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INTELLIGENT CONTROL FOR ELECTRO-HYDRAULIC PROPORTIONAL POSITION SERVO SYSTEM①

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ABSTRACT The structure and performance of the electrohydraulic proportional position servo system (EHPPS) were discussed. The intelligent pole placement position control strategy was presented, and its existence was proved. Besides, according to the characteristic of the flow discontinuity for symmetric valve controlling unsymmetric cylinder, a method of digital flow compensation was given. Simulations and experiments showed that the system has good control performance and robustness.

Key word intelligent control pole placement digital flow compensation electrohydraulic proportional control

1 INTRODUCTION

Although many feedback control system can be satisfactorily controlled by conventional control means, it is often difficult to satisfy the demand of control performance when the parameters of the controlled system exist time varying and nonlinearity or even a complete lack of the knowledge of the system. A number of approaches were proposed to handle these systems, such as adaptive control, variable structure control, predictive control, robust control, and finally intelligent control. Adaptive control system can provide the ability to adjust operation parameters on-line according to input, output and state variables of the control system, which makes the controlled system have good control performance. But some complex systems with fast dynamic response, such as robot manipulators and high speed servo control system, are often found to suffer great difficulties in adaptive control, because the required time to implement adaptive algorithms is more than the sample theorem. Recently some different intelligent control methods have been presented in electro-hydraulic proportional position system (EHPPS) . El-Ibiary Yehia presented "Theory Design and Application of Expert Hydraulic Servos" [1], Zhao Tienan presented "Theoretical and Experimental Analysis on Fuzzy control of a hydraulic position servo"[2], and some good results have been obtained in these papers. According to the parameters varying and nonlinear in EHPPS , a new intelligent pole placement strategy with digital flow compensation (DFC) has been presented in this paper, and it has been realized by single chip microcomputer, which improves the control performance and simplifies the structure of the EHPPS. Since the system was successfully researched in 1993, it has been applying in the areas of machine tool, mechanical engineering etc.

2 SYSTEM STRUCTURE

2.1 *The Model of the System*

The EHPPS discussed in this paper is shown in Fig. 1. It consists of an unsymmetric hydraulic cylinder, four way symmetrically proportional valve, digital controller, PWM driving circuit, displacement and pressure sensors.

In EHPPS, the dynamic performance of the system mainly depends on the hydraulic natural frequency and damping ratio. Generally, the EHPPS can be expressed as three - order model

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shown in Fig. 2 under conditions of $B_{\mathrm{p}}k_{ce}/A_p^2 \ll 1$ and without spring load. The output displacement $y(s)$ can be obtained as follows[5]:

$$y(s) = \frac{K_v\omega_n^2R - (K_{ce}/A^2)\times(1+ V_t/4\beta_eK_{ce})W_h^2F}{S^3+ 2\zeta_h\omega_nS^2+ \omega_h^2S+ K_v\omega_h^2}$$

Because the hydrualic natural frequence, damping ratio and disturbance of the load are often varied in a wide range, which makes the dynamic response of the EHPPS be not easily satisfied, a new control strategy is needed to control EHPPS for improving its control performance.

2. 2 *Pressure Jumping*

In our EHPPS, A single piston cylinder is used for simplifying the structure of the system. According to the results of reference[5], in the switching transient of symmetric four way valve controlling unsymmetric cylinder, large pressure jumping will occur, which makes flow discontinuity and unsteady moving of the system. In this paper, DFC is presented to overcome pressure jumping.

3 CONTROL STRATEGY

3. 1 *Pole Placement*

Fig. 1 Intelligent digital EHPPS

In order to improve dynamic performance of EHPPS, a state feedback controller shown in Fig. 3 is used for pole placement, the eigen equation of closed-loop system can be obtained as follows:

$$S^3 + (K \cdot h_3 + 2 \cdot \zeta_h \cdot \omega_h) S^2 + (K \cdot h_2 + \omega_h^2) S + K \cdot h_1 = 0 \qquad (2)$$

where $K = K_v * \omega_h^2$

Let the eigen equation be

$$[S^2 - (l_1 + \bar{l}_1) S + l_1 \cdot \bar{l}_1](S + l_2) = 0 \qquad (3)$$

where l_1, $\bar{l}_1$ are a pair of conjugate complex roots, l_2 is a real root.

It is preferable and more practical to place l_2 far away from imaginary axis so that the eigen equation has two predominant poles which are decided by the damping ratio and natural frequency of closed-loop system. Thus equation (3) can be expressed as follows:

$$S^3 + (l_2 + 2 \cdot \zeta_b \cdot \omega_b) S^2 + (2 \cdot \zeta_b \cdot \omega_b \cdot l_2 + \omega_b^2) S + \omega_b^2 \cdot l_2 = 0 \qquad (4)$$

where ζ_b, ω_b are respectively damping ratioand natural frequency of the state feedback closed-loop system.

According to equations (2), (4), the feedback control parameters can be obtained as follows:

$$h_1 = l_2 \omega_b^2 / K$$

Fig. 2 The simplified diagram of EHPPS

Fig. 3 The diagram of EHPPS with state feedback, intelligent paramenter turning and digital flow compensation

$$h_2 = (2\cdot\zeta_b\cdot\omega_b\cdot l_2 + \omega_b^2 - \omega_h^2)/K$$
$$h_3 = (l_2 + 2\cdot\zeta_b\cdot\omega_b - 2\cdot\zeta_h\cdot\omega_h)/K$$

3. 2 *Intelligent Parameter Turning (IPT)*

The IPT is based on pattern recognition approach, the parameters (h_1, h_2, h_3) are turned when parameters of the controlled system (ζ_h, ω_h) are varied or a load disturbance occurs. The error singal between the set point and the displacement output of the EHPPS is monitored and compared with the desired peaks of error e_1, e_2, e_3 as shown in Fig. 4.

Fig. 4 The step response

From equation (2), the action of h_1 is the system gain, h_2 increases frequency bandwidth of the controlled system, and h_3 increases damping ratio of the controlled system. By making $|e_1| \leqslant \sigma_1$, $|e_2| \leqslant \sigma_2$, $|e_3| \leqslant \sigma_3$, and $a_1 < t_r < a_2$, we can turn h_1, h_2, h_3 in its action. The knowledge of turning h_1, h_2, h_3 is mainly used as follows:

(1) If $|e_1| < \sigma_1$, $|e_2| < \sigma_2$, $|e_3| < \sigma_3$ but $t_r > a_2$, then h_1 and h_2 should be increased, $\triangle h_1/\triangle h_2$ can be equal to a constant K_1.

(2) If there is no overshoot, then h_1 should be increased and h_3 should be decreased, $\triangle h_1/\triangle h_3$ can be equal to a constant K_2.

(3) If $|e_1| > \sigma_1$, then h_3 should be increased and h_1 should be decreased, $\triangle h_3/\triangle h_1$ can be equal to a constant K_3.

(4) If $|e_1| < \sigma_1$, $|e_2| > \sigma_2$, then h_3 should be increased.

(5) If $t_r < a_1$, then h_1 and h_2 should be decreased, $\triangle h_1/\triangle h_2$ can be equal to a constant K_4.

(6) $\triangle h_i/h_i$ is equal to 0.01, K_i is equal to 10, $i = 1, 2, 3, 4$ respectively.

3. 3 *Exsitential Theorem of Intelligent Parameter Adjusting*

Suppose the controlled system is adjusted by using the parameters(h_1, h_2, h_3) of closed-loop pole placement, and at the area of $[h_1 + \triangle h_1, h_2 + \triangle h_2, h_3 + \triangle h_3]$, respectively adjusting h_1, h_2, h_3, the system has steady and monotonic performance index J, and also J is continuous and differential for h_1, h_2, h_3, then a set of optimum parameters $[h_1 + \triangle h_1^*, h_2 + \triangle h_2^*, h_3 + \triangle h_3^*]$ certainly exists, which makes the system have optimum performance index $J^*[h_1 + \triangle h_1^*, h_2 + \triangle h_2^*, h_3 + \triangle h_3^*]$. where optimum index can be

$$\min\int_0^{\infty} e^2 dt \text{ or } \min\int_0^{\infty} |e|\, t\times dt$$

and so on, which can be proved as follows.

$$\because J^*[h_1 + \triangle h_1^*, h_2 + \triangle h_2^*, h_3 + \triangle h_3^*]$$
$$= J[h_1, h_2, h_3] + OJ[h_1, h_2, h_3]$$

According to the supposion, we get

$$J^*[h_1 + \triangle h_1^*, h_2, h_3] \leqslant J[h_1, h_2, h_3]$$
$$J^*[h_1, h_2 + \triangle h_2^*, h_3] \leqslant J[h_1, h_2, h_3]$$
$$J^*[h_1, h_2, h_3 + \triangle h_3^*] \leqslant J[h_1, h_2, h_3]$$
$$\therefore J^*[h_1 + \triangle h_1^*, h_2 + \triangle h_2^*, h_3 + \triangle h_3^*]$$
$$= J^*[h_1^*, h_2^*, h_3^*] < J[h_1, h_2, h_3]$$

where $h_1^* = h_1 + \triangle h_1^*$, $h_2^* = h_2 + \triangle h_2^*$, $h_3^* = h_3 + \triangle h_3^*$, $[h_1^*, h_2^*, h_3^*]$ is optimum adjusting parameters, they can make index optimized.

3. 4 *Digital Flow Compensation*

In Fig. 1, the load flow of the four way proportional valve can be expressed as:

$$Q_{L1} = C_d W X_v \sqrt{(P_S - P_{L1})/\rho} = K_1 I_1 \sqrt{P_S - P_{L1}} \qquad (5)$$

$$Q_{L2} = C_d W X_v \sqrt{(P_S - P_{L2})/\rho} = K_2 I_2 \sqrt{P_S - P_{L2}} \qquad (6)$$

where $K_1 = C_d W K_x \sqrt{1/\rho}$

$$K_v = K_x I$$

let

$$I_1 = K_u U = K_u e \sqrt{DP_S/(P_S - P_{L1})} \quad e > 0 \tag{7}$$

$$I_2 = K_u U = K_u e \sqrt{DP_S/(P_S - P_{L2})} \quad e > 0 \tag{8}$$

where D is a constant which can be selected between 0.5 to 1. From equation (6) to (9), we get $Q_L = Q_{L1} = Q_{L2} = K_1 K_u e(DP_S)^{1/2}$ therefore, after DFC, the load flow is only proportional to error voltage, and it is not affected by load pressure. The value of parameter D infleunces the flow gain, it should be adjusted in the actual application.

4 SIMULATION AND EXPERIMENT RESULTS

4.1 *Simulation Results*

Considering the EHPPS shown in Fig. 1, let the parameters of the controlled system be $\zeta_h = 0.2$, $\omega_h = 26$, $k = 400$; and selecting the parameters of the state feedback closed-loop control system $\zeta_b = 0.7$, $\omega_b = 30$, $l_2 = 10$, the simulation result of tracking a square-wave reference signal is shown in Fig. 5. The step response of parameter varying is given in Fig. 6, curve 1 shows $\zeta_h = 0.2$ varying to $\zeta_h = 0.4$, curve 2 shows $\omega_h = 26$ varying to $\omega_h = 20$, curve 3 shows $k = 400$ varying to $k = 300$. It is clearly seen that the control strategy presented in the paper not only possesses better response performance but also has much better robustness with response to the system's parameter varying.

4.2 *Experiment Results*

The dynamic performance of the experiment equipment for tracking a sine-wave reference singal is shown in Fig. 7, and step response of the displacement output is shown in Fig. 8. Satisfactory dynamic and steady characteristics can be seen in Fig. 7 and Fig. 8.

5 CONCLUSIONS

(1) The pole placement control method associated with intelligent parameters adjusting can obtain good dynamics and steady response of the EHPPS, this control strategy can be used at other servo control system.

(2) The alogorithm of intelligent parameter adjusting is convergence for monotonic and diff-

Fig. 5 Square-wave response

Fig. 6 The step response with parametens varying

Fig. 7 The sine-wave response of EHPPS

Fig. 8 The step respose of EHPPS

erential system, but it should be futher researched for speeding up its speed of convergence.

(3) DFC is a digital nonlinear compensation method, it can overcome flow jumping which is caused by pressure jumping, and improve the positioning precision of the EHPPS.

(4) Intelligent parameter adjusting approach takes less time than adaptive control method, and can be easily realized by single chip processor, thus results in the reduction of the system hardware and cost. Therefore it can be applied in industrial fields.

Nomenclature

P_s: supply pressure

K_v: flow gain of the valve

ω_h: natural frequence of the system

ξ_h: damping ratio of the system

K_{ce}: total leakage coefficient

A: effective area of the cylinder piston

V_t: the volume of the cylinder

β_e: equivalent bulk modulus elasticity

F: external disturbance force

R: displacement input singal

Y: displacement output of the EHPPS

P_{L1}: load pressure at one port

P_{L2}: load pressure at other port

δ_1, δ_2, δ_3, a_1, a_2, D: positive constant

t_r: rising time of the system

e: the error between input and output

ω_b: natural frequence of the closed-loop system

ξ_b: damping ratio of the closed-loop system

l_2: the pole of closed-loop system which is far away from the imaginary axis

K: the closed-loop gain

h_1, h_2, h_3: the state feedback parameters

K_u: $K_u = I/U$, U is voltage of providing to proportional valve, I is current of providing to proportional valve

X_v: the valve spool movement of the proportional valve

Q_{L1}: load flow at one port

Q_{L2}: load flow at other port

W: port width of the valve

C_d: flow coefficient

ρ: density of the working fluid

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