

H^∞ Control Technology of the Hydraulic System

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Abstract. We have designed a high-performance hydraulic controller for the hydraulic servo system with nonlinear characteristics based on the H^∞ technology, which the high-performance TMS320LF2407 DSP has been adopted as main processor chip. With the designed controller, we have developed a new set of hydraulic servo system. For the designed H^∞ controller has a faster responded speed and smaller overshoot time under the perturbing of parameter, the developed system has a better stability and a faste responded speed . The reported works are also interesting for DSP in automatic control and in real-time control field.

Introduction

With the rapid development of computer technology and PHNC (Power Hydraulic Numerical Control) technology, high speed hydraulic control system has entered into the era of digital control. The hydraulic servo control system^[1] occupies a very important position in the field of automation, which is used in the complex control system with a large power, fast and accurate reflection. In the occasion of high dynamic requirements, the control system must contain the servo loop of feedback sensor and an electronic controller, with the continuous improvement complex control methods and control requirements, DSP technology and H^∞ control method are favored quickly. According to the requirements, the advanced digital signal processor (DSP) is used for the hydraulic servo control system, TMS320LF2407 DSP^[2-3] chip is used as the core of the control circuit of the system structure and mathematical model of the hydraulic servo controller^[4-6], the system control algorithm and software realization method have been established.

Model established of hydraulic system

High speed hydraulic servo control system combines the advantages of the two aspects of electrical and hydraulic, which has the advantages of high control precision, fast response, flexible signal processing and high output power , the application is very wide. The electro-hydraulic servo control system based on DSP is mainly composed of DSP intelligent controller, amplifier, high speed on-off valve, hydraulic cylinder, load, and sensor. The hydraulic control system structure diagram is shown in figure 1.

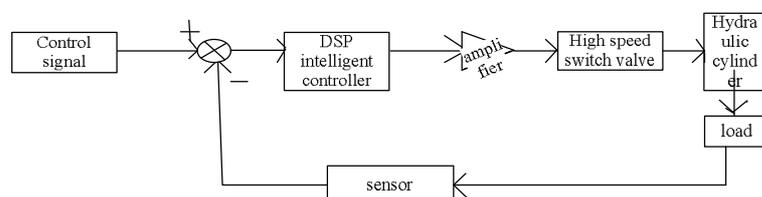


Fig.1 The hydraulic control system structure diagram

According to the working characteristics of high-speed on-off valve and the hydraulic cylinder [5] can get their characteristic equation as follows:

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

$$q_1 = C_{d1} A_w t \sqrt{\frac{2(P_{s1} - P_1)}{r}} \quad (1)$$

Type, q_1 —the mean flow of high speed on-off valve output, C_{d1} —flow coefficient of high-speed on-off valve, A_w —max opening area of high speed on-off valve port, 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.

(2) the characteristic equation of the liquid controlled reversing valve

$$\text{flow continuity equation: } q_1 = A_v \frac{dx_v}{dt} \quad (2)$$

$$\text{Spool dynamic force balance equation: } P_1 A_v = K_v X_v \quad (3)$$

$$\text{The flow rate of the hydraulic cylinder without rod cavity: } q_2 = C_d W x_v \sqrt{\frac{2(P_s - P_1)}{r}} \quad (4)$$

$$\text{Hydraulic cylinder with rod cavity flow: } q_3 = C_d W x_v \sqrt{\frac{2P_s}{r}} \quad (5)$$

$$\text{Load flow is: } q_L = \frac{q_2 + q_3}{2} \quad (6)$$

$$\text{Load pressure: } P_L = P_1 + P_2 \quad (7)$$

$$\text{Also and, } h = \frac{q_1}{q_2}, \quad a = \frac{1+h}{\sqrt{2(1+h^2)}}$$

$$q_L = a C_d W x_v \sqrt{\frac{(P_s - \frac{x_v}{|x_v|} P_L)}{r}} \quad \text{We will get the next type of linearization to it:}$$

$$q_L = K_x x - k_p \quad (8)$$

A_v —valve spool end area, K_v —valve spool on the elastic coefficient of spring, X_v —valve spool displacement. C_d —reversing valve flow coefficient, W —reversing valve opening area gradient, P_s —oil supply pressure, P_2 —oil cylinder without rod chamber pressure, P_3 —oil cylinder with rod chamber pressure, K_x 、 K_p —respectively for reversing valve zero flow gain and flow—pressure coefficient.

(3) the characteristic equation of the oil cylinder

$$\text{Cylinder flow continuity equation: } q_L = A_n \frac{dy}{dt} + C_i P_L + \frac{V_e}{4b} \frac{dp_L}{dt} \quad (9)$$

Cylinder piston dynamic force balance equation : $M_t \frac{d^2y}{dt^2} + B_p \frac{dy}{dt} + K_s y + f = A_1 P_1 - A_2 P_2$ (10)

An— the average area of cylinder piston, y—piston displacement volume , Ct—cylinder leakage coefficient, Ve—equivalent volume of cylinder, system, *b* —the effective volume of the elastic coefficient, Mt—the total mass of piston and load equivalent to the piston, Bp—General viscous damping coefficient , Ks—load spring stiffness, F—disturbance force, A₁,A₂—oil cylinder without rod cavity and with rod cavity area.

(4) the mathematical model of the system

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

$$y(s) = \frac{\frac{K_x A_v K_{q1} t(s)}{A_m (A_v^2 S + K_v K_{c1})} - \frac{K_t}{A_e A_m} \left(\frac{V_e}{4 b K_t} S + 1 \right) f_e}{\left(\frac{S^2}{w_h^2} + 2 \frac{x_h}{w_h} S + 1 \right) S} \quad (11)$$

Among: $w_h = 2 \sqrt{\frac{A_e A_m b}{V_e M_t}}$ $x_h = K_t \sqrt{\frac{M_t b}{V_e A_e A_m}} + \frac{B_p}{4} \sqrt{\frac{V_e}{M_t b A_e A_m}}$

Fe - equivalent disturbance force (total load), Ve - equivalent volume cylinder.

System hardware circuit design

TMS 320C2000 series chip is widely used in the industrial control, the TMS320LF2407A chip is the most widely used. It is digital electro-hydraulic servo control system of the kernel, it is a high performance 16 bit fixed-point DSP device, which is used for real-time control. In this paper, we use TMS320LF2407A to realize digital control of electro hydraulic servo system. The hardware circuit of digital control system is shown in figure 2.

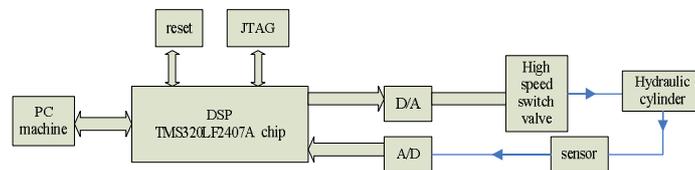


Fig.2 The hardware circuit of digital control system

From the function, the digital servo controller based DSP has complete function in this paper, the use of interface is flexible, which can be used for electro hydraulic servo and electronic universal control system. And, TMS320LF2407A chip is a kind of super processor of all 2000 series processor, there is the processing ability of low cost, low power consumption, high performance.

Software system design

The function of the hydraulic servo controller is actually decided by the software which is installed

in the DSP, and hardware controller is widely used in the traditional control system. For this control, if the system is determined, the parameters of the controller are relatively solidified, when the external environment changes, the parameters can not be determined. For the hydraulic servo control system, the controller is the core part of the whole system, the whole system control quality is determined by the control algorithm in the program. And the practical hydraulic system is composed of the high-speed on-off valve, there are many uncertain parameters, such as the volume of oil, the viscosity of the oil and the oil elastic modulus. In order to overcome these uneasy to determine the parameter of the system, We used the H^∞ control.

(1) H^∞ control algorithm^[9-10]

Hydraulic servo control system is a nonlinear system, under the parameter variations and external disturbances, there are the weakness of the parameters difficult to determine and the robustness not to be strong enough, at the same time, it is difficult to solve the contradiction between the dynamic performance and steady state accuracy. With the improvement of the control precision and dynamic performance of the hydraulic servo system, the traditional PID control can not meet the requirements of the system. So we used H^∞ control in the paper.

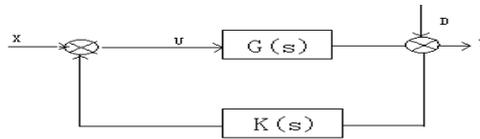


Fig.3 The single variable feedback system

The single variable feedback system is shown in Figure 3, if the object $G(s)$ is strictly regular, and there is no pole-zero on the imaginary axis. Design objective is to design controller $K(s)$ for given weights $w_1, w_2, w_1 > w_2, \varepsilon$ (minimum positive), the closed-loop system is the stability and meet the performance index

$$\|W^K S\|_\infty < \varepsilon \quad (12)$$

Among them, $W(s) = (w_1^{-1}s + 1)/(w_2^{-1}s + 1)$, $S(s)$ is sensitivity function, $S = (1 + GK)^{-1}$. $G(s)$ is in RH_∞ and RH_∞ is a stable, regular, real rational function of the set, the addition and multiplication is closed, and $1 \in RH_\infty$.

$G(s)$ is strictly regular, there is no zero-pole on the imaginary axis, and there is no zero-pole on the right half plane, then the optimal sensitivity controller is:

$$k(s) = \frac{1}{G(s) \left[(w_2^{-1}s + 1)^n - 1 \right]} \quad (13)$$

The n is order of relative in the formula (pole number minus zero point).

(2) H^∞ Optimal sensitivity $K(s)$ design

The high-speed on-off valve duty cycle $t(s)$ is as the input signal of the system, cylinder displacement $y(s)$ is as the output signal of the system, and the transfer function description is shown as follows:

$$G(s) = \frac{k}{S(S + p)(S^2 + 2x_h w_h S + w_h^2)} \quad (14)$$

Form in, $k = \frac{K_x K_{q1} w_h}{A_v A_m}, \quad P = \frac{K_v K_{c1}}{A_v^2}$

Because an object $G(s)$ is strictly regular, there is no zero-pole on the imaginary axis, and it is in line with the above lemma, so we add weight function: $1/(w_2^{-1}s+1)^n$, when $n = 4$, from the type (13) and (14), we can get the optimal sensitivity controller for this system

$$K(s) = \frac{(S + p)(S^2 + 2x_h w_h S + w_h^2)}{k(w_2^{-4}S^3 + 4w_2^{-3}S^2 + 4w_2^{-2}S + 4w_2^{-1})} \quad (15)$$

Take $W_2 = 10$

Simulation results

The data is substituted into the system with H^∞ controller and PID controller and simulation is done, When the interference force (load) F_e is 2500N and the control signal is unit step, and the hydraulic cylinder displacement response curve with H^∞ controller and the hydraulic cylinder response curve with the PID controller are shown in Figure 4. When the interference force (load) F_e is 5000N and the control signal is also unit step, and the hydraulic cylinder displacement response curve with H^∞ controller and the hydraulic cylinder response curve with the PID controller are shown in Figure 5.

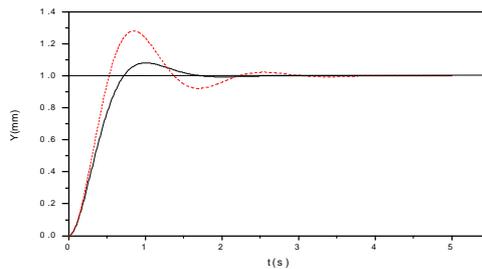


Fig.4 When the interference force (load) F_e is 2500N, Response curve with H^∞ controller and the PID controller (The dotted line represents PID, the real line represents H^∞)

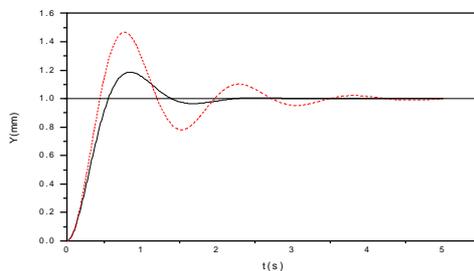


Fig.5 When the interference force (load) F_e is 5000N, Response curve with H^∞ controller and the PID controller (The dotted line represents PID, the real line represents H^∞)

Conclusions

The response curve of Figure 4 and Figure 5 can be seen, in two cases, the effect of the traditional

PID control is significantly lower than that of the H^∞ control. The H^∞ control is used to improve the stability and rapidity of the system.

Therefore, from the simulation results show the superiority of the H^∞ control is very obvious. It not only is interference extremely insensitive and after the object parameters (load) changes, the response curve shape with H^∞ control almost don't change. and when the PID control is used, outside interference of the effects is obvious. This fully shows that the H^∞ controller has strong robustness.

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