SIMULATION OF DOUBLE ACTING PNEUMATIC CYLINDER CONTROL

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Abstract. Implementing optimal control in a pneumatic driven system is not a very cheap or easy process. The control subsystem of a pneumatic driven system has to distinctive direction: the control from pneumatic point of view and the control from automatic point of view. The present papers offer a cheaper solution to choose an optimal control and command system from both perspectives. The solution offered is to simulate such a system using Matlab-Simulink toolbox.

Keywords: command, control, pneumatics, cylinder, Matlab-Simscape

1. Introduction

The pneumatic actuating servo systems used in automatic devices have two major parts: the power and control subsystems (Figure 1) [1].

The main part of the power subsystem is the motor, which may be of the rotating or linear type. The linear motion system widely uses the pneumatic cylinder, which has two major configurations: single or double action. A double-action actuator can be actively controlled in two directions.

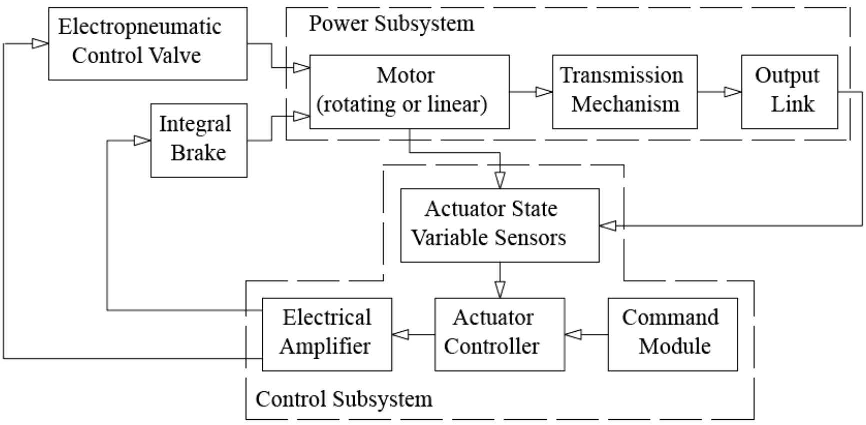

Figure 1. Block diagram of the pneumatic actuating system [1]

The important part of the control subsystem is the command module (or task controller), which stores the input information (such as desired positioning points, trajectory tracking, velocity, or force value) and selects them via input combinations.

The central element of the control subsystem is the controller, which provides control, processing, comparing, and diagnostic functions. In general, the controller may be of both types: analog and digital. Currently, more than 90% of all controllers in industry are of the digital type.

The most common form of process controller used industrially is the PID (proportional + integral + derivative) controller. PID control is an effective method in cases where the plant is expressed as a linear model, and the plant parameters do not change with wide or prolonged use. Owing to the compressibility characteristic of the air and high friction force, the pneumatic actuator system is very highly nonlinear, and the system parameters are time variant with changes in the environment. There are main causes, which are limited application of PID control in the pneumatic actuator systems.

The present paper is focused on simulation, using Matlab-Simscape toolbox, of a double acting pneumatic cylinder, controlled using a PID controller. The toolbox contains some of the component of this system, but not all of them.

2. Pneumatic control of double acting pneumatic cylinder

Pneumatic actuating systems contain a pneumatic control defined by the control valves used in the circuit. These valves may be used to control the flow direction, pressure and flow rate.

Most of the control valves are electro-pneumatic valves that controls flow to the actuator according to the drive current or voltage from the control system. Thus, an electro-pneumatic servo valve is the power element (together with actuator), in which a small-amplitude, low-power electrical signal is used to provide a high response modulation in pneumatic power. The dynamic response, null shift, threshold, and hysteresis are the most critical valve parameters that strongly influence the dynamic and static characteristics of the pneumatic actuator [1].

Simulations were done based on data sheets of MPYE-5/3-1/8 pneumatic directional valve, offered by Festo. This valve is a very complex one and has high level of applicability and to be able to simulate it has to be considered that there are four subsystems that define it: electric, magnetic, mechanic and pneumatic subsystem. In Table 1 are synthesized the input data used for these four subsystems (data were chosen based on data sheets and specialized papers [2, 3])

Table 1. Input data of the subsystems

Electric and magnetic subsystem	
controlled voltage source	24 V
mechanical converter	k_{em} = 1 N/A
resistor	R_{em} = 22 Ω (24 V, 1100 mA)
Mechanical subsystem	
coulomb friction	included in perturbation
spool mass	m_p = 10 g
spring	no pretension, k_e = 100 N/m
damper	c_v = 0.01 N/(m/s)
translational hard stop	spool displacement 5 mm
command bloc	bidirectional command valve
Pneumatic subsystem	
pressure source	ideal compressor: $6 \cdot 10^5$ Pa
initial condition	atmospheric pressure: 101325 Pa; temperature: 293.15 K; specific heat$\|_{p=cst.}$: $1.005 \cdot 10^3$ J/(kg·K); specific heat$\|_{V=cst.}$: 717.95 J/(kg·K); dynamic viscosity: $1.821 \cdot 10^{-5}$ s·Pa
proportional valve	discharge coefficient: C_d = 0.82; minimum area: 10^{-10} m^2
variable section throttles	linear characteristic for valve spool displacement between – 5 and 5 mm

3. PID control of double acting pneumatic cylinder

The pneumatic system contains a double acting pneumatic cylinder, which is a linear actuator. For the simulation was considered DSNU-20-100-PPV-A [4] cylinder from Festo and were analysed three different conditions: idling function, loaded at constant 100 N and loaded at ramp force (0 to 100 N). During simulations were assumed the following:

– piston mass: m_p = 80 g;

– translational hard stop determine force at maximum displacement: C_{dap}= 100 N·s/m – upper bound of 100 mm;

– convection transfer heat based on data sheet: k = 25 W/(m^2K), A_{ac} = 3770 mm^2, A_{bc} = 2945 mm^2, A_{ca} = 6911.5 mm^2, thermic mass 258.8 g;

– there were considered motor resistant force, position, speed and force sensors.

The simulation inputs are the pressures from the two chambers of the actuator and there are impulse inputs. The outputs were displacement, speed and force parameters of the actuator.

After the simulation of the double acting cylinder it could be concluded that this type of system may be used in systems that have hard stop, without implementing a force control loop. Mechanical switches, implemented allow obtaining precision at end stroke but they are rigid elements that allow only manual control of displacement. These switches generate a minimal control loop.

Analysing the results of simulation it can be concluded that the directional valve has a small influence on simulation dynamic parameters: response times slightly increase; speeds slightly decrease and cylinder's force is smaller.

Considering these remarks, it was implemented the control only for the cylinder (Figure2).

In Matlab-Simscape toolbox there is no such as double acting pneumatic cylinder as component and that is for the pneumatic cylinder was simulated based on two pneumatic piston chambers (Figure 2).

PID controller was implemented on feedback loop (Figure 2) and has as input the position measured by a position transducer and output is the input of pressure control circuit. Pressure proportional controller corresponds to the circuit consisting from MPPES–3–1/4–6–010 regulator and MPZ–1–24DC–SGN–65W control element, both from Festo Company.

The simulations were done by three different types of reference signals: R1 – triangular signal; R2 – pulse and R3 – variable [5].

PID block is a predefined one in Matlab and is based on classical equation for such a controller

$$u(t) = K_P \cdot e(t) + \frac{K_P}{T_i} \int_0^t e(\tau) d\tau + K_P \cdot T_d \frac{de(t)}{dt} \qquad (1)$$

Matlab-Simscape toolbox offered the possibility to tune manually or auto-tune the parameters of the PID controller, thus obtaining the appropriate control for each system. During the simulation presented in the paper the PID controller was auto-tuned.

In Figures 3, 4 and 5 are presented the results of the simulations for the three input references and the position responses (constant resistant force 100 N).

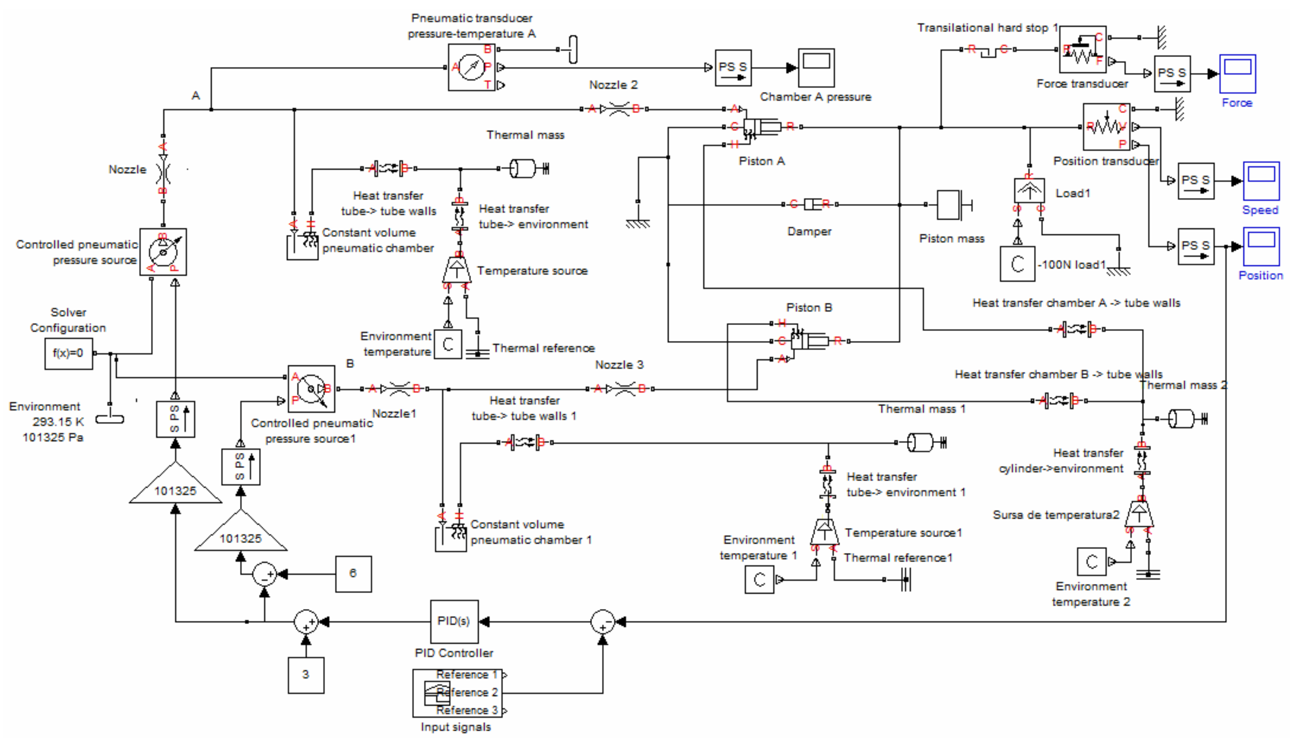

Figure 2. Pneumatic system double acting cylinder with PID controller

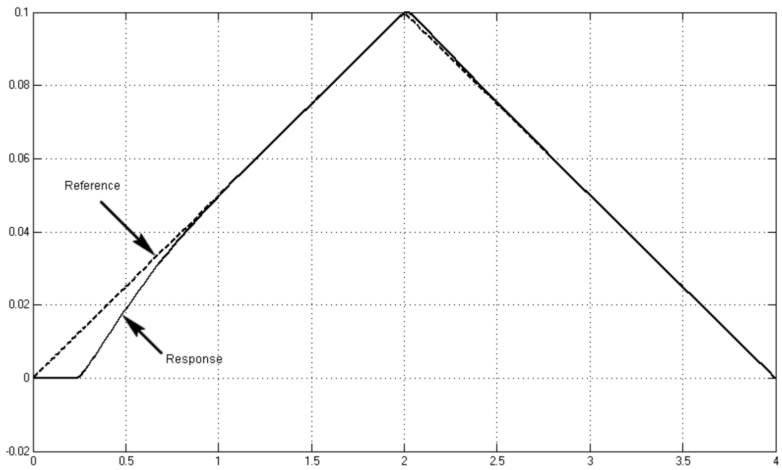

Figure 3. Triangular reference and the response of the controlled system (100 N constant perturbation)

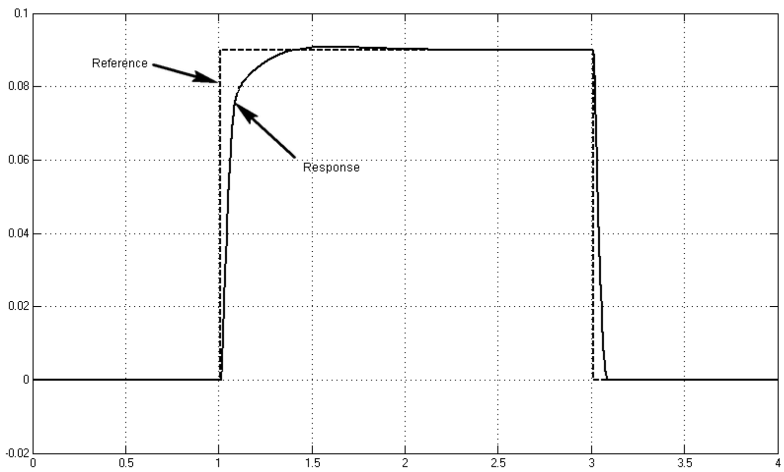

Figure 4. Pulse reference and the response of the controlled system (100 N constant perturbation)

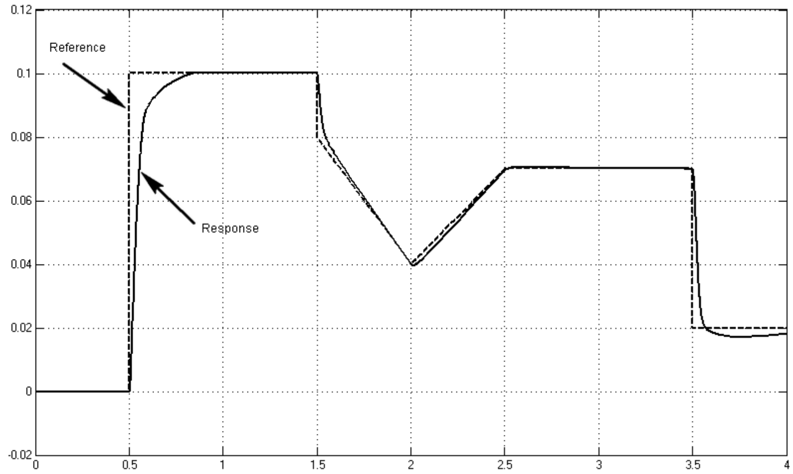

Figure 5. Variable reference and the response of the controlled system (100 N constant perturbation)

Analysing the gained results it can be underlined that steady-state time is 0.385 s for variable reference, or 1 s for pulse reference. The positive aspect relative to responses is that there is no peak value for either reference. Thus, the results with the set values of PID controller are good enough (the parameters for the PID controller was pre-chosen based on some data from scientific papers [5÷7]).

The same coefficients for PID controller were applied to the system that has a linear variable perturbation (between 0 and 100 N). The results are presented in Figures 6, 7 and 8.

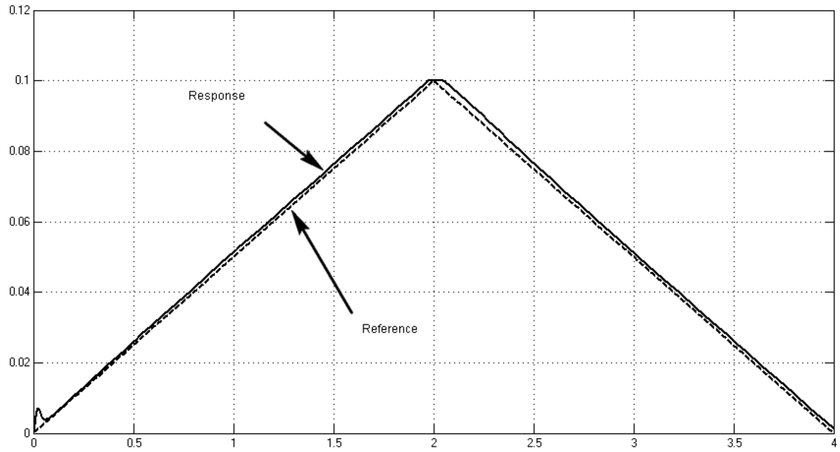

Figure 6. Triangular reference and the response of the controlled system (linear variable 0 - 100 N perturbation)

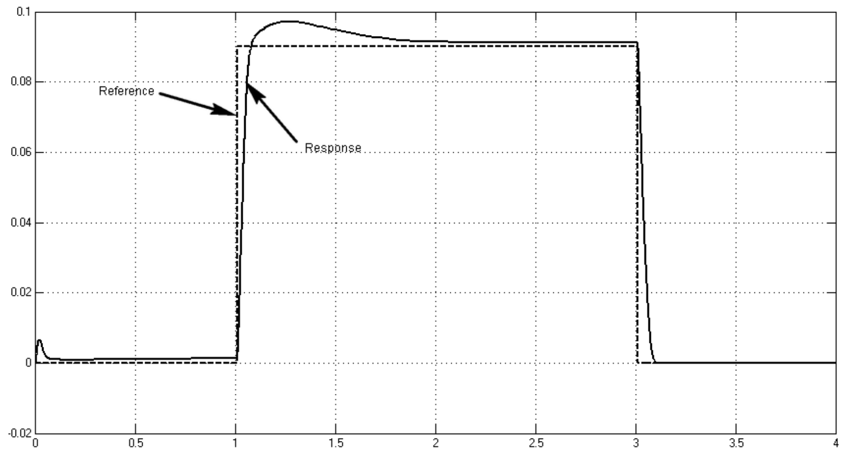

Figure 7. Pulse reference and the response of the controlled system (linear variable 0 - 100 N perturbation)

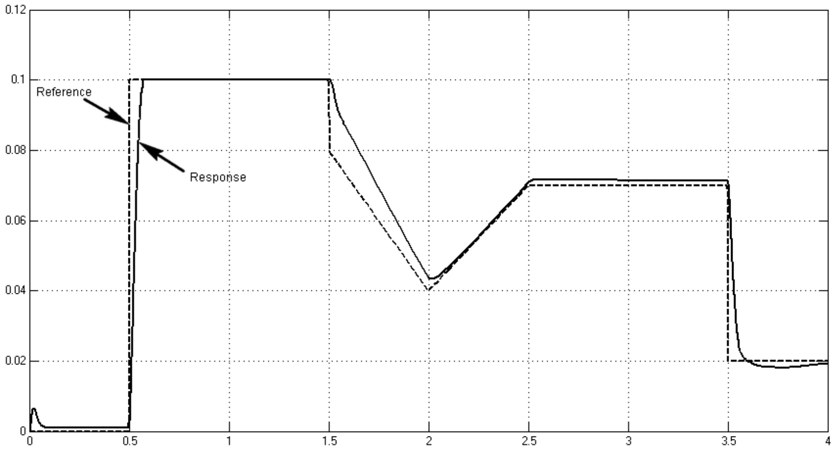

Figure 8. Variable reference and the response of the controlled system (linear variable 0 - 100 N perturbation)

Analysing the results it can be underlined that, in the case of pulse reference, there is a peak-value and the steady-state time is 1 s. The most disadvantageous reaction is the steady-state value, which is greater that the reference, determining a positioning error. The response to triangular reference is better than that for constant perturbation.

Response to variable reference has some deviations from the initial signal, signifying that the system (with this PID controller) is not easy adaptable to changes of the input, especially when the signal drops suddenly or high slope decrease. The PID controller should be tuned thus the system may not be so slow (high inertial system).

4. Conclusion

The PID controller may be adapting to different gains: to track the reference, to reduce output/ input perturbation, etc. The problem is to find out the appropriate parameters for this controller to be able to obtain optimum reaction independently of the input signal.

Simulation diagrams shown in present paper modelled, in detail, each pneumatic phenomenon that appears in the considered pneumatic system. These diagrams are particularized, based on constructive data, for Festo components. Despite this, the diagrams are flexible, adaptable to any other pneumatic component distributed by any other company, or used in any other system.

Simulation diagrams are detailed, relevant, verifiable, confirmed, flexible, customizable, and can be used as sub-modules in the simulation of other complex systems, without affecting the accuracy of the simulations.

Present paper is focused to simulation and validation of simple automated electro-mechanical-pneumatic systems, leaving room for creative development of other researchers in this field, and beyond.

The author of the present paper extended the research in the field of artificial pneumatic muscle simulations, using some of the element introduced in the present simulation.

References

1. Krivts, I.L., Krejnin, G.V. (2006) *Pneumatic actuating systems for automatic equipment: structure and design*. CRC Press Taylor & Francis, ISBN 978-08-493296-47, New York, USA
2. Movellan, J.R. (2009) *Pneumatic cylinder model*. Available at: http://mplab.ucsd.edu/tutorials/Pneumatics.pdf. Accessed: 03/05/2012
3. *** *Festo. Proportional directional control valves MPYE*. Data sheets. Available at: http://xdki.festo.com/xdki/data/doc_ENGB/PDF/EN/MPYE_EN.PDF. Accessed: 03/05/2012
4. *** *Festo. Standard cylinders DSNU/DSNUP/DSN/ESNU/ESN, ISO 6432*. Data sheets. Available at: www.festo.com/cat/en-gb_gb/data/doc_engb/PDF/EN/DSNU-ISO_EN.PDF. Accessed: 03.05.2012
5. Syed, S.S.N., Mohd Fua'ad, R., Ahmad'Athif, F.M., Zool, H.I., Noorhazirah, S. (2014). *Position Control of Pneumatic Actuator Using Self-Regulation Nonlinear PID.* Mathematical Problems in Engineering Journal, ISSN 1563-5147, vol. 2014, p. 1-12. Available at: http://dx.doi.org/10.1155/2014/957041. Accessed: 05.07.2014
6. Tsung, T.T., Chang, H., Chen, L.C., Wu, J.L, Han., L.L. (2004) *Study of frequency response of control components in a pneumatic system*. Journal of Testing and Evaluation, ISSN 0090-3973, vol. 32, no. 1, p. 46-55. Available at: http://dx.doi.org/10.1520/JTE12186J. Accessed: 05.07.2014
7. Mehmood, A., Laghrouche, S., El Bagdouri, M. (2013) *Modeling identification and simulation of pneumatic actuator for VGT system*. Journal of Sensors and Actuators, ISSN 0924-4247, vol. 165, p. 367-378. Available at: http://dx.doi.org/10.1016/j.sna.2010.11.006. Accessed: 04.03.2014

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