Technical science and innovation

Volume 2020 | Issue 2 Article 1

7-23-2020

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Recommended Citation

Kasimov, F. O. and Ismailov, M.A. (2020) "MODELING THE STATISTICAL CHARACTERISTICS OF A MEMBRANE PNEUMATIC VALVE IN MATLAB," *Technical science and innovation*: Vol. 2020 : Iss. 2 , Article 1.
Available at: https://uzjournals.edu.uz/btstu/vol2020/iss2/1

UDC: 62-522.7

MODELING THE STATISTICAL CHARACTERISTICS OF A MEMBRANE PNEUMATIC VALVE IN MATLAB

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Abstract. *To create static models of actuators, linear or polynomial equations are used. Such models do not provide the necessary accuracy for the entire system, although they give an adequate result in a specific area of the process under consideration. In addition, the technical values of the coefficients in polynomial equations cannot always be explained. Analytical modeling of the static characteristics of the object allows us to analyze the influence of the parameters of the object on the overall model. After the model structure is built, the experimental determination of its coefficients ensures that an adequate model can be achieved faster.*

In this work, a static model of a membrane pneumatic actuator is constructed by the analytical method. The coefficients of the model parameters were determined experimentally. The model and actual results of the process were comparatively analyzed.

Key words: *membrane pneumatic valve; a saddle; a stock; transmitter; valve; static model; Matlab; computer model.*

Introduction

In biochemistry, food industry, oil refining, most technologies are organized on the basis of fluid flow. In this case, the process is carried out by monitoring and controlling the flow, temperature, level and other parameters of the liquids.

The control valves are mainly used to control the liquid level. That valves vary in volume, design, type of used energy, and a number of other parameters. Among them, pneumatic diaphragm control valves are widely used in organizing the main processes of most enterprises (Fig, 1).

a) b)

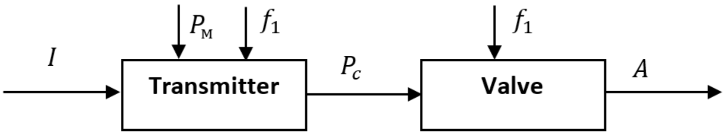
Fig, 1. Diaphragm pneumatic control valve: a) photo of the valve; b) valve drawing; 1) output channel; 2) valve body; 3) inlet channel controlling pressure; 4) membrane; 5) drive; 6) a saddle and a lock; 7) stock

Formulation of the problem

This valve is controlled by air pressure. Typically, such valves are manufactured in conjunction with electro-pneumatic converters. In this case, the function of the transmitter is to convert the electrical signal into a pneumatic. The valve operates in the following order: the control signal from the controller is transmitted to the valve converter, the converter creates an air pressure proportional to the signal, due to an external source. The resulting air pressure is transferred to the membrane chamber. Since the chamber is hermetically closed, overpressure causes the membrane to slide. Due to the membrane is directly connected to the rod, its displacement is proportional to the sliding of the rod. The rod, on the other hand, moves the saddle, which is attached to the end and changes the surface along which the fluid flows from the nozzle [1,2].

The solution of the problem

Based on the valve operating mode, we can conclude that the control parameter is an electric signal coming from the regulator, and the stem displacement is a controlled parameter [3]. The block diagram of the valve together with the actuator is as follows (Fig. 2).



Fig, 2. The structure scheme of diaphragm pneumatic adjustment valve

In Figure 2, the control signal is a current I. The limit of change of the control signal is 4-20 mA. $P_{\text{м}}$ - source pressure. The transducer converts the source pressure to the control pressure $P_{\text{б}}$ with exciting effects f_1. The valve, on the other hand, opens in an amount A in accordance with the control pressure for various mixing effects. If the valve has a linear characteristic, the degree of opening A is equal to the degree of displacement of the stem.

$$A = h \tag{1}$$

External exciting effects are mainly due to two forces acting on the membrane without taking it into account. These are pressure forces applied to the membrane (2),

$$F_{\text{м}} = P_M S_M \tag{2}$$

and the spring force that resists it (3).

$$F_{\text{п}} = kh \tag{3}$$

In expression (2), P_M is the pressure applied to the membrane, $S_{\text{м}}$ is the surface of the membrane. In expression (3), k is the coefficient of the spring, h is the distance of the rod. when two opposing forces are in equilibrium, the following expression can be written.

$$P_M S_M = kh \tag{4}$$

From the expression (4), the stem displacement is determined.

$$h = \frac{P_M S_M}{k} \tag{5}$$

The change in pressure in the membrane occurs under the influence of the control pressure P_{con}.

$$P_M = P_K + P_{con} \tag{6}$$

In expression (6), $P_{\text{к}}$ is the pressure inside the membrane chamber. According to the Mendeleev-Clapeyron equation, the pressure inside the chamber can be expressed as follows.

$$P_K V = \frac{m}{M} RT \tag{7}$$

In Equation (7), m is the mass of air in the chamber, M is the molecular mass of air ($M = 28{,}29 \left[\frac{gr}{mol}\right]$), R is the universal gas constant ($R = 8{,}31 \left[\frac{J}{mol*\text{К}}\right]$), T is the air temperature inside the chamber.

According to the laws of thermodynamics, when a gas is compressed, its temperature changes. Since the temperature change in this process is very small, it can be assumed that the gas temperature does not change T = 20 °C.

It is advisable to set the mass of air in equation (7) by its density and the volume that it occupies. If the change in air density under the influence of pressure in the chamber is not taken into account, the mass is expressed as follows.

$$m = \rho_{air} V \tag{8}$$

If the volume of the membrane chamber is conditionally assumed to have a cylindrical shape, the change in the volume of the chamber is written according to expression (9).

$$V = hS_{\text{м}} \tag{9}$$

Substituting expressions (8) and (9) into equation (7),

$$P_K = \frac{\rho_{air} RT}{MS_{\text{м}}} \tag{10}$$

Substituting the resulting expression (10) into (6), we write equation (11).

$$P_M = \frac{\rho_{air} RT}{MS_{\text{м}}} + P_{con} \tag{11}$$

Substituting expression (11) into (5) forms the final model of the object under study.

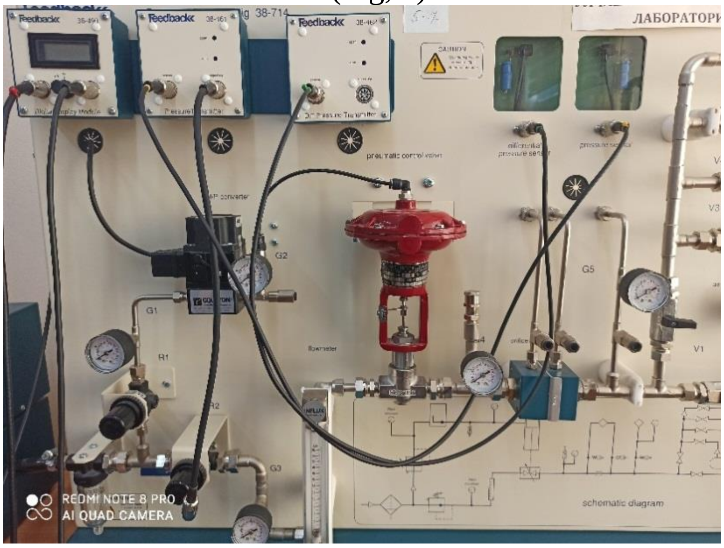
$$h = \frac{\frac{\rho RT}{MS_{\text{м}}} + P_{con}}{k} \tag{12}$$

In the resulting model, k is the stiffness coefficient of the diaphragm pneumatic adjustment valve spring, which was determined experimentally. This model is created in the Matlab program as follows (listing 1).

Listing 1

```
I=[4:20];
P_b=5000*I;
Ro=1.2928;
R=8.31;
T=20;
M=28.97;
S=0.000157;
K=1.0;
h=@(p_b) ((Ro*R*T/M + p_b)*S)/K;
plot (I,h(P_b))
```

In the experiment, signals in the range of 4–20 mA were given to control the valve, and the displacement of the valve stem was measured (Fig, 3).



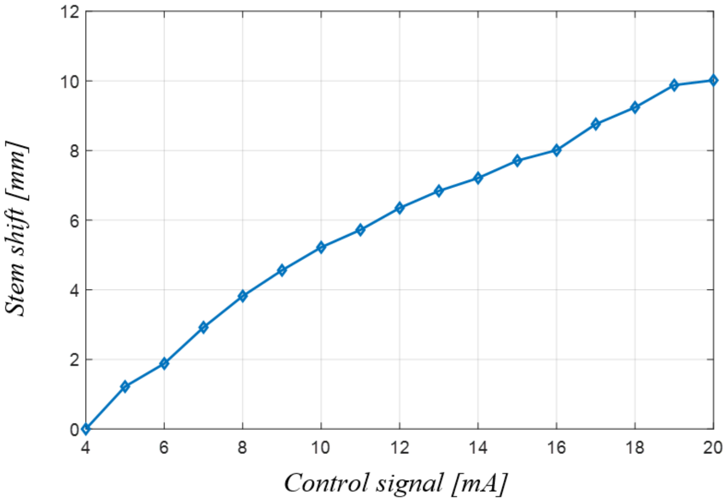
Fig, 3 Laboratory bench for training valve characteristics.

Table 1.

The following results were obtained from the experiment

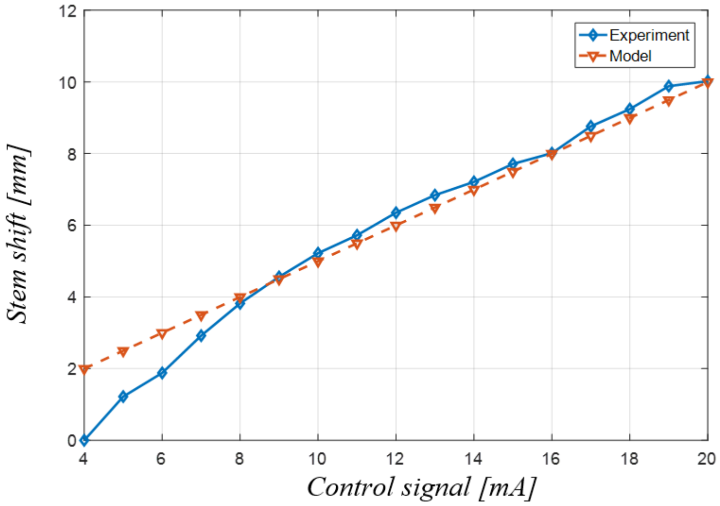
Table 1. Static characteristics of diaphragm pneumatic control valve																	
Control signal [mA]	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
Stem shift [mm]	*0*	*1.22*	*1,88*	*2,92*	*3,82*	*4,56*	*5,22*	*5,72*	*6,35*	*6,84*	*7,21*	*7,71*	*8,01*	*8,76*	*9,24*	*9,88*	*10.02*

According to the results of the experiment, the static characteristic of the valve is as follows (Fig, 4).



Fig, 4. Graph of static characteristic of the valve

By changing the coefficients of the spring in the computer model, the value of the model closest to the actual process was determined. When this coefficient had a value of K = 1.5712, the model gave the values closest to the actual process (Fig, 5).



Fig, 5. Static characteristic of the valve and graph of the experimental result

To assess the quality of the generated model, a table was created consisting of input parameters, model results and actual process results (Table 2).

Table 2.

Results of experiment

Inputs	**Model results**	**Real process results**	**Quadratic error**	**Relative error**
4	*2,00*	*0*	*2,00*	*0,00*
5	*2,50*	*1,22*	*1,28*	*1,05*
6	*3,00*	*1,88*	*1,12*	*0,59*
7	*3,50*	*2,92*	*0,58*	*0,20*
8	*4,00*	*3,82*	*0,18*	*0,05*

9	*4,50*	*4,56*	*0,06*	*0,01*
10	*5,00*	*5,22*	*0,22*	*0,04*
11	*5,50*	*5,72*	*0,22*	*0,04*
12	*6,00*	*6,35*	*0,35*	*0,06*
13	*6,50*	*6,84*	*0,34*	*0,05*
14	*7,00*	*7,21*	*0,21*	*0,03*
15	*7,50*	*7,71*	*0,22*	*0,03*
16	*7,99*	*8,01*	*0,02*	*0,00*
17	*8,49*	*8,76*	*0,27*	*0,03*
18	*8,99*	*9,24*	*0,25*	*0,03*
19	*9,49*	*9,88*	*0,39*	*0,04*
20	*9,99*	*10,02*	*0,03*	*0,00*

Based on the calculations performed on the basis of the data presented in table 2, the mean square error was 0.45 mm, and the average relative error was 0.13.

Conclusion.

As can be seen from fig, 5, the error was relatively high in a small number of signals. This error can be explained by the fact that the coefficients of friction and inertia of the moving body were not taken into account in the study of the valve, and changes in the density of air pressure inside the chamber were ignored.

The computer model gave good results for cases where the control signal was from 7 mA to 20 mA. The resulting static characteristic equation can be used to control processes that do not require very high accuracy. In addition, another positive feature of this model is that it does not perform complex operations such as rooting or differentiation. This helps speed up the management process.

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