Simulation analysis and optimization of hydraulic speed control system

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Abstract

In this paper, we established a transfer function model of the electro-hydraulic servo speed control system, analyzes the dynamic performance of the system, the system to make use of the MATLAB modeling and rational analysis of stability, introducing correction link in order to improve the performance of the servo speed control system.

Keywords

MATLAB, pump controlmotor, Speed control system.

1. Introduction

As shown in Fig. 1, the speed control system consists of servo amplifier, electro-hydraulic servo valve, hydraulic motor and speed measuring motor. Speed motor shaft load used in the detection of shaft speed, the speed of detected signal and poor command signal (error signal) by the servo amplifier power amplifier, the current is used to control the electro-hydraulic servo valve core position, the electro-hydraulic servo valve pressure oil output rotation driven by hydraulic motor and load[1].Control principle is shown in Fig. 2, the control signal after proportional amplifier, input to the electrohydraulic servo valve, the electro-hydraulic servo valve produced is proportional to the input signal flow output to the hydraulic cylinder, hydraulic cylinder displacement feedback to the input terminal of the servo amplifier output form deviation signal, controlled object is controlled by deviation signal[2].

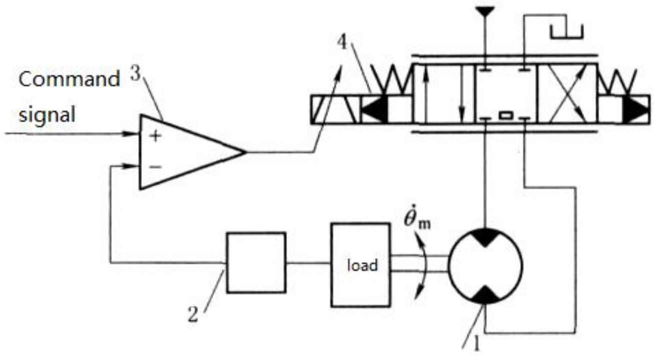

Fig. 1 Valve control hydraulic motor electro-hydraulic servo speed system

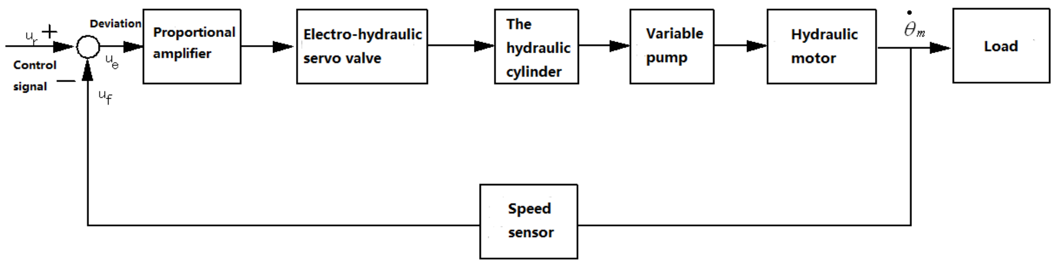

Fig. 2 Working principle of pump control motor closed-loop speed control system

1.1 Section Headings

Firstly, the control loop of the pump inclination Angle is analyzed, and the closed-loop characteristic of this loop is made, then the whole loop can be analyzed[3]. The block diagram of the control loop of the pump inclination Angle position is shown in Fig. 3.

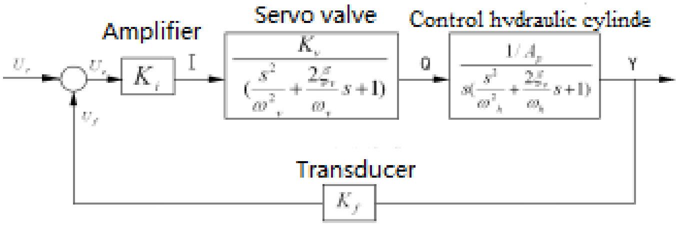

Fig.3 Block diagram of pump swashplate position control loop

1.2 The transfer function of electro-hydraulic servo valve and the transfer function of control hydraulic cylinder

The gain of the servo valve is:

$$\mathrm{k}_v = \frac{q_0'}{I_0} = \frac{655\times10^{-7}}{0.01} = 6.55e-3(m^3/s)/A \tag{1}$$

The dynamic characteristic parameters of the servo valve are based on the selected mode [4].

Thus, the transfer function of the servo valve is:

$$\frac{Q(s)}{I(s)} = \frac{6.55e-3}{(\frac{s^2}{1000^2}+\frac{2\times0.6}{1000}s+1)} \tag{2}$$

Calculation: the volume of the hydraulic cylinder and the servo valve to the hydraulic cylinder are combined $V_t = 8.8e-5m^3$;The rotation part of the oblique disc is converted to the mass of the piston rod and the mass of the hydraulic cylinder pistonm=19.63kg;A=1/630m2; $\beta_e = 6900e5Pa$. Therefore, the transfer function of the hydraulic cylinder is controlled:

$$\frac{Y(s)}{Q(s)} = \frac{630}{s(\frac{s^2}{2000^2}+\frac{2\times0.1}{2000}s+1)} \tag{3}$$

1.3 Transfer function of displacement sensor

In this system, the displacement sensor is the proportional part [5]. Set the sensor gain $K_f = 5e-2V/m$ .According to the above parameters, the position control system model of the pump is drawn using simulink as shown in Fig.4.

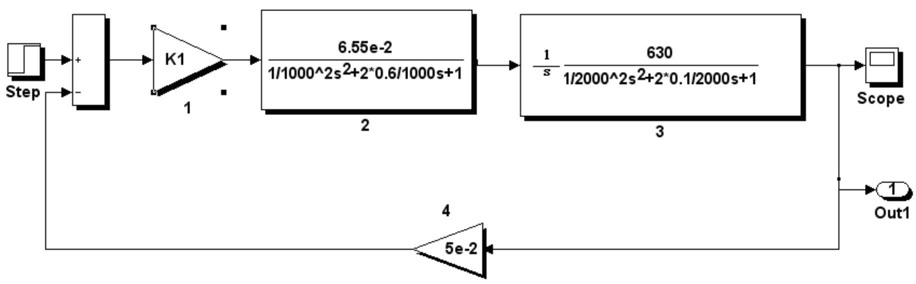

Fig.4 Block diagram of pump inclination position control system

The open loop transfer function of the available system is:

$$G(s)H(s) = \frac{K_1\times630\times6.55\mathrm{e}-3\times5e-2}{s(\frac{s^2}{2000^2}+\frac{2\times0.1}{2000}s+1)(\frac{s^2}{1000^2}+\frac{2\times0.7}{1000}s+1)} \tag{4}$$

1.4 Transfer function of control system

The transmission function of electro-hydraulic servo valve can be simplified with typical link [6]. The transmission function of electro-hydraulic servo valve can be simplified as:

$$G_{sv} = \frac{\mathrm{Q(s)}}{\mathrm{I(s)}} = K_v / \left(\frac{s^2}{w_v^2} + \frac{2\xi_v}{w_v} s + 1 \right) \quad (5)$$

Among them, K_V is the gain of electro-hydraulic servo valve; w_v is the natural frequency of electro-hydraulic servo valve; ξ_v is the damping ratio of electro-hydraulic servo valve.

Control hydraulic cylinder transfer function is:

$$\frac{\mathrm{Y(s)}}{Q(s)} = \frac{630}{s(\frac{s^2}{2000^2} + \frac{2\times 0.1}{2000} s + 1)} \quad (6)$$

The open loop transfer function of the available system is:

$$G(s)H(s) = \frac{K_1 \times 630 \times 6.55e\text{-}3 \times 5e-2}{s(\frac{s^2}{2000^2} + \frac{2\times 0.1}{2000} s + 1)(\frac{s^2}{1000^2} + \frac{2\times 0.7}{1000} s + 1)} \quad (7)$$

1.5 Analysis of dynamic characteristics of the whole speed control system

1) Integral amplifier

The specific value of the gain Ka of the integrator will be determined by the system stability condition after the Bode diagram of the system is made [7].

2) Pump inclination Angle position control system

The closed-loop frequency characteristic function of this system is $\phi'(s)$.

3) Control the displacement of piston displacement y and the transfer Angle between the rotary Angle of the pump and 1 / R [8].

The structure size of the pump can be seen, the oblique circle radius is R=6.8m;1/R=14.71m-1。

4) Transfer function of pump control hydraulic motor

$$\frac{\dot{\theta}_M}{\theta_p} = \frac{k_B n_B / D_M}{(\frac{s^2}{\omega_h{}^2} + \frac{2\times\xi_h}{\omega_h} s + 1)} \quad (8)$$

In the type, Dm——The motor displacement, Dm=100 e^{-6} m^3/s;

n—— The pump speed, n=152rad/s.

The pump has a razors kp=54.2 m^3/rad/(°).

The inlet volume of the motor was calculated as V_o=565 e^{-6} m^3,The natural frequency of the motor is:

$$\omega_h = \sqrt{\frac{\beta_e D_M}{V_0 J}} = \sqrt{\frac{6900e5\times 99e-6\times 99e-6}{565e-6\times 41}} = 5.4rad/s \quad (9)$$

set $\xi_h = 0.4$,So the transfer function of the pump control motor is:

$$\frac{\dot{\theta}_M}{\theta_p} = \frac{74.6}{(\frac{s^2}{5.4^2} + \frac{2\times 0.4}{5.4} s + 1)} \quad (10)$$

5) Speed sensor

The static gain of normal speed sensor is 20V/(1000 r/min).

The open loop transfer function of this system is:

$$G(s)H(s)=\frac{K_a\times 14.7\times 74.6\times 0.19}{s(\frac{s^2}{5.4^2}+\frac{2\times 0.4}{5.4}s+1)}\bullet\phi'(s) \tag{11}$$

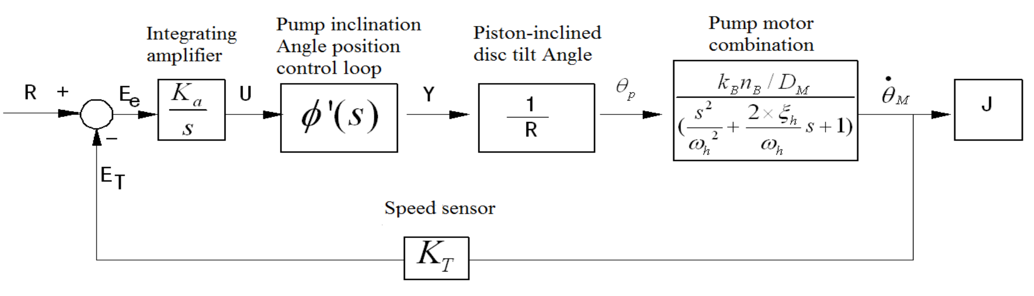

Fig.5 Block diagram of closed-loop speed control system

It can be seen from Fig.5 that the self-oscillation frequency of each second phase of the pump control system is much higher than that of the motor load combination [9]. Therefore, the closed-loop function of the pump control system can be written approximately:

$$\phi'(s)=\frac{1400\times 6.55e-3\times 630}{s+1400\times 6.55e-3\times 630\times 5e-2}=\frac{20}{0.0034s+1} \tag{12}$$

Therefore, the open loop transfer function of the whole system is:

$$G(s)H(s)=\frac{K_a\times 20\times 14.7\times 74.6\times 0.19}{s(0.0034s+1)(\frac{s^2}{5.4^2}+\frac{2\times 0.4}{5.4}s+1)} \tag{13}$$

2. System Simulation and Calibration

Draw a system model using simulink. The simulation output curve is obtained by the transient response analysis of the above model [10]. Due to slow response, system calibration is required.

Calibration process: when Ka=1, open loop Bode diagram with MATLAB. By the graph, you can see that the gain value is negative, reduce Ka and makes the phase margin gamma = 56° or so, the amplitude frequency is six dB margin Gm, cutoff frequency omega c material 2.5rad/s, the system of the open-loop gain Kv=Ka×20×14.77×4.6×0.19 in phase gain of 64°, amplitude under the condition of the stability of the gain is 6dB when can be concluded that $Ka=6\times 10^{-4}$. Draw the open loop Bode diagram of the system, as shown in FIG.6. As you can see in FIG.6 system amplitude margin Gm=4.63dB, phase margin Pm = 55.6°, system is a stable system.

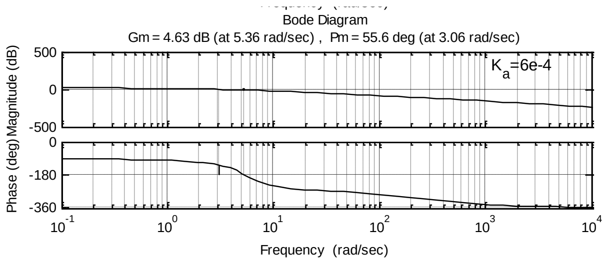

Fig.6 Bode diagram of the entire speed control system

The output curve of the system is shown in FIG.7. The dynamic performance indexes of the system were calculated using Matlab programming: the overshoot was calculated by the amount of sigma %= 23.1%, the peak time tp=0.882s, and the adjustment time ts=2.9s. As you can see, the curve converges and the system is stable.

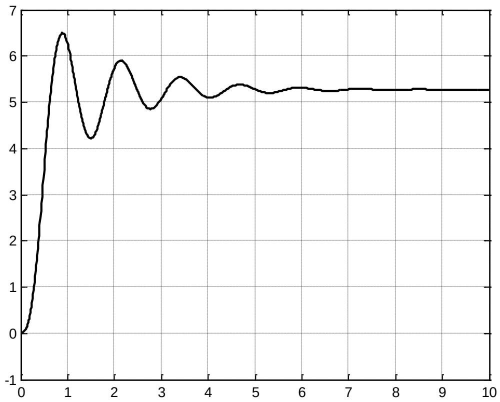

Fig.7 Output simulation results of the system

3. Conclusion

The system dynamic and static performance are calculated and the system stability is calibrated with MATLAB. The results show that the system has high efficiency, high control accuracy, good stability and quick response.

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