Work Characteristic Analysis of the Single-Rod Symmetric Cylinder

SHEN Wei (沈伟）[1*]，LI Yang (李阳）[2]，ZHANG Di-jia（张迪嘉）[3]，SUN Yi（孙毅）[4], JIANG Ji-hai （姜继海）[3]

1 Department of Mechatronics Engineering, University of Shanghai for Science and Technology, Shanghai 200093, China
2 Tianjin URANUS Hydraulic Machinery Co. Ltd
3 School of Mechatronics Engineering, Harbin Institute of Technology, Harbin 150080, China
4 Beijing Institute of mechanical and electrical control equipment, Beijing 100076, China

Abstract – Hydraulic cylinders are divided into single-rod asymmetric cylinders and double-rod symmetric cylinders. The single-rod asymmetric cylinder has advantages of small size and simple structure, but its speed characteristic is not symmetric. The double rod symmetric cylinder has symmetric speed characteristic, but it cannot be used in some special occasions. In this paper, one special hydraulic cylinder, which is the single-rod symmetric cylinder, is developed. Firstly, characters of this type cylinder are introduced. Then, the system model is constructed by using Simulation X. Moreover, one single rod asymmetric cylinder is designed and the test rig by using the symmetric valve to control single-rod symmetric or asymmetric cylinder is constructed. Both of the simulation and experimental results show that the symmetric valve control single-rod symmetric cylinder servo system has symmetric speed characteristic, which can be used in the practical occasion.

Keywords: Single-rod symmetric cylinders; Simulation X; Servo system;

Introduction

The single-rod asymmetric cylinder and double-rod symmetric cylinder are two types of cylinders which are used widely[1-5]. The single-rod asymmetric cylinder possesses a multitude of advantages, such as small size and simple structure, which can be applied to different working conditions. However, since its speed characteristic is not symmetric because of the different working area of the two chambers[6-9], the complex control system should be investigated in order to obtain high-precision performance. Alternatively, another method is to adopt the asymmetric servo valve, but the cost would be extremely high because of the complex structure of the valve. Moreover, although the double rod symmetric cylinder has symmetric speed characteristic, quite a few occasions are limited because of the space requirement, for example, the 6-DOF platforms and road simulation systems[10-12]. Therefore, a new type cylinder that combining the advantages of both the single-rod and symmetric structure should be a promising choice. The detail is to make the areas of two chambers equal by using suitable structure design method. Then, there are several positive merits behind the improvement. Firstly, the sudden pressure change can be avoided when the direction of motion is changed, and the system dynamic performance can be improved. Secondly, a normal symmetric valve can be used to control symmetric cylinder without complex control algorithm[13,14]. Finally, the flow of hydraulic source is reduced.

There are several famous companies which have released the products of the single-rod symmetric cylinder, such as Haenchen, CAE and Rexroth, etc. Especially, Haenchen company gains the tremendous market share by relying on the cost-effective characteristic of their products, and these products have beenapplied to a majority of flight simulators, such as the simulator for Airbus A340 and A380, in which the maximum amplitude of the cylinder could reach 6.5m. Moreover, the scholars from Delft University of Technology investigated the control performance considering the influence of friction and leakage. Several universities and enterprises in China have presented detail methods for applying the single-rod symmetric to hydraulic elevator or pumping unit[15-17]. Hence, the single-rod symmetric cylinder is one promising component to meet the high control performance requirement, especially under the space-limited-condition.

In this paper, the general structure of the single-rod symmetric cylinder is introduced, and then the simulations including the comparison of single-rod symmetric and asymmetric are conducted. The experimental results show the single-rod symmetric cylinder has the better control performance in both directions.

1 Basic principle

The structure of the single-rod symmetric cylinder is shown as Fig.1, in which the areas of two chambers(A_1 and A_2) are equal. It is worth noting that the rod has two functions, one is to be used as the piston and the other one is as the piston

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* Correspondence should be addressed to SHEN Wei，E-mail: shenwei@usst.edu.cn

barrel. Hence, in order to meet the second requirement, the piston should be hollow, moreover, the high surface accuracy of the hole is supposed to be guaranteed. The piston is divided into two parts and they were processed respectively, the processing technologies include welding, finish turning and chrome plate.

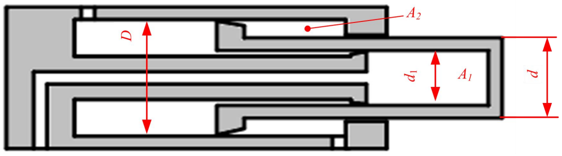


Fig.1 Structure of the single-rod symmetric cylinder

Fig.2 shows the schematic of the single-rod symmetric cylinder controlled by the servo valve. According to the fundamental definitions, the parameter are listed in Tab.1. shown in Table 1.

Table 1 Pressure characteristics of symmetric valve control single-rod symmetric cylinder

Classification	Pressure of bore side x	Pressure of rod side	Force
$x_v > 0$	$p_1 = \dfrac{p_s + F_L / A}{2}$	$p_2 = \dfrac{p_s - F_L / A}{2}$	F_L
$x_v = 0$	$p_{10} = \dfrac{p_s}{2}$	$p_{20} = \dfrac{p_s}{2}$	0
$x_v < 0$	$p_1^{'} = \dfrac{p_s - F_L / A}{2}$	$p_2^{'} = \dfrac{p_s + F_L / A}{2}$	$-F_L$
Δp	$\Delta p_1 = -F_L / A$	$\Delta p_2 = F_L / A$	—

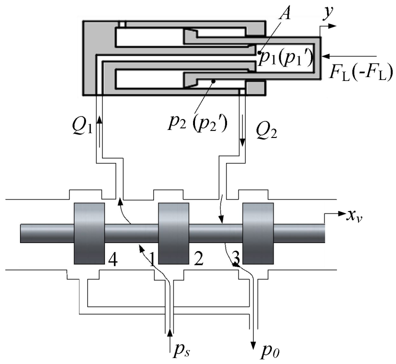


Fig.2 Simplified schematic diagram of single-rod symmetric cylinder controlled by the servo valve

Using the pressure characteristic expressions to describe the two chamberschambers of the hydraulic cylinder in Table 1, the curve of the pressure characteristic is shown in Fig.3. Parameters of the curve are the same as the experiment, p_s=10MPa, A=3.1×10^{-3}m^2.

Two conclusions can be drawn from Fig.3:

(1) Pressure characteristics of the single-rod symmetric cylinder's two chambers are the same, with no phenomenon of cavitation and overpressure.

(2) When the cylinder motion reverses, the pressure suddenly changes, whose value is only related to the load force F_L when the area of the cavity is determinate.

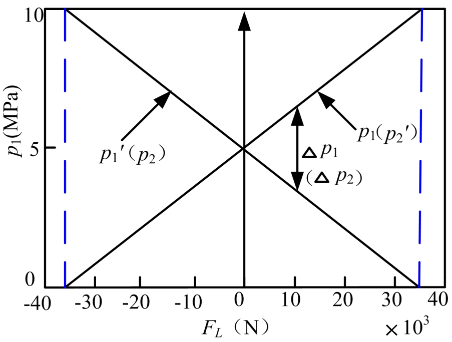


Fig.3 Pressure characteristics of the single-rod symmetric cylinder controlled by the symmetric valve

1.1 Output characteristics

$x_v > 0$, the stretch-out speed of the rod

$$v = \frac{Q_1}{A} = \frac{c_d w x_v}{A}\sqrt{\frac{2}{\rho}(p_s - p_1)} = \frac{c_d w x_v}{A}\sqrt{\frac{2}{\rho}(p_s - \frac{F_L}{A})} \tag{1}$$

$x_v < 0$, the retraction speed of the rod

$$v' = \frac{Q_2'}{A} = \frac{c_d w x_v}{A}\sqrt{\frac{2}{\rho}(p_s - p_2')} = \frac{c_d w x_v}{A}\sqrt{\frac{2}{\rho}(p_s - \frac{F_L}{A})} \tag{2}$$

Output characteristics of symmetric valve control single-rod symmetric cylinder are shown in Fig.4.

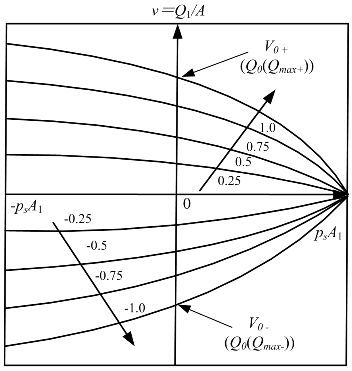


Fig.4 Output characteristics of symmetric valve control single-rod symmetric cylinder

The equation can be obtained from comparing the force range which is:

$$-p_s A \le F_L \le p_s A \tag{3}$$

Hence, the load force transformation range of a symmetric valve control single-rod symmetric cylinder system is larger than a symmetric valve control single-rod asymmetric cylinder system.

1.2 Modeling

In order to test the control performance of the cylinder we designed and compare it with the traditional cylinders, a single-rod symmetric cylinder prototype is constructed. However, some simulations by using Simulation X3.3 are operated before it was manufactured. The model is assembled by using the elements which are defined in Simulation X3.3. According to the simulation, friction descriptions, end stops and leakage models can be regulated easily. Moreover, a simulation model of the cylinder servo system controlled by the symmetric valve is constructed in order to prove the single-rod symmetric cylinder's advantages mentioned above.

Fig.5 shows a single-rod symmetric hydraulic cylinder electro-hydraulic servo system model. Furthermore, for comparing and analyzing, a single-rod asymmetric cylinder electro-hydraulic servo system model is also made, as shown in Fig.6, and the main simulation parameters are listed in Table 2.

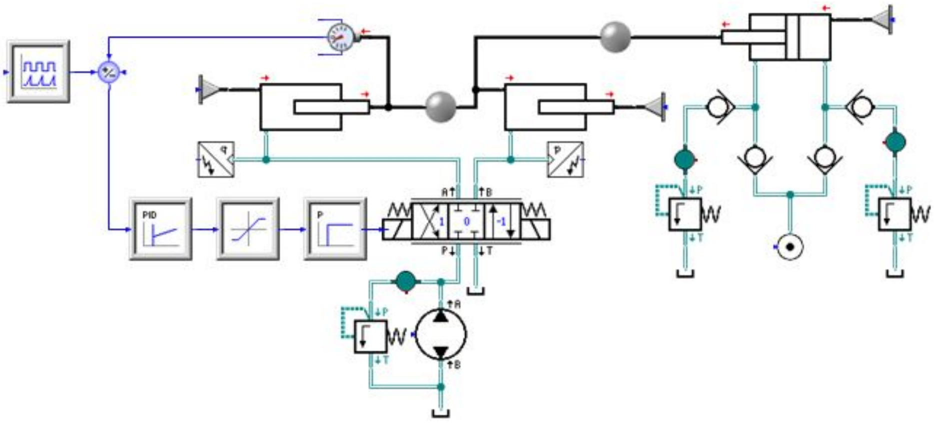


Fig.5 A single-rod symmetric hydraulic cylinder electro-hydraulic servo system model

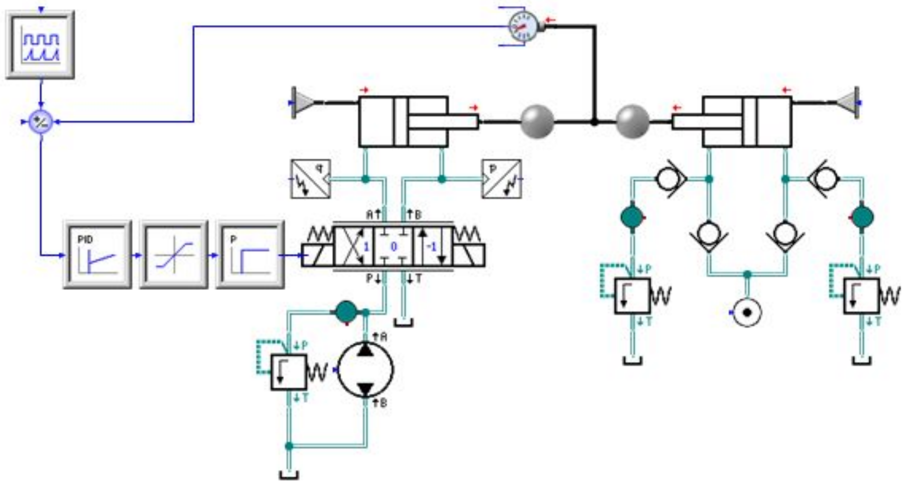


Fig.6 A single-rod asymmetric hydraulic cylinder electro-hydraulic servo system model

Table 2 Simulation parameters

Symbol	Value	Unit
Maximum control current	I_{max}	40mA
Minimum control current	I_{min}	1mA
Natural frequency	f_0	45Hz
Damping ratio	D	0.6
Rated pressure	P_r	21Mpa
Rated flow	Q_r	100L/min

2 Simulation analysis

2.1 Frequency domain analysis

To obtain the frequency domain analysis result of the Single-rod asymmetric hydraulic cylinder electrohydraulic servo system, a closed-loop Bode diagram is obtained by using the Simulation X software after analyzing the input-output process. Fig.7 shows the result obtained from the condition of the load is 10kN and supplying pressure is 10MPa. It can be concluded from the closed-loop Bode diagram that the width of system band at -3dB is 9Hz.

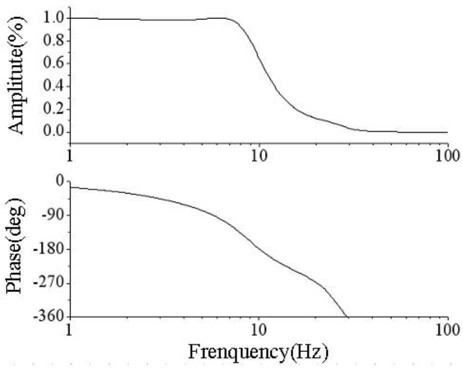
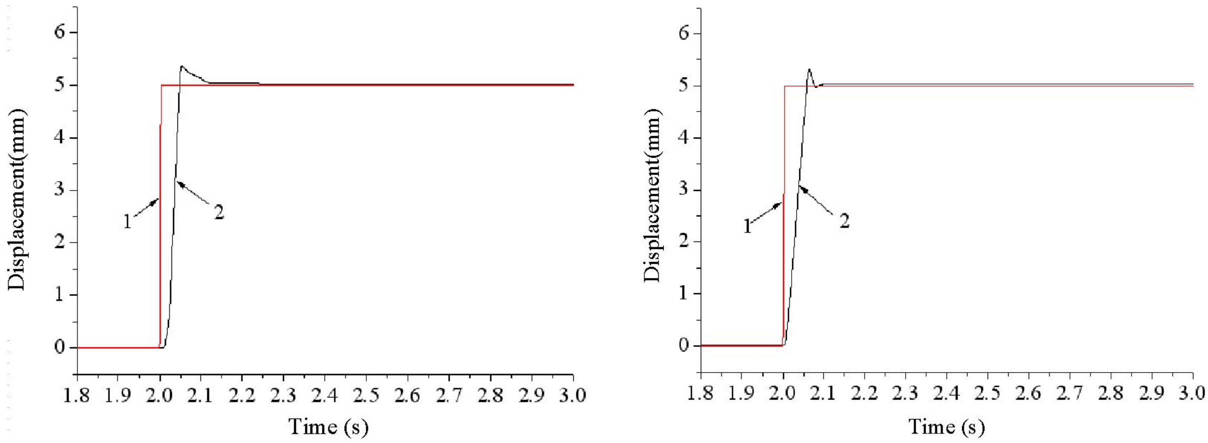


Fig.7 A closed-loop Bode diagram of a single-rod symmetric hydraulic cylinder electro-hydraulic servo system

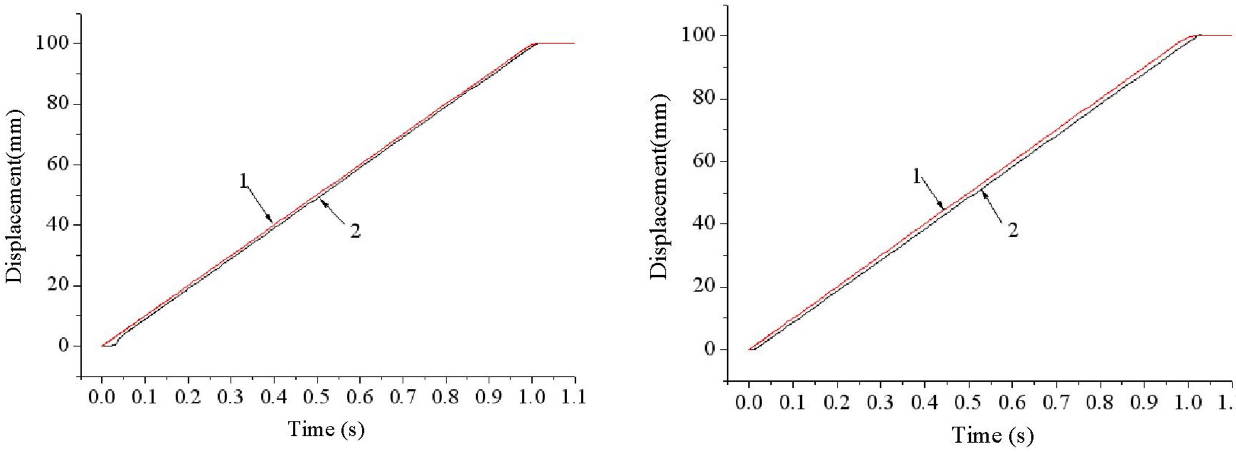
2.2 Time domain analysis

In this paper, the step, ramp and sinusoidal signal are used to investigate the response of the electro-hydraulic servo system. In order to make a fair comparison, the response during retracting process of the single-rod asymmetric cylinder is chosen. The following part is the response curve of each group (1 is the given signal, 2 is the response signal). It can be found from Fig. 8 that the rising time are basically identical, both of them are about 0.5s.



(a) Single-rod symmetric cylinder (b) Single-rod asymmetric cylinder

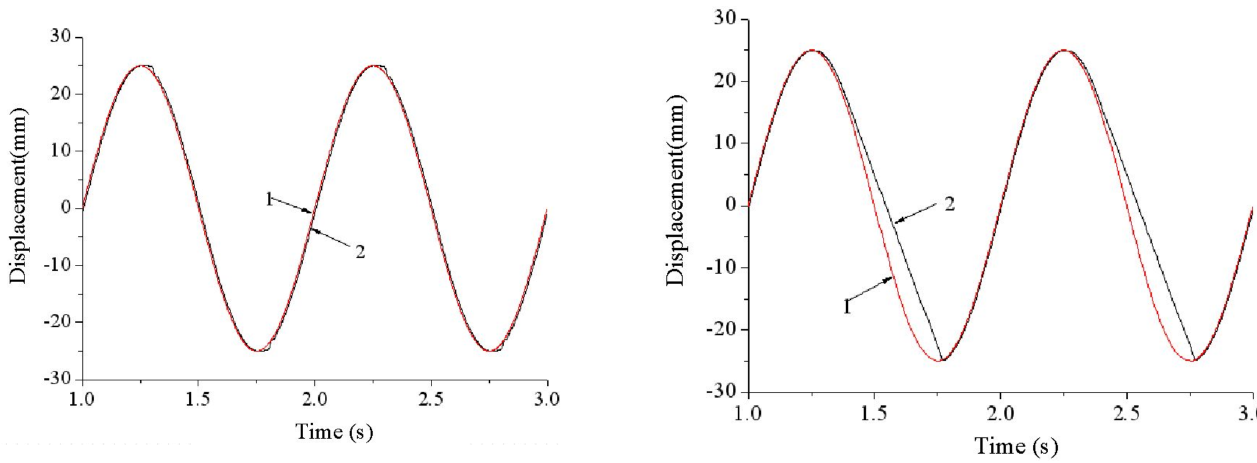
Fig.8 Step signal response curve



(a) Single-rod symmetric cylinder k = 100mm/s (b) Single-rod asymmetric cylinder k = 100mm/s

Fig.9: Ramp signal response curve

Fig.9 shows the ramp signal response of tracking 100mm/s signal. Conclusion drawn from (a) and (B) is that delay time of the single-rod symmetric cylinder electro-hydraulic servo system is 0.010s and 0.014s respectively. It means the constant speed tracking ability of the two systems is basically the same. However, the steady error of the single-rod symmetric cylinder is smaller.



(a) Single-rod symmetric cylinder A = 25mm f=1Hz (b) Single-rod asymmetric cylinder A = 25mm f=1Hz

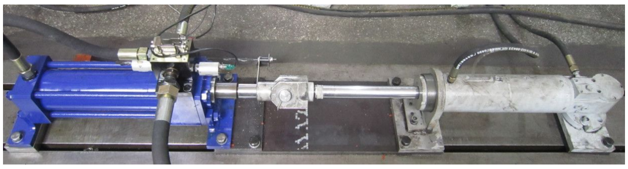
Fig.10 Sinusoidal signal response curve

The sinusoidal response is shown in Fig.10. It can be found that the single-rod symmetric cylinder has symmetric speed characteristic. However, the asymmetric cylinder performs different speed responses during the extending and retracting.

3 Experimental analyses

The experimental system includes experimental part and load part; the load part is shown in Fig.11(a). The experimental part is shown in Fig.11(b). The contrastive experiments were done by changing the single-rod symmetric hydraulic cylinder and the single-rod asymmetric hydraulic cylinder.

(a)



(b)

Fig.11 The single-rod symmetric cylinder test rig

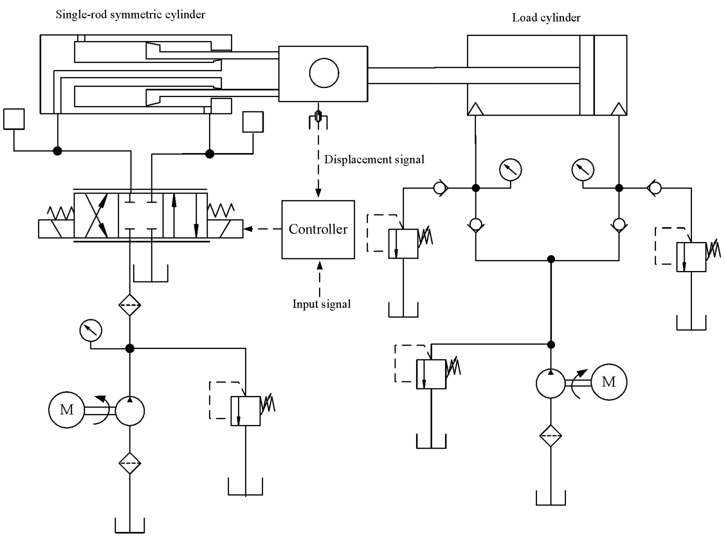
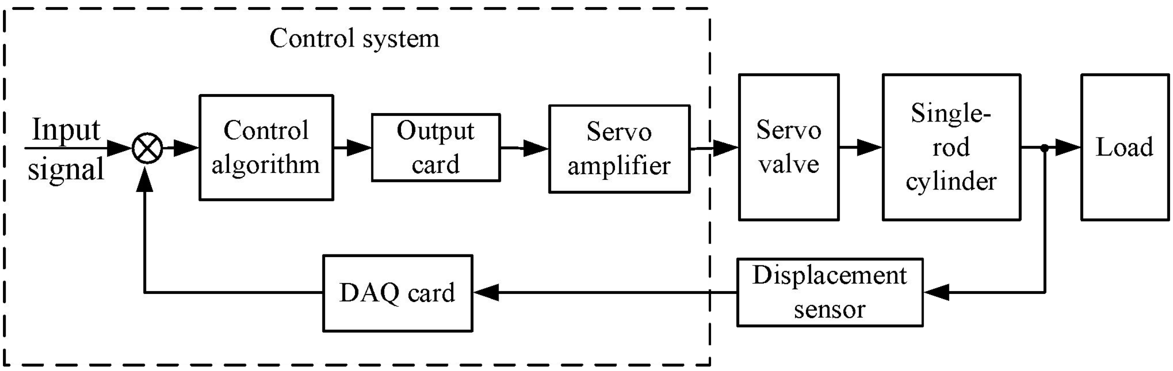


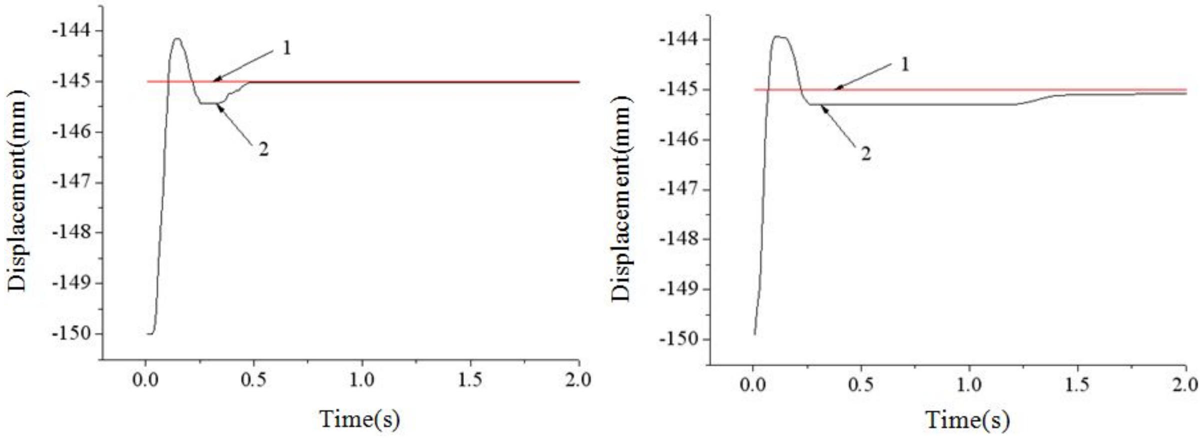
Fig Schematic of the single-rod symmetric cylinder test rig



(1) Step response experiments

Two kinds of system step response experiments are compared in this paper. The single-rod step response experiment of asymmetric hydraulic cylinder is done when the piston is back. Figure 12 shows the load step response curve for the two kinds of system.

Step response curves of single-rod symmetric cylinder and single-rod asymmetric cylinder electro-hydraulic servo system are shown in Fig.12(a) and (b), in which the amplitude is 5mm. It can be found from (a) that rising time of the single-rod symmetric cylinder electro-hydraulic servo system is 0.11s and the steady state error is 0.02m. The conclusion drawn from (b) is that rising time of the single-rod asymmetric cylinder electro-hydraulic servo system is 0.10s and the steady state error is 0.1. Hence, rise time of the two systems is basically the same.

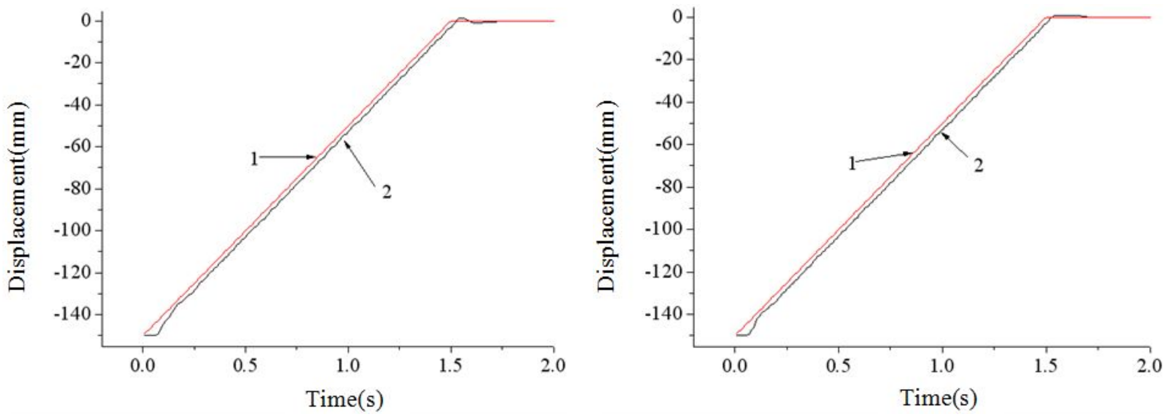


(a) single-rod symmetric cylinder (b) single-rod asymmetric cylinder

Fig.12 Step response curve

(2) Ramp response experiments

Then, ramp response experiments were finished. In order to be comparable, the single-rod step response experiment of asymmetric hydraulic cylinder is done when the piston is retracting. For the load case, neither of the two kinds of systems can track the ramp signal for 200 mm/s slope. But they can track the ramp signal for 100 mm/s slope well. Ramp response curve of single-rod symmetric cylinder and single-rod asymmetric cylinder electro-hydraulic servo system is shown as in Fig.13(a) and (b), in which the slope is 100mm/s. Conclusion drawn from (a) is that delay time of the single-rod symmetric cylinder electro-hydraulic servo system is 0.030s. Conclusion drawn from (b) is that the delay time of the single-rod asymmetric cylinder electro-hydraulic servo system is 0.033s. So the constant speed tracking ability of the two systems is basically the same.

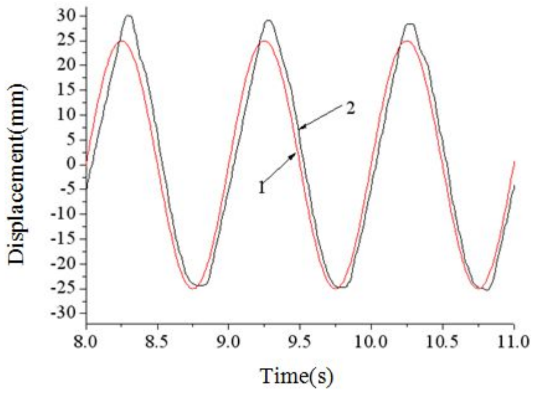


(a) single-rod symmetric cylinder k = 100mm/s (b) single-rod asymmetric cylinder k = 100mm/s

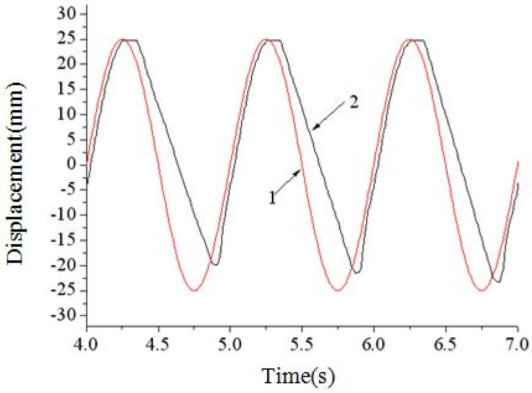
Fig.13 Ramp response experiment

(3) Sinusoidal response experiments

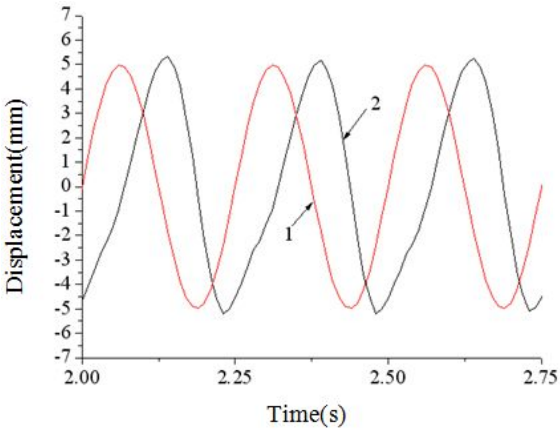
Finally, sinusoidal response experiments were conducted. Fig.14 shows the load sinusoidal response curve for the two kinds of systems.



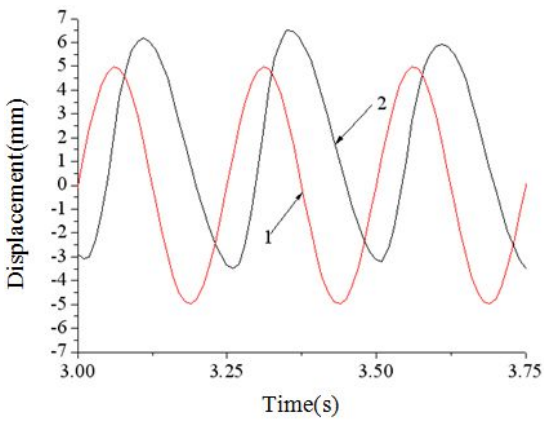
(a) Single-rod symmetric cylinder
A = 25mm f =1Hz



(b) Single-rod asymmetric cylinder
A = 25mm f =1Hz



(c) Single-rod symmetric cylinder
A = 5mm f =4Hz



(d) Single-rod asymmetric cylinder
A = 5mm f =4Hz

Fig.14 Sinusoidal response curve

Sinusoidal response curves of single-rod symmetric cylinder and single-rod asymmetric cylinder electro-hydraulic servo system are shown in Fig.14(a) and (b) where the amplitude is 25mm and frequency is 1Hz. Conclusion drawn from comparison is that for single-rod asymmetric cylinder, the extending speed is bigger than the retracting speed obviously. But for the single-rod symmetric cylinder, they are almost the same.

Moreover, the different working condition experiment of sinusoidal signal response are shown by Fig.13(c) and (d), where the amplitude is 5mm and frequency is 4Hz. Forward and reverse phase lag of the single-rod symmetric cylinder is almost -90º. Forward phase lag of the single-rod asymmetric cylinder is smaller than the reverse phase lag. Forward overshoot, reverse attenuate, reverse phase lag reaches -90º; forward overshoot reaches 10%. Experimental results show that both of two systems are unable to track the signal which possesses the characteristics of high frequency and low amplitude. According to different signal responses, two kinds of systems have the similar performance, however, the single-rod symmetric cylinder possesses the symmetric characteristic.

4 Conclusions

(1) A single-rod symmetric cylinder is designed and the test rig for the performance experiment is conducted. The step signal tracking results show that both of the two kinds of systems possess almost the same response.

(2) By importing the sinusoidal signal into the simulation model, it can be concluded that the symmetric valve control symmetric cylinder servo system has symmetric speed characteristic, however, the symmetric valve control asymmetric cylinder servo system does not have the performance.

(3)Experiment results verify that the single-rod symmetric cylinder system can be obtained the same performance compared with the asymmetric one, it also possesses the identical merit during extending and retracting. Hence, it can be used in the practical working condition.

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摘要：现有的液压缸主要分为单出杆非对称液压缸和双出杆对称液压缸两类。其中，单出杆非对称液压缸具备体积小巧和结构简单的优点，但是由于其作用面积不同导致在控制上显现出在两个运动方向速度特性不对称的特点。而双出杆对称液压缸具备对称的速度特性，但是由于其工作体积较大所以限制了应用范围。本文设计了一种单出杆对称液压缸。首先，对于该液压缸的结构特点进行了介绍，然后，利用多学科交叉的仿真软件Simulation X进行了系统建模。在开发了单出杆对称液压缸的原理样机以后，分别搭建了伺服阀控制单出杆非对液压缸和单出杆对称缸的控制系统实验台。仿真和实验结果表明所设计的单出杆对称液压缸相对于非对称液压缸具备双向的速度控制对称特性，兼顾了体积小巧和控制性能较好的特点，具备实际的工程应用能力。