressure drop in the branches on the shut-off and control element, which was carried out in a number of designs of flow dividers.

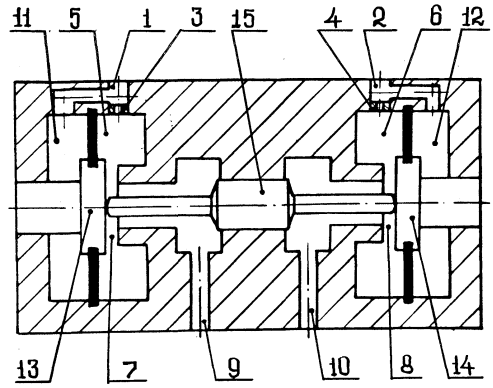

Fig. 8. General view of the membrane type flow divider with compensation rods

Figure 8 shows a design diagram of a throttle flow divider with a compensation rod, the principle of operation of which is as follows.

The working fluid enters the control chambers 5,6 through the inlet openings 1,2 and the inlet resistances 3,4, and through the outlet resistances of the flat valve type 7 and 8 - into the outlet openings 9 and 10. If the loads in the branches are the same, then the flow rates through the input resistances 3 and 4 are the same, and therefore the pressure losses on them are the same.

In this case, the pressures in chambers 5 and 6 differ by the same amount from the pressures in their respective auxiliary chambers II and 12. Since the effective areas of the membrane elements 13 and 14 are the same, then the forces from the pressure drop on them transmitted to the movable rod of variable cross-section 15 are also the same, and since they are directed in opposite directions, the membrane elements will remain stationary, and the pressure losses on variable resistances of the flat valve type 7 and 8 are equal.

If in one of the hydraulic motors connected, for example, to the outlet 10, the load is greater than in the second, then the flow rate in this branch, and therefore through the input resistance 4, will decrease, and the pressure drop on this resistance will decrease. As a result, the force of the pressure drop on the membrane element 14 will be less than on the membrane element 13. This will lead to the movement of the rod 15 together with the membrane elements 13 and 14 towards the closure of the variable resistance 7. Its hydraulic resistance will increase, and the costs in the branches will level out.

3 Results and discussion

The introduction of a movable rod of variable cross-section into the design makes it possible to compensate for the effect of an adjustable pressure drop on the membrane elements, which significantly improves the static characteristics of the divider. The presence of the same rod of variable cross-section allows for a constant volume of control of the divider, which increases its dynamic capabilities.

In addition, in this design, the membrane elements always experience pressure drops in one direction, which allows the use of both flat and corrugated membrane elements. This, in turn, makes it possible to vary the stiffness of the membrane elements in a wide range, including zero.

Thus, in the design of the divider under consideration (see Fig. 8) it is possible to regulate the ratio of expenses in the branches depending on changes in working conditions, which none of the DDP described above allows. And the fact that when regulating the divider, not the pressures in the branches are compared, but the pressure losses on the throttles, allows it to be used both for the purpose of dividing and for the purpose of summing flows.

4 Conclusion

The analysis shows that of the presented throttle flow dividers of non-spool type, the flow dividers presented in Figures 7 and 8 are of the greatest interest from the point of view of their use in synchronous hydraulic drives of technological machines, which make it possible to ensure synchronous operation of hydraulic drives with high accuracy at minimal cost.

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