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Research on Resistance Furnace Temperature Control System based on Fuzzy Adaptive PID

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Abstract

In the industrial control system, the temperature control system of the resistance furnace is a very common control system. With the development of industry, higher requirements are put forward for the temperature control of resistance furnace. However, the temperature control of resistance furnace has the characteristics of nonlinearity, large inertia, and large delay, which brings challenges to its control. Fuzzy PID control is based on PID control through fuzzy rules to modify PID parameters to achieve better control effects. The simulation test in simulink shows that fuzzy adaptive PID has better dynamic characteristics than traditional PID.

Keywords

Resistance Furnace, PID Control, Fuzzy Adaptive PID Control, Simulink Simulation.

1. Research Background and Significance

Since the 1920s, resistance furnaces have been used in industry. In many production processes, temperature measurement and control are closely linked to major technical and economic indicators such as production safety, production efficiency, product quality, and energy conservation. Therefore, the accuracy, stability, and reliability of resistance furnace temperature control in various fields are becoming higher and higher. PID control has a good control effect for a certain temperature system, but it is difficult to guarantee the control quality for a large lag, large inertia, and time-varying temperature system. Therefore, we focus on intelligent control and try to use intelligent control methods to ensure the control accuracy, anti-interference ability, stability and other performance of the control system.

2. The Establishment of Mathematical Model of Resistance Furnace

2.1 Introduction to Resistance Furnace

A heating furnace that uses resistance wires or resistance bands as heating elements is called a resistance furnace. Since the discovery of the thermal effect of current (the Lenz-Joule law), the electrothermal method was first used in household appliances and later in small electric furnaces in laboratories. With the invention of nickel-chromium alloys, resistance furnaces have been widely used in industry by the 1920s. The resistance furnace used in industry is generally composed of electric heating elements, masonry, metal shell, furnace door, furnace machinery and electrical control system. The electric heating element has high heat resistance and high temperature strength, very low temperature coefficient of resistance and good chemical stability.

What this text adopts is sx-4-10 box type resistance furnace as the research object, its working frequency is 50HZ, the rated voltage is 220V, the total power is 4KW. The control system has a large overshoot and a poor control effect. Therefore, it has been studied to make the overshoot smaller and the adjustment time shorter.

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Figure 1. Physical map of box-type resistance furnace

2.2 Mathematical Model of Resistance Furnace

From practical applications, it can be known that the resistance furnace is an object with self-balancing ability. Taking the temperature in the furnace chamber of the resistance furnace as the only variable, its ordinary differential equation can be written. When the furnace temperature of the resistance furnace is stable, the heat Q_t emitted by the heating element at a certain moment should be equal to the sum of the heat Q_1 accumulated in the furnace at that moment and the heat Q_2 lost through the furnace body, namely:

$$Q_t = Q_1 + Q_2 \tag{1}$$

Q_1 and Q_2 can be expressed by the following formula:

$$Q_1 = C\frac{dT_K}{R} \tag{2}$$

$$Q_2 = \frac{T_K - T_0}{R} \tag{3}$$

In formulas (2) and (3), C is the heat capacity of the resistance furnace; T_K is the furnace temperature; t is the sintering time; T_0 is the ambient temperature; R is the thermal resistance of the resistance furnace (insulating materials and furnace, Produced by external flowing gas).When the furnace temperature T_K is much greater than the ambient temperature T_0 , T_0 can be ignored, so:

$$Q_t = C\frac{dT_K}{R} + \frac{T_K}{R} \tag{4}$$

Take the Laplace transform on both sides of (4):

$$Q_t(s) = C \cdot S \cdot T_K(s) + \frac{1}{R}T_K(s) = \left(C \cdot S + \frac{1}{R}\right)T_K(s) \tag{5}$$

That is:

$$\frac{T_K(s)}{Q_t(s)} = \frac{1}{C \cdot S + \frac{1}{R}} \tag{6}$$

Due to the hysteresis of the measuring element and the inherent thermal inertia of the resistance furnace itself, there is a hysteresis link τ between the control signal and the measured value. We set $Q_t(s) = kU(s)$,$\mathrm{Y(s)} = T_K(s)$,so:

$$\frac{\mathrm{Y(s)}}{U(s)} = \frac{T_K(s)}{U(s)} = \frac{k}{C{\cdot}S+\frac{1}{R}}e^{-\tau s} = \frac{Ke^{-\tau s}}{TS+1} \tag{7}$$

In the formula: K=kR, is the static gain; T=CR, is the time constant, so the ideal model of the resistance furnace system is:

$$\mathrm{G(s)} = \frac{Ke^{-\tau s}}{TS+1} \tag{8}$$

In this article K=2, T=144,$\tau = 30$,So the resistance furnace model is:

$$\mathrm{G(s)} = \frac{2\mathrm{e}^{-30\mathrm{t}}}{144\mathrm{s}+1} \tag{9}$$

3. Traditional PID Control

PID control is one of the most widely used control methods in industrial applications. It is a well-deserved universal control. If you can master the design and implementation process of PID control algorithms, you can solve many control problems. What is commendable is that in many control algorithms, PID control is the simplest control method that can best reflect the feedback thought, and it can be described as a classic among the classics.

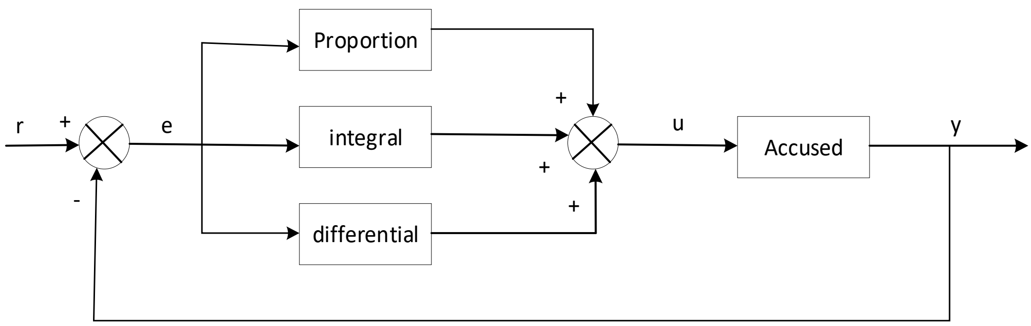

Figure 2. PID control principle diagram

The PID algorithm controls the controlled quantity through the error signal, and the controller itself is the sum of the three links of proportional, integral, and derivative.

(1) Ratio link

The output of the controller is proportional to the input deviation value. Once the system has a deviation, the proportional adjustment immediately produces an adjustment effect to reduce the deviation. Features: The process is simple and fast, and the proportional effect is large, which can speed up the adjustment and reduce the error; but the stability of the system is reduced, resulting in instability, and there is a margin.

(2) Points link

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The integral link is mainly used to eliminate the static difference. The so-called static difference is the difference between the output value and the set value after the system is stable. The integral link is actually the process of deviation accumulation, adding the accumulated error to the original system to offset the static difference caused by the system.

(3) Differential link

The differential signal reflects the change law of the deviation signal, or the change trend, and advances the adjustment according to the change trend of the deviation signal, thereby increasing the rapidity of the system.

The differential equation of the PID controller is:

$$\mathrm{u(t)} = K_p \left[e(t) + k_i \int_0^t e(t)dt + k_d \frac{de(t)}{dt} \right] \tag{10}$$

Among them, k_p,k_i,k_d are proportional gain, integral gain, and derivative gain respectively.

According to the resistance furnace temperature control system model $\mathrm{G(s)} = \frac{2e^{-30t}}{144s+1}$,Use Ziegler-Nichols parameter tuning method to tune PID parameters.

The empirical formula for setting is:

$$K_p = \frac{1.2T}{K\tau} \qquad T_i = 2\tau \qquad T_d = 0.5\tau$$

From K=2, T=144, we can get k_p=2.88, T_i=60, T_d=15, In the simulation, the sampling time is 1s, it can be known thatk_i=0.048, k_d=43.2.

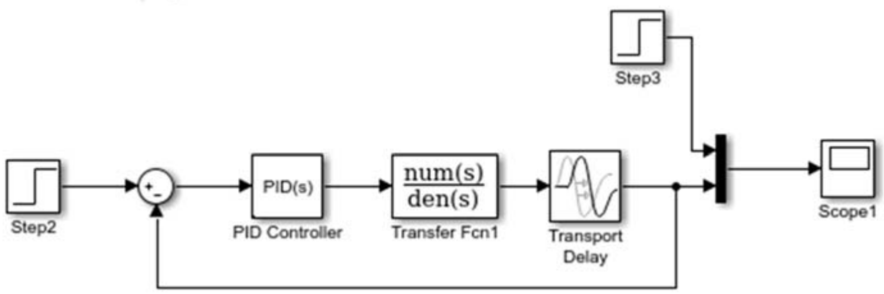

Figure 3. PID control simulation diagram of resistance furnace

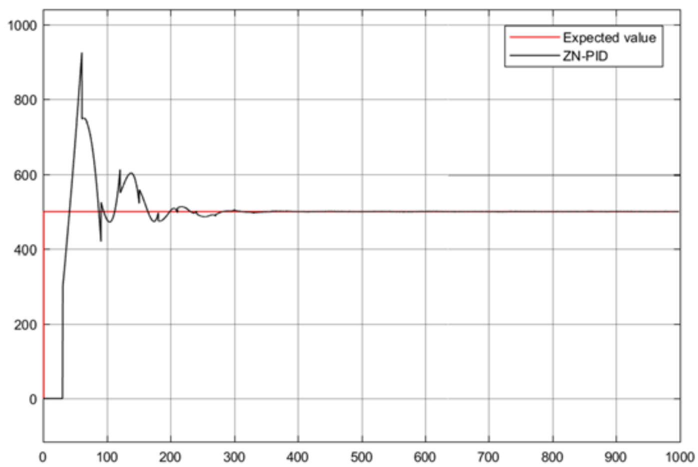

Figure 4. PID control response curve of ZN tuning method

It can be seen from the figure that the ZN tuning method obtains the adjustmenttime t_s=282s, the overshoot δ%=86.4%, and the steady-state error e_{ss}=0.

If using the ISTE optimal control tuning method tok_p=2.1277, k_i=0.0139, k_d=28.4793, the response curve is shown in Figure 5.

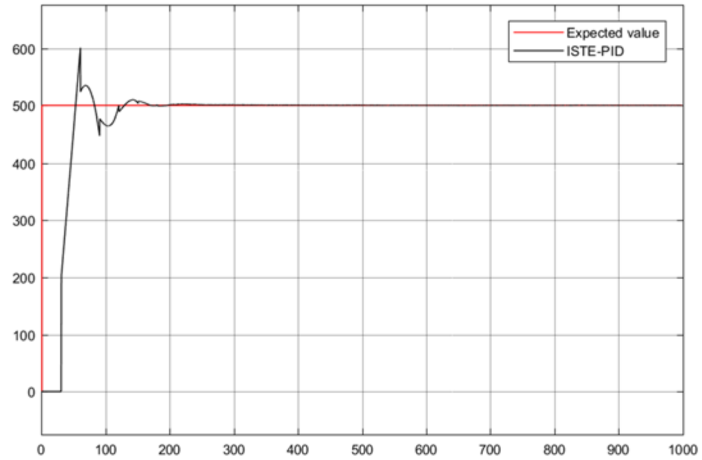

Figure 5. PID control response curve of ISTE optimal tuning method

It can be seen from the figure that the ZN setting method obtains the adjustment time t_s=200s, the overshoot δ%=20.4%, and the steady-state error e_{ss}=0.

The overshoot of the above two tuning methods is relatively large and easy to produce oscillations, so we need to find a better method for optimal control.

4. Fuzzy PID Control

4.1 Principle of Fuzzy PID

The fuzzy PID controller uses the error e and the error rate of change ec as the input of the controller. After the input is fuzzy and fuzzy inference, the output value of the fuzzy controller is obtained. The PID controller performs its own parameters according to the output value of the fuzzy control. adjust. The schematic diagram of the fuzzy PID controller used in this article is shown in Figure 6.

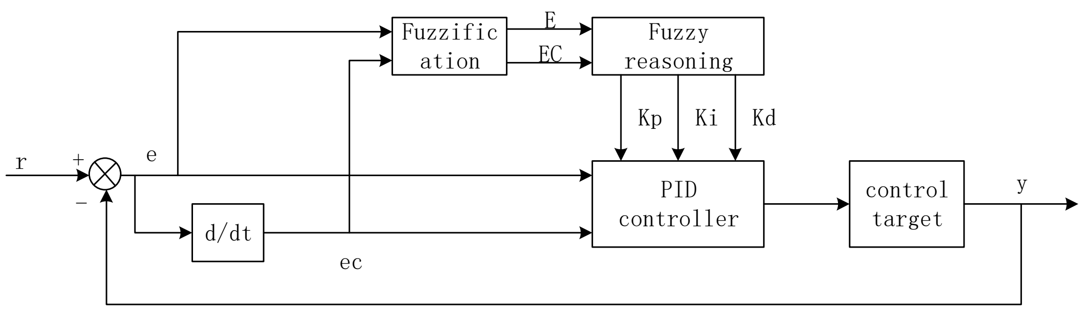

Figure 6. Fuzzy PID control principle diagram

The purpose of introducing a fuzzy self-adjusting PID controller is to continuously detect the size of the system response error e and its rate of change ec at each sampling moment, and then obtain the correction amount of the PID parameters according to the formulated fuzzy rules, so that the PID controller is It can actively adjust the size of its own parameters according to the changes of the

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system response, thereby enhancing the system's dynamic response performance and robustness to external interference. Generally, the tuning principles of PID controller parameters k_p,k_i,k_d under different conditions are:

(1) When the deviation |e| is large: the value of k_p should be increased, so that the deviation can be reduced quickly; due to the effect of k_p, the deviation can be rapidly reduced, but at the same time, a large deviation change rate is generated. Suppress the rapid increase of the differential action, and further limit the control action to change within a reasonable range. The smaller k_d should be adopted. Because the cumulative action of the integral link on the error will cause integral saturation due to the larger error, the control action will exceed the allowable Range, so k_i=0 is usually taken, and the integral effect is removed.

(2) When |e| and |ec| are in the middle size: In order to avoid the overshoot of the system caused by the larger k_p, the value of k_p should be appropriately reduced; at the same time, a smaller value of k_i can be used; due to the differential link It will suppress the change of the deviation in advance, and the value of k_d will have a greater impact on the dynamic performance of the system. At the same time, in order to ensure the response speed of the system and reduce the adjustment time, an appropriate size should be selected.

(3) When |e| is small: In order to obtain good steady-state performance and further reduce the steady-state error, the values of k_p and k_i should be increased; the value of d has a greater impact on system performance, in order to avoid system performance For unstable phenomena that oscillate near the steady-state value, a reasonable value of k_d should be used. Usually when ec is smaller, the larger k_d is used, and when ec is larger, the smaller k_d is used.

(4) The size of |ec| indicates the rate of change of the system deviation. When the value of ec is large, the value of k_p should be smaller and the value of k_i should be increased.

4.2 Design of Fuzzy PID Controller

The temperature deviation e and its rate of change ec are selected as the input variables of the fuzzy controller. After the quantization factor is applied, the fuzzy controller is input into the fuzzy controller to obtain the fuzzy variables e, ec, and the output fuzzy variables are k_p,k_i,k_d.

Their language variables, basic domains, fuzzy subsets, and fuzzy domains are shown in Table 1.

Table 1. System input and output variables

Actual variable	e	ec	k_p	k_i	k_d
Linguistic variables	E	EC	Kp	Ki	Kd
Basic domain	[-3 3]	[-3 3]	[0 3]	[0 3]	[0 31.5]
Fuzzy subset	{nb nm ns zo ps pm pb}	{nb nm ns zo ps pm pb}	{zo ps pm pb}		
Fuzzy domain	[-3 3]	[-3 3]	[0 3]	[0 3]	[0 3]

For the convenience of calculation, the membership functions of the fuzzy subsets of all linguistic variables are in the shape of an isosceles triangle, as shown in Figure 7.

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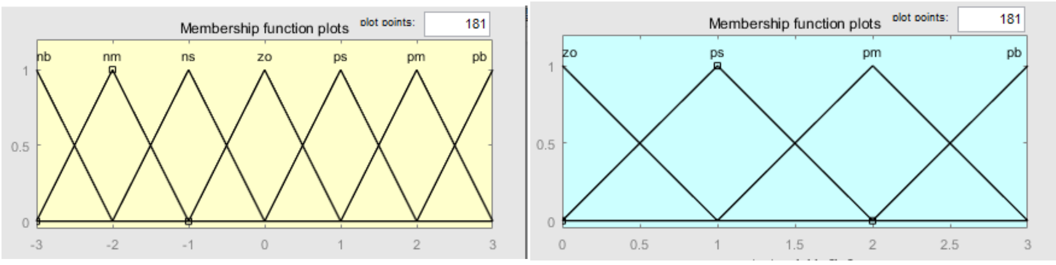

Figure 7. Membership function of fuzzy subset

According to the above-mentioned self-tuning principle of parameters k_p,k_i,k_d, under different deviation e and deviation change ec, the fuzzy control rule table of Kp, Ki, Kd is obtained as shown in Table 2,3 and 4.

Table 2. Kp's fuzzy rule control rule table

E	EC						
	nb	nm	ns	zo	ps	pm	pb
nb	pm	ps	pm	pm	pm	ps	pm
nm	pb	pm	pb	pb	pb	pm	ps
ns	pb	pm	pb	pb	pb	pm	ps
zo	pb	pm	pb	zo	pb	pm	ps
ps	pb	pm	pb	pb	pb	pm	ps
pm	pb	pm	pb	pb	pb	pm	ps
pb	pm	ps	pm	pm	pm	ps	pm

Table 3. Ki's fuzzy rule control rule table

E	EC						
	nb	nm	ns	zo	ps	pm	pb
nb	zo	ps	pm	pb	pm	ps	zo
nm	zo	ps	pb	pb	pb	ps	zo
ns	zo	zo	pb	pb	pb	zo	zo
zo	zo	zo	pb	pb	pb	zo	zo
ps	zo	zo	pb	pb	pb	zo	zo
pm	zo	ps	pb	pb	pb	ps	zo
pb	zo	ps	pm	pb	pm	ps	zo

Table 4. Kd's fuzzy rule control rule table

E	EC						
	nb	nm	ns	zo	ps	pm	pb
nb	ps	pb	pb	ps	ps	pb	pb
nm	ps	ps	pm	pm	zo	ps	ps
ns	ps	zo	zo	ps	pm	zo	ps
zo	pb	pb	ps	ps	ps	ps	zo
ps	zo	ps	pm	zo	ps	ps	ps
pm	ps	ps	ps	ps	ps	pm	ps
pb	pb	pb	ps	ps	pb	pb	ps

Then according to the 49 fuzzy control rules set out in the above fuzzy control rule table, the three parameters k_p,k_i,k_d are self-tuning and correcting.

4.3 Fuzzy PID Control is Simulated in Simulink

Build a simulation model through the fuzzy controller module in simulink, enter the fuzzy command in the matlab command window to call up the fuzzy controller, and set the membership function and fuzzy rules in the controller.

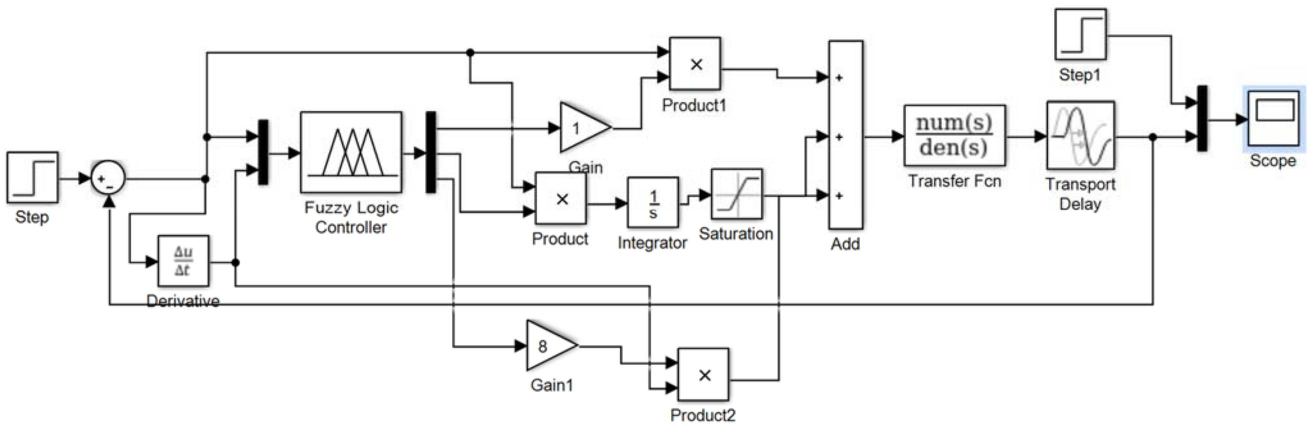

Figure 8. Fuzzy PID control system simulation diagram

When the given temperature value is 500℃, the fuzzy port of the resistance furnace temperature control system adapts to the PID control simulation response curve as shown in Figure 9:

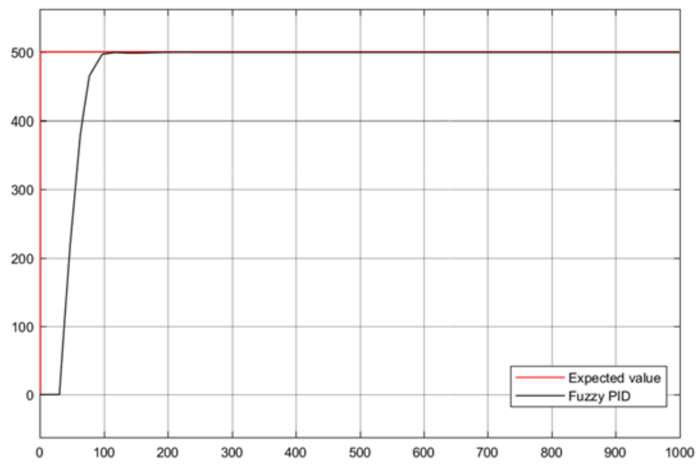

Figure 9. Fuzzy PID control system response curve

It can be seen from the figure that under the fuzzy white adaptive PID control, the performance indicators of the resistance furnace temperature control system are: adjustment time ts= 90s, overshoot $\delta\%$ = 0.18%, steady state error e_{ss}= 0.

From the simulation results of the resistance furnace temperature control system based on fuzzy adaptive PID control, it can be concluded that when the resistance furnace temperature control system adopts fuzzy adaptive PID control, the stability of the system is strong, the adjustment time is short, and the overshoot is less than 0.5% And the steady-state error is 0, which can achieve the result we want.

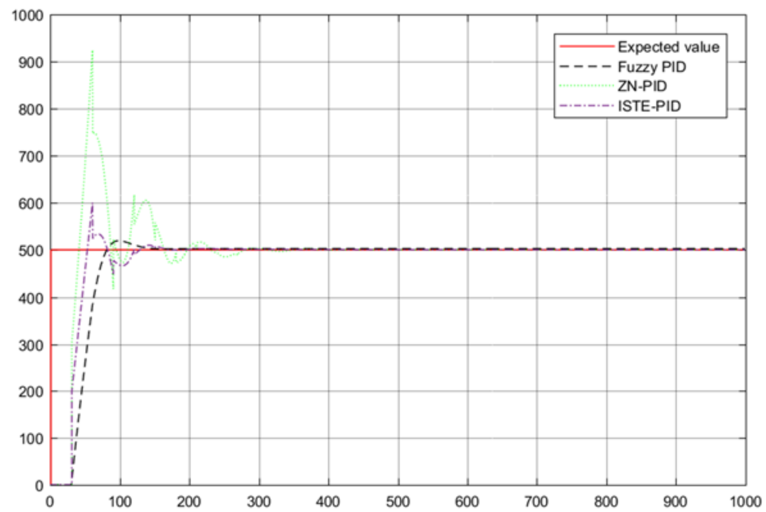

Figure 10. Comparison of response curves of PID control and fuzzy PID control systems

5. Conclusion

Starting from the temperature control of the resistance furnace, this article first designs a PID controller for it, and uses the ZN tuning method and the ISTE optimal tuning method to obtain the PID parameters, and then designs a fuzzy adaptive PID controller to control the temperature. By comparison, we can know that, compared with the traditional PID, the fuzzy adaptive PID has a smaller overshoot in the resistance furnace temperature control, a shorter adjustment time, and a better control effect.

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