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Experimental Verification of Pneumatic Cylinder External Pneumatic Cushioning

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Abstract. This paper deals with the possibilities of the pneumatic cylinder piston end-position cushioning. The introductory part describes the cushioning methods - elastic, hydraulic and internal pneumatic. The second part describes the external pneumatic cushioning, its experimental verification and the measurement results for a specific case.

1 Introduction

The motion speed of pneumatic linear motors may commonly be up to $1\,m\cdot\,s^{-1}$. This speed, together with the connected load, represents a relatively large kinetic energy at the end of the stroke. It is stated that if the piston moves at a velocity greater than $0.5\,m\cdot\,s^{-1}$, it is necessary to dampen the kinetic energy. If at high speed the kinetic energy is not dampened, the cylinder may be damaged due to the piston impact on the cover. Different types of external or integrated dampers, or a combination of them, can be used to dampen. Various methods of damping will be presented below.

2 Types of damping

As already mentioned, damping may be either external or integrated directly into a linear or semi-rotary motor. Damping can be further divided into mechanical and elastic, hydraulic and pneumatic.

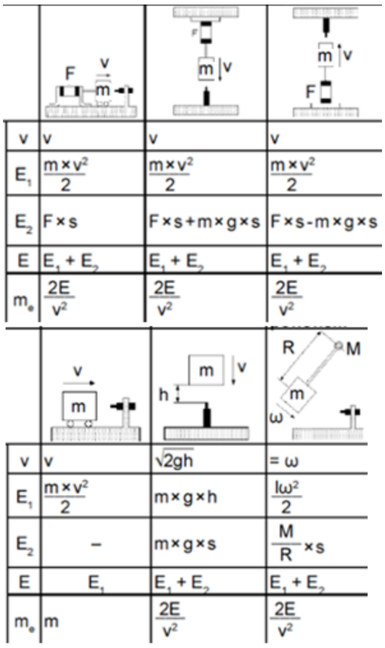
The simplest type of damping is an external rubber damper, or coil spring. The types are suitable for devices with low demands on the course of kinetic energy damping.

Fig. 1. Hydraulic damper [1]

For more demanding applications, external hydraulic dampers, Figure 1, can be used. These can be divided into constantly set and adjustable. Both methods (elastic and hydraulic damping) can also be used as internal damping. In case of elastic damping, different damping plates or rings are placed either on the piston or on the cylinder covers. Hydraulic dampers can be mounted on some types of pneumatic motors, such as semi-rotary motors, as shown in Figure 2.

Fig. 2. Damping of semi-rotary motor [2]

When we choosing a damper, we must consider not only the kinetic energy but also the pressure energy along the damping path performed by the pneumatic motor. Figure 3 shows the calculation of total energy for different situations. Based on the total energy, we then choose the damper.



v	v	v	v
E_1	$\frac{m\times v^2}{2}$	$\frac{m\times v^2}{2}$	$\frac{m\times v^2}{2}$
E_2	$F\times s$	$F\times s+m\times g\times s$	$F\times s-m\times g\times s$
E	E_1+E_2	E_1+E_2	E_1+E_2
m_e	$\frac{2E}{v^2}$	$\frac{2E}{v^2}$	$\frac{2E}{v^2}$

v	v	$\sqrt{2gh}$	$=\omega$
E_1	$\frac{m\times v^2}{2}$	$m\times g\times h$	$\frac{I\omega^2}{2}$
E_2	–	$m\times g\times s$	$\frac{M}{R}\times s$
E	E_1	E_1+E_2	E_1+E_2
m_e	m	$\frac{2E}{v^2}$	$\frac{2E}{v^2}$

Fig. 3. Calculation of total energy [3]

v - velocity ($\mathrm{m\cdot s^{-1}}$)
g – grav. acceleration ($\mathrm{m\cdot s^{-2}}$)
h – free fall height (m)
ω – angular speed ($\mathrm{rad\cdot s^{-1}}$)
R – arm radius (m)
m – weight (kg)
I – mom. of inertia ($\mathrm{kg\cdot m^2}$)
F – force of motor (N)
s – damper stroke (m)
M – torque (Nm)
E – total energy (Nm)
E_1 – kinetic energy (Nm)
E_2 – pressure energy (Nm)
m_e – effective weight (kg)

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The internal pneumatic cushioning uses the conversion of kinetic energy to pressure energy. Adjustable pneumatic cushioning is the most commonly used. It works like this. The cushion ring closes a certain amount of air before the end position. Further movement results in air compression and thus braking effect. Air exhaust and thus the cushioning intensity can be adjusted by means of a throttle valve, Figure 4.

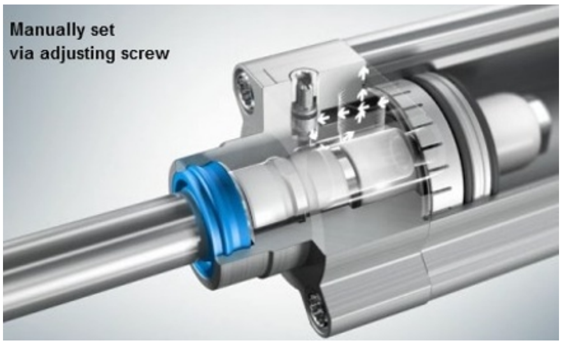

Fig. 4. Adjustable cushioning [2]

The Figure 5 shows an example of a pressure increase in the cushioning space, a full red curve. At the same time, there is a decrease in speed, a black dot line. Measurements were performed on a cylinder with a piston diameter of 32 mm and a stroke of 80 mm with the lowering weight 10 kg.

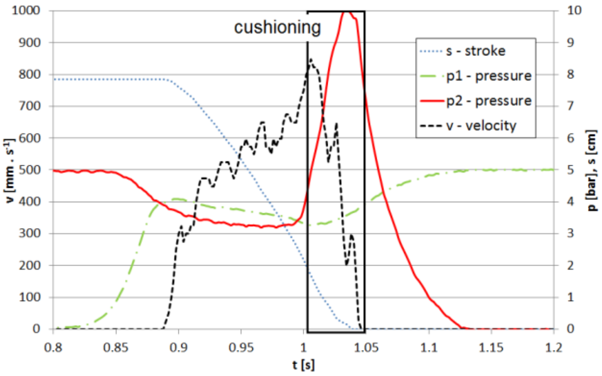

Fig. 5. Course of the pressure and velocity during cushioning

Similarly works so-called self-adjusting cushioning. In this case, the air flows through the grooves in the cushioning ring, see Figure 6. The depth of grooves decreases towards the piston. This results in a gradual increase in throttling.

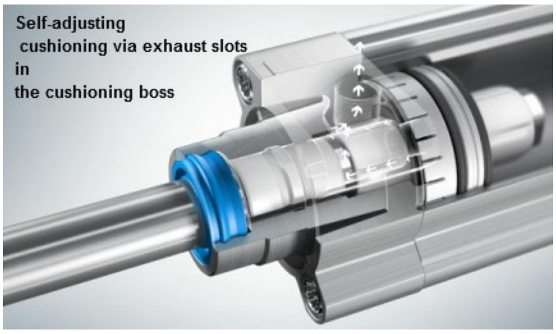

Fig. 6. Self-adjusting cushioning [2]

Even in the case of pneumatic damping, a check should be made. The pneumatic cylinder cushioning check is performed on the basis of the kinetic energy at the end of the stroke. The kinetic energy $E_k[J]$ is calculated from the mass $m\ [kg]$ attached to the piston rod and the velocity $v\ [m \cdot s^{-1}]$ at the end of the stroke.

$$E_k = \frac{1}{2} \cdot m \cdot v^2$$

The resulting value is then compared to the maximum damped energy listed in the catalogue of pneumatic cylinder.

The second possibility is to check by a graph. In this way we can determine the maximum possible weight attached to the piston rod at the given velocity or the maximum velocity at the given load. An example of the graph is on the Figure 7.

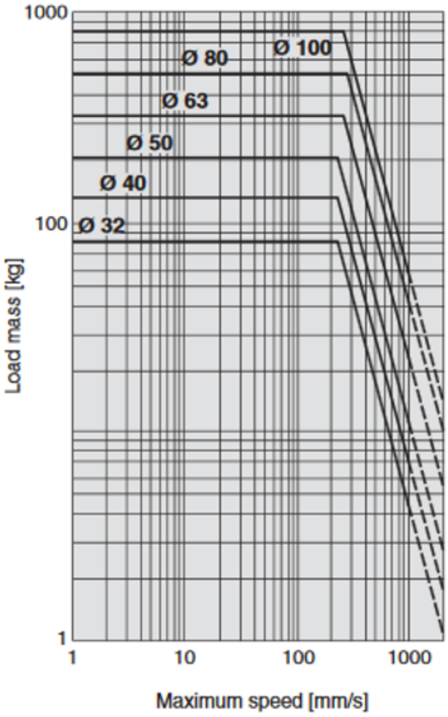

Fig. 7. Check of internal pneumatic cushioning [4]

If the cushioning intensity is not sufficient, you need to select a larger cylinder or choose external dampers. Mechanical and hydraulic dampers have already been mentioned, and now we will look at the implementation of external pneumatic cushioning. External pneumatic cushioning principally corresponds to the internal but it is realized with the added valves. The upper part of Figure 8 shows replacement of cushioning adjustable by the built-in throttle valve. First, the air leaves the cylinder through the 2/2 valve. In the desired position of the piston rod, the valve closes and air flows through the throttle valve. At this point, cushioning started. The replacement of the self-adjustable damping (shown in Fig. 8 by the conical part of the piston rod) can be realized by gradually closing the throttle valve depending on the position of the piston rod.

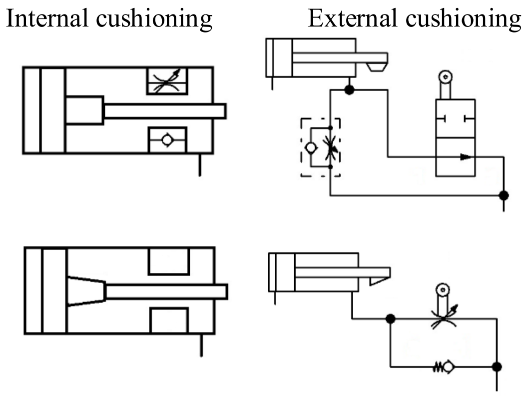

Fig. 8. Implementation of external cushioning

Another option is to use the ASQ valve from the SMC company, Figure 9. In this case, the closing of the 2/2 valve does not depend on the piston position but on the pressure in cylinders chamber. The Figure 9 also shows an ASR valve for air savings, more see [5].

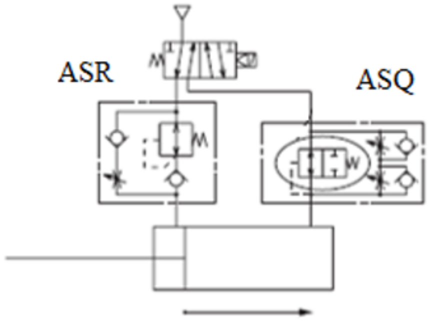

Fig. 9. Connection of ASQ valve

3 System design and experiment

At our workplace we dealt with the design of external cushioning for the following case. The machine door should be opened and closed in the vertical direction. The door weight was 12 kg.

The aim was to design not only the drive, but also the optimal composition of the pneumatic system and its setting of cushioning in the lower position.

For the drive of the door a rodless cylinder with diameter of 20 mm was chosen. Then the damping method was chosen and the whole system was designed. Figure 10 shows a pneumatic circuit. The valve 1V1 controls the direction of movement (lifting and lowering the door). The valve 1V2 controls the air discharge. After the piston moves to the proximity sensor S3, the valve 1V2 switches and the air flows through the throttle valve 1V6.

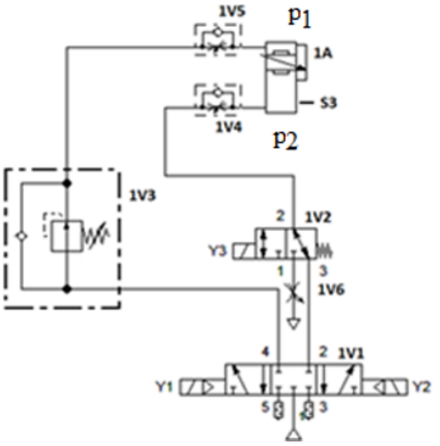

Fig. 10. Pneumatic circuit

In the laboratory, we have compiled test equipment. The aim of the experiment was to find out the appropriate system settings, ie the position of the contactless sensor and the throttle valve setting. First, we measured the system without damping. From Figure 11 it can be seen that the piston impact to cover of cylinder at a speed of about 650 $mm \cdot s^{-1}$. It causes great shock and could damage the cylinder or other parts. Subsequently, we have identified the optimal position of the proximity sensor, which gives signals to initiate cushioning. We found that before the system responds, the piston moves approximately 80 mm. Therefore, we placed the sensor 110 mm before the end position. We finally looked for a suitable throttle valve setting. If the throttle valve is too closed, the piston stops completely 30 mm before the end position and then comes to an end with a jerk, Figure 12. When the valve is correctly set, the motion stops and the piston moves smoothly to the end position, Figure 13.

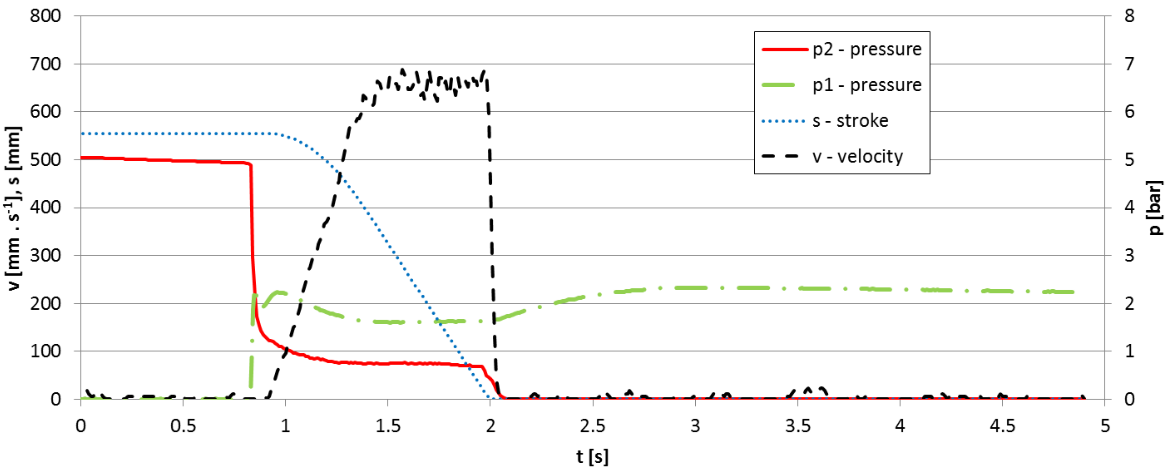

Fig. 11. Measuring results of system without cushioning

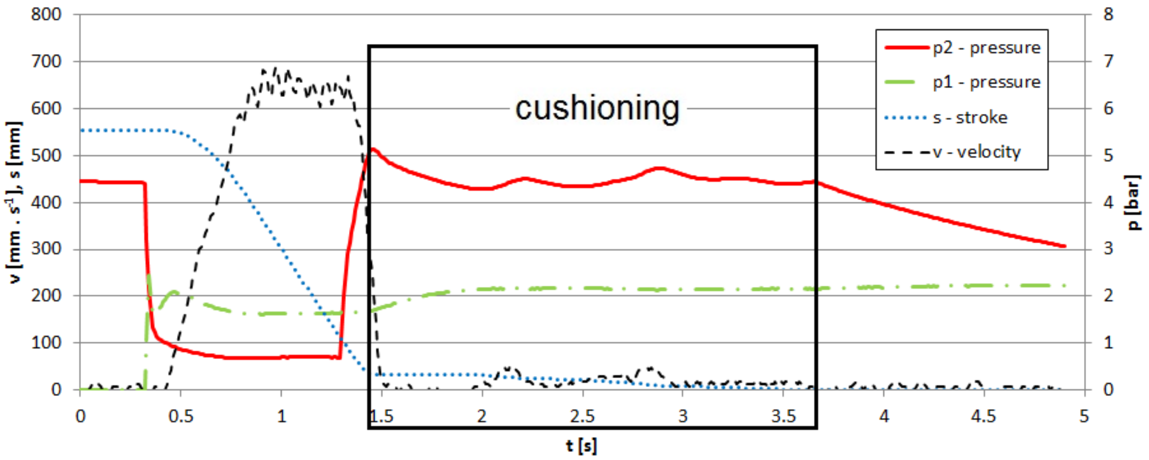

Fig. 12. Measuring results of system – throttle valve is too closed

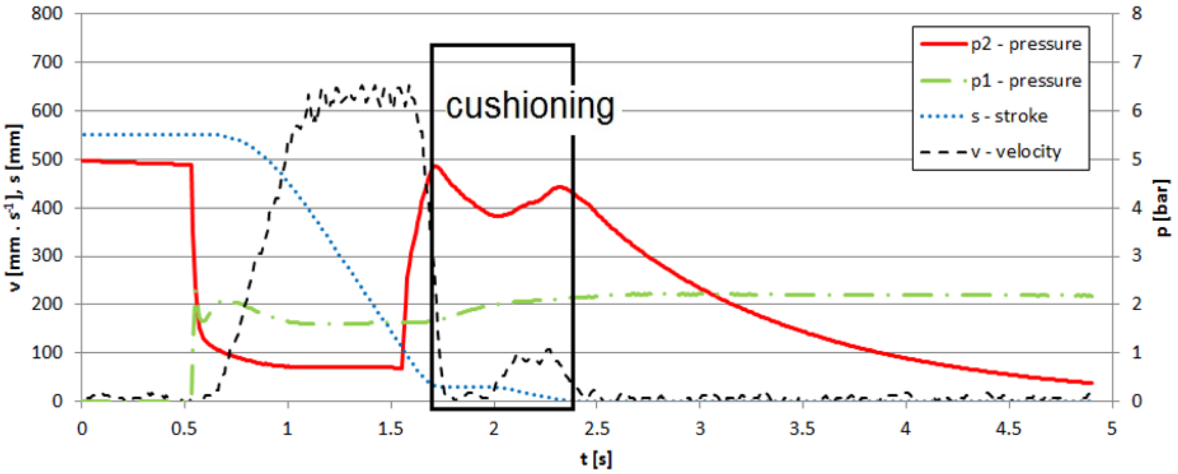

Fig. 13. Measuring results of system – optimal settings

4 Conclusion

In cases where internal cushioning is not effective enough, we can use external cushioning. This offers great variability of settings, for example, it is possible to include additional valves and control speed in several stages. For each case, an individual setting is required.

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