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Pressure simulation of an electro-hydraulic proportional piston pump

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Abstract: In this paper, the pressure model of an electro-hydraulic proportional variable plunger pump is set up through mathematical modeling, and the simulation analysis is carried out with the MATLAB tool. The dynamic response characteristics are obtained, which provides some reference for the research of the electro-hydraulic proportional variable plunger pump.

Composition of an electro-hydraulic proportional piston pump

Electro-hydraulic proportional control technology is a control technology that converts analog or digital signals into continuous flow or pressure in the hydraulic system. It is an electro-hydraulic control system which has a certain control precision developed to meet the requirements of modern industry.

Applying the electro-hydraulic proportional control technology to the control of the variable pump is to change the pressure difference between the two ends of the pressure difference control valve through the change of the system load, so as to change the flow of the oil in the control plunger cavity, change the stroke of the control plunger, change the inclined angle of the plunger pump, change the output flow of the plunger pump, and change the proportion of the electric and liquid. The composition of the plunger pump is shown in Fig. 1.

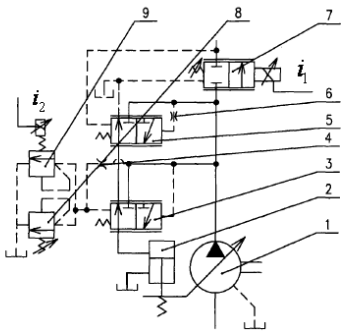

Fig. 1 The composition of the electro-hydraulic proportional piston pump

1- variable piston pump; 2- control plunger; 3- differential pressure control valve; 4- throttle orifice; 5- flow control valve; 6- throttle orifice; 7- electro hydraulic proportional flow valve; 8- safety valve; 9- electro-hydraulic proportional relief valve

The establishment of pressure model

According to the continuity equation of flow, the output flow of the pump is composed of the following parts:

$$Q_P = \frac{V}{E}\frac{dP}{dt} + x_P P + Q_3 + A_3\frac{dx_3}{dt} + Q_L + Q_4 \qquad (1)$$

Q_P is the output flow of the pump, m^3/s; V is the volume of the high pressure cavity of the pump,m^3; E is the modulus of elasticity of hydraulic oil,Pa;P is the output pressure of the pump,Pa; x_p is the leakage coefficient in the pump; Q_3 is the through the pressure difference control valve 3, m^3/s; A_3 is pressure difference control valve 3 valve core end area, m^2;

x_3 is the displacement of the 3 valve core moving by the pressure difference control valve, m;

Q_L is the flow of flow to the load, m^3/s;

Q_4 is the flow through the throttle valve 4, m^3/s;

Linearization of the formula (1) and then Laplace transform, we can obtain as follows:

$$Q_P(s) - Q_3 - Q_4 - Q_L - A_3 s x_3(s) = (\frac{V}{E}s + x_P)P(s) \qquad (2)$$

We can get the relationship between pump output pressure P(s) and flow rate Q_P from formula (2).

We can get the relationship between piston displacement x_c（s）and pump output flow Q_P is as follows:

$$x_c(s) = \frac{A_c}{M_c s^2 + (f_c + g_2)s + (g_1 + k_e)} P_3(s) \qquad (3)$$

Mc is the mass of the plunger, kg;
Fc is the viscosity coefficient between the plunger and the sleeve;
Ac is the end area of plunger, m^2;
x_c is displacement of plunger, m;
K_x is elastic stiffness of a skew plate, N/m;
L_1 is the distance between the plunger and the center of the cylinder block, m;
L_2 is the distance between the slanted disc spring and the center of the cylinder body, m;
E is the center distance of inclined disk center and cylinder block, m;

$$k_e = k_x(\frac{L_2 + e}{L_1 - e})^2$$

According to the continuity equation of flow, the flow rate into the plunger chamber is:

$$Q_3(s) = A_c s x_c(s) + \frac{V_c}{E} s P_3(s) + x_c P_3(s) \qquad (4)$$

Vc is the volume of the high pressure cavity of the plunger, m^3;

x_c is the leakage coefficient of plunger pair;

The relationship between P3 (s) and x_3(s) is as follows,

$$K_{Q3} x_3(s) + K_{P3} P(s) - A_c s x_c(s) = (\frac{V_c}{E}s + (x_c + K_{P3}))P_3(s) \qquad (5)$$

From the electro-hydraulic proportional overflow valve 9, we can obtain that:

$$x_9(s) = \frac{(A_9 - 0.57 W_9 x_{90} - C_3)P_9(s) - K i_2(s)}{M_9 s^2 + L C_d W_9 C_2 s + 0.57 W_9 P_{90}} \qquad (6)$$

K is the electromagnetic force coefficient of the valve 9 electromagnet, N/A;
i_2 is valve 9 current in electromagnetic iron, A;
W_9 is the area gradient of valve 9 valve core, m;
M_9 is the quality of valve 9 valve core, kg;
The flow equation of the throttle valve 4 is

$$Q_4 = C_d a_0 \sqrt{\frac{2}{r}(P - P_9)} \qquad (7)$$

C_d is the discharge coefficient;
a_0 is the flow area of the throttle valve, m^2;

Linearization of the formula (7) and then Laplace transform, we can obtain as follows:

$$Q_4(s) = C_d a_0 \frac{1}{\sqrt{2r(P_0 - P_{90})}}(P(s) - P_9(s)) \qquad (8)$$

According to the flow continuity equation, it can be obtained

$$Q_4(s) = Q_9(s) \qquad (9)$$

From the formula (8) and (9), it can be obtained

$$(\frac{V_9}{B}s + C_{31} + C_4)P_9(s) = C_4 P(s) - (A_9 s + C_1\sqrt{P_{90}})x_9(s) \qquad (10)$$

In the formula, $C_{31} = \frac{C_d W_9 x_{90} \sin a}{C_2}$, $C_4 = C_d a_0 \frac{1}{\sqrt{2r(P_0 - P_{90})}}$

r is oil density, kg/m^3.

According to the formula (1) ~ (10), we can get the relationship between the current $i_2(s)$ of the electromagnet and the output pressure of the electro-hydraulic proportional pump P (s).

Pressure simulation

The initial parameters of the system are as follows: $E=2.01\times10^9$ Pa ; r =880kg/m^3; K=64.4; i=500mA;Cd=0.63;L1=80mm,L2=70mm ; e=7mm;M_9=0.005kg ; d_4=1.2mm 。 The simulation analysis of the model is carried out. Simulation analysis shows that the dynamic response curve of the outlet pressure of the electro-hydraulic proportional variable piston pump is shown in Fig. 2. As shown in Fig. 2, the steady state value of the dynamic response of the plunger pump is 13.2Mpa, the rise time is 6.5ms, the adjustment time is 23ms, and the overshoot is 8.2%.

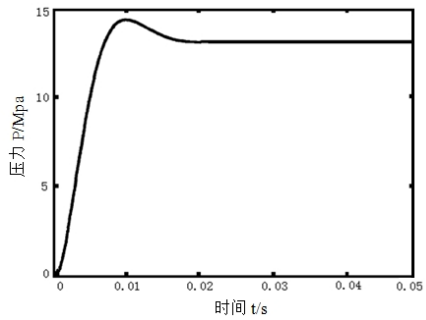

Fig. 2 Dynamic response curve of outlet pressure of electro-hydraulic proportional variable displacement piston pump

Conclusion

In this paper, a pressure model of an electro-hydraulic proportional piston pump is established and simulated. The dynamic response characteristic curve is obtained. The steady state value is 13.2Mpa, the rising time is 6.5ms, the adjustment time is 23ms, and the overshoot is 8.2%. It provides a reference for the research of electro-hydraulic proportional variable piston pump.

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