$H\infty$ Control of High-speed On/off Valve Hydraulic Position Control System

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Abstract: Based on PWM(pulse-width-modulation) hydraulic position control of high-speed on/off valve ,in order to conquer uncertain parameter to disturb control system . Design a method of single variable $H\infty$ controller in this article .By simulation and analyzing ,the $H\infty$ controller was proved to be an effective method.

Introduction

Nowadays, the development of the hydraulic servo control technology is very rapid, it is widely used with its fast response and high control precision. Hydraulic servo control technology is a kind of closed loop control technology, the reason that the control precision is high because the output signal can be fed back to the system by the control system with feedback device and can be used to generate an error signal further to control signal output. Hydraulic servo control technology[1-3] is an important branch of the development of hydraulic transmission technology.

The essence of hydraulic servo control system is a closed loop control system, and it is relatively open loop control system. The development of open loop control technology is earlier and also relatively simple. The original signal of the input is used directly to control the signal of the need to be generated. And closed loop control technology is increased the feedback element or feedback device on the basis of this, this kind of element (device) can receives the the signal of output terminal, then this signal are compared with the ideal or need signal, and there is deviation, finally the error signal is used to control signal needed,which continue to reduce the size of the error signal, finally we can get the ideal signal.

The working principle of the system and the establishment of the model [4-7]

The working principle of the system

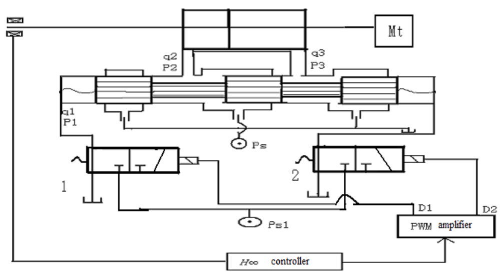

Fig.1 the structure diagram of high-speed on-off valve controlled hydraulic cylinder position system

The structure diagram of PWM high-speed on-off valve controlled hydraulic cylinder position control system is shown in Figure 1, the direction and position of the cylinder is controlled by liquid control reversing valve with two two position three-way high speed on-off valve. The average flow is controlled by High-speed on-off valve using pulse width modulation (PWM) . The pulse width modulation is to regulate ratio of the width of the opening time t_{on} and t_s in certain pulse period t_s ,and the ratio size of accounts for wider meet the requirements of the control. $T_s=T_{on}+T_{off}$, $\tau=T_{on}/T_s$.

The establishment of mathematical model of the system

The mathematical model can be obtained according to its working principle:

(1) The characteristic equation of high speed on-off valve

$$q_1=C_{d1}A_w\tau\sqrt{\frac{2(p_{s1}-p_1)}{\rho}} \tag{1}$$

In type, q_1— the mean flow of high speed on-off valve output, C_{d1}— flow coefficient of high-speed on-off valve, Aw—valve port open area of high speed on-off valve, P_{s1}—oil source pressure of high-speed on-off valve control, P_1—outlet pressure of high-speed on-off valve, ρ—liquid density. On equation of linearization,

$q_1=K_{q1}\tau-K_{c1}P_1$

K_{q1}, K_{c1}—flow gain and zero flow pressure coefficient of high speed on-off valve.

(2) The characteristic equation of the hydraulic control valve

Spool flow continuity equation:

$$q_1=A_v\frac{dx_v}{dt} \tag{2}$$

The valve dynamic force balance equation: $P_1A_v=K_vX_v$ (3)

A_v—valve spool end area, valve spool on the spring elastic coefficient, the displacement of valve spool.

The hydraulic cylinder rodless cavity flow: $q_2=C_dWx_v\sqrt{\frac{2(P_s-P_1)}{\rho}}$ (4)

The hydraulic cylinder rod chamber flow: $q_3=C_dWx_v\sqrt{\frac{2P_s}{\rho}}$ (5)

C_d—The flow coefficient valve, C_d—valve opening area gradient, P_s—oil source system of Ps - P2 —pressure cylinder rodless cavity pressure, P3— cylinder rod chamber pressure.

The load flow is:

$$q_L=\frac{q_2+q_3}{2} \tag{6}$$

Load pressure:

$$P_L=P_1+P2 \tag{7}$$

Also and $\eta=\frac{q_1}{q_2}$, $a=\frac{1+\eta}{\sqrt{2(1+\eta^2)}}$ Is to get the next type of linearization:

$$q_L=K_xx-k_p \tag{8}$$

Including: K_x, K_p respectively valve flow gain and zero flow pressure coefficient.

(3) The characteristic equation of the oil cylinder

Continuity equation of Cylinder flow: $$q_L = A_n \frac{dy}{dt} + C_t P_L + \frac{V_e}{4\beta}\frac{dp_L}{dt} \tag{9}$$

Anthe average piston area of oil cylinder, cylinder piston displacement, cylinder total leakage coefficient, the equivalent volume of cylinder, β—the effective volume elasticity coefficient of the system.

Dynamic force balance equation of the cylinder piston:

$$M_t \frac{d^2y}{dt^2} + B_p \frac{dy}{dt} + K_s y + f = A_1 P_1 - A_2 P_2 \tag{10}$$

Mtthe total mass of the piston and the load to the piston, BpTotal viscous damping coefficient, Ksload spring stiffness, Fexternal disturbance force, A1, A2 cylinder area without rod cavity and rod cavity.

(4) Mathematical model of the system

The mathematical model of the system can be obtained as follows:

$$y(s) = \frac{\dfrac{K_x A_v K_{q1} \tau(s)}{A_m (A_v^2 S + K_v K_{c1})} - \dfrac{K_t}{A_e A_m}\left(\dfrac{V_e}{4\beta K_t} S + 1\right) f_e}{\left(\dfrac{S^2}{\omega_h^2} + 2\dfrac{\xi_h}{\omega_h} S + 1\right) S} \tag{11}$$

Among: $\omega_h = 2\sqrt{\dfrac{A_e A_m \beta}{V_e M_t}}$ $\quad \xi_h = K_t \sqrt{\dfrac{M_t \beta}{V_e A_e A_m}} + \dfrac{B_p}{4}\sqrt{\dfrac{V_e}{M_t \beta A_e A_m}}$

Fe—Equivalent disturbing force (total load), Ve—Equivalent capacity of oil cylinder .

The design process of $H\infty$ controller

(1) Description and solution of single variable feedback system

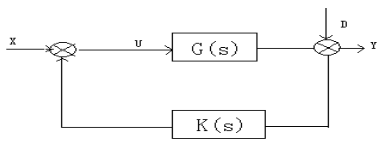

Fig.2 single variable feedback system

Single variable feedback system is shown in Fig.2, if the object G(s) is strictly regular, and there is no pole and zero on the imaginary axis. Design objective is to design controller K (s) by givenw_1, w_2(w_1>w_2),ε, and the closed-loop system is stability and meet the performance indexes.

$$\| W^K S \|_\infty < \varepsilon \tag{12}$$

Where $W(s)=(w_1^{-1}s+1)/(w_2^{-1}s+1)$, S(s) is the sensitivity function $S=(1+GK)^{-1}$. The G(s) will be maken a coprime factorization in RH_∞.

$$G=N/M \tag{13}$$

$$XM-YN=1 \tag{14}$$

Among them, $M,N,X,Y \in RH_\infty$. So all the controllers K what make G stable can be parameterized as:

$$K=-(Y-MQ)/(X-NQ), \quad Q \in RH_\infty \tag{15}$$

Type (13) and (15) are expressed into the sensitivity function,using type (14), can be simplified as:

$$S=M(X-NQ) \tag{16}$$

So the design problem becomes to seek $k\geq 1$ and $Q\in RH_\infty$, so that

$$\|W^K\ M(X-NQ)\|_\infty<\varepsilon \tag{17}$$

Order $T_1=W^kMX$, $T_2=W^kMN$, apparently $T_1,T_2 \in RH_\infty$,(17) type can be written as $\|T_1-T_2Q\|_\infty<\varepsilon$.

Actually , the minimum value of $\|T_1-T_2Q\|_\infty$ is unable to achieve, namely the optimal solution Q does not exist. But the polynomial must be introduced into in order to solve this problem:

$$B(s)=(s+1)^n \tag{18}$$

Among them, n is the relative order of T_2, that is, the pole number of T_2 minus the number of zeros:

$$\inf\{\|T_1-T_2BQ_1\|_\infty : Q_1\in RH_\infty\} \tag{19}$$

Attention to the T_2B is a regular but no strict regular, type (19) has optimal solution Q_1. Based on this definition $Q=BQ_1$. Q is for no regular. In order to obtain a regularized solution, we introduce a weight function: $1/(w_2^{-1}s+1)^n$, making $Q_p=Q/(w_2^{-1}s+1)^n$, then type (15) can be expressed as:

$$K=-(Y-MQ_p)/(X-NQ_p)\ ,\quad Q_p\in RH_\infty \tag{20}$$

That is, the type (20) is been soluted for the request.

When G(s) is the minimum phase system, we have the following lemma:

Object G(s) is strictly regular, there are no poles and zeros on imaginary axis, and there is no right half plane zeros and poles. Ditto design purpose, optimal sensitivity controller is shown as:

$$k(s)=\frac{1}{G(s)\left[\left(w_2^{-1}s+1\right)^n-1\right]} \tag{21}$$

In the formula, w_2 and n is the the same sense of as above.

(2) Design of $H\infty$ optimal sensitivity K(s)

The high-speed on-off valve duty cycle τ (s) is as the input signal of the system, cylinder displacement y(s) is as the output signal of the system, the transfer function can be described as:

$$G(s)=\frac{k}{S(S+p)(S^2+2\xi_h\omega_h S+\omega_h{}^2)} \tag{22}$$

In the formula, $P=\dfrac{K_vK_{c1}}{A_v^{\,2}}$

Because an object G(s) is also strictly regular,there is no pole zero on virtual axis, and they are in line with the above lemma, so We add weight function $1/(w_2^{-1}s+1)^n$, when n=4, then We can be to get the $H\infty$ optimal sensitivity controller for this system by the type (21) and (22):

$$K(s)=\frac{(S+p)(S^2+2\xi_h\omega_h S+\omega_h{}^2)}{k(\omega_2{}^{-4}S^3+4\omega_2{}^{-3}S^2+4\omega_2{}^{-2}S+4\omega_2{}^{-1})} \tag{23}$$

$w_2=10$.

System simulation

System with $H\infty$ controllers and without $H\infty$ controller has been simulated by Simulink of MATLAB, Figure(3) is displacement response curve with $H\infty$ controller of cylinder in interference force Fe=5000N and the unit step jump input; Figure(4) is displacement response curve with $H\infty$ controller of cylinder in variable load (Fe=2500N) and the the same unit step jump input . Figure(5) is displacement response curve without controller of cylinder in the interference force (Fe=5000N) and the unit step jump input; Figure(6) is displacement response curve without controller of cylinder in the change interference force Fe=2500N and the unit step jump input.

Analysis results

The response curve of comparison Fig. (3) and Fig. (4) can be seen that the two response curve is the same shape . the response curve of comparison Fig. (5) and Fig. (6) can be seen that the shape of the two curves has changed, and their response speed have changed.

Therefore , the simulation results have shown the superiority of the $H\infty$ optimal sensitivity controller is very obvious. Not only it is insensitive to interference extremely, the response curve shape with $H\infty$ optimal sensitivity controller is almost no change after the object parameters (load)take place, but also we can see that the effects of external interference is very obvious without controller. This fully shows that $H\infty$ controller has strong robustness.

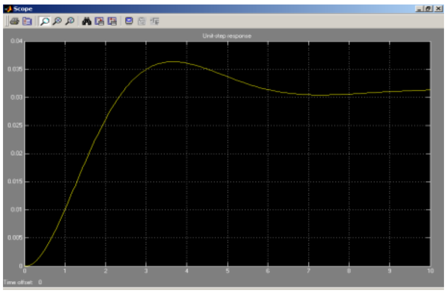

Fig.3

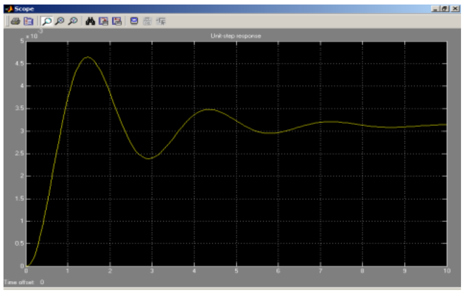

Fig.4

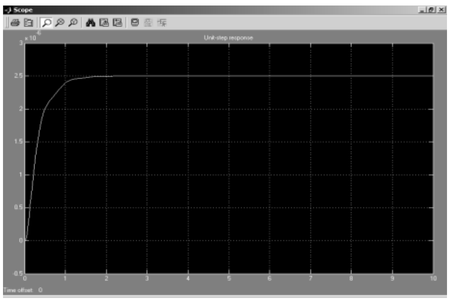

Fig.5

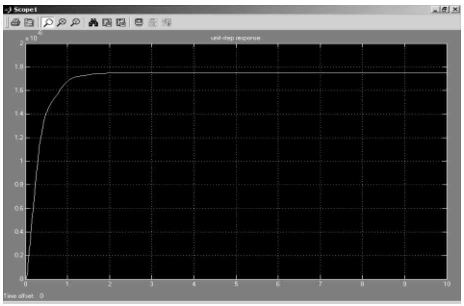

Fig.6

Fig.3 is displacement response curve with $H\infty$ controller of cylinder in interference force Fe=5000N;Fig.4 is displacement response curve with controller of cylinder in variable load (Fe=2500N);Fig.5 is displacement response curve without controller of cylinder in the interference force (Fe=5000N);Fig.6 is displacement response curve without controller of cylinder in the change interference force (Fe=2500N).

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