Adaptive Fuzzy PID Control for Servo Motor Direct-drive Pump Control System

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ABSTRACT: The direct-drive pump control system has been gradually applied to the industrial control field due to its high control precision, fast response, small throttle loss and compact structure. This paper adopts the fuzzy PID control method to resolve the hydraulic cylinder position servo control of direct-drive pump control system. The system model and fuzzy PID control algorithm was established by using AMEsim/Simulink joint simulation platform. The step response and Sine tracking performance of the system with PID and fuzzy PID control algorithms was investigated by simulation. At the same time, the performance of PID and fuzzy PID control was studied on the self-developed electro-hydraulic servo control experiment table. The results show that the adaptive fuzzy PID control can greatly improve the performance of the PID control, and has the characteristics of fast response, short rise time, small time delay and overshoot.

Categories and Subject Descriptors:
I.5 [Pattern Recognition]: I.5.1 [Fuzzy Models]: I.2.8 [Problem Solving]: Control Methods, and Search

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1. Introduction

The hydraulic servo system, especially the electro-hydraulic servo system has been played a very important role in the field of military, aviation and industrial automation. It has been applied extensively when the high-power, rapid and accurate reaction control system comes to need to use. In the field of defense industry, the electro-hydraulic servo system is mainly used for the manipulation control system of aircraft, missile and artillery, etc, and in general industrial areas, it was mainly used in the control system of machine tools, metallurgy and steel rolling, construction machinery and ship, etc [1]-[2]. Therefore, research and development of the hydraulic servo control system has great significance. The electro-hydraulic servo system can be divided into two categories of valve control and pump control. Currently the most widely used is the valve control system which has the shortcomings of high requirements to the media, short lifetime of components, low efficiency, large waste of energy and so on, so the application of this system was limited in many occasions [1]. Direct-drive pump control electro-hydraulic servo system is the product of the combination of the AC servo motor technology and hydraulic technology. The most important feature of this system is that the hydraulic cylinder is driven by bidirectional constantflow pump which is driven by the AC servo motor directly. The control of movement direction and speed of the piston-rod of hydraulic cylinder is realized by changing the rotating direction and speed of the servo motor. The advantages of this system are that a more ideal power match between the hydraulic source and load can be achieved as well as low power loss, high efficiency and compact structure [2].

However, as the same with all other hydraulic systems, the direct-drive volume control electro-hydraulic servo systems also have serious non-linear characteristic due to their own characteristics and the external interference factors, the traditional PID control method is difficult to meet the requirements of static and dynamic specifications of the system. Compared with the conventional control methods, the fuzzy control method does not require a precise mathematical model and has better robust, so it has been implemented in many industrial fields successfully [5]-[10], but the ability of fuzzy control itself to eliminate the steady state error is relatively poor. In this paper, in order to meet adaptive adjustment of the controller parameters and improvement the ability to eliminate the steady-state error, the fuzzy control is utilized to improve the classical PID control. Self-tuning PID parameters is achieved by adding a fuzzy inference module to the PID controller. The position servo control is realized for direct-drive pump control system. The simulation and experimental results show that the method has good dynamic characteristics and strong robustness to external interference.

2. Composition and working principle of the direct-drive pump control system

Direct-drive pump control system established in this paper as shown in Figure 1, the system is mainly composed of the servo motor speed control module, closed volume control module, computer control module, auxiliary hydraulic loop module and loaded module.

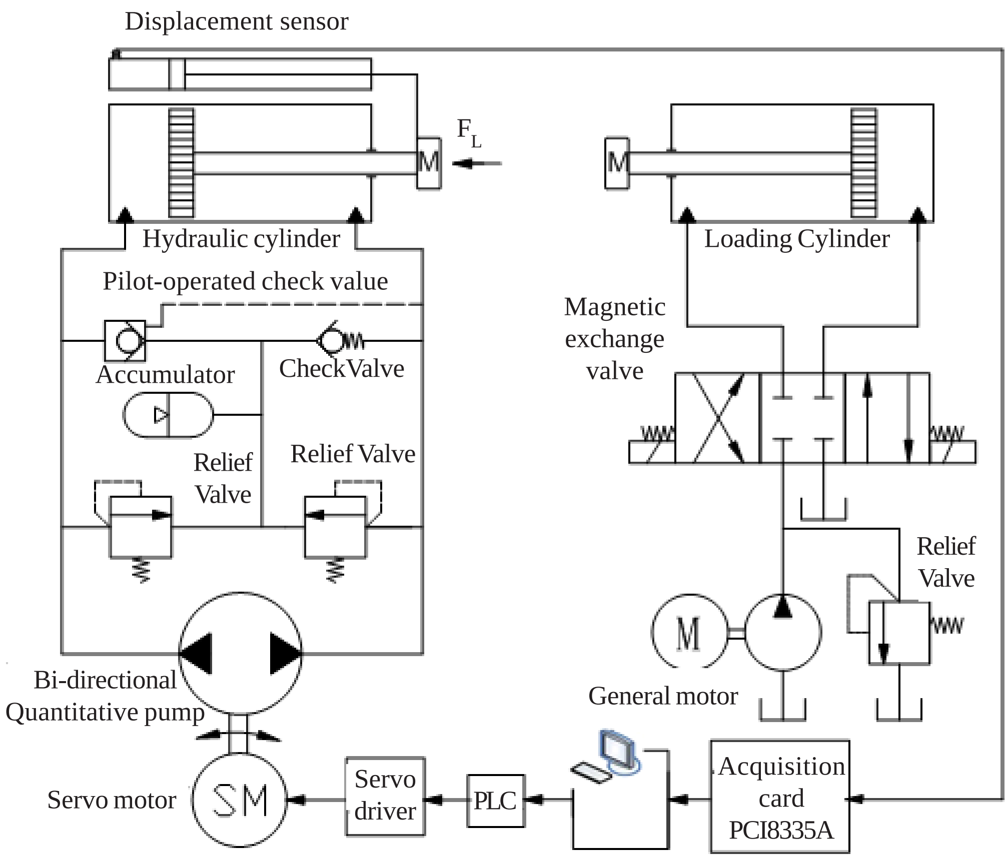


Figure 1. Schematic diagram of direct-drive pump control system

The motor speed control module includes servo motor and servo driver, which completes the control of motor speed, angle and torque. The closed volume control module is composed of the bi-directional axial piston pump and piston cylinder, which controls the speed and direction of piston by controlling flow rate, pressure, rotation direction of the pump. The auxiliary hydraulic loop module consists of the relief valve, check valve, pilot-operated check valve and accumulator, in which, the two relief valves connected with tank and main oil circuit play a role of unloading when overload, the check valve and pilot-operated check valve are mainly to solve the flow balance of the asymmetric piston cylinder between the rod-side and the piston-side, the accumulator plays the functions of the oil storage and oil leakage. The working principle of auxiliary hydraulic loop module is as follow, the discharge of low pressure oil in rod side is less than the inflow of high-pressure oil in piton side when the piston extended, so the supplement of oil is insufficient in the inlet of pump, at this time, the check valve opens reversely and the shortage of oil is suctioned from accumulator; on the contrary, the quantity of outflow oil in piston side is more than outflow oil in rod side when the piston retracts, the pilot-operated check valve opens reversely to the accumulator through the control circuit shown in dot line, therefore, the flow balance between rod side and piton side of the hydraulic cylinder is realized for the bi-directional axial piston pump. The loaded module is a conventional valve control cylinder system, shown in right side of Figure 1.

3. Simulation model of pump control cylinder system based on AMEsim/Simulink

AMEsim is a kind of modeling and simulation software developed by the French company for fluid, driving system and hydraulic/mechanical system, which provides users with a modeling method based on the principle diagram of the system, it is easy for engineering and technical personnel to grasp and use [3]. Simulink in Matlab simulation platform can be easily used to set up the various models and change the simulation parameters with the help of powerful calculation function of Matlab. Because AMEsim provides interface with Matlab software, this paper takes AMEsim as modeling and simulation tool for hydraulic system, and Simulink as design platform for control system. Point-to-point AMEsim-Simulink interface provides a convenient and effective tool for coupling analysis between the controlled object model and control system model. At the same time, taking the advantages of AMEsim and Simulink, the reconstruction of complex model is avoided between the different platforms [4].

Under the AMESim/Simulink joint simulation environment, the simulation model established based on the above direct-drive pump control system is shown in Figure 2.

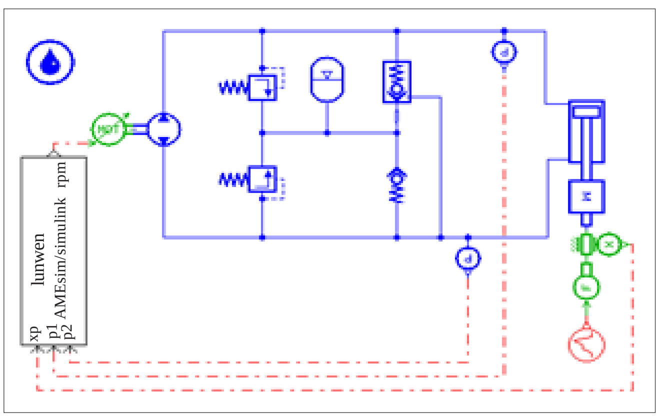


Figure 2. The AMESim/Simulink simulation model of pump

The system parameters is set as follows, the piston diameter is 36mm, the cylinder diameter is 63mm, the hydraulic cylinder stroke is 0.15m, the max motor speed is 1500r/min, the pump displacement is 16mL/r, the adjusting pressure of relief valve is 7MPa; the nominal flow rate of the hydraulic pipe is 40 L/min, the damping ratio is 0.7, the displacement sensor gain is 10, other parameters use default value.

The specific implementation process of AMESim and Simulink joint simulation is as follow, the sub-model of direct-drive pump control system established in AMESim generates the S-function that can be used by Simulink through the system compiling and parameter setting, etc, then the S-function generated from AMEsim model is added to the Simulink model of the system in Simulink simulation environment, thereby the joint modeling and simulation is achieved based on the AMESim/Simulink.

4. Fuzzy PID controller design for direct-drive pump control system

4.1 Structure of adaptive fuzzy PID controller

Based on the characteristics of direct-drive pump control system, a kind of adaptive fuzzy PID controller is designed by combination the advantages of PID control and fuzzy control in this paper. Its structure is shown in Figure 3. A fuzzy reasoning module is added to the conventional PID controller, which can adaptively adjust PID parameters k_p, k_i, k_d according to the error and change in error. The fuzzy reasoning module adopts the structure of two input variables and three output variables. The input variables are error e and change in error ec. The output variables are increment Δk_p, Δk_i, Δk_d of the PID parameters k_p, k_i, k_d. The fuzzy reasoning module establishes the nonlinear mapping relationship between inputs and outputs by making use of the PID controller parameter tuning experience knowledge and fuzzy set theory. Real-time adjustment the PID parameter is achieved according to the control system parameters and control errors, and the control system performance and the ability to adapt to the environment are improved.

4.2 Adaptive fuzzy PID controller design based on Labview

This paper develops the fuzzy PID controller by using the graphical virtual instrument software Labview 8.2 and the Fuzzy Logic Toolbox (Fuzzy Control Toolkit). The design steps are as follows:

4.2.1 Fuzzification of Input and output variables

Fuzzification processing is accomplished with Fuzzy Set Editor in Labview development environment. First run the Fuzzy Logic Controller Design module, then set the fuzzy domains of input and output variables as well as the shapes of membership function of each linguistic variable in Fuzzy Set Editor, see Figure 4. All of the input and output variables adopt the triangular shape membership function in this paper. The domain ranges of the input and output variables are all transformed into uniform fuzzy domain [–6, 6], and which is divided into seven language variables of positive big (PB), positive middle (PM), positive small (PS), zero (ZO), negative small (NS), negative medium (NM) and negative big (NB).

4.2.2 Establishment the fuzzy inference rules

The fuzzy inference style is set as "*IF THEN*" with Rulebase Editor in Fuzzy Logic Controller Design module, see Figure 5, then the appropriate inference algorithm and reconciliation fuzzy method are determined. In this paper, 49 fuzzy inference rules are established based on the expert knowledge and simulation results. The weighted value of each rule is set as the default 1. Max-min fuzzy reasoning algorithm is used to conducted fuzzy synthesis, and the maximum membership degree method is applied to de-fuzzy.

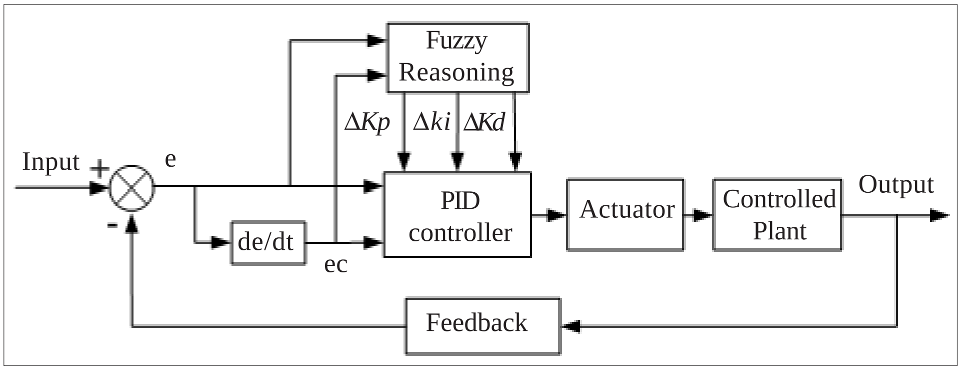


Figure 3. Structure of adaptive fuzzy PID controller

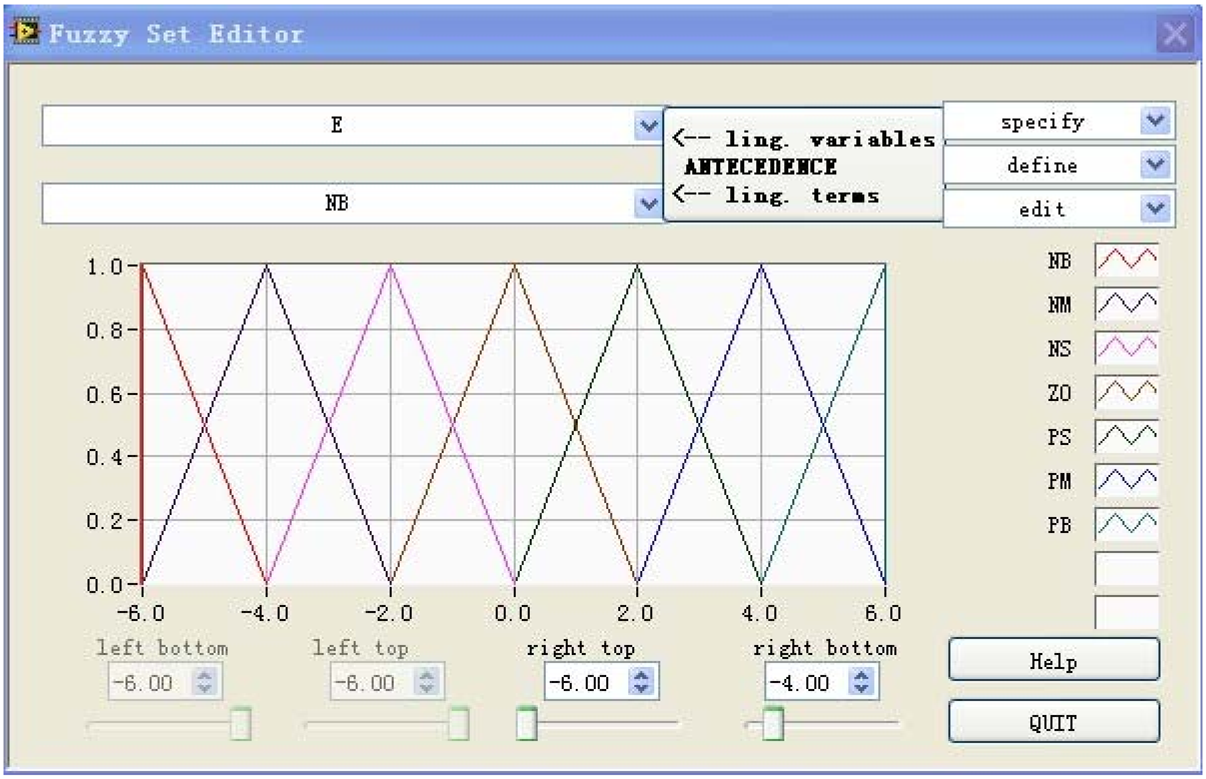


Figure 4. Membership functions of input and output

4.2.3 Testing of the fuzzy controller

In order to verify the adequacy and rationality of control rules, and carry out the necessary modification and optimization, the output characteristics of designed fuzzy controller are tested through I/O Characteristic.

4.2.4 Saving and calling of the fuzzy controller

The designed fuzzy controllers are saved as Kp.fc, Ki.fc and Kd.fc, which can be directly called by the application program.

5. Simulation and experiment for direct-drive pump control system

The CQYZ-D electro-hydraulic servo control test bench established in this paper is shown in Figure 6. The speed regulation and position servo control performances were studied by simulations and experiments. The proposed fuzzy PID control algorithm was proved to be effective for direct-drive pump control system by using step and Sine signals as control targets.

The tracking curves of step and Sine signals are shown in Figure 7 and Figure 8 by using the traditional PID and adaptive fuzzy PID control based on the AMEsim/Simulink joint simulation.

As shown in Figure 7, the step response speed gradually accelerates along with increase of k_p, k_i, and decrease of k_d in PID position closed-loop control, but the overshoot also increases and the setting time is extended, so it can be seen that the traditional PID control is difficult to solve the contradiction between the speed of response and setting time. The fuzzy PID control adopts the strategy of adaptive tuning PID control parameters according to the error and change in error. Therefore, the optimization synthesis can be achieved among the response speed, steady-state accuracy and regulation time for the position servo control of direct-drive bump control system.

Figure 5. Fuzzy control rules

Figure 6. CQYZ-D electro-hydraulic servo control test bench

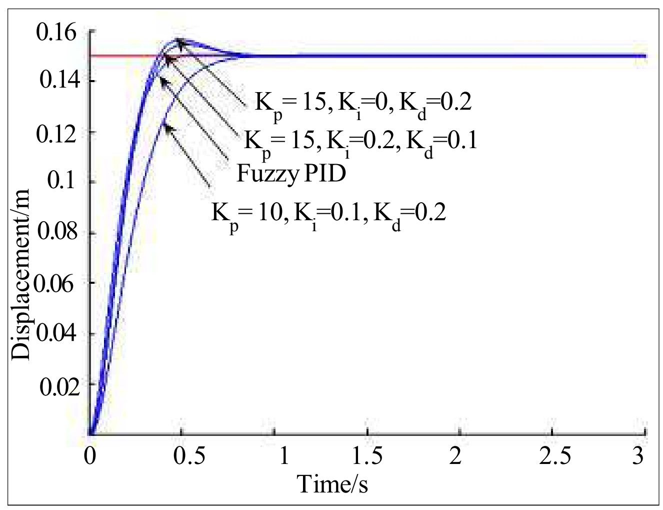


Figure 7. Step response simulation curves of PID and fuzzy PID control

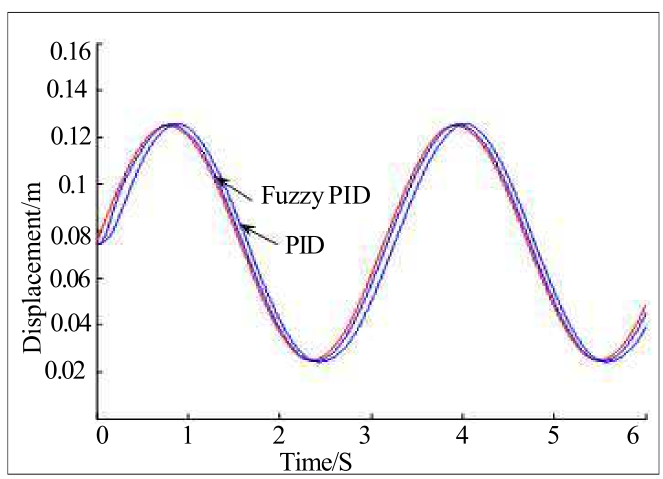
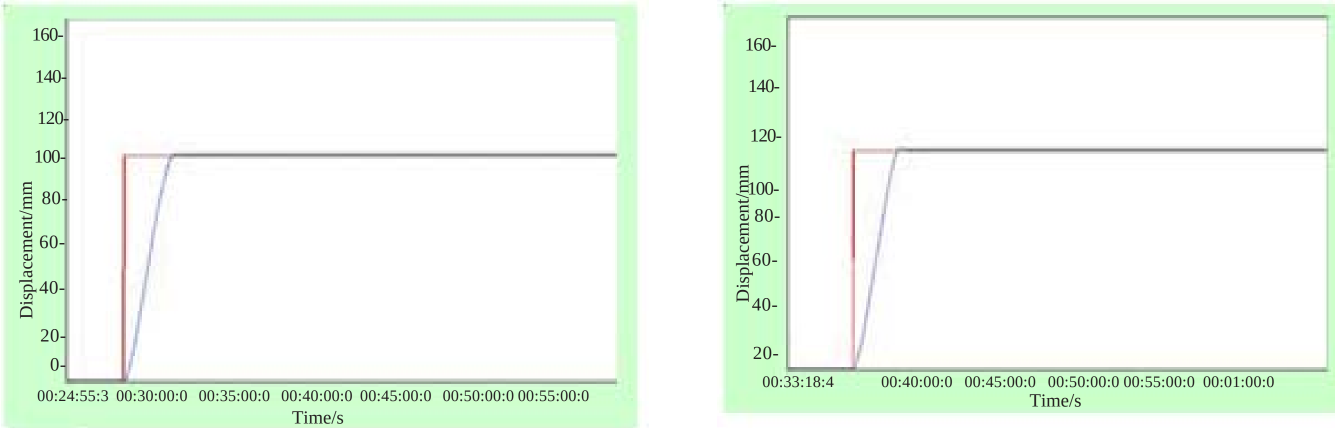


Figure 8. Sine signal tracking curves of PID and fuzzy PID control

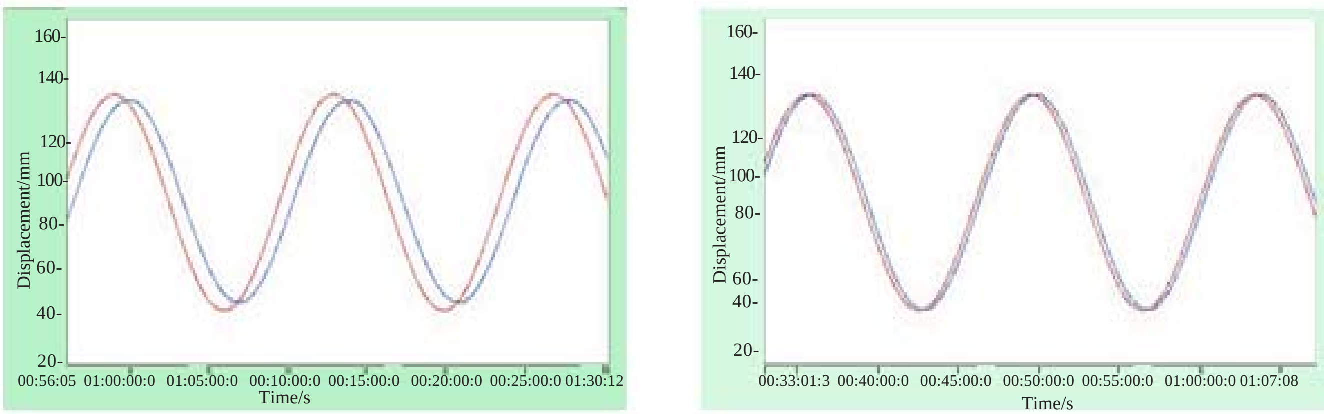
The simulation results of Sine signal tracking are shown in Figures 8. The results show that a better control effect can be obtained with fuzzy PID control, the tracking accuracy is higher and the delay time is shorter compared with traditional PID control.

Figure 9 is the experimental results of position closed-loop step response by using PID and fuzzy PID control for direct-drive pump control system. As can be seen from Figure 9, the experiment and simulation results are basically identical, and the performances fuzzy PID control are still superior to the traditional PID control. The differences between the experiment and simulation are mainly in the lag time and overshoot. The experimental system has longer delay time, and furthermore, their response speed and accuracy have some differences.



(a) PID control (b) Fuzzy PID control

Figure 9. Step response experimental results with PID and fuzzy PID control



(a) PID control (b) Fuzzy PID control

Figure 10. Sine tracking experimental results with PID and fuzzy PID control

Figure 10 is the experiment results of Sine tracking by using PID and fuzzy PID control for direct-drive pump control system. It can be seen that the phenomenon of time delay exists between the system output and control objectives with two control strategies for the Sine curve tracking control of direct-drive pump control system because the servo motor and pump controlled cylinder system all have the characteristics of time delay. But the actual output curve with the fuzzy PID is more consistent with the target curve. The errors and delay time of the fuzzy PID control are greatly less than traditional PID control.

From the above researches we can see, because the fuzzy PID control takes the control strategy of the adaptive tuning PID parameters according to the error and change in error, the response speed, control precision and anti-interference ability have been significantly improved compared with traditional PID control, and it can better meet the needs of position servo control for direct-drive pump control system.

6. Conclusions

This paper presents a direct-drive electro-hydraulic servo system, whose position servo control performances are studied by using the conventional PID and fuzzy PID control. The simulation and experiment results show that the traditional PID control has the shortcomings of slow response speed, long time delay and low accuracy for the direct-drive pump control system. However, the fuzzy PID control can greatly improve the position servo performances of direct-drive pump control system because its PID parameters can be adaptively tuned according to the error and change in error. The faster response speed and higher control precision can be obtained compared with PID control. In addition, the fuzzy PID controller has also inherited the advantages of traditional PID controller, such as the good dynamic characteristics and anti-interference ability.

7. Acknowledgements

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