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Research on Dual-motor Synchronization Based on Fuzzy Neural PID Control

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Abstract

In order to solve the problem of double motor synchronous error in the hydraulic lifting system of large crane, fuzzy control and neural network control are combined to realize the dynamic correction of PID parameters. With the use of cross-coupling control method in the control process based on the dynamic characteristics of the hydraulic system, both the pressure difference of hydraulic motor outlet and displacement of steel wire rope are regard as control index on the simulation and experimental research to improve the accuracy of synchronous control. The results show that this control strategy has strong ability of anti-interference, and effectively improving the synchronization control precision of the two motors.

Keywords: *Crane; fuzzy neural network; Cross coupling; Synchronous control*

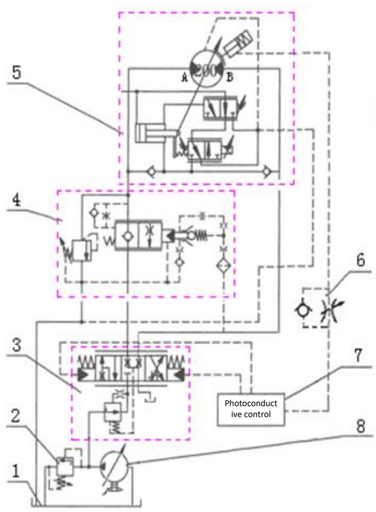
1 Introduction

The large crane hoisting system often uses two hydraulic motor to improve the load, but for the negative influence of factors included with leakage and prone to synchronization error, the crane's working performance is limited, or even cause accidents. In order to ensure the operation safety, effective control strategy ought to be adopted to keep the two motors with high synchronization precision.

The control method for now is applied the master-slave control mode to the hydraulic synchronization, whose References is cited in the text just by square brackets [1].Although it has better control effect, it is not suitable for large variations in load situations. Conventional PID control is the most widely used in control strategy, which is simple and easy to implement [2], however, because of the fixed parameter, real-time adjustment application is limited. Through the analysis for the dynamic characteristics of the crane hoisting system, we find out the factors influencing the synchronization accuracy; According to the characteristics of hydraulic transmission, nonlinear time-varying fuzzy control and neural network control combined fuzzy neural PID control strategy is proposed, for the purpose of achieving real-time adjusting PID parameters. At the same time, the cross-coupling control method is used to simulate the hydraulic pressure and the displacement of the steel wire rope.

2 Characteristic Analysis of Hoisting System

The lifting system of the large crane is composed of two independent groups of pump control motor system, which are coordinated by the controller to realize the synchronous control [3]. The structure of the subsystem is shown in figure 1.



1- variable pump; 2- reversing valve; 3- balance valve; 4- variable motor, 5-Variable motor;6-One-way throttle valve;7-pilot control valve;8-Constant power variable pump

Figure 1 Structure of crane hydraulic lifting system

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In order to get the ideal synchronization control precision, it is essential to control the speed synchronization of two hydraulic motors. The variable mechanism of variable pump is composed of proportional valve and variable cylinder [4,5]:

Flow continuity equation of variable cylinder:

$$Q_1 - C_{tg}p_1 + C_{ig}p_2 - = \frac{dV_1}{dt} + \frac{V_1}{\beta_e}\cdot\frac{dp_1}{dt} \quad (1)$$

$$C_{ig}p_1 - C_{tg}p_2 - Q_2 = \frac{dV_2}{dt} + \frac{V_2}{\beta_e}\cdot\frac{dp_2}{dt} \quad (2)$$

Where: V_1—Volume of rodless cylinder of variable cylinder;
V_2—Volume of the cylinder in the variable cylinder;
β_e—Elastic modulus of hydraulic oil;
C_{ig}—Cylinder internal leakage coefficient;
C_{tg}—Cylinder leakage coefficient;
Q_1, Q_2—Flow rate of oil inlet and return chamber.

Force balance equation of cylinder.

$$m\frac{d^2X}{dt^2} + B\frac{dX}{dt} + KX + F_L = Ap_1 - Ap_2 \quad (3)$$

Where: m—Load and total piston mass;
B—Viscous damping coefficient of hydraulic oil;
F_L—Load force;
X—Piston displacement;
K—Spring stiffness;
A—Effective working area of piston.

Force balance equation of valve core:

$$m_v\frac{d^2Y}{dt^2} + B_v\frac{dY}{dt} + K_vY = K_iI - K_yY \quad (4)$$

Where: m_v—Spool quality;
Y—Spool displacement;
K_v—Spring stiffness;
K_i—Current gain;
I—Control current;
K_y—Displacement force gain;
B_v—Damping coefficient.

3 Control Strategy Research

3.1 Control mode

At present, there are three kinds of control methods used in hydraulic synchronization, which are equal control, master-slave control and cross coupling control [6-8].

3.1.1 Equal-status

Equal-status refers to the hydraulic system in the implementation of several components at the same time with an ideal input signal as the target, tracking output, so as to achieve synchronization control, as shown in figure2.

3.1.2 Master-slave

Master-slave mode refers to a way achieved by the synchronization control of the output including two components: one is the target, the other is the tracking control, to achieve a way, as shown in figure 3.

3.1.3 Cross-coupling

Cross coupling control mode refers to an ideal input as the goal, by coupling variables, to achieve synchronization control and implementation of all the components of the tracking control, then the output of the two actuators are compared, whose deviation signal is obtained as an additional signal feedback, such as shown in figure 4.

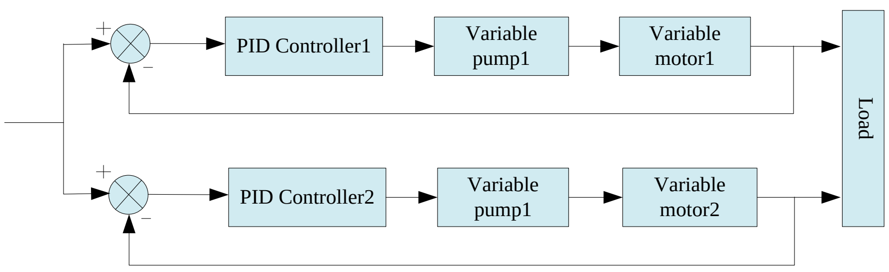

Figure 2 Equal-status control principle

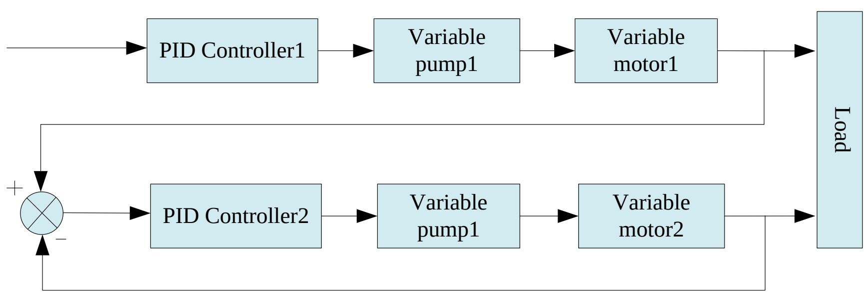

Figure 3 Master-slave control principle

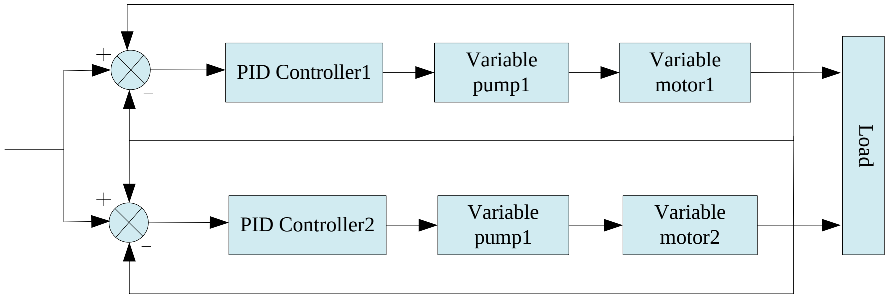

Figure 4 Cross-coupling control principle

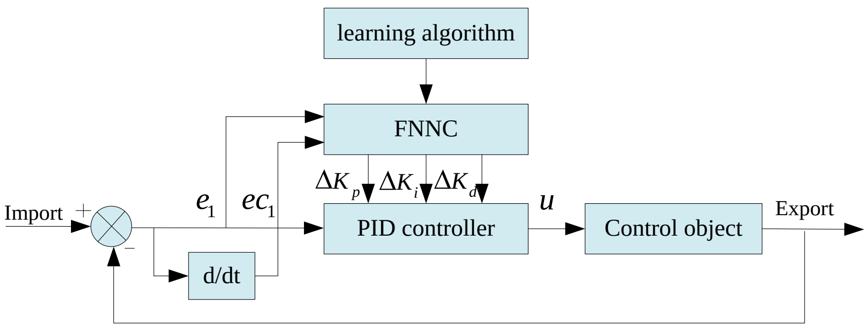

Figure 5 PID structure of fuzzy neural network

The above three methods can achieve both double motor synchronous control and satisfactory control effect, the first two methods have the advantages of simple structure and easy realization, but they are not suitable for load changes in the larger situation, which causes that it is difficult to achieve synchronization in the true sense. While by the cross-coupling control method, a coupling signal is added between each subsystem, which can improve the accuracy of the synchronization control.

3.2 Control strategy

Hydraulic lifting system is a very complex system, so as that it is difficult to establish accurate mathematical model. In order to obtain the optimal control effect, it is necessary to adjust the parameters in real time to counteract the disturbance caused by the disturbance. A parameter self-learning PID controller is designed based on fuzzy neural network, as shown in figure 5. The weights of the neural network are calculated by fuzzy rules, and the parameters of the traditional PID controller can be adjusted online in real time [9].

The fuzzy neural network model in this paper adopt five layers of structure, there are two input nodes and three output nodes, the input node corresponding to the error and error change rate of the output, after processing [10-12], the three parameters of the output node corresponding to the PID controller, as shown in figure 6.

The first layer is the input layer with two nodes, which are connected with the input vector, and the function is to change the error and error change rate of the input network.

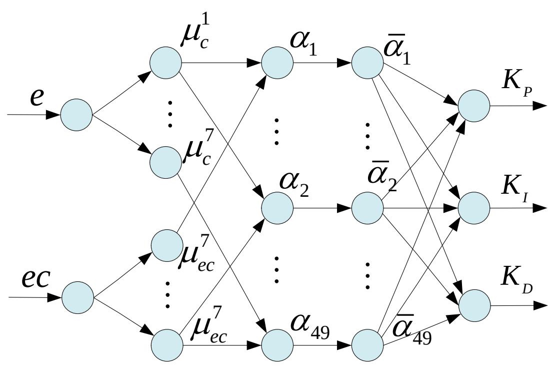

Figure 6 Topological structure of fuzzy neural network

The second layer is the language variable layer, also called fuzzy layer. Each node corresponds to a language variable value, whose function is to determine the amount of input into fuzzy vector as the input of the controller, using the normal function as its membership function:

$$\mu_i^j = \exp[-(x_i - c_{ij})^2] / \sigma_{ij}^2 \tag{5}$$

Where: c_{ij}—Center of membership function;

σ_{ij}^2—Width of membership function.

The third layer is the fuzzy inference layer, and each node represents a fuzzy rule. By connecting with the fuzzification layer to complete the matching of fuzzy rules, the corresponding weighting coefficients are obtained through the combination of each node, and the calculation of each application of the rules.

The fourth layer is the normalized layer, which is normalized.

The fifth layer is the output layer, when the fuzzy variables has been clear, it has the function to determine the parameters of the PID controller.

Obviously, the designed fuzzy neural network is also a kind of multilayer forward feed network, which can adjust the parameters by the method of error feedback:

$$e = \frac{1}{2}\sum_{i=1}^{3}(r_i - y_i)^2 \quad (6)$$

Where: r_i—Expected output;

y_i—Actual output.

The learning rule of connection weights is:

$$\omega_{ij}(k+1) = \omega_{ij}(k) + \eta(r_i + y_i) + \lambda[\omega_{ij}(k) - \omega_{ij}(k-1)] \quad (7)$$

Where: η—Learning rate;

λ—Smoothing factor, and $0 < \lambda < 1$.

4 Simulation Analyses

Based on the cross-coupling control mode, the fuzzy neural network control strategy is used in the double motor synchronous control system of the crane, and combined with the traditional PID control, respectively, to control the two hydraulic motors, as shown in figure 7.

Taking the variable pump displacement of 0～145mL/r, the engine speed of 1000r/min, motor displacement of 160mL/r, sampling frequency of 50Hz, and the motor pressure cut-off valve set value of 20MPa, simulation analysis is carried out under different working conditions and control strategies.

(1) Taking the minimum displacement difference of wire rope as the target

When the displacement of two steel ropes is not at the same time, using the deviations with two hydraulic pump displacement to control the controller, thereby together with changing the system flow, the motor speed changes. The displacement is equal to two steel ropes, and the displacement difference is zero, through which it can achieve synchronous control.

Assuming that the initial displacement difference between the two steel ropes is 1.2mm, crane weights 200 tons, the results shown in figure 8～9.

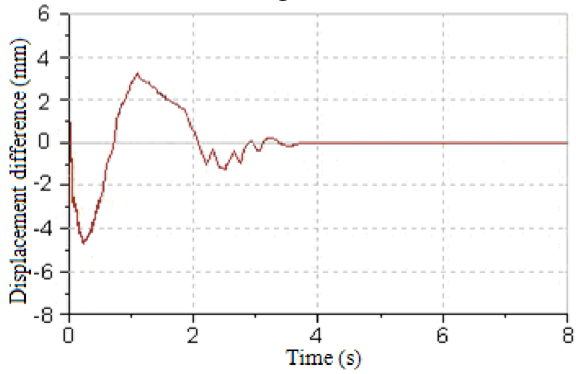

Figure 8 Traditional PID control

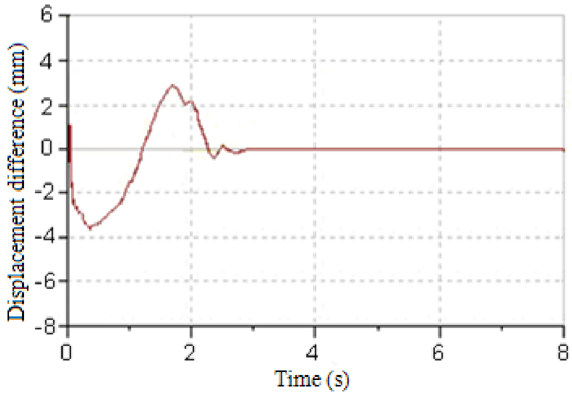

Figure 9 Fuzzy neural PID control

The simulation results show that the displacement difference of the two steel ropes will be close to 0 after the synchronization control. When using the traditional PID control strategy, the difference between the maximum displacement of steel wire and rope change rate reached 4.8mm, in 3.7 seconds to 0, while the fuzzy neural PID control strategy when the maximum displacement difference range is 3.6mm, up to 0 values in 2.8 seconds, the control precision and the convergence speed is improved obviously.

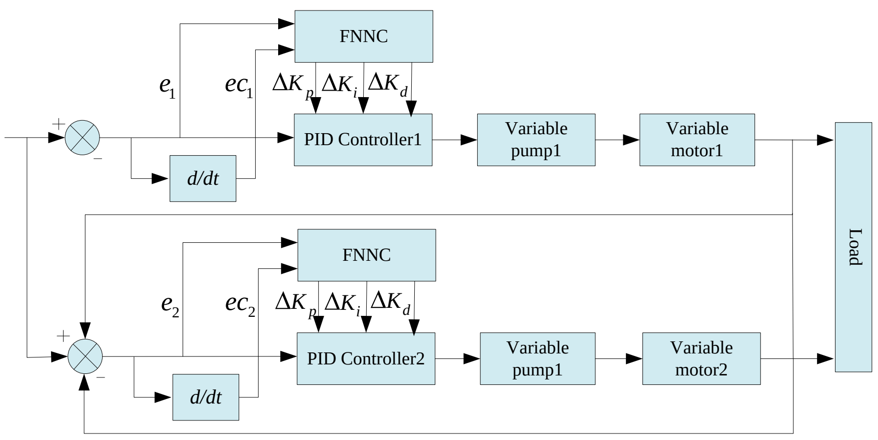

Figure 7 Diagram of double motor synchronous control system

(2) Taking the minimum pressure difference as the simulation target

When there is a synchronization error, the load will be inclined, which will lead to the unbalanced force of the wire rope, so that the load cannot be evenly distributed to the two hydraulic systems, leading to the inconsistence of the pressure of their corresponding position. Taking the exit pressure of two hydraulic motor as the index, the result is shown in figure 10～12.

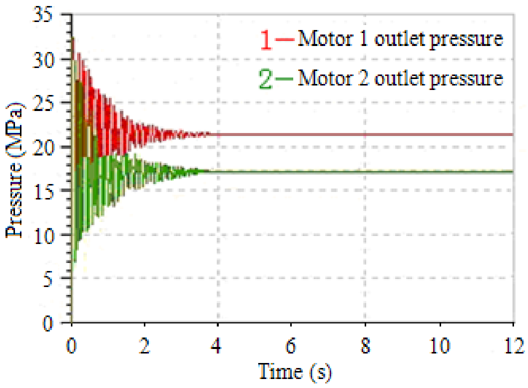

Figure 10 No synchronization control

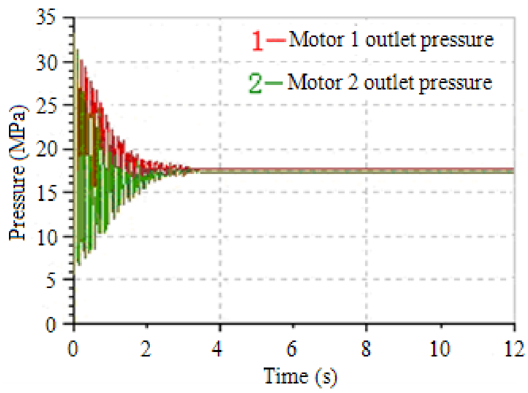

Figure 11 Traditional PID control

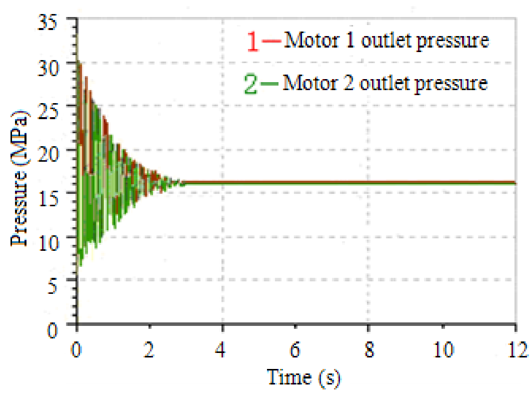

Figure 12 Fuzzy neural PID control

The results show that when the system synchronization error occurs, it will result in the deviation of the pressure of the two hydraulic systems. Compared with the traditional PID control strategy, the fuzzy neural PID control effect is better.

5 Experimental Study

In order to verify the correctness of the simulation analysis and the practicability of the control method, a crane is taken as the research object, and the experiment is carried out with the same parameters. The results are shown in figure 13～14.

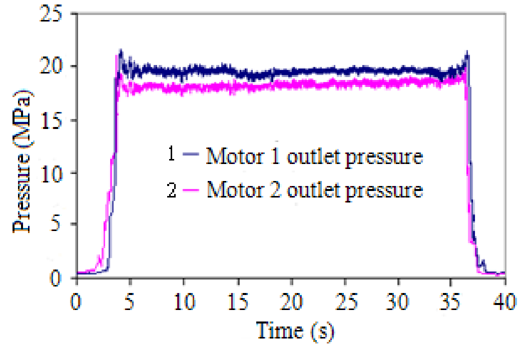

Figure 13 Traditional PID control

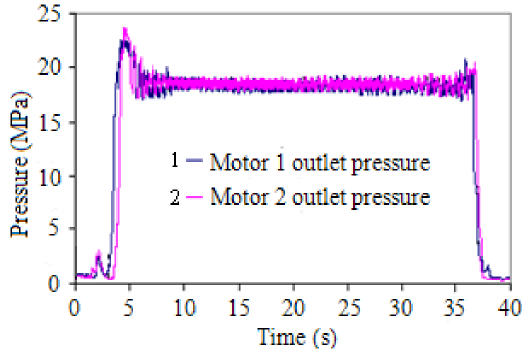

Figure 14 Fuzzy neural PID control

The results of above experiments show that the fuzzy neural PID control strategy has strong anti-interference ability, which greatly reduces the pressure difference between the two subsystems, further improves the control accuracy, and verifies the correctness of the simulation results.

6 Conclusion

In order to improve the precision of double motor synchronous control, the dynamic characteristics of the hydraulic lifting system are analyzed, and we find out the relationship among the parameters. By combining fuzzy control with neural network control, a fuzzy neural PID control strategy is proposed, which overcomes the shortcoming of the traditional PID control strategy lacking of adjustment on line. The simulation and experimental results show that the method has good dynamic response and robustness, high control precision, furthermore, it has certain value for applications.

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