RESEARCH OF INFLUENCE OF BRAKE DEVICE ON DYNAMIC PROPERTIES OF ELECTRO-PNEUMATIC VALVE

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S u m m a r y : The results of mathematical simulation of dynamic processes of opening and closing electro-pneumatic valve and optimization of geometrical parameters of brake device are presented.
K e y w o r d s : jet actuating devices, electro-pneumatic valve, brake device, dynamic properties, mathematical model, numerical experiment.

INTRODUCTION

One of the most perspective directions of solution the problem of the reliability increasing and operation life of control system by the powerful streams of liquids and gases is the use of jet executive devices (JED) as a regulative and locking valve. Especially it is actual for industries with extreme operating conditions – coal, chemical, power, transport, agriculture etc., where the classic devices of the mechanical operating fail much more quickly comparing with normal operating conditions [2, 4, 6, 7, 9, 17, 18]. It is caused by more intensive wear of movable parts of regulative organs.

Researches that conducted in V.Dahl EUNU, allowed to create the row of the systems with jet executive devices on the basis of vortex regulative device [14, 15]. Experience of their operation showed that increasing working characteristics of interface unit has considerable reserve. In modern control system the most simple and reliable electro-pneumatic transformers are electro-pneumatic valves (EPV) with cylindrical core (fig. 1).

They successfully work as a part of the pneumatic drives of jigging machines on the coal-concentrating factories of Ukraine, Russia and other countries.

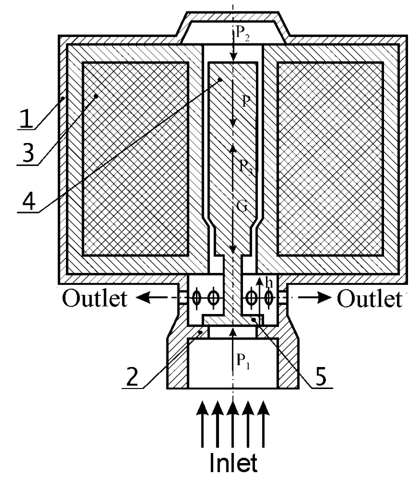

Fig. 1. Structural chart of electro-pneumatic valve 1 – housing; 2 – saddle; 3 – electromagnet; 4 – core; 5 – core locking part

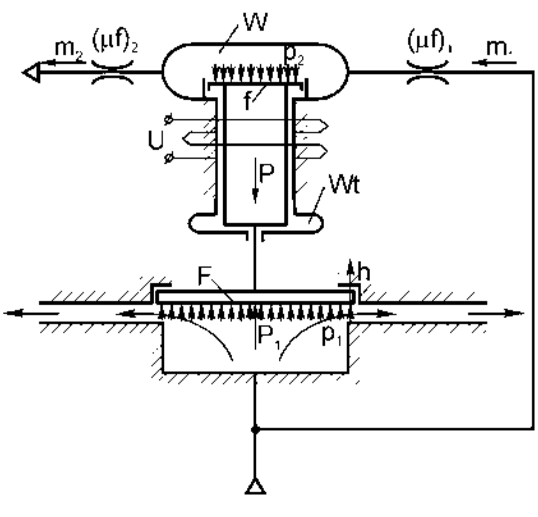

Fig. 2. Calculation chart of EPV with unloading and core braking

The researches that directed on modernization of the valves of such a type [16] showed, that using the discharging device along with the substantial increase of their carrying capacity and improvement of fast-acting, to the rev-up of landing on the saddle of locking organ, i.e. to the increase of the shock loadings. To decline this negative effect we offer the construction of EPV with a damping device.

RESEARCH OBJECT

A calculation chart and mathematical model of electro-pneumatic valve with unloading and core braking at the end of motion is presented below [10-13].

$$\begin{cases} \frac{dh}{dt} = V; \\ M\frac{dV}{dt} = P - P_1 + p_2 f - k_d V + Mg - P_t; \\ P = f(i,h); \\ P_1 = \int\limits_F p_1 df; \\ P_t = p_t \cdot f_t; \\ \frac{dLi}{dt} + R \cdot i = U(t); \\ \frac{W_0 + f(h_{\max} - h)}{kRT_{01}}\frac{dp_2}{dt} + \frac{p_2}{RT_{01}} f \cdot V = m_1 - m_2; \\ \frac{W_{0t} + f_t h}{kRT_{01}}\frac{dp_t}{dt} + \frac{p_t}{RT_{01}} f_t \cdot V = 0; \\ m_1 = (\mu f)_1\, p_n \sqrt{\frac{2k}{(k-1)RT_{01}}\left[\left(\frac{p_2}{p_n}\right)^{\frac{2}{k}} - \left(\frac{p_2}{p_n}\right)^{\frac{k+1}{k}}\right]}; \\ m_2 = (\mu f)_2\, p_2 \sqrt{\frac{2k}{(k-1)RT_{01}}\left[\left(\frac{p_{атм}}{p_2}\right)^{\frac{2}{k}} - \left(\frac{p_{атм}}{p_2}\right)^{\frac{k+1}{k}}\right]}; \end{cases}$$

where: h is core's displacement; V is speed of core; t is time; M is the reduced mass of movable parts; P is electromagnetic force; P_1 is aerodynamic force; P_t is braking force; p_n is feeding pressure; p_a is atmospheric pressure; p_2 is pressure in unloading cavity; p_t is pressure of braking; F is area of locking organ; f is area of core; f_t is braking area; k_d is damping coefficient; L, R is inductance and active resistance of solenoid coil; U, i is tension and current in solenoid coil; W_0, W_{0t} are dead volumes of unloading and braking chambers; m_1, m_2 are mass charges of the unloading system; $(\mu f)_1$, $(\mu f)_2$ are effective areas of filling and upcast tracks of unloader; k is adiabatic index; R is gas permanent; T_{01} is braking temperature.

The decision of mathematical model equations was realized by the Runge-Kutt method of the forth order of exactness in the application package for engineering's and scientific calculations with the opened source code Freemat® at the followings terms:

- Initial conditions: $t = 0$; $h = 0$; $V = 0$; $p_t = p_a$ $i = 0.2\,A$; $p_2 = p_a$; $U = 24\,V$.
- Boundary conditions: $0 \le h \le h_{\max}$.
- Assumptions:

1. The thermodynamics process is adiabatic.
2. $T_{01} = const$.

RESULTS OF RESEARCH

To establish the approximating dependence of speed of valve's closing V from the parameters of brake device (relative length $\overline{h}_t = h_t/h_{\max}$ and relative «dead» volume of brake chamber $\overline{W}_t = W_t/F_t h_{\max}$) the two factor numerical experiment was planned by the Boks-Wilson method [1, 3, 8]. The matrix of factors encoding and planning matrix is resulted below.

Table 1. Factors encoding

	-1.41	-1	0	1	1.41
$\overline{h}_t$	0.1	0.23	0.55	0.87	1
$\overline{W}_t$	2.149	2.463	3.224	3.985	4.299

Table 2. Planning matrix

Experience №	X_1	X_2	Y
1	-1	-1	0.49
2	-1	1	0.516
3	1	-1	0.394
4	1	1	0.46
5	-1.41	0	0.533
6	1.41	0	0.434
7	0	-1.41	0.404
8	0	1.41	0.484
9	0	0	0.458

The results of experiment were processed on least-squares method and resulted on fig. 3 as a surface of response.

Equation of regression for speed (in meters per second) of valve closing at confidence probability $\alpha = 0{,}95$ and square Pirson's correlation coefficient can be presented in a kind [1]:

$$V = 0.4580 - 0.0366 \cdot X_1 + 0.0257 \cdot X_2 + 0.0131 \cdot X_1^2 - 0.0067 \cdot X_2^2 + 0.0100 \cdot X_1 \cdot X_2$$

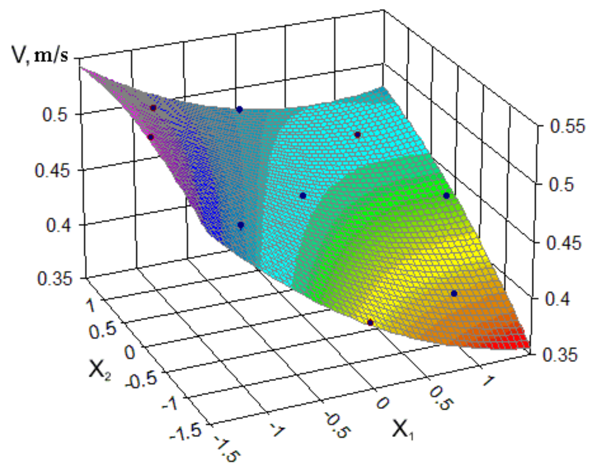

Fig. 3. Surface of response of speed of valve closing

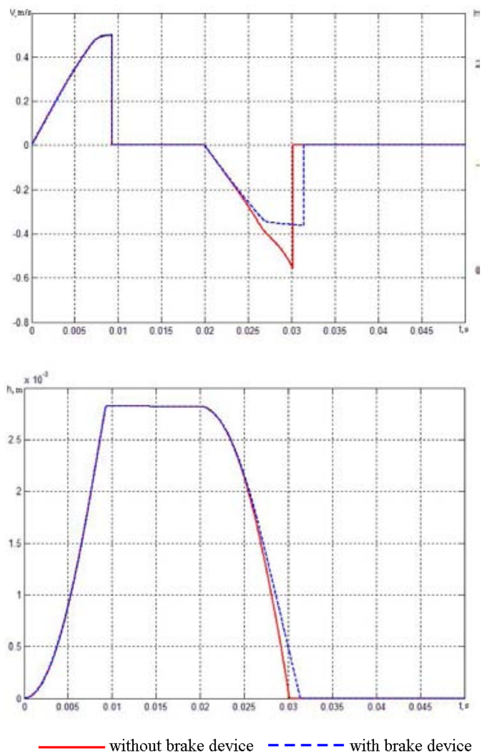

Fig. 4. Transient processes in electro-pneumatic valve

The value of global minimum, found by standard method (i.e. equality of the first derivatives to zero) showed that it lays out of limits of the investigated area. Therefore minimum time of transient process was on the border of the investigated area.

$$V_{\min} = 0.4580 - 0.0366 \cdot 1.41 + 0.0257 \cdot (-1.41) + 0.0131 \cdot 1.41^2 - 0.0067 \cdot (-1.41)^2 + 0.0100 \cdot 1.41 \cdot (-1.41) = 0.363\,(m/s).$$

To determine the influence of brake device on the fast-acting of EPV the calculation of transient processes for two variants (with a brake device and without it) was realized. The analysis of charts (fig. 4) showed that using the brake device practically did not influence on the EPV fast-acting (decrease does not exceed 4% here). The use of brake device allows to decrease speed of mandrel at the end of motion in 1,5 time.

CONCLUSIONS

1. The developed mathematical model of working process of electro-pneumatic valve adequately describes the dynamic processes of core displacement jointly with a locking device as poppet valve. The model is based on equations of dynamic equilibrium of the system «core – locking organ», equations of indissolubility, equations of gas charges at a subsonic flow in the elements of valve flowing part, equations of the working environment state and equations of electric processes with initial and boundary conditions.
2. Using the brake device allowed to reduce core's speed at the end of motion in 1.5 time, i.e. to reduce the impact force of valve at a saddle more than twice.
3. The brake device does not reduce the fast-acting of electro-pneumatic valve much. The increase of transient process time does not exceed 4% .

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ИССЛЕДОВАНИЕ ВЛИЯНИЯ ТОРМОЗНОГО УСТРОЙСТВА НА ДИНАМИЧЕСКИЕ ХАРАКТЕРИСТИКИ ЭЛЕКТРОПНЕВМАТИЧЕСКОГО КЛАПАНА

Дмитрий Семин, Ярослав Мальцев, Марина Мальцева

Аннотация. Приведены результаты математического моделирования динамических процессов при открытии и закрытии электропневматического клапана и оптимизация геометрических параметров тормозного устройства.

Ключевые слова: струйное исполнительное устройство, электропневматический клапан, тормозное устройство, динамические характеристики, математическая модель, численный эксперимент.