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A New Smith Predictor for Control of Processes with Long Time Delays

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Abstract. The long time delay system is known as one of the difficulties in the industrial control. Processes with significant time delay present poor stability and large overshoot by using the conventional Smith predictor. In this paper, an improved fuzzy adaptive PID-Smith predictor is proposed .It uses a fuzzy self-tuning PID controller as the primary controller instead of the PID controller. In addition, a feedback loop and an adaptive regulator are imported to ensure the stability and enhance the adaptability of the variable environment. Experimental verification is used to demonstrate the advancement of the modified predictor.

Keywords: modified predictor; fuzzy self-tuning PID controller; adaptive regulator; feedback loop

1 Introduction

Control of integrating processes with long time delays is a challenging problem. The standard Smith predictor (SP), and its many extensions, can be considered as the first control method for the long time delay system. The main advantage of the SP is that the time delay is eliminated from the characteristic equation of the closed loop system. Thus, the analysis and control design problems for processes with delay can be converted into one system without delay. That's why the Smith predictive control is widely used in recent years [1-2]. Unfortunately, the controller designed by the conventional Smith predictive control theory is only a PID controller, which is difficult to obtain satisfied control performance for the long time delay process. What's more, the Smith predictor control scheme requires the knowledge of the precise model of the plant. However, the mismatch between the plant and the predicted model is inevitable, and it leads to unacceptable performance in the process closed-loop response [3-4].

In order to reduce the negative impact caused by model mismatch, an improved fuzzy adaptive PID-Smith predictor is proposed. The simulation results show that the

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new scheme, which combines the fuzzy self-tuning PID controller and the gain adaptive regulator, not only can solve the large overshoot of the long time delay system, but also holds a better stability and adaptive capacity.

2 Design of the Fuzzy Adaptive PID-Smith Predictor

The main reason that the Smith predictor is so sensitive to model mismatch lies in that both the PID controller and the Smith predictor are designed based on precise mathematical model [5]. Once the model mismatch occurs in the actual production process, the system response will be unstable and have substantial oscillation. As a result, it is difficult to obtain satisfied performance for the conventional Smith predictor. In order to get a better performance, a fuzzy self-tuning PID Smith prediction controller, which combines fuzzy self-tuning PID controller and the Smith predictor to improve the robustness and stability, is proposed in [6]. However, this method is just suitable for the model parameters changes within 20%.When it reaches more than 20%，the effect of the fuzzy self-tuning PID controller will be small and the performance will be significantly worse, even divergent, taking +40% parameter changes in this paper for an example. For the limitations of above predictor controllers, a new fuzzy adaptive PID-Smith predictor controller is developed by combining the fuzzy self-tuning PID controller and the gain adaptive regulator, and its structure is shown in Fig.1.Where $R(s)$ is the input of the system, $Y(s)$ is the output of the system, k_m is the proportional controller. $G_m(s)e^{-\tau_m s}$,$G(s)e^{-\tau s}$ and $G_c(s)$ are, respectively, the plant's dynamic model, and the transfer functions of the plant and the primary controller which uses the self-tuning PID controller instead of the traditional PID controller.

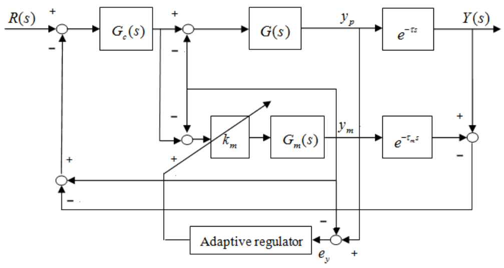

Fig. 1. The structure of the fuzzy adaptive PID-Smith predictor

3 Experimental Verification

Simple models and clear to understand control structures are very important in the process industry. So, most production process can be simplified into a first-order transfer function plus a dead-time, which is given by

$$G(s) = \frac{K}{(Ts+1)} e^{-\tau s} \tag{1}$$

Selecting an industrial electric furnace as the controlled object whose transfer function is

$$G(s) = 1 \cdot e^{-40s} / (60s+1) \tag{2}$$

When there are +40% change in the all of the parameters of the plant, that is, the plant becomes:

$$G(s) = 1.4 \cdot e^{-56s} / (84s+1) \tag{3}$$

At this time, the system responses are shown in Fig. 2.

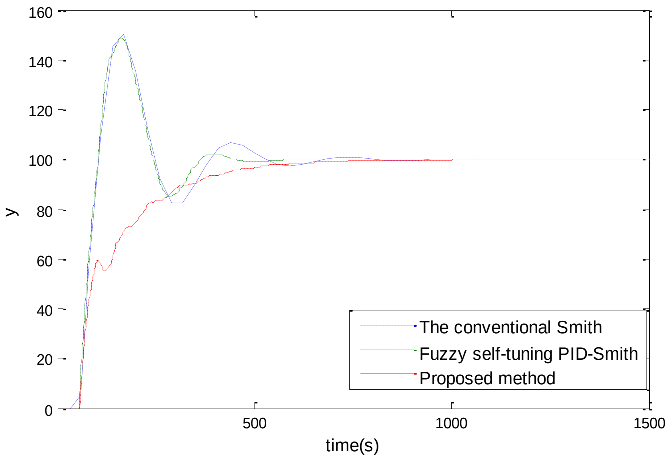

Fig. 2. The dotted (blue) line is the response of the conventional Smith control and the dash (green) line is the response of fuzzy self-tuning PID-Smith control and the solid (red) line is the response of proposed method.

According to the simulation results of Fig. 2, some important performance indicators are given and they are listed in Table 1.

Table 1. Performance indicators.

	Maximum overshoot (%)	Maximum adjustment time (s)	Stability

The conventional Smith	50.5	1000	stable
The fuzzy self-tuning PID-Smith	48.9	1000	stable
Proposed method	0.1	875	stable

It can be seen that both the fuzzy self-tuning PID-Smith control and the conventional Smith control exist large overshoot. It indicates that the effect of the fuzzy self-tuning PID controller is small when the model mismatch comes to 40%. Compared with the other methods, the proposed method only has a little overshoot. What's more, it has shortened the adjustment time and has small oscillation amplitude, even when the model mismatch rate comes to 40%. As a result, the proposed method not only can solve the large overshoot of the long time delay system, but also holds a better stability and adaptive capacity.

4 Conclusion

In order to solve the difficulties for industrial control processes with time-varying parameters and time delays, a new fuzzy self-tuning PID-Smith predictor controller, which combines the fuzzy self-tuning PID controller and the gain adaptive regulator, is proposed in this paper. This method holds excellent stability and adaptability, eliminates the steady-state error, and has improved the dynamic performance of the system, even when the model mismatch rate comes to 40%.The simulation results show that the proposed predictor controller is effective for long time delay processes, so it has great practical value

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