Research Article
Research on Pressure Jump Characteristics of Valve Controlled Asymmetric Cylinder System

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Abstract: The study introduces a method which can eliminate pressure jump when asymmetrical cylinder is moves backward. It shares the flow of the cylinder non-rod end chamber by auxiliary servo valve to guarantee symmetrical flow of main servo valve. The paper gives an overview of the program principles, theoretical analysis and calculation; at last, it makes simulation based on software of AMESim. Results show that this method can eliminate pressure jump of cylinder when moves backward. This method can bring new applications to engineering practical value.

Keywords: AMESim simulation, asymmetric cylinder, auxiliary servo valve, pressure jump

INTRODUCTION

In coal mining, as the main supporting equipment, hydraulic support will badly influenced because of the Asymmetric hydraulic cylinder's use, which will cause system vibration and pressure jump when the hydraulic system does reversing movement. Shown in Fig. 1, as asymmetric hydraulic cylinder has a lot of characteristics, such as small space usage, simple structure, compact, low cost, large carrying capacity, etc., the servo-system with it has been widely used in the hydraulic system. If use the symmetrical hydraulic valve to control asymmetrical hydraulic cylinder, when the hydraulic cylinder change its direction, because the effective area of the two chambers are not equal, it will make different pressure drop at both ends on the valve port and then generates pressure jump on the two chambers of asymmetrical cylinder when the piston rod change its directions.

The pressure jump will make noise and vibration, make the entire system work abnormally; meanwhile, the frequent pressure shock may damage the connections and lead to oil leak, which may also damage the main components; if the pressure suddenly increases or decreases, it will cause over-pressure or cavitation too; in addition, the pressure jump may cause the pressure relay to send wrong signals, then interfere the system's normal work, finally affect the reliability and stability of the system (Wang, 2004). In order to solve this problem, some people use asymmetric valve in instead of symmetric valve to control asymmetrical hydraulic cylinder. Although this method can solve the problem of the pressure jump (Yao, 1999; Guan, 2001),

it will need a lot of experiments to test which kind of asymmetrical servo valve matches well with the asymmetrical hydraulic cylinder. (Zhang, 2000), which makes more difficulty in large-scale practical industrial applications (Wang, 1996; Shi, 2003).

In response to these problems, this study gives a method that uses system of two-valve-controlled asymmetric hydraulic cylinder to eliminating the pressure jump. This scheme will enlarge the applied range of asymmetric hydraulic cylinder, including in the high precision-required mechanical systems. Then we use the software of AMESim to analyze the dynamic characteristics about its control system and give its simulation results. The result proved the theoretical feasibility of the scheme.

The theory analysis about system of two-valve-controlled asymmetric hydraulic cylinder: The program of the two-valve-controlled asymmetric hydraulic cylinder is shown in Fig. 2. The principle of system to eliminating pressure jump is that the non-rod chamber uses both the main servo valve and the auxiliary servo valve to supply and return oil, while the rod chamber only uses the main servo valve. When the system working, firstly we got the derivative from the displacement sensor signal, secondly transformed the results to the piston's speed signal, then multiplied by the area gap between the two chambers of the asymmetric cylinder, transformed the outcome to the flow difference signal, finally use the flow difference signal as the auxiliary servo valve's input signal to control its valve element displacement. The amount of the additional flow from the non-rod chamber more
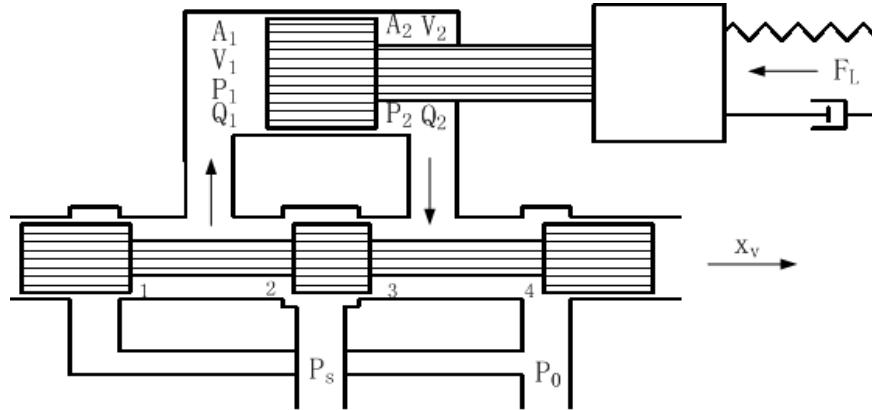
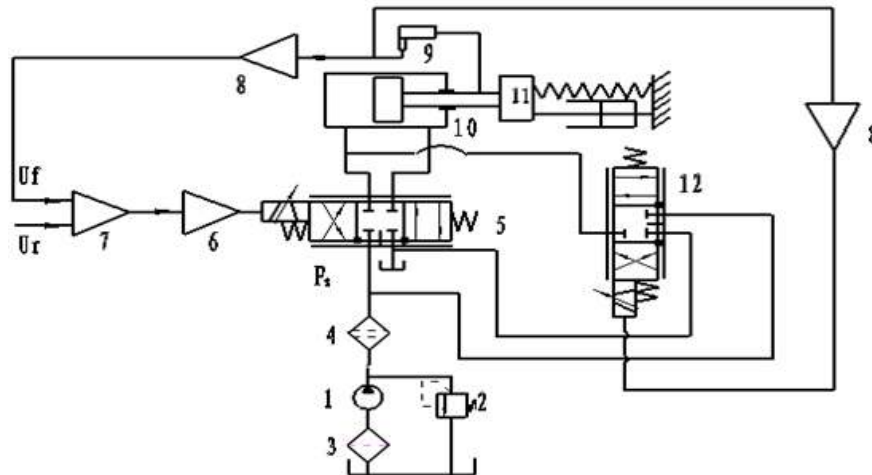Fig. 1: The schematic of symmetrical valve controlled asymmetric hydraulic cylinder

Fig. 2: The schematic of system about two-valve-controlled asymmetric hydraulic cylinder
1: Power station; 2: Pressure relief valve; 3: Simple filter; 4: Fine filter; 5: Main servo valve; 6: Servo amplifier; 7: Comparator; 8: Signal amplifier; 9: Sensor; 10: Cylinder; 11: Load; 12: Auxiliary servo valve

than the rod end chamber in the asymmetric cylinder supplies or returns oil through the auxiliary servo valve, which makes the flow through the main servo valve element ends is always equal and the pressure drop is equal too, then eliminates the pressure jump.

MATERIALS AND METHODS

The theoretical analysis of pressure characteristics about two cylinder's chamber in system of two-valve-controlled asymmetric hydraulic cylinder:

- When hydraulic cylinder piston moves forward ($X_v > 0$) (Yang, 2006; Zhao, 1996):
  The flow into the non-rod chamber through main servo valve is:

$$Q_1 = C_d w x_v \sqrt{\frac{2}{\rho}(P_s - P_1)} \tag{1}$$

The flow into the non-rod chamber through auxiliary servo valve is:

$$Q_1' = C_d w x_v' \sqrt{\frac{2}{\rho}(P_s - P_1)} \tag{2}$$

where, Q_1' is the flow into non-rod chamber through auxiliary servo valve, unit: *L/min*; x_v' is the valve element position of auxiliary servo valve, unit: *mm*;
The flow out of the hydraulic cylinder rod end chamber is:

$$Q_2 = C_d w x_v \sqrt{\frac{2}{\rho}P_2} \tag{3}$$

By equation $Q_1 = Q_2$, we can get:

$$P_s = P_1 + P_2$$

By equation $\frac{Q_1 + Q_1'}{A_1} = \frac{Q_2}{A_2} = v$, we can get:

$$\frac{Q_2}{Q_1 + Q_1'} = \frac{A_2 v}{A_1 v} = \frac{A_2}{A_1} = n = \sqrt{\frac{P_2}{P_s - P_1}} \frac{x_v}{x_v + x_v'}$$

So we can get equation as follows:

$$P_s = \frac{1}{n^2} \frac{x_v^2}{(x_v + x_v')^2} P_2 + P_1$$

Combine two equations of force balance equation and force-pressure equation on hydraulic cylinder:

$$F_L = A_1 P_1 - A_2 P_2$$

$$P_L = \frac{F}{A_1} = P_1 - P_2 \frac{A_2}{A_1} = P_1 - n P_2$$

Then the following pressure expressions can be obtained about two chambers of hydraulic cylinder:

$$P_1 = \frac{n^3 \frac{(x_v + x_v')^2}{x_v^2} P_s + F_L / A_1}{1 + n^3 \frac{(x_v + x_v')^2}{x_v^2}} \tag{4}$$

$$P_2 = \frac{n^2 \frac{(x_v + x_v')^2}{x_v^2} (P_s - F_L / A_1)}{1 + n^3 \frac{(x_v + x_v')^2}{x_v^2}} \tag{5}$$

Make Eq. (4), (5) into Eq. (1) and (3), we can get:

$$Q_1 = C_d w x_v \sqrt{\frac{2}{\rho} \frac{P_s - P_L}{1 + n^3 \frac{(x_v + x_v')^2}{x_v^2}}}$$

$$Q_2 = C_d w x_v \sqrt{\frac{2}{\rho} \frac{n^2 \frac{(x_v + x_v')^2}{x_v^2} (P_s - P_L)}{1 + n^3 \frac{(x_v + x_v')^2}{x_v^2}}}$$

Make $Q_1 = Q_2$, we can get: $\frac{x_v'}{x_v} = \frac{1}{n} - 1$.

Now, pressure expressions of two chambers can be described as:

$$P_1 = \frac{n P_s + F_L / A_1}{1 + n} \tag{6}$$

$$P_2 = \frac{(P_s - F_L / A_1)}{1 + n} \tag{7}$$

- When hydraulic cylinder piston moves back ($X_v < 0$):

The flow out of the non-rod chamber through main servo valve is:

$$Q_1 = C_d w x_v \sqrt{\frac{2}{\rho} P_1} \tag{8}$$

The flow out of the non-rod chamber through auxiliary servo valve is:

$$Q_1' = C_d w x_v' \sqrt{\frac{2}{\rho} P_1} \tag{9}$$

The flow into the hydraulic cylinder rod end chamber is:

$$Q_2 = C_d w x_v \sqrt{\frac{2}{\rho} (P_s - P_2)} \tag{10}$$

Similarly we can get pressure expressions of two chambers when hydraulic cylinder piston backward movement (Lv, 2007):

$$P_1 = \frac{n P_s + F_L / A_1}{1 + n^3 \frac{(x_v + x_v')^2}{x_v^2}} \tag{11}$$

$$P_2 = \frac{P_s - n^2 \frac{(x_v + x_v')^2}{x_v^2} F_L / A_1}{1 + n^3 \frac{(x_v + x_v')^2}{x_v^2}} \tag{12}$$

Make Eq. (11), (12) into Eq. (8) and (10), we can get:

$$Q_1 = C_d w x_v \sqrt{\frac{2}{\rho} \frac{n P_s + P_L}{1 + n^3 \frac{(x_v + x_v')^2}{x_v^2}}}$$

$$Q_2 = C_d w x_v \sqrt{\frac{2}{\rho} \frac{n^3 \frac{(x_v + x_v')^2}{x_v^2} P_s + n^2 \frac{(x_v + x_v')^2}{x_v^2} P_L}{1 + n^3 \frac{(x_v + x_v')^2}{x_v^2}}}$$

Make $Q_1 = Q_2$, we also can get: $\frac{x_v'}{x_v} = \frac{1}{n} - 1$
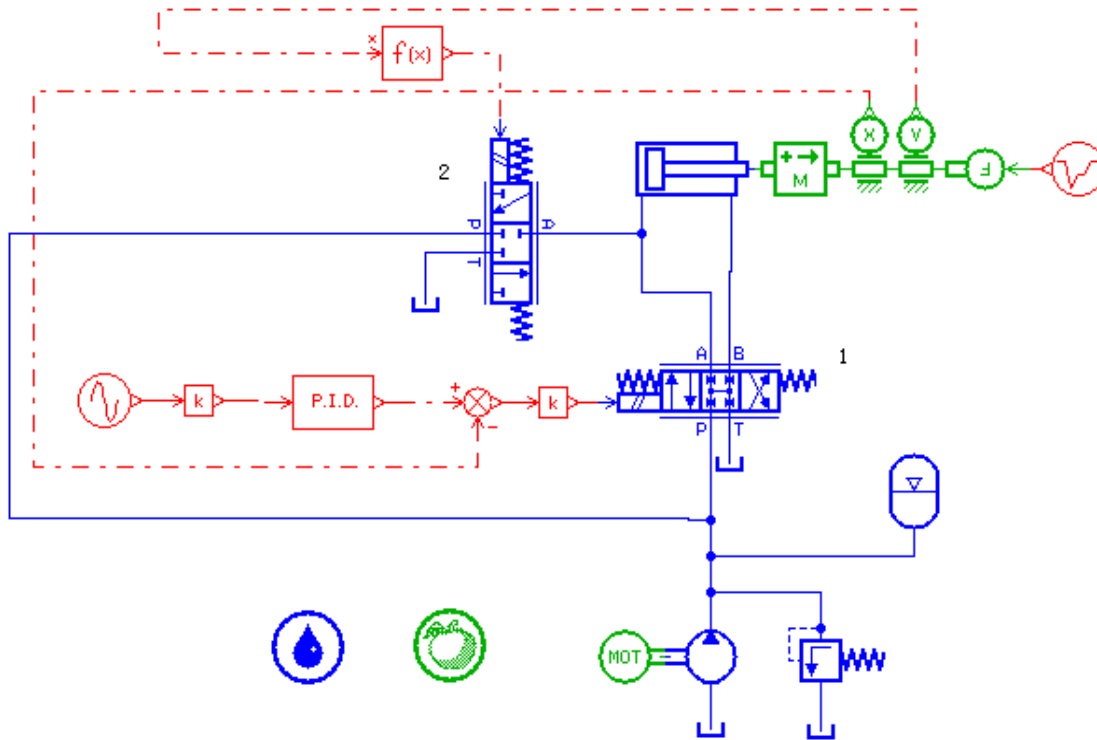
Fig. 3: The model of two-valve-controlled asymmetric hydraulic cylinder

Now, pressure expressions of two chambers can be described as:

$$P_1 = \frac{nP_s + F_L / A_1}{1+n} \tag{13}$$

$$P_2 = \frac{(P_s - F_L / A_1)}{1+n} \tag{14}$$

Comparing (13), (6) and (14), (7), it can be concluded that no matter the hydraulic cylinder piston is moves forward or backward, the pressure expressions of hydraulic cylinder' s two chambers are the same. Related parameters, such as the working pressure, load force and area ratio are the same too. So, we can get the Conclusion: in this program, there is no pressure jump in theory when the system is working.

The parameters of the system such as working pressure 21 MPa, the load force 200 kN, area ratio is 0.36, piston diameter is 200 mm and so on, make these parameters into the above expressions, the theoretical pressure values of non-rod chamber and rod end chamber will be get.

Non-rod end chamber:

$$P_1 = \frac{nP_s + F_L / A_1}{1+n} = 10.24MPa = 102.4bar$$

Rod end chamber:

$$P_2 = \frac{(P_s - F_L / A_1)}{1+n} = 10.76MPa = 107.6bar$$

The dynamic simulation based on AMESim simulation software about system of two-valve-controlled asymmetric hydraulic cylinder: The modle of two-valve-controlled asymmetric hydraulic cylinder with the help of AMESim simulation software is shown in Fig. 3.

In simulation model, the parameters are set as follows: the diameter of hydraulic cylinder piston is 200 mm, the rod diameter is 160 mm, piston stroke is 0.25 m, initial displacement is 0.1 m, moving mass is set to 2 000 kg, the natural frequency of main servo valve and auxiliary servo valve is 50 Hz, damping ratio is 0.8, rated current is 200 mA, the pump displacement is 63 cc/rev, motor speed is 1500 r/min, the gain of positioning sensor is 10, preamplifier gain is 250, load force is 200 kN; working pressure is 21 Mpa, the given signal curve is shown in Fig. 4.

When give sinusoidal signal as the input, the simulation results of piston displacement curves was got and shown in Fig. 5 (Liu, 2006).

RESULTS AND DISCUSSION

Figure 4 and 5 shows, under the input of sinusoidal signals, the piston of two-valve-controlled asymmetric hydraulic cylinder can accurately move in accordance
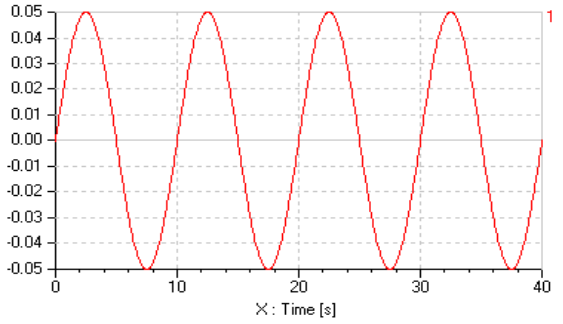
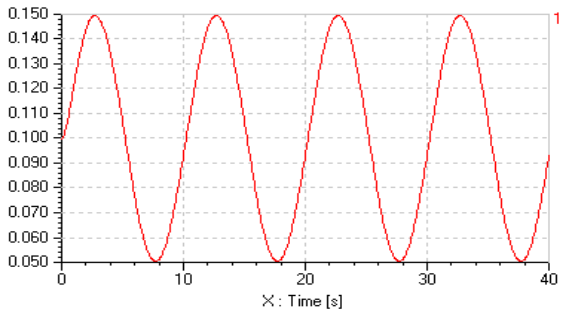Fig. 4: The input signal of main servo valve

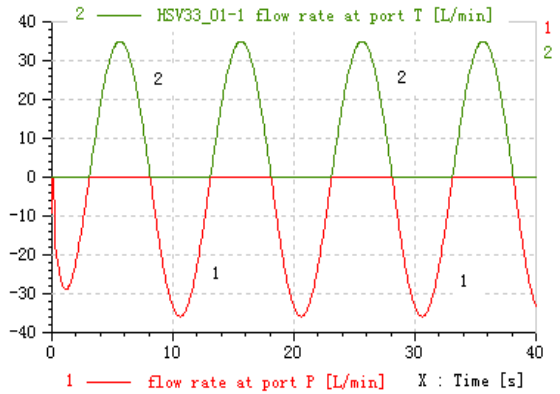Fig. 5: The piston displacement curves under the input sinusoidal signal

Fig. 6: The P, T port flow curves of auxiliary servo valve
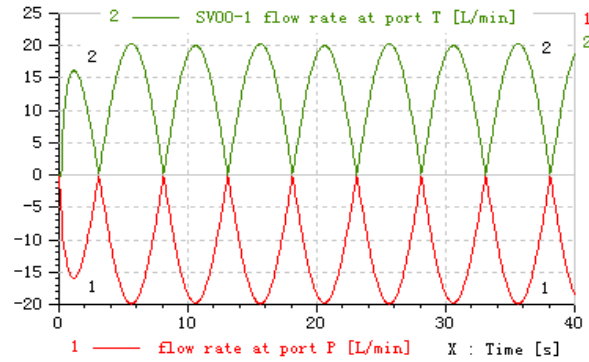1: P port flow curve; 2: T port flow curve

Fig. 7: The P, T port flow curves of main servo valve
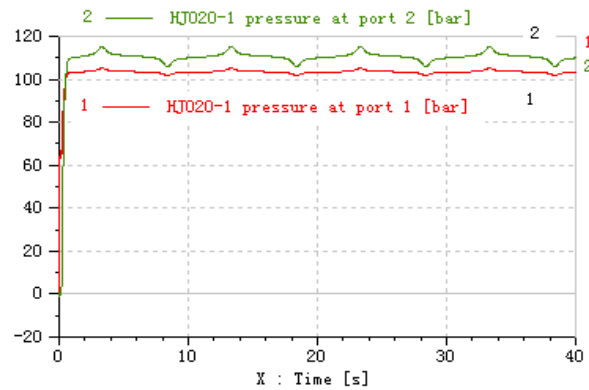1: P port flow curve; 2: T port flow curve

Fig. 8: The pressure curves about two-valve-controlled asymmetric hydraulic cylinder
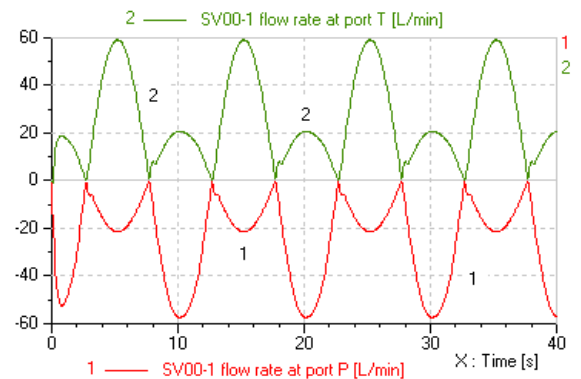1: Non-rod chamber's pressure curve; 2: Rod end chamber's pressure curve

Fig. 9: The P, T port flow curves about single valve controlled asymmetric cylinder
1: P port flow curve; 2: T port flow curve

with specified law of motion. From Fig. 6 and 7, we can see that in the program of two-valve-controlled asymmetric hydraulic cylinder, with the auxiliary servo valve's continuous adjustment, the extra flow which the non-rod chamber is more than the rod end chamber in asymmetric cylinder goes in or out through the auxiliary servo valve, by which the flow in the main servo valve is symmetrical. As can be seen from Fig. 8 and 9, after achieving the flow symmetry in main servo valve by using the auxiliary servo valve, the pressure of the two chambers about asymmetric cylinder has become stable. Although there is still a bit of pressure jump, the maximum is only 0.2 Mpa; compared with

Fig. 10's 17 Mpa which uses single valve controlled asymmetric cylinder system, it has virtually eliminated the pressure jump due to the flow symmetry on servo valve; from Fig. 8 we can also find out that the non-rod chamber's pressure stabilized at around 10.2 Mpa, rod end chamber's pressure stabilized at around 10.8 Mpa.
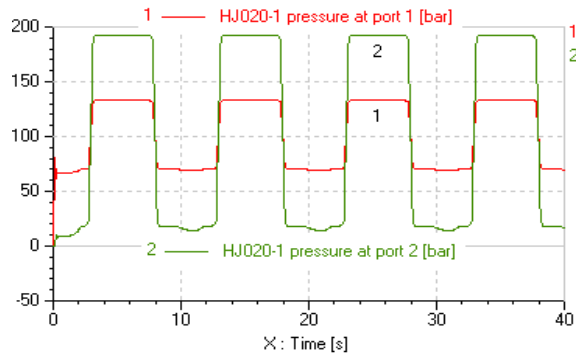
Fig. 10: The pressure curves about two chambers of single valve controlled asymmetric cylinder
1: Non-rod chamber's pressure curve; 2: Rod end chamber's pressure curve

Compared with the previous theoretical calculation that non-rod chamber's pressure is 10.24 Mpa and rod end chamber's pressure is 10.76 Mpa, the conclusions can be obtained that within allowable range of interference deviation, it can be considered equal.

CONCLUSION

- By adding an auxiliary servo valve on bypass circuit to ensure main servo valve's flow symmetry, in theory, it can effectively solve the problems of pressure jump in the system of single valve controlled asymmetric cylinder.

- Through practical system simulation analysis about the system of two-valve-controlled asymmetric hydraulic cylinder, we can see that after using this method, non-rod chamber's pressure is only 0.1 Mpa and rod end chamber's pressure is only 0.2 Mpa. Compared with the pressure jump of 17 Mpa in system of single valve controlled asymmetric cylinder, it can be negligible within the range of allowable error.

The above analysis shows, using auxiliary servo valve to share the flow in the cylinder non-rod chamber to guarantee symmetrical flow on main servo valve, it can eliminate the problem of pressure jump when the piston changes its direction in the system of symmetrical valve controlled asymmetric hydraulic cylinder. The problem of nonlinear characteristics of asymmetric cylinder has been solved, which can enlarge the applied range of asymmetric hydraulic cylinder, making it can be applied in the high precision-required of mechanical systems.

REFERENCES

Guan, J., 2001. Dynamic characteristic analysis of unsymmetrical cylinder controlled by unsymmetrical valve [J]. J. Tongji Univ., 29(9): 1130-1134.

Liu, H., 2006. Modeling and simulation software AMESim and its application for hydraulic-mechanic system [J]. Mach. Tool Hydraulic., 6: 124-126.

Lv, Y., 2007. Modeling in frequency domain for valve controlled asymmetric hydraulic cylinders [J]. Chinese J. Mech. Eng., 43(9): 123-125.

Shi, Q., 2003. Plain discussion about the design of hydraulic servo cylinder [J]. Hydraulic. Pneum. Seals, 5: 14-15.

Wang, X., 1996. A study of the pressure jump of the servo system with asymmetric cylinder [J]. Modular Mach. Tool Autom. Manufact. Tech., 11: 15-17.

Wang, C., 2004. Research on dynamic characteristics of asymmetric cylinder controlled by symmetric four-way valve [J]. China Mech. Eng., 15(6): 471-474.

Yang, J., 2006. Nonlinear modeling and feedback linearization of valve-controlled asymmetrical cylinder [J]. Chinese J. Mech. Eng., 42(5): 203-206.

Yao, G., 1999. Internal differential hydraulic cylinder and its applications [J]. Hydraulic. Pnenm. Seals, 2: 21-23.

Zhang, J., 2000. A symmetric hydraulic cylinder system characteristics of chamber pressure [J]. Mach. Tool Hydraulics, 5: 63-64.

Zhao, J., 1996. Theoretical study of the characteristic of an asymmetric hydraulic cylinder controlled by an asymmetric valve [J]. J. China Univ., Min. Technol., 25(4): 22-27.