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Procedia Engineering 29 (2012) 257 – 261

Procedia Engineering

www.elsevier.com/locate/procedia

2012 International Workshop on Information and Electronics Engineering (IWIEE)

Application of Expert Fuzzy PID Method for Temperature Control of Heating Furnace

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Abstract

In order to solve the problem of non-linearity, large delay and time variant of heating furnace, the combination of fuzzy PID control and the expert decision is used to regulate the temperature, and an expert fuzzy PID controller is designed. In this controller, The PID parameters are adjusted by fuzzy reasoning algorithm, so it has self-adapting ability. The expert decision can decrease the temperature shock near the set value. When the error is higher than the set value, the fuzzy PID is used to control the temperature. Otherwise, the expert is selected. The simulations and experimental results show that the temperature control system based on expert fuzzy PID algorithm has the merits of faster response, smaller overshoot and higher robustness than classical PID.

Keywords: Expert control; Fuzzy PID control; heating furnace; temperature control

1. Introduction

Because the heating furnace has the disadvantages of non-linearity, time-variant and large delay, its control effect is often not satisfactory [1,2]. Therefore, it is very important to seek an effective and accurate method to control the temperature of heating furnace. In recent years, with the continuous development of the fuzzy theory and neural network theory, the intelligent control of heating furnace has become a hot topic and an important research field [3,4].

Fuzzy PID control technology has been widely used in many fields, especially in the temperature control of heating furnace because of its simplicity, flexibility, practicality, stability, high precision and high robustness [5]. However, the control rules and membership functions of fuzzy controller are

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1877-7058 © 2011 Published by Elsevier Ltd.
doi:10.1016/j.proeng.2011.12.703

artificially set, so it is difficult to meet the dynamic requirements of time-varying and hysteresis [6,7]. Therefore, in order to meet the requirements of real-time control, the expert system is introduced. The experience knowledge is stored in computer, and the knowledge database according with the practice is formed to improve the control effect. The expert controller can make the system go into stable state in shorter time.

In this paper, a temperature control system is designed according to the combination fuzzy PID control with expert control, and the expert fuzzy PID controller is described in details.

2. Structure of temperature control system for heating furnace

Fig.1 shows the structure of temperature control system for heating furnace, and its main control unit is an expert fuzzy PID controller.

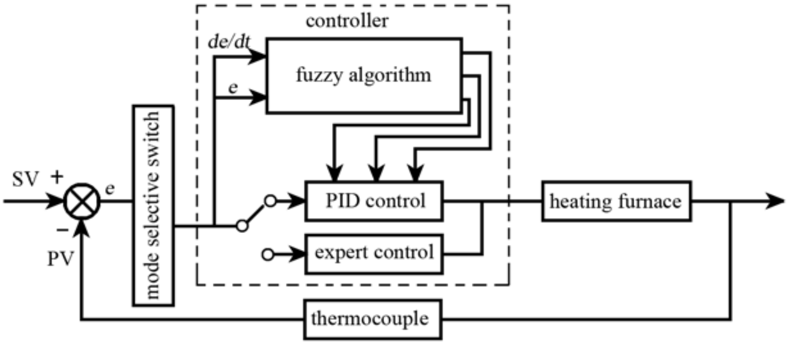

Figure 1 Temperature control system of heating furnace based on expert fuzzy PID

When the temperature in heating furnace is measured by the thermocouple, it is compared with the set temperature. As a result, the error *e* and the error change rate *ec* will be got, and they are the input parameters. According to the set value of the mode selective switch, either the fuzzy PID control or the expert control will be chosen. When the error *e* is higher than the set value, the fuzzy PID control will be used. On the contrary, when the error *e* is lower, the expert control will be selected.

Therefore, the ways of controlling temperature can be regulated flexibly according to the real-time error *e* and error change rate *ec*. It not only has the merits of quick regulation of the expert control, but also high precision and good stability of fuzzy PID control.

3. Design on expert fuzzy PID controller

The fuzzy PID control is developed from tradition PID. Based on the fuzzy control theory, the fuzzy relationship between three PID parameters K_P, K_I, K_D and the error *e* and error change rate *ec* can be established. According to different *e* and *ec*, the parameters K_P, K_I, K_D can be self-adjusted online in order to make the controlled object have a good dynamic and static performance, which can meet different control requirement.

In general, fuzzy control has no knowledge database, and not has the adaptive ability, and the flexibility and interactivity are not very good. Contrarily, the expert systems often can not directly used to controlled object or production process. So, the combination the fuzzy PID and expert control will bring their respective advantages into play.

Expert controller mainly plays the function of retaining temperature invariable when the measured temperature reaches the range of experimental precision. Therefore, it can make the furnace temperature stabile and avoid the temperature shock in the error range, rapidly meeting the test requirements. Expert PID controller is mainly composed of expert decision in form of the program statements "if-then".

The expert fuzzy PID controller is mainly composes of fuzzification, fuzzy reasoning, defuzzification and expert decision, and the design process can be described as follows.

3.1. Fuzzification

Generally speaking, the classical PID controller can be given:

$$u(k) = K_P e(k) + K_I \sum e(k) + K_D \left[e(k) - e(k-1) \right] \quad k = 0,1,\cdots,n \tag{1}$$

When the parameters of PID are adjusted by the fuzzy control, the classical PID controller becomes the fuzzy PID controller, and the formula can be shown as:

$$\begin{aligned} K_P &= K'_P + k_p \\ K_I &= K'_I + k_i \\ K_D &= K'_D + k_d \end{aligned} \tag{2}$$

where, K'_P、K'_I、K'_D are the initial PID parameters, and k_p, k_i, k_d are the adjusted PID parameters。

If the fuzzy set domain of the error *e*, the error change rate *ec*, the PID parameters k_p, k_i, k_d is defined as {-6, -5, -4, -3, -2, -l, 0, 1, 2, 3, 4, 5, 6}, the fuzzy set is {*NB*, *NM*, *NS*, *ZO*, *PS*, *PM*, *PB*}. The membership function can be defined as linear or nonlinear function. In this study, this function is Gaussian distribution, namly:

$$\mu(x) = e^{-\left(\frac{x-a}{b}\right)^2} \tag{3}$$

where, $b > 0$, and a can be +6, +4, +2, +0, -0, -2, -4, -6 responding to fuzzy sets *PB*, *PM*, *PS*, *ZO*, *NS*, *NM*, *NB*.

3.2. Fuzzy rule

After the membership function is defined, the appropriate fuzzy rules of k_p, k_i, k_d can be established according to the expert experiences, and they are shown in Table 1, Table 2 and Table 3, respectively.

Table 1 Fuzzy rule of k_p

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

Table 2 Fuzzy rule of k_i

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

Table 2 Fuzzy rule of k_d

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

3.3. Fuzzy reasoning and defuzzification

According to the fuzzy tables, we can get 49×3 fuzzy rules and they can be described the following statements.

If $E=A_i$ and if $EC=B_j$ then k_p (k_i、k_d)=C_{ij}

where, A_i, B_j and C_{ij} are the fuzzy sets of the error *E*, the error change rate *EC* and PID parameters k_p, k_i, k_d respectively.

So, the membership function of R is $u_R(x,y,z)=u_{Ai}(x)\wedge u_{Bi}(y)\wedge u_{Ci}(z)$, and the following expression of the PID parameter k_p can be given.

$$u_{k_p}(z)=uR(x,y,z)\wedge u_{Bi}(y)\wedge u_{Cij}(z) \tag{4}$$

Consequently, the output of K_P is as follows.

$$K_P=\frac{\sum_{j=-6}^{j=6} j\cdot u_{k_p}(j)}{\sum_{j=-6}^{j=6} u_{k_p}(j)} \tag{5}$$

Similarly, the outputs of K_I and K_D can be also got

3.4. Expert decision

When the measured temperature is near to the set value and it reaches the accuracy requirement, the expert control will be selected through the mode selective switch. In this moment, the output of the controller retain invariable, namely, $u(k)=u(k\text{-}1)$. So, the temperature of heating furnace will stabilize. When the stable temperature is beyond the error range, the switch will turn to the fuzzy PID control.

4. Experiments and result analysis

The temperature control of heating furnace can be expressed by a pure time delay plus an inertia input. According to the experiment, the model can be written as the following equation.

$$G(s)=\frac{11}{50s+1}e^{-80s} \tag{6}$$

Under the condition of the unit step input, the results of the temperature system controlled by classical PID and expert fuzzy PID respectively are shown in Fig.2.

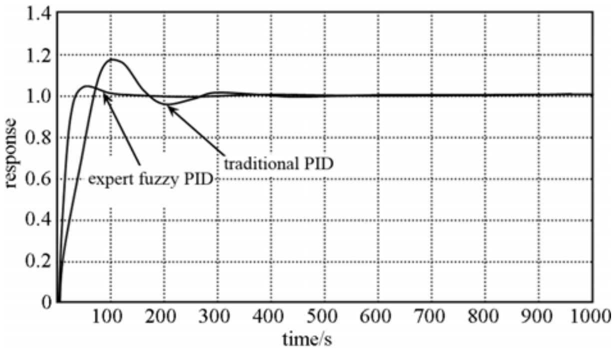

Figure 2 Simulation results of PID and Fuzzy-PI control

It can be seen from Fig.2 that the overshoot of expert fuzzy PID algorithm is about 2% and the overshoot of classical PID algorithm is about 12%. In addition, the adjusting time of expert fuzzy PID algorithm is about 65s while the adjusting time of PID algorithm is above 100s. Thus, expert fuzzy PID control algorithm has the advantages of fast response, small overshoot, short adjusting time and good stability.

Some trial experiments on the temperature control system of heating furnace are preformed in the laboratory. After the control temperature is stabilized at 750℃, the set value is suddenly elevated from 750℃ to 780℃, and the temperature adjusting curve is shown in Fig.3.

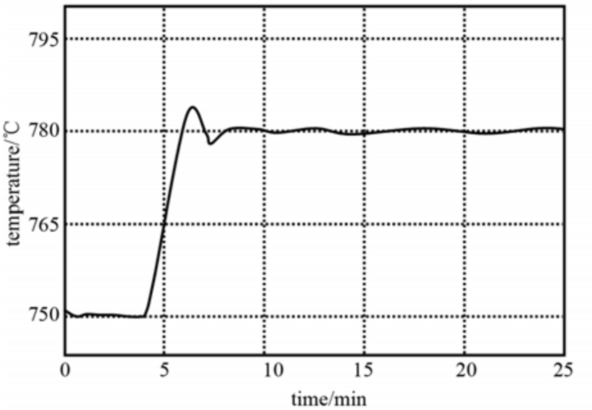

Figure 3 Temperature control curve of resistance-heated furnace

It can be seen from Fig.3 that the temperature will be re-stabilized at 780℃ after 230s and the temperature fluctuation is very small. It indicates that this system have a good control performance and high robustness.

Conclusions

The expert fuzzy PID method is used to regulate the temperature of the heating furnace, and an expert fuzzy PID controller is designed. This controller has many advantages of high precision of fuzzy control and fast response of expert control. Simulation results show that the expert fuzzy PID controller is superior to conventional PID controller in the overshoot, rise time and response speed. The practical experiments on heating furnace also show that the temperature control effect is better and the temperature can quickly reach stable.

Acknowledgment

The authors would like to acknowledge Y. L. Wang and J. L. Zhang for useful discussions and experimental supports. This work was supported by *NNSF* (51105121), Natural Science Foundation of Heilongjiang Province (E201129), China Postdoctoral Science Special Foundation (2011044447) and Heilongjiang Postdoctoral Science Foundation (LBH-210106).

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