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Adaptive fuzzy PID control of hydraulic servo control system for large axial flow compressor

Yannian Wang, Peizhi Wu and Chengtao Liu

Department of Electronic Information, Xi'an Polytechnic University, Xi'an, China

Abstract. To improve the stability of the large axial compressor, an efficient and special intelligent hydraulic servo control system is designed and implemented. The adaptive fuzzy PID control algorithm is used to control the position of the hydraulic servo cylinder steadily, which overcomes the drawback that the PID parameters should be adjusted based on the different applications. The simulation and the test results show that the system has a better dynamic property and a stable state performance.

1. Introduction

As a combination of hydraulic technology, electronic and electrical technology, electro-hydraulic servo control system with high precision and rapid regulation response ability has the advantages of large inertia control and high-power output. Since the hydraulic system is easy to be affected by the temperature, load and other parameters, servo controller with quick and stable adjustment abilities is particularly important to ensure a stable operation of the large axial compressor. A general control system using conventional PID control algorithm cannot change its parameters for different working conditions, which is unable to provide a good dynamic quality. The fuzzy control do not depend on the exact model of the controlled object and can effectively control the object that is difficult to establish the exact mathematical model which are advantages. Therefore, to overcome the incapacity of adaptation, ineffective control of a time-varying or nonlinear system and other problems for the conventional PID,a system is proposed in this paper using a control algorithm which combines the fuzzy control with the conventional PID to improve the performance of the control system.

2. The composition and working principle of electro-hydraulic position servo control system

Electro-hydraulic position servo control system is mainly composed of hydraulic servo controller, electro-hydraulic servo valve, servo cylinder, position transmitter and other components. In this paper, the design of the intelligent hydraulic servo control system is focus on large axial compressor hydraulic servo device. Its working principle includes 3 steps. Firstly, after comparing the given position signal of the system(SP) and the feedback signal of the position transmitter(PV), the servo controller outputs a current signal to the electro-hydraulic servo valve. Then,the electro-hydraulic servo valve converts the current signal into a Hydraulic cylinder oil signal. Finally, that oil signal is used to drive the movement of the cylinder in the direction of deviation, which adjusts the position of the servo hydraulic cylinder. In the whole electro-hydraulic position servo control system, the servo controller is the core part.This paper presents a self-developed, dual-core processor based intelligent servo controller, in which DSP and ARM processors communicate with each other through the SPI. Because of using the adaptive fuzzy PID control algorithm, the PID parameters can be adjusted without manual intervention. According to the control deviation of the user expectation value from the actual output feedback, the position of the hydraulic servo cylinder can be controlled precisely, which is one of the key elements in the designed servo control system.

3. The design of adaptive fuzzy PID controller

3.1 The analysis of adaptive fuzzy PID control strategy

In the process of industrial production, the traditional PID method is limited because of the inaccurate description of the operator's experience, difficult qualitative representation of various semaphores and their evaluation during the control process. Fuzzy inference is an effective way to solve these problems. Using the basic theory and method of fuzzy mathematics, fuzzy sets are used to represent the condition of the rules and operations. These fuzzy control rules and related information are stored in the computer knowledge base. Then, using the fuzzy inference, computers can automatically achieve the best adjustment of PID parameters based on the actual response of the control system. The practical experiences of PID parameters' adjustment are organized as rules and stored in the servo controller. According to the site condition, the servo controller can adjust the parameters of the PID control algorithm, such as the scale factor K_P, the integral factor K_I and the differential factor K_D, to realize a real-time adjustment of the controller. That is the idea of the adaptive fuzzy PID control algorithm applied in this system, and its structure is shown in Figure 1.

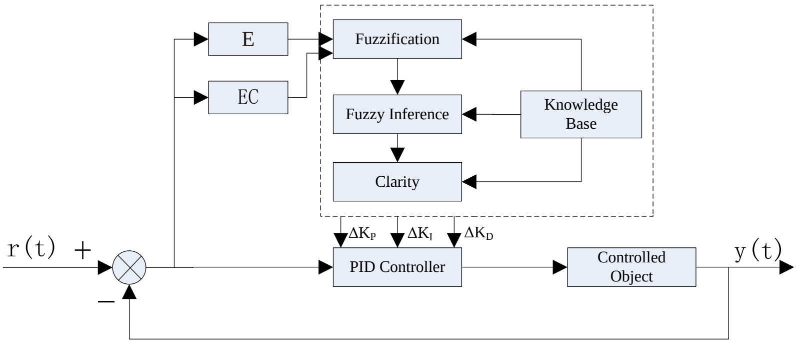

Figure 1 The structure of the system

3.2 The design of adaptive fuzzy PID controller system

In this paper, the fuzzy inference system of fuzzy controller is a 2x3 Mamdani inference system. The inputs of the fuzzy controller are the control deviation E and the deviation change rate EC of the user's expected value from the actual output feedback. Due to random measurement noise of the system input data, a triangular function is used as the membership function to fuzz the input data. The fuzzy domain of E, EC, ΔK_P, ΔK_I and ΔK_D has a range of [-3,3]. Seven selected fuzzy subsets,with the corresponding fuzzy linguistic variables,are NB, NM, NS, Z, PB, PM and PS. According to the real-time step response of the system, the fuzzy control rule table is established and shown in TABLE1 - TABLE3. The adaptive fuzzy PID control algorithm maps the current E and EC to a fuzzy subset, and then obtains the corresponding fuzzy control rule by querying the fuzzy control rule table. Because the output of the fuzzy inference is still a fuzzy quantity, it is necessary to convert the fuzzy quantity into a clear quantity. In this paper, the maximum membership method is used to convert that fuzzy quantity. During the fuzzification, the input parameters are transformed from the basic domain to the fuzzy domain, in which a scale factor is multiplied by a quantization factor. Similarly, three output parameters of clarification ,ΔK_P, ΔK_I and ΔK_D,also need to be multiplied by the defuzzification factors,k_p, k_i and k_d,respectively. According to the above conclusions, K_P,K_I, K_D are the parameters of PID after the setting:

$$K_P=K_{P0}+\Delta K_P*k_p \quad (1)$$

$$K_I=K_{I0}+\Delta K_I*k_i \quad (2)$$

$$K_D=K_{D0}+\Delta K_D*k_d \quad (3)$$

where, K_{P0}, K_{I0}, K_{D0} are the initial values of the PID parameter.

TABLE 1 ΔK_P fuzzy control rules table

	EC						
E	NB	NM	NS	Z	PS	PM	PB
NB	NB	PB	NM	NM	PS	Z	Z
NM	NB	PB	NM	NM	NM	NS	Z
NS	PM	PM	PS	NS	NS	Z	PS
Z	PM	Z	PS	Z	PS	PS	NM
PS	PS	PS	Z	NM	PS	PM	PM
PM	Z	NS	NM	NM	NM	PB	NB
PB	Z	Z	NM	NM	NM	PB	PB

TABLE 2 ΔK_I fuzzy control rules table

	EC						
E	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NM	Z	Z	Z	Z
NM	NB	NB	NM	NS	NS	NS	Z
NS	NB	NM	PS	Z	PS	NM	NM
Z	NM	NM	PS	Z	PS	NM	NM
PS	NM	Z	Z	NS	NS	NM	NB
PM	Z	Z	Z	Z	NM	NB	NB
PB	Z	Z	PS	PM	NM	NM	NB

TABLE 3 ΔK_D fuzzy control rules table

	EC						
E	NB	NM	NS	Z	PS	PM	PB
NB	PB	PM	PS	PM	PM	PB	PB
NM	PB	PM	PS	PS	PM	PB	PB
NS	PS	NS	NS	Z	Z	PM	Z
Z	Z	PS	NS	Z	PS	PM	Z
PS	Z	Z	Z	Z	Z	NS	PS
PM	PB	PS	PM	PS	PS	PM	PM
PB	PB	PM	PM	PM	PS	PM	PB

4. Simulation analysis and system tests

Electro-hydraulic position servo system is a nonlinear, system with large time delay and high order complex, in which an accurate mathematical model is difficult to be established. In this paper, we use MATLAB to simulate the system and regard the controlled object as a three-dimensional system. In the simulation, the values of the parameters,P, I, and D are preset to: K_{P0}=0.35, K_{I0}=0.001, K_{D0}=0.00, respectively. The controlled object is:

$$G(s)=\frac{523500}{s^3+87.35s^2+10470s} \quad (4)$$

The sampling period is $1ms$. For a step signal input, the conventional PID control algorithm and the proposed adaptive fuzzy PID control algorithm are used for simulation and analysis. The simulation results are shown in Figure 2.

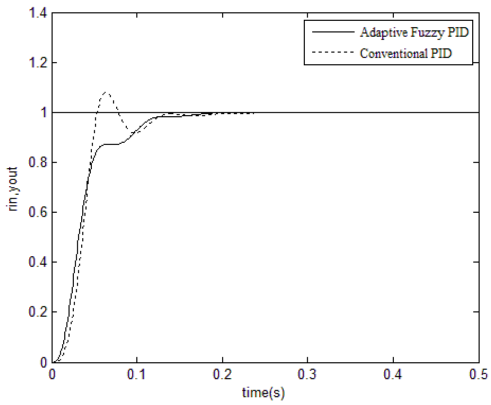

Figure 2 A comparison of step responses.

The simulation results show that,the characteristic of adaptive fuzzy PID control response is superior to the conventional PID control. The step response curve of the adaptive fuzzy PID control system is a close to steady of state around 0.15*s*, while that of the conventional PID control system is close to the steady state of around 0.25*s*. The degree of volatility decreases when the system tends to be in a steady state. The overshoot of the adaptive fuzzy PID control system is obviously reduced. When the system enters the steady state and adds a disturbance signal at 0.3*s,* the adaptive fuzzy PID controller can effectively suppress the random interference and re-enter the steady state quickly (see Figure 3). The combination of the fuzzy control and the conventional PID control algorithm can eliminate the steady-state chattering phenomenon of the conventional fuzzy controller,improve the control precision, steady state performance and dynamic quality of the control system obviously. Therefore, using the adaptive fuzzy PID control algorithm in the hydraulic servo control system of large axial compressor is meaningful and useful.

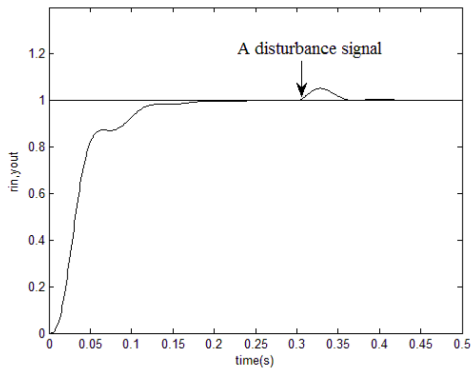

Figure 3 The anti-interference characteristics of the adaptive fuzzy PID

The system is further tested on the basis of the simulation analysis. The servo controller is set to the a local given mode with an inputted analog signal from 4 to 20 *mA*. The test was carried out in the electro-hydraulic position servo control test bench. The position detection sensor is a differential transformer displacement sensor, whose range is 0 to 200*mm*. The test results are shown in Table 4. Through the data analysis, the servo control system using the adaptive fuzzy PID control algorithm has more ideal performance, improved stability, less steady-state error,vershoot and shorter adjustment time than the bench mark. The system can reach the predetermined technology index.

Table 4 Test results of the servo control system

Instruction (target location)	Comparative Test	Actual location	Stability	Overshoot	Adjustment time
60mm	Adaptive fuzzy PID	59.93mm	No fluctuation	1.00mm	0.50s
	Conventional PID	59.90mm	1-2mm	5.00mm	0.65s
80mm	Adaptive fuzzy PID	79.87mm	No fluctuation	1.00mm	0.70s
	Conventional PID	79.75mm	1-2mm	6.65mm	0.93s
100mm	Adaptive fuzzy PID	99.90mm	No fluctuation	1.90mm	1.55s
	Conventional PID	99.70mm	1-2mm	8.80mm	1.90s
120mm	Adaptive fuzzy PID	120.00mm	No fluctuation	2.00mm	1.80s
	Conventional PID	119.90mm	1-2mm	10.00mm	2.37s

5. Conclusions

In this paper, the software of the system has been improved based on the self-developed special intelligent servo controller, which uses an adaptive fuzzy PID control algorithm to obtain the parameters of online self-tuning. It can achieve a precise control of the hydraulic servo device of the large axial compressor in the complex and changeable working conditions. The design of the servo control system is more consistent with the actual control law, flexible adjustment and strong practicability than the bench mark.

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