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Hardware and Software Structure of a Pneumo-Hydraulic Positioning System

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Abstract: The paper presents the hardware and software structure of a linear unit for pneumo-hydraulic positioning, developed by the authors. The unit features two identical cylinders, one pneumatic and one hydraulic, mounted in parallel. The speed control is achieved by the use of two check valves of original construction. Mathematical model, simulation results and experimental results are also provided.

Keywords: mechatronics, pneumatics, hydraulics, positioning system, mathematical model.

1. INTRODUCTION

Pneumatic actuation and control of the driven load speed through a hydraulic control circuit are specific features of pneumo-hydraulic units. Even if their construction is more complex, it eliminates the shortcomings of the speed control of pneumatic units, caused by the high compressibility and low viscosity of the working fluid. The rigorous control of the load speed opens the way to the development of high accuracy positioning units.

2. THE EXPERIMENTAL MODEL

The principle scheme of the unit that is subject of this paper is presented in figure 1. The following equipments can be identified:

- *MLP-H* –linear pneumo-hydraulic motor;
- SPC_1 and SPC_2 – controllable check valves that can be unlocked if a proportional signal is applied;
- *DPC* – classical pneumatic direction control valve;
- *Tp* – position sensor.

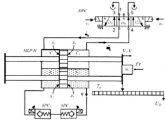

Fig. 1. The principle scheme of the unit.

The following features are specific to the proposed structure:

- the pneumo-hydraulic linear motor *MLP-H*, constituted by two identical cylinders with bilateral piston rods, mounted in parallel; their rods are joint by stiff clamps; the incremental position sensor is integrated in the construction;
- two identical equipments of original construction – SPC_1 and SPC_2 – are used in order to control the speed of the mobile unit; these equipments are in fact controlled check valves that can be unlocked if a proportional signal is applied; such an equipment allows the free flow of the fluid in one direction, through a section equal to the nominal section of the equipment; the flow is possible in the opposite direction only in the presence of an electric control signal; it is thus possible to control the fluid flow rate in the hydraulic circuit and therefore the control of the load speed; the valve SPC_1 must be unlocked in order to move the load from left to right (fig.1); the valve SPC_2 must be unlocked for the displacement of the load in the opposite direction.

Figure 2 presents the 3D model of the system, built using SolidWorks graphical environment. It can be seen also the air preparation unit *GPA*, needed for the good functioning of the system. The components of the system are mounted on the base plate *PB*.

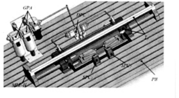

Fig. 2. Three-dimensional model of the unit.

$$q(x)=\begin{cases} S_c(x)\cdot\sqrt{\frac{2}{\rho}\cdot(P_2-P_1)} & if\ P_2>P_1 \\ 0 & if\ P_2=P_1 \\ -S_c(x)\cdot\sqrt{\frac{2}{\rho}\cdot(P_1-P_2)} & if\ P_2<P_1 \end{cases} \tag{10}$$

The flow section through the valve is equal to:

$$S_c(x)=k_1\cdot x-k_2\cdot x^2 \tag{11}$$

where k_1 and k_2 are constants:

$$k_1=\pi\cdot D\cdot\sin\alpha\,,$$

$$k_2=\pi/2\cdot\sin\alpha\cdot\sin 2\alpha\,.$$

In the relations presented before, D is the diameter of the seat and α is the angle of the valve cone.

- the equation that describes the movement of the valve seat:

$$\begin{aligned} & m\cdot\frac{d^2x}{dt^2}+B\cdot\frac{dx}{dt}= \\ & =F_A+(P_1-P_0)\cdot\frac{\pi}{4}\cdot D^2-k_{arc}(f_0+x)-F_c \end{aligned} \tag{12}$$

where:

F_c – flow force through the section controlled by the check valve, that can be computed as:

$$F_c=2\cdot\cos\alpha\cdot A_c(x)\cdot(P_2-P_1)/\rho \tag{13}$$

F_A – force developed by the actuator A if it is supplied with the voltage u; the construction of the actuator A must be considered in order to establish the expression of the force; the actuator, of type P-287, is endowed with a piezoelectric stack integrated in a mechanical structure that achieves a high resolution, frictionless amplification of the displacement; the elastic structure is manufactured by wire electro-erosion; for this model, the amplification factor is $k_m=12[-]$; the stack parameters are similar to the model P-007.40, for which:

$$\begin{cases} k=19[N/\mu m] \\ d=500\cdot 10^{-12}[m/V] \end{cases},$$

where k denotes the equivalent stiffness of the stack and d the piezoelectric coefficient.

In the case of a piezoelectric stack, the relation that gives the force is, Belmut (2007):

$$F_{STACK}=k\cdot(x_{STACK}-d\cdot u)$$

Thus the force developed by the actuator A for a supply voltage u will be equal to:

$$F_A=\frac{k}{k_m}\cdot\left(\frac{1}{k_m}x-d\cdot u\right) \tag{14}$$

The model can be simplified if it is supposed that there is a delay between the actuation of the direction control valve DPC and of the check valve SPC (fig.1). Therefore the initial conditions of the model become, as shown in figure 4:

$$\begin{cases} P_3=P_a \\ P_4=P_1=P_0 \\ P_2=P_1+[(P_3-P_4)\cdot S_1-F]/S_2 \end{cases}$$

Consequently, the flow sections through the pneumatic direction control valve DPC can be computed as:

$$A_1=A_2=A_n=\alpha_2\cdot\pi\cdot D_n^2/4 \tag{15}$$

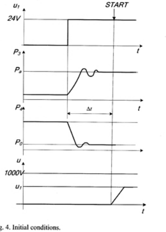

Fig. 4. Initial conditions.

The flow rates controlled by the DPC are equal to:

$$\dot{m}_3=\begin{cases} \frac{K\cdot P_a}{\sqrt{T_a}}\cdot A_n\cdot N\left(\frac{P_3}{P_a}\right) & if\ \ 0<\frac{P_3}{P_a}<1 \\ 0 & if\ \ \frac{P_3}{P_a}=1 \\ -\frac{K\cdot P_3}{\sqrt{T_a}}\cdot A_n\cdot N\left(\frac{P_a}{P_3}\right) & if\ \ 1<\frac{P_3}{P_a} \end{cases} \tag{16}$$

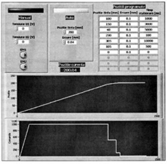

Fig. 10. The control panel of the application.

A target value of the programmed position (fig.11 – position y = 200mm) was established in order to study the dynamic behaviour of the unit. Initially, the unit was brought to the 0 position. The positioning of the load in the target position was achieved with an error of 0.04mm.

If only the target position was changed during similar experiments, there were situations when the positioning was achieved with overshoot. After some oscillations round the programmed position, the stop was achieved with the error imposed by the program.

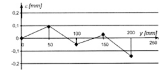

Fig. 11. Positioning accuracy of the unit in a number of given points.

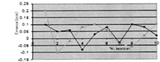

Fig. 12. Results of test performed in order to establish the precision of the unit.

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