The qualitative assessment of pneumatic actuators operation in terms of vibration criteria

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Abstract. The work quality of pneumatic actuators can be assessed in terms of multiple criteria. In the case of complex systems with pneumatic actuators retained at end positions (with occurrence of piston impact in cylinder covers) the vibration criteria constitute the most reliable indicators. The paper presents an impact assessment on the operating condition of the rodless pneumatic cylinder regarding to selected vibrational symptoms. On the basis of performed analysis the authors had shown meaningful premises allowing an evaluation of the performance and tuning of end position damping piston movement with usage the most common diagnostic tools (portable vibration analyzers). The presented method is useful in tuning of parameters in industrial conditions.

1. Introduction

Pneumatic actuators have gained great popularity in the industry, thanks to the many advantages among other things cleanliness of work, design simplicity, simple adjustment of durability and high resistance to external factors. Additionally a control of the operational parameters of pneumatic drives does not provide complex problem [1, 3]:

- change of speed (linear or rotational) - throttling the working medium (throttle or non-return throttle valves),
- force or torque modifications - controlling a values of the supply pressure.

Rodless cylinders are often used in design of pneumatic manipulators, linear movement mechanisms and applications with high loads of forces and bending moments. Described drives are equipped with end-position cushioning circuits allowing minimization of piston strokes at lids.

Cushioning at end positions has the following advantages:

- a reduction of internal and external shocks [1] and machine noises,
- a minimization of maintenance activities [2, 3].

2. Measuring station and experiment plan

Primary aims of presented researches are connected with determination a suitability of vibration diagnostic methods for an evaluation of the operation quality of pneumatic systems and minimization of a kinetic energy in a braking phase.

The basis of studies results from a lack of methods allowing tuning of linear pneumatic actuators in order to life increasing, minimization of inertia and vibrations [3, 4] of machines in industrial
conditions (with usage of well-known diagnostic methods). In most cases a maintenance service of production plants based on experience without evaluation of measured parameters.

The researches were carried out according to the plan of the experiment shown in the table 1. The selected pressure values have been matched to indicate a normal level in the installation (6 bars) and decrease of pressure (3 bars). For the purposes of researches the electropneumatic tests stand consistent with the scheme shown in figure 1 has been developed.

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) 50 border (limiting a movement smoothness) | 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). |

During the measurements, the following parameters were recorded (figure 2):
- pressure at the outlet of draining chamber (cushioned side) with usage of integrated throttle valve (pneumatic throttling),
- vibration level (effective values of velocity) measured with sensors mounted on moving elements (connected rigid with the piston) and cylinder cap (at the top side).

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

The actuator has been inclined with respect to a horizontal direction (figure 2) to determine an effect of a braking weight on the speed and vibrations (in respect of force and torque loads).

The test system has been 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),
- 5/2-way double solenoid valve actuated by solenoids and pneumatic piloting in both directions, manual overrides (P2LAX511EENDB49 series),
- analog pressure sensor (PI3054) - monitoring of discharging chamber parameters,
- modules of relays and momentary action switches.
Figure 2. Views of: a) the measurement path configuration, b) the laboratory stand.

The measurements were performed at the maximum speed available at non-throttled flow within the range of selected pressure. The cushioning factor CF relates to throttle valves installed in the rodless cylinder.

3. Results
From the point of view of the operating conditions important vibrational symptoms can be collected from two independent measuring points: a movable table (the VS01 sensor) and actuator covers (the VS02 sensor). Each measuring cycle consisted of data registration from starting position, movement at distance equals 500 millimeters and a velocity descent in the end position (using pneumatic cushioning with different parameter settings).

The impact value on the actuator covers is directly dependent on a speed of the piston and the total weight of moving parts. The additional mass PM (in case of movement in the direction from the bottom to the top) causes a deceleration of the piston. This solution is one of the possibilities used to reduction of the detrimental impact of the piston strokes in cylinder covers.

A small value of the effective velocity (figure 3, 4) results from the use of additional mechanical damping (the plastic liner). Such solution causes faster wear of sealing package, especially in the case of large masses. Throttling of pneumatic medium (CF = 50%) manifested at a slight increase of the effective velocity (figure 5, 6), which is associated with the appearance of the elastic force of the air and increasing pressure on the draining chamber (resulting from throttling).

Setting the value of the damping factor CF = 100% (corresponding to completely close of the throttle valve) causes oscillations (figure 7, 8) around an equilibrium point of the moving part. Higher value of pressure in the chamber enlarges a rigidity of the system, thereby increasing an attenuation value of less velocity and time. It is also visible in decrease of the vibration measured at actuator housing.
Figure 3. Time characteristics of effective velocity values (p=3 bar, CF=0%).

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

Figure 5. Time characteristics of effective velocity values (p=3 bar, CF=50%).
Complete closure of the throttle valve causes positioning errors proportional to a value dependent on the design of damping elements. In presented case a precise adjustment of the supply pressure test system was not used.

The values of pressure (figure 9) are the results of measurements on draining chamber. In the course of measurements values of the damping time was determined (vibration registered on the housing and the piston).
Measurements of effective velocity (table 2) indicate a necessity of settings the upper ranges of CF coefficient (volumetric elasticity coefficient proportional to pressure changes). Vibration measurement enclosure is not meaningful indicator to assess the quality of operation of pneumatic drives. The location of the sensor on the machine frame (rigidly connected with the drive) allowing evaluation of the vibrations propagation on machine parts, but the quality of detention depends on the parameters measured directly on the moving parts. Another important element is an influence of lubrication on the uniformity of a speed of moving parts and actuator subassemblies.

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   | 19.6 | 4.5  | 0.73 10^{-3} | 0.71 10^{-3} |
|           | PM   | 17.2 | 6    | 0.74 10^{-3} | 0.69 10^{-3} |
| p=6, CF=0 | WM   | 27.2 | 5    | 0.71 10^{-3} | 0.51 10^{-3} |
|           | PM   | 25.3 | 6.9  | 0.98 10^{-3} | 0.73 10^{-3} |
| p=3, CF=50| WM   | 26.1 | 4.5  | 0.83 10^{-3} | 0.49 10^{-3} |
|           | PM   | 21.7 | 5.1  | 0.77 10^{-3} | 0.73 10^{-3} |
| p=6, CF=50| WM   | 28.6 | 4.6  | 0.89 10^{-3} | 0.43 10^{-3} |
|           | PM   | 32.8 | 6.9  | 1.28 10^{-3} | 0.75 10^{-3} |
| p=3, CF=100| WM   | 25.9 | 0.4  | 1.26 10^{-3} | 0.69 10^{-3} |
|           | PM   | 27   | 0.5  | 1.21 10^{-3} | 1.24 10^{-3} |
| p=6, CF=100| WM   | 36.8 | 0.6  | 1.31 10^{-3} | 0.51 10^{-3} |
|           | PM   | 38.5 | 0.7  | 1.91 10^{-3} | 0.66 10^{-3} |

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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