Research on Robust Smith Internal Model Control for Time-delay Systems

Xin Haiyan, Zuo Mei, Yu Jiajia, Lu Qingru, Huang Hui
School of Electron & Computer, Chengxian College, Southeast University,
Nanjing, Jiangsu Province, 210088, P. R. China

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Abstract: For the time-delay system, this paper combines the traditional Smith predictive control with the internal model control. According to the simulation results, it can be seen that compared with the traditional Smith control method, when the controlled object model is accurate, the Smith internal model has the advantages of short response time, good anti-disturbance and good robustness. However, when the controlled object model mismatches, it can still have good performance by adjusting the value.

1. Introduction

In the process control system of process industrial production, there is a general phenomenon of time delay. The existence of time delay makes the controlled quantity cannot timely reflect the disturbance suffered by the system, which will lead to the increase of system dynamic error, the decrease of stability margin and even the oscillation of the system. Therefore, the control method of time-delay process has always been a hot topic in the research of control theory and control engineering. Many scholars have proposed a variety of design methods of port controllers for time-delay systems, mainly including PID controller and controller design method based on Smith estimation structure.

In this paper, Smith predictive control and internal model control are combined to make the system have good following characteristics of given values, fast response, interference suppression characteristics and good robustness.

2. Model

Internal model control design is the controlled object model and the actual control object in parallel connection, the disturbance information and model mismatch information feedback to the input side, the internal model controller chooses dynamic inverse model of controlled object, internal model controller by adjusting the filter link or add the filter in the feedback channel, to ensure the robustness of the closed-loop system.

2.1 Internal model control

The basic structure of the internal model control is shown in fig.1. The internal model control structure improves the robustness of the system by connecting the filtering link in the feedback channel. In figure 1, $G_{IMC}(s)$, $G(s)$, $G_m(s)$ respectively represent the internal model controller, the actual control object without delay and the controlled object model without delay. $e^{-\tau s}$, $e^{-\tau_m s}$ respectively represent the delay link of the actual control object and the delay link of the controlled object model. $F(s)$ is a feedback channel filter; $X_r(s)$ is the system input given value; $X_d(s)$ is a system disturbance; $X_c(s)$ is the system output.

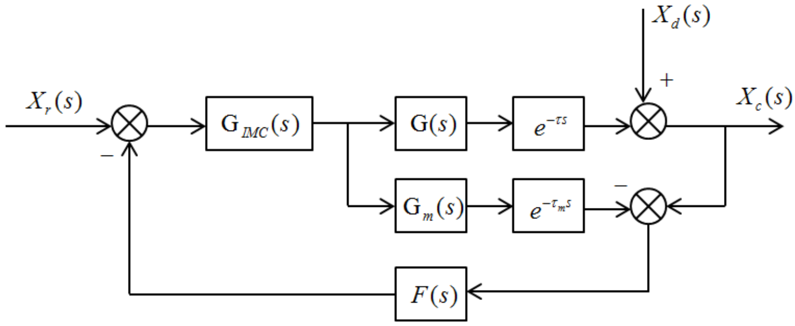

Fig.1 Basic structure diagram of internal model control

2.2 The design of internal mode controller

As can be seen from figure 1, the internal model control is mainly composed of the controlled object model, the internal model controller and the filter. The design of internal model control can be divided into two steps: The first step is that without considering robustness and constraints, Design the ideal controller $G_{IMC}(s)$**;** The second step is to design a feedback channel filter $F(s)$, and the structure and parameters are adjusted to improve the dynamic performance and robustness of the system.

2.2.1 The design of internal model controller $G_{IMC}(s)$

①Factorization of the controlled object model without delay $G_m(s)$

$$G_m(s) = G_{m+}(s) \bullet G_{m-}(s) \tag{1}$$

Where, contains the zero point of the right half plane, $G_{m-}(s)$ is the transfer function of the minimum phase part.

②The design of Internal model controller. In order to improve the stability and robustness of the system, a filter element is added to the minimum phase part $G_{m-}(s)$ of the controlled object model.

$$G_{IMC}(s) = \frac{1}{G_{m-}(s)} \bullet f(s) \tag{2}$$

Considering the effect of the step function, the structure of the filtering link of the internal mode control is selected as follows:

$$f(s) = \frac{1}{(\lambda s + 1)^n} \tag{3}$$

Where, $f(s)$ is the low-pass filter; λ is the filtering time constant; n is the relative order of the controlled object model, According to equations (2) and (3), $n = 1$ can meet the control requirements.

2.2.2 The design of Feedback channel filter $F(s)$

As can be seen from figure 1, the error between the actual output of the system and the output of the model is fed back to the input end through a feedback channel filter $F(s)$, When the model mismatch or interference exists in the system, the feedback channel filter $F(s)$ plays a role and directly affects the robustness and anti-disturbance of the system. The first-order low-pass filter is usually selected, and its structure is as follows:

$$F(s) = \frac{1}{\lambda s + 1} \tag{4}$$

3. The control of Robust Smith Internal Model

The traditional Smith predictive control model is shown in fig.2, $G_C(s)$ represents the Smith predictive controller. The stability of the traditional Smith predictive control can only be shown when the control object is consistent with the reference model. However, in the actual industrial process, it is always accompanied by uncertainty, and it is difficult to obtain the accurate model of the controlled object. It is not appropriate to use only the traditional Smith estimator, so the application of Smith estimation control method is limited.

In this paper, Smith and internal model control are combined to make full use of internal model control to ensure the robustness and implementability of the system when the model mismatches. The structure of Smith internal model control is shown in fig3.

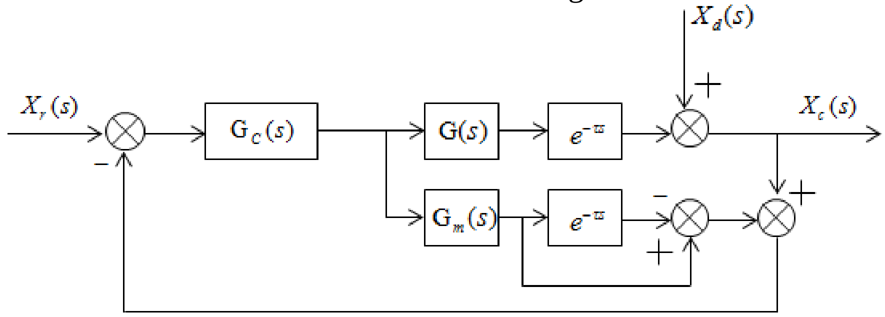

Fig.2 The structure diagram of Smith control system

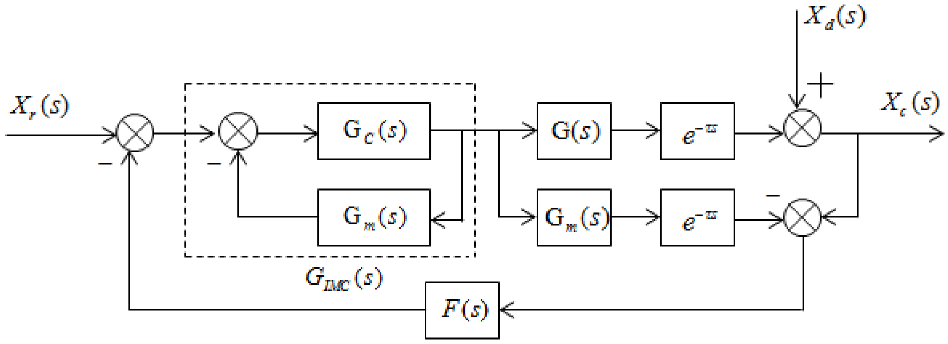

Fig.3 The structure diagram of Smith internal model control

As can be seen from fig.3, when the controlled object is stable, the transfer function of the internal mode controller is:

$$G_{IMC}(s) = \frac{G_C(s)}{1 + G_C(s)G_m(s)} = \frac{f(s)}{G_{m-}(s)} \tag{5}$$

4. Simulation Research

In the system simulation, a temperature sensor with first order inertia and large pure lag is selected as the research object, and its mathematical model is set as $G(s) = \frac{1.6}{120s+1}$, The pure delay time is $80s$, Set the target value input of the temperature system is $30^{o}C$, When the internal models match, and $\lambda = 10$, According to formula (5), the transfer function of the internal mode controller is: $G_{IMC}(s) = \frac{120s+1}{16s+1.6}$, Traditional Smith predictive control and Smith internal model control were used for simulation respectively. The simulation results are shown in fig.4.

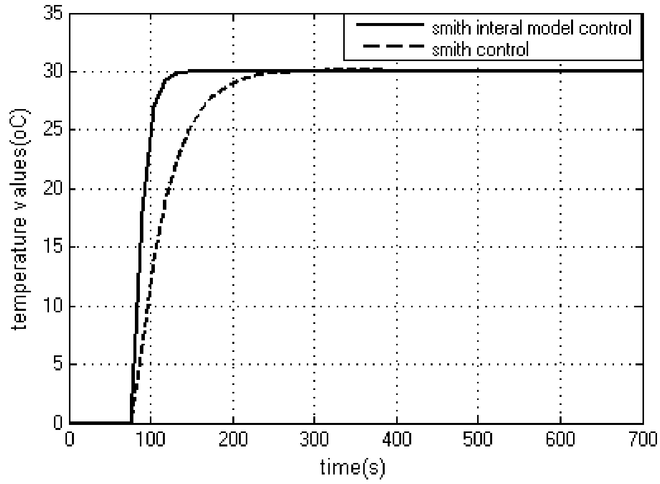

Fig.4 simulation results of the two methods when the model is matched

As can be seen from figure 4, when the internal model is matched, the adjustment time of traditional Smith estimated control method is relatively long, while that of Smith internal model control method is short and has good anti-interference characteristics.

When the internal model mismatches, the object of the controlled first-order temperature sensor is considered as $G(s)=\frac{1.62}{121s+1}e^{-82s}$, The traditional Smith predictive control and Smith internal model control methods are used for control, and the simulation results are shown in fig. 5. Where, curve 1 is the simulation result of Smith internal model control method when $\lambda=1$; curve 2 is the simulation result of Smith internal model control method when $\lambda=10$; curve 3 is the simulation result of Smith internal model control method when $\lambda=25$.

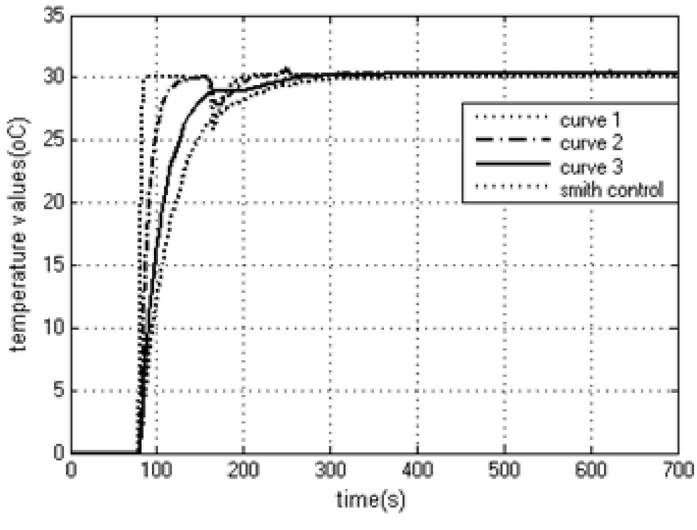

Fig.5 simulation results of the two methods when the model mismatches

As can be seen from fig.5, the adjustment time and anti-interference characteristics of the traditional Smith predictive control method are still relatively long, while the response speed of the Smith internal model control method is relatively fast, but there is a certain oscillation. However, the Smith internal model control effect can be good by adjusting the value.

5. Conclusion

For large time-delay control systems, the traditional Smith estimation control method is often used, but the system response time is relatively long. In the traditional Smith prediction control, on the basis of the internal model control, can effectively shorten the system to adjust time, speed up the response speed of system, the system has good tracking and anti-interference characteristics, especially when the control system of model mismatch, the system still has very strong robustness, and the effectiveness of the proposed method is verified by simulation.

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