Acta Technica *62* (2017), No. 5B, 633–642

Characteristic analysis of electro hydraulic force servo system with research on control strategy of particle swarm optimization

Li Jianying[2], Zhao Zhongqiang[2], Wang Yanwei[3], Li Shiming[2], Dong Fatang[2], Han Guihua[2]

Abstract. Electro hydraulic force servo system has good dynamic performance in practical application, including fast response, large power to volume ratio, strong resistance to load, etc. However, due to the nonlinear characteristics of the electro hydraulic force servo system and the uncertainty of the parameters with modeling uncertainty and the complexity of the system itself, so, it is difficult to study the system.

In view of the above problems and the main factors affecting the accuracy of the model, and considering the time-varying characteristics of the small disturbance and the important dynamic parameters of the servo valve spool under the working condition, we use linear PID controller to adjust the system and study its effect. In the case of not ideal, we redesign the particle swarm optimization control strategy for PID control. we use it to find the optimal solution through collaboration and information sharing among individuals in the group, the computing process is simple and efficient, the convergence speed is fast and so on. So we can solve the optimization of the parameters of the new controller, so as to produce a new good control effect. Through simulation and experiment, we verify the correctness and effectiveness of the research process and the new control method based on particle swarm optimization algorithm.

Key words. Electro hydraulic force servo system; Dynamic performance; Nonlinear characteristics; Parameters uncertainty; modeling uncertainty; Particle swarm optimization.

---

[1] Acknowledgement - This work is supported by National Natural Science Foundation of China (51405113).

[2] Workshop 1 - Harbin University of Science and Technology, School of Mechanical and Power Engineering, Harbin, 150080,china

[3] Workshop 2 - Harbin University of Commerce, School of Finance, Harbin, 150028

1. Introduction

Due to the nonlinear characteristics of electro hydraulic force servo system, the modeling uncertainty caused by parameter uncertainty, and the complexity of the system itself with the large external load disturbance in the process of operation, these make the conventional linear PID control method difficult to play a role[1]. At the same time, the system has dynamic uncertainty??especially high frequency uncertainty, because it is difficult to know their structure, order and specific parameters, therefore, the model error will affect the accuracy of the model, this also makes it difficult to accurately analyze the design of the system and controller . The problem of stochastic dynamic parameters is also present in the electro hydraulic force servo system [2]. We should take full account of the servo valve spool displacement perturbation, as well as the dynamic parameters of the flow gain, hydraulic natural frequency and hydraulic damping ratio directly affect the stability and rapidity of the system, and the hydraulic damping ratio is difficult to be accurately calculated, the zero damping ratio is small, and the working range is larger [3]. In order to solve these problems, we must design a suitable and effective controller, the stability of the system can be stable when the system is disturbed and a certain degree of uncertain model dynamics and parameters are changed, and the system can guarantee a certain dynamic performance quality.

2. Electro hydraulic force servo system

The electro hydraulic force servo system in this paper mainly includes hydraulic power mechanism composed of four side slide valve and symmetrical hydraulic cylinder and load device, at the same time, including force sensor, servo amplifier and hydraulic auxiliary device. The schematic diagram of the system is shown in Fig. 1.

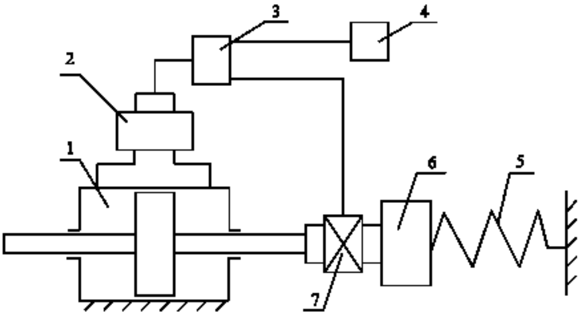


Fig. 1. Schematic diagram of electro hydraulic force servo system

1 hydraulic cylinder 2 electro-hydraulic servo valve 3 controller 4 signal generator 5 elastic load 6 inertia load 7 force sensor

When building the system model, we make the assumptions . We take the zero operating point and the worst performance as the research condition, at this point, if the system can work stably, she system can work well at other operating points, namely the piston is in the middle position, the system has the lowest hydraulic natural frequency. According to the above diagram, we can get the three basic equations of the system :

From three basic equations, we can get the spool displacement x_v to hydraulic cylinder output driving force F_g transfer function is as follows:

$$\frac{F_g}{x_v} = \frac{\frac{K_q}{K_{ce}} A_p \left(\frac{S^2}{\omega_m^2} + 1\right)}{\left(\frac{S}{\omega_r} + 1\right)\left(\frac{S^2}{\omega_0^2} + \frac{2\xi_0}{\omega_0} S + 1\right)} \tag{1}$$

Where: $\omega_m = \sqrt{\frac{K}{M_t}} ??\omega_r = \frac{K_{ce}}{A_p^2} / (\frac{1}{K_h} + \frac{1}{K})\, \omega_0 = \omega_m \sqrt{1 + \frac{K_h}{K}} ??\xi_0 = \frac{1}{2\omega_0} \frac{4\beta_e K_{ce}}{V_t(1+(K/K_h))}$; K_q- Spool flow gain (m2/s); K_{ce}-Total flow pressure coefficient (m3/s Pa); A_P-Piston area (m2);

When establishing the transfer function model of electro hydraulic servo valve, The servo valve model is determined by the current increment ΔI as the input and the no load flow Q_0 as the output, we use it as the two order link, the transfer function is[4]:

$$K_{sv} G_{sv}(s) = \frac{Q_0}{\Delta I} = \frac{K_{sv}}{\frac{s^2}{\omega_{sv}^2} + \frac{2\zeta_{sv}}{\omega_{sv}} s + 1} \tag{2}$$

Where:Q_0-No flow of servo valve (m3/s),ΔI-Servo valve input current increment (A),K_{sv}-Servo valve flow gain (m3/s A),ω_{sv}- Natural frequency of servo valve (rad/s),ζ_{sv}-Damping ratio of servo valve,T_{sv}-Time constant of servo valve (s)

The transfer function of the force sensor of the system is equivalent to a proportional link:

$$U_f = K_f F_g \tag{3}$$

Where:U_f-Displacement feedback signal (V),K_f-Voltage force coefficient of sensor (V/m).

The output current I of the power amplifier is approximately proportional to the input voltage$U$, and can be regarded as a proportional link, the mathematical model is:

$$I(s) = K_a U(s) \tag{4}$$

Where:I-Amplifier output current (A) K_a-Servo amplifier gain (A/V)??U-Input voltage signal (V).

From the above analysis, we can get the block diagram model of the electro hydraulic force servo system, as shown in Fig. 2:

3. Simulation analysis of electro hydraulic force servo system

In the simulation of the system, the main parameters are: Cylinder diameter of hydraulic cylinder $D = 0.05$m; Piston rod diameter $d = 0.035$m; Effective area of piston rod $A_P = 1 \times 10^{-3}$(m2); Maximum displacement of hydraulic cylinder piston

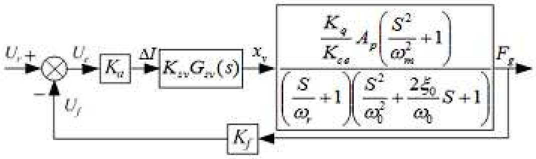


Fig. 2. the block diagram model of the electro hydraulic force servo system

$L = 0.2$m; Effective volume of hydraulic cylinder piston $V_t = 2 \times 10^{-4}$(m3); Effective bulk modulus $\beta e = 7 \times 10^8$(Pa); Total flow pressure coefficient of valve controlled cylinder $K_{ce} = 4.8 \times 10^{-12}$(m3/s Pa); Load conversion quality $M_t = 25$kg; Power amplifier magnification $K_a = 0.016$(A/V).

$\omega_h = 748.33$(rad/s);$\zeta_h = 0.085$;$Q_0 = 30$(L/min);$P_s = 21$(MPa);$\Delta I = 50$(mA);Amplitude bandwidth$\geq$ 100(Hz);Phase bandwidth$\geq$ 100(Hz);ω_{sv}=628(rad/s);ζ_{sv}=0.5. Rated flow $Q_0 = 30$(L/min) valve actual supply pressure is $P_s^{'} = 4.5$(MPa), Q_{0m}= 2.315×10^{-4}(m3/s); Valve flow gain is $K_{sv} = 0.00579$(m3/s A).

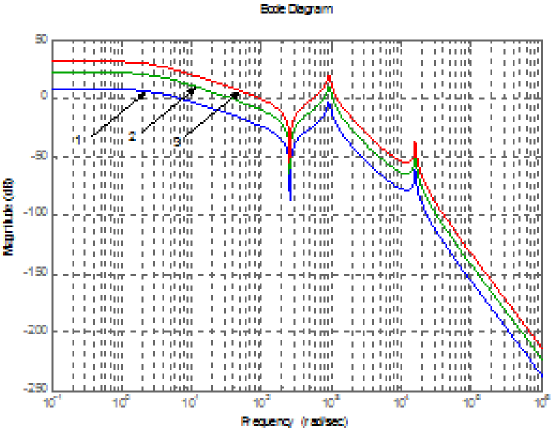


Fig. 3. Simulation curve of electro hydraulic force servo system

Fig. 3 is the open loop frequency characteristic of the electro hydraulic force servo system based on the block diagram model and the combination of the formula (??) and the above parameters, the controller is proportion controlling, and the proportion parameter can be adjusted. Simulation of the proportional parameter K1< placeK2< K3, they correspond to the curve 1, curve 2 and curve 3. It can be seen from the graph and the simulation curve. With the increase of the scale factor, the precision of the system is improved, crossing frequency increased and the response frequency of the system increases too. However, the open loop amplitude frequency characteristic curve of the system exceeds zero dB atω_0, therefore, the system can not work steadily, and it must be corrected. It is difficult to solve the contradiction problem between the control precision, the rapidity and the stability of the system by simply increasing the proportion control coefficient, the system needs to be controlled by a better control strategy.

4. Research on control strategy of particle swarm optimization algorithm for electro hydraulic force servo system

Particle swarm optimization is a swarm intelligence optimization algorithm to simulate the behavior of birds [5]. It has been used in the field of image processing, pattern recognition and so on, because it is not dependent on the objective function, the algorithm is easy to implement, the parameters are few, and it can effectively solve the complex optimization problem [6]. Particle swarm optimization is an evolutionary algorithm based on population; the basic idea is to find the optimal solution through the cooperation and information sharing among the individuals in the group. In each iteration process, we can produce a set of optimal solutions to meet the requirements of this iteration. Because the particle swarm optimization algorithm is simple operation and fast convergence [7], the algorithm can be used to optimize the parameters of the electro hydraulic force servo system controller; therefore, the system has a good control effect on the contradiction problem.

PID controller has the advantages of simple structure, easy adjustment, good stability and so on, and be widely used. It is based on the given value of $r(t)$ and the actual output value $y(t)$ constitute the control deviation $e(t) = r(t) - y(t)$, and the proportional control, integral and derivative comprehensive control function are applied to the deviation value, so to control the controlled object, and the control law of discretization is [8]:

$$u(k) = K_P\{e(k) + \frac{T}{T_I}\sum_{i=0}^{k} e(i) + \frac{T_D}{T}[e(k) - e(k-1)]\} \tag{5}$$

Where:K_P-Scale factor; T_I-Integral time constant; T_D-Differential time constant.

The control algorithm of this system is realized by digital control, at the same time, the dead time and saturation characteristics, the friction characteristics and the nonlinear flow characteristics of the slide valve stage are discussed. On the basis of the traditional discrete PID controller, three nonlinear characteristics are introduced in this paper, that is, the integral limit, the conditional integral, and the output limiting.

The optimal position of at least one individual in the population is recorded as g, the location is considered as the movement experience of population, and mastered by each particle . The flight speed of each individual can be adjusted according to the current speed and the relationship between the individual and p and g, this decision process can be expressed as a mathematical expression:

$$v_i^{(k+1)} = w_i v_i^{(k)} + c_1 \times r_1^{(k)} \times (p_i^{(k)} - s_i^{(k)}) + c_2 \times r_2^{(k)} \times (g_i^{(k)} - s_i^{(k)}) \tag{6}$$

Where: $v_i^{(k)}$-The current speed of individual i at the k iteration, $v_i^{(k+1)}$- Particle i update rate, placeStatewi- Particle i inertia weight, c1, c2- Normal number, $s_i^{(k)}$- Particle i current position, r1, r2- Random numbers on closed interval [8], $p_i^{(k)}$- Particle i optimal position, g- particle swarm optimal position. The new position of the particle can be expressed as:

$$s_i^{(k+1)} = s_i^{(k)} + v_i^{(k+1)} \tag{7}$$

The minimum objective function is chosen as the parameter selection by using the integral performance index of error absolute value, In order to prevent excessive control value, adding the square of the control input to the objective function. At the same time, the overshoot is also regarded as one of the best indexes, that is, to avoid overshoot in the process of adjusting the system, the optimal index is:

$$J = \int_0^\infty (\omega_1 |e(t)| + \omega_2 u^2(t) + \omega_4 |ey(t)|)dt + \omega_3 t_u \tag{8}$$

Where: e(t)-system error, u(t)- Controller output, tu- Rise time, ω_1,ω_2,ω_3,ω_4- Correlation weight. In the process of implementing control strategy, particle swarm optimization algorithm iterative diagram shown in Fig. 4.

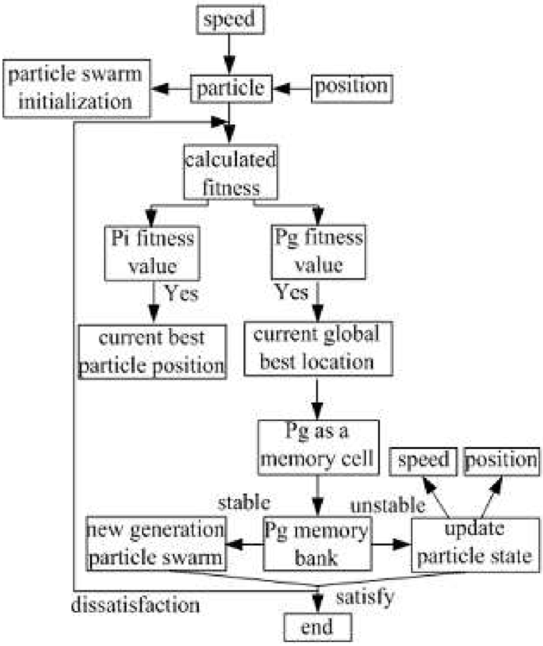


Fig. 4. Particle swarm optimization algorithm iterative diagram

Fig.5 is the particle swarm optimization control strategy applied to the PID control; get the new controller for electro hydraulic force servo system in the frequency domain simulation curve. As can be seen from the graph, the gain of low frequency system is improved obviously, proving the control precision of the system is greatly improved; under the premise of ensuring the stability margin of the system, the crossing frequency of the system is improved??the results show that the system's fast performance is improved effectively on the premise of stability, therefore, the mid frequency overall performance of the system has been improved. At the same time, the simulation of the proportion of the parameters gradually increase the corresponding curve is the graph 1, curve 2 and curve 3, visible from curves, with the increase of the scale coefficient, the curve is still gradually rising, until the open loop amplitude and frequency characteristic curve of the system exceeds zero dB at the peak value. It can be seen that the system can not work stably when the scale coefficient is increased to a certain value, the results show that the application of particle swarm optimization control strategy to obtain a new controller to improve the stability of the system is still subject to certain restrictions.

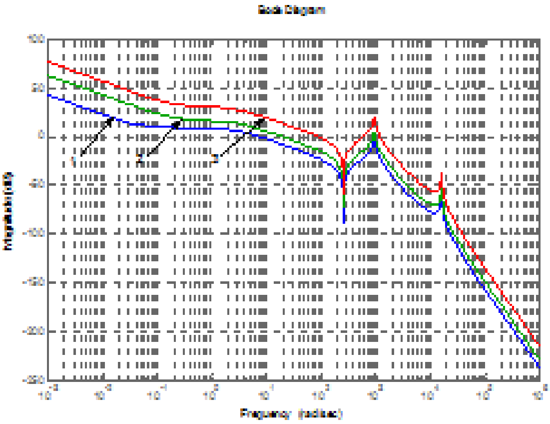


Fig. 5. Simulation curves of electro hydraulic force servo system based on particle swarm optimization

5. Experimental study of electro hydraulic force servo system

In order to verify the characteristics of the electro hydraulic force servo system in this paper, and the actual effect of the new controller using particle swarm optimization algorithm, experimental research on real time control of the system is done. Real time monitoring system using high performance computer in the experiment, it can collect the real time data of the power output parameters. At the same time, signal generator and manual operation can be used as signal source; it can provide different input signals for the automatic and debugging process of the experimental platform. The experimental system is implemented using a rapid control prototype technique [9-10].

In order to compare the actual control effect of the two controllers, the experimental study is carried on the electro hydraulic force servo control system experimental station shown in Fig. 6. The experimental station is including high performance

Fig. 6. Electro hydraulic force servo system experimental platform picture

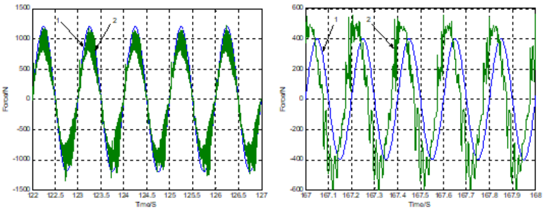
computer, electric control panel, the main experimental platform(experimental bench, servo valve, servo hydraulic cylinder, force sensor, bearing rail, mass load, and flexible link and so on) and hydraulic oil source structure auxiliary components, such as four parts.

Fig. 7 and Fig. 8 show the sine response curve of experimental station system under the action of the PID control method and the particle swarm optimization algorithm control strategy controller, and curve 1 and curve 2 are respectively the input and output curves of the system.

Comparing Fig. 7 and Fig. 8, we can see when using PID controller, the amplitude of the output curve of 1Hz is attenuated seriously, and the vibration at the peak intensifies, the output force is difficult to stabilize the value; the phase error of the output curve of 5Hz is obvious, the amplitude of peak overshoot is 25%, this shows that the control effect of PID controller is poor. When using particle swarm optimization algorithm as the new controller, the output precision of the system is improved obviously at low frequency, amplitude attenuation phenomenon has been greatly improved, and vibration at the peak decreases obviously; the phase error of the output curve of 5Hz is greatly reduced, it is reduced by about 50%, at the same time, the overshoot of the amplitude at the peak disappears and decays slightly??the smoothness of the output curve is also improved. All these make the comprehensive output characteristics of the system improved obviously, and these verify the effectiveness of the new controller using particle swarm optimization algorithm too.

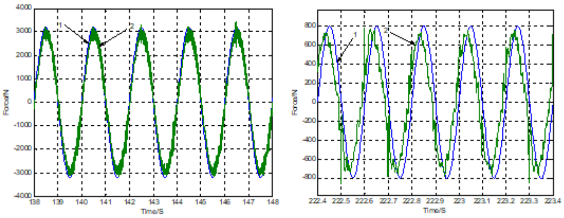
6. Summary

According to the characteristics of electro hydraulic force servo system itself in this paper, especially its nonlinear characteristics, parameter uncertainty, the complexity of the system itself and external load disturbance, and so on, the modeling,



1-Input curve; 2-Output curve

Fig. 7. Sine response experiment curves of system controlled by PID controller



1-Input curve; 2-Output curve

Fig. 8. Sine response experiment curves of system by new controller using particle swarm optimization algorithm

simulation and experimental research of electro hydraulic force servo system are carried out. It is found that the contradiction between the precision of the system, the rapidity of the response and the stability of the system is difficult to solve, all of these affect the crossing frequency of the system, and make the system unstable and oscillation, lower bandwidth, nonlinear problems. In order to solve these problems, the new controller with particle swarm optimization algorithm control strategy is applied to the electro hydraulic force servo system to correct the system, to improve the integrated output characteristics of the system, the simulation and experiment results show that the control effect is very obvious. The control results are compared with those of the conventional PID controller, it is found that the control effect of the former is better than that of the latter in restraining overshoot, increasing the output amplitude accuracy, reducing the peak oscillation and reducing the phase error. The integrated dynamic characteristic of electro hydraulic force servo system controlled by the new controller is improved obviously.

References

[1] J. S. Tomar, D. C. Gupta, N. C. Jain: *Research on Electro-hydraulic Force Servo Control System Based on Fuzzy PID Control.* Industrial Control Computer *27* (2014), No. 9.

[2] J. S. Tomar, A. K. Gupta: *Experiment Modeling and Parameter Estimation of Electro-Hydraulic Force Servo System.* Journal of Shanxi University(Nat.Sci.Ed.) *98* (1985), No. 2, 257–262.

[3] R. H. Gutierrez, P. A. A. Laura: *Study of the Optimal Control Method Based on Electro-Hydraulic Force Servo System.* Machine Tool and Hydraulics (2003), No. 5.

[4] R. P. Singh, S. K. Jain: *Nonlinear Control of Friction in Passive Force Servo System.* Journal of Jilin University (Engineering and Technology Edition) *7* (2004), No. 1, 41–52.

[5] M. N. Gaikwad, K. C. Deshmukh: *Stochastic Particle Swarm Optimization Algorithm Based on Cluster Analysis.* Computer Engineering and Applications *29* (2005), No. 9, 797–804.

[6] S. Chakraverty, R. Jindal, V. K. Agarwal: *BP Algorithm Based on Improved Particle Swarm Optimization.* Computer Simulation *12* (2005) 521–528.

[7] N. L. Khobragade, K. C. Deshmukh: *Modified Particle Swarm Optimization Algorithm and its Convergence Analysis.* Computer Engineering and Applications *30* (2005), No. 4, 555–563.

[8] Y. F. Zhou, Z. M. Wang: *A Nonlinear PID Controller Based on Genetic Tuning Algorithm.* Control and Decision *316* (2008), Nos. 1–5, 198–210.

[9] R. Lal: *Development of a Robotic Manipulator Control System Based on the xPC Target.* Automation & Instrumentation *34* (2003), No. 4, 587–606.

[10] R. Lal, Y. Kumar: *Application of Rapid Control Prototyping Technology in Hydraulic Servo Control.* Machine and Hydraulic *20*, (2013), No. 4, 264–275.

Received November 16, 2017