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Design of pneumatic proportional flow valve type 5/3

P A Laski[1], D S Pietrala[1], J Zwierzchowski[1], K Czarnogorski[1]

[1]Department of Automation and Robotics, Faculty of Mechatronics and Machine Design, Aleja Tysiaclecia Panstwa Polskiego 7, 25-314 Kielce, Poland

E-mail: pawell@tu.kielce.pl

Abstract: In this paper the 5/3-way pneumatic, proportional flow valve was designed and made. Stepper linear actuator was used to move the spool. The valve is controlled by the controlled based on a AVR microcontroller. Virtual model of the valve was created in CAD. The real element was made based on a standard 5/3-way manually actuated valve with hand lever, which was dismounted and replaced by linear stepper motor. All the elements was mounted in a specially made housing. The controller consists of microcontroller Atmega16, integrated circuit L293D, display, two potentiometers, three LEDs and six buttons. Series of research was also conducted. Simulation research were performed using CFD by the Flow Simulation addition to SolidWorks. During the experiments the valve characteristics of flow and pressure was determined.

Nowadays, proportional valves are becoming increasingly popular in industrial applications. They perfectly fill the application area between conventional control technology and servo-valve technology [1, 2] [3]. Proportional elements are very well suited for controlling the direction, flow rate and operating pressure [4][5]. This project will present a design of a pneumatic proportional flow valve type 5/3. A stepper motor integrated in the screw-nut mechanism was used to move the valve slider. The valve is controlled by a controller built on an AVR microcontroller. The mechanical parts design was made in 3D-CAD software, which created three-dimensional models that were subsequently analyzed for CFD (Computional Fluid Dynamics), as well as the preparation of technical documentation. Based on solid and commercial models, the Prema ™ 5/3 type lever-controlled mechanical valve has a prototype that is subjected to physical testing. During the experimental study, flow and pressure characteristics of the valve were determined. The valve driver consists of an Atmega16 microcontroller, an L293D integrated circuit, a display. At the design stage, a number of simulation studies were conducted using the SolidWorks Flow Simulation environment.

1. Construction assumptions

The proportional valve design is based on the prema 5/3 type divider with manual control, from which the lever to change the position of the slider was removed in order to use another type of control.

It was assumed that the proportional valve piston would control the stepper motor with an integrated screw-nut mechanism. The engine connection with the valve slider was done by cutting the thread on the plunger and screwing in the actuator's clamping handle. An adapter in 3D printing technology was used to connect the motor to the valve body. Figure 1 shows the solid model of the analyzed valve.

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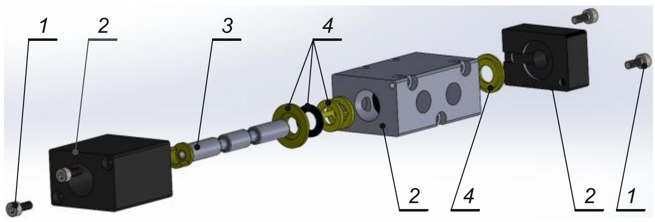

Figure 1. Components of 5/3 valve, 1 –M3 screws, 2 – valve parts, 3 – slider, 4 – sealing.

2. Valve slider drive

As already mentioned, the miniature stepper motor L35BYZ-B04601B was used to move the valve slider, which provides precise linear motion. Inside the engine, the rotary motion is converted into linear, which has a range of 0-75 mm. The feed rate of the slider is 0.025 mm per step for full-speed control and 0.0125 mm for semi-speed control. The maximum power that the drive generates is 55 N at 100 pulses per second. The actuator is powered by a rated voltage of 5 V and the phase current is 0.46 A, the resistance is 11 Ω, and the inductance of the winding is 8 mH. Such parameters are sufficient and allow dynamic control of the valve slider. In idle state, the windings supply the full torque maintenance and hence the constant valve slide force, even after the pneumatic supply is switched on. The most important advantage of the L35BYZ-B04601B engine used in the context of a proportional valve design is that it relies on the rotation of the device from the input pulses and control is possible in the open loop.

Figure 2 shows the solid models of the parts that comprise of the 5/3 divider, the linear stepper actuator L35BYZ-B04601B, the housing made on a 3D printer, and the M3 screws..

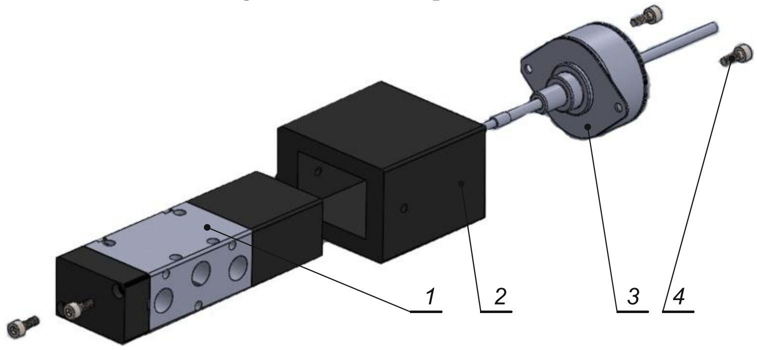

Figure 2. Components of the proportional valve design, 1 - 5/3 valve, 2 – casing, 3 –L35BYZ-B04601B linear actuator, 4 –M3 screws.

On the other hand, the actual prototype of the designed 5/3 type valve is shown on Figure 5.

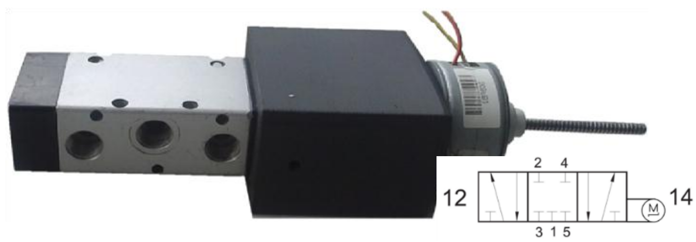

Figure 3. Proportional 5/3 valve prototype.

3. Design assumptions of proportional valve control

A linear stepper actuator controller, moving the divider slider, was made, based on the Atmega microcontroller. L293D integrated circuits are used to power the motor coils. The current status of the device is displayed on the two-line display. Two operating modes are implemented in the controller - full-speed and semi-speed.

The applied drive (L35BYZ-B04601B actuator) is controlled like a typical stepper motor with bipolar winding in which the current pulses are converted into the correct rotation and then the linear motion. The stator of the stepper motor has windings that are split into two phases. Their cyclic power causes rotor rotation. In full-speed control, the motor moves at a basic angle per step. The second type of work is semi-speed control. It achieves steps two times lower than full-speed, but together with a slight increase in resolution, the torque also slightly drops.

4. Model research by cfd method

Within model research, air flow was simulated through the designed valve and simulated flow characteristics was determined. For the analysis of workflow flow, the geometry of models of parts prepared in 3D-CAD software was directly used. Figure 4 shows a model designed for use in the airflow test along with the selected work area.

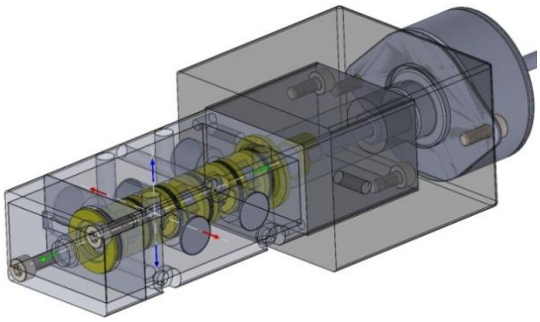

Figure 4. Solid model for flow analysis in proportional valve type 5/3.

The simulation of the air flow in the valve consisted of moving the model valve slider by a specified value equal to ten full steps of the linear actuator and then performing numerical analysis using the CFD method [6]. The input is set at a constant pressure of 0.63 MPa and at the outlet pressure of 0.1 MPa. Flow tests were performed for each of the roads. For example, the flow trajectories of the air through the valve for sliding the slider by 5.75 mm, or 230 full steps of the engine, on the road 1-2 are depicted in Figure 5. In contrast, the velocity distribution of air on the same road is shown n Figure 6.

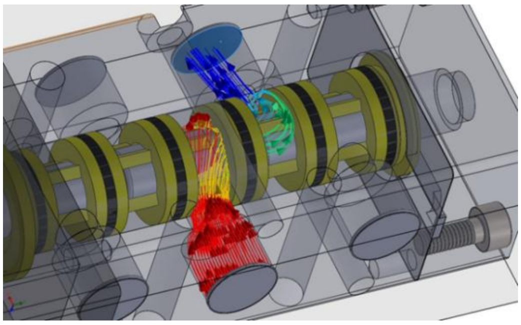

Figure 5. Exemplary air flow trajectories through the proportional valve on road 1-2, with the slider extending 5.75 mm.

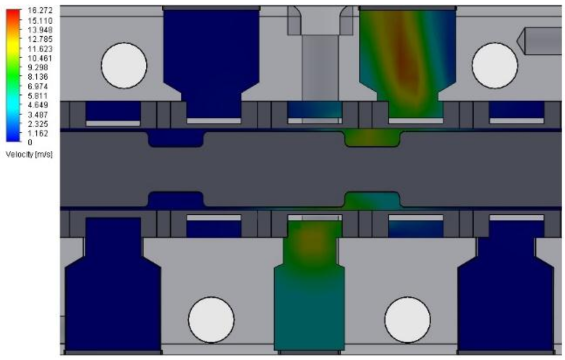

Figure 6. Distribution of air velocity through the proportional valve on the road 1-2, with the slider extending 5.75 mm.

5. Determination of experiment flow characteristics

Basic flow characteristics determines the relationship between the fluid flow and the degree of valve opening, with constant pressure drop in the setting element. The diagram of the station used to determine the flow characteristics is shown in Figure 7.

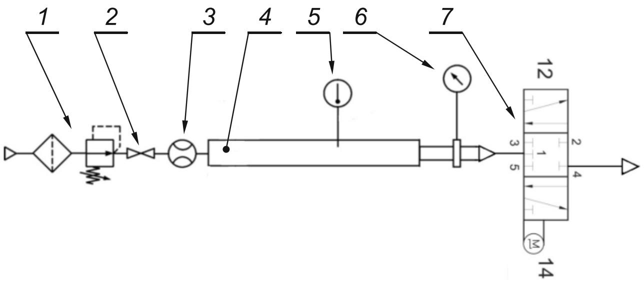

Figure 7. Diagram of the station for determining flow characteristics of the valve: 1 - air preparation unit, 2 - shutoff valve, 3 - flow meter, 4 - laminate tube, 5 - thermometer, 6 - pressure gauge, 7 – tested proportional valve.

The compressed air flows through the air preparation unit, the shutoff valve and the flow meter to the laminating tube. At this point the transient (turbulent) flow is brought to a steady state (laminar). Then the air flows through the specified valve paths, depending on the connection of the element. During this time, the flow meter measures the volume of the air stream. The actual appearance of the station is shown in Figure 8.

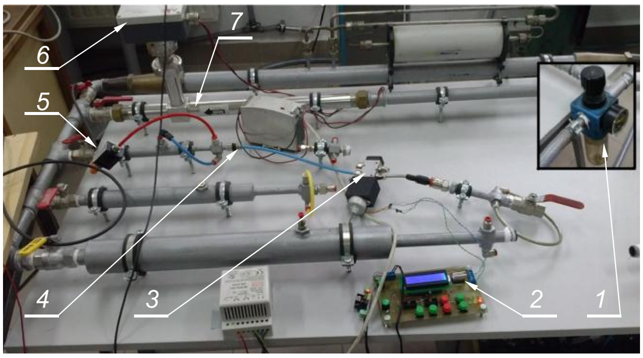

Figure 8. Appearance of the research station for testing flow characteristics: 1 – Air preparation unit, 2 - Proportional valve controller, 3 - Proportional valve tested, 4 - 1/8 "connection, 5 - Shutoff valve, 6 - Flow meter, 7 – Laminate tube.

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The test involved moving the valve slider to the characteristic points where there was a distinct change in air flow through the valve and then recording the flow value with the *Sensyflow VT-S* program integrated with the ABB flowmeter. Working pressure was 0.63MPa. The full movement of the slider from one extreme position to the other required 350 full-speed linear actuators of 0.025 mm each. Determination of flow characteristics was made for each of the proportional valve operating paths. The obtained results from the simulation and experimental studies are presented in the diagram on Figure 9.

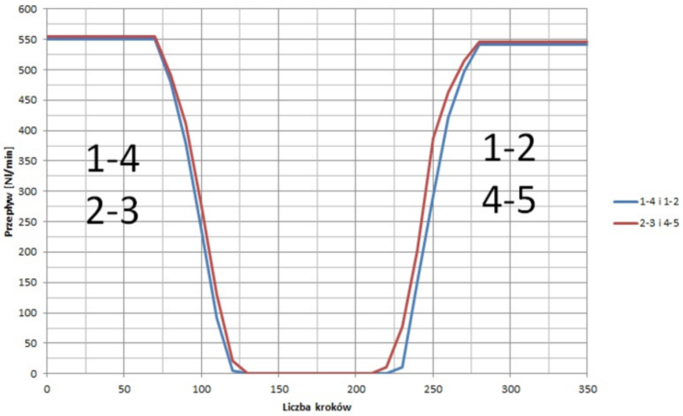

Figure 9. Flow characteristics of the designed proportional valve, blue color simulative, red color experimental.

By analyzing both the simulative and experimental results obtained, it can be seen that the valve has hysteresis in the middle and around the extreme positions of the slider. Whereas, at the opening and closing points of the control path, the curve may take shape similar to the linear characteristic, which will have a positive effect on the operation of the element. As you can see from the experimental study, the proportional valve does not work fully symmetrically. It has hysteresis in the middle part of it and around the extreme position of the slider, which has already been shown in the simulation studies. In contrast, in the opening and closing of the control path, the curve adopts a shape similar to the linear characteristic.

6. Determination of experimental pressure characteristics

The pressure characteristic determines the relationship between the pressure of the flowing fluid and the degree of opening of the valve. The test involves moving the valve slider from one extreme position to the other and continuously recording the results. The diagram of the position used to determine this characteristic is shown in Figure 10.

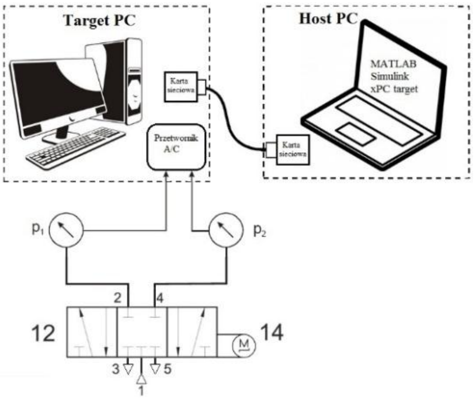

Figure 10. Diagram of the station for determining valve pressure characteristics.

Pressure gauges integrated with the measuring card are connected to the valve outlet. It transmits current measurement results to the real time machine *Speedgoat*, where they are displayed on the screen as diagrams. *Host PC* communicates with *Target PC* using *Matlab Simulink*, downloading data and displaying it as pressure characteristics. The obtained pressure characteristic of the proportional valve is shown in Figure 11.

Figure 11. Pressure characteristic of proportional valve.

7. Conclusions

In this article one attempts to design and execute a pneumatic proportional flow valve type 5/3. Instead of the standard control of the electromagnet in this type of element, a linear stepper actuator is used to move the valve slider. The valve is controlled by a driver based on the AVR microcontroller. The virtual valve model was created in a 3D CAD environment. The actual valve model was based on a standard 5/3 type valve mechanically controlled by a lever that was removed from it and replaced with a stepped linear actuator.

The results of simulations and experiments for the valve are presented. Simulation testing was done using the SolidWorks add-on called Flow Simulation. During the experimental study flow and pressure characteristics of the valve were determined. By analyzing the results of the simulation and experimental studies, it can be concluded that the valve has a hysteresis in the middle and around the extreme positions of the slider. In contrast, in the opening and closing of the control path, the curve adopts a shape similar to the linear characteristic. As part of the further development of the valve, it will be necessary to modify the shape of the valve piston edge and thus the size of the flow windows. It is also opportune to introduce a closed-loop feedback loop control system by using a miniature distance sensor. It would determine the degree of ejection of the valve slider, the data received would be analyzed by the microcontroller in the controller.

The developed prototype of the 5/3 type proportional valve could be used in the control systems of slowly changing technological processes to become an alternative to the valves currently in use.

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