IMPROVED FUZZY-SET TEMPERATURE DISTRIBUTION CONTROL FOR ELECTRIC FURNACE

著者	DOTE Yasuhiko, HONMA Masayoshi
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IMPROVED FUZZY-SET TEMPERATURE DISTRIBUTION CONTROL FOR ELECTRIC FURNACE

土 手 康 彦・本 間 雅 美

Yasuhiro DOTE, Masayoshi HONMA

Abstract

In many control applications, it has always been a challenge to the control engineer to control complex system or non-linear system. To overcome these difficulties this paper presents an improved fuzzy-set control method whose derivation is based on knowledge of variable control systems rather than operator's experience. Therefore, the proposed fuzzy controller is more simply designed, since a sliding curve (reference model) is utilized. The improved fuzzy-set controller which requires less computational time is proposed. A fuzzy control algorithm is, generally, used to implement linguistically expressed heuristic control policies. Then it is applied to controlling a temperature for an electric furnace. The resulting system, which has multi-structures, yields better control performance unrealized by linear controllers such as a PID controller.

Key Words : fuzzy-set controller, variable control theory, sliding mode, rodust control

1. Introduction

Complex industrial processes such as batch chemical reactors, blast furnaces, cement kilns and basic oxygen steelmaking are difficult to control automatically. This difficulty is due to their non-linear, time varying behavior and the poor quality of available measurements. In such cases automatic control is applied to those subsidiary variables which can be measured and controlled, for example temperatures, pressures and flows. The overall process control objectives, such as the quality and quantity of product produced, has in the past been left in the hands of the human operator.

In some modern plants with process control computers, plant models have been used to calculate the required controller settings automating the higher level control function. The plant models whether they are based on physical and chemical relationships or parameter estimation methods are approximations to the real process and many require a large amount of computer time. Some successful applications have been reported, but difficulties have been experienced where processes operate over a wide range of conditions and suffer from stochastic disturbances.

Thus, an alternative approach to the control of complex process is to investigate the control strategies employed by the human operater. In many cases the process operater can control a complex process more effectively then an automatic system. When he experiences difficulty, this can often be attributed to the rate or manner or information display or the depth to which he may evaluate decisions.

The process operator's control strategy is based on intuition and experience, and can be considered as a set of heuristic decision rules or 'rules of thumb'[1]. However it is usually difficult to express and obtain operator's experience. Therefore, in this paper, a decision rule part of a fuzzy set regulator is derived on the bases of knowledge on variable control system theories[2]. A little knowledge of experience is introduced when the control rules are made.

Then, It is practically applied to a model following temperature distribution decoupled tracking for an electric furnace. As the electric furace has time lag, we use the information of the output forced model at the future time as the controller input variable. Experimental results are given. The proposed controller is superior to the conventional PID controller.

2. Description Of Control System

An improved fuzzy-set control is practically applied to decoupled thermal control for an electric furnace with three noninsulated fictitious chambers shown in Fig. 1. This process presents a number of significant nonlinearities along with time lags and diffusion effects which makes the controller design particularly challenging. One of the nonlinearities is shown in Fig. 2. The thermal resistance during heating is different from that during cooling. Also its dynamic characteristics with parameters varying widely as a function of the operating point (set point) change considerably. Chamber temperatures are interacting on one another which can be observed in Fig. 3. Each chamber temperature is controlled by requlating each thyristor controlled electric heater and on-off controlled electric fan. Measurements of chamber temperratures are made with C. A. type thermocouples which possess nonlinear characteristics. Therefore they are compensated by utilizing a look-up table and an interpolation technique. A nonlinear and moving average digital filters are used to cancel noises containing in the measured signals. The thyristor power amplifier is linearized so that the output power is proportional to the input signal by solving numerically nonlinear algebraic equations with "real time". This hardware consists of a CPU, an interface device, a thyristor phase controller, a fan controller, thermocouples and A/D converter shown in Fig. 4. The proposed control strategies are implemented with a microcomputer (PC-9801 NEC). A flow chart of algorithms used is shown in Fig. 5. A block diagram for the overall control system is illustrated in Fig. 6.

3. Fuzzy Set Controller

A fuzzy controller whose algorithm is derived on the basis of the variable structure theory, is designed for controlling the process. Therfore, the proposed fuzzy controller is more simply designed, since a sliding curve (reference model) is utilized. The sliding mode method is as follows. Setting a switching line on the phase plane, we change the structure of controller to force the trajectory to stay on the line. A fuzzy control algorithm is, generally, used to implement linguistically expressed heuristic control policies. The resulting system, which has multi structures, yields better control performance unrealized by a linear controller.

The design procedure is described in detail as follows.

1) define the discrete fuzzy-set label shown in Table. 1.

2) define the controller input variables SL and Δ M and the controller output variable U. SL is defined by equation (1), Δ M is the slope of the output forced model at the time d ahead and Δ U is the derivative of control.

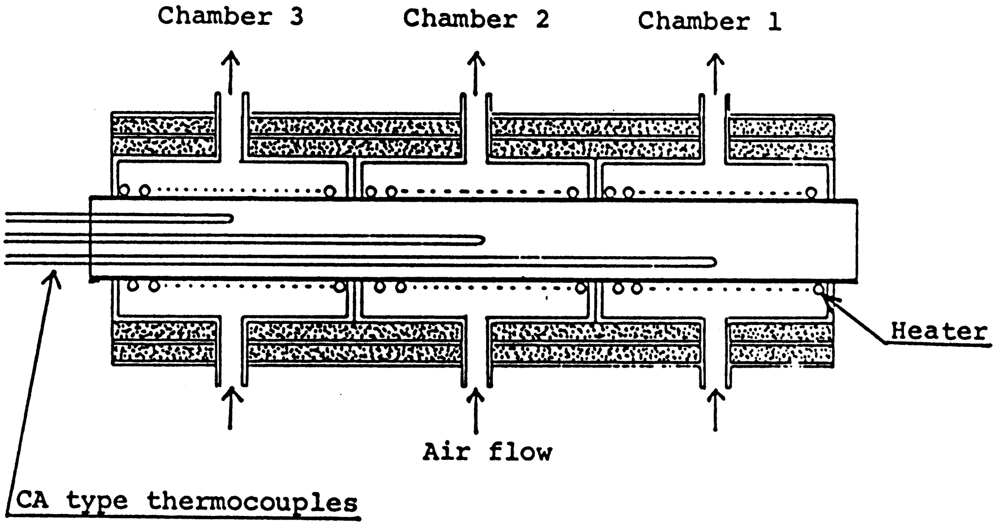

Fig. 1 Schematic diagram of electric furnace configration.

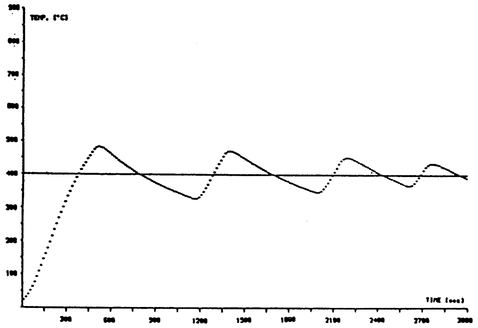

Fig. 2 Nonlinear characteristic of electric furnace.

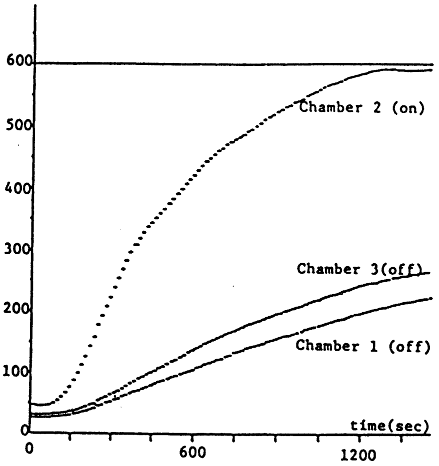

Fig. 3 Interactions among chamber temperature.

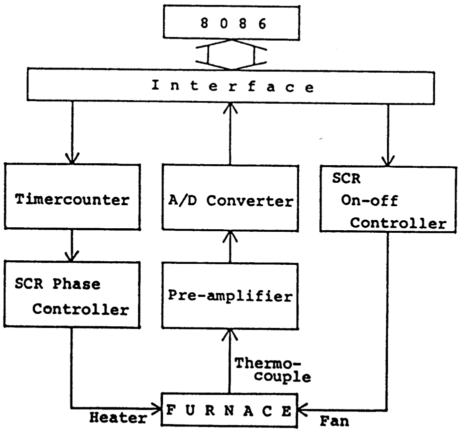

Fig. 4 Block diagram of the overall control system.

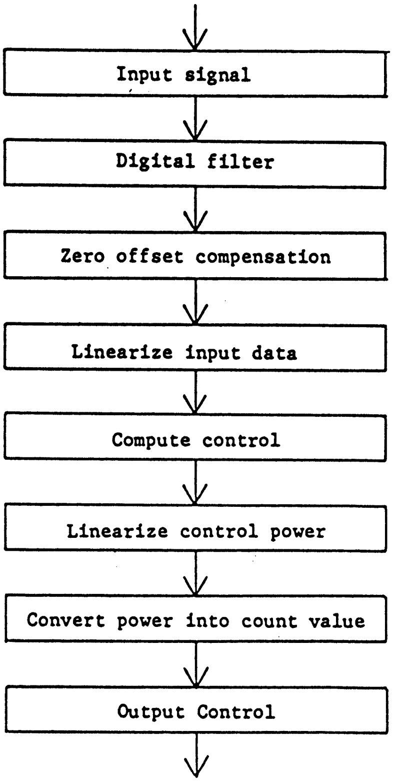

Fig. 5 Flow chart of control algorithm.

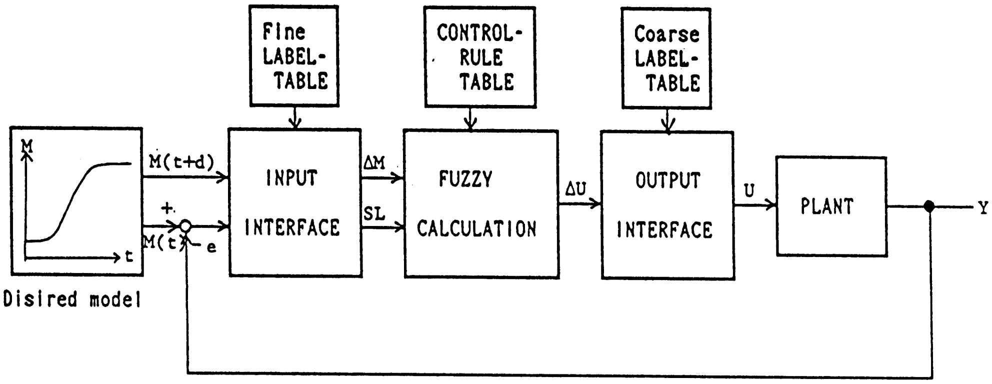

Fig. 6 Control scheme.

$$SL = C \cdot E + \Delta^2 E \tag{1}$$

$$\Delta^2 E = M(t+d) - \Delta T(t)$$

Where E is the error, C is positive constant and ΔT is the slope of the plant output.

control rules are expressed as

"if SL is X1 and ΔM is X2 then ΔU is X3"

Where X1, X2 and X3 are fuzzy labels

3) determine the control rules shown in Table. 2 on the basis of the variable structure theory.

The fuzzy inference is described in detail as follows.

1) detect the error and the force model then calculate SL and ΔM.

2) calculate the fuzzy control outputs Δu_i ($i = 1, 2, \cdots, m$ where m is the total number of rule). Let membership functions of SL, ΔM and ΔU be μ_{SL}, $\mu_{\Delta M}$, $\mu_{\Delta U}$ respectively. $\mu_{\Delta u_i}$ calculated as follows.

$$\mu_{\Delta u_i} = \min \{ \mu_{SL_i}(SL^\circ), \mu_{\Delta M_i}(\Delta M^\circ) \} \wedge \mu_{\Delta U_i} \tag{2}$$

3) evaluate the control u from equation (3).

$$\Delta u^\circ = \sum_j \bigvee_i \mu_{\Delta u_i}(j) \times j \Big/ \sum_j \bigvee_i \mu_{\Delta u_i}(j) \tag{3}$$

4) determine the control u (n+1)

$$u(n+1)=u(n)+\Delta u^{\circ} \tag{4}$$

Fig. 7 shows an example of the derivation of the proposed contorol explanation.

The membership functions of the fuzzy label are given by the discrete table for shorter computational time. On this table, if the resolution of the quantized value is better, the control is more accurate but more computational time is required. Because it takes much time to calculate the total fuzzy inference and the center of gravity. So, we prepares two kinds of the discrete label tables.

One is by fine quantitization, the other is by coarse quantitization. The former is adopted to take the membership function value about the input value. The latter is used to calculate the total fuzzy inference and the center of gravity. Thus we obtain high performance control.

4. Experimental Resultsl And Remarks

System time responses were obtained from actual measurements and stored in the computer, displayed on the CRT and printed out. Fig. 8 shows the time responses of the chamber temperatures for the proposed control methodology. Noninteracting smooth control were achieved. This method is an effective means of decoupled thermal controls for general electric furnaces. With a PID controller, interactions among chamber temperatures are observed in Fig. 9. This PID controller may not be optimum, however, to find the optimal PID controller parameters is tedious procedure for such a slow process. Even the tuned PID controller can be easily detuned for system parameter variations which often occur in general processes.

5. Conclusion

An improved fuzzy controller whose derivation is based on the variable structure theory is designed for the purpose of reducing the undesirable chattering in the sliding mode control. The proposed controller is superior to the conventional PID controller in its robustness and easy design procedure.

References

[1] P.J.King and E.H.Mamdani,"The application of Fuzzy control Systems to Industrial Processes", Automatica Vol. 13, 1977.

[2] V.I.Utkin,"Variable Structure Systems with Sliding Wodes",IEEE Trans. on AC, Vol AC-22, 1977.

Table. 1 Fuzzy labels.

PB : Positive Big

PS : Positive Small

NB : Negative Big

NS : Negative Small

ZO : Zero

Table. 2 Control rule table.

		SL				
		NB	NS	ZO	PS	PB
ΔM	PB	PB	PS	ZO	ZO	NS
	PS	PB	PS	ZO	NS	NS
	ZO	PB	PS	ZO	NS	NB
	NS	PS	PS	ZO	NS	NB
	NB	PS	ZO	ZO	NS	NB

RULE 1 " if SL is X1 and ΔM is X2 then ΔU is X3 "

RULE 2 " if SL is X2 and ΔM is X2 then ΔU is X2 "

RULE 3 " if SL is X2 and ΔM is X3 then ΔU is X1 "

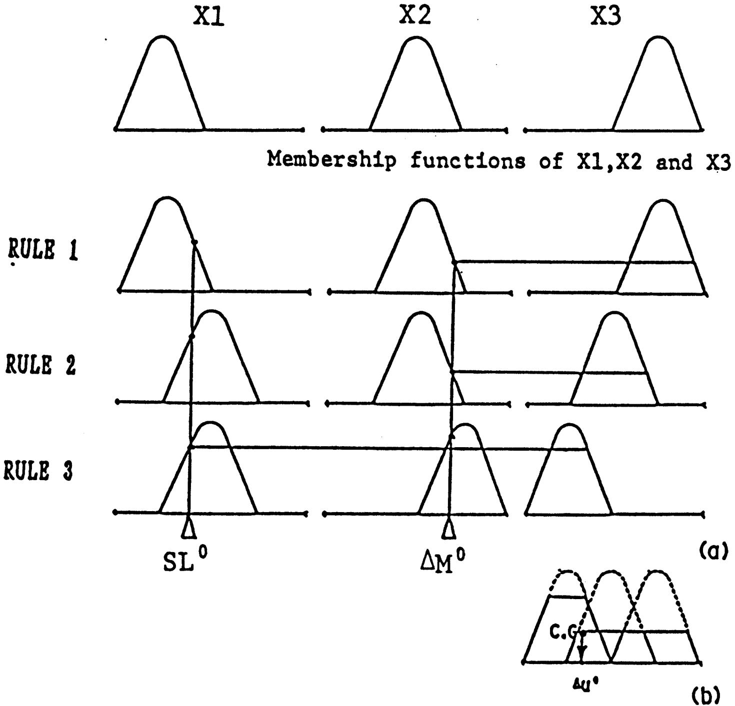

Fig. 7 Examples.

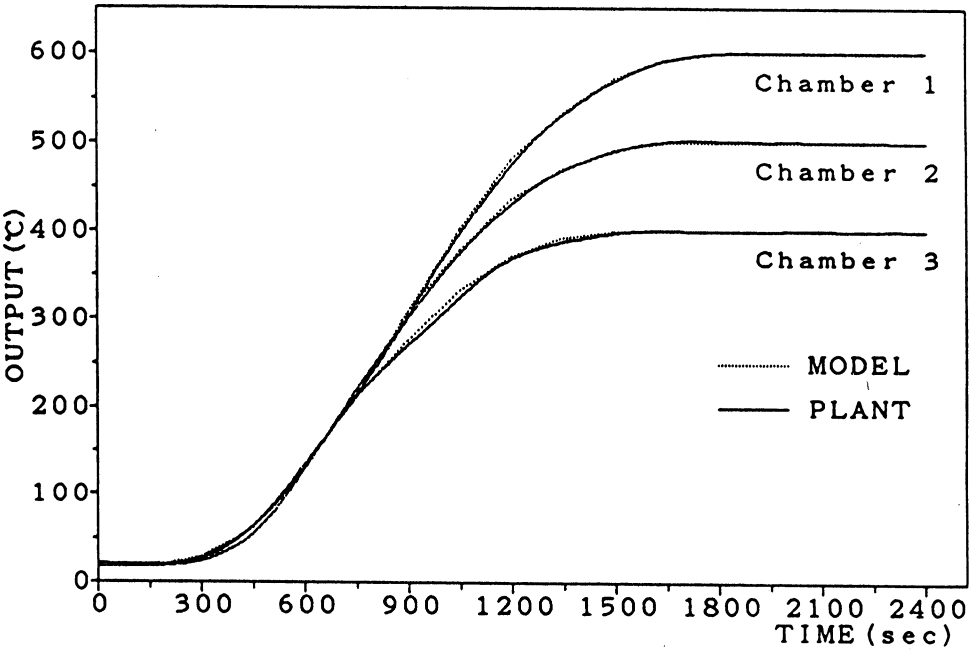

Fig. 8 Responses of the plant using proposed fuzzy-set control.

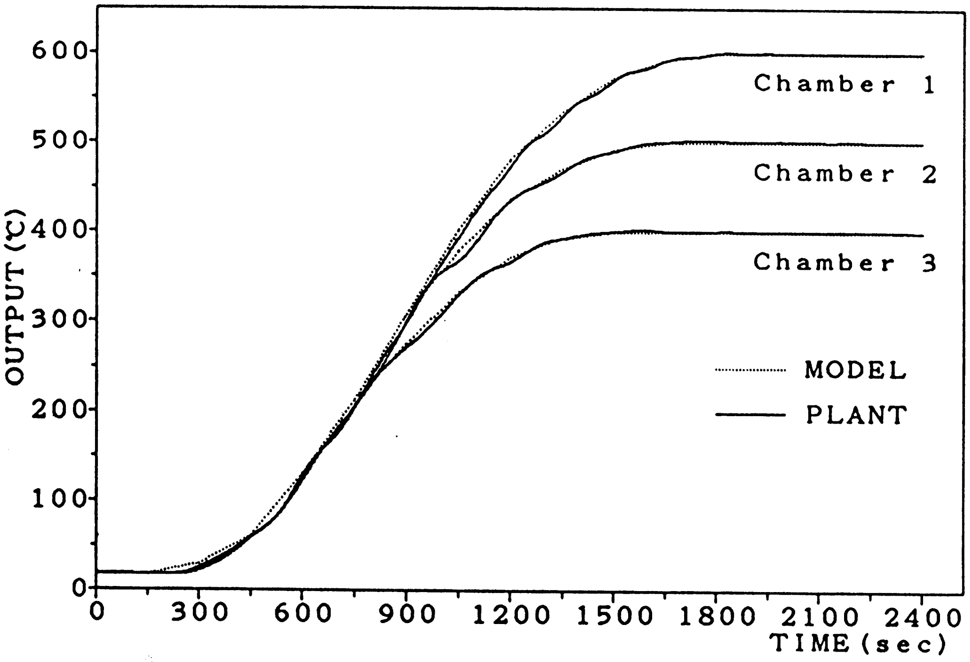

Fig. 9 Responses of the plant using PID control.