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## Methods of dealing with mutual loading of joint hydraulic actuators

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# Methods of dealing with mutual loading of joint hydraulic actuators

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## Abstract

When developing a hydraulic actuator with several executive engines, it is necessary to take into account their mutual influence on each other, caused by many reasons - technological errors in the manufacture of parts, compressibility of the working fluid, pipeline contamination, etc. In practice, the problem of interference is encountered when using actuators with actuators of translational movements - hydraulic cylinders. In this case, the mutual loading is the greater, the greater the desynchronization of the executive engines. Therefore, we need to achieve synchronization of hydraulic cylinders. This article discusses possible methods for solving this problem.

## Introduction

In a hydraulic actuator with several executive engines, it is important to achieve synchronization of the executive engines. In case of non-simultaneous operation of several hydraulic cylinders, their mutual loading occurs [1] - [4]. Mutual influence is caused by many factors: compressibility of the working fluid, different values of overlap in hydraulic distributors, inequality of resistance of hydraulic lines, different loads on hydraulic rams, etc. Since improving the methods of controlling, the amount of overlap does not allow leveling other causes of mutual loading, and errors in forming equality overlaps are inevitable, this method can only be used in combination with other methods. Mechanical synchronization methods also do not eliminate the above factors. Therefore, this article will consider various methods of leveling mutual loading in order to obtain general recommendations for solving this problem.

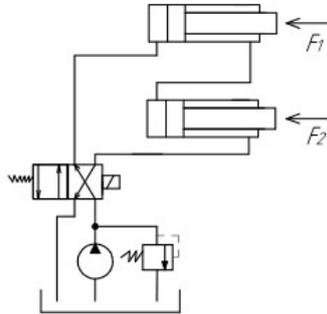
### Methods of dealing with the mutual loading of executive hydraulic motors

Sequential connection of hydraulic cylinders (see Fig. 1) does not solve the problem of mutual loading even under the condition of perfect synchronization of hydraulic cylinders - the pressure in the discharge cavity of the leading hydraulic cylinder is determined by the sum of the pressure drops on both hydraulic cylinders.

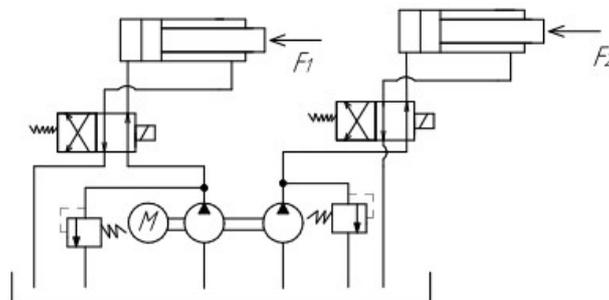
Synchronization of hydraulic cylinders with different loads can be ensured by using a two-piece pump (Fig. 2). The disadvantages of the system are limited range of two-piece pumps, relatively low accuracy, due to the manufacturing error and pollution of the hydraulic system, which increases the resistance of hydraulic lines.



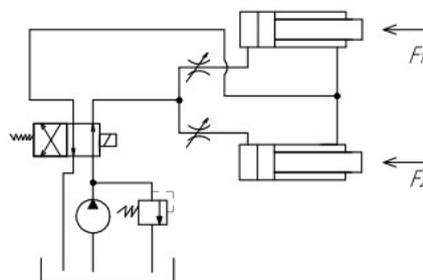
One of the simplest methods for synchronizing the operation of hydraulic cylinders is using throttles (Fig. 3) installed in front of the hydraulic cylinders and tuned to the same flow rate of oil passing through the hydraulic lines.



**Fig. 1.** Series Hydraulic Cylinder Coupling

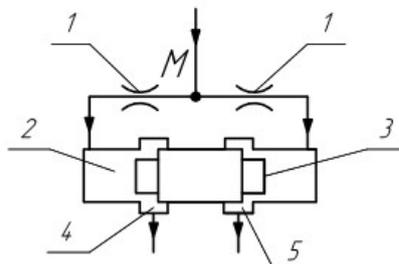


**Fig. 2.** Hydraulic drive scheme with a two-piece pump

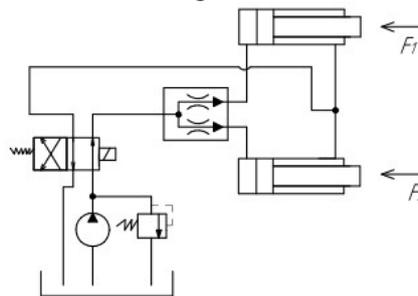


**Fig. 3.** Synchronization scheme using throttles

The most common method is the use of a flow divider (Fig. 4), the principle of which is based on self-regulating throttling [5]. At point M, the flow is divided into two, each of which passes through a constant throttle 1, and then supplied to sleeve 2 with a floating piston 3 regulating the size of the area of the holes 4 and 5. The piston stops when pressure and flow in the right and left cavities of the sleeve. Therefore, the output speeds of both hydraulic cylinders (Fig. 4) will be equal. Synchronization accuracy is from 1 to 5% and depends on the difference of loads on the rods.

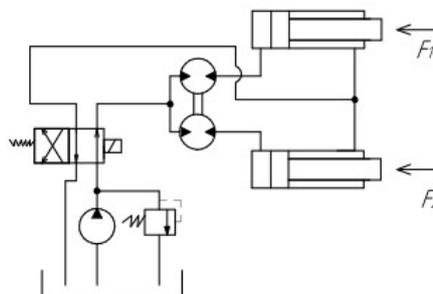


**Fig. 4.**Schematic diagram of the flow divider.



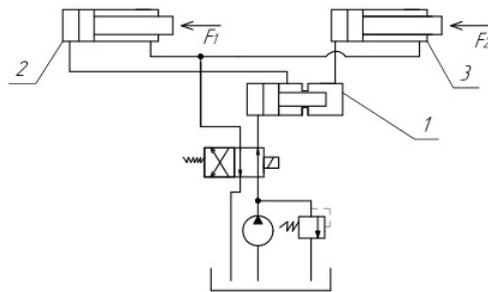
**Fig. 5.**Synchronization scheme using a flow divider.

Another common method is to use a pair of unregulated hydro motors (see Fig. 6), which will be interconnected by a rigid shaft to ensure equality of costs at the outlet of the hydro motors. In case of inequality of costs, one of the hydro motors goes into pump mode and restores equality of flows in the hydro lines. Synchronization accuracy depends on the type of hydraulic motors and reaches 1% when using axial-piston machines [6].



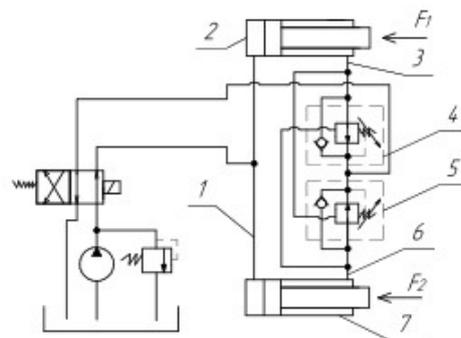
**Fig.6.**Synchronization scheme using hydraulic motors.

An energetically beneficial method of synchronization is the use of a reciprocating dispenser (Fig. 7). The hydraulic cylinder 1 performs the role of a metering device, providing synchronization of the hydraulic cylinders 2 and 3 with an error value of not more than 0.4 mm when lifting loads by 250 mm. The disadvantage of the method is an increase in the execution time of operations and large dimensions of the system.



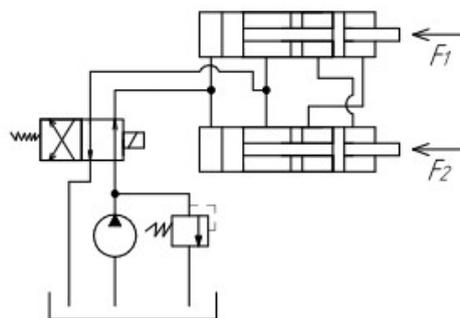
**Fig. 7.** Synchronization scheme with the use of a linear motion meter.

Very interesting and relatively simple in execution are systems with synchronized backpressure (Fig. 8). The principle of operation is that stopping cylinder 2 causes the oil supply to open valve 5, valve 5 closes line 6 and stops cylinder 7. This method was implemented in the lift system of the weighing machine in a system with sequential cylinders, [6] and was obtained 1 mm error for 250 mm stroke.



**Fig. 8.** Synchronization with backpressure

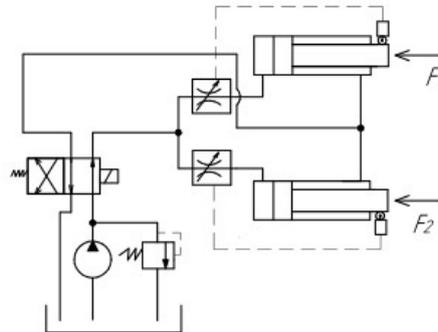
The use of tandem cylinders to synchronize the course has proven itself with asymmetric loads. The synchronism of the stroke is achieved by maintaining the same pressure in the rod cavities (Fig. 9).



**Fig. 9.** Schematic diagram of the drive using tandem cylinders

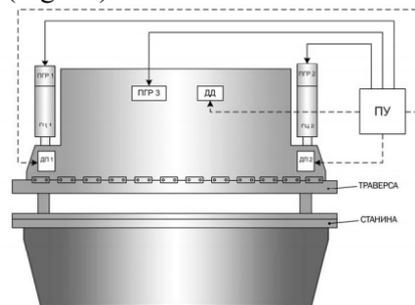
To improve the accuracy of synchronization, they began to try to apply methods using sensors and regulators. For example, a hydraulic circuit using throttles (see Fig. 3) can be supplemented by adding linear sensors to the circuit that measure the extension of the hydraulic cylinder rods (Fig. 10). At the slightest deviation of the parameters of the first sensor from the second, the sensor gives an electrical

impulse to the throttle, which in turn opens or closes the throttle valve, thereby regulating the flow to each cylinder.



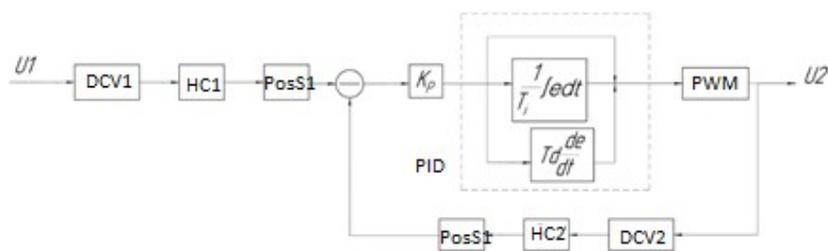
**Fig. 10.** Scheme of synchronization of hydraulic cylinders using linear sensors

Another method using linear sensors is a system with master and slave hydraulic cylinders. This scheme is applied in a press brake (Fig. 11).



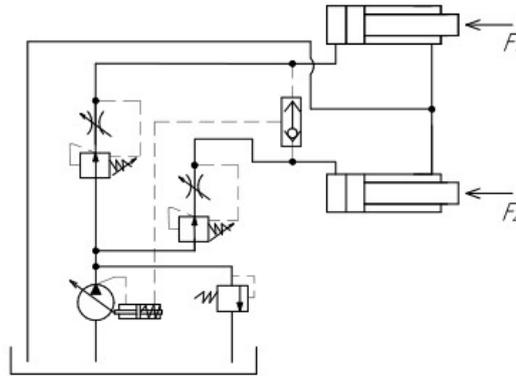
**Fig. 11.** Diagram of the control system and control hydraulic press

This system consists of proportional directional control valves (DCV), a control panel (CP), position sensors (PosS), a pressure sensor (PS) and hydraulic cylinders (HC). In the machine to control the linear movement of the cylinders used absolute optical displacement sensors, transmitting signals to the microcontroller, which, according to a given algorithm, generates a control signal for the slave cylinder. To reduce the error, the PID controller is used, shown in the block diagram of the control system of hydraulic cylinders (see Fig. 12). It should be noted that this model of the regulator could be changed [7]. The developed control system made it possible to achieve synchronized movement of hydraulic cylinders with an accuracy of 0.05–0.01 mm. The use of multi-coordinate control is required for the systems moving in three-dimensional space.



**Fig. 12.** Hydraulic cylinder control block diagram

Considering the problem of mutual loading, it should be noted systems in which different load on the hydraulic cylinders. It is necessary to distinguish the hydraulic scheme of the system with LS-regulation (Fig. 13), in which the first hydraulic cylinder maintains a constant speed regardless of the load on the second hydraulic cylinder [8]. This system combine's volume and throttle control.



**Fig.13.**Hydraulic circuit with LS-regulation

### Research results

1) For synchronization of hydraulic cylinders with approximately the same load on the rods and synchronization accuracy up to 5%, it is possible to apply circuit methods based on throttling.

2) Synchronization with the help of volumetric regulation allows achieving an order of magnitude greater order of magnitude than with throttle regulation with less power consumption, the asymmetry of the load has less effect.

3) The greatest accuracy is achieved with the help of displacement sensors and various regulators, well proven in other areas of technology [9] - [13]; the asymmetry of the load has the least effect.

### Conclusions

The application of the methods directly depends on the specified accuracy and the difference in loads on the hydraulic cylinders. For drives of low accuracy and rare inclusion, methods based on throttle control should be applied. These methods are simple, cheap, but energetically unprofitable. For drives of greater accuracy and higher switching frequency, one should either use volumetric methods for solving the problem, or use various sensors. However, their implementation is more expensive and not always constructively possible. The choice between these two directions should be made because of considerations of the required accuracy (linear sensors are needed for greater accuracy) and energy efficiency (volumetric synchronization methods have the best efficiency). It should be noted that the most common regulator is the PID controller, which has been used in many systems [14] - [21].

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