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MATLAB-SIMULINK MODEL OF ELECTROPNEUMATIC PROPORTIONAL PRESSURE CONTROL VALVE

MATLAB-SIMULINK MODEL ELKTROPNEUMATICKÉHO PROPORCIONÁLNÍHO TLAKOVÉHO REGULAČNÍHO VENTILU

Abstract

In the paper the selected results of scientific researches carried in Department of Process Control on electro-pneumatic proportional technique were described. Mathematical modelling process of proportional pressure control valve was described here. Mathematical model based on block diagram of investigated valve including electrical, mechanical and pneumatical signals flow was carried out. Results of mathematical modelling was compared to the response of real valve obtained during laboratory researches.

Abstract

V příspěvku jsou popsány vybrané výsledky výzkumu elektro-pneumatické proporcionální metody získané na Katedře řízení procesů. Dále je popsán proces matematického modelování proporcionálního tlakového regulačního ventilu. Matematický model je postaven na blokovém diagramu zkoumaného ventilu včetně plynoucích elektrických, mechanických a pneumatických signálů. Bylo provedeno srovnání výsledků matematického modelování s odezvou reálného ventilu během laboratorních testů.

1 INTRODUCTION

Electropneumatic proportional valves produced nowadays directly allow control of compressed air flow or pressure. Indirectly they can control speed, linear and angular displacement as well as force and torque. This is possible due to the newest pneumatic technology, fine mechanics and up-to-date electronics connection. Pneumatic systems built with proportional valve can achieve more flexibility of machines and devices operation. They can even make different kinds of programmable control systems and drives possible. Advantages of using such valves mainly depend on decreasing number of pneumatic elements needed for pneumatic system construction. They can improve properties of developed pneumatic system as well because of the continuous motion parameter changes possibility.

Mathematical modelling of proportionally operated valves allows decreasing cost connected with searching new area applications of such elements. It also allows proper choice of control and drive elements without making expensive attempts.

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2 PROPORTIONAL VALVE PROPERTIES

For mathematical modelling one-stage proportional pressure valve with output pressure feedback and integrated electronic has been chosen (Figure 1). Graphic symbol of investigated valve shown on Figure 1 distinguished important elements it consists of. Structure of this valve was shown on the Figure 2. This kind of electro-mechanical transducer applied in this valve makes possible to use them in adjustment and control systems working in slow-acting process.

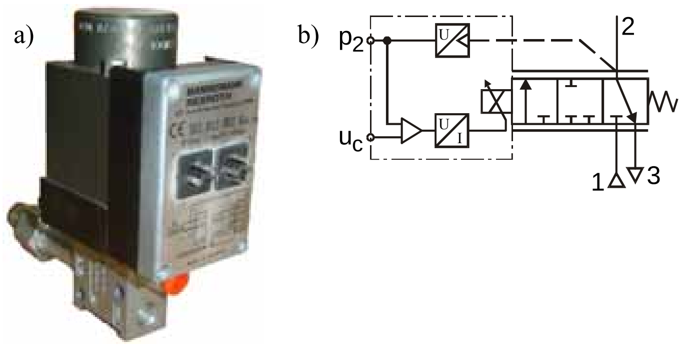

Fig. 1 Investigated proportional pressure control valve with output pressure feedback: a) view, b) ISO symbol

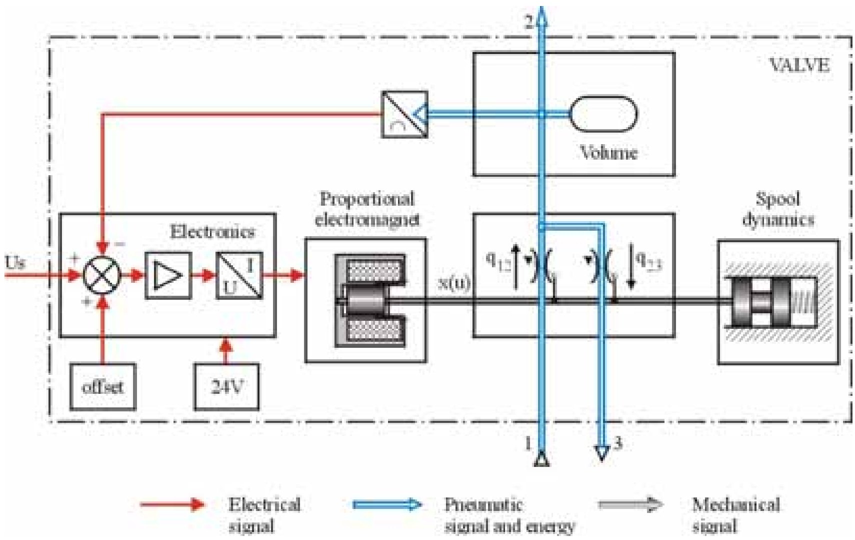

Fig. 2 Structure of investigated proportional valve

Presented proportional valve is controlled by voltage control signal between 0 and 10 [V] what is equivalent for the output pressure changes from 0.01 to 0.6 [MPa]. Manufacturer [3] announces that valves operational hysteresis amount to 0.02 [MPa]. Valve nominal flow rate amounts to 350 [Nl/min] and has been given for supply absolute pressure $p_1 = 0.7$ [MPa] and pressure drop $\Delta p = 0.02$ [MPa]. Remaining parameters necessary in mathematical modelling process have been determined according to parameters mentioned above or assumed on the basis of references.

3 MATHEMATICAL MODEL

Due to practical reasons synthesis of proportional pressure valve mathematical model has been started from decomposition of the system to pneumatic and mechanic parts.

3.1 Flow properties of the valve

Proportional pressure valve construction suggests that it works being based on principles of a 3/3 type directional control valve (three ways valve with three main positions). Such construction gives the opportunity to use this valve in two different fail-safe modes. During control signal failure the output of the valve could be connected to the exhaust or, in second mode, to the supply pressure.

Pneumatic element computational schema of the proportional valve has been shown in Figure 3. Flow properties of distinguished pneumatic amplifier of the valve have been modelled as the set of throttling elements, which is called pneumatic half bridge. On that basis the balance equations of the mass flow rates has been written as formula (1).

$$q_2 = q_{12} - q_{23} \tag{1}$$

According to ISO 6358 standard the compressed air mass flow rate q_{ij} of pneumatic throttling elements 12 and 23, has been written in according to formula (2).

$$q_{ij} = C_{ij} \cdot p_i \cdot \rho_0 \sqrt{\frac{T_0}{T_i}} \cdot \Psi(r) \tag{2}$$

where:

C_{ij} – conductance of the throttling elements *ij* $\left[\frac{\mathrm{s \cdot m^4}}{\mathrm{kg}}\right]$,

p_i – absolute pressure in the inlet of the throttling elements *i* [MPa],

ρ_0 – air density in the standardised reference conditions $\left[\frac{\mathrm{kg}}{\mathrm{m^3}}\right]$,

T_0 – air reference temperature [K],

T_i – air temperature in the inlet of pneumatic throttling element [K].

The auxiliary function $\Psi(r)$ is given by the formula (3).

$$\Psi(r) = \begin{cases} \sqrt{1 - \left(\frac{r-b}{1-b}\right)^2} & dla \quad b < r < 1 \\ 1 & dla \quad 0 \le r \le b \end{cases} \tag{3}$$

where:

r – outlet to inlet absolute pressure ratio corresponding to considered throttling element [-],

b – critical value of the pressure ratio [-].

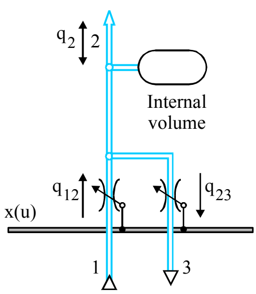

Fig. 3 Flow properties schema of proportional pressure valve

Precise analysis of pneumatic amplifier mechanical construction having an effect to their flow properties was not carried out for the sake of sufficient data lacks as well as due to mathematical model simplification.

Additionally in mathematical model clearance volume has been taken into consideration. Clearance volume has taken an important effect to pressure changes speed in outlet 2.

3.2 Electromechanical transducer

Physical properties of the electro-mechanical transducer, which is connected with working element of the pneumatic amplifier, have been approximate as the first order inertial object (Figure 4). Force $F(t)$ generated by proportional electromagnet interact to a valve working element, which is distinguished in the Figure 4 as lumped mass M and supported by spring with stiffness k. Resistance to motion as a consequence of applied type of sealing elements and the slide geometry in the valve has been written mainly as viscous damping ratio c. Due to parameters M, k and c are unknown, the gain and time constant of inertial object have been arbitrary assumed and corresponds closely to dynamic properties of real valve.

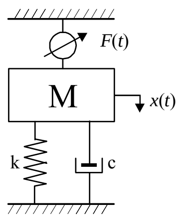

Fig. 4 Physical model of dynamic properties of proportional pressure valve

Generated by proportional electromagnet force $F(t)$ as a function of control current has been mapped on the basis of real characteristic shown in Figure 5. Additionally hysteresis, transducer dead zone as well as displacement saturation of proportional electromagnet armature have been taken into consideration. In according to [2] paper, linear range of static characteristics of proportional electromagnet has been chosen and became the basis of assumption that armature displacement of an electromagnet would not exceed $x = 2$ [mm].

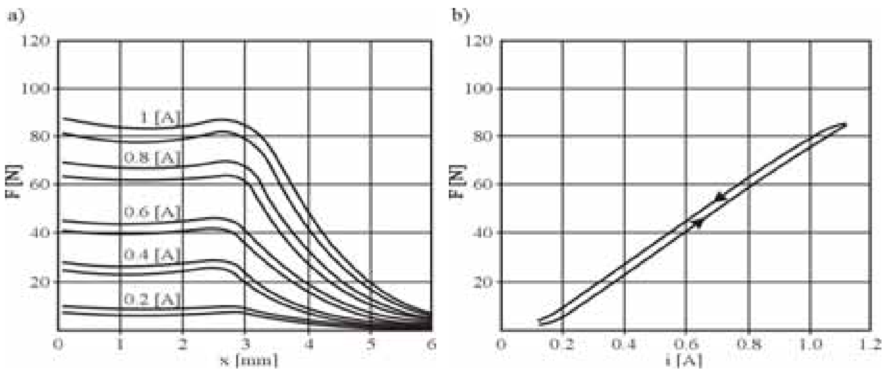

Fig. 5 Force characteristics of proportional electromagnet:
a) function of armature displacement, b) function of coil current

4 EXPERIMENT

Before numerical experiments run in MATLAB-Simulink package software, some parameters must be determined. Mass flow rate formulas based on equations (1), (2) and (3) used in simulations demand knowledge about conductance of pneumatic element C as well as critical value of the pressure ratio b of investigated valve. Conductivity C can be obtained from equations (2) and (3) by replacing nominal flow rate and pressure value given by the producer. Because of the lack of knowledge according to critical value of the pressure ratio b, an assumption has been made that mentioned parameter can vary in range $0.2 \div 0.5$ what was described by [4]. Results of numerical experiments has been obtained for $b = 0.3$.

The next important parameter necessary for run numerical experiments is connected with clearance volume V of the valve. This parameter was unknown as well. In such a situation an assumption was made that $V = 2$ [cm^3]. Another necessary data used in simulations such as hysteresis and nominal flow rate has been obtained from catalogue published by the vale producer[3].

At first complex structure of the investigated valve demanded to determine properties of described model components. In case of pneumatic component of the mathematical model some parameters according to real ones have been compared, such as flow rate for the nominal opening of the valve, or shape of the flow rate characteristics as valve opening. Then electromechanical transducer has been tested. It was important that characteristics obtained from simulations should correspond with real ones.

Mathematical model synthesis of chosen type of proportional pressure valve needs to combine model components to become the whole. Because of the fact that investigated valve has an integrated electronics including output pressure feedback from pressure p_2, this element has been taken into consideration in mathematical model as well. Prepared model in Matlab-Simulink has been shown in Figure 6.

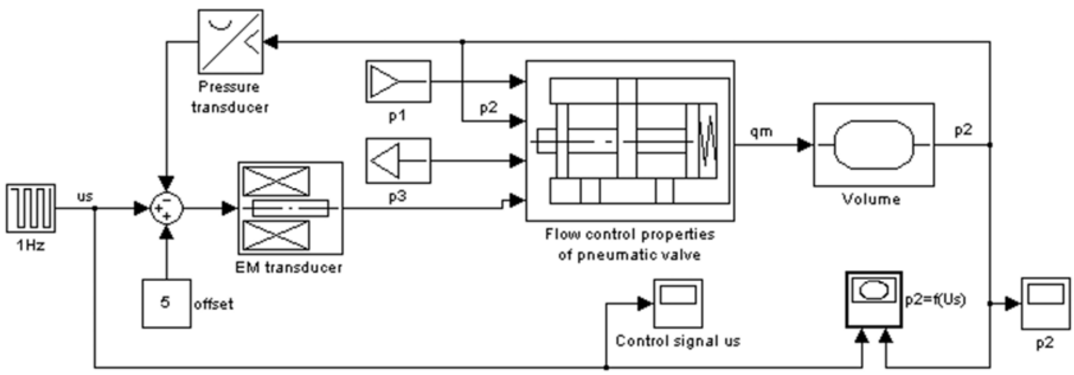

Fig. 6 Mathematical model of proportional pressure control valve prepared in Matlab-Simulink

The aim of numerical experiments was to map static characteristics of the valve as well as dynamic ones. The quality of developed mathematical model shows e.g. that the results coming from experiment and simulations converge well. The step response of modelled and real valve has been shown in Figure 7 as an example of the obtained results where square control signal had the frequency 1 [Hz] and amplitude 5 [V]. The shown results have been obtained for valve with blinding output 2.

The nature of real valve output pressure changes shows that it has been characterized by the time of lag according to the control signal changes as well as step changes nature of the output pressure. Probably the observed phenomenon was connected with friction appeared in valve or with the construction of valve working element. Unfortunately, insufficient knowledge about mechanical construction of valve pneumatic amplifier could not allow unambiguously to settle this problem. That was the main reason of abandon the further mathematical model development.

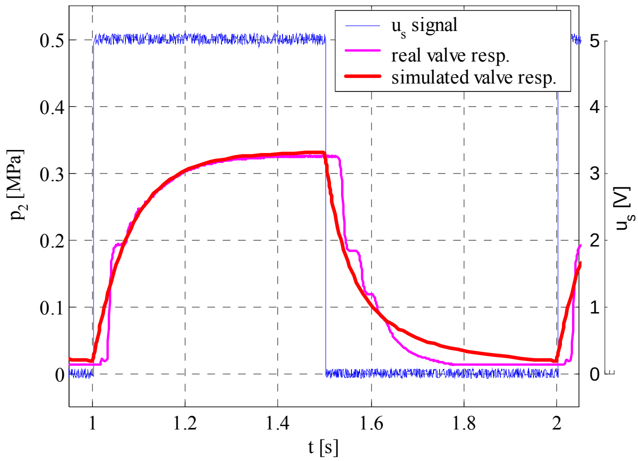

Fig. 7 Step response of real and modelled valve

5 CONCLUSIONS

This paper has been concerned mathematical modelling of electro-pneumatic proportional pressure valve. The advantages of such a technique were taken into consideration by MATLAB-Simulink software package usage available in The Department of Process Control. Mathematical model of such valve becomes the next element in library among large number of hydraulic and pneumatic proportionally operated elements. In spite of some discrepancy between response of real and modelled pneumatic valve, the main goal related to mapping of the most important static and dynamic properties was achieved.

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