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Researching on YH100 Numerical Control Servo Press Hydraulic Control System and Control Algorithm

Kai LI, Lingfeng TANG, Youmin WANG, Chun ZHAO
School of Mechanical and Automotive Engineering, Anhui Polytechnic University,
Wuhu, Anhui province, 241000, China
Tel.: 15056472867
E-mail: LKStar@yeah.net

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Abstract: In order to study the numerical control (NC) servo press hydraulic control system and its control algorithm. The numerical control servo press performance and control principle of hydraulic control system are analyzed. According to the flow equation of the hydraulic control valve, hydraulic cylinder flow continuity equation and the force balance equation of the hydraulic cylinder with load press, the mathematical model of hydraulic control system is established. And the servo press hydraulic system transfer function is deduced. Introducing the suitable immune particle swarm control algorithm for servo press hydraulic system, and the control system block diagram is established. Immune algorithm is used to optimize new control parameters of the system and adopt the new optimization results to optimize the system simulation. The simulation result shows that the hydraulic system's transition time controlled by the immune particle swarm algorithm is shorter than traditional ones, and the control performance is obviously improved. Finally it can be concluded that immune particle swarm PID control have these characteristics such as quickness, stability and accuracy. Applying this principle into application, the obtained YH100 numerical control servo press hydraulic control system meets the requirement. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Numerical control servo press, Hydraulic system, PID control, Immune particle swarm optimization algorithm, Simulation.

1. Introduction

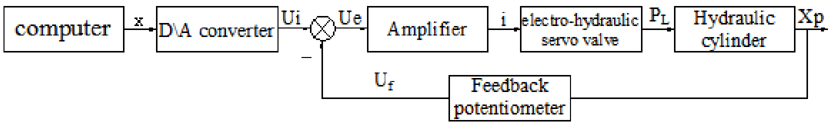
Servo press usually refers to the use of servo motor drive control of the press. Servo press can be divided into mechanical drive servo press and hydraulic servo press. Mechanical drive servo press converts the rotary motion of the motor into linear motion of the slider on the basis of discarding the traditional mechanical press's flywheel and clutch and some other energy consumption parts, depending on pressing force [1] provided by the servo motor instantaneous torque, through the screw, crank connecting rod, toggle actuator. This can realize the slider's movement being controlled and meet the requirement of intelligent stamping machining flexibility. Hydraulic drive servo press is consisted of controller, servo valve, all kinds of sensors, the oil cylinder and oil circuit. Adopt servo motor drive main transmission oil pump, calm down control valve circuit and control hydraulic machine slider. Hydraulic system is a key part of the servo press, which will affect the quality of the design of servo press. At present the system commonly uses control methods of PID control, optimal control, robust control, adaptive control, etc. PID control which is conducted on the basis of the simplified model becomes one of the main industrial control technologies because of its simple structure, good stability, reliability and easiness to adjust. However, the traditional PID controller using a linear combination of methods is difficult to reconcile the contradiction between speed and stability. In the case with parameter variations and external disturbances, it is difficult to ensure that the system has good robustness. And the optimal control requires accurate mathematical model. Accurate mathematical model of the servo press is too complex to apply to practical application. Robust control and adaptive control work well. But the control performance would be impacted due to the interference of uncertain factors [2].

The immune particle swarm control has such advantages as a nonlinear mapping, self-study, self-organization, adaptive, etc. This paper applies the immune particle swarm control method to servo press hydraulic control system, and compare with PID control method. Simulation results show that the immune particle swarm algorithm has fast response speed, small peak and good stability.

2. Control System Modeling

2.1. Schematic Diagram of Control System

Fig. 1 shows the control diagram of hydraulic control system of the servo press:



x is the command signal; U_i is the command voltage; U_e is the bias voltage; i is the current; P_L is the flow; X_p is the valve displacement; U_f is the feedback voltage.

Fig. 1. Servo press hydraulic control principle diagram.

Its principle is: After the computer sends command signals, digital to analog converses the command voltage is compared with the feedback voltage [3], then voltage deviation is obtained. Through the amplifier to drive electro-hydraulic servo valve, so as to drive the hydraulic cylinder.

2.2. Modeling of Hydraulic Control System

In order to deduct the transfer function of the hydraulic dynamic element, the basic equations should be listed first [4], that is the flow equation of the hydraulic control valve is defined as Equation (1), hydraulic cylinder flow continuity equation is defined as Equation (2) and the force balance equation of the hydraulic cylinder with load is defined as Equation (3).

$$q_L = K_q X_v - K_c p_L \,, \tag{1}$$

$$q_L = A_p \frac{dx_p}{dt} + C_{tp} p_L + \frac{V_t}{4\beta_e}\frac{dp_L}{dt} \,, \tag{2}$$

$$A_p p_L = m_t \frac{d^2 x_p}{dt^2} + B_p \frac{dx_p}{dt} + Kx_p + F_L \,, \tag{3}$$

where C_{tp} is the total leakage coefficient of hydraulic cylinder, $C_{tp} = C_{ip} + \frac{C_{ep}}{2}$; m_t is the total mass of the piston and its load converted on; B_p is the viscous damping of the piston and the load; K is the spring stiffness load; F_L is active at any external load force on the piston.

Equations (1)-(3) are the three basic equations of valve controlled hydraulic cylinder, they completely describe the dynamic characteristics of valve controlled hydraulic cylinder. The Laplace transform of them are Equations (4)-(6).

$$Q_L = K_q x_v - K_c P_L \,, \tag{4}$$

$$Q_L = A_p s X_p + C_{tp} P_L + \frac{V_t}{4\beta_e} s P_L \,, \tag{5}$$

$$A_p P_L = m_t s^2 X_p + B_p s X_p + K X_p + F_L \,, \tag{6}$$

By the three basic equations, a linear transfer function block diagram can be obtained, which is shown as Fig. 2.

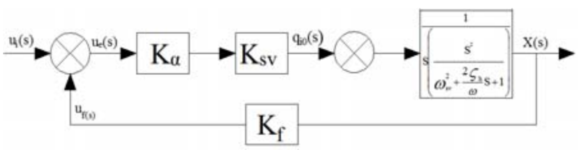


Fig. 2. System transfer function block diagram.

The system open-loop transfer function can be obtained from Fig. 2, which is shown as Equation (7).

$$G(s)H(s) = \frac{K_v}{s(\frac{s^2}{\omega_h^2} + \frac{2\delta_h}{\omega_h}s + 1)}, \quad (7)$$

The parameters of the system transfer function assignment: K_f is the displacement sensor gain, K_f=200 V/m; K_α is the servo amplifier gain, K_α=2.6 A/V; K_{sv} is the proportional servo valve gain, $K_{sv}=43.6\times10^{-3}m^3/(s\cdot A)$; K_v is the open-loop amplification factor; $\omega_h = 3572 rad/s$, $\delta_h = 0.2$.

The open-loop transfer function of the system can be expressed as Equation (8).

$$G(s)H(s) = \frac{22.7}{s(\frac{s^2}{3572^2} + \frac{2\times0.2}{3572}s + 1)}. \quad (8)$$

3. Researching of Servo Press Hydraulic System Immune Control Algorithm

3.1. The Basic Principle of Immune Particle Swarm Optimization

The immune particle swarm optimization is on the basis of framework of particle swarm algorithm, introducing the immune principle of life science into the particle swarm algorithm. On one hand, use the immune memory and self regulation mechanism to maintain the fitness level of particles to keep a certain concentration, ensuring the diversity of population. On the other hand, introduce the vaccine and other operations. Purposely and selectively guide the evolution process, which can improve the search performance of the algorithm [5].

This paper introduces immune particle swarm algorithm to overcome convergence of the particle swarm algorithm which cause loss of diversity issues. This method not only retains the briefness and easiness of particle swarm algorithm, but also overcomes the premature phenomenon of the optimization process [6], which makes the algorithm faster and stronger at totally searching.

3.2. PID Controller Design Based on Immune Algorithm

Classical PID algorithm is widely used in industrial application. But because of the complicated system model as well as the operator's lacking of experience and other reasons, it is difficult to determine control various signal process and evaluation index accurately. Using the immune particle swarm optimization to set the three parameters of PID controller, it can optimize the appropriate parameters rapidly and accurately [7].

The control block diagram of servo press hydraulic system based on immune particle swarm optimization is shown in Fig. 3.

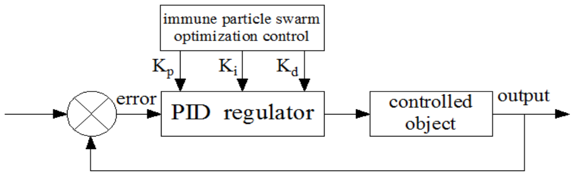


Fig. 3. The immune particle swarm control system.

In order to obtain satisfactory excessive dynamic characteristics, the IAE performance index is used as the minimum objective function in parameter selection. In order to prevent too much control energy, join the square of control input items in the objective function. Choose the Equation (9) as a parameter to select the optimal index [8].

$$J = \int_0^\infty \left(\omega_1 |e(t)| + \omega_2 u^2(t)\right) dt + \omega_3 t_u, \quad (9)$$

where t_u is the rising time; e(t) is the system error; u(t) is the output of immune particle swarm controllers, ω_1, ω_2, ω_3 are the weight.

In order to avoid overshoot phenomenon [9], which refers that the current output of the controlled system is less than the previous output. Put the difference before and after the output of the absolute value of the weighting system as the optimal index by using penalty function. This can solve the problem of overshoot effectively. The optimal index is shown in Equation 10.

$$\text{if } ey(t) < 0, \quad J = \int_0^\infty \left(\omega_1|e(t)| + \omega_2 u^2(t) + \omega_4|ey(t)|\right) dt + \omega_3 t_u, \quad (10)$$

where $ey = y(t) - y(t-1)$, $y(t)$ is the output of the controlled object, ω_4 for weights, and $\omega_4 \gg \omega_1$.

Due to the fact that the bigger the fitness is, the better the particle swarm algorithm [10] are. Select the fitness function is $f = \frac{1}{J}$. The smaller the J is, the bigger the fitness f is.

Parameter optimization process is shown in Fig. 4.

4. System Simulation and Analysis

4.1. Determine the Parameters of Immune Control

Selecting the initialization number of the particle swarm is N=30, Learning factor C1, C2 value is 2.

Inertia weight coefficient $\omega = 0.7298$. The number of iterations MaxDT=100, the search space dimension D=10, crossover probability Pc=0.8. Mutation probability Pm=0.1-[1:1:N]*(0.01)/N, that's to say the mutation probability is associated with the size of the fitness. The bigger the fitness is, the smaller the mutation probability is. The range of K_p is [0,20], the range of K_i and K_d are [0,10], weights $\omega_1 = 0.98$, $\omega_2 = 0.002$, $\omega_3 = 1.5$, $\omega_4 = 100$.

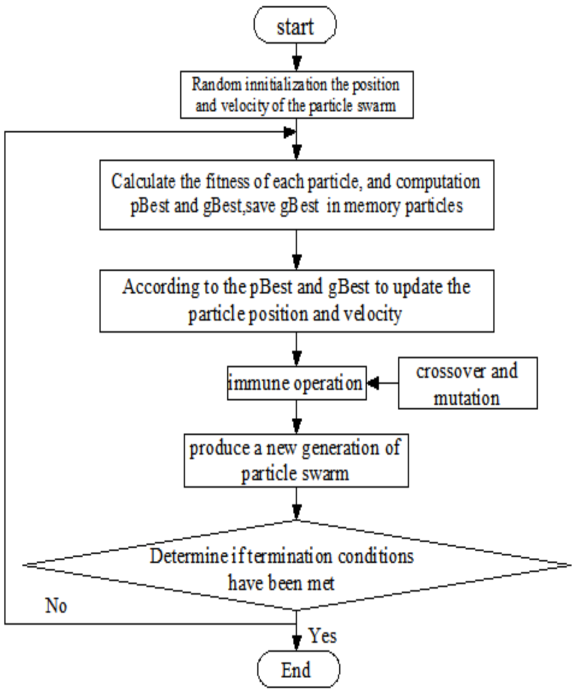


Fig. 4. Optimization process diagram.

4.2. Parameter Optimization

Servo press hydraulic system is the system of the single-input and single-output. The iterative optimization process of optimal index J is shown in Fig. 5.

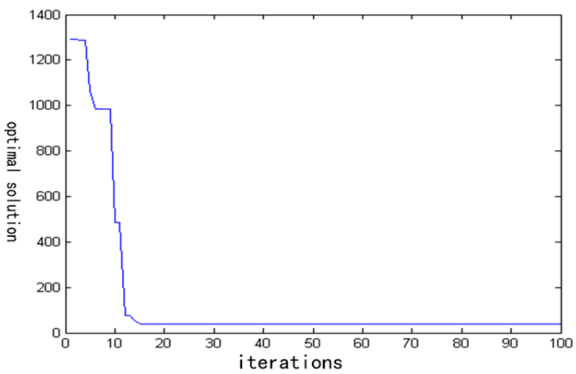


Fig. 5. The iterative optimization process of the optimal index.

The proposed immune particle swarm optimization algorithm is used for parameter optimization. The optimization results are shown as follows: K_p=19.0648, K_i=0.7498, K_d=0, optimal solution J=38.9256, fitness f=0.0257.

4.3. System Simulation and Analysis

After entering the unit step signal, its simulation results is shown in Fig. 6. The time of Immune particle swarm optimization PID control and plateauing time of traditional PID control are 0.025 s and 0.064 s respectively. The simulation results show that the response speed of immune particle swarm optimization control is faster, the stable time is short, and have no overshoot response curve, the system is stable.

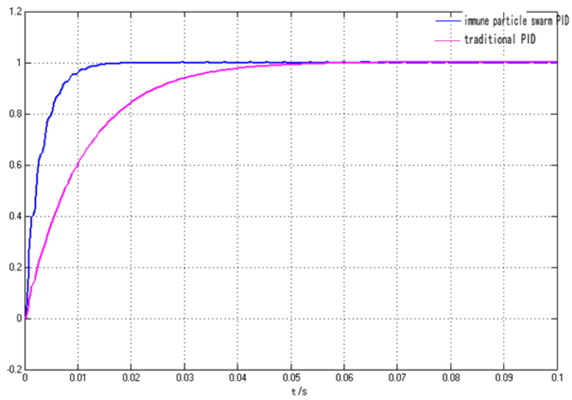


Fig. 6. The results of simulation diagram.

5. Experimental Verification

5.1. Experimental Principle

This experiment is completed on process integrated automation control system experimental platform. The experiment uses the boiler liner as a controlled object, and the boiler liner water temperature is the controlled variable of the system. The experiment requires water temperature in the boiler tank keeping to given value, and choose the boiler tank temperature TT1 signal detected by platinum resistance as the feedback signal. Use the difference of compared given value to control an output voltage of three phase voltage regulator module (The three-phase voltage of the electric heating tube) to achieve the purpose of controlling the boiler water tank.

The experiment adopts the scheme of adding cooling water into the jacket of the boiler as the external signal interference to verify the effect of the 3 parameters proportional, integral, differential based on immune particle swarm algorithm on controlling the experiment process of boiler temperature.

5.2. Experimental Content

Storing enough water in the water storage tank before the experiment. Start the instrument, select the PID control law, set the parameters according to the adjusted parameters of PID controller. Switch the regulator to "automatic" state when the boiler liner water temperature is stable on the given value. After the water temperature is balance, increase (decrease) the set value to let it has a positive (or negative) step incremental change (That is step interference, this increase should not be too large, usually 5 % to 15 % of the set value). So the boiler liner water temperature can leave the original equilibrium state, which is shown in Fig. 7. The water temperature stability is turned to a new setting value after a period of adjustment time. Record the setpoint of the intelligent instrument, the output value and instrument parameters. The response curve process of the liner temperature is shown in Fig. 8.

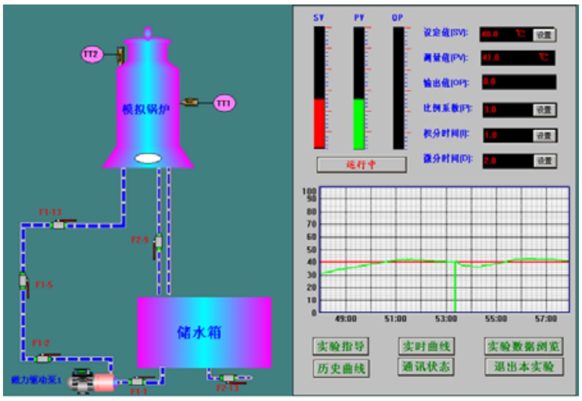


Fig. 7. PID control based on immune particle swarm subject to external interference.

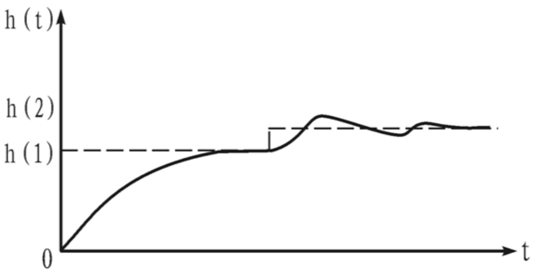


Fig. 8. The boiler liner water step response curves.

5.3. Experiment Parameter Input and Analysis of Experimental Results

Set the temperature at 40°. Entered the three parameters based on engineering experience $K_p=3$, $K_i=1$, $K_d=2$ into the system control interface. Entered the three parameters drew by immune particle swarm optimization $K_p=3$, $K_i=0.5$, $K_d=1$ into the system control interface.

After entering controlling experimental parameters into the system interface, the curve graph of the boiler tank water temperature constant value control transition is shown in Fig. 8. When the boiler tank water temperature reaches to the specified temperature of 40°C, the system would inject a certain amount of cold water to the tank for cooling automatically. After the first external interference, though the traditional PID control it can be seen that the time which system need to get back to the stable state is 5 min in the Fig. 9. If applying the same external disturbance again after the system being back to stable state, as it can be seen from Fig. 11, the time which system needs to get back to the stable state is 3 min. Compared with the previous one, the overshoot is decreased. It can be concluded that the immune particle swarm algorithm PID control can achieve the set temperature under the interference signals quickly and steadily, which proves the immune particle swarm algorithm PID control is superior to the traditional PID control. At the same time it proves the rationality and the correctness of the algorithm.

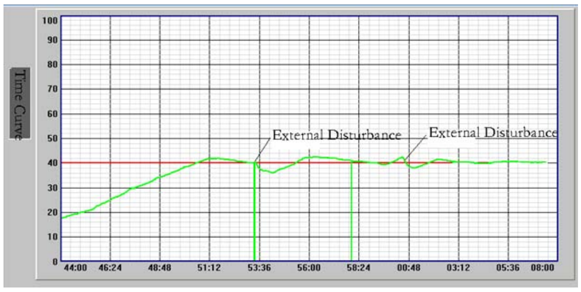


Fig. 9. Servo press hydraulic system control process curve.

6. Hydraulic System Pressure Test and Trial Operation

Appyling the results into application, it produces the YH100 NC servo press hydraulic control system which meets the requirement. Fig. 10 is a servo hydraulic system and press boarded experiment.

Fig. 10. The boarded of NC servo press hydraulic system.

7. Conclusions

1) Through the flow equation of the hydraulic control valve, hydraulic cylinder flow continuity equation and the force balance equation of the hydraulic cylinder with load, the control system model is established. The stability of the system's transfer function analysis shows that the system is stable.

2) NC servo press hydraulic control system's immune particle swarm optimization algorithm is developed. The simulation and experiment results show that immune control algorithm increases the system's convergence speed and global searching capability and effectively and can avoid "premature" phenomenon. The immune particle swarm optimization algorithm PID controller is designed. Through the parameter optimization, identify the output system of K_p, K_i and K_d under the excitation signal. The simulations reveal that when compared with the traditional PID control of NC servo press hydraulic system, the indicators of the NC servo press hydraulic system based on immune particle swarm control are significantly improved and its control characteristic is obvious.

3) Verify the accuracy and the advantages of the immune particle swarm optimization algorithm. Test shows that the immune particle swarm algorithm PID control is superior to the traditional PID control. At the same time it proves the rationality and validity of this algorithm. Applying the results into application, the YH100 NC servo press hydraulic control system is produced and it meets the requirements.

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