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Application and Research of Fuzzy PID Control in Resistance Furnace Temperature Control System

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Abstract. The resistance furnace temperature control system has the characteristics of large time delay and large inertia, etc. The traditional PID control method is not ideal. Therefore, a fuzzy PID control method is proposed, which can adjust PID parameters in real time according to temperature deviation and temperature deviation rate. The simulation experiment shows that the control method can make the furnace temperature control system faster in dynamic response, more robust, more precise and steady, smaller and overshoot, stronger in anti disturbance and better in control effect.

1. Introduction
The temperature control of the resistance furnace has the characteristics of nonlinear, large time delay, large inertia and time change. Although the traditional PID control is simple and easy to realize, it depends on the precise mathematical model of the controlled object. If the conditions change slightly, the control parameters also need to be adjusted. For some high precision control system, the traditional PID control methods have different degrees of overshoot or oscillation. Fuzzy control is based on artificial experience. It does not need to know the mathematical model of the control object. It uses language variables to describe the characteristics of the system, and uses the dynamic information of the system and fuzzy control rules to reason about the appropriate control quantity. It is suitable for solving problems of nonlinear systems. Research shows that the combination of fuzzy control and PID control has good control effect on complex control systems and high-precision servo systems[1]. In this paper, a fuzzy PID controller is designed. The PID parameters are adjusted online by fuzzy logic, and the temperature control of the resistance furnace is realized.

2. System structure and working principle
The temperature sensor detects the temperature of the resistance furnace and directly converts it into a digital signal and inputs the single-chip microcomputer. The single-chip microcomputer carries out the intelligent operation according to the input various commands to obtain the control quantity output pulse signal, and drives thyristor through the trigger circuit. The single-chip microcomputer changes the width of the control pulse through the I/O port, namely changes the conduction time of the thyristor in a fixed control period Tc, so the temperature of the resistance furnace changes with the

change of the average input power of the resistance furnace, and achieved the purpose of temperature control[2]. The control principle is shown in Figure 1.
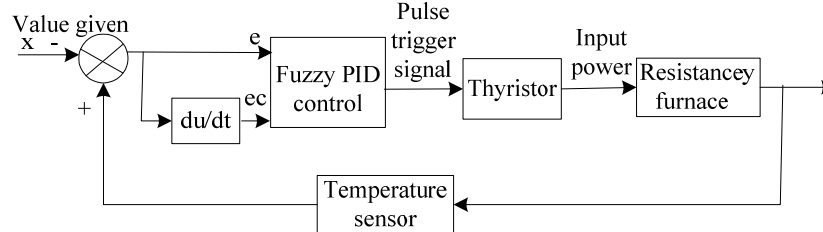

Figure 1. Furnace temperature control schematic diagram

3. Structure design of fuzzy PID controller

3.1. The principle of fuzzy PID control

The structure of the fuzzy PID controller is shown in Figure 2. The fuzzy controller is designed as a two-dimensional input and three-dimensional output system. The temperature deviation e and the change rate of temperature deviation ec are used as input. The 3 gain adjustment of PID is $\triangle K_P$，$\triangle K_I$ and $\triangle K_D$ as output. The working principle of fuzzy PID control system: The accurate values of temperature deviation e and temperature deviation change rate ec are fuzzed and then input to the fuzzy controller. Using fuzzy rules, fuzzy reasoning and inverse fuzzy to get the adjustment $\triangle K_P$，$\triangle K_I$ and $\triangle K_D$ of PID parameters, and input PID controller using formula (1) to set on-line PID parameters K_P, K_I and K_D. Finally, the control quantity u is calculated according to the PID algorithm (formula 2) to realize the real-time control of the furnace temperature[3].

Formula (1)

$$K_P = K'_P + \Delta K_P$$
$$K_I = K'_I + \Delta K_I \qquad\qquad （1）$$
$$K_D = K'_D + \Delta K_D$$

In the formula: K'_P, K'_I and K'_D is a previously set parameter. According to Ziegler-Nichols condition [4], PID controller parameters are obtained by MATLAB software programming.

Formula (2)

$$u(k) = K_P e(k) + K_I \sum_{j=1}^{k} e(j) + K_D \Delta e(k) \qquad\qquad (2)$$

In the formula: K_P, K_I and K_D is the ratio, integral and differential coefficient of regulator.

3.2. Fuzzification of input and output parameters

According to the actual detection and control accuracy of the furnace temperature, the basic domains of temperature deviation (e) and variation rate of deviation (ec) are set to {-15, 15}and {-6, 6}, and the quantization domain is set to {3,3}. The quantized factors are $Ke=3/15=0.2$ and $Kec=3/6=0.5$, respectively. The basic domains of the output $\triangle K_P$, $\triangle K_I$ and $\triangle K_D$ are{ 0.3,0.3}, {0.06,0.06} and {0.03,0.03}．The quantized domain is {3, 3}, and the quantized factors are 0.1, 0.02 and 0.01 respectively[5]. The fuzzy subset of e, ec, $\triangle K_P$, $\triangle K_I$ and $\triangle K_D$ are divided into seven levels: {negative big, negative middle, negative small, zero, positive small, middle, positive}, usually simply recorded as {NB, NM, NS, ZO, PS, PM, PB}.The membership function of fuzzy subset is selected as triangle, as shown in Figure 3.
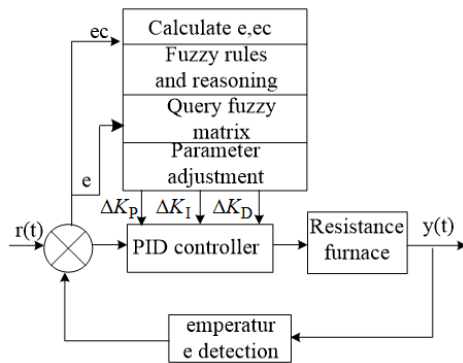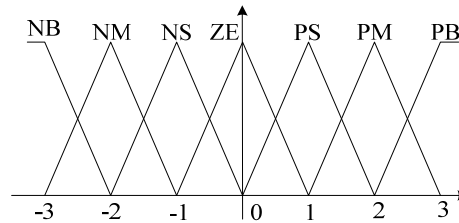
Figure 2. Structure diagram of fuzzy PID controller

Figure 3. e, ec, ΔK_P, ΔK_I and ΔK_D membership function curve

3.3. Design of fuzzy control rules

In fact, The fuzzy control rule is a set of multiple fuzzy conditional sentences formulated by summarizing the control experience of an operator or an expert . In the form of "IF A and B THEN C and D and E"[5], the control rule is finally determined through repeated trial and comparison, as shown in Table 1. The design of fuzzy rules should follow that the output of the control volume is not only eliminate quickly the error but also avoid the system oscillation, to ensure the stability of the system.

Table 1. ΔK_P, ΔK_I and ΔK_D self-tuning rule table

EC/E	NB	NM	NS	Z0	PS	PM	PB
NB	PB/NB/PS	PB/NB/NS	PB/NM/NB	PM/NM/NB	PS/NS/NB	Z0/Z0/NM	Z0/Z0/PS
NM	PB/NB/PS	PB/NM/NB	PB/NM/NB	PM/NS/NM	PS/NS/NM	Z0/Z0/NS	NS/PS/Z0
NS	PM/NB/Z0	PM/NM/NS	PB/NS/NM	PS/Z0/NM	PS/Z0/NS	Z0/PS/NS	NS/PS/Z0
Z0	PM/NM/Z0	PM/NM/NS	PS/NS/NS	Z0/Z0/NS	NS/PS/NS	NS/PM/NS	NM/PM/Z0
PS	PS/NM/Z0	PS/NS/PM	Z0/Z0/PS	NS/PS/Z0	NM/PS/Z0	NM/PM/PS	NB/PB/Z0
PM	PS/Z0/PS	Z0/Z0/PB	NS/Z0/PS	NM/PS/PS	NM/PM/PB	NB/PM/PB	NB/PB/PS
PB	Z0/Z0/PB	Z0/Z0/PM	NM/PS/PM	NM/PM/PS	NB/PM/PB	NB/PB/PS	NB/PB/PB

According to the fuzzy rules, the degree of membership of all fuzzy values under different temperature difference e and temperature change rate ec can be obtained by fuzzy reasoning [6]. According to the value of temperature difference e and temperature difference rate ec, and the combination of a single-finger fuzzer and a center-averaged defuzzifier, the PID parameters can be adjusted online by equations (1) and (3) to (5)[6]. Then

$$\Delta K_P = \frac{\sum_{l=1}^{n} \bar{y}_P^l \mu_{Al}[e(t)]\mu_{Bl}[ec(t)]}{\sum_{l=1}^{n} \mu_{Al}[e(t)]\mu_{Bl}[ec(t)]} \tag{3}$$

$$\Delta K_I = \frac{\sum_{l=1}^{n} y^{-l}{}_I \mu_{Al}[e(t)]\mu_{Bl}[ec(t)]}{\sum_{l=1}^{n} \mu_{Al}[e(t)]\mu_{Bl}[ec(t)]} \tag{4}$$

$$\Delta K_D = \frac{\sum_{l=1}^{n} y^{-l}{}_D \mu_{Al}[e(t)]\mu_{Bl}[ec(t)]}{\sum_{l=1}^{n} \mu_{Al}[e(t)]\mu_{Bl}[ec(t)]} \tag{5}$$

In the formula[4], $\mu_{Al}[e(t)]$—the temperature deviation e to the membership degree of the fuzzy subset Al; $\mu_{Bl}[ec(t)]$—the temperature deviation rate ec to the membership degree of the fuzzy subset B1;n—the number of rule condition statements.

4. Simulation of fuzzy PID control system
The controlled object of this paper is the furnace temperature control system, which is a complex system with nonlinear, large time delay and multivariable coupling. The first-order inertial hysteresis can be used to describe the mathematical model of the furnace temperature control system[3]. The transfer function is expressed as

$$G(s) = \frac{k \cdot e^{-\tau s}}{Ts + 1} \tag{6}$$

In the formula, k— the static gain of the object; T—object time constant; τ—pure delayed time of the object.
 According to the literature [4], parameter tuning is performed by using the step response curve method (also called the flying-rising curve method), and the parameters are determined manually to obtain k = 0.87, $T = -27$ and $\tau = 162$.
The transfer function of the control object is

$$G(s) = \frac{0.87 \cdot e^{-162s}}{-27s + 1} \tag{7}$$

The model of resistance furnace temperature control system is created by fuzzy PID control and conventional PID control in Simulink under MATLAB is shown in Figure 4. The simulation curve observed through the Scope window is shown in Figure 5.
The result of the simulation output of the Scope observation system is known: The fuzzy PID control has no overshoot, short adjustment time and stable control process. And when the system meets various disturbances, it adjusts the control function in time, and re-enters the preset steady-state operating point with smaller deviation and faster speed.

5. Conclusion
A control method of resistance furnace temperature based on fuzzy PID is presented in this paper. The simulation results show that the fuzzy PID control can modify on-line the PID parameters according to the temperature error e and the error rate ec, which can be well adapted to the requirements of the temperature control precision of the resistance furnace in the actual production process. The control system has also achieved a very good control effect through practical application and has a very broad application prospect.
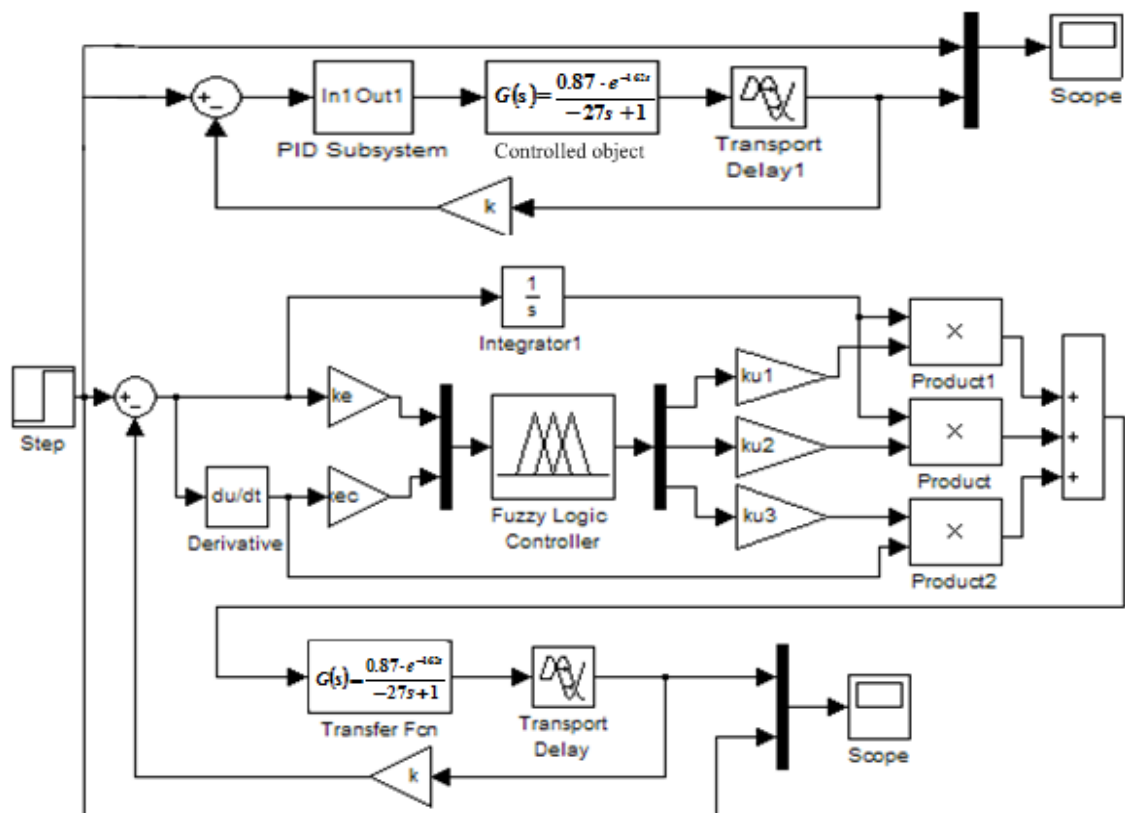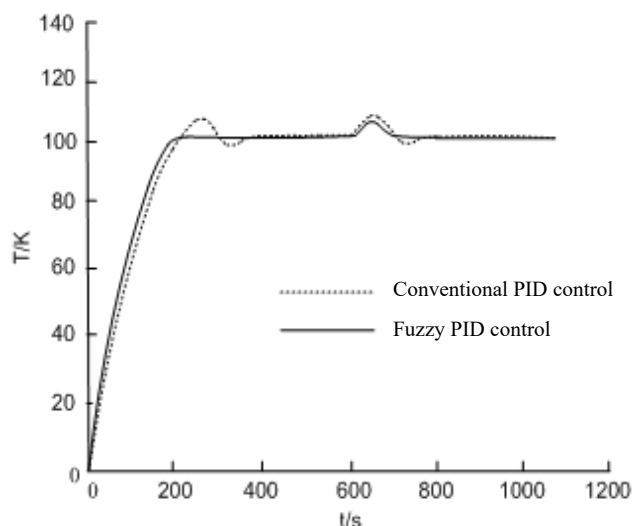
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Figure 4. Fuzzy PID simulation system structure

Figure 5. Output characteristic curves of conventional PID and fuzzy PID control

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