Proceedings of the 6th JFPS International
Symposium on Fluid Power, TSUKUBA 2005
November 7-10, 2005

Study on the Over-shoot of Cylinder Halfway Stop System

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ABSTRACT

This paper makes modeling and simulation for some simple cylinder halfway stop systems with valves of different center configuration. Simulation gives the displacement curves of the piston in the working stroke and over-shoot values are also obtained according to each kind of halfway stop system. Furthermore, experimental systems are built and displacement curves are also achieved in these experimental systems, which has validated the simulation research. Comparison analysis and characteristic summary are dealt with different systems.

KEY WORDS

Cylinder halfway stop system, Over-Shoot, Modeling, Simulation and experimental investigation

NOMENCLATURE

A : Area of the piston (m^2)
Qm: Mass flow (Kg/s)
R : Gas constant (287JKg^{-1}K^{-1})
L : Full stroke of the cylinder (m)
T : Temperature (K)
x : Displacement of the piston (m)
t : Time (s) ;
k : Specific heat ratio, k=1.4 for the air
X_0 : Initial remaining length of the cylinder
C_q : Flow coefficient (0.7)
A_q : Synthesis flow area of the valve, the speed controller, and the cube (m^2)
M : Mass of the air (Kg)
a : Coulomb friction (N)
b : Slip friction coefficient
F_1 : Friction between the piston and the cylinder (N)
F_2 : Friction between the load and the linear rail (N)
M_W: Mass of the load and the piston rod (Kg)
F : Total friction (N)

Subscripts

'1' and '2': Parameters of left and right sides respectively.
'a' and 's': Parameters of atmosphere and air supply respectively.

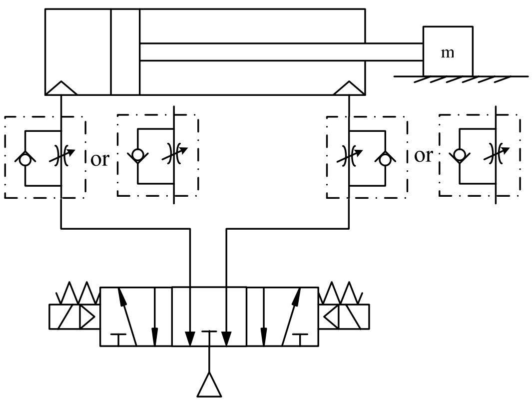
INTRODUCTION

Cylinder halfway stop system, made up of 3 positions and 5 ports valve, exhausted-center or closed-center, and speed controllers of meter-in or meter-out, is widely used in safe doors of machines as its simplicity and low-cost. However, over-shoot often occurs because of some difficultly unavoidable factors such as gas compressibility, switching delay of the solenoid valve, and so on when the cylinder is controlled to halfway stop. Therefore, it is significant for life safety to know this over-shoot in designing phase. In this paper, modeling, simulation and experimental investigation for the cylinder halfway stop system are completed, which can provide theoretical foundation and practical validity.

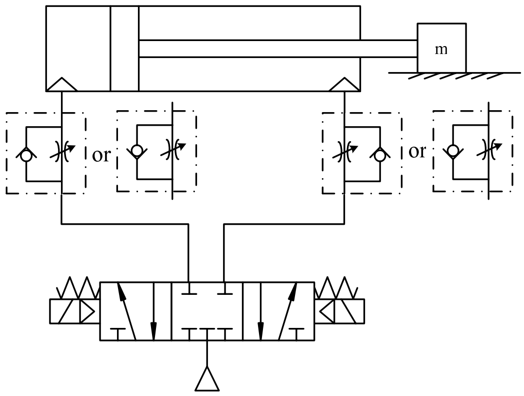
MODELING

Simple cylinder halfway stop system is controlled by the exhausted-center or closed-center valve of 3 positions and 5 ports, with speed controllers of meter-in or meter-out. Therefore, four familiar loops, as shown in Fig.1, will be studied in this research. The different kinds of speed controller only shows different flow characteristics in and out of the cylinder. So, generally speaking, the four loops can be classified to two types, exhausted-center and closed-center systems by the valve configuration. To simplify the modeling and calculation, conventional hypotheses are quoted as following.

1) The working medium, air is the ideal gas.
2) The air supply is stable with no fluctuation.
3) Internal Leakage of the cylinder and the valve is neglected.
4) The working course is adiabatic, and it is approximately a thermodynamic static course.



(a) Exhausted-center system



(b) Closed-center system

Fig.1 Simple cylinder halfway stop system

Exhausted-center system

The piston of the cylinder is initialized to the left position. The initial pressure of left side is atmospheric pressure and that of the right side is pressure of the air supply. Then, the valve is controlled, the left side of the cylinder is charged and the right side discharged, the piston is moving to right. When the piston arrives halfway, the valve is switched to center. Because the valve is exhausted-center, the left side is discharged and right side continues to be discharged. For any solenoid valve, there is switching delay when it is controlled. This delay time must be considered when simulation.

The pressure equations:

Left side is charging course,

$$\frac{dp_1}{dt} = -\frac{kp_1}{X_{01}+x}\cdot\frac{dx}{dt} + \frac{kRTQ_{m1}}{A_1(X_{01}+x)} \tag{1}$$

Right side is discharging course,

$$\frac{dp_2}{dt} = \frac{kp_2}{X_{02}+L-x}\cdot\frac{dx}{dt} - \frac{kRTQ_{m2}}{A_2(X_{02}+L-x)}\left(\frac{p_2}{p_s}\right)^{\frac{k-1}{k}} \tag{2}$$

The flow equations:

Left side is charging course,

$$Q_{m1} = C_q A_q p_s \sqrt{\frac{2}{RT}}\varphi\left(\frac{p_1}{p_s}\right)$$

$$\varphi\left(\frac{p_1}{p_s}\right) = \begin{cases} \sqrt{\dfrac{k}{k-1}\left[\left(\dfrac{p_1}{p_s}\right)^{\frac{2}{k}} - \left(\dfrac{p_1}{p_s}\right)^{\frac{k+1}{k}}\right]} & 0.528 \le \dfrac{p_1}{p_s} \le 1 \\ \left(\dfrac{2}{k+1}\right)^{\frac{1}{k-1}}\sqrt{\dfrac{k}{k+1}} & 0 \le \dfrac{p_1}{p_s} \le 0.528 \end{cases} \tag{3}$$

Right side is discharging course,

$$Q_{m2} = C_q A_q p_2 \sqrt{\frac{2}{RT}} \varphi(\frac{p_a}{p_2})$$

$$\varphi(\frac{p_a}{p_2}) = \begin{cases} \sqrt{\frac{k}{k-1}\left[\left(\frac{p_a}{p_2}\right)^{\frac{2}{k}} - \left(\frac{p_a}{p_2}\right)^{\frac{k+1}{k}}\right]} & 0.528 \le \frac{p_a}{p_2} \le 1 \\ \left(\frac{2}{k+1}\right)^{\frac{1}{k-1}} \sqrt{\frac{k}{k+1}} & 0 \le \frac{p_a}{p_2} \le 0.528 \end{cases} \quad (4)$$

The force equations:

$$M_W \cdot \frac{d^2x}{dt^2} = p_1 A_1 - p_2 A_2 - F \quad (5)$$

In Eq. (5), F is the total friction in the system, which is composed of two parts. One is the friction F_1 between the piston and the cylinder. When the pressure difference between both sides of the piston is not greater than the maximum friction of the piston, the piston is static and the friction is the force owing to the pressure difference. When the pressure difference between both sides of the piston is greater than the maximum Coulomb friction of the piston, the piston is moving and the friction is proportional to the velocity of the piston [3]. The other is the Coulomb friction F_2 between the load and the linear rail.

$$\begin{aligned} F &= F_1 + F_2 \\ F_1 &= a \cdot \mathrm{sign}(\frac{dx}{dt}) + b\frac{dx}{dt} \\ F_2 &= \mu \cdot mg \cdot \mathrm{sign}(\frac{dx}{dt}) \end{aligned} \quad (6)$$

Closed-center system

It is little different from the exhausted-center system. When the valve is switched to center, both the left and right sides are closed because the valve is closed-center. Air in both sides is regarded as the ideal gas. So, it can be modeled with the ideal gas state equation. Similarly, there is switching delay when the valve is controlled. This delay time should be considered when simulation. Except for the pressure equations, flow equations and fore equations, the ideal state equations are also used in the modeling.

Left side,

$$\begin{aligned} M_1 &= \frac{X_{01} p_a A_1}{RT} + \int Q_{m1} \\ p_1 A_1 (X_{01} + x) &= M_1 RT \end{aligned} \quad (7)$$

Right side,

$$\begin{aligned} M_2 &= \frac{(L + X_{02}) p_s A_2}{RT} - \int Q_{m2} \\ p_2 A_2 (L + X_{02} - x) &= M_2 RT \end{aligned} \quad (8)$$

SIMULATION

Based on above modeling, simulation is done with the tool of Simulink of Matlab for the system made up of the cylinder of MB32-400, the valves of SY5420 (exhausted-center) or SY5320 (closed-center), the speed controllers of AS2311F (meter-in) or AS2301F (meter-out), which are all from SMC. In order to acquire actual parameters, some test experiments are carefully done. The first experiment is to test the switching delay time of the valves. Experimental system is built up as shown in Fig.2. By acquiring the output pressure of the valve, we can get the pressure response of port A, shown in Fig.3 (for SY5320, p_s=0.5MPa), when the left solenoid is electrified, which indicates obvious switching delay, about 30ms. This experiment adopts the interrupt at 100K sample rate with the FIFO of the DAQ card as the A/D DAQ method.

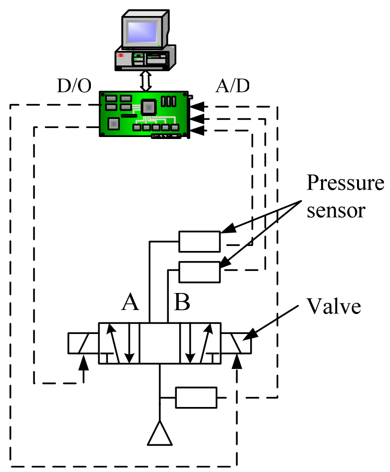


Fig.2 Experimental system to test the switching delay time of the valve

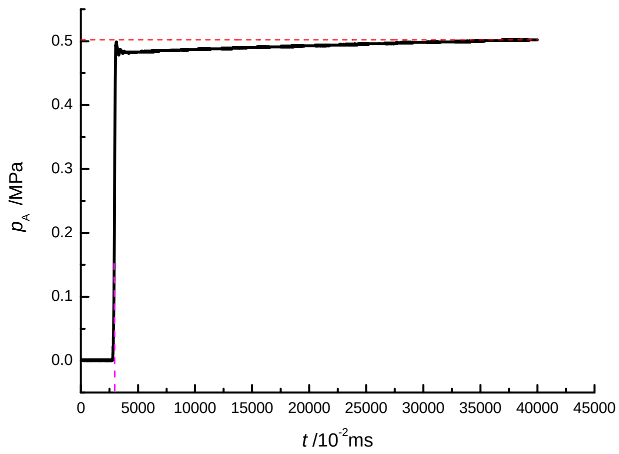


Fig.3 Experimental results of testing the switching delay time of the valve

The second experiment is to test the flow area of the speed controllers, the valve and the cube with the traditional methods of discharging in the velocity. The third experiment is to test the maximum Coulomb friction between the piston and the cylinder. It can be calculated by acquiring the pressure of the left and the right sides when the piston starts to move by adjusting the speed controllers.

Fig.4 (for the system of the cylinder MB32-400, load=30Kg and p_s=0.5MPa) gives the displacement curves of the piston in the working stroke and over-shoot values according to each kind of halfway system.

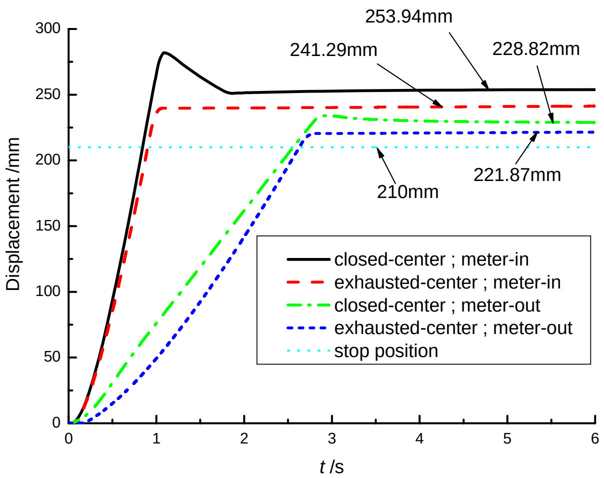


Fig.4 Simulation of the over-shoot of simple cylinder halfway stop system

Through simulation, we can analyze the factors influence on the over-shoot. Over-shoot of the closed-center system is greater than that of the exhausted-center system. Over-shoot of the meter-in system is greater than that of the meter-out system. Besides, simulation shows that the more mass of the load the more over-shoot, and the switching delay time of the valve also has much influence on the over-shoot.

EXPERIMENTAL INVESTIGATION

Experimental systems are built as the Fig.5 shows. The DAQ hardware is from ADVANTECH of Chinese Taiwan. The displacement of the piston rod is measured by a raster code sensor and acquired by the PCL-833, and the Digital I/O is realized by PCI-1710, PCLD-782 and PCLD-785. The DAQ software is developed with NI/LabVIEW.

The experiment course is expressed as following. Firstly, the solenoid B is electrified, the piston goes to the left position. Then, the solenoid A is electrified and B un-electrified, the piston moves to right. When it arrives the halfway, e.g. the magnetism switch in the middle of the full stoke is on, A and B are simultaneously un-electrified, the valve is switching to the center, and the cylinder implements halfway stop. The displacement curves can be also achieved during the experiment course.

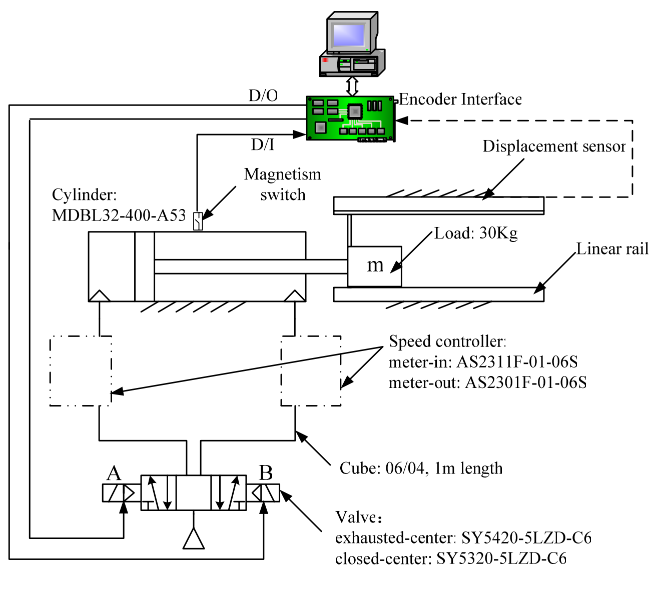
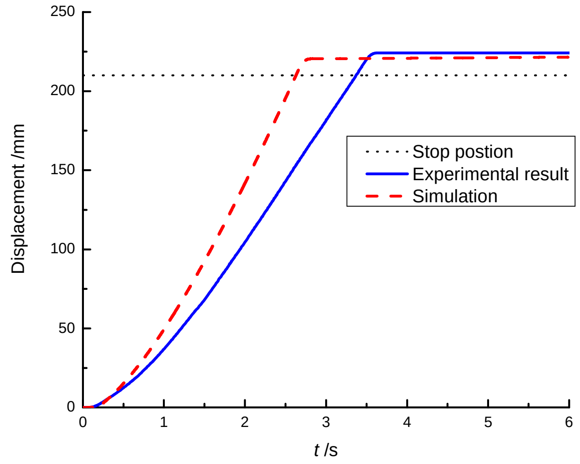
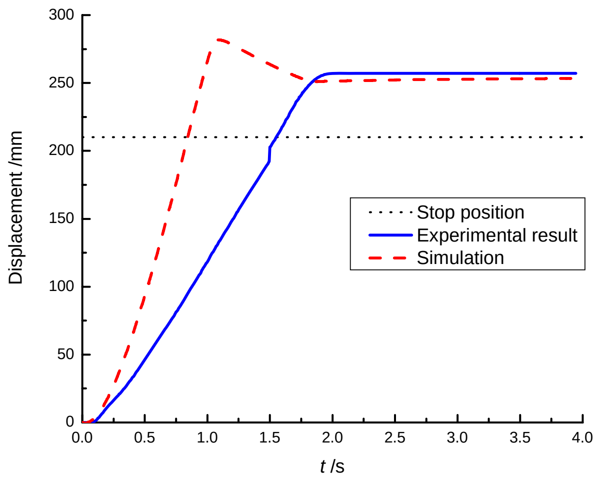


Fig.5 Experimental system of simple cylinder halfway stop system

Fig.6-a (for the system of MB32-400, exhausted-center, meter-out, load=30kg and p_s=0.5MPa) and Fig.6-b (for the system of MB32-400, closed-center, meter-in, load=30kg and p_s=0.5MPa) show the comparison between the simulation and experiment results.



(a) System of MB32-400, exhausted-center, meter-out, load=30kg and p_s=0.5MPa



(b) System of MB32-400, closed-center, meter-out, load=30kg and p_s=0.5MPa

Fig.6 Comparison between simulation and the experimental result

Some possible reasons result in the difference between the simulation and the experiment.

1) The air supply of experiments is not stable. Due to the dynamic response of the regulator, the flow of air supply can not satisfy the ideal supply as the modeling. So, the response of experimental result is slower than that of the simulation.
2) The friction model of cylinder in the simulation may not be accurate.
3) The valve response has obvious influence on the over-shoot.
4) The hypotheses in the simulation ignore the internal leakage of the cylinder and the valve and neglect the thermodynamic exchange.

These factors will be deeply studied in the future research work to make the simulation more accurate. Our final destination is to provide actual over-shoot of every halfway stop system by our simulation software when engineers design this kind of system.

CONLUSION

Modeling and simulation of simple cylinder halfway stop system are completed. Over-shoot of the piston is achieved by simulation. And factors taking effect on the over-shoot are also analyzed. Besides, experimental systems are set up to validate the simulation. The research lays foundation for the future software to provide the over-shoot in the designing phase for engineers.

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