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Design of an Intelligent Temperature Control System Based on the Fuzzy Self-tuning PID

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Abstract

Temperature control system is increasingly playing an important role in industrial production. Recently, lots of researches have been investigated for the temperature control system based on various control strategies. A temperature-control system based on the fuzzy self-tuning PID controller is proposed in this paper. The new algorithm based on fuzzy self-tuning PID can improve the performance of the system. Also, it's fit for the complicated variable temperature control system. The simulation results show that the validity of the proposed strategy.

Keywords: Temperature, Fuzzy self-tuning, Matlab

1. Introduction

Recently, Vacuum metallurgy technology plays an important role in the modern metallurgical industry for its advantages such as low-energy-waste, pollution-free, high recovery, beneficial results etc. [1]. Temperature control system also is an important part of vacuum smelting process. In general, most of the vacuum smelting temperature control systems use the conventional PID regulator as it is non-linear, time-varying and big lag. However, the conventional PID for this non-linear system is difficult to achieve the desired effect of control. In addition, the parameters of PID regulator need make the corresponding adjustment when the characteristic of controlled object changes.

Various strategies have been applied on the temperature control system, such as PID [2], Fuzzy [2], Artificial Intelligence [2], Fuzzy Self-tuning PID, etc. The Fuzzy Self-tuning PID algorithm [3], which is easy to implement and effective, has been widely used in the temperature control system.

This paper mainly focuses on designing the new fuzzy self-tuning PID algorithm in order to control temperature. The purpose is to improve the performance of the system and decrease the temperature fluctuation.

The outline of the paper is as follows: the model of the system is presented in Section II. The design of fuzzy self-tuning PID controller is provided in Section III. Simulation results on analysis of the algorithms are presented in Section IV. Finally, concluding remarks are made in Section V. Simulation results illustrate the effectiveness of the proposed method.

2. The model of the system

From the above description, the control object of the vacuum metallurgy is a typical first-order delay system in the view of control. It can be expressed as follows：

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$$G(S)=\frac{K\cdot e^{-\tau s}}{TS+1}, \quad (1)$$

where K is a static gain of the controlled object and τ is the pure lag time of the controlled object, T is the time-constant of the controlled object.

The PID is a very famous controller. It is wildly used as an control field. The conventional PID transfer function can be expressed as $Kp(1+\frac{1}{T_i S}+T_d S)$. The on-off control diagram is shown in the Fig. 1. So the model of the system mathematical based on the conventional PID is shown in Fig.2.

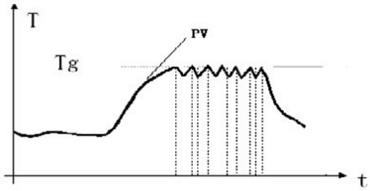

Figure.1. The on-off control diagram.

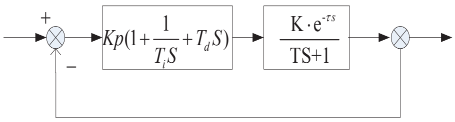

Figure.2. The model of the control system.

3. The design of fuzzy self-tuning PID controller

3.1 The principle of fuzzy self-tuning PID controller

The new fuzzy-PID controller takes conventional PID as the foundation, which uses the theory of fuzzy reason and variable discourse of universe to on-line regulate the parameters of PID automatically. The structure of fuzzy self-tuning PID controller is shown in Fig.3.

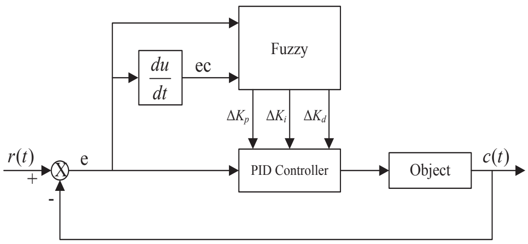

Figure.3. The Fuzzy self-tuning PID controller.

From the Fig.2, we can get that the error and error changing rate are used as the input variables in the controller, and the output variables are the parameters of PID control, those are ΔKp, ΔKi and ΔKd. Here, e denotes the system error, ec denotes the system error changing rate.

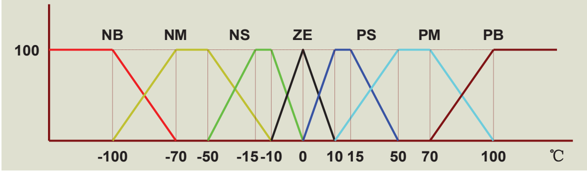

Figure.4. The domain of error.

Where NB, NM, NS, 0, PS, PM and PB are linguistic values. They respectively represent “negative big”, “negative medium”, “negative small”, “0”, “positive small”, “positive medium” “positive big” [4].

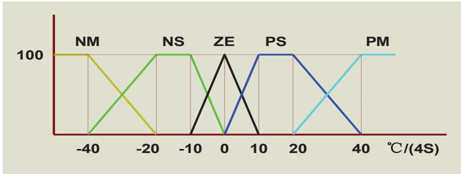

Figure.5. The domain of error changing rate.

3.2 The control rules of fuzzy self-tuning PID controller

To set of linguistic rules is the essential part of the fuzzy logic controller. In many cases it is easy to translate an expert’s experience into such rules [5]. Any number of rules can be created to define the actions of the fuzzy controller. In this paper, the fuzzy control rules design is based on the medical robot can approach the target quick and stable. The application of conventional fuzzy conditions and fuzzy relations “If e is A and ec is B then ΔKp is C, ΔKi is D, ΔKd is E” [6] can establish fuzzy rules, the finally determined fuzzy rules are shown in the following table.

Table 1. Fuzzy Rule for ΔKp .

ec \ e	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 for ΔKi .

ec \ e	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 3. Fuzzy Rule for ΔKd

ec \ e	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

After constructing the table of fuzzy control rule (ΔKp 、 ΔKi , ΔKd), we can make adaptive correction by the following method [7] [8]：

$$Kp = Kp' + \Delta Kp \tag{2}$$

$$Ki = Ki' + \Delta Ki \tag{3}$$

$$Kd = Kd' + \Delta Kd \tag{4}$$

Based on the above analysis, according to the principle of self-tuning parameters of PID, the model of fuzzy self-tuning PID can be presented in Fig.6.

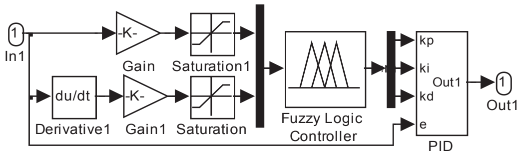

Figure.6. The model of fuzzy self-tuning PID.

4. The simulation result

Using the integrated fuzzy control toolbox “Fuzzy Logic Toolbox” in Simulink toolbox in MATLAB set up a simulation model. In order to get the step-response, we give the system an initial step signals to detect the dynamic response performance.

In order to obtain perfect performances of the control of the fuzzy control, it is essential to choice appropriate error quantification factor, error change quantification factor and proportionality factor. It is enormous influence to the fuzzy controller performance that big or small and relative relations of error quantification factor Ke , the error change quantification factor Kec , and the proportionality factor Kp , Ki , Kd . When Ke is big, the overshoots of the control system is large, the transition process will long. When Kec is big, the control system overshoot will reduce, the Kec choice more big the control system overshoots will be less. However, the control system response speed will slow [8-9]. Therefore, we should consider the requirements of the operation tasks when choose these quantification factors.

According to these rules for the various response parameters in the system, through repeated simulation and adjusted comparison, we can get a group optimal parameters： $Ke = 0.0037$, $Kec = 0.5$, $Kp = 0.001$, $Ki = 0.003$, $Kd = 0.001$.

Besides, the mathematical model of the temperature control system parameters are set as： K=80 , T=150 , $\tau = 20$. The parameters should be modified in different systems.

The parameters of the conventional PID control are $Kp\_0 = 0.016$, $Ki\_0 = 0.0009$, $Kd\_0 = 0.001$.

The simulation model of conventional PID controller and the simulation model of fuzzy self-tuning PID controller are shown in Fig.7.

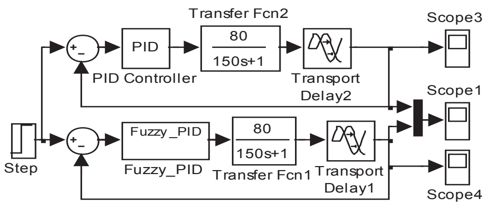

Figure.7. The system simulation model.

The reference temperature is set to 500, 800 and 1000 respectively. The simulation time is set to 2000s.

Simulation results are presented in Fig.8, Fig.9 and Fig.10.

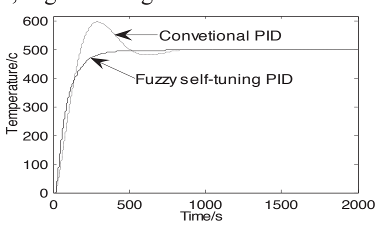

Figure.8. The performance of the two controllers when reference temperature is 500.

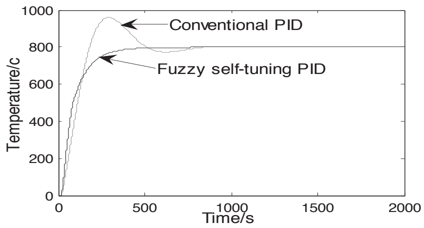

Figure.9. The performance of the two controllers when reference temperature is 800.

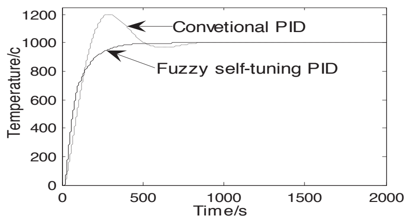

Figure.10. The performance of the two controllers when reference temperature is 1000.

From the results above, compared to the conventional PID controller, the fuzzy self-tuning PID controller has almost no overshoot and a shorter adjustment time of the characteristic, and has the better dynamic response and steady-state characteristic. The control accuracy of fuzzy self-tuning PID control is 0.005℃ and PID control is 0.2℃.

5. Conclusion

Under the guidance of variable universe of discourse, a new type of fuzzy self-tuning PID controller has been designed. By simulation testing, the results show that this controller achieves a better effect to increase the accuracy of temperature control. Also, its performance is superior to conventional PID. According to the simulation results, the proposed algorithm is reasonable and feasible for the temperature system to the system get better performance than before.

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