

Fuzzy Immune PID Control of Hydraulic System Based on PSO Algorithm

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Abstract

This paper takes the permanent magnet servo motor-driven hydraulic system as the research object. The hydraulic system power source uses servo motor instead of the original asynchronous motor, becoming a new energy-saving, fast response, and easy to realize closed-loop control hydraulic power systems. Aiming at variability of the load for the hydraulic system, immune algorithm is introduced to incremental PID controller and derive control law. Using fuzzy strategy approximating antibodies inhibit adjustment function to enhance the stability and robustness of the system, and designing fuzzy immune PID controller, parameters of controller are self-optimized by particle swarm (PSO) algorithm. This controller is applied to a hydraulic system, and achieved the precise control of the system flow in a variety of typical conditions. Simulation results show that: the controller can immune modulate automatically according to the dynamic changes of load of the hydraulic system, with fast tracking, small overshoot, and strong robustness advantages.

Keywords: Particle swarm optimization, Fuzzy reasoning, Immune PID

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1. Introduction

Hydraulic drive technology is widely used in mechanical engineering with its smooth transmission, convenient speed adjustment, easy remote operation control. However, the traditional hydraulic drive technology has overflow of energy and throttling losses, resulting in huge energy losses. From the point of view in optimized design of hydraulic components and hydraulic circuit, energy saving potential is quite limited. But there is a certain energy saving potential in the composition of the hydraulic system and control strategy.

Therefore, the hydraulic system in this paper uses high-performance permanent magnet servo motor (with natural energy-saving features) to drive constant pump as hydraulic power source. This system overcomes shortages of complex structure, high energy consumption, high fever, high noise, pressure vibration in traditional hydraulic valve control system. At present, PID control is still widely used in the control strategy. Due to the strong coupling characteristics of flow and pressure in the changing process of load in hydraulic system, control object is still uncertain, time-varying and highly nonlinear, so the traditional PID control is ineffective.

Immune control algorithm is the simulation of the biological immune system. Immune system as a living body's main defense mechanism plays an important role in the maintaining of organism physiological balance. Immune function can respond positively to outside interference, and be adjusted to overcome outside interference. This function is similar to feedback adjust from the effects. In this paper, the immune system's feedback adjusting principle is combined with the traditional PID; using fuzzy strategy approximating antibodies inhibit adjustment function to further enhance the stability and robustness of control system.

According to the idea mentioned above, intelligent PID controller is deigned based on the traditional PID controller, which combines fuzzy logic with immune control algorithm, and uses PSO algorithm to solve parameter adjustment problem. And apply it to the permanent magnet servo motor-driven hydraulic system, simulation experimental verifies the system has good dynamic and static performance in changing typical conditions.

2. Hydraulic System Structure and its Model
2.1. Hydraulic System Structure

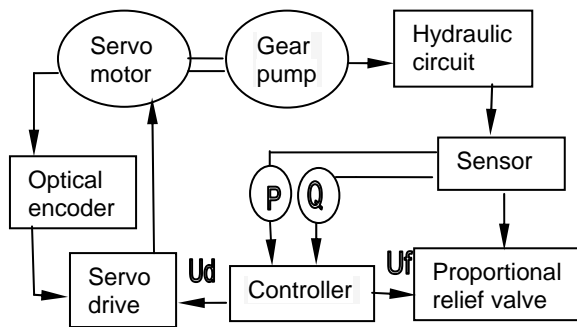


Figure 1. Diagram of the Hydraulic System

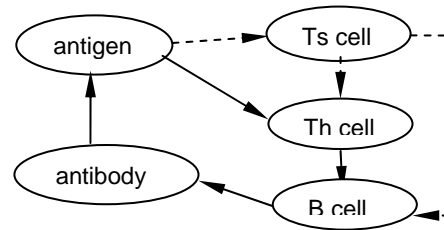


Figure 2. Diagram of Immune System

System diagram is shown in figure1: The hydraulic system is driven by a permanent magnet motor, proportional relief valve simulate actual load, simple, convenient, avoid the inconvenience of installing the actual load. Hydraulic flow is detected directly by the flow sensor, the system pressure is detected by the pressure sensor and sent to the controller, form a closed-loop control with load simulation system of proportional relief valve. The hydraulic source can provide exactly matching pressure and flow according to the desired pressure and flow of the simulated load, and avoid the overflow and throttling energy brought by the traditional valve controlled hydraulic circuit.

2.2. Hydraulic Power Source Model

Mathematical model of permanent magnet motor is complex, we usually chose dq rotating vector control mathematical model based on park transformation. It can be expressed as:

$$u_d = r_s i_d + p \psi_d - \omega_r \psi_q \tag{1}$$

$$u_q = r_s i_q + p \psi_q + \omega_r \psi_d \tag{2}$$

$$\psi_d = L_d i_d + \psi_f \tag{3}$$

$$\psi_q = L_q i_q \tag{4}$$

$$T_e = 1.5p(\psi_d i_q - \psi_q i_d) \tag{5}$$

- where u_d, u_q — d, q axis stator voltage component
- i_d, i_q —d, q axis stator current component
- ω_r —Rotor angular velocity
- r_s —Stator winding resistance
- L_d, L_q —Stator direct axis and quadrate axis inductance
- ψ_f —Flux generated by the permanent magnets of the rotor
- ψ_d, ψ_q —d, q axis stator flux
- T_e —Electromagnetic torque

The main gear pump model:
 The flow equation is:

$$Q_p = \omega D_p / (2\pi) - P_p C_p - P_p \omega D_p / (2\pi \beta_e) \tag{6}$$

where Q_p —Actual flow

$\omega D_p / (2\pi)$ —theoretical flow of the pump

$P_p C_p$ —amount of leakage of the pump

$P_p \omega D_p / (2\pi \beta_e)$ —Fluid volume amount of compression

The torque balance equation of pump drive shaft:

$$T_L = J_p d\omega / dt + B_p \omega + D_p P_p / (2\pi) \quad (7)$$

where T_L —The input torque of the pump (the load torque of the motor)

$J_p d\omega / dt$ —Inertia torque

$B_p \omega$ —The damping torque of the pump

$D_p P_p / (2\pi)$ —The torque generated by the oil pressure

3. Fuzzy Immune PID Control

3.1. Artificial Immune Feedback Principle

Immunity is characteristic physiological reaction of the organisms [8]. Biological immune system can produce the corresponding antibodies to resist alien violated antigen. Biological immune system consists of lymphocytes and antibody molecules. Lymphocyte is composed of T cells (the helper cells T_H and inhibit cells T_S) generated by the thymus and B cells generated by marrow. When antigen enters the body and digested by the surrounding cells, the information is passed to the T cell, that is passed to the helper cells T_H and inhibit cell T_S , then stimulate B cells, B cells produce antibodies to eliminate the antigen. When there are more antigen, there also be more cells T_H in the body, but the cells T_S are small, which will produce more B cells. With the reduction of the antigen, T_S cells within the body are increased, it inhibits the generation of the T_H cells, which B cells also reduced. After some time interval, the immune feedback system will tend to balance. Its simplified process is shown in figure 2. Solid line represents a positive role, and the dotted line represents counterproductive.

Immune controller is put forward based on the immune feedback principle in this paper: assume the number of NO.k generation antigen is $\varepsilon(k)$, output of T_H cells stimulated by the antigen is $T_H(k)$, the effect of T_S cells on B cells is $T_S(k)$, the total stimulation of B cells received is $S(k)$, then

$$S(k) = T_H(k) - T_S(k) \quad (8)$$

$$T_H(k) = K_1 \varepsilon(k) \quad (9)$$

$$T_S(k) = K_2 f(S(k), \Delta S(k)) \varepsilon(k) \quad (10)$$

where $f(S(k), \Delta S(k))$ is a selected non-linear function, which represents the capacity of cells inhibiting the stimulation; K_1 and K_2 are undetermined coefficients.

The quantity $\varepsilon(k)$ of the antigen was used as deviation $e(k)$, B cells receive the total stimulation $S(k)$ was used as control input $u(k)$, then obtained $\Delta S(k) = \Delta u(k)$. Feedback control law is

$$u(k) = K[1 - \eta f(u(k), \Delta u(k))] e(k) \quad (11)$$

where $K = K_1$, $\eta = K_2 / K_1$, this shows the essence of the immune controller is a nonlinear proportional controller, $f(S(k), \Delta S(k))$ is nonlinear function.

3.2. Fuzzy Immune PID Controller Design

The nonlinear function of the immune proportional controller has an important impact on the performance of the entire controller [10]. In this paper , a fuzzy controller is used to approximate nonlinear functions $f(u(k), \Delta u(k))$, the input of fuzzy controller is $u(k)$ and $\Delta u(k)$, $u(k)$ is the input of control object, the output of fuzzy controller is $f(S(k), \Delta S(k))$. The fuzzy rules is shown in Table 1.

Table1. Fuzzy Control Table for Non-linear Function

u	Δu			
	PB	PS	NS	NB
PB	NB	NM	NS	Z
PS	NM	NS	Z	PS
NS	NS	Z	PS	PM
NB	Z	PS	PM	PB

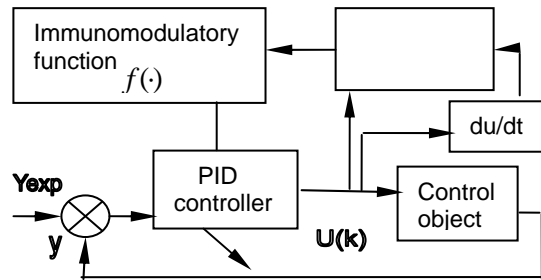


Figure 3. Fuzzy Immune Control System

Input variables are fuzzificated by four fuzzy set , that is “positive large PB” “positive small PS” “negative small NS” and “negative large NB”, output variables are fuzzificated by seven fuzzy set, that is “positive large PB” “positive medium PM” “positive small PS” “zero O” “negative small NS” “negative medium NM” and “negative large NB”. Above membership functions are defined in the entire real interval. Fuzzy immune control system is shown in figure3. y_{exp} is the desired output, y is the actual output.

3.3. Controller Parameters PSO Algorithm Adjustment

The introduction of a non-linear function of the immune controller $f(u(k), \Delta u(k))$, controller parameters K, η, K_i, K_d , are more difficult to determine using conventional analytical method. At present, there are many parameter optimization methods, such as the simplex method, gradient descent method etc, although these methods have a good optimization characteristics, simplex method is more sensitive to initial values, easy to fall into local optimum, the gradient descent method also has a similar disadvantage. GA is random search method based on natural selection and genetic evolution, overcoming the dependence on the initial value, but there is precocious and solving real-coded disadvantage. PSO algorithm is different compared to GA, it finds the optimal solution through collaboration between individuals, especially solving continuous domain optimization problem. In this paper, use the linear decreasing weight strategy of global PSO algorithm to optimize immune PID controller parameters. The algorithm formula is as follows:

$$V_{id}(k+1) = \omega V_{id}(k) + c_1 r_1 P_{id}(k) - X_{id}(k) + c_2 r_2 P_{gd}(k) - X_{id}(k) \tag{12}$$

$$X_{id}(k+1) = X_{id}(k) + V_{id}(k) \tag{13}$$

$$\omega = (\omega_{ini} - \omega_{end}) \cdot (T_{max} - t) / T_{max} + \omega_{end} \tag{14}$$

where, $i=1,2,\dots,M$, M is the total number of particles in the group ; $V_{id}(k)$ is d- dimensional component of the k-th iteration particle i flight velocity vector ; $X_{id}(k)$ is the d-dimensional components of the k-th iteration particulate i position vector; $P_{id}(k)$ is d-dimensional component of individual best position of the particles i ; $P_{gd}(k)$ is the best position of the d-dimensional components of the best position in groups; c_1 and c_2 are learning factors; $rand()$ is a random function, generates a random number of $[0, 1]$; ω is Inertia weight function; T_{max} is the maximum

evolution generation; ω_{ini} is the initial inertia weight; ω_{end} is the termination of the inertia weight.

To be optimized controller parameters are (K, η, K_i, K_d) , therefore, the length of the particles is 4. Other parameters are: The number of particles $M=80, c1=c2=2.1, \omega_{ini} = 0.9, \omega_{end} = 0.1, T_{max}=100$. The objective function is the most commonly and intuitive indicators, that is integral type error indicators ITAE, commonly used in servo control system. Minimum objective function is $J(x)$, and the individual fitness function: $F(x) = 1 / J(x)$. In order to ensure the integration convergence, the steady-state value of the system error must be zero, that is:

$$J = \int_0^{+\infty} (t|e(t)|)dt = \min \tag{15}$$

$$e(\infty) = \lim_{x \rightarrow \infty} e(t) = 0 \tag{16}$$

4. Results and Analysis

Permanent magnet servo motor-driven hydraulic power system is taken for the research object, which uses negative feedback of flow and pressure adaptive closed-loop control. In the pressure adaptive mode, the working pressure of the pump automatically adapt to the load pressure. System pressure becomes large when the load is increased, inside leakage of the pump increases so that the output flow becomes small, the servo controller compares the flow signal Q_p with the set value Q_r and control the motor's speed to increase, so that the system flow reaches the set value, and adapts to the requirements of the load pressure. This mode is suitable for larger changing of load and more stable speed occasion.

According to typical working conditions, use conventional PID, fuzzy immune PID, and the proposed particle swarm optimization algorithm to adjust fuzzy immune PID to optimizing the system flow, and give simulation and comparison results.

The main parameters of the permanent magnet motors are as follows: Model GK6073-6AC31, Rated power $P_w= 2.2KW$; Rated speed $n_N=2000$ r/min; Torque $T_N=11N.m$; Stator impedance $R_s=2.8750 \Omega$; The stator d phase winding inductance $L_d=0.0085H$; The q phase winding inductance $L_q=0.0085H$; The pole pair number $p=4$.

The main parameters of the gear pump: Mode CBK1004-AIFL; Rated pressure $P_N=25MP_a$; Rated speed $n=3500r/min$; Displacement $D_p=4.25 \times 10^{-6} m^3/r$; Rotational inertia $J_p=4.2 \times 10^{-5} kg.m^2$.

When the load is constant value 6Mp, system flow step response is shown in figure 4. using proportional relief valve simulate system load. The abscissa represents time, the ordinate represents flow in graph.

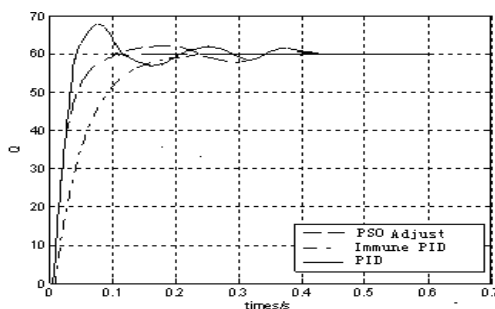


Figure 4. 6Mp Load Flow Response

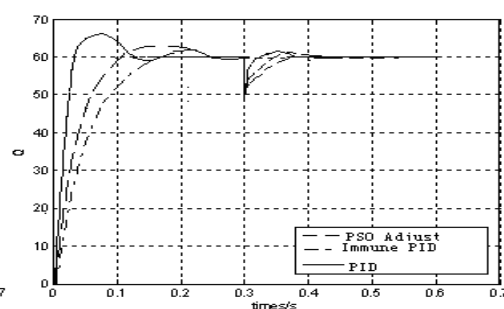


Figure 5. Step Load Flow Response

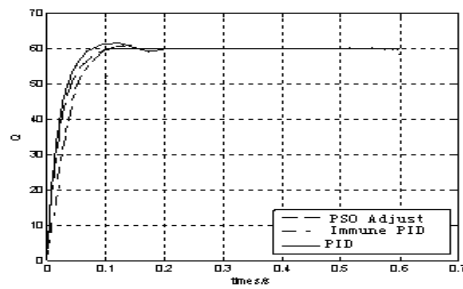


Figure 6. Ramp Load Flow Response

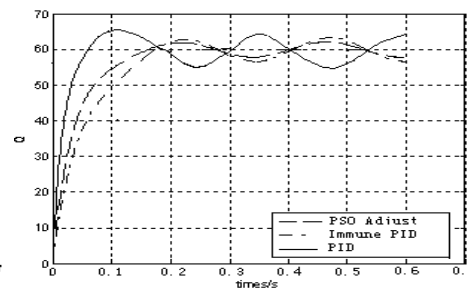


Figure 7. Sine Load Flow Response

When the system flow is stable, downward step response of system flow is shown in figure 5. Proportional relief valve simulate ramp load, the response of the system flow is shown in figure 6, Proportional relief valve simulate sine load, the response of the system flow is shown in figure 7.

It can be concluded from the simulation results of the figure 4 to 7: Regardless of load in any complex working conditions, the controller is able to maintain a good dynamic and static characteristic. It's proved that the proposed particle swarm adjusting fuzzy immune PID controller has better control effect, strong robustness, and it can be put in the actual control system.

5. Conclusion

(1) This paper uses a permanent magnet servo motor driven gear pump as a new type of hydraulic power source, which has the characteristics of energy-saving, fast response, easy to control advantages.

(2) It can be seen from the simulation results: Fuzzy immune PID controller optimized by particle swarm is applied to the flow control of the hydraulic system, being feasible and its control effect is satisfying. It can achieve precise control of flow in a variety of typical working conditions, control performance is superior to the traditional PID control.

References

- [1] Li Jiejia, Liu Daiyan, Qu Rui. The strategy of construction equipment energy-saving control. *Telkomnika*. 2012; 10(4): 706-712.
- [2] Khairdin Mohammad, Mohamed Zaharuddin, Husain Abdul Rashid. Dynamic model and robust control of flexible link robot manipulator. *Telkomnika*. 2011; 9(2): 279-286.
- [3] Takahashi K, Yamada T. Application of an immune feedback mechanism to control systems. *JSME Series C*. 1998; 41(2): 184-191.
- [4] Ibrahim Kaya. IMC based automatic tuning method for PID controllers in a Smith predictor configuration. *ISATransactions*. 2003; 42(4): 559-575.
- [5] Leszek Kasprzyzak, Ewald Macha. Selection of settings of the PID controller by automatic tuning at the control system of the hydraulic fatigue stand. *Mechanical Systems and Signal Processing*. 2008; 22(6): 1274-1288.
- [6] Qin Xiaoyu, Hua Sun. Fuzzy parameters PID Control and simulation experiment of permanent magnet linear synchronous motor. *Advanced Materials Research*. 2012; 2608-2611.
- [7] Roopaei M, Zolghadri Jaharomi. Chattering-free fuzzy sliding mode control in MIMO uncertain systems. *Nonlinear Analysis, Theory, Methods and Applications*. 2009; 71(10): 4430-4437.
- [8] Si tuying, Tian Lianfang, Mao Zongyua. Design and Optimization of Nonlinear Fuzzy Immune PID for MIMO System. *Computer Simulation*. 2009; 26(4): 204-207.
- [9] Liu Hongda, Li Dianpu, Ma Zhongli. Improvement of ship PID autopilot based on prtle swarm optimization. *Journal of Southeast University*. 2006; 36(1): 197-201.
- [10] Wang Shuangxin, Jiang Yan, Li Yaguang. *Fuzzy immune PID Control of the turbine Governing System Based on Compound Chaos optimization Strategy*. Proceedings of the Chinese Society for Electrical Engineering. 2006; 21(16): 71-76.
- [11] Xia Changliang, Liu Dan, Wang Yingfa, Zhang Maohu. Control of Brushless DC Motors Using Fuzzy Set Based Immune Feedback PID Controller. *Transactions of China Electrotechnical Society*. 2007; 22(9): 68-73.

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- [12] Jia Yongfeng, Gu lichen. System Design and Experimental Analysis for Hydraulic Power Unit with Permanent Magnet Synchronous Motor Drive. *Chinese Mechanical Engineering*. 2012; 23(3): 186-190.
 - [13] Li Shiyong. Fuzzy control, neural control and intelligent control theory. Harbin: Harbin Institute of Technology Press. 1996.
 - [14] Demirli Kudret, Vijayukumar Sujikumar. Fuzzy logic based assignable cause diagnosis using control chart patterns. *Information Sciences*. 2010; 180(17): 3258-3272.