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Simulation Research of Fuzzy Auto-tuning PID Controller Based on Matlab

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***Abstract*—in this paper, the fuzzy control and the PID control are combined, and the fuzzy inference method is utilized to realize the on-line auto-tuning of PID parameters. By applying the fuzzy control toolbox and the $Simulink$ in $Matlab$, it takes the electric steering gear as the object to simulate. By setting the fuzzy auto-tuning controller, the paper draws a conclusion that this method surpasses the conventional PID with higher control accuracy, smaller overshoot, and better dynamic performance.**

***Keywords*—fuzzy PID controller, parameters on-line auto-tuning, Matlab Simulink, the electric steering gear**

I. THE INTRODUCTION

The conventional PID, owning to its easy adjustment and fixed form, has wide applications in industrial production. However, for nonlinear, time invariant controlled object, its accurate mathematical model is not easy to obtain, so its control effect is not ideal. In view of the above situation, the PID parameters are adjusted by fuzzy control every minute, enhancing the practicability.

II. THE MATHEMATICAL MODEL OF ELECTRIC STEERING GEAR [1]

The electric actuator is very crucial in industry, so the establishment of its mathematical model has realistic significance. The following differential equation can be listed according to the voltage balance of the circuit of three-phase windings

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} R_a & 0 & 0 \\ 0 & R_a & 0 \\ 0 & 0 & R_a \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} p \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a & e_b & e_c \end{bmatrix}^T \quad (1)$$

Under the condition of star connection and no center line, we have:

$$i_a + i_b + i_c = 0 \quad (2)$$

also,

$$\begin{cases} Mi_a + Mi_c = -Mi_b \\ L_d = L - M \\ e_d = K_e \omega, T_m = k_m i_d \\ T_m = J\dfrac{d\omega}{dt} + T_1, \dfrac{d\theta}{dt} = \dfrac{\omega}{N} \end{cases} \quad (3)$$

After finishing the Laplace transformation, the transfer function of whole motor system (ignoring load torque) is:

$$G(s) = \frac{\theta(s)}{U(s)} = \frac{1}{NK_m s(T_m s+1)(T_1 s+1)} \quad (4)$$

In the formula, the time constant of motor system is $T_m = \frac{R_a J}{K_e K_m}$; the $T_1 = \frac{L_d}{R_s}$ is the electromagnetic time constant of armature circuit.

III. THE CONVENTIONAL PID PARAMETER SETTING METHOD

The conventional PID control has a wide range of application for it using easily. Therefore, it is the most extensive control method widely at present as shown in fig 1.

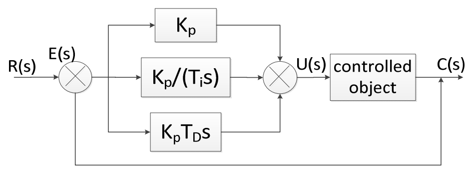

Fig.1 system frame of conventional PID controller

The current widely used PID parameter tuning method is the PID tuning of based on the $Ziegler-Nichols$ method. That is, by repeatedly trying, it is found that the oscillation point to determine the KP, and then the formula is used to calculate the other two parameters.

IV. THE PID PARAMETER SELF-TUNING [2] FUZZY CONTROLLER DESIGN

A. The fuzzy control system structure

The parameter auto-tuning fuzzy PID logic block is shown in fig 2.

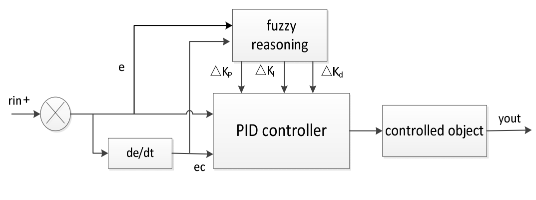

Fig. 2 fuzzy PID system frame diagram

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The error E and error variety rate EC input fuzzy reasoning model, then it alters the output parameters on-line on the basis of the fuzzy rules all the time, which forms a parameter auto-tuning fuzzy-PID controller. The concept of fuzzy inference in mathematics is brought in the PID parameter tuning.

B. Fuzzy PID parameter auto-tuning algorithm analysis

The conventional PID control algorithm [3] Formula are only fit for the condition that K_P, K_I, K_D stay a constant value. However, for the PID parameter auto-tuning fuzzy control algorithm, K_P, K_I, K_D values are changing constantly according to the different e , ec , so the formula form need make the corresponding change as follow

$$u(k) = K_P(k)e(k) + \sum_{j=1}^{k} K_I(j)e(j) + K_D(k)[e(k) - e(k-1)] \quad (5)$$

$$u(k-1) = K_P(k-1)e(k-1) + \sum_{j=1}^{k-1} K_I(j)e(j) + K_D(k-1)[e(k-1) - e(k-2)] \quad (6)$$

$K_P(k), K_I(k), K_D(k)$ are respectively provided by the fuzzy controller of K_P, K_I, K_D at k time, incremental formula can be derived from the formula (5) (6)

$$\Delta u(k) = [K_P(k) + K_I(k) + K_D(k)]e(k) - [K_P(k-1) + K_I(k-1) + K_D(k-1)]e(k-1) + K_D(k-2)e(k-2),$$

$$u(k) = u(k-1) + \Delta u(k). \quad (7)$$

Define K_P, K_I, K_D parameter adjustment formula respectively as

$$\begin{cases} K_P = K_{P0} + \Delta K_P \\ K_I = K_{I0} + \Delta K_I \\ K_D = K_{D0} + \Delta K_D \end{cases} \quad (8)$$

K_P, K_I, K_D are the parameters of PID controller; K_{PZ}, K_{IZ}, K_{DZ} are the initial parameters, they are calculated by conventional methods; $\Delta K_P, \Delta K_I, \Delta K_D$ are correction of PID parameters. That is, on the basis of the original parameters, new parameters vary with the change of external inputs.

C. PID parameter setting principle

Generally speaking, the form and algorithm of PID controller are fixed. The control quality mainly depends on the reasonability of control parameters selection .The PID control parameters are summarized as table1:

TABLE 1 PID PARAMETER SETTING PRINCIPLE

e	K_P	K_I	K_D
B	B	Z	S
M	S	P	P
S	B	B	P

PS:'B','M','S','P' respectively represent 'Big', 'Middle' ,'Small' ,'Proper'. So do the following tables

D. The design of fuzzy controller[4]

In this design, the idea of PID parameter auto-tuning is to establish the fuzzy relationship between K_P, K_I, K_D (PID three parameters)and e (the error value), ec (the error variety ratio).

1) The determination of input and output variables

Based on the analysis of the system, we will regard the error e and the error variety ratio ec as the inputs of fuzzy controller, the three parameters of PID controller ΔKp , ΔKi and ΔKd as outputs.

2) The membership function of input and output variables.

E , ec and K_P, K_I, K_D fuzzy discussion domains are

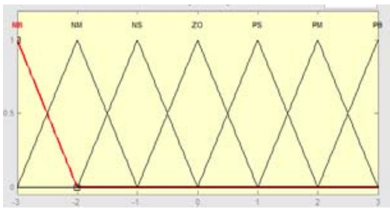
$$\{e, ec\} = \{-3, -2, -1, 0, 1, 2, 3\}$$
$$\{K_P, K_I, K_D\} = \{0, 1, 2, 3\}$$

Fuzzy subsets of e 、 ec and K_P, K_I, K_D are

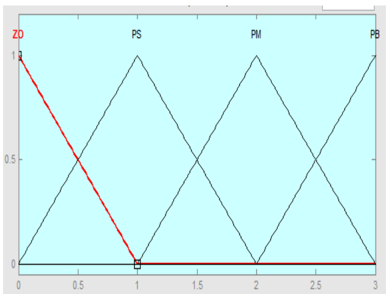
$$\{FD, FZ, FX, L, ZX, ZZ, ZD\}$$
$$\{L, ZX, ZZ, ZD\}$$

E , ec and K_P, K_I, K_D are all subjects to trim distribution.

The membership function curves of input and output variables are shown in Figure 3, (a) and (b).



(a) The input e , ec membership function curve



(b) The output K_P, K_I, K_D membership function curve

Fig.3

3) The establishment of control rule table

Based on 4.3 inductive setting principle of the parameter, combine with operation experience and professional knowledge of engineering technologists. List the tables of parameter adjustment rule in table 2 to table 4.

TABLE 2 K_P FUZZY CONTROL RULE TABLE

K_P |e| / |ec|	Z	S	M	B
Z	Z	S	M	B
S	B	B	M	B
M	B	B	M	B
B	M	M	S	S

TABLE 3 K_I FUZZY CONTROL RULE TABLE

K_I |e| / |ec|	Z	S	M	B
Z	B	M	Z	Z
S	B	M	Z	Z
M	B	B	S	Z
B	B	M	S	Z

TABLE 4 K_d FUZZY CONTROL RULE TABLE

K_D |e| / |ec|	Z	S	M	B
Z	Z	S	M	B
S	Z	S	M	B
M	Z	S	M	B
B	Z	Z	M	S

In *MATLAB* command window, input '*Fuzzy*' into the Fuzzy logic editor, Using *If...then* input fuzzy control rules, take and (*and*) method to min, or (*or*) method for max and reasoning (*implication*) method for min, synthesis (*aggregatin*) method for max, rescission fuzzy (*defuzzification*) method for the weight average method (*centroid*), and thus establish a FIS system files, named *mohupid.fis*.

V. SYSTEM SIMULATION

A. Using the Simulink simulation of control system

The simulation model can be established in the *Simulink* window. We open the *Fuzzy Logic Controller* dialog box, input *readfis('path\f.fis')* .This fuzzy controller block diagram has been copied parameter from fuzzy reasoning matrix, so complete the connection of the Fuzzy toolbox and *Simulink*. Quantization factor and scaling factor are 1, the *Simulink* structure of parameter fuzzy self-tuning PID controller as shown in figure 4 [5].

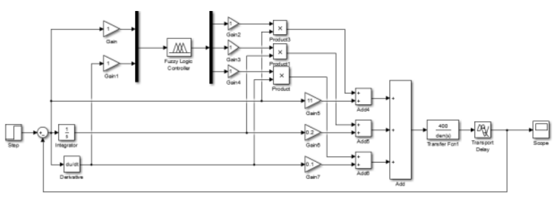


Fig.4 *Simulink* simulation structure of fuzzy *PID* controller

According to the formula 4, we assume that the transfer function of the whole electric steering gear (ignoring the load torque) is:

$$G(s)=\frac{\theta(s)}{U(s)}=\frac{1}{NK_m s(T_m s+1)(T_1 s+1)}=\frac{400}{s^3+30s^2+200s}$$

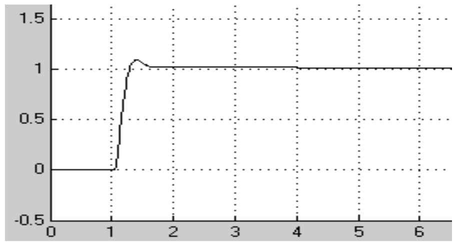


Fig.5 step function response of conventional *PID* controller

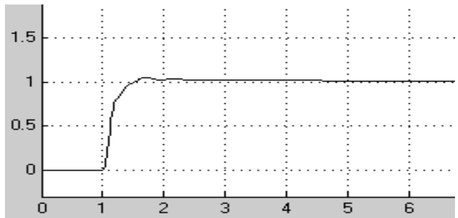


Fig.6 step function response of parameter fuzzy self-tuning *PID* controller

B. Simulation results analysis

Through the analysis of step response above simulation curve, by contrast with conventional *PID* controller, when using parameter fuzzy self-tuning *PID* controller, the system has the advantages of regulation time shorter, no overshoot and oscillation, improving adjustment accuracy and obtaining better steady-state performance. Above all, this new algorithm is able to meet better application requirement of the system.

VI. CONCLUSION

In this paper, the parameter auto-tuning fuzzy-PID control system (on the basis of the electric steering gear)is designed by using the toolbox of .The compound control algorithm, effectively enhances the control capability of servo system, improves the adaptability of model parameter variation, ensures the flexibility of the motion control system, shortens the time of dynamic adjustment. The control effect is good.

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