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THE DESIGN OF A PROPORTIONAL SLIT VALVE WITH A PIEZOELECTRIC ACTUATOR

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Abstract: *The article is devoted to a proportional valve controlling the direction of flow in liquid pneumatic systems. Based on the analysed reference books, it can be stated that there are no power saving proportional flow and pressure valves with control times shorter than 0.005s with retaining mass intensity of flow at the level of 0.06kg/s or higher. The article presents the design of a slit separating valve and model determination of characteristics of mass intensification of flow for working paths (flow surface).*

Keywords: power saving, proportional valve, piezoactuator, fast response pneumatic valve.

1. Introduction

The main purpose for which the valve had been designed is programmed and follow-up control of pneumatic drives, including muscles and actuators. Shaping curvilinear characteristics of movement of pneumatic drives is a difficult problem, but it is necessary in advanced and developed robots and manipulators with parallel structures (Andrs et al., 2012) (Huscio & Kolodziejczyk, 2013)(Trochimczuk, 2013)(Koruba et al., 2010). Sometimes in technological processes the synchronization of drives is required and it is particularly difficult for muscles and pneumatic actuators. The follow-up control of pneumatic valves requires ultra-quick valves with the controlled flow of the working agent (Krzysztofik, 2012). As a result of conducted research it was found that that there are no valves for follow-up control of pneumatic drives for diameters above 40 mm with ensuring sufficient accuracy of recreation of the set movement trajectory. It results from the lack of sufficiently quick and precise proportional flow and pressure valves. Most often slide separating valves are used for controlling pneumatic and hydraulic actuators (Krzysztofik & Koruba, 2012). Their task is to separate the stream of liquid between valve flow surface (Janecki, Dariusz & Zwierzchowski, 2015). Separation of the stream is done by suitably shaped edges of the valve slide and its body (Miko & Nowakowski, 2012)(Janecki, D et al., 2015). With the use of the CFD software, vector speed fields and pressure distributions were determined and presented in the cross-sections of valve flow surface. Based on the conducted research, flow characteristics in the function of slide valve shift were determined. On the basis of the determined characteristics, it can be stated that the construction of a proportional pneumatic separating valve with high flow values is possible.

2. Actuators used in valves

In the solutions used for controlling fluid valves described in the reference books and patent applications two types of piezoactuators are used. In the first type, the piezoactuator (Błasiak & Kotowski, 2009) (Tuma et al., 2013) has the shape of a plate of small thickness and usually it is fixed with one end with the body, while the other end moves opening and closing the flow surface of the mini-valve. In such a solution, the piezoactuator may move with high frequency with great displacement of several millimetres, but the force does not exceed several Newtons. This type of valves are mostly used as preliminary degrees of control for pressure valves and separation with much greater flows (Ohuchi et al., 2000) (Yun et al., 2010). A similar group of valves encompasses the valves in which the controlling element has the shape of a disc of small thickness in relation to the diameter. As a result of polarization of the piezoactuator the middle part is moved and flow surface are opened (Sobocinski et al., 2009). The second group of valves where at present piezoactuators are used includes structures in which a piezoeletric

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actuator has the form of a multi-layer stack. There are solutions in which a piezoactuator directly opens and closes flow surface, but the displacements of the piezoelectric drive usually do not exceed 100 μm. Such a small displacement makes the construction more difficult and requires the application of high precision when making elements. The solutions in which the valves with the multi-layer actuator are directly used include injectors and pump-injectors of diesel engines (Bart, 1977) (MacLachlan et al., 2004). Another type of valves with multi-layer piezoeletric stacks includes structures where a slight displacement of the actuator is multiplied by levers and mechanical cams. In this way, a greater displacement of the drive can be seen at the cost of the decrease of force and frequency of operation (Reuter, 2013) (Claeyssen et al., 2007). In the considered structure of the valve, the drive and at the same time control element is the multi-layer piezoactuator with a mechanical amplifier in the form of a clamp. The maximum displacement of the applied drive amounts to 500 μm, and the maximum blocking force amounts to 570 N, the frequency of operation amounts to 460 Hz. The multi-layer actuator of the valve in the form of a piezoeletric stack allows in an ultraquick way to displace slit separating plates opening proportionally the flow surface of the valve(Suranek et al., 2013).

2.1. The principle of operation of a slit separating valve type 5/3

In a valve, the flow and separation of the liquid stream is done by properly shaped groups of slits creating flow surface. In this solution there is no classic separating slide. It appears from the experimental research carried out by the author that programmed positional control for pneumatic valves with the diameter of 25 mm requires the valves that have the frequency of operation at the level of at least 70 Hz and the flow of 700 l/min with power pressure of 0.6 MPa. It can similarly be observed in the case of muscle drives the only difference being that they require precise control of pressure changes. The principle of operation of the valve is shown on Fig. 1 to Fig 3. In the said valve, a single slit has the shape of a rectangle with one side equal to a half of piezoactuator's displacement. On the other hand, the size of the other side of the rectangle of the flow window is adjusted to the designed flow value and the total number of slits. In each flow window of the valve the flows from individual slits are summed up and the nominal valve flow is obtained. The selection of the number of slits in a unit corresponds to the surface of a flow window for a single valve path. The valve has the following flow paths: *1, 2, 3, 4, 5* in marked body (10) and slit groups: *1',2', 3', 4', 5'* in the upper plate cylinder (6) as well as the corresponding groups of slits: *1'', 2'', 3'', 4'', 5''* in any plate cylinder (7). The lower plate cylinder is joined with the possibility of disconnection with one of the arms (8) of the amplifier of displacement piezoactuator (9). The second arm of the amplifier of displacement is mounted to the body (10) of the valve. In neutral position (Fig 1) the flow paths of the valve are completely closed. Outermost positions of slit plane of the valve are shown on Fig 3. The piezoactuator allows for controlling the valve in a proportional way, then the lower plate cylinder may occupy an intermediate position in relation to the upper plate cylinder, and the flow through flow paths will depend on the degree of opening of the groups of slits.

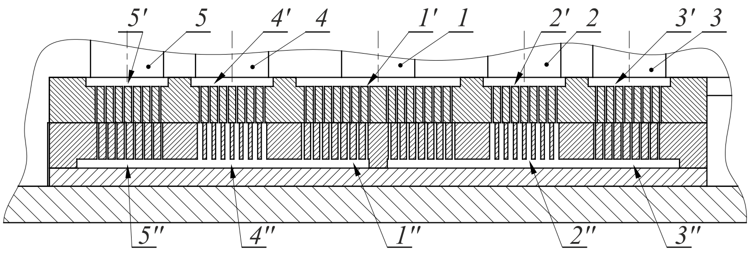

Fig. 1: A fragment of the cross-section of 5/3 valve. a) neutral position, b) a graphic symbol of the valve with a pneumatic actuator.

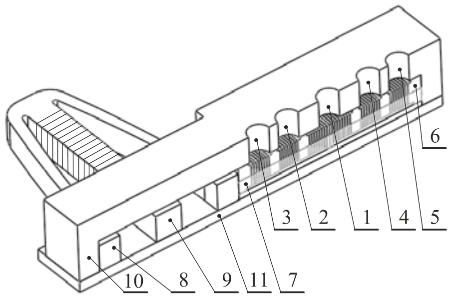

Fig. 2: An axonometric view with a partial cross-section, a) lower plate cylinder and a piozoelectric actuator.

The total surface of slits in a group creating a flow window is at least equal to the surface of the service line of valve G1/4" (~34mm2). The increase of the surface of flow does not constitute a structural problem because it is done by adding new groups of slits and maintaining the distance of piezoactuator's displacement. In the considered separating valve, a single slit has the size of 0.25x45x5 mm. Fig.2. shows the valve in an axonometric view with a partial cross-section.

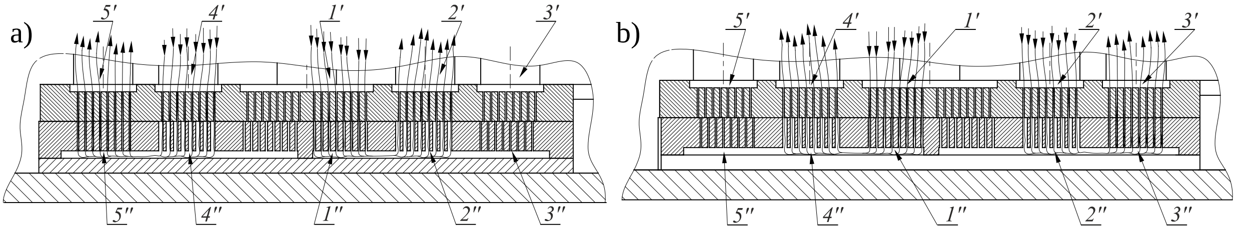

Fig. 3: 5/3 valve in outermost positions of the lower slit cylinder, a) full flow between paths 1-2 and 4-5, b) full flow through flow paths 1-4 and 2-3.

3. Flow simulation (CFD)

Fig. 5 shows the results of simulation research in the CFD software (Wawrzyniak & Peszynski, 2014)(Blasiak, Slawomir, 2015a)(Blasiak, Slawomir, 2015b)(Blasiak, S & Zahorulko, 2016). In order to conduct the analysis, a spatial computational grid with irregular structure was adopted. Groups of slits in which the minimum size of a grommet amounted to 1μm were the pivotal area of grid assumption. In order to shorten the time of performing numerical calculations, the model was divided along symmetrical axes. Half of the volume of the analysed air amounted to $1.0047{\cdot}10^{-5}m^3$ where the number of units amounted to ~3.3 million of units corresponds to 14.7 million elements. Fig. 4 shows an enlarged fragment of the grid of slit flow surface of the valve.

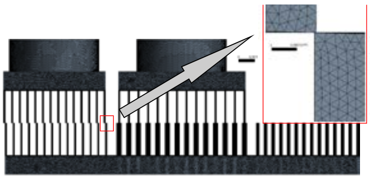

Fig. 4: The view of a computational grid for the valve filling agent.

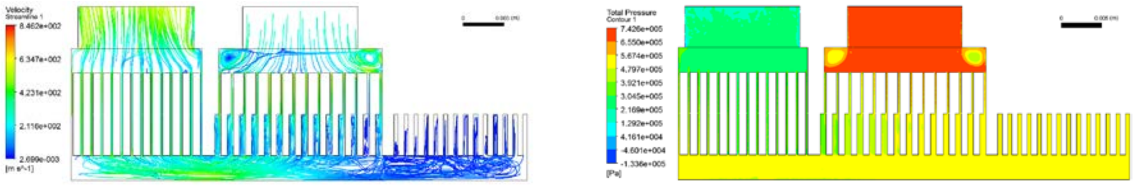

Fig. 5: The view of the cross-section of the capacity of valve slits, a) medium speed distribution (streamline), b) medium pressure distribution.

The conducted model research confirmed the conjecture that a small asymmetry of the working agent flow may occur in the valve. It appears directly from the width of flow surface in the moving cylinder of the valve. Varied width of flow surface of the moving cylinder is necessary to perform the function of a 5/3 valve and close in-flow and out-flow paths. Fig. 6 shows minimum differences of flow values for different feed paths 1-2 and 1-4 in relation to out-flow paths 2-3 and 4-5. In extreme positions of the valve, more dynamic outflow will occur on outflow paths. Maximum mass flow rate for routes 1-2 and 1-4 amounts to 0.058kg/s

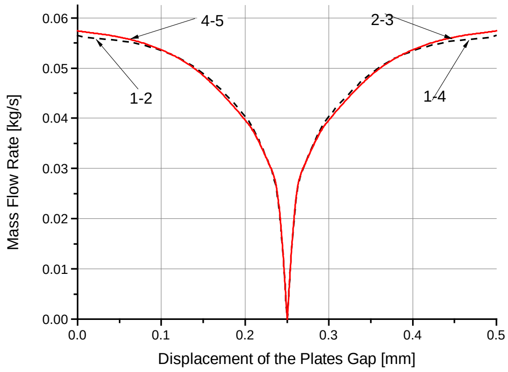

Fig. 6: Mass flow rate vs signal and measurement set-up.

4. Conclusions

The presented valve has many features that differentiate it from the produced comparable products. It appears from the analysis of the market of producers of pneumatic devices, and the patent applications that there is no solution that would allow for achieving the flow through the flow surface of the valve above 0.06 kg/s and actuation times above 75 Hz. The slit structure of separating plates of the valve allows for adding up the flow from individual surface and thereby the construction of a valve of flows unattainable till now amounting to a couple thousand litres per minute. Moreover, the innovative structure of flow surface allows to design valves with any flows adjusted to technological processes. The valve is protected with patent no. PL 213836 B1. **Acknowledgement:** The work was performed within the framework of the research project NCN and NCBiR TANGO no. TANGO1/270131/NCBR/2015.

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