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Research on Variable Domain Electro-hydraulic Proportional Valve Control Technology

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Abstract: As the control system of the ship's crane is nonlinear , time-varying and large inertia, the traditional way to control is difficult to achieve control requirements. The text have the deck crane' electro-hydraulic proportional valve as the research object, use the way of optimizing input's fuzzy domain which called variable domain fuzzy PID, to solve the weakness of traditional control and bring out the Marine crane hoisting speed lord's optimization control. The experimental results show that, compared with the conventional PID and fuzzy PID, variable domain fuzzy PID has advantages of good real-time performance, fast response, strong anti-interference characteristics and good dynamic characteristics. The new way also has good control effect, can better able to meet the system control requirements. *Copyright © 2013 IFSA.*

Keywords: Electro-hydraulic proportional valve, Fuzzy control, Variable domain, Fuzzy PID.

1. Introduction

In recent years, with electro-hydraulic proportional control technology development, the electro-hydraulic proportional party valve with its low cost, strong ability to fight pollution etc, and also can realize flow and direction control, and can be realized the computer control, the electro-hydraulic proportional valve in many occasions have more and more applications [1-4]. Electro-hydraulic proportional valve is an important part of Marine crane, and is the key parts of the speed control system. As the main components of speed control system, electro-hydraulic proportional valve control performance improvement has become the further improvement of the main deck cranes performance link. The traditional control mode is used mostly PID control technology, it has a simple, reliable, parameter setting convenience etc. But because the hydraulic system by temperature, the influence of the parameters such as the load change bigger, so the control performance requirements of high often cannot meet the requirements of occasions. In recent years, the fuzzy control in complex industrial control is also get used extensively, and simple fuzzy control in variable classification are not enough, there will be little near in balance the oscillation phenomena [5-7]. According to this phenomenon, this paper put become domain by introducing the fuzzy control strategy PID control, to form a variable fuzzy PID control domain compound, and used it in electro-hydraulic proportional control system, finally using Simulink complete electro-hydraulic proportional valve control system dynamic simulation [8-20]. The experimental results show that good results have been achieved.

2. Mathematical Model of the System

2.1. Transfer Function for Proportion Amplifier

Electro-hydraulic proportional valve is current control type element, its proportional electromagnetic valve and coil has large inductance. Proportional valves' driving circuit is a lot wider than hydraulic inherent frequency band, so in the course of the study, it can be regarded as amplification link, namely

$$K_a = \frac{I(s)}{U_r(s)}, \tag{1}$$

where U_r(s) is the input voltage of proportion amplifier, I(s) is output current of proportion amplifier and K_a is coefficient of proportion amplifier.

2.2. Transfer Function for Electro-hydraulic Proportional Value

High performance electro-hydraulic proportional valve is generally higher than the dynamic response of the power of components of the dynamic response, and its natural frequency is far outweigh the power of components of the inherent frequency, so in here the proportional valve of the transfer function will be look as proportion links:

$$K_b = \frac{X_v(s)}{I(s)}, \tag{2}$$

where X_v(s) is the valve core displacement of proportion amplifier.

2.3. Transfer Function for Hydraulic Motor

As a hydraulic component, in the process of analysis, we need establish the flow equation in the rotary piston, hydraulic motor flow continuity equation, hydraulic motor and load of force balance equation the three basic equations according to automatic control theory. By Laplace transform to the above three basic equations, the obtained three Laplace transform type can be completely describe the dynamic characteristics of hydraulic pressure motor.

1) Linear flow equation of electro-hydraulic proportional value.

$$q_L = K_q X_V - K_c P_L, \tag{3}$$

where q_L is the load flow of electro-hydraulic proportional value, K_c is the flow-the pressure coefficient of electro-hydraulic proportional value, P_L is the load pressure and K_q is the stable working point flow gain of electro-hydraulic proportional value.

2) Dynamic flow continuity equation of hydraulic motor.

Hydraulic motor load flow is composed of three parts: motor rotation flow the called Q1, motor for internal and external leak loss called Q2 and percentile additional flow because compression called Q3.

$$q_L = D_m \frac{d\theta_m}{dt} + C_{tm} P_L + \frac{V_t}{4\beta_e}\frac{dP_L}{dt}, \tag{4}$$

where D_m is the radian displacement of hydraulic motor, θ_m is angular displacement of hydraulic motor, C_{tm} is Total leak coefficient of hydraulic motor, V_t is the total volume of hydraulic motor, proportional valve chamber and connecting pipe, and β_e is the elastic modulus of the effective volume of working oil.

3) The motor shaft moment balance equation.

The dynamic characteristics of hydraulic power components are influenced by load characteristics. Load bearing generally includes the inertial force, viscous damping force, the elastic force and as accident load bearing. According to Newton's second law, we can get motor and load torque balance equation for:

$$D_m P_L = J_t \frac{d^2\theta_m}{dt^2} + B_m \frac{d\theta_m}{dt} + G\theta_m + T_L, \tag{5}$$

where J_t is the total rotation inertia that hydraulic motor core and load convert to turn on the motor shaft, B_m is viscous damper coefficient of load and hydraulic pressure motor, G is torsion spring stiffness of load and T_L is external load torque that role in the motor shaft. This system is mainly made up by inertial load , and since the motor and load is rigid connection, elastic load effect can be neglected. So in this system G=0, $B_m K_{ce}/D_m^2 << 1$ and, $\theta_m(s)S = W_m(s)$, Laplace transform to (3), (4), (5),we can get transfer function for available motor shaft tachometer output to the displacement and the load torque:

$$\frac{W_m(s)}{X_v(s)} = \frac{\frac{K_q}{D_m}}{\frac{s^2}{W_h^2} + \frac{2s\xi_h}{W_h} + 1}, \tag{6}$$

$$\frac{W_m(s)}{T_L(s)} = \frac{\frac{-K_{ce}}{D_m^2}\left(1 + \frac{S_{vt}}{4\beta_e K_{ce}}\right)}{\frac{s^2}{W_h^2} + \frac{2s\xi_h}{W_h} + 1}, \tag{7}$$

Based on (1), (2), (6), and (7) we can get the transfer function for the whole system:

$$G(s)=\frac{W_m(s)}{U_r(s)}=\frac{\frac{K_aK_b}{D_m}}{\frac{s^2}{W_h^2}+\frac{2s\xi_h}{W_h}+1}=\frac{1}{a_2s^2+a_1s+a_0} \quad (8)$$

$$a_2=\frac{D_m}{w_h^2K_aK_b},\ a_1=\frac{2\xi_kD_m}{w_h^2K_aK_b},\ a_0=\frac{D_m}{K_aK_b}$$

3. Design for Variable Domain Fuzzy Controller

3.1. Introduction of Variable Domain System

Fuzzy control has good robustness and dynamic performance and it doesn't need accurate mathematical model. How to choice domain appropriately, so that achieve the best control effect is an issue that is worth studying. Variable domain thought have a good way on solving the problem. Variable domain fuzzy control is introduced appropriate adjustable factor in the control process to make fuzzy domain change according to the input or output domain specific changes, namely in fuzzy control relation is changeless, when the input error is bigger, make fuzzy domain expanding; when the controller error is smaller, make fuzzy domain narrowing. Compared with the traditional fuzzy control, variable domain fuzzy control improve the control accuracy to some degree, makes the control effect is better. Fig. 1 is Domain change principle diagram.

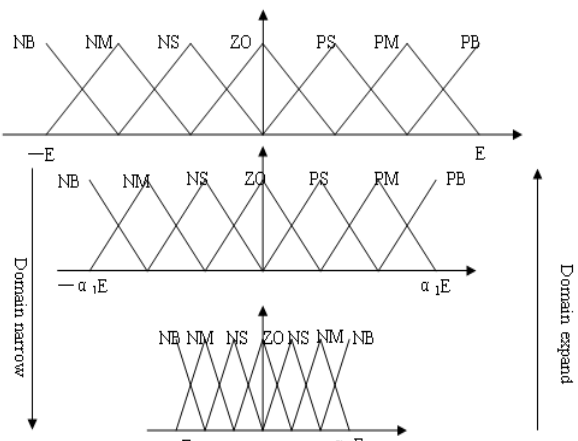

Fig. 1. Domain change principle diagram.

Suppose input is $X_i(i=1,2,3,4)$ and output y, their domains are $X_i=[-E,E], Y=[-U,U]$, where einput stretch factor is $\alpha(x_i)$ and output stretch factor is $\beta(y_i)$, so the input domain is $X_i(x_i)=[-\alpha(x)E,\alpha(x)E](i=1,2,3,4)$,and output domain is $X_i(x_i)=[-\alpha(x)E,\alpha(x)E](i=1,2,3,4)$.

Now the adjustable factors of variable domain fuzzy control algorithm have no unified form, based on the characteristics, this paper use variable domain fuzzy control according to fuzzy reasoning, based on the error and error rate, we describe the domain adjustable change by the form of table with fuzzy rules, through the fuzzy reasoning, it can automatic realize to the adjustment of the domain system so as to avoid the function model and its expansion factor to the selection of parameters. Fig. 2 is the structure of variable domain fuzzy control.

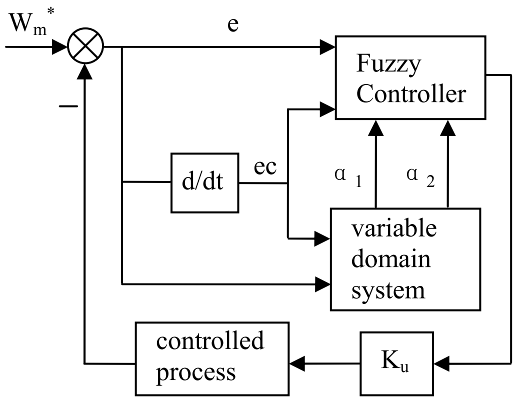

Fig. 2. The structure of variable domain fuzzy control.

3.2. Design for Variable Domain Fuzzy Controller

When e and ec are big, the system mainly is to reduce the error, this time the e and ec should take the control of large quantity, so the input domain should take larger domain, namely the input domain should be proper reduces; When e and ec is small, the system is stable and therefore, we should narrow input system domain. Through the above rules, we can build system of variable domain fuzzy control rule table. The input variables of the fuzzy controller for error is e, the rate of change is ec, output is u. Variable domain fuzzy controller's fuzzy variable is B, M, S, ZO. Each part of the fuzzy rules listed in Table 1 and Table 2 below.

When e is big, in order to make the system has good fast tracking performance, the system should take larger Kp and smaller Kd; When e is small, to make the system has better stability and Kp, Ki, Kd should take the value of moderate; When e is medium, in order to make the system with low overshoot, we should take appropriate Ki [21]. According to the above rules and practical experience, write the fuzzy rules listed in Table 3 Table 4 and Table 5 below.

Table 1. The fuzzy rule table for stretch factor α_1.

α_1		E						
		NB	**NM**	**NS**	**0**	**PS**	**PM**	PB
EC	**NB**	B	B	M	S	M	B	B
	NM	B	M	S	S	S	M	B
	NS	M	M	S	ZO	ZO	M	M
	0	M	S	ZO	ZO	ZO	S	M
	PS	M	M	S	ZO	S	M	M
	PM	B	M	S	S	S	M	B
	PB	NB	NM	NS	ZO	PS	PM	NB

Table 2. The fuzzy rule table for stretch factor α_2.

α_2		E						
		NB	**NM**	**NS**	**0**	**PS**	**PM**	PB
EC	**NB**	B	B	M	M	M	B	B
	NM	B	B	S	S	S	B	B
	NS	M	M	S	ZO	ZO	M	M
	0	M	S	ZO	ZO	ZO	S	M
	PS	M	M	S	ZO	S	M	M
	PM	B	B	S	S	S	B	B
	PB	B	B	M	M	M	B	B

Table 3. The fuzzy rule table of ΔKp.

ΔKp		E						
		NB	**NM**	**NS**	**0**	**PS**	**PM**	PB
EC	**NB**	PS	NS	ZO	ZO	ZO	PB	PS
	NM	NS	NS	NS	NS	ZO	NS	NS
	NS	NB	NB	NM	NS	ZO	PS	NB
	0	NB	NM	NM	NS	ZO	PS	NB
	PS	NB	NM	NS	NS	ZO	PS	NB
	PM	NM	NS	NS	NS	ZO	PS	NM
	PB	PS	ZO	ZO	ZO	ZO	PB	PS

Table 4. The fuzzy rule table of ΔKi.

ΔKi		E						
		NB	**NM**	**NS**	**0**	**PS**	**PM**	PB
EC	**NB**	PB	PB	PM	PM	PS	PS	PB
	NM	PB	PB	PM	PM	PS	ZO	PB
	NS	PM	PM	PM	PS	ZO	NS	PM
	0	PM	PS	PS	ZO	NS	NM	PM
	PS	PS	PS	ZO	NS	NS	NM	PS
	PM	ZO	ZO	NS	NM	NM	NM	ZO
	PB	ZO	NS	NS	NM	NM	NB	ZO

Table 5. The fuzzy rule table of ΔKd.

ΔKd		E						
		NB	**NM**	**NS**	**0**	**PS**	**PM**	PB
EC	**NB**	NB	NB	NB	NM	NM	ZO	NB
	NM	NB	NB	NM	NM	NS	ZO	NB
	NS	N	NM	NS	NS	ZO	PS	NM
	0	N	NS	NS	ZO	PS	PS	NM
	PS	NS	NS	ZO	PS	PS	PM	NS
	PM	ZO	ZO	PS	PM	PM	PB	ZO
	PB	ZO	ZO	PS	PM	PB	PB	ZO

4. The System Simulation and the Result Analysis

The system studies the performance of the system in the unit step response, the system transfer function is $G(s)=\frac{20}{s^2+3s+5}$, the system's simulation time is 20 s, ΔK_p, K_i, K_d respectively get by fuzzy rules of Fuzzy2 table. By testing system, it is determined that the K_p '= 0.12, K_i' = 2.8, K_d '= 0.008.

Variable domain fuzzy PID simulation figure in the picture below.

According to the simulation, we can get the conventional PID, fuzzy PID and variable domain fuzzy PID simulation results are shown Fig. 3 below for the PID simulation model, Fig. 4 for the fuzzy PID simulation model and Fig. 5 for PSO to optimize the fuzzy PID simulation model below:

According to the simulation curve above, we can get the following conclusion:

1) In unit step, the traditional PID control response speed of the system is slow, and the fuzzy control, fuzzy PID control, variable domain control's response speed is faster, also variable domain fuzzy PID control is faster than fuzzy PID control, and fuzzy PID control is faster than fuzzy control.

2) According to the simulation curve, it can be found that fuzzy control and fuzzy PID has certain overshoot, but overshoot are smaller, at 5 %, and it does not affect the basic operation of the system. Variable domain control doesn't find domain in

overshoot, and have no the concussion, it has better control effect, and the stability of system is better.

By above contrast we can see, in the same input cases, the fuzzy control is better than the conventional PID control, fuzzy PID control effect is better than that of the fuzzy control, Variable domain fuzzy PID control is better than that of fuzzy PID control effect, variable domain fuzzy control has the best effect.

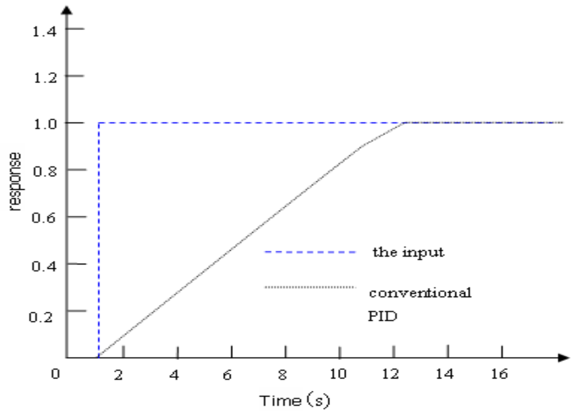

Fig. 3. The PID simulation model.

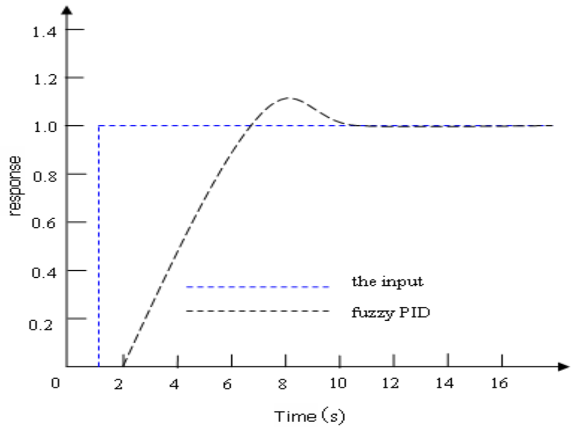

Fig. 4. The fuzzy PID simulation model.

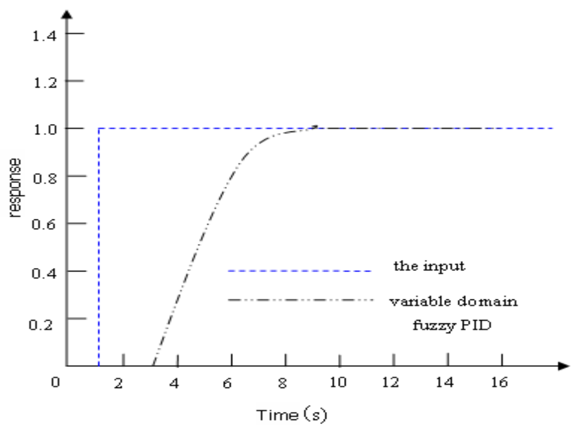

Fig. 5. PSO to optimize the fuzzy PID simulation model.

4. Conclusion

This paper sets up the transfer function model for the electro-hydraulic proportional valve. For proportional valve design variable domain adaptive fuzzy PID control algorithm, and application of valve software MATLAB simulation.

The simulation results show that: compared to the conventional PID control and fuzzy PID control, variable domain fuzzy PID have no overshoot, and fast response, stability good characteristic, variable domain fuzzy PID control system can improve the dynamic characteristics and certainty, choose variable domain adaptive fuzzy PID control algorithm to control the electro-hydraulic proportional valve has the advantage.

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