Design of Fuzzy Self-adaptive PI-Smith Predictor Process Controller

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Abstract *-The long time-delay is often existent in industrial processes. A Fuzzy-PI-Smith controller for a system with the long time-delay was proposed to solve the problem of big overshoot and regulating time during the long time-delay control .Combines the Smith predictive control with fuzzy self-adaptive proportional-integral controller (PI) in this paper. The traditional-proportional-integral (PI) controller in Smith predictive control was replaced by fuzzy PI controller which utilizes the principle of fuzzy control to tune parameters of PI controller on-line. The results of simulation for heat exchanger shows, that the method have the advantages of short regulating time, no over shoot, excellent control accuracy, and good adaptive ability to the system parameter uncertainties.*

Keywords- *fuzzy self-adaptive PI control, Smith predictive process control, Fuzzy Set*

I. INTRODUCTION

The long time-delay system is known as one of the difficulties in the industrial control, and Smith predictive control is often used for this kind of system. However, the controller designed by conventional Smith predictive control theory is only a PID controller, which is difficult to obtain satisfying control performance for the long time-delay process which has time-varying parameters or lacks of precise mathematical model. As we all know, fuzzy controller is not sensitive to parameters variation and it has good robustness, some researchers have applied fuzzy-Smith algorithm to improve control performance [1], but since fuzzy control does not have the integrator, steady-state error is not eliminated and it is difficult to achieve high control accuracy in these researches.

As the effect of differential in PID is not very obvious in engineering practice, the fuzzy self-adaptive PI-Smith control method is proposed, which combines fuzzy control, PI control, and conventional Smith predictive control. Fuzzy control is used to automatically adjust the parameters of PI control on-line, it can improve traditional PID controller whose parameters tuned by people using trial and error in most cases. At the same time, the principle of Smith predictor control is used to overcome the impact on system of long time-delay. The combination of fuzzy adaptive PI and Smith control can achieve complementary effects for the long time-delay system. The simulation for heat exchanger system using the fuzzy self-adaptive PI-Smith controller has been conducted. The results show that the method can eliminate steady-state error, shorten the settling time, depress the overshoot, and get good control quality in a certain range of model error.

II. STRUCTURE OF CONTROL SYSTEM

A. *Smith Predictive Control Configuration and Analysis*

The block diagram of the convention Smith predictive control is shown in Fig. 1. Gc(s) denotes a rational function characterizing the compensator called primary controller. Go(s) denotes a stable, strictly proper rational function characterizing the delay-free part of the plant. Denotes a positive constant standing for the time-delay. Go (s) and τ are obtained through modelling process. The inner loop works to eliminate the actual delayed output as well as to get the feedback of the predicted output to the primary controller. This makes it possible to design the primary controller assuming no time-delay in the control loop.

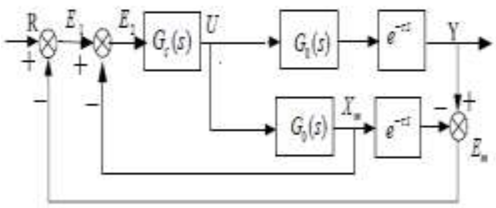

Fig.1 Block diagram of the conventional Smith Predictive Control System

From Fig. l, the transfer function of the closed-loop system after compensation is:

$$\emptyset(s) = \frac{D(s)G_o(S)}{1 + D(s)G_o(s)} e^{-\tau s} \qquad (1)$$

The expression Eq. (1) is equivalent to the block diagram shown in Fig. 2.

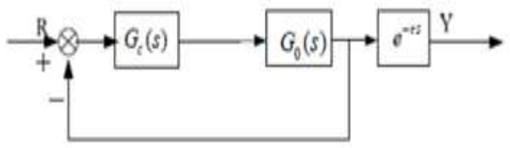

Fig. 2 Equivalent block diagram of the conventional Smith predictive control

This would move the time delay outside the control loop. Since there would be no delay in the feedback signal, the response of the system would be improved. That is, the system can eliminate the influence of time-delay on system [3].

B. *Fuzzy Self-adaptive PI-Smith Predictor Process Controller*

In view of the long time-delay characteristics of system, fuzzy self-adaptive PI-Smith control method is proposed. The method makes use of Smith predictive control to compensate for time-delay, fuzzy control overcome change of model parameter uncertainty, at the same time, adjustable PI controller is tuning on-line by fuzzy logics to improve the control accuracy in steady state [5]. Control block diagram is shown in Fig. 3.

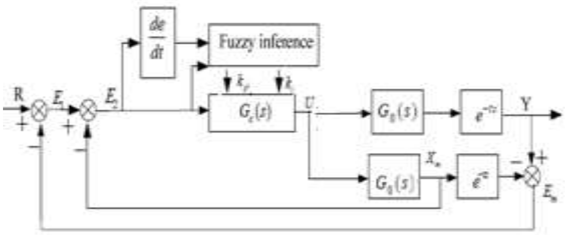

Fig. 3 Block diagram of the Fuzzy self-adaptive PI-Smith control system

The process of the fuzzy self-adaptive PI-Smith control system is firstly, to identify different combinations between the two parameters of PI controller and the error e, the change in error c. Then constantly detecting e, c in the operation, the controller amends the two parameters of the PI controller on-line through fuzzy inference so as to meet the different e and c to the different requirements of the controller parameters. Finally, Smith predictor compensates the time-delay to make entire control system has good effects [5].

C- Design of controller

1) PI controller

Over 90% of the controllers in operation today are PID controllers. This is because PID controllers are easy to understand, easy to explain, and easy to implement. Unfortunately, many of the PID controllers are often not properly tuned (e.g., due to plant parameter variations or operating condition changes), so there is a significant need to develop methods for the automatic tuning of PID controller

Taking into account the differential effect which is not obvious in engineering practice and the good robustness of fuzzy control, fuzzy control theory is used to tune the parameters of PI controller in this paper. The basic formula for the PI controller is

$$u(t) = K_P\left[e(t) + \frac{1}{T_I}\int_0^t e(t)dt\right] = K_P e(t) + K_I\int_0^t e(t)\,dt \qquad (2)$$

Where K_P is the proportional gain, K_I is the integral gain.

2) Definition of Fuzzy Set and Domain

In view of the accuracy and speed of system, the error $e(KT) = R(KT) - Y(KT)$ and change in error $c(KT) = [e(KT) - e(KT - T)]/T$ are chosen as inputs to the fuzzy controller. ΔK_P and ΔK_I are chosen as outputs to modify the parameters K_P and K_I to PI controller. K_P and K_I are calculated as follows:

$$K_P = K_P + \Delta K_P \qquad (3)$$
$$K_I = K_I + \Delta K_I \qquad (4)$$

Where K_P and K_I are the respective initial values of K_P and K_I, ΔK_P and ΔK_I are the outputs to fuzzy controller; K_P and K_I are the total outputs to PI controller.

The universes of discourse for the error e, the change in error c, ΔK_P, and ΔK_I are $\{-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6\}$, the fuzzy subsets are {NB,NM,NS,ZE,PS,PM,PB}, where NB, NM and NS are the abbreviation for negative big, negative medium, and negative small; ZE is the abbreviation for zero; PS, PM and PB are the abbreviation for positive small, positive medium and positive big. The corresponding membership functions are shown in Fig. 4 and Fig 5

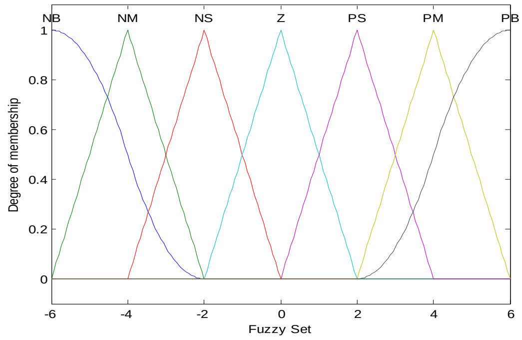

Fig. 4 The Membership functions of e and c

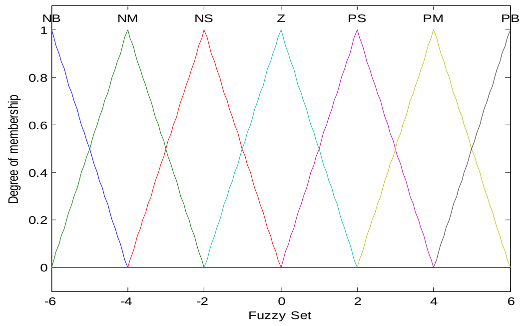

Fig. 5 The Membership functions of ΔK_P and ΔK_I

3) Fuzzy Rules

The self-tuning approach for the parameters ΔK_P and ΔK_I are summarized as follows: when the absolute value of the error e is large, take the great ΔK_P and $\Delta K_I = 0$ to speed up the system response and to avoid large overshoot. When the absolute value of the error e is medium, take the small ΔK_P and the appropriate ΔK_I so that the system response with smaller overshoot is obtained. When the absolute value of the error e is small, take the greatΔK_P and the great ΔK_I so that the system response with better stability state performance is obtained.

Based on the above approach of self-tuning PI parameters and the past experiences, the control rules for output variables ΔK_P and ΔK_I are listed in Tables l and 2.

Table 1 Fuzzy control rule table for ΔK_p

ΔK_p		ec						
		PB	PM	PS	ZE	NS	NM	NB
e	PB	PB	PB	PB	PB	PB	PB	PB
	PM	NM	NM	NS	NS	ZE	PS	PS
	PS	NS	NS	ZE	PS	PS	PM	PM
	ZE	NS	ZE	PS	PS	PS	PM	PM
	NS	PB	PB	PM	PM	PS	NS	NS
	NM	PM	NM	PB	PB	PB	PM	PM
	NB	PB	PB	PB	PB	PB	PB	PB

Table 2 Fuzzy control rule table for ΔK_I

ΔK_I		ec						
		PB	NM	PS	ZE	NS	NM	NB
e	PB	ZE	ZE	ZE	ZE	ZE	ZE	ZE
	PM	ZE	ZE	NS	NS	NM	NM	NM
	PS	ZE	NS	NS	NS	NM	NM	NB
	ZE	PM	PM	PS	ZE	NM	NB	NB
	NS	NM	NS	NS	ZE	ZE	PS	NB
	NM	NM	NS	NS	ZE	ZE	NS	NM
	NB	ZE	ZE	ZE	ZE	ZE	ZE	ZE

4. Results and Discussion

The system step response is shown in Fig. 6. The both curves have no overshoot because the time-delay of the whole system was estimated in advanced by the Smith predictor. In comparing fuzzy self-adaptive PI-Smith control with PI-Smith control, the rising time and the regulating time had been shorten significantly. The reason is that fuzzy control contains **du/dt** which is equal to PD (proportional derivative). That improves the dynamic performance.

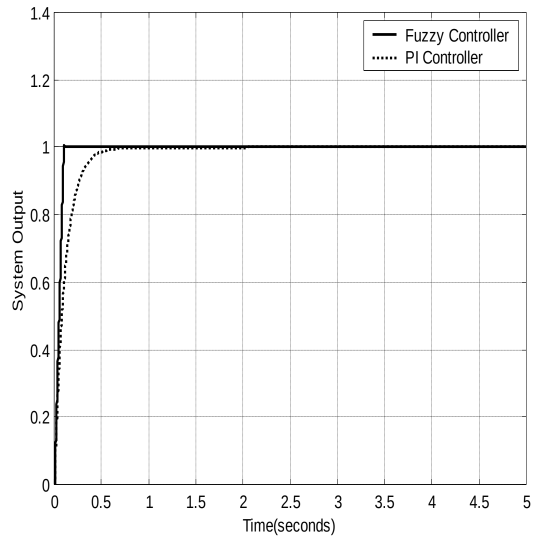

Fig. 6 Simulation output of fuzzy self-adaptive PI-Smith and the PI-Smith control system

The system step response is shown in Fig. 7. The step response of fuzzy self-adaptive PI-Smith control system has good adaptability when the system parameter uncertainties. Compared with the conventional Smith controller, the fuzzy self-adaptive PI-Smith controller can improve the dynamic characteristic of time-delay process with a short regulating time, little overshoot, and an excellent control accuracy. As the fuzzy control does not rely on the mathematical model of the controlled object, it has good control effect even if the parameter uncertainties. However, the conventional Smith predictive control has the precondition that the model should be same with the system, at least almost the same, or the control effect would be out of expectation.

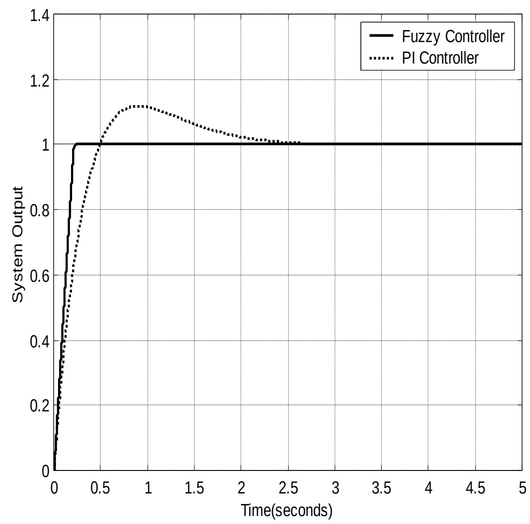

Fig. 7 Simulation output of fuzzy self-adaptive PI-Smith control with system parameter uncertainties

III. CONCLUSIONS

In order to solve the control difficulties for industrial processes with long time-delay, a fuzzy adaptive PI-Smith control method is proposed in this paper. Combined the fuzzy control, PI control, with Smith predictive control, this method has improved the dynamic performance of the system, eliminated the steady-state error, and has good adaptability when system parameter uncertainties.. The simulation results show that the method is effective for long time-delay processes.

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