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AN APPLICATION OF NEURO - FUZZY ADAPTIVE PID CONTROLLER A DIRECT DIVE VOLUME CONTROL HYDRAULIC PRESS

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Abstract*-A new kind of volume control servo hydraulic press is presented in this paper. Electro-hydraulic actuators (EHAs) is a very nonlinear system and have a wide range of applications where force or position control with high accuracy is exceedingly necessary. Among them, hydraulic press machines applied EHAs are more and more used in the heavy industry. This paper presents a Neuron Fuzzy Adaptive PID controller for the development of high Position control precision in the hydraulic press machines. The mathematic model is constructed at first based on the physical laws. Then, the main control unit employs the Neuron Fuzzy Adaptive PID structure of which membership function (MF) optimization is considered as a system identification problem. A smart selection procedure (SSP) is implemented to pick out only fuzzy input and output MFs activated at each running step, to minimize the control error and change in error. Step response and position tracking are implemented on this system. Simulation results demonstrate that the Neuron Fuzzy Adaptive PID controller has effectively improved the performance as compared with the conventional PID controller.*

Keywords: Direct drive position servo system, Adaptive control, Position controlling, Hydraulic Press

1. INTRODUCTION

Electro-hydraulic proportional systems have been frequently used in large erecting mechanism of many machineries and equipment, for example, the crane, hydraulic press and some armaments. Because they provide many advantages compared to electric motors, including high power capability and mechanical efficiency, good positioning capability, and fast response characteristics. However, the hydraulic systems have many uncertainties, time varying and highly nonlinear characteristics due to the flow pressure relationship, oil leakage, dead zone of valve, volume flow unbalance of asymmetrical cylinder, oil temperature variation and so on [1]. Hydraulic press is widely used in machinery manufacture fields such as hydraulic punching, pressing and bending machines, and molding technology because of its high power/mass ratio, fast response, high stiffness and high load capability. A typical hydraulic press is shown in Fig. 1.

Fig.1: A typical hydraulic press.

However, the conventional hydraulic press adopting the valve-controlled hydraulic system has had such drawbacks as complex structure, much energy consumption, plentiful heat generation, high noise, serious vibration, high precision requirement of oil filtrating and throttle losses at the control valves.

With the gradual maturity of motor speed governing and servo control techniques, the volume control electro-hydraulic servo systems driven directly by various kinds of servo motors have emerged in recent years, which overcome the disadvantages of valve-controlled system radically. With the research and development of mathematics, control theory, computer technology, electronic technology and the basic theory of hydraulic, hydraulic control technology has been greatly developed and has been widely used in the aerospace, military and civilian industries. However, the certain deficiencies of valve control servo system, such as medium high requirements, components short life, low efficiency, energy waste and so on, which have limited the application of the technology. Direct drive volume control electro-hydraulic servo system was the product of the combination of servo motors and hydraulic technology and was the technological achievements of cross-disciplinary integration over the past decade. Electro-hydraulic servo control system has the double advantages that the flexibility of motor control and hydraulic large output, in certain situations, it can replace the use of servo valve hydraulic servo systems, especially for dual-use electro-hydraulic servo system [2]. Furthermore, the closed volume control loop driven by servo motor directly possess a series of advantages such as wide speed governing range, high control accuracy, good performance of energy saving, and easy realization distribution intelligent control with wire to transfer power instead of steel tube[3, 4]. Since Sprockhoff introduced the pump controlled motor loop into the control of hydraulic cylinder and studied the dynamic behavior of pump-controlled symmetrical cylinder in 1979, many kinds of closed volume control loops are put forward to solve the balance of volume flow and to improve the response frequency of the volume control system [5]. The performances similar to valve-controlled system are obtained. The volume control electro-hydraulic systems have been used in plastic injection moulding machine, aircraft actuation system and mobile machinery. This technique has also caused the extensive attentions in Japan owing to its energy saving characteristic. The direct drive volume control hybrid servo pump has been developed, and applied in CNC pipe bending machines and hydraulic servo control of steering system for ship successfully [6, 7]. In China, much research work has been done on the properties and efficiency of valveless electro-hydraulic servo system [8, 9, and 10]. It can be seen that the valve less volume control system is an ideal approach to overcome the disadvantages of traditional valve controlled hydraulic systems. Thus, it has been improved and applied rapidly in the past 20 years.

In this paper, the volume control technique is introduced into the field of hydraulic press servo control to reduce energy consumption. A kind of novel volume control hydraulic press driven directly by SRM is developed to substitute the SRM direct drive volume control system for the primary valve-controlled system. However, the SRM direct drive volume control electrohydraulic servo system similar to other hydraulic systems is inherent in having many uncertain, time-variant and highly nonlinear characteristics due to the flow–pressure relationship, oil leakage, dead zone of SRM, volume flow unbalance of asymmetrical cylinder, etc. Consequently, the conventional control approaches based on a linear model may not guarantee satisfactory control performance for the SRM direct drive volume control position servo systems.

In order to solve the electro-hydraulic servo control problems, some research efforts on adaptive control approaches were made. One of the intelligent control methods is fuzzy control which imitates the logical thinking of humans and is independent from accurate mathematical model of the controlled object. Accordingly, the fuzzy control has extensively been implemented in electro-hydraulic servo control for overcoming some shortcomings of the traditional PID. An adaptive fuzzy controller was used to control two processes of upsetting and thixoforging for a hydraulic forging machine [11]. A new fuzzy controller using the phase plane was proposed for an electrohydraulic fin servo system of a missile [12]. The hydraulic punch trajectory was assured by a fuzzy logic controller that was proved to have a good relation between performance and difficulty to implement and tune [13]. A two-degree-of-freedom fuzzy controller, consisting of a one-step-ahead fuzzy prefilter in the feed-forward loop and a PI-like fuzzy controller in the feedback loop, has been proposed for foot trajectory tracking control of a hydraulically actuated hexapod robot [14]. An integrated fuzzy controller comprising of a feed forward controller and a fuzzy tracking controller was proposed to achieve a synchronous positioning objective for a dual-cylinder electro-hydraulic lifting system [15]. However, the design of fuzzy rules depends largely on the experience of experts or input–output data. There is no systematic method to design and examine the number of rules, input space partitions and membership functions. The control precision is usually not ideal because the fuzzy control is a nonlinear method and the output of the controller has a static error. For these reasons, the fuzzy PID control which combines the traditional PID control and the fuzzy control algorithm has proved to be a good solution. In order to improve pressure control and to adapt it to the variations, a self-adjusting hybrid fuzzy PD controller was used to meliorate the dynamic and static behavior in the control of variable displacement pumps. The pressure control experience indicates that self-adjusting fuzzy PD controllers could effectively be applied to hydraulic systems with variable loads [16]. A researcher introduced a PID controller tuning by genetic algorithm and fuzzy logics for sharp memory alloy actuators [17].

In this paper, a Neuron Fuzzy Adaptive PID controller is introduced and which can adaptively capable to solve the position servo control of SMR direct drive volume control hydraulic press. This controller is designed to compensate nonlinearity of the system. To demonstrate the effectiveness of the controller, a series of simulation are performed in this system. The simulation results show that it can improve the performance and robustness of the system response to the nonlinearity. And the Neuron Fuzzy Adaptive PID control scheme performs more accurate response and better stability, as compared with the conventional PID control.

2. WORKING PRINCIPLE OF DIRECT VOLUME CONTROL HYDRAULIC PRESS

The working principle of the volume control hydraulic press is illustrated in Fig. 2. The flow pressure, volume and direction of working medium can be controlled by using a motor to drive the axial piston pump directly. Hence the movement speed, position and direction of hydraulic press slider are controlled by pump without valve. The volume control module is made up of a bi-directionally dischargeable pump and an asymmetric piston cylinder, and controls the movement velocity, position, pressure and direction of piston by changing the turning speed and direction of pump. The auxiliary hydraulic loop module is composed of two relief valves and two check valves connected with oil tank and the oil pipes of main loop. The relief valves play a role of unloading when overload and the check ones solve the unbalance of volume flow between the rod-side and piston-side. When the piston moves downwards, the pump delivers the hydraulic oil towards piston head but with less volume of oil returned from the rod side. The supplement of oil is insufficient in the inlet of pump and the pressure in rod side decreases. The check valve is opened reversely and the shortage of oil is suctioned from oil tank. However, as the piston movesupwards, the quantity of outflow oil in piston side is more than that of the inflow oil in rod side. As shown in Fig. 2, the pilot check valve is opened reversely to return the surplus oil to the reservoir by the control pipe shown in dot line. The balance of flow volume is realized for the volume control of asymmetric cylinder.

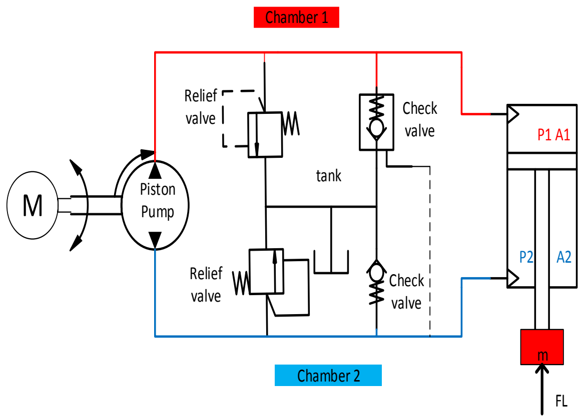


Fig.2: Schematic diagram of the direct-drive volume control hydraulic press

3. MATHEMATICAL MODEL OF DIRECT ELECTRO-HYDRAULIC SERVO SYSTEM

3.1 Flow Continuity Equation

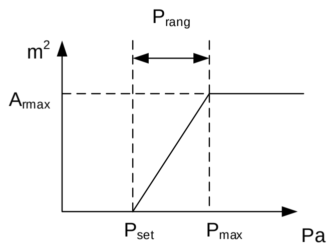
Applying the continuity equation to the fluid flowing in each chamber of the cylinder. In chamber 1 and 2, following expressions can be derived.

$$\frac{dP_1}{dt} = \frac{\beta}{V_{1(x)}}\left(Q_1 - Q_{r1} + Q_{ck1} - A_1\dot{x} - \lambda(P_1 - P_2)\right) \quad (1)$$

$$\frac{dP_2}{dt} = \frac{\beta}{V_{2(x)}}\left(-Q_1 - Q_{r2} + Q_{ck2} + A_1\dot{x} + \lambda(P_1 - P_2)\right) \quad (2)$$

where, Q_1 the flow rate of pump is given by $Q_1=D_p n_p$, $Qr_1$the flow rate through the relief valve 1, $Qck_1$the flow rate flow rate going from tank to chamber 1, Qr_2 the flow rate through the relief valve 2, Qck2 the flow rate flow rate going from tank to chamber 2, Qr1 the flow rate through the relief valve 1, A_1 piston side cylinder area, A2 rod side cylinder area. λ the leakage coefficient of cylinder.

The orifice equations can be depicted by following way



$$Q_{r1} = C_d A_{r1}\sqrt{\frac{2}{\rho}P_1}$$

$$Q_{r2} = C_d A_{r2}\sqrt{\frac{2}{\rho}P_2};\ A_r = \begin{cases} 0, & P \le P_{set} \\ \dfrac{A_{rmax}(P-P_{set})}{P_{rang}}, & P_{set} < P < P_{max} \\ A_{rmax}, & P \ge P_{max} \end{cases} \quad (3)$$

where, p is pressure differential across the valve, $P_{rang}$is regulation range, P_{set} is valve pressure, P_{max} is maximum pressure, and A_{max} is full open valve passage are.

And the check valve equations can be depicted by following way

$$Q_{ck1} = C_d A_{ck1}\sqrt{\frac{2}{\rho}|P_1|}$$

$$Q_{ck2} = C_d A_{ck2}\sqrt{\frac{2}{\rho}|P_2|};\ A_{ck} = \begin{cases} 0, & P_B < P_A \\ A_{ckmax}, & P_B > P_A \end{cases} \quad (4)$$

3.2 Dynamic Equation

Based on the Newton's law of motion, the force balance equation of the cylinder can be obtained as follows

$$m\ddot{x} = P_1A_1 - P_2A_2 - B_p\dot{x} - F_L \quad (5)$$

where, m is equivalent mass of the piston including the slider and die. F_L is the external load, B_p is viscous friction coefficient.

4. SIMULINK MODEL OF THE SYSTEM

Simulink model has been developed for ensuring system response. Based on above descriptions, the simulation model using Matlab/Simulink is given by following Fig. 3 and the system response are shown in Fig. 4. From Fig. 4 it is cleared that piston of the cylinder is working properly and pressure inside of the chamber 1 and 2 are developing as a real system. It depicted that Simulink model is perfectly model.

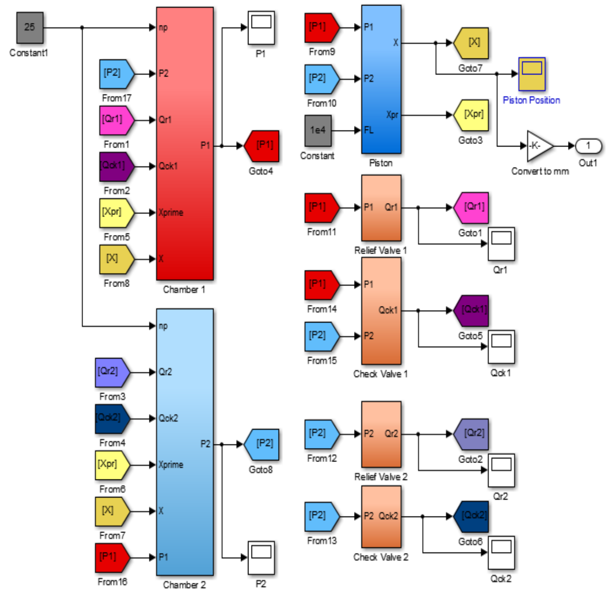


Fig.3: Simulink model of the system.

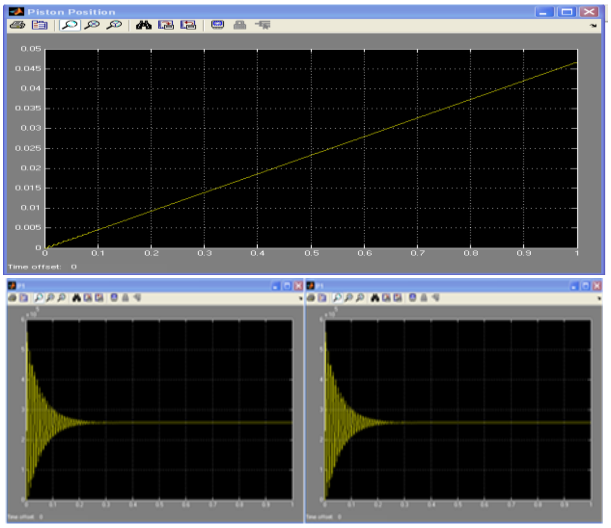


Fig.4: System response and pressure.

Parameters in this system are given in Table 1and this value are taken from a real system.

Table 1: The characteristic value of volume control hydraulic press

Parameters	Symbols	Values	Units
Pump speed	n	25	rpm
Piston side cylinder area	A_1	3.14e-2	m^2
Rod side cylinder area	A_2	1.18e-2	m^2
Density	ρ	870	kg/m^3
Discharge coefficient	C_d	0.6	
Mass	m	120	kg
Viscous friction coefficient	Bp	0.04	Ns/m
External load	F_L	0.6	N
Elastic stiffness of load	K	10e5	N/m
Leakage coefficient of cylinder	λ	7e-11	$m^3/s.Pa$
Displacement of pump	D_p	6e-5	m^3/rev

5. NEURON FUZZY ADAPTIVE PID CONTROLLER DESIGN

5.1 Structure and Principle of a PID Controller

PID controller consists of a Proportional element, an Integral element and a Derivative element, all three connected in parallel. All of them take the error as input. K_p, K_i, K_d are the gains of P, I and D elements respectively. The control signal can expressed in the time domain as in equation and Fig. 5 shows Simulink model of PID controller.

$$u_{PID}(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \qquad (6)$$

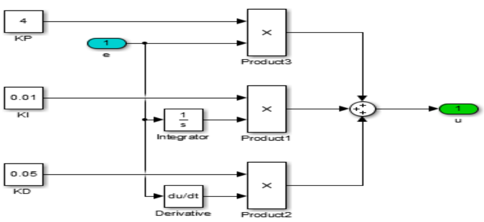


Fig.5: PID controller in Simulink

5.2 Structure and Principle of a Neuron Fuzzy Adaptive PID controller

The erecting system is a complicated nonlinear system as introduced in section 1. Applying the conventional PID controller is difficult to achieve high control precision and good performance due to the influences of the nonlinear and uncertain factors existed in the erecting system. Meanwhile, it is poor in turning parameters in different conditions. For these reasons, a Neuron Fuzzy Adaptive controller has been introduced in this paper. The structure of a Neuron Fuzzy Adaptive PID controller is shown in Fig. 6.

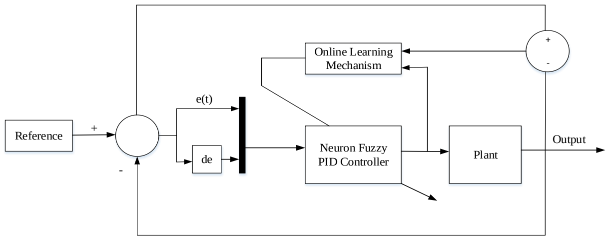


Fig.6: Structure of a Neuron Fuzzy Adaptive PID controller

By the fuzzy logic and neural network, the fuzzy PID tuners that the tune PID parameters can be established through this equation

$$K_a = K_{a0} + U_a \Delta K_a, U_a \in [0,1] \qquad (7)$$

where, U_a is the parameter obtained from the output of the neural-fuzzy controllers, $\Delta K_a = K_{a1} - K_{a0}$ is the allowable deviation of K_a, K_{a0}, K_{a1} are the minimum and maximum value of K_a determined from experiment. There are two inputs to the fuzzy controllers, one is error e(t) and another is derivative of error de(t). Structure of the fuzzy controller without using toolbox are shown in Fig. 7.

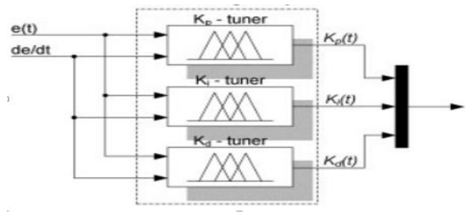


Fig.7: Structure of fuzzy controller.

For each input variables, triangle membership functions (MFs) are requested to use, those are shown in Fig. 8.

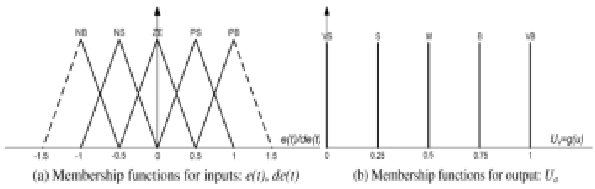


Fig.8: Fuzzy membership functions.

Membership functions can be expressed by equation and that is

$$f_{ji}(x)=\begin{cases}1+\dfrac{(x-a_{ji})}{b_{ji}^{-}} if\,(-b_{ji}^{-})\le(x-a_{ji})\le 0\\ 1-\dfrac{(x-a_{ji})}{b_{ji}^{+}} if\,0\le(x-a_{ji})\le(b_{ji}^{+}),\ j=1,2,......,N\\ 0(otherwise)\end{cases} \quad (8)$$

where, x is the input, a_{ji}, b^{-}_{ji} and b^{+}_{ji} are the centroid, left half width and right half-width of the jth triangle membership function of the ith input, respectively. N is the numbers of triangles.

For computing controller output Up, Ui, or Ud with a pair of inputs

$$u_i=\frac{\sum_{j=1}^{M}\mu_j w_j}{\sum_{j=1}^{M}\mu_j} \quad (9)$$

where, μ_j and Wj are the height and the weight of the control output. From the outputs Ua equation is

$$U_a=\frac{1}{1+e^{-u_i}} \quad \text{(a is P, I, or D)(10)}$$

The fuzzy PID controller is modified by using a neural network. The idea of the proposed controller is using a back propagation algorithm to tune the input membership functions shape and the weight of the controller outputs during the system operation process. The decisive factors of the input membership functions aj, bj and the weights of the outputs wj are automatically updated by using a neuron network. So, the following equation shows the back propagation algorithm. Consider an error function in equation (11) and back propagation algorithm in equation (12).

$$E=\frac{1}{2}(y-y_r)^2 \quad (11)$$

$$\begin{cases}a_{j(i+1)}=a_{ji}-n_a\dfrac{\partial E}{\partial a_{ji}}\\ b_{j(i+1)}=b_{ji}-n_b\dfrac{\partial E}{\partial b_{ji}}\\ w_{j(i+1)}=w_{ji}-n_w\dfrac{\partial E}{\partial w_{ji}}\end{cases} \quad (12)$$

$$\frac{\partial E}{\partial y}=e(t)=y(t)-y_r(t) \quad (13)$$

$$\frac{\partial y}{\partial u_{PID}}=\frac{\Delta y}{\Delta u_{PID}}=\frac{y(t)-y(t-1)}{u_{PID}(t)-u_{PID}(t-1)}$$

$$\frac{\partial u_{PID}}{\partial U_p}=\Delta K_p.e(t);\frac{\partial u_{PID}}{\partial U_i}=\Delta K_i.\int e(t)dt;\frac{\partial u_{PID}}{\partial U_d}=\Delta K_d.\frac{de(t)}{dt}$$

$$\frac{\partial U_a}{\partial u_i}=U_a(1-U_a);\frac{\partial u_i}{\partial w_i}=\frac{\mu_i}{\sum\mu_{ki}}$$

$$\frac{\partial E}{\partial a_i}=\frac{\partial E}{\partial u_i}\frac{\partial u_i}{\partial \mu_i}\frac{\partial \mu_i}{\partial a_i}=\frac{\partial E}{\partial y}\frac{\partial y}{\partial u_{PID}}\frac{\partial u_{PID}}{\partial U_a}\frac{\partial U_a}{\partial u_i}\frac{\partial u_i}{\partial \mu_i}\frac{\partial \mu_i}{\partial a_i}$$

$$\frac{\partial u_i}{\partial \mu_i}=\frac{\sum_{k=1}^{M}\mu(w_i-w_k)}{\left(\sum_{k=1}^{M}\mu_k\right)^2} \quad (14)$$

$$\frac{\partial \mu_i}{\partial a_i}=\mathrm{sgn}(x-a_i)\frac{2}{b_i} \quad (15)$$

The factor $\partial E/\partial b_{ji}$ can obtain by this way

$$\frac{\partial E}{\partial b_i}=\frac{\partial E}{\partial u_i}\frac{\partial u_i}{\partial \mu_i}\frac{\partial \mu_i}{\partial b_i}\frac{\partial \mu_i}{\partial b_i}=\frac{2|x-a_i|}{b_i^2} \quad (16)$$

Simulink model of the Neuron Fuzzy Adaptive PID controller shows in Fig. 9.

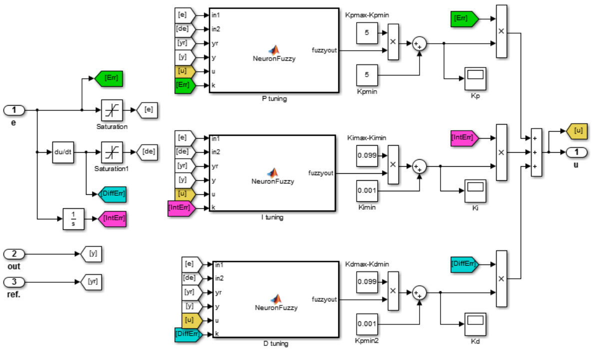


Fig.9: Neuron Fuzzy Adaptive PID controller in simulink

6. SIMULATION RESULTS

In order to demonstrate the performance of the Neuron fuzzy adaptive PID controller, some of simulations are implemented on the system under different conditions. The simulation model is built in versatile software Matlab/Simulink using the derived equations in section 5. Fig. 10 shows this simulation model, and Table 1 shows the characteristic parameters of the system.

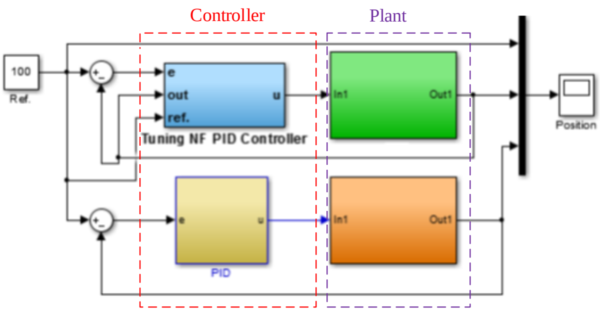


Fig.10: Simulink block diagram of the system

The step response simulation results of the position closed loop system by using PID and Neuron fuzzy adaptive PID control are shown in Fig. 11for the direct drive volume control hydraulic press. It can be seen that the step response speed of PID position closed loop control system increases and that the steady-state error of that decreases gradually with increase of kp, ki and decrease of kd, but the rising time is low. For going to pick point its takes time. Therefore, it is difficult to solve the contradiction between response speed and regulation time by using conventional PID control. However, Neuron fuzzy adaptive PID can realize the optimization among the response speed, steady-state precision and adjustment time, because it takes the strategy of adaptive regulating PID controller parameters.But the set speed of Neuron fuzzy adaptive PID is quicker than that of the traditional one, which shows that, for the anti-disturbance ability, Neuron fuzzy adaptive PID is superior to traditional PID. In Neuron fuzzy adaptive PID controller, there are no overshoot and the raising time is faster than the PID controller. It takes 0.5 for rising to peak value and the steady-state error become almost zero after 0.7Sec. So form Fig. 11 it is cleared that this introduced controller has better ability to adopt whatever the conditions.

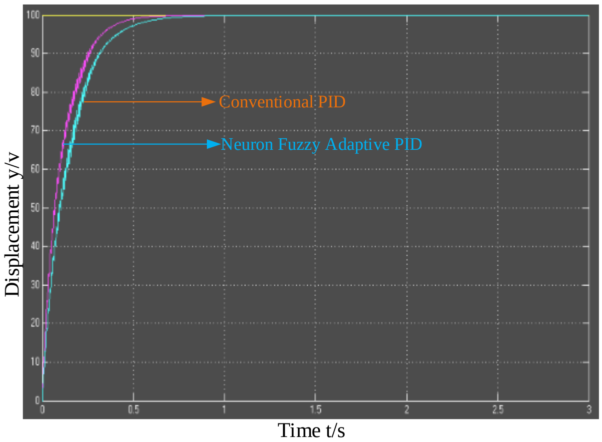


Fig.11: Simulation results of step response

7. CONCLUSION

This paper presents a volume control hydraulic press. Neuron fuzzy adaptive PID controller is developed and applied to the position servo control of hydraulic press slider successfully. On-line adaptive tuning of PID controller parameters is realized by using a fuzzy logic. The better performance and higher control precision have been obtained in the position servo control compared with conventional PID controller.

The simulations have been carried out to evaluate the effectiveness of the Neuron fuzzy adaptive PID control method for direct drive volume control electro-hydraulic servo system. The step response simulation show that the Neuron fuzzy adaptive PID controller solves contradiction between response speed and steady state, and realizes fast response and high accurate. The tracking simulation result demonstrate that the Neuron fuzzy adaptive PID controller presents faster and more accurate performance compared with the conventional PID controller.

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