Influence of throttling of pneumatic actuators at the positioning accuracy

M P Hetmanczyk and P Michalski
1Silesian University of Technology, Faculty of Mechanical Engineering, Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Konarskiego 18A, 44-100 Gliwice, Poland

E-mail: mariusz.hetmanczyk@polsl.pl

Abstract. Changing the dynamic motion parameters of pneumatic equipment requires control of pressure and the volumetric flow rate. The article presents a study of the impact of setting control parameters and external disturbances on the positioning accuracy of pneumatic rodless double acting actuator. Testing process was carried out at different values of the parameters (adjusted to the actuator) and external loads. The probe mass was selected within guidelines (a cushioning diagram) so that the operating point was placed on the curve of limiting movement speed of the actuator.

1. Introduction
Machines based on pneumatic drives belong to units with high reliability indexes. Despite many advantages a problem connected with the positioning [1] of linear and rotary actuators still exists. The main cause of problems is among other things the air compressibility.

Furthermore at positioning of the moving parts of pneumatic drives directly affect:

- selected value and fluctuations of a supply pressure;
- pressure drops (directional control valves, throttling valves, pneumatic hose, etc.);
- applied lubrication and operating temperature (affecting the density of the used oil or lubricant);
- air filtration (incorrectly selection of filter causes a penetration of dirt from entering the system and increase frictional resistance);
- characteristics of the load (force: mass or concentrated, fixed or variable).

Additionally the frictional force [4] varies within a change in movement speed of the piston and the pressure in the actuator cylinder. In most cases, the movement speed setting is made by the operator in a manner dependent on the experience.

2. A purpose and characteristics of the test method
The primary objective of presented studies was determination of relationships between the three main parameters that affect the positioning accuracy of pneumatic linear drives (supply pressure, velocity and mass of conveyed element). The researches were carried out according to the plan shown in Table 1. Measurements were carried out in the extreme values of the attenuation coefficient (CF) setting on non-return throttle valves. The border factor was defined as a value resulting in the loss of motion smoothness at the stage of the movement and positioning on the given parameters of the
medium. For the purposes of researches the electropneumatic tests stand consistent with the scheme shown in figure 1 has been developed.

During the measurements, the following parameters were recorded: pressure at the outlet of draining chamber (cushioned chamber), vibration level (based on the effective values of velocity) measured with sensors mounted on the moving elements (connected rigid with the piston) and cylinder cap (at the top side), positioning accuracy (O1D100 position sensor).

### Table 1. The scheme and main parameters of the experimental research.

| Cushioning factor CF [%] | Value of the supply pressure p [bar] | Active load (where: WM, PM – measurements with and without additional mass) |
|--------------------------|--------------------------------------|--------------------------------------------------------------------------|
| 0 (throttle valve fully opened) | 3 and 6 bars (setting on the pressure reducing valve - air preparation system) | WM – approximate weight of moving parts about 200 grams, PM – additionally mounted steel cylinder with weight of 500 grams (total weight about 700 grams). |
| 50 border (limiting a movement smoothness) |                                      |                                                                          |

The test system was configured with the following components:
- pneumatic linear drive (OSP-P25020000500) with adjustable end cushioning at both sides with connected non-return throttle valves (throttling at the outlet),
- 5/3-way single solenoid valve closed in mid-position (position spring-centered, manual override in both directions), actuation in both directions by solenoids with one winding and pneumatic piloting (P2LAX611EENDDB49 series),
- analog position sensor (O1D100) and noncontact switch (a proximity sensor for piston carrier stopping) connected to modules of relays.

![Figure 1. Functional schemes of: a) the pneumatic subsystem, b) the electric subsystem.](image)

The time constant related to the system response is dependent on the value of a delay-time resulting from an activation of relay systems and the induction sensor (figure 2). In order to ensure the measurement reproducibility an automatic interruption has been implemented (in phase of extension movement). The control system provides fully repeatable measurements (power has been switched off when the solenoid actuator came across face of inductive sensor).

Due to an implementation of the inductive sensor applied trigger have form of a metal tag with respectively matched length.
3. Results

The basis of the research was a simulation of an emergency stop phase with different settings of parameters. As a reference position of the axis of stopping assumed distance from the sensor to the starting position of the piston equals 225 millimeters. Time used to a determination of the steady state conditions has been determined up to the moment when the peak to peak oscillation does not exceed 0.18 mm/s (or 0.09 mm/s).

Before each cycle (an upward movement of the cylinder) a chamber has been filled with compressed air at a pressure equal to the supply pressure set at regulator valve (compressed air preparation system). The charts (figure 3-8) show the measured values from the sensor mounted on the moving components. Recorded peak velocities of the actuator housing are summarized in table 2.

Oscillations of the piston actuator stem directly from the nature of the control parameter settings. In addition at the accuracy has influence also values:

- supply pressure,
- cushioning factor settings:
- \( CF = 0\% \) - passage through the stop position with simultaneous exceeding of value that define assumed position (figure 3, 4),
- \( CF = 50\% \) - stopping in a position close to defined value (figure 5, 6),
- \( CF = \text{border} \) - settings of the factor at the border values (ie. crawling of moving parts) leads to a slow pressure equalization before and after the non-return throttle valve and stopping before fixed position (figure 7, 8),
- actuator load.

Another negative phenomenon is a piston subsidence under the influence of the compressibility of air trapped in the chamber of the actuator, valve and supply lines.

In the present case a displacement of conveyed mass after stopping was no noticed what results directly from the small value of the load. Differences in reaching the target position are shown in figure 9. The resulting inaccuracies are associated with factors dependent on the time constant of the sensor, an applied weight, orientation of the actuator and the setting of the valves controlling air flow rate.
Figure 3. Time characteristics of effective velocity values (p=3 bar, CF=0%) of piston carrier.

Figure 4. Time characteristics of effective velocity values (p=6 bar, CF=0%) of piston carrier.

Figure 5. Time characteristics of effective velocity values (p=3 bar, CF=50%) of piston carrier.
Figure 6. Time characteristics of effective velocity values (p=6 bar, CF=50%) of piston carrier.

Figure 7. Time characteristics of effective velocity values (p=3 bar, CF=border) of piston carrier.

Figure 8. Time characteristics of effective velocity values (p=6 bar, CF=border) of piston carrier.
Despite the different effective speed values and operating parameters (mass actuated) attenuate the real time value to the minimum level does not differ from each other in a meaningful way. The only difference is the instantaneous value of the amplitude changes the effective speed. Oscillations around the equilibrium position depend on the time equalization of pressures in fed and discharging chambers. Increasing the degree of throttling leads to rigid suppression characteristics what results in increasing of the vibration energy recorded by the sensor.

**Table 2.** Summary of effective velocity peak values and cushioning times.

| Settings | Load | $V_{\text{peak}}$ [mm/s] | Time of cushioning $T_c$ [ms] |
|----------|------|-----------------|-------------------------------|
|          |      | VS01 | VS02 | VS01 | VS02 |
| p=3, CF=0 | WM  | 401.8 | 0.3  | $12.3 \times 10^3$ | $0.2 \times 10^3$ |
|          | PM  | 378.5 | 0.3  | $12.7 \times 10^3$ | $0.3 \times 10^3$ |
| p=6, CF=0 | WM  | 390.3 | 0.4  | $12.1 \times 10^3$ | $0.7 \times 10^3$ |
|          | PM  | 412.8 | 0.4  | $11.8 \times 10^3$ | $0.6 \times 10^3$ |
| p=3, CF=50 | PM | 394.1 | 0.2  | $11.7 \times 10^3$ | $0.4 \times 10^3$ |
| p=6, CF=50 | WM | 428.4 | 0.2  | $12.0 \times 10^3$ | $0.3 \times 10^3$ |
| p=3, CF=100 | WM | 373.1 | 0.2  | $12.1 \times 10^3$ | $0.4 \times 10^3$ |
| p=6, CF=100 | PM | 421.6 | 0.2  | $12.3 \times 10^3$ | $0.2 \times 10^3$ |
| p=3, CF=100 | WM | 426.2 | 0.3  | $13.3 \times 10^3$ | $0.1 \times 10^3$ |
| p=6, CF=100 | PM | 391.4 | 0.3  | $13.2 \times 10^3$ | $0.2 \times 10^3$ |
| p=3, CF=100 | WM | 388.5 | 0.2  | $11.9 \times 10^3$ | $0.2 \times 10^3$ |
| p=6, CF=100 | PM | 410.7 | 0.2  | $11.6 \times 10^3$ | $2.2 \times 10^3$ |

Tuning the operational parameters in order to stop in an intermediate position or in Safe Mode requires considerable experience and tools allowing determination and control of actuator dynamics [4].

**4. Conclusions**

The positioning accuracy of pneumatic cylinders depends on several parameters. Among other things: user-configurable variables (pressure, volumetric flow rate, control and sensor subsystems). External disturbances (pressure fluctuations, improper lubrication or filtration, additional masses).

On the basis of presented researches the impact of a series of sizes on the spool valve positioning accuracy and quality of motion it has been also observed (smaller crosswise sections of distributor induces deterioration caused traffic flow and reducing a value of the border coefficient).
The accuracy of the stop position depends on the load. Speed and direction of movement of the piston. The vector direction of the transported mass. Improvement of the accuracy of positioning may occur through the use of precise pressure regulator placed into the system before or after the divider. In case of industrial equipment (despite of the same location, construction, selection of settings and load value) significant differences in the lifetime of machines still exists [2, 3, 5].

**References**

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