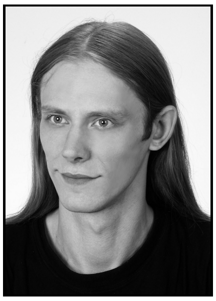
Mariusz JURCZYŃSKI, Mariusz OLSZEWSKI
INSTYTUT AUTOMATYKI I ROBOTYKI, POLITECHNIKA WARSZAWSKA

Methods of Discrete Pneumatic Drive Control that Ensures the Shock Absorption During the Last Part of the Movement

Mgr inż. Mariusz JURCZYŃSKI

Absolwent, obecnie doktorant i asystent w Zakładzie Urządzeń Wykonawczych Automatyki i Robotyki Instytutu Automatyki i Robotyki. Studia na wydziale Mechatroniki Politechniki Warszawskiej ukończył w 2003r.

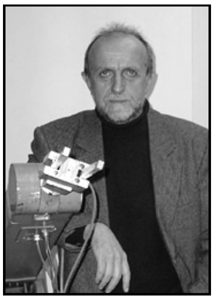
e-mail: m.jurczynski@mchtr.pw.edu.pl



Prof. nzw. dr hab. inż. Mariusz OLSZEWSKI

Dyrektor Instytutu Automatyki i Robotyki na Wydziale Mechatroniki Pol. Warszawskiej, stypendysta niemieckiej Fundacji Alexandra v. Humboldta, członek konsorcjum Europejskiej Sieci Centrów Techniki Płynowej (FPCE). Specjalista i autor publikacji, książek, podręczników, patentów i wdrożeń z zakresu budowy i sterowania urządzeń wykonawczych automatyki, robotyki przemysłowej i mechatroniki. Ma duże doświadczenie w kierowaniu projektami krajowymi i międzynarodowymi.

e-mail: m.olszewski@mchtr.pw.edu.pl



Abstract

In order to increase the production efficiency, the discrete manufacturing processes tend to have higher and higher speed, therefore producers of actuators for such processes have to manufacture devices that could achieve higher and higher velocity. This paper presents the analysis of the servomotor driver breaking processes implemented with the use of typing breaking devices, as well as the comparison of the breaking process with the one that ensures the dynamic overload minimization. The systems of the velocity control have also been presented that can be applied instead of the special-construction shock absorbers, and simultaneously give us the possibility to influence the braking process itself during the system operation.

Keywords: pneumatic, braking, shock absorption.

Metoda dyskretnego sterowania pneumatycznym napędem tłokowym zapewniająca amortyzację dobiegu

Streszczenie

Wynikająca z dążenia do polepszania wydajności produkcji tendencja zwiększania szybkości realizacji dyskretnych procesów produkcyjnych zmusza producentów elementów wykonawczych do konstruowania elementów zdolnych do osiągania coraz większych prędkości. W niniejszej pracy przedstawiono analizę procesów hamowania napędów siłownikowych, realizowanych z wykorzystaniem typowych urządzeń hamujących i porównanie z przebiegiem procesu hamowania zapewniającego minimalizację przeciążeń dynamicznych. Przedstawiono również systemy sterowania prędkością które, mogą być stosowane zamiast amortyzatorów dając jednocześnie możliwość wpływania na sam proces hamowania w trakcie pracy układu.

Słowa kluczowe: pneumatyka, hamowanie, amortyzacja.

1. Introduce

In devices of automatic control and robotization of discrete industrial manufacturing processes, e.g., automated assembly lines, manipulators, feeders, conveyors, transporters, sorting devices, orienting mechanisms, packing devices, food industry devices, textile industries, etc., many elements and unit exist that are set into motion, and then stopped, or set in a reverse motion. Both during the acceleration, as well as in the deceleration (breaking) phase, such elements or units are subjected of dynamic overloads. In devices used for the automatic control of manufacturing processes, switching drives are most often applied, in which the acceleration and deceleration processes are not controlled. Breaking the systems that are driven by such drives consists in the collision of the system with a movement limiter. In general, the overloads during the acceleration phase are not dangerous since they depend on the driving element power. The overloads generated during the deceleration phase may be much higher since the movement limiter properties decide on the magnitude of these overloads.

In order to increase the production efficiency, the discrete manufacturing processes tend to have higher and higher speed, therefore producers of actuators for such processes have to manufacture devices that could achieve higher and higher velocity. In most of the cases, the pneumatic servomotors act as such driving units. The higher the attained speed, however, the disproportionally more difficult are the problems related to the limiting of the dynamic overloads that exist during the moving element breaking. The energy that should be taken from the braked units increases in proportion to the square of the velocity. Either the breaking length and time are higher or the braking negative acceleration (deceleration) is higher. This causes the dynamic overloads to be higher and that influences the implemented process as well as the environment in a different and unfavourable way. Therefore, the limiting or elimination of such unfavourable phenomena pose as a serious technical problem. The method of protection against the possibility of the existence of excessive dynamic overloads has a decisive effect on the operational parameters of devices with moving elements. \devices supplied with systems that limit or minimize the dynamic overloads can have a lighter construction, can operate more efficiently and precisely, are more durable and more friendly to the process operators, as well as to the environment. Due to the scope of applications of devices having pneumatic drives to the automatic control systems and to the more flexible manufacturing, the problem of the dynamic overload minimization in such devices is very important. Thus, the problems related to the pneumatic drives breaking are described in many papers [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12].

In order to stop (brake) the units that are set into motion by the pneumatic servomotors, the construction elements of the servomotor itself – inner shock absorbers, or external breaking devices – shock energy absorbers, can be applied. This papers presents an analysis of the servomotor drive breaking processes implemented with the use of typical braking devices, as well as their comparison with the braking process that ensures the dynamic overload minimisation.

2. Methodology of Investigation of the servomotor Drive Breaking

A computer simulation model of the pneumatic drive created on the grounds of the following mathematical description was applied to the investigations.

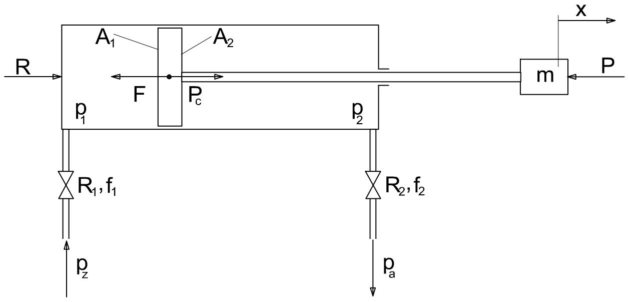


Fig. 1. Idealized pneumatic drive
Rys. 1. Wyidealizowany napęd pneumatyczny

The dynamics of the drive moving unit is described by the equation of the equilibrium of forces that act on the unit

$$-m\cdot\frac{d^2x}{dt^2}+F+P+P_c+R=0 \tag{1}$$

where:
m - mass of moving parts,
x - length distance travelled by the moving unit from its initial position,
$-m\cdot\frac{d^2x}{dt^2}$ - force of inertia of the moving parts,
F – resultant friction force that acts of the moving unit,
P - external influences force,
P_C - force of the pressure influences on the piston,

$$P_c=A_1\cdot(p_1-p_a)-A_2\cdot(p_2-p_a) \tag{2}$$

p_a - atmospheric pressure,
p_1, p_2 - absolute pressures in the servomotor chambers,
A_1, A_2 - active surfaces of the piston (fig. 1),
R - the reaction of the servomotor cover on the piston (in the extreme left-sided position of the piston).

The reaction of the cover is the passive force that appears only when the piston exerts a pressure on the cover.

Let us assume that forces pointing right have a positive sign, and forces pointing left, a negative one. It is possible to write:

$$\begin{aligned}&\text{for } x=0 \text{ and } P_C+P\le 0 \text{ this is } R=-(P_C+P),\\&\text{for } x=0 \text{ and } P_C+P>0 \text{ this is } R=0,\\&\text{for } x>0 \text{ this is } R=0,\end{aligned} \tag{3}$$

The solutions of Eq. (1) depend on the course of the friction forces F, external influences forces P, and pressures in the servomotor chambers.

In the position initial piston (displacement $x = 0$) the friction forces F represented by the static friction only. It was assumed that:

$$\begin{aligned}&\text{for } x=0 \text{ and } P_C+P<0 \text{ this is } F=0,\\&\text{for } x=0 \text{ and } P_C+P\ge 0 \text{ this is } F=-\min(F_1,P_C+P),\end{aligned} \tag{4}$$

where: F_1 – denotes the static friction force maximum value.

In the movement phase, up to the moment in witch the velocity begins to decrease, the friction can be described by the following equation:

$$F=-\left[F_2+k_v\cdot v+(F_1-F_2)\cdot e^{-\frac{v}{v_0}}\right] \tag{5}$$

F_2 - kinetic friction force minimum value,
k_v - dynamic friction coefficient,
v - piston velocity,
v_0 - coefficient that describes the speed of the exponential function changes.

In the subsequent phase of the piston movement, the friction force can be described by the following equation:

$$F=-\left[F_2+k_v\cdot|v|\right]\cdot \operatorname{sign} v \tag{6}$$

Expressions that define the velocity of the pressure changes in the piston chambers that are being filled up and emptied:

$$\frac{dp_1}{dt}=\frac{n}{x_{01}+x}\cdot\left(\frac{R\cdot T_0\cdot p_0^{\frac{1-n}{n}}}{A_1\cdot p_1^{\frac{1-n}{n}}}\cdot G_1-p_1\cdot\frac{dx}{dt}\right), \tag{7}$$

$$\frac{dp_2}{dt}=\frac{n}{S+x_{02}-x}\cdot\left(p_2\cdot\frac{dx}{dt}-\frac{R\cdot T_0\cdot p_0^{\frac{1-n}{n}}}{A_2\cdot p_2^{\frac{1-n}{n}}}\cdot G_2\right), \tag{8}$$

where:
n - gas transformation exponent,
x_{01}, x_{02} - piston dead positions,
R - gas constant for air,
T_0, p_0 - air supply temperature and pressure, respectively,
G_1, G_2 - air mass flows that flow in and out of the servomotor, respectively.

In order to calculate values of G_1 and G_2, the following formulas were applied to the sub-critical flows:

$$G_1=C_1\cdot p_0\cdot\rho_N\cdot\sqrt{\frac{T_N}{T_0}}\cdot\sqrt{1-\left(\frac{\varepsilon_1-b}{1-b}\right)^2} \tag{9}$$

$$G_2=C_2\cdot p_2\cdot\rho_N\sqrt{\frac{T_N}{T_2}}\cdot\sqrt{1-\left(\frac{\varepsilon_2-b}{1-b}\right)^2} \tag{10}$$

As well as their suitable simplifications in the case of critical flows, where:
C_1, C_2 - inlet and outlet resistance sound conductivity, respectively,
ρ_N, T_N, - reference normalised atmosphere density and temperature, respectively,
T_2 - temperature of the emptied chamber (calculated on the grounds of the assumed gas transformation),
ε_1, ε_2 - ratios of pressures behind the resistances to the ones in front of them,
b - real critical ratio of pressures (assumed to be identical for both resistances).

Using the simulation model [9] designed on the grounds of the above written dependences, one can define courses of the length, velocities, accelerations and pressures in the processes of the driving system servomotor piston displacement for the above assumed values of particular parameters. The breaking processes can be simulated by taking into account the external force along the braking distance, the course of which corresponds with the properties of an applied shock absorber.

3. Braking Methods

Ideal Braking

In general, it is required that the braking had a possibly short distance, its time was the shortest possible, and the deceleration did not exceed its assumed limited value. However, it is known that lowering the braking distance or time increases the deceleration value. The most advantageous relation between the above mentioned requirements can be obtained if the braking process is the uniformly retarded motion. Therefore most often, although not always, the uniformly retarded motion is the required one during the braking process. Real braking processes, however, depart from the uniformly retarded motion model.

Internal Shock Absorber

The servomotor internal shock absorber should minimize of the effect of the piston hitting the servomotor cover. In the case of servomotors having low diameters, only elastic elements exist. Larger servomotors are supplied with additional internal pneumatic shock absorbers.

Operation of internal pneumatic shock absorbers consists in the step increase of throttling of air flowing out of the emptied chamber. Internal shock absorption which is set by the manufacturer is practically sufficient in the case of the piston rod that is not loaded with an additional mass. However, it does not cause the stop of the piston movement but the decrease of its velocity only. The results of such a process simulation are shown in Fig. 2 (the lack of an external mass load and a suitable friction forces lowering were taken into account; the outlet resistance conductivity decrease by 80% was assumed).

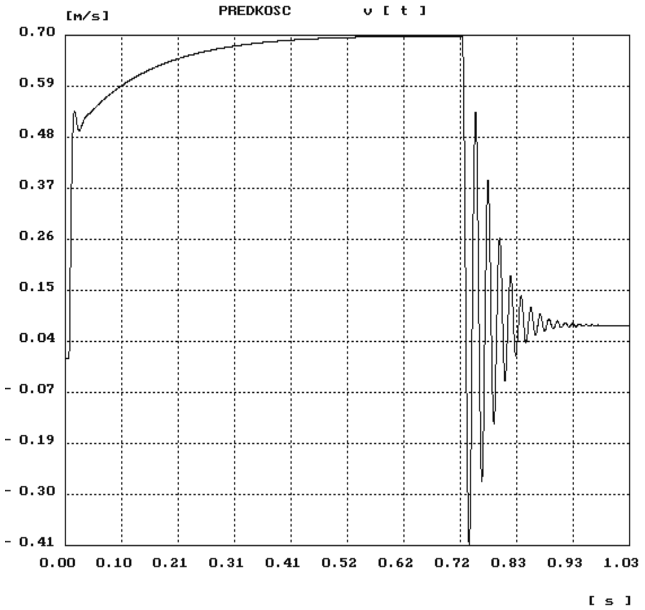


Fig. 2. Changes of the piston velocity for a servomotor having an internal shock absorption vs. time
Rys. 2. Przebieg prędkości tłoka siłownika z pneumatyczną amortyzacją wewnętrzną w funkcji czasu

In reality, the piston velocity oscillation are much smaller since the outlet resistance throttling change is not immediate as it was assumed in the model.

External Shock Absorber

Modern industrial shock absorbers are mainly hydraulic ones. Their principle of operation is present in Fig. 3.

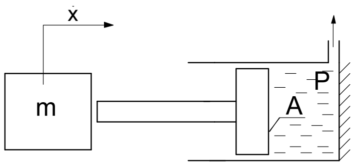


Fig. 3. Principle of operation of a hydraulic shock absorber
Rys. 3. Zasada działania amortyzatora hydraulicznego

The unit being braked, acting on the shock absorber piston, presses the liquid out of the shock absorber chamber through a throttling system. The pressure in the shock absorber chamber as well as the breaking force, depend on the throttling level at the outlet, and on the piston velocity. In the case of the free mass braking and a constant throttling, the braking force decreases with the decrease of the velocity. Different method applied in order to make the throttling dependent on the piston position [2, 3, 8] allow us to obtain an approximately constant braking force in the case of braking the systems having a free mass character, or system with a constant driving force what ensures the braking of such systems with a constant deceleration. In the case of systems driven in a pneumatic way, such shock absorbers do not ensure that the braking process has a constant deceleration.

Shock Absorbers with Magnetorheological Fluids

An application of a magnetorheological fluid to external shock absorbers allows us to change the braking force during the movement, as well as its adaptation to the load condition without the necessity of the construction change of the shock absorber itself.

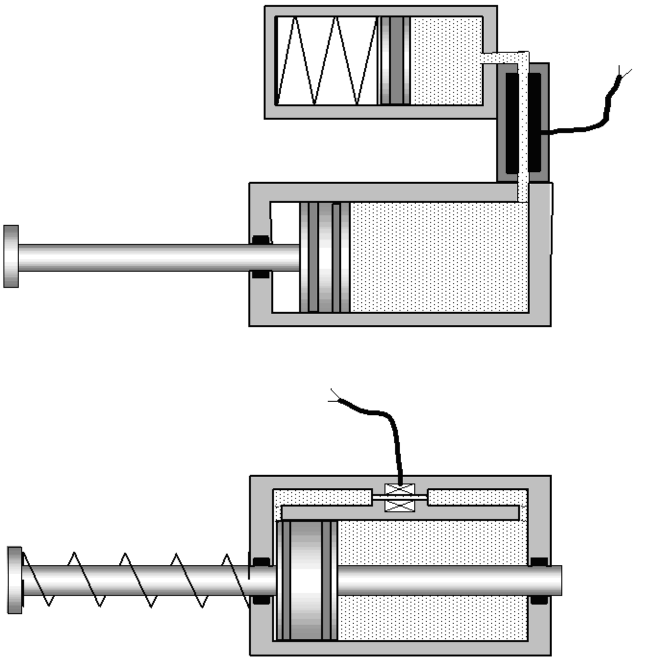


Fig. 4. Various constructions of shock absorber with magnetorheological fluid
Rys. 4. Różne konstrukcje amortyzatorów z cieczami magnetoreologicznymi

The absorber operation is similar to the operation of an ordinary hydraulic shock absorber in which the braking force arises due to an increase of pressure during the fluid being pressed through an adequately selected orifice [7]. In the cases of orifices having a small distance between the walls that create the orifice (from several micrometers to several tenths of millimetre), a laminar flow exists for which the velocity has a parabolic distribution. It is disturbed when a magnetorheological fluid being applied is subjected to the influence of an external field. A suitably designed electronic circuit for the control of the magnetic field generator allows us to obtain the braking force in the shock absorber being in proportion to the supply voltage of the coil.

The majority of devices in which controllable rheological fluids are applied assure the braking process with the constant deceleration not only for systems having a free mass character but also for pneumatic drives that have often a changing driving force, load and friction.

Drives Having a Last Part of the Movement Controlled in an Electronic Way

Modern systems applied to the pneumatic drives positioning that include proportional flow-controlling valves can be easily adapted to a less demanding process of the servomotor final part of its movement until it reaches the end position. Such a system requires that an adequate control algorithm be developed that ensures the impactless stop of the servomotor piston in the find positions. An adequately selected algorithm allow us to obtain the braking the most of applied pneumatic drives, and the elimination of undesirable dynamic phenomena during their stopping.

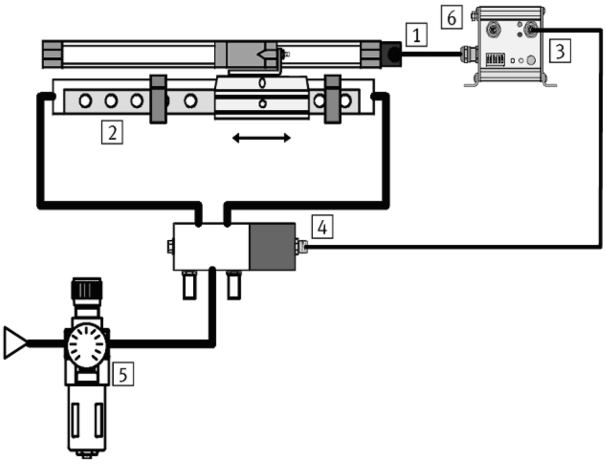


Fig. 5. Diagram of a shock absorption system with the last part of the movement controlled in an electronic way
Rys. 5. Schemat układu amortyzacji ze sterowanym elektronicznie dobiegiem

The shock absorber operation consists in the proper proportional control of a flow-controlling valve that ensures the creation of a braking force value that is adapted to the load. The braking force exists due to the pressure in the pneumatic drive emptied chamber, and its value as well as its duration are defined on the grounds of the velocity and position measurements by the electronic control system.

4. Adequate Selection of the Shock Absorption System

Each one of the above presented systems of the pneumatic servomotor piston braking during the last part of its movement to the extreme positions has its advantages and disadvantages. The properly designed shock absorption system allows us to: decrease the dynamic loads, decrease the noise and vibrations, increase the operation durability and reliability, as well as the construction of lighter and more effective devices. The pneumatic drive having a special construction that implements the inner shock absorption is the one applied most often. The reason of it is the fact that such a design is the easiest one to be implemented in existing systems. One has only to remove the old servomotor, and replace it with a new one having a special construction. However, if one wrongly assumes that this will do, and that an additional adjustment of the throttling valves is unnecessary, then the valves would not operate in full.

Due to do this, as well as due to many other reasons, the new designs are constantly looked for. One of them consists in the design of an adequate control system which would ensure a proper control of a conventional dividing valve on the grounds of available measurement signals in order to limit the driving moving element dynamic overloads. The control be characterised by the high reliability, minimal ingerention of the operator into the braking process, possibility of its application (modification) to existing driving systems, self-control, tuning and adaptation to the system operation conditions (load change, drive wear, drive replacement, drive operation parameters change).

The controlled braking process that could be adapted to the system operation conditions gives us the possibility to have an influence over this process during movements implemented by the pneumatic drive.

5. Summary

In the case of pneumatic drives, modern industrial shock absorber (internal or external) do not ensure the advantageous – having the constant deceleration – course of the braking process. The dynamic overloads existing in the braking process exceed over twice the values that are possible to be obtained during the constant-deceleration braking. The dynamic overloads minimization can be obtained by the application of hydraulic shock absorbers having properties adapted to the pneumatic drive dynamic properties [2, 3, 6, 8], by the introduction of shock absorbers having a controlled braking force, e.g., with the use of a fluid having a controlled viscosity [7], or by the introduction of pneumatic drives having a controlled velocity [4, 11].

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