

# Self-Adjusted Fluid Drive of Translational Motion

K.S. Ivanov

**Abstract—** Now in fluid engineering the fluid drives with one degree of freedom are used. Such drive provides univocal constraint between input and output links motion. However it is necessary to use the variable transfer ratio between input and output links for overcoming of variable resistance force and inertia forces. Use of electronic control systems for force and volume regulating leads to extreme complication of drives, decrease of their reliability, raise of manufacturing cost and service. Recently the principle of creation of the fluid-flow self-controlled mechanism by use of fluid system with two degree of freedom has been developed. In the paper the compact adaptive mechanism which provides force self-regulation without a control system is developed on this principle.

**Index Terms—** fluid drive, self-regulation, fluid adaptive mechanism, closed fluid contour

## 1. INTRODUCTION

The fluid drives of translational motion are intended for transfer of motion from the pump to executive tools of machines. The control, change of speeds and reverse are controlled and automated by means of fluid drives [1].

Now in fluid engineering the fluid drives with one degree of freedom are used. Such drive provides univocal constraint between input and output links motion. However for overcoming of variable force of resistance it is necessary to use the variable transfer ratio between input and output links. The adjustable fluid drive should contain a complex fluid control system.

Canadian Space Agency (CSA) engineers have developed an innovative method for the emulation of electrical actuation by using fluid actuators for robotic systems. Inventor Wen-Hong Zhu has created the Adaptive Output Force Tracking Control Device of Fluid Cylinders [2]. From this invention a commercial product was created that has a control algorithm, including a software package. This product also offers a sophisticated parameter tuning procedure for adaptive control of fluid actuators and ancillary equipment for robotic applications.

The presented control system contains the strain sensors taking into account the Coulomb -viscous friction, the control unit of output force, the feedback, the device of updating of the friction model parameters etc. Such control system appears too complex and does not provide the instant reaction and adequate work.

Use of systems of electronic control for force and volume regulating leads to extreme complication of drives, decrease of their reliability, raise of cost of manufacturing and service.

The electronic control system should contain in fluid engineering numerous sensing transducers, amplifiers, feedback systems, converters of signals etc. Fluid engineering should use adjustable valves, butterfly governors, slide valves, pressure regulators etc [1].

The operated fluid engineering represents the most complicated mechanical system. Such system demands constant adjustment to working conditions. It is not capable to provide absolute and continuous adequacy of motion of an end effector to a variable load with an inertia forces. Such fluid system has changing temperature properties of a liquid, a friction and other factors.

The operated fluid engineering has low reliability, high cost and demands highly skilled service.

Recently the principle of creation of the fluid-flow self-controlled mechanism on the basis of use of the closed stream in system with two degree of freedom has been developed [3, 4].

Ivanov K.S. has developed and has taken out a patent for the adaptive fluid-flow mechanism [5]. However in the presented aspect the mechanism is difficult for practical purposes using because of the big sizes and inconsistency of movements of links in the presence of two degree of freedom.

The purpose of the present work is to develop the compact circuit design of the self-controlled adaptive fluid-flow mechanism in which the co-ordinated motion of links takes place.

Researches are executed on the basis of mechanics and hydraulics laws.

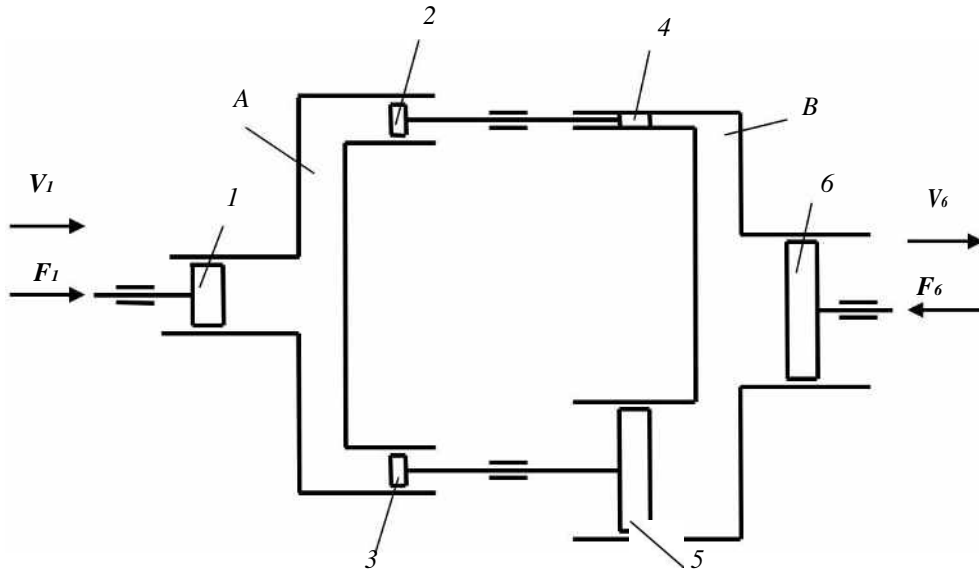
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**2. Description of the adaptive fluid mechanism**

The adaptive drive of the piston of the fluid mechanism is presented on fig. 1.

The drive contains input reservoir *A* , output reservoir *B* , the input piston 1, intermediate blocks of pistons 2-4 and 3-5 and output piston 6. Pistons 1, 2, 3 are placed in cylinders of input reservoir *A* . Pistons 4, 5, 6 are placed in cylinders of output reservoir *B* . We will denote  $S_i; i = 1...6$  - the squares of pistons.  $V_i; i = 1...6$  - speeds of motion of pistons.



**Fig. 1** Adaptive drive of the piston of the fluid mechanism

Blocks of pistons 2-4 and 3-5 together with reservoirs *A* and *B* create the closed fluid contour placed between the input piston 1 and output piston 6.

Motive force  $F_1$  is acting on the input piston. Resistance force  $F_6$  is acting on the output piston. In an operating time the force  $F_1$  on the input piston 1 creates pressure  $p_1 = F_1 / S_1$  in the input cylinder and moves blocks of pistons 2-4 and 3-5. Pistons 4 and 5 create in the output cylinder pressure  $p_6 = F_6 / S_6$  and move the output piston 6.

The closed fluid contour provides adaptation of system to output loading. Only in stroke is considered on fig. 1.

**3. Interconnection of parameters**

Let's compile the equations of fluid rate in reservoirs *A* and *B* .

The piston 1 is moving to the right. The block of pistons 2-4 is moving to the right, because  $S_2 > S_4$  . The block of pistons 3-5 is moving to the left, because  $S_3 < S_5$  . The piston 6 is moving to the right. We will consider the positive speed directed into the reservoir.

The equation of fluid rate in reservoir *A*

$$S_1 \cdot V_1 - S_2 \cdot V_2 + S_3 \cdot V_3 = 0 . \tag{1}$$

The equation of fluid rate in reservoir *B*

$$S_4 \cdot V_4 - S_5 \cdot V_5 - S_6 \cdot V_6 = 0 . \tag{2}$$

Or taking into account  $V_4 = V_2$  ,  $V_5 = V_3$

$$S_4 \cdot V_2 - S_5 \cdot V_3 - S_6 \cdot V_6 = 0 . \tag{3}$$

Let's multiply the equation (1) on  $p_1$  and the equation (3) on  $p_6$  . Taking into account  $p \cdot S = F$  we will receive after commutations

$$F_1 \cdot V_1 = F_2 \cdot V_2 - F_3 \cdot V_3 . \tag{4}$$

$$F_6 \cdot V_6 = F_4 \cdot V_2 - F_5 \cdot V_3 . \tag{5}$$

Let's subtract the equation (5) from the equation (4), we will receive

$$F_1 \cdot V_1 - F_6 \cdot V_6 = F_2 \cdot V_2 - F_3 \cdot V_3 - F_4 \cdot V_2 + F_5 \cdot V_3 \text{ . Or}$$

$$F_1 \cdot V_1 - F_6 \cdot V_6 = (F_2 - F_4) \cdot V_2 - (F_3 - F_5) \cdot V_3 \text{ .} \quad (6)$$

The left side of an equation (6) represents an algebraic sum of powers of external forces. The right side of an equation (6) represents an algebraic sum of powers of internal forces. If the fluid system is in equilibrium then according to a principle of virtual works the sum of powers (or works) of internal forces in the presence of ideal constraints is equal to null.

$$(F_2 - F_4) \cdot V_2 + (F_3 - F_5) \cdot V_3 = 0 \text{ .} \quad (7)$$

Hence, and the left side of an equation (6) is equal to null

$$F_1 \cdot V_1 - F_6 \cdot V_6 = 0 \text{ .} \quad (8)$$

The equation (8) represents additional analytical constraint between parameters of the fluid system with two degree of freedom. This constraint imposes restriction on motion of links of system and provides definability of system at presence only one input.

The equation (8) allows determining of the output speed  $V_6$  on the given constant input power  $P = \frac{F_1 \cdot V_1}{1}$  and on the given variable output resistance force  $F_6$

$$V_6 = F_1 \cdot V_1 / F_6 \text{ .} \quad (9)$$

The equation (9) defines brand new property of a fluid system with two degree of freedom - fluid adaptation. At any given output force of resistance  $F_6$  the output speed  $V_6$  accepts automatically matching value. The fluid system with two degree of freedom is independently accommodated for external loading without use of any control system. External loading is controlling by output speed. Such fluid system is self-controlling system.

The closed contour in a fluid system with two degree of freedom creates brand new precedent: it first, imposes the additional constraint leading to definability of motion, and secondly, creates effect of force adaptation.

In the equation (7) we will denote  $F_{35} = F_3 - F_5$  - full force on the block of pistons 3 - 5,  $F_{24} = F_2 - F_4$  - full force on the block of pistons 2 - 4. We have:  $-F_{53} = F_5 - F_3$ , because  $F_5 > F_3$ . Then from the equation (7) we will receive

$$F_{24} \cdot V_2 = F_{53} \cdot V_3 \text{ .} \quad (10)$$

The equation (10) represents the equation of internal circulating energy. Internal forces  $F_{53}$ ,  $F_{24}$  generally are not equal among themselves; however the equilibrium is performed by a principle of virtual works at the expense of speeds.

We will determine the internal speeds  $V_3$ ,  $V_2$  of blocks of pistons 3-5 and 2-4 by solving system of the equations (1), (3) on known values of speeds  $V_1$ ,  $V_6$ . Speed  $V_1$  is given, and speed  $V_6$  is determined from the equation (9).

Let's multiply the equation (1) on  $S_5$  and the equation (3) we will multiply on  $S_3$ . We will receive

$$S_1 \cdot S_5 \cdot V_1 - S_2 \cdot S_5 \cdot V_2 + S_3 \cdot S_5 \cdot V_3 = 0 \text{ .} \quad (11)$$

$$S_3 \cdot S_4 \cdot V_2 - S_3 \cdot S_5 \cdot V_3 - S_3 \cdot S_6 \cdot V_6 = 0 \text{ .} \quad (12)$$

Let's add the equation (12) with the equation (11), we will receive

$$S_1 \cdot S_5 \cdot V_1 - S_3 \cdot S_6 \cdot V_6 = (S_2 \cdot S_5 - S_3 \cdot S_4) \cdot V_2 \text{ . From here}$$

$$V_2 = \frac{S_1 \cdot S_5 \cdot V_1 - S_3 \cdot S_6 \cdot V_6}{S_2 \cdot S_5 - S_3 \cdot S_4} \text{ .} \quad (13)$$

From the equation (1)

$$V_3 = \frac{S_1 \cdot V_1 - S_2 \cdot V_2}{S_3} \text{ .} \quad (14)$$

Internal forces are determined under formulas

$$F_{35} = p_1 \cdot S_3 - p_6 \cdot S_5 \text{ .} \quad (15)$$

$$F_{24} = p_1 \cdot S_2 - p_6 \cdot S_4 \text{ .} \quad (16)$$

It is possible to perform the check of balance of circulating energy on the equation (10), using the formulas (13), (14), (15), (16).

From the equation (8) it is following  $S_1 \cdot p_1 \cdot V_1 - S_6 \cdot p_6 \cdot V_6 = 0$ . From here we will receive constraint between pressures in reservoirs  $A$  and  $B$

$$p = \frac{S_6 \cdot V_6}{S_1 \cdot V_1} \cdot p_6 \text{ .} \quad (17)$$

The transfer ratio of a fluid system

$$u_{16} = V_1 / V_6 = F_6 / F_1 . \quad (18)$$

At constant input power  $P = F_1 \cdot V_1$  the transfer ratio is depending on the variable output force of resistance

$F_6$ .

#### 4. Compact adaptive fluid drive

The adaptive fluid drive has been developed earlier for the module of manipulator [3, 4]. However this drive had the complex design and did not provide conservation of the fluid rate balance on direct stroke and back stroke.

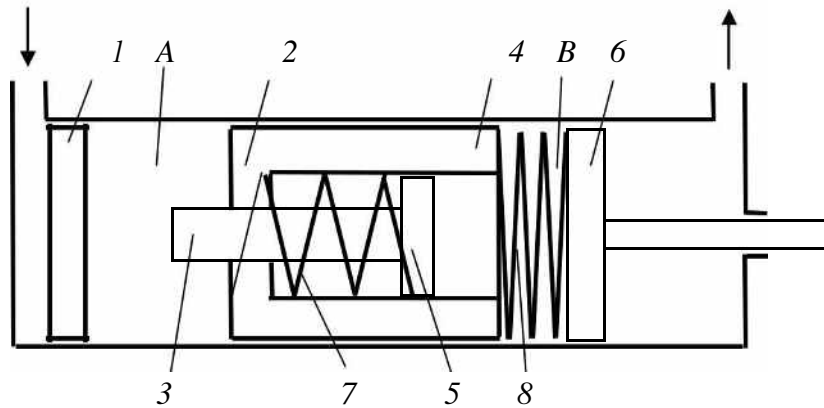


Fig. 2. Compact adaptive fluid-flow drive

The compact adaptive fluid drive (fig. 2) matches to the adaptive drive of the piston (fig. 1), is executed under the compact circuit design [6] and provides a conservation of the fluid rate balance on direct stroke and back stroke.

Designations of basic parts of this drive completely match to drive designations on fig. 1.

The drive contains input basin *A*, output basin *B*, input piston 1, intermediate block of pistons (converter) 2-4, intermediate block of pistons (converter) 3-5, output piston 6 and return springs 7 and 8. (It is necessary to note, that the piston 1 can be removed from a mechanism design).

Each intermediate block of pistons is executed in the form of the piston, having two various contact surfaces with a liquid in basins *A* and *B*.

Pistons 1, 2, 3 are placed in input basin *A*. Pistons 4, 5, 6 are placed in output basin *B*. Input and output pistons are connected with a pump feeding system of a liquid. We will use former designations:  $S_i$   $i = 1 \dots 6$  - squares of pistons.  $V_i$   $i = 1 \dots 6$  - speeds of pistons motion.

Work of the compact return adaptive fluid drive on direct stroke is analogous to work of the adaptive drive of the piston (fig. 1). In an operating time the drive makes a return translational motion of the executive tool together with the piston 6.

At performance of back stroke the return springs 7 and 8 result a hydraulic system in an initial position and provide balance of the fluid rate between basins *A* and direct stroke and back stroke.

Compact fluid-flow adaptive drives of the module of the manipulator and gripper are developed in [3, 4]. The adaptive fluid mechanism possesses unique property. It is capable to work as in a regime of self-regulation with two degree of freedom, and in an extreme regime with one degree of freedom. The extreme operating mode occurs, when the maximum loading exceeds maximum permissible value. In this case the target piston of the mechanism is shut down, and the mechanism passes in a condition with one degree of freedom when the entrance piston continues traffic in some limits. It is possible to name such operating mode a stop regime. The stop regime allows avoiding mechanism breakage at an overloading. The overloading leads to a stop of the tool with possibility to continue work after overloading elimination, or after change of working conditions. Mechanism transition in a stop regime occurs automatically without control system use. One of possible alternatives of use of a stop regime is an adaptive fluid actuator of the manipulator gripper.

Regularity of interconnection of parameters of the compact adaptive hydraulic mechanism completely matches to the analytical regularity of interacting of parameters resulted above.

Mechanism synthesis consists in definition of the squares of pistons cross-sections on the set range of transfer ratios and also in definition of rigidity of return springs on a condition of maintenance of retrace of pistons into an initial position after the return termination.

#### CONCLUSION

The self-controlled compact adaptive fluid drive working without a fluid control system and without an electronic control system provides absolute adequacy to variable force loading.

The adaptive fluid drive is extreme simple in design. Efficiency of perfection of fluid mechanism is not consisting in boundless complication of computer control, but in use of unprecedented properties of mechanics.

Undoubtedly fluid adaptive systems will find wide application in all branches of engineering, especially in modern robotics because the use of paradoxical properties of mechanics allows gaining the elementary, compact, reliable and adequate fluid drive instead of the usual fluid cylinder equipped with the most complicated and expensive control system.

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