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Application of PID in Position Control of Multi-Articulated Robotic Arms in Rock Drilling Trolleys

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Abstract. This paper studies the electro-hydraulic proportional position control system of a hydraulic rock drilling jumbo. First of all, the composition of the system is introduced and the transfer function of the system components is established,and the mathematical model of the whole system is finally obtained through calculation and simplification.Then, the PID and the fuzzy PID control strategy were designed by MATLAB software, and the system model was built in simulink. Finally, the results indicate that the fuzzy PID controller has better anti-interference ability,and the response speed is more advantageous than that of PID.

Keywords. Hydraulic drilling jumbo, electro-hydraulic proportional control, matlab, PID and fuzzy PID.

1. Introduction

Recently,with the substantial improvement of China's modernization construction and productivity level,people have been dissatisfied with the development and utilization of resources in the ground space.Domestic transportation,mine development,municipal construction and national defense and military projects are increasing day by day, and a large number of tunnel excavation projects have been derived. As an indispensable key rock drilling equipment in infrastructure projects, rock drilling trolley [1-2] has many advantages, such as high rock drilling efficiency, good safety performance, improved working environment, improved gun hole utilization and blasting effect[3-6]. Therefore, it plays an irreplaceable role in the process of tunneling and rock excavation.

Drill arm, an important actuator for drilling positioning of rock drilling trolleys, is usually a connecting rod structure composed of a propulsion beam,a drill pipe, a rock drill and multiple control cylinders.In the process of movement, it is mainly driven by hydraulic cylinders. Therefore, in order to better control the contraction of the hydraulic cylinder, two control strategies are introduced, they are PID and fuzzy PID [7-9].

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2. Control System Composition

Figure 1 is a block diagram of a positioning closed-loop control system,the entire system is mainly composed of a proportional valve, hydraulic cylinder, controller and position feedback sensor[10], through the negative feedback of the sensor continuously adjust the parameters of the controller, and finally the controlled amount reaches the desired value.

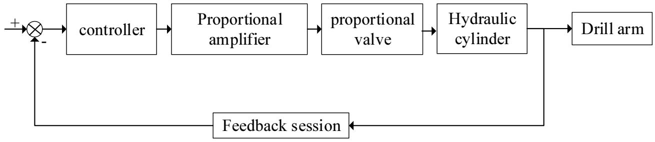

Figure 1. Block diagram of a positioning closed-loop control system

In figure 1, the proportional amplifier is treated as a proportional section whose transfer function is shown in equation (1).

$$K=\frac{I(\mathrm{s})}{U(s)} \tag{1}$$

in equation (1), I is the proportional amplifier output electric current, U is the proportional amplifier input voltage.

The proportional valve transfer function has a variety of components [11-12], the paper regards it as a second-order oscillation section, the calculation is shown in equation 2.

$$G_1(s)=\frac{K_v}{\frac{1}{{\omega_v}^2}s^2+\frac{2\xi_v}{\omega_v}s+1} \tag{2}$$

in equation (2), K_v is the flow gain coefficient, ω_v is the proportional valve bandwidth, ξ_v is the proportional valve damping ratio.

The hydraulic cylinder transfer function is shown in equation (3).

$$G_2(s)=\frac{K_{ce}}{A^2}(1+\frac{V}{4K_{ce}\beta_e}s)-\frac{\frac{1}{A}}{s(\frac{1}{{\omega_h}^2}s^2+\frac{2\xi_h}{\omega_h}s+1)} \tag{3}$$

in equation (3), A is the actual effective working area of the hydraulic cylinder, K_{ce} is the total pressure flow coefficient of the hydraulic cylinder, ξ_h is the hydraulic damping ratio of the hydraulic cylinder, V is the total volume of the control chamber of the valve-controlled hydraulic cylinder.

$\xi_h = \frac{K_{ce}}{A}\sqrt{\frac{\beta_e M}{V}}$, M is a total inertia of the moving load, β_e value is 700-1400 Mpa[13].

It is calculated that the transfer function of the whole system is shown in Equation (4).

$$\frac{0.0837}{s(8.57\times10^{-5}s^2+0.012s+1)(8.393\times10^{-5}s^2+0.027s+1)} \tag{4}$$

3. Controller Design

3.1. Conventional PID Controller

3.1.1. PID Principle of Control

The controller consists of three parameters, the given target value is r(t), the deviation signal is e(t), the PID output is u(t), the controlled object output is c(t), see figure 2 for details.

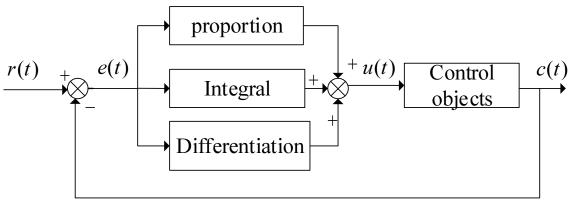

Figure 2. PID Block diagram of a control system

The error calculation is represented in equation (5) below.

$$\mathrm{e}(t) = r(t)\text{-}\mathrm{c}(\mathrm{t}) \tag{5}$$

The control output of the PID is shown in equation (6).

$$\mathrm{u}(t) = K_p(e(t) + \frac{1}{T_i}\int_0^t e(t)dt + \frac{T_d d\mathrm{e}(t)}{dt}) \tag{6}$$

The PID transfer function is shown in Equation (7).

$$G(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} + K_d s \tag{7}$$

in Equation (7), K_p is a scale factor, T_i is an integral time constant, T_d is a differential time constant.

The important part of PID control is to adjust its three parameters, so the influence of the three values on the system is presented, and the role of each part is as follows.

(1) Proportion section

The proportional section is mainly to control the size of the deviation signal (the difference between the input signal and the output signal), which makes dynamic characteristics better, if the scale coefficient is small, the control result is not obvious, the adjustment accuracy is low, and the response speed is slow, resulting in a longer adjustment time. However, when the scale coefficient is too large, it is easy to produce a large overshoot, which causes the system to oscillate, and even destabilizes the systems.

(2) Integral section

The integration section can reduce or eliminate the steady-state error, however it mainly depends on the value of the integration time constant, the larger the value of the integration constant, the more likely it is to produce the phenomenon of integration saturation at the beginning of the response process, which will also increase the overshoot of the system, make the system unstable, and thus affect the dynamic response speed of the system. Conversely, the integration constant value is too small, it is difficult to decrease the static error of the system, which will also affect the adjustment accuracy.

(3) Differential calculus

The differential calculus reflects the trend of the system deviation signal, and the degree of regulation of the system is affected by the differential time constant. When the value is too large, the response will be advanced.however, the adjustment time will become longer, and the anti-interference performance of the system is not high. Generally ,in the actual system, we can add an effective signal to correct the deviation and correct it ahead of time before the deviation becomes too large. This reduces both the amount of overshoot of the system and the adjustment time, thereby improving the stability and dynamic characteristics of the system.

For the process of adjusting the PID parameter, its essence is to determine the coefficient problem of the proportional section, the integration section and the differential calculus, so that the control effect can reach a better state. There are many commonly used PID tuning methods, mainly including theoretical calculation and engineering tuning methods [14-15], of which the engineering tuning method includes empirical trial method, attenuation curve method, preferred method and critical proportionality method. Because the empirical trial method is a more effective tuning method summarized in the production process, the method is simple to use, practical and suitable for a variety of control systems. Generally following the principle of first proportionality, then integration, and then differentiation. After a trial method, the parameters are finally determined, the value of K_p is 20, the value of K_i is 15 and the value of K_d is 0.15.

3.1.2. PID controls the Simulation Effect

With the help of MATLAB's simulink tool to build a system simulation model as shown in figure 3, the running time is set to 30s, and the disturbance signal is added at 10s, and the result is demonstrated in figure 3.

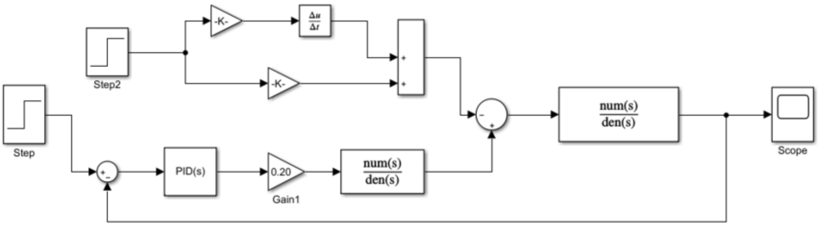

Figure 3. Simulation model

The result graph in figure 4.

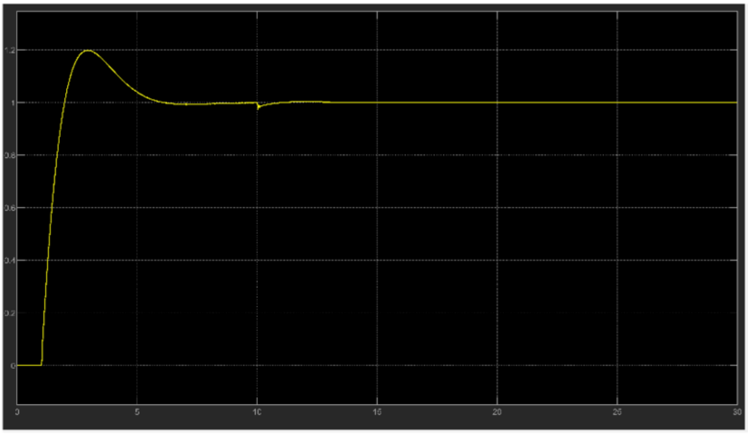

Figure 4. Step response

You can see that the system adjustment time is about 7s, when the disturbance is added at 10s, it tends to a stable state after 2s, and the system is accompanied by about 20% overshoot, making the system unstable.

3.2. Fuzzy PID Controller

3.2.1. Fuzzy Controller Composition

Figure 5 is the fuzzy PID block diagram is contains two parts ,the fuzzy controller and the PID controller. The main function of the fuzzy controller is to adjust the parameters in the PID controller online, take the error e and the error change ec as inputs, and then fuzzy, fuzzy reasoning, output solution blur (clarity), and finally, like ordinary PID, output K_p, K_i and K_d.

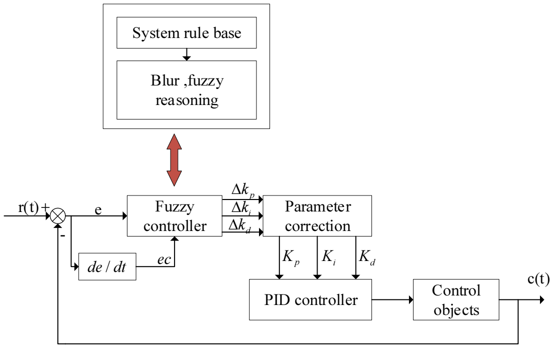

Figure 5. Fuzzy controller control block diagram

3.2.2. Fuzzy Controls Variable Fuzzing

The system fuzzes the displacement deviation e and the amount of change of the displacement deviation ec as a fuzzy variable to determine the basic domain, which generally needs to be converted into a discrete domain of finite integers, which are {negative big, negative medium, negative small, zero, positive small, positive medium, positive big}. In this text,

The discourse domain of the displacement e is [-6,6].

The range of variations of the displacement ec is [-3,3].

The discourse domain of Kp is [-6,6].

Ki's discourse domain is [-3,3].

Kd's discourse domain is [-3,3].

The fuzzy system control diagram is shown in figure 6, including 2 inputs (e, ec) and outputs with 3 (kp, ki, kd).

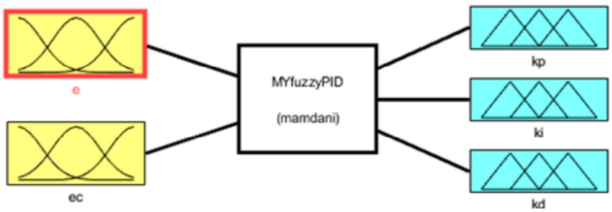

Figure 6. Blur system control chart

The algorithm selection of the fuzzy logic controller is shown in figure 7, the And algorithm is min, the Or algorithm is max, the Implication algorithm is min, the Aggregation algorithm is max, and the Defuzzification algorithm is centroid.

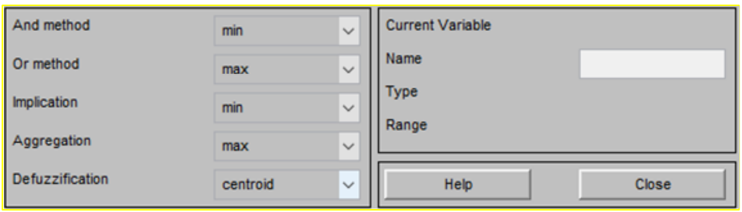

Figure 7. Controller algorithm selection

By calculating with the quantization factor, the actual input of the system is converted into the input amount in the fuzzy controller, if the actual conversion range of the displacement deviation amount e is $X=[-x,x](x>0)$ and the fuzzy amount theory domain of the displacement deviation is $X_2=[-x_1,x_1](x_1>0)$, then the calculation formula for the system quantization factor K_e is shown in equation (8).

$$K_e=\frac{x_1}{x} \tag{8}$$

Corresponding to the quantization factor, the transformation factor required to convert the output displacement fuzziness amount into the actual control amount of the displacement is called the scale factor, and the fuzzy theory domain of the output displacement y is $Y=[-y,y](y>0)$, then the actual output adjustment displacement of the engineering quantity Y varies from $Y_1=[-y_1,y_1](y_1>0)$, and the system scale factor K_u calculation formula is shown in equation (9).

$$K_u=\frac{y_1}{y} \tag{9}$$

The size of the quantization factor and scale factor directly affects the accuracy of the fuzzy control. The size of the quantification factor determines the fuzzy domain range and the sensitivity. The size of the scale factor determines the range of output control quantities, which influences the speed of response and stability.

3.2.3. The Fuzzy Control Membership Function is Determined

Membership functions chosen during the design of fuzzy controllers often carry personal subjective judgments, but functions with continuous, symmetric, and convex set characteristics are usually preferred as membership functions[16]. There are several main ways to determine membership functions.

(1) Expert empirical method. Determine the approximate scope of the membership function according to actual experience, and then repeatedly verify the membership function.

(2) Functional method. There are three commonly used triangles, trapezoids and normal distributions.

The normal distribution function is shown in equation (10).

$$\mu(x)=e^{-(\frac{x-a}{2})},b>0 \tag{10}$$

The trigonometric distribution function is shown in equation (11).

$$\mu(x)=\begin{cases}0 & x<a,或x\geq c\\ \frac{1}{b-a}(x-a) & a\leq x<b\\ \frac{1}{b-c}(x-c) & b\leq x<c\end{cases} \tag{11}$$

The trapezoidal distribution function is shown in equation (12).

$$\mu(x)=\begin{cases}1 & b\leq x<c\\ \frac{1}{b-a}(x-a) & a\leq x<b\\ \frac{1}{d-c}(d-x) & c\leq x<d\end{cases} \tag{12}$$

Based on the membership determination method described above, the membership function used in this article is the triangle membership function.

3.2.4. The Fuzzy Control Rules are Determined

The most critical thing in the fuzzy controller is to establish the rules of fuzzy control, which is similar to the brain of the human body, and the signal input from the outside world can only be judged correctly after the fuzzy control rules. Fuzzy rules have three forms of representation, namely linguistic fuzzy rules, tabular fuzzy rules, and formulaic fuzzy rules. Among them, the most commonly used fuzzy rule is the use of linguistic fuzzy rules. It consists of some ambiguous condition statements, if... then... statements are composed.

Table 1 shows the blur control rules table for kp.

Table 1. kp fuzzy rules

e	**ec**						
	NB	**NM**	**NS**	**ZERO**	**PS**	**PM**	**PB**
NB	PB	PB	PM	PM	PS	ZERO	ZERO
NM	PB	PB	PM	PS	PS	ZERO	NS
NS	PM	PM	PM	PS	ZERO	NS	NS
ZERO	PM	PM	PS	ZERO	NS	NM	NM
PS	PS	PS	ZERO	NS	NS	NM	NM
PM	PS	ZERO	NS	NM	NM	NM	NB
PB	ZERO	ZERO	NM	NM	NM	NB	NB

Table 2 shows the fuzzy control rule table of ki.

Table 2. ki fuzzy rules

e	ec						
	NB	**NM**	**NS**	**ZERO**	**PS**	**PM**	**PB**
NB	NB	NB	NM	NM	NS	ZERO	ZERO
NM	NB	NB	NM	NS	NS	ZERO	ZERO
NS	NB	NM	NS	NS	ZERO	PS	PS
ZERO	NM	NM	NS	ZERO	PS	PM	PM
PS	NM	NS	ZERO	PS	PS	PM	PB
PM	ZERO	ZERO	PS	PS	PM	PB	PB
PB	ZERO	ZERO	PS	PM	PM	PB	PB

Table 3 shows the blur control rule table for kd.

Table 3. kd fuzzy rules

e	ec						
	NB	**NM**	**NS**	**ZERO**	**PS**	**PM**	**PB**
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	ZERO
NS	ZERO	NS	NM	NM	NS	NS	ZERO
ZERO	ZERO	NS	NS	NS	NS	NS	ZERO
PS	ZERO	ZERO	ZERO	ZERO	ZERO	ZERO	ZERO
PM	PB	NS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

According to the blur rule table given in table 1, table 2, table 3, double-click the controller to edit the fuzzy rule, and the edit box is shown in figure 8 .

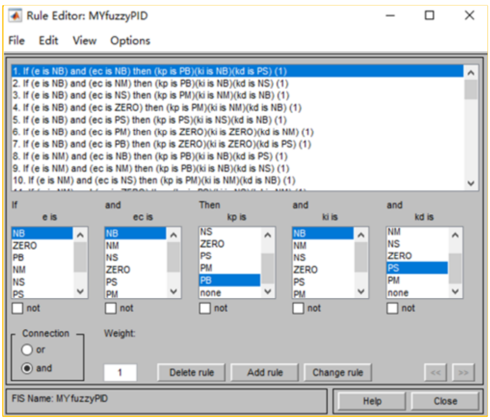

Figure 8. Fuzzy rule editing window

The surface plot can be observed through the surfice under the rule observation window, and the result is shown in figure 9-11.

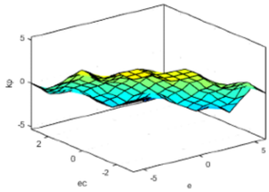

Figure 9. kp Output surface

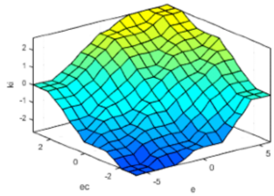

Figure 10. ki Output surface

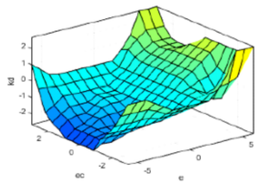

Figure 11. kd Output surface

3.2.5. Fuzzy PID Controls the Simulation Effect

With the help of MATLAB's simulink tool to build a system simulation model, as shown in figure 12, the same set running time is 30s, and a disturbance signal is added at 10s, and the operation result is shown in figure 13.

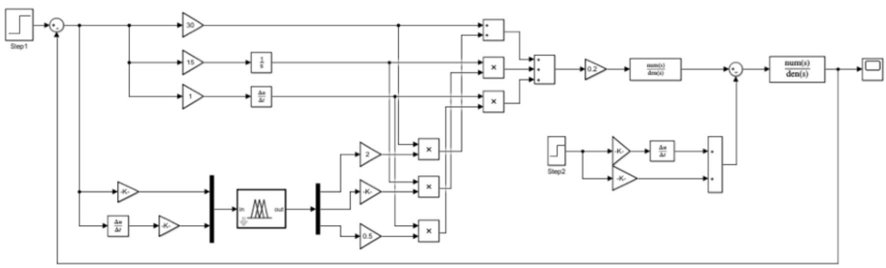

Figure 12. Fuzzy PID control simulation model

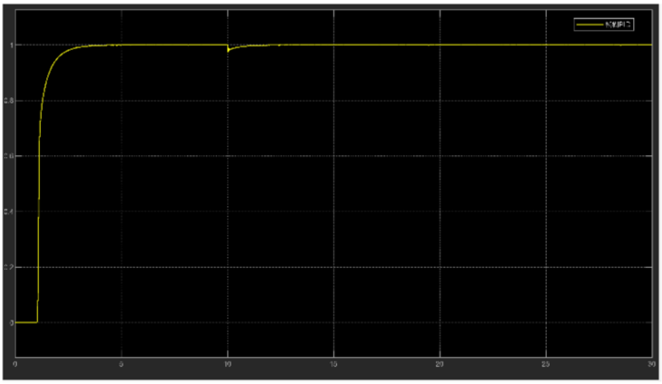

Figure 13. Step response

As can be seen from figure 13, the adjustment time using the fuzzy PID control is about 3s, and under the disturbance action, the stable state is restored to about 0.5s, while eliminating the overshoot of the system and keeping the system stable.

4. Comparative Analysis of Simulation Results

By comparing figure 4 and figure 13, it can be seen that the fuzzy PID can better adjust the system, not only the adjustment time is shortened, but also the rise time is shortened. At the same time, for the same system, when a perturbation signal is added at the same time, the fuzzy PID shows better tuning performance, and only 0.5s time can be restored to the steady state, while the PID needs 2s to reach the steady state. Therefore, the fuzzy PID is a better control method to solve the complex control object.

5. Conclusion

In this paper, two PID control strategies are used to discuss the position control system of the multi-joint robot arm of the rock drilling trolley, and the basic steps and implementation methods of the fuzzy control implementation are given in detail, and the controller is built with the help of MATLAB's fuzzy toolbox, and the step response curve is obtained by establishing a simulation model in simulink, and through comparison, it is better explained that the fuzzy PID is more good to complex control objects.

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