The influence of initial parameters of pneumatic accumulator on the dynamic characteristics of the actuator during braking back pressure

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Abstract. A pneumatic drive with back pressure braking is considered. The braking energy is recovered to the pneumatic accumulator. A schematic diagram of a regenerative pneumatic drive is given. The question of the influence of the initial parameters of the pneumatic accumulator on the dynamic characteristics of the pneumatic actuator is considered. The following initial parameters were set in the pneumatic accumulator: volume; pressure. The following were evaluated in a pneumatic drive: pressure in cavities before and after braking; output link speed. The energy consumption and speed of the pneumatic drive were determined critically. Graphic dependencies of the dynamic processes of the pneumatic drive are presented. The relationship of the initial parameters of the pneumatic accumulator with the criteria of energy consumption and speed is established.

1. Introduction
Pneumatic drive is actively used in industry. This is due to such advantages as the availability and environmental friendliness of the working environment, ease of automation and mechanization, centralization of the energy source, speed [1], [2]. However, the inertia of the output links, the compressibility of the working medium, and, as a result, the impact or “overrun” of the output link at the breakpoint forces it to significantly limit its speed [1], [2]. To ensure an unstressed stop, specialized changes are made to the design of the air motor, and the air compressed during braking is released [2].

A variety of approaches to solving this problem leads to the presence of a large number of ways to set the law of braking of the output link of the pneumatic drive [3], [4], [5], [6], [7]. The most promising of them is the method of braking the output link in the brake cavity of the air motor. This method has several advantages, the main of which is the possibility of energy recovery, therefore, the braking of the output link of the pneumatic actuator with backpressure reduces energy consumption due to the subsequent use of compressed air during braking [1], [2], [7]. The use of a pneumatic accumulator in the implementation of this method allows not only to increase energy recovery, but also to expand the range of control of the braking parameters of the pneumatic drive. Changing the initial parameters of the pneumatic accumulator allows you to provide rational energy-speed characteristics of the pneumatic actuator [8], [9], [10].

The aims of the work are as follows: to study the influence of the initial parameters of the pneumatic accumulator on the energy-speed characteristics of the pneumatic actuator during braking...
by the backpressure method, and to establish a mathematical relationship between the initial parameters of the pneumatic accumulator and the criteria for speed and energy consumption.

2. The main part of the research

A schematic diagram of a pneumatic drive with energy recovery to the pneumatic accumulator is shown in Figure 1. The output link is braked by completely blocking the pressure and exhaust lines with a distributor (D1). At this point, a pneumatic accumulator (AV) with a predetermined volume and initial pressure in it is connected to the exhaust manifold. Further, the movement of the output link is accompanied by compression of the air in the brake cavity of the air motor and the pneumatic accumulator connected to it with a simultaneous drop in pressure in another expanding cavity of the air motor. The potential energy of compressed air during braking is recovered in the pneumatic accumulator. The accumulated energy is used to reverse the movement of the air motor without load. The fixation of the executive body is carried out by a pneumofitsirovannym emphasis on the "rebound" of the rod (not shown in the figure).

![Figure 1. Principal circuit of the pneumatic drive with energy recuperation in the pneumatic accumulator.](image)

By setting the initial parameters of the pneumatic accumulator, pressure and volume, the braking force on the piston of the air motor is regulated, which allows not only to perform an unstressed stop of the actuator, but also to ensure rational speed and energy consumption of the pneumatic actuator [8], [9], [10]. The initial parameters of the pneumatic accumulator are set by switching the distributor (D2), from the line, in which the pressure is set by a pressure reducing valve (RV). Switching to braking of valves D1,2 is carried out by limit sensor S2. Sensor S1 signals that the rod has reached the initial position of the air motor.

After confirming the adequacy of the mathematical model that describes the dynamic processes in the proposed pneumatic actuator [11], [12], [13], [14], a computational experiment [15] was conducted. The volume of the pneumatic accumulator (h) and the initial pressure in the pneumatic accumulator (p) were taken as controlled and independent from each other factors affecting the speed and energy consumption. Factors varied at five levels. As a performance criterion (Y1), the working
stroke time of the output link of the pneumatic drive \((t \text{ (s)})\) was taken. For the criterion of energy consumption \((Y_2)\), the ratio of the product of the volume of the pneumatic accumulator and the initial pressure in it to the product of the final pressure in the brake cavity and the total volume of the brake cavity was used. Based on the results of the analysis of the experimental data, the regression equations were compiled and solved:

\[
Y_1 = 0.934 + 9.9166 \cdot 10^{-2} (h - 0.3) - 4.1666 \cdot 10^{-8} (p - 300000) - \\
6.875 \cdot 10^{-8} (h \cdot p - 300000 h - 0.3 p + 90000) + 7.5 \cdot 10^{-2} (h^2 - 0.6 h + 0.09) + \\
+ 2.125 \cdot 10^{-13} (p^2 - 600000 p + 9 \cdot 10^{10}) \\
Y_2 = 2.2395 - 3.6988 (h - 0.3) + 1.5074 \cdot 10^{-7} (p - 300000) - \\
- 2.9559 \cdot 10^{-7} (h \cdot p - 300000 h - 0.3 p + 90000) + 9.50413 \cdot \\
(h^2 - 0.6 h + 0.09) + 2.933 \cdot 10^{-13} (p^2 - 600000 p + 9 \cdot 10^{10})
\]

where \(h \text{ (m)}, p \text{ (Pa)}\) — the amount of additional volume reduced to the area of the piston of the air motor and the absolute initial pressure in the additional volume, respectively.

Graphically, the dependence of the performance and energy consumption criteria of the pneumatic actuator on the parameters of the initial parameters of the battery is shown in figure 2.

**Figure 2.** The dependence of energy-speed criteria on the initial parameters of the pneumatic accumulator \((p; h)\): a) - speed \((Y_1)\); b) - energy consumption \((Y_2)\).

An analysis of the dependences shown in figure 2 (a, b) obtained after the computational experiment allows us to assess the degree of influence of the experimental factors on the speed of movement of the output link and pressure in the rod and piston cavities of the air motor. Maximum performance is achieved with a minimum pneumatic accumulator volume of 42 cm\(^3\) and a maximum initial absolute pressure in it of \(5 \cdot 10^5\) Pa (figure 2, a). The minimum energy consumption corresponds to the initial parameters of the pneumatic accumulator: pressure \(1 \cdot 10^3\) Pa and volume 210 cm\(^3\) (figure 2, b).

Figure 3 shows graphical dependences of the speed of the output link \((v)\), pressures in the discharge cavity \((P_p)\) and the exhaust cavity \((P_v)\) of the air motor with varying the initial value of the volume of the pneumatic accumulator with a constant absolute initial pressure in it - \(1 \cdot 10^5\) Pa. Figure 3 shows the same dependences as in figure 4, but the initial absolute pressure in the pneumatic accumulator is \(5 \cdot 10^5\) Pa.
Figure 3. The dependence of the parameters of the pneumatic actuator on the parameters of the pneumatic accumulator with an initial absolute pressure of $1 \times 10^5$ Pa and initial volumes of 42; 84; 126; 168; 210 cm$^3$: a) - output link speed ($v$); b) - pressure in the discharge cavity of the pneumatic actuator; c) - pressure in the brake cavity of the pneumatic actuator.

The maximum consumption of compressed air for accelerating the piston of the pneumatic cylinder corresponds to the initial pressure in the pneumatic accumulator - $5 \times 10^5$ Pa and the volume of the pneumatic accumulator - 210 cm$^3$ (figure 4). As it can be seen from figure 4, this combination of factors corresponds to the maximum “shelf” of pressure growth in the exhaust cavity ($P_v$) until switching to braking. The speed of the output link and the greatest force of resistance to movement will be at an initial pressure in the pneumatic accumulator of $5 \times 10^5$ Pa and a volume of 210 cm$^3$ (figure 4). The maximum recovery pressure in the pneumatic accumulator is achieved with a volume of 42 cm$^3$ and an initial pressure in it of $5 \times 10^5$ Pa (figure 4).
Figure 4. The dependence of the parameters of the pneumatic actuator on the parameters of the pneumatic accumulator with an initial absolute pressure of $5 \times 10^5$ Pa and initial volumes of 42; 84; 126; 168; 210 cm$^3$: a) - output link speed ($v$); b) - pressure in the discharge cavity of the pneumatic actuator; c) - pressure in the brake cavity of the pneumatic actuator.

3. Conclusion
The maximum speed is achieved at an initial pressure in the pneumatic accumulator of $5 \times 10^5$ Pa, but the maximum costs of compressed air for accelerating the piston of the pneumatic cylinder are obtained at the same pressure and volume of the pneumatic accumulator of 210 cm$^3$. The minimum energy consumption in the pneumatic actuator corresponds to the initial pressure in the pneumatic accumulator - $2 \times 10^5$ Pa and its volume - 210 cm$^3$.

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