Simulation of BP-PID Control for Electro-hydraulic Proportional Position Servo System

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Abstract—**The electro-hydraulic proportional position servo system is a kind of highly non-linear and time-varying system as well as parameter uncertainties. It is often difficult to achieve satisfactory control results with the traditional control methods. Considering that the adaptive neural network PID control method has the characteristics of online learning and adjustment PID control parameters adaptively, this paper puts forward to adopt BP-PID control method for the position servo control of electro-hydraulic proportional system. An online adaptive BP-PID controller is designed. The simulation model of the system is established based on Simulink platform. The step response and Sinusoidal tracking characteristics are researched through simulations and experiments. The results show that BP-PID has a strong ability of online learning and self-tuning PID parameters. Compared with the traditional PID control method, the BP-PID control has strong self-adaptability and robustness, and can significantly improve the step response speed and tracking control precision.**

Index Terms—**Electro-hydraulic proportional system, BP-PID control, Step response, Sinusoidal tracking**

I. INTRODUCTION

The electro-hydraulic proportional position servo system is extensively used in production and experiment at present. It can make the actuator to complete the appropriate actions in accordance with the requirements by controlling the pressure, flow rate and flow direction of working fluid. Hong has summarized the characteristics of the various electro-hydraulic servo systems, and indicated that it can realize complex program control and remote control by using electrical signals as well as has higher control precision by using feedback [1]. At the same time, Li and Ding have studied the position servo control of the electro-hydraulic proportional system. The results show that this kind of system is highly nonlinear and time-varying systems with parameter uncertainties, it is difficult to establish the precise mathematical model. Furthermore, the traditional control methods can not be met in practice with higher and higher performance requirements for control system [2-3]. The general PID control has the advantages of simple structure and easy implement, but it is far from being able to meet the requirements of complex electro-hydraulic coupling systems. Ding has discussed the performances of hydraulic servo system with PID controller, and pointed out that the parameters of general PID controller can't be adjusted according to the operation state of system, so it is poor in performance and ability of adapting to the environment [3]. Yousef has studied steam-hydraulic turbines load frequency control with the conventional PID controller, and the results proved that the PID controller had large overshoot and long settling time [4]. Furthermore, the conventional PID control is often dependent upon experience other than science. Therefore, people have been seeking the PID controller parameters self-tuning technology for a long time in order to meet the complex and high performance control requirements. Charles Nippert has obtained the optimal controller settings for a non-cylindrical tank by using an adaptive PID controller [5].

Neural network has been extensively studied and applied in the control field owing to its powerful capabilities of nonlinear mapping, parallel processing and self-learning. Quan has obtained the optimal self-adaptive PID control by using this kind of non-linear mapping relationship learning from the real system [6]. Yousef has successfully used neural network model predictive controller to improve dynamic performances of the power system over a wide range of operating conditions [7]. Wang and Xiao have designed BP-PID controller by combination of the neural network and PID control, and the simulation results have proved that BP-PID can automatically adjust the parameters of PID controller according to the state of system operation [8-9].

In this paper, the BP-PID controller has been established to carry out position servo control for the electro-hydraulic proportional system. The simulation and experimental results proved that the BP-PID control method can achieve performance optimization through self-learning and self-tuning the PID parameters, the response speed and control accuracy of which are superior to the traditional PID control.

II. PRINCIPLE AND COMPOSITION OF ELECTRO-HYDRAULIC PROPORTIONAL SYSTEM

The constitution diagram of electro-hydraulic proportional system is shown in Figure 1, which mainly consists of the servo cylinder, electro-hydraulic proportional directional valve, quantitative pump, relief valve, tank, displacement sensor and controller. Its basic working principle is as follow, the hydraulic oil flows into electro-hydraulic proportional directional valve after being pressurized by quantitative pump, subsequently, the pressurized hydraulic oil flows into the hydraulic cylinder to push the piston rod move. The movement direction and speed of piston rod is decided by the pressure, flow rate and flow direction of hydraulic oil flowing through the electro-hydraulic proportional directional valve. The opening degree and direction of electro-hydraulic proportional directional valve is controlled by voltage/current input to the electromagnet. The displacement sensor feed the piston rod position information back to the controller of electro-hydraulic proportional position servo system. The controller calculates the control signal according to the errors between the control target and feedback signal. Therefore, the closed loop control of piston rod movement speed and displacement can be realized.

According to working principle of the above electro-hydraulic proportional system, the simulation model is established by using Matlab7.5/simulink. This modeling method which directly uses the system components to establish the model avoids the defects existed in modeling process with the transfer function, for example, excessive simplification to the system, difficult to establish an accurate model.

The component parameters of simulation model are set based on CQYZ-D electro-hydraulic proportional control test bench established in this paper. The components needed to set parameter mainly include servo cylinder, electro-hydraulic proportional directional control valve and quantitative pump etc. In which, the type of electro-hydraulic proportional directional valve is 4WRE6E8-10B/24Z4/V, whose parameters are as follow, the path is 6mm, the maximum flow area is 2.7e-5 m^2, the maximum opening degree is ±4.5mm, the flow coefficient is 0.7, the critical Reynolds number is 12, the valve leakage is 1e-12 m^3. The parameters of servo cylinder are as follow, the diameter of hydraulic cylinder is 63 mm, the piston rod diameter is 36 mm, the maximum stroke is 0.15 m, the dead zone of hydraulic cylinder is 1e-4m^3, the contact stiffness is 1e7 N/m, and the contact damping is 650 Ns/m. The type of quantitative pump is 16MCM, the displacement of pump is 1.6e-5 m^3/rad, the volumetric efficiency is 0.9, the overall efficiency is 0.8, the rotational speed of pump is 200 rad/s, the coefficient of dynamic viscosity is 18 cSt. The name of hydraulic oil is HyJet-4A, the oil density is 981.986 kg/m^3, the coefficient of viscosity is 10.0367, the bulk modulus of elasticity is 1.2586e9 Pa.

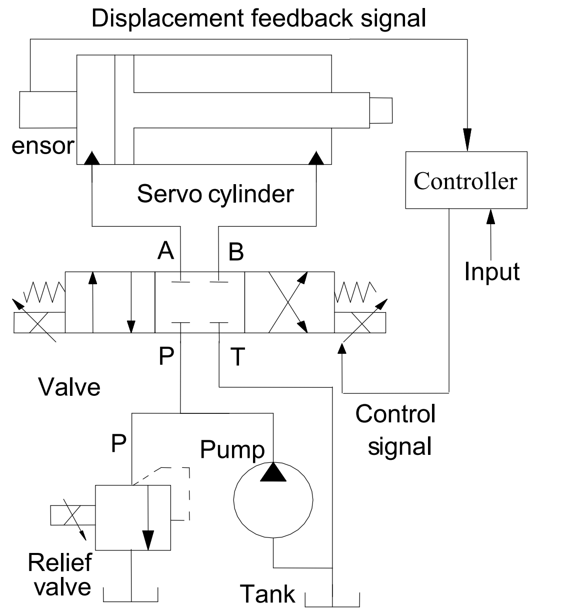

Figure 1. Schematic diagram of electro-hydraulic proportional system

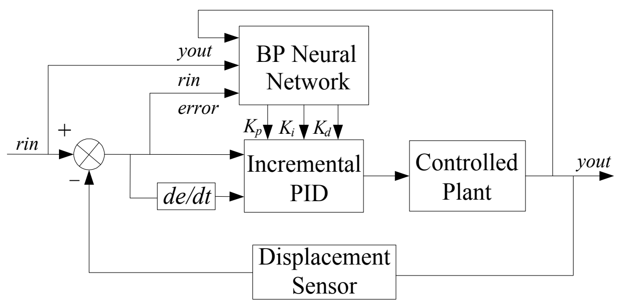

Figure 2. The structure diagram of BP-PID controller

III. PRINCIPLE AND COMPOSITION OF ELECTRO-HYDRAULIC PROPORTIONAL SYSTEM

In the field of industrial control, PID control is the most widely used control method. In order to get optimal control effect with PID control, the three control actions of proportion, integral and differentia must be adjusted adaptively. Both interaction and mutual restriction relationships existed in the above control actions, therefore, Zhang and Tu pointed out it was very difficult to find out the best nonlinear combination from boundless changes [10-11]. The neural network has the ability to express any nonlinear relationship and has strong robustness and adaptability, so it has been widely used in the field of industrial control. In this paper, a BP-PID control method which has the advantages of both is applied to improve the control effect of electro-hydraulic proportional position servo system.

A. The Principle of BP-PID Control

BP neural network is a kind of feed-forward network with multiple hidden layers, which is based on the gradient descent optimization method. The network errors are minimized by continuously revising the connection weights between neurons. Zhang and Tu have taken the advantages of BP neural network to improve the traditional PID control, and proved that BP neural network was a good choice to achieve optimal control for nonlinear industrial control plant [10-11].

BP-PID control is the combination of BP neural network and PID control. The structure of BP-PID controller established in this paper is shown in Figure 2. It mainly consists of two major parts of BP neural network and closed loop PID, in which, the classical PID controller completes the closed-loop control of controlled plant, the BP neural network modular completes adaptive adjustment the parameters of PID controller according to the system operation state.

B. Designing of BP Neural Network Modular

As shown in Figure 2, the inputs of neural network include three parameters, which are the input instruction *rin*, the actual output of the system *yout* and the error value between the input and output *error*. The outputs of neural network also include three parameters, which are the proportion gain K_p, integral time K_i and differentia time K_d. So the three layer structure of BP neural network is adopted in this paper, both input layer and output layer take three neurons correspond to input and output variable. The number of hidden layer neurons has a direct relationship with complexity of the problem and the number of input and output neurons. At present, there is no reasonable method to decide the number of hidden layer neurons, so the following empirical formula is often used to determine it.

$$q = \sqrt{n+m} + f \tag{1}$$

Wherein n and m are the number of input output layer neurons, q is the number of hidden layer neurons, f is the empirical constant, which often takes 1~10.

Based on the formula (1), $\sqrt{n+m}$ takes the value between 2~3, so the taking value interval of q is 3~13. Because too many of network neuron number may lead to increase the amount of calculation, and too little is not very good approximation to a given function. Taking all factors into account, the number of hidden layer neurons q takes the value 5 for the BP-PID controller. The structure of BP neural network established in this paper is shown in Figure 3.

IV. SIMULATIONS AND EXPERIMENTS OF BP-PID CONTROL

A. Simulation Model of BP-PID Control

The simulation model created in Simulink platform for BP-PID control of electro-hydraulic proportional system is shown in Figure 4, which mainly consists of two parts: BP-PID control module and electro-hydraulic proportional system module. According to the above BP-PID controller structure and BP neural network algorithm procedure, a Matlab function that can realize BP-PID control calculation is written to save in the folder of bin. The simulation model calls this Matlab function to complete BP-PID control calculation. The errors between the control instruction and the actual position of piston rod are feedback to BP-PID control module, and the simulation of closed loop BP-PID control can be realized for electro-hydraulic proportional system by using the model shown in Figure 4.

B. Simulations of BP-PID Control

Learning rate is a very important parameter in the learning process of neural network, which affects the stability and quickness of neural network learning. In this paper, a large number of simulations have been done to research the influences of learning rate upon the BP-PID performance, finally, it has been found that the performance of BP-PID control is optimal when the learning rate η=0.2 and inertia coefficient α=0.05.

The simulation results of step response are shown in Figure 5 by using the traditional PID and adaptive BP-PID control.

It can be seen that the PID parameters k_p, k_i, and k_d have an important influence upon the speed of step response in PID position closed-loop control of electro-hydraulic proportional system. The speed of step response markedly accelerates along with the increase of k_p, but the overshoot and oscillation start to occur and aggravate. So the traditional PID control that adopts fixed PID parameters is difficult to obtain the optimal control effect. The BP-PID control method can automatically adjust the PID parameters through self-learning according to the error between the control instruction and the actual position of piston rod, therefore, the optimization synthesis can be achieved among the response speed, steady-state accuracy and regulation time for the position servo control of electro-hydraulic proportional system.

In order to accurately compare the performances of two control methods, four performance index parameters of step response simulation with PID and BP-PID control are extracted, the results are shown in Table 1.

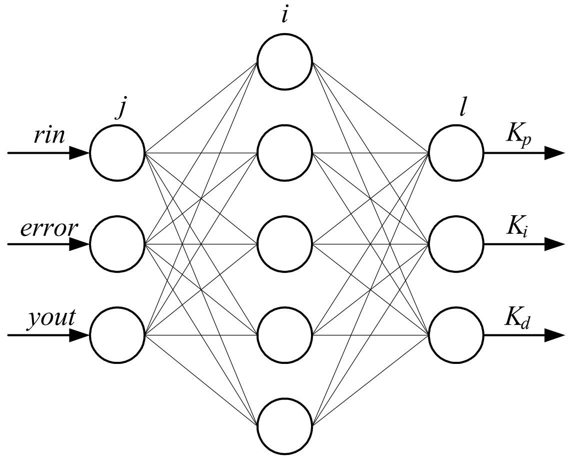

Figure 3. The structure of BP neural network

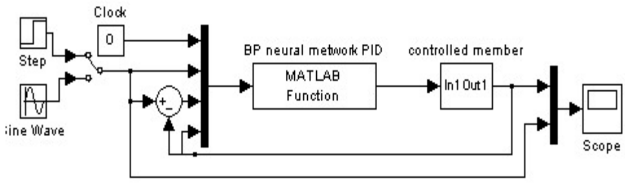

Figure 4. The BP-PID control simulation model

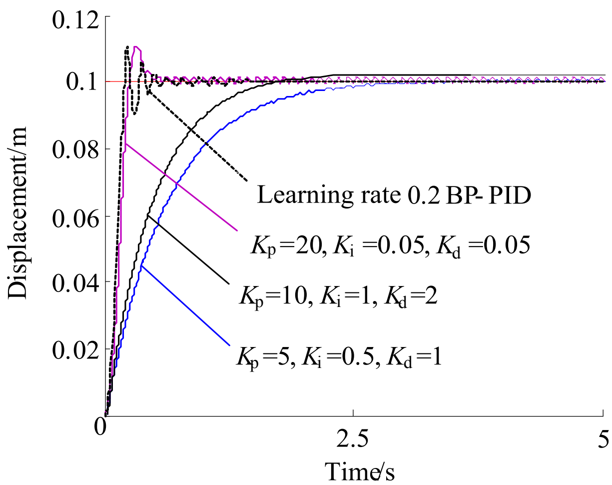

Figure 5. Simulation results of step response

TABLE I.
PERFORMANCE INDEXES OF STEP RESPONSE SIMULATIONS WITH PID AND BP-PID CONTROL

Condition of step response	Performance index			
	Rise time	*Setting time*	*static error*	*Overshoot pos*
K_p=20, K_i=0.05 K_d=0.05	0.2379	0.4622	0.001	10.7%
K_p=15, K_i=0.1 K_d=0.5	0.8272	0.9533	0.0009	2.37%
K_p=10, K_i=1 K_d=2	1.7537	1.4917	0.0014	0.6%
K_p=5, K_i=0.5 K_d=1	2.0869	2.2255	0.0007	0.50%
BP-PID	0.1945	0.5075	0.0003	10.36%

It can be seen that the performance indexes of BP-PID control is superior to traditional PID control except the early stages of learning for the electro-hydraulic proportional system.

The simulation results of Sinusoidal tracking are shown in Figure 6. It can be seen that a better control effect can be obtained with BP-PID control owing to adaptive adjustment the PID parameters according to the actual operation state of system. The Sinusoidal tracking result with traditional PID control has the longer delay time and larger tracking error, whose maximum values reach 0.003m. However, the Sinusoidal tracking result with BP-PID control is essentially coincident with the target curve, the delay phenomenon almost completely disappeared, and the maximum tracking error is only 0.0003m. Therefore, the BP-PID control is effective to eliminate the phenomenon of time delay, and can dramatically improve the tracking precision compared with the traditional PID control.

C. Experiments of BP-PID Control

According to the above working principle of electro-hydraulic proportional system shown in Figure 1 , the CQYZ-D electro-hydraulic proportional control test bench developed in this paper is shown in Figure 7.

In which, the computer control system accomplishes data acquisition and closed loop control of electro-hydraulic proportional position servo system. The programs of data acquisition and BP-PID control are developed based on Labview virtual instrument development platform. The performances of electro-hydraulic proportional position servo control were studied by a large number of experiments. The proposed BP-PID control algorithm is proved to be effective for the servo control of electro-hydraulic proportional system.

Figure 8 is the experimental results of position closed-loop step response by using PID and BP-PID control for electro-hydraulic proportional system. It can be seen that both the step response speed and steady state accuracy of BP-PID control are superior to the traditional PID control.

The specific performance indexes of step response for PID and BP-PID control are shown in Table 2. The great differences can be seen between the experiment and simulation results through the comparison of Figure 5 and Figure 8. The emain differences are manifested in system delay and overshoot. In experiment, serious delay phenomenon existed in electro-hydraulic proportional system has been observed, but in simulation, almost no delay phenomenon is found. Meanwhile, the overshoot and oscillation in experiment are far less than that in simulation, and the step response speed and steady state accuracy in experiment are lower than that in simulation. The reason is that many nonlinear factors such as dead zone, time-lag and friction are ignored in the modeling process by using Simulink.

Figure 9 is the experiment results of Sinusoidal tracking by using PID and BP-PID control for electro-hydraulic proportional system. The results show that the tracking accuracy of BP-PID control is significantly higher than that of traditional PID. The tracking curve of BP-PID control is coincidental with objective curve, the maximum tracking errors are 0.00128m. However, the phenomenon of time delay exists between the system output and control objective with traditional PID control, the maximum tracking errors are 0.0058m.

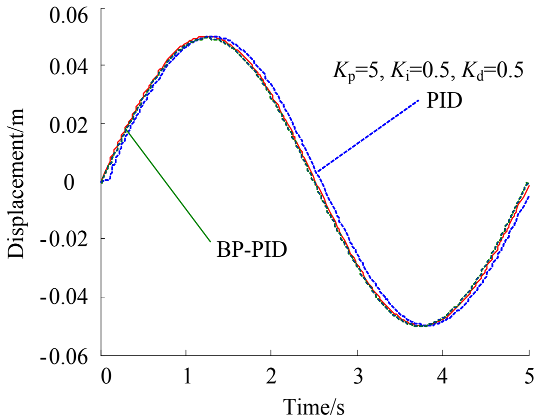

Figure 6. Simulation results of Sine tracking

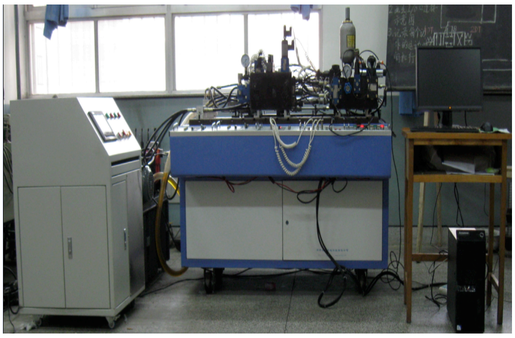

Figure 7. CQYZ-D electro-hydraulic proportional control test bench

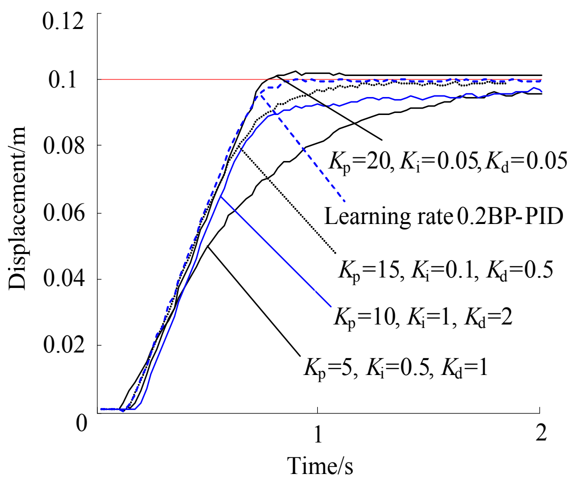

Figure 8. Experimental results of step response

TABLE II.
PERFORMANCE INDEXES OF STEP RESPONSE EXPERIMENTS WITH PID AND BP-PID CONTROL

Condition of step response	Performance index			
	Rise time	*Setting time*	*static error*	*Overshoot pos*
K_p=20, K_i=0.05 K_d=0.05	0.78	1.08	0.001	1.39%
K_p=15, K_i=0.1 K_d=0.5	1.0047	1.35	0.0015	No
K_p=10, K_i=1 K_d=2	1.246	3.70	0.0018	No
K_p=5, K_i=0.5 K_d=1	1.615	4.10	0.0026	No
BP-PID	0.8571	0.93	0.0006	0.64%

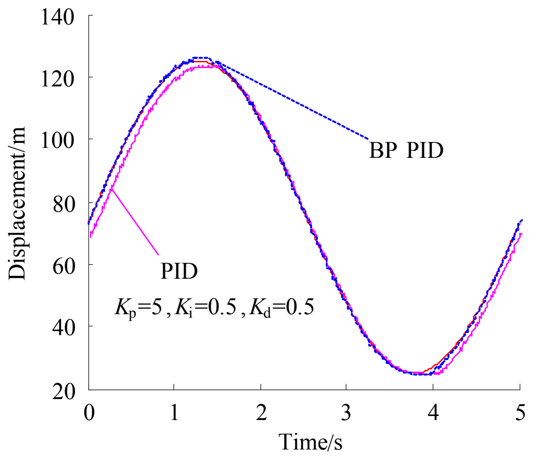

Figure 9. Experimental results of Sine tracking

From the above researches we can see, because the BP-PID control takes the control strategy of self-learning to adjust the PID parameters according to the running state of the system, the response speed and control precision of BP-PID are markedly superior to traditional PID control, and it can better meet the needs of position servo control for electro-hydraulic proportional system.

V. CONCLUSIONS

This paper presents a kind of BP-PID control method for the position servo control of electro-hydraulic proportional system. The simulation model is established based on Simulink, and the BP-PID controller is developed based on Labview virtual instrument development platform. The step response and Sinusoidal tracking performances with the conventional PID and BP-PID control are studied by a large number of simulations and experiments. The results are as follows, the BP-PID control has powerful abilities of self-learning and self-adaption. Both the step response speed and steady state accuracy of BP-PID control are superior to the traditional PID control. The main differences between the experiment and simulation results are manifested in system delay and overshoot. The overshoot and oscillation in experiments are far less than that in simulations, and the step response speed and steady state accuracy in experiments are lower than that in simulations. On the other hand, the Sinusoidal tracking accuracy of BP-PID control is also significantly higher than that of traditional PID. In experiment, the tracking curve of BP-PID control is coincidental with objective curve, the maximum tracking errors are only 0.00128m, however, the phenomenon of time delay exists between the system output and control objective with traditional PID control, the maximum tracking errors are 0.0058m. According to the research results we can see that the BP-PID control method proposed in this paper can better meet the needs of position servo control for electro-hydraulic proportional system.

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REFERENCES

[1] Hong Y. U. Nonlinear control for a class of hydraulic servo system. Journal of Zhejiang University Science, 5(11): 1413-1417, 2004. http://dx.doi.org/10.1631/jzus.2004.1413

[2] Li X. L., Xia Q. X., Zhou S. C. Technology and Strategy of Electro-hydraulic Proportional Control and Its Application in the Forging Equipment. Machine Tools and Hydraulics, 38(11): 119-126, 2010.

[3] Ding S. G., Wu W. P., Gui G. S. The Research of Hydraulic Servo System Control on Neural Networks PID. Control and Test, 3: 49-51, 2009.

[4] Yousef, Ali M., Khamaj, Jabril A., Oshaba, Ahmad Said. Steam-hydraulic turbines load frequency controller based on fuzzy logic control. Research Journal of Applied Sciences, Engineering and Technology, 4(15): 2375-2381, 2012.

[5] Charles Nippert, Rebecca Coburn, Brendan Shea. Adaptive Control of a non-cylindrical tank. International Journal of Online Engineering, 9(2): 50-52, 2013. http://dx.doi.org/10.3991/ijoe.v9i2.2546

[6] Quan L. Current state, problems and the innovative solution of electro-hydraulic technology of pump controlled cylinder. Chinese Journal of Mechanical Engineering, 44(11): 87-92, 2008. http://dx.doi.org/10.3901/JME.2008.11.087

[7] Yousef, Ali M. Neural network predictive control based power system stabilizer. Research Journal of Applied Sciences, Engineering and Technology, 4(8): 995-1003, 2012.

[8] Wang A., Li X. J. The application of BP neural network PID control system in blow molding machine. The computer simulation, (29): 153-156, 2010.

[9] Xiao C. Q., Zheng L. C., Xiao Z. F. Research on Self-turning of PID Control Based on BP Network in Synchronous Control of Push Bed. Machine Tools and Hydraulics, 39(17): 29-32, 2011.

[10] Zhang X. Y., Gao P. J., Liu Y. The Researching and Simulation of BP Neural Network PID Controller in Industry's Control System. Control Theory and Applications, 29(5): 9-12, 2010.

[11] Tu C. C., Zhu F. W., Li T. Study and Simulation of BP Neural Network PID Controller. Chinese Agricultural Mechanization, (2): 151-154, 2012.

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