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A MODIFIED STANDARD PNEUMATIC VALVE WITH FLOW CONTROL CAPABILITY

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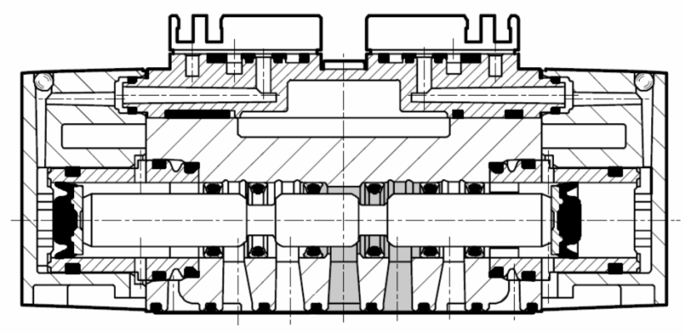
Abstract: A standard 5/2 piloted pneumatic valve is modified in such a manner that its spool can be actuated proportionally to a programmed input digital value. Tests are conducted to determine the ability of the system to control the flow and thus the speed of a pneumatic cylinder.

1. INTRODUCTION

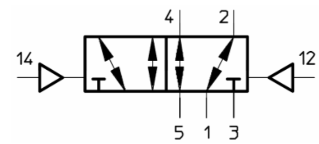
Flow control combined with directional control are desirable properties of a versatile pneumatic valve, but those prove to be difficult goals to achieve mainly because of the physical limitations of the operating medium itself and also due to inherent design and construction challenges. The paper presents a modified standard pneumatic valve, in terms of spool actuation, that is able to control both flow and direction at the same time.

2. THE STANDARD PNEUMATIC VALVE

The valve used is a standard FESTO pneumatic valve, of the 5/2 piloted type. It uses compressed air with pressure up to 10 bar, in order to provide directional control for actuators, with a maximum flow of 500 l/min. The valve uses a steel cylindrical spool that slides inside a cast aluminum body, under the action of the pilot pressure. This pressure is independently applied to the faces of the two piston type seals found at each end of the spool. Sealing is insured by nitrile rubber o-rings mounted in recesses machined in the valve's body. The valve itself is mounted on a sub-base plate containing pneumatic connections and the silencers. Picture 1 represents a sectional view of the valve and its schematic symbol. The main pneumatic characteristics of this valve are detailed in Table1, as per FESTO datasheet (product code: J-5/2-D-02).



a) sectional view



b) schematic symbol

Fig.1. The standard pneumatic valve

Table 1. Valve specifications

Valve function	5/2 bistable
Type of actuation	pneumatic
Width	18 mm
Standard nominal flow rate	500 l/min
Operating pressure	-0.9 - 10 bar
Design structure	Piston slide
Nominal size	6 mm
Exhaust-air function	throttleable
Sealing principle	soft
Type of piloting	direct
Pilot air supply	Internal
Flow direction	reversible
Pilot pressure	2 - 10 bar
Switching time reversal	6 ms
Operating medium	filtered compressed air, grade of filtration 40 μm, lubricated or unlubricated
	Vacuum
Pilot medium	filtered compressed air, grade of filtration 40 μm, lubricated or unlubricated

This type of valve was chosen due to its availability at the research location and because by forcing the spool in a central, symmetrical position, it functions as a 5/3 valve in the neutral position. The central section of the spool extends over both seals by approximately 0.2mm, one obtaining in this position a positive coverage spool, suitable for flow control with a certain precision.

3. THE MODIFIED VALVE

By removing the pilot assemblies from the standard valve, it reveals the outermost sections of its spool, at both ends. In order to transform this result into a controllable proportional valve, linking of the spool mechanically to a linear electro-mechanical actuator is mandatory.

The method approached in this paper (see figure 2) is to have a stepper motor (2) elastically coupled (3) to a screw & nut mechanism (4). Practically there are two nuts (5) mounted with an elastic washer between them (for backlash compensation) and forced into a plastic sleeve (6) that in its turn is thermally forced over one end of the spool. Because the spool is cylindrical there is a tendency of rotation when actuated by the screw, and here comes into play a steel locking rod (8) rigidly forced into another plastic sleeve (6) mounted at the other end of the spool. The rod is allowed to slide inside a fixed tube. Also in this sleeve is mounted a small black plastic flag which is used as an infrared barrier for the optical home switch (9). As the stepper motor has a small amount of axial play that could influence the operating of the system, a lamellar spring (1) was bolted against the motor's shaft in order to overcome this play.

In this setup the spool still slides inside the valve's body (not drawn) at full stroke, as the space normally occupied by the pilot assemblies (cylinders and piston-seals) inside the body are now replaced by the plastic sleeves.

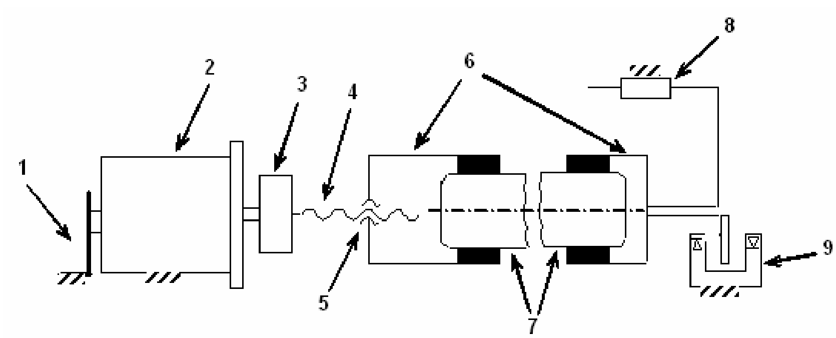


Fig.2. The modified valve. Principle of actuation

In order to determine a relation between the steps of the motor and the displacement of the spool, the mechanical parameters of the kinematic chain must be established first.

The stepper motor is of unipolar type, having a precision of 18 degrees/step and because it is driven in "half-step" mode it achieves a resolution of 40 steps per full revolution. The screw is of type M5 having 1mm pitch, with an usable length of 20mm. Knowing these, it can be concluded that there is a relation of direct proportionality between the motor steps and the spool displacement:

$$d_s = \frac{s_p}{n_s} \tag{1}$$

where: d_s is the spool displacement in mm, s_p is the pitch of the screw (mm) and n_s is the number of steps the motor turns. By applying this formula to the known parameters it gives that for each half-step of the motor, the spool moves by 0.025mm.

4. TEST STAND AND PRELIMINARY RESULTS

In order to investigate the ability to perform of such a modified valve a test stand was set up (figure 3). This consists of the valve-actuator assembly, a source of compressed and regulated air (represented by a Jun-Air silent compressor and a FESTO Series D filter-regulator unit), a standard double acting cylinder (DSNU-20-100-PPV-A) and two FESTO digital pressure sensors (only used for pressure monitoring) branched from the cylinder's air supply.

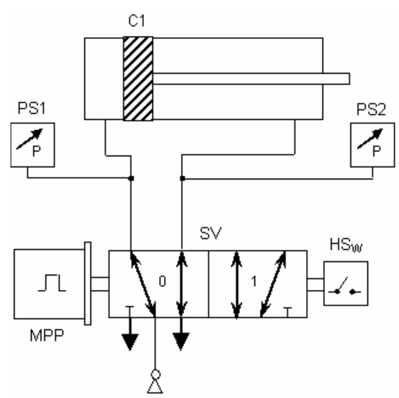


Fig.3. Test stand setup

The electrical part of the stand (figure 4) consists of a power supply having 12V and 5V (regulated), a power Darlington matrix for the motor's coils, the motor itself, the optical sensor acting as the "home switch", a parallel port connector and the interconnecting wires.

A classical approach of controlling the stepper motor via 4 data bits of a PC parallel port was selected for this application as it gives more flexibility in programming. The home switch is linked to an input bit on the parallel port, thus providing the required "home" information.

Programming was made under VB6 and making use of a third party parallel port interface (io.dll) that has predefined function prototypes for controlling the port in VB.

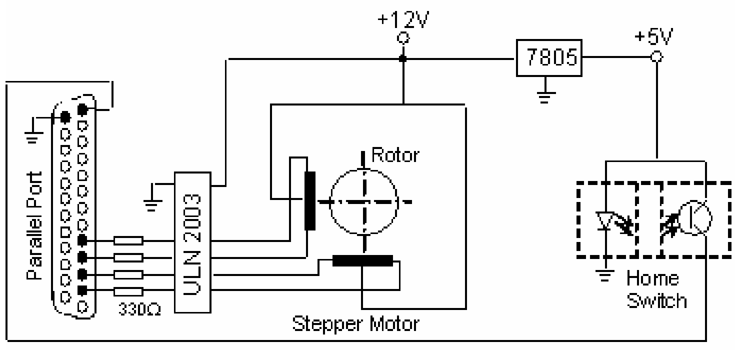


Fig.4. Test stand. Electrical schematics

The dynamic performance (speed) of the system was limited on two bases: it works in open-loop by counting steps, so it cannot pass the limit stepping frequency of the motor and the programming gives only millisecond accurate port control. As a result the stepping frequency was limited at 5 ms per half-step, thus giving a displacement speed of the spool of 0.2 sec/mm. This allows for a full stroke (6mm) to be effected in 1.2sec. If the application is not critical (fast positioning) then this speed is acceptable. For the spool to move from neutral (home) to a full open position it takes 2.8mm and 0.56 sec respectively (112 steps).

The hysteresis of the system is present and constant but very small (less than one full step) and it is due to the inherent elasticity and remaining backlash in the assembly. But it is still fair reasonable compared to a solenoid actuated spool, as the coulombian friction and residual pressure generate a smaller force than the minimum actuator thrust and it also can be counteracted partially by the presence of the home switch.

A general view of the testing stand can be seen in figure 5, having in the right part the valve assembly with the electronic module, port connector and power supply connector, in the lower part the double acting cylinder and in the upper part the two pressure sensors.

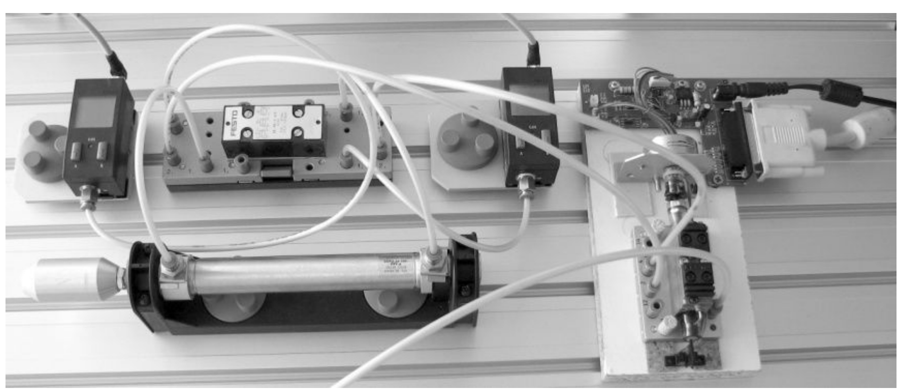


Fig.5. General view of the test stand

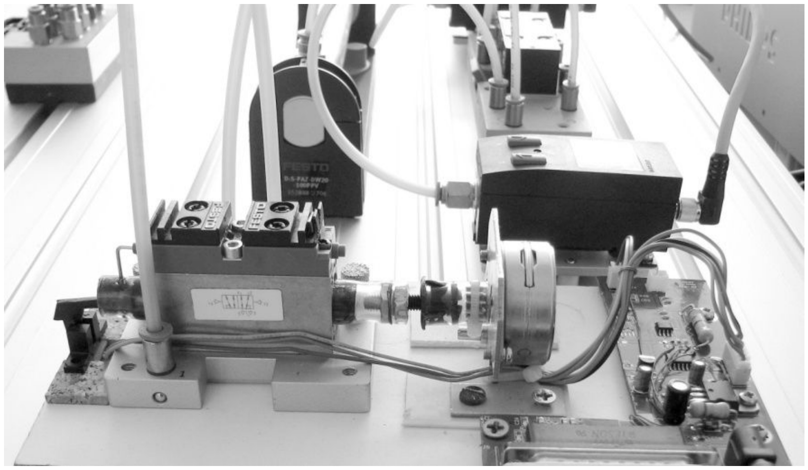


Fig.6. Close-up of the modified valve assembly

Figure 6 represents a close-up of the valve assembly, showing the valve body mounted on the connector sub-base, having the spool attached to the stepper motor via the screw-nut-sleeve mechanism. Also the anti-rotating rod and home switch are visible.

5. CONCLUSIONS

By making use of the intrinsic design of a standard directional pneumatic spool valve, it is possible to adapt it, in terms of spool actuation, in a way that such a valve to be able to maintain directional control and to have another very important specification: flow control. The test stand revealed that for non speed-critical applications the approach described in this paper offers reasonable flow control with good repeatability and low hysteresis. For the system presented here, there is more to follow in terms of determining the flow curves and other dynamic performance parameters and also to determine the reliability of the proposed approach.

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