

# Research and Simulation of Improved Smith Prediction Algorithm Based on PLC

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## ABSTRACT

Aiming at the problem of excessive overshoot caused by large delay in temperature control process, based on the research of Smith predictive control algorithm, an improved gain adaptive Smith predictive control scheme is proposed, which can track the change of gain in real time. The simulation program is written based on TIA Botu and configuration software, and the operation results show that the improved scheme improves the lag effect and the adaptability to the model, and it still has good control quality after the parameter changes.

## KEYWORDS

Smith predictor, Gain adaptive, PID, PLC

## 1. INTRODUCTION

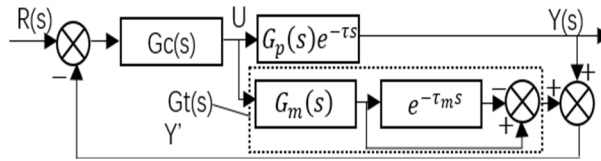
In industrial production processes, most systems have time-delay characteristics. Because of time-delay effect, the controlled variables cannot respond to the interference received by the system in a timely manner. This can easily lead to overshoot or oscillation during the control process, resulting in poor quality of the system control. Overcoming time delay is a key issue in improving the quality of lag process control[1][2]. In particular, temperature control systems with large time delays are recognized as one of the most challenging problems.

Swedish scientist Smith proposed the predictive control in 1957, which theoretically can eliminate the problems caused by time delay. However, in practical applications, it is limited by the accuracy of the object model. With the development of technology, Dahlin algorithm, internal model control, fuzzy control[3], and expert systems have emerged to some extent to reduce the dependence on model accuracy. However, these algorithms also have their own shortcomings and are less commonly used in actual production. Smith's predictive control and its improvement plan are still one of the most effective control strategies for large lag processes. In 1977, Giles and Bartley proposed a gain-adaptive Smith predictive compensation scheme, which can compensate for changes in system gain in real-time through a divider and an identifier and has good model adaptation ability. However, when simulating time-delayed objects, it is prone to operational errors. Based on this, a feedback incremental adaptive predictive control algorithm is proposed here, which uses feedback increment instead of divider and adder instead of multiplier, which can effectively solve the problem of gain-adaptive compensation control in simulation.

## 2. SMITH PREDICTIVE COMPENSATION CONTROL ALGORITHM AND ITS IMPROVEMENT PLAN

### 2.1. Smith Predictive Control Algorithm Introduction

The proposal of the Smith predictive algorithm was to solve the problem of time delay. Its control idea is to estimate the dynamic characteristics of the object, and to compensate by paralleling a predictive model on the controlled object and obtain a regulated variable without delay and send it to the controller. enabling the controller to react in advance[4][5]. This can effectively reduce overshoot and adjustment time, making the system achieve lag-free regulation. The Smith predictive compensation control structure is shown in Figure 1.



**Figure 1** Smith estimated compensation control structure diagram

In Figure 1,  $G_c(s)$  is the controller,  $G_p(s)e^{-\tau s}$  is the controlled object,  $G_t(s)$  is the compensation link,  $G_m(s)$  is the prediction model,  $e^{-\tau_m s}$  is the prediction pure delay link.

When no compensation link is added, the transfer function between the controller output and the system response is shown in Equation (1).

$$\frac{Y'(s)}{U(s)} = G_p(s)e^{-\tau s} \quad (1)$$

After adding the compensator, the transfer function between the controller output and the system response is as shown in formula (2).

$$\frac{Y'(s)}{U(s)} = G_p(s)e^{-\tau s} + G_t(s) \quad (2)$$

To make the transfer function no longer contain a pure hysteresis link, the compensation link should be.

$$G_t(s) = G_p(s) - G_p(s)e^{-\tau s} \quad (3)$$

Right now,  $G_m(s) = G_p(s)e^{-\tau_m s} = e^{-\tau s}$ , Then the transfer function between controller output and system response is as formula (4).

$$\frac{Y(s)}{U(s)} = G_p(s) \quad (4)$$

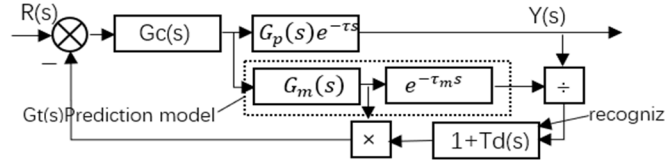
At this time, the system closed cycle transfer function is as formula (5).

$$\frac{Y'(s)}{U(s)} = \frac{G_c(s)G_p(s)e^{-\tau s}}{1 + G_c(s)G_p(s)e^{-\tau s} + G_c(s)G_p(s)(1 - e^{-\tau s})} = \frac{G_c(s)G_p(s)e^{-\tau s}}{1 + G_c(s)G_p(s)} \quad (5)$$

From equation (5), it can be seen that when the predictive model is consistent with the process model, the denominator of the system closed cycle transfer function no longer contains pure lag terms, and theoretically, the influence of time delay can be completely eliminated. However, in actual industrial production, the process object is relatively complex, and its accurate mathematical model cannot generally be obtained. Therefore, the control effect of using only the Smith predictive algorithm is not ideal and it is difficult to meet the actual process requirements[5][6], further improvements are needed.

## 2.2. Gain adaptive Smith predictive control algorithm

Based on Smith's prediction method, Giles and Bartley proposed a gain-adaptive prediction compensation scheme in 1977. The control idea is: add a divider and differential identifier between the process output and the compensator output. The divider obtains the gain change. After passing through the differential identifier, the gain change can enter the multiplier at time  $T_d$  ( $T_d = \tau$ ) in advance. The multiplier sends the product of the estimated model output and the differential identifier output as a measured value to the controller to realize the gain change. tracking, which enhances the robustness to changes in model parameters to a certain extent. The gain adaptive Smith prediction control structure is shown in Figure 2.

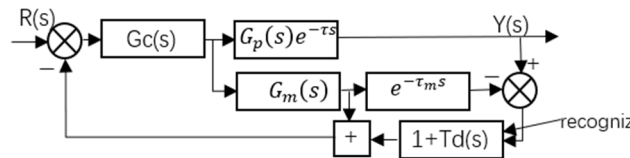


**Figure 2** Gain Smith prediction control structure diagram

Under ideal conditions, if the prediction model is consistent with the process object, the output of the divider is 1, which is equivalent to a conventional Smith predictor. However, in actual production, ideal conditions are rare, and there is generally a deviation between the prediction model and the process object. Here we mainly analyze the gain deviation. When the gain increases by  $A$ , the output of the divider is  $(Kp+A)/Kp$ . After passing through the identifier, the output of the multiplier is  $(Kp+A)Gp(s)$ . The feedback signal gain can follow the gain change of the process object. In the gain of the process object Full compensation can still be achieved after changes. However, due to the existence of hysteresis, the compensator output is 0 at the initial moment, making the divider output infinite, which may cause a simulation error and cause the system to stop running.

## 2.3. Feedback incremental adaptive Smith predictive control algorithm

To solve the problems existing in the simulation of gain-adaptive Smith predictive control, feedback increment is used to replace the divider, and the adder is used to replace the multiplier, the identifier is not changed, and the process output and the compensator output are differentiated. The difference is as an increment, the adder sums the outputs of the identifier and the predictor as a feedback signal, still retains the gain compensation function of the gain-adaptive Smith predictor, and solves the problems caused by the divider. The feedback increment adaptive Smith prediction compensation control structure is shown in Figure 3.



**Figure 3** Feedback incremental adaptive Smith prediction control structure diagram

When the model matches, the subtractor output is 0, which is equivalent to the conventional Smith compensator. At this time, the system closed cycle transfer function is as formula (6).

$$\Phi(s) = \frac{Gc(s)Gp(s)e^{-\tau s}}{1 + Gc(s)Gm(s) + (1 + Td(s))Gc(s)(Gp(s)e^{-\tau s} - Gm(s)e^{-\tau_m s})} = \frac{Gc(s)Gp(s)e^{-\tau s}}{1 + Gc(s)Gp(s)} \quad (6)$$

When the model does not match, Figure 3 can be equivalent to a compensation system with a variable increment link  $\Delta Y$ ,  $\Delta Y$  is determined by the process object and the output value of the compensation model. The predictive compensator with variable increment is shown in Figure 4.

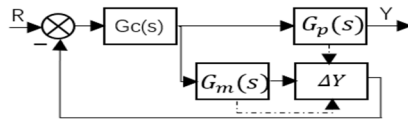


Figure 4 Predictive compensator with variable increment

### 3. SYSTEM SIMULATION AND RESULT ANALYSIS

#### 3.1. Model building

Taking a laboratory resistance furnace as the research object, its heating process is affected by its own characteristics and has characteristics such as large lag, time variability, and nonlinearity[7][8]. Under normal circumstances, pure hysteresis links and inertia links are often used to simulate, and the transfer function is as shown in formula (7).

$$G(s) = \frac{Kp}{Ts + 1} e^{-\tau s} \quad (7)$$

The relationship between time domain input and output is as formula (8).

$$y(t) = Kp(1 - e^{-\frac{t-\tau}{T}})Q(t) \quad (8)$$

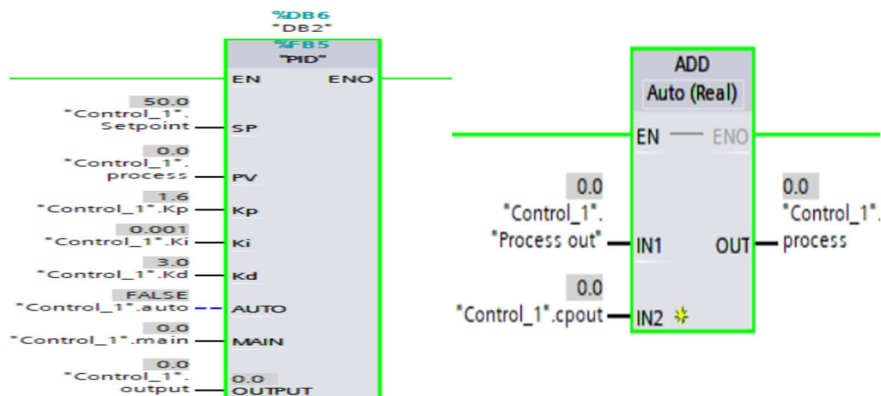
In equation (8),  $y(t)$ 、 $Q(t)$ 、 $Kp$ 、 $T$ 、 $\tau$  are the controlled temperature, thermal mass flow rate, system gain, inertia time, and pure lag time respectively.

#### 3.2. Program writing and simulation result analysis

Based on the above controlled objects, S7 1500 PLC is used as the control core, and the control program and host computer screen are written through TIA Portal software to complete the simulation of conventional PID control, Smith predictive control, and feedback increment adaptive Smith predictive control algorithm. , compare the control effects of several algorithms before and after the process model gain changes, and verify the robustness of the improved scheme to changes in model parameters.

##### 3.2.1. Programming

The program mainly includes the preparation of PID controller and estimated compensation link. Use function blocks FB2 and FB5 to write the PID control module and estimated compensation module respectively, use data block DB1 to store global data, and call it in the organization block OB30, with a cycle period of 10ms. The PID controller and predictive compensation module are shown in Figure 4.



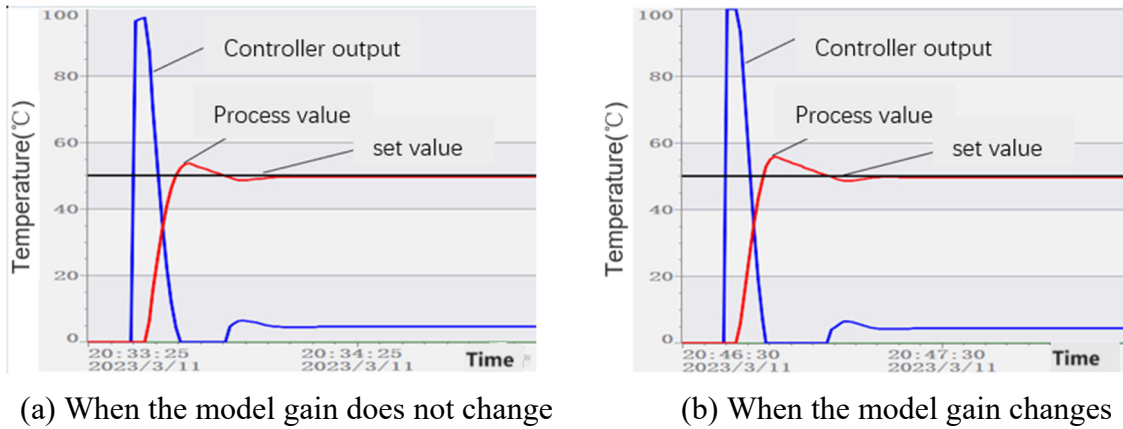
(a) PID controller module

(b) Predictive compensation module

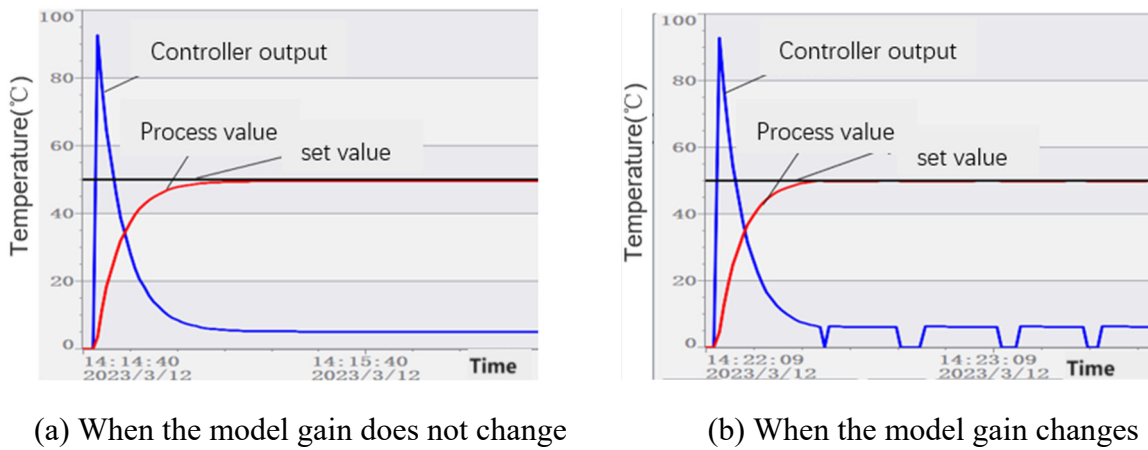
Figure 4 PID controller module and estimated compensation module

### 3.2.2. Simulation results and analysis

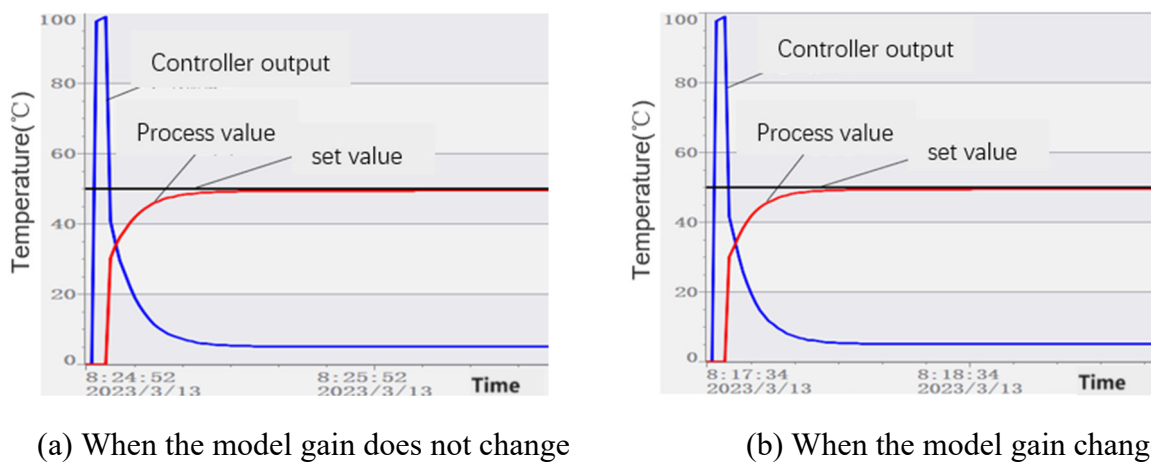
Set the target temperature to 50°C, the controller parameter to  $K_p = 1.6, K_i = 0.01, K_d = 3$ , and start the simulation. The response curves of the three solutions are shown in Figures 5, 6, and 7 respectively.



**Figure 5** Conventional PID control algorithm step response curve



**Figure 6** Smith predictive control algorithm step response curve



**Figure 7** Feedback incremental adaptive Smith predictive control algorithm step response curve

As shown in Figures 5, 6, and 7 that when the model gain does not change, there is a large overshoot in conventional PID control, while the overshoot in Smith predictive control and improved Smith predictive control is 0, and the adjustment time is short. It shows that when the estimation model is consistent with the process model, Smith predictive control can completely compensate for the time lag, and the system control effect is better; when the gain increases by 10%, the PID control overshoot

increases, but it can still tend to be stable. Although Smith predictive control There is no overshoot, but it keeps oscillating and is difficult to stabilize. The improved Smith estimation control has basically the same response curve before and after the model gain is changed. It can be seen that the improved scheme is more robust to the model parameters and has certain practical value.

## 4. CONCLUSION

To solve the problem of excessive overshoot caused by large lag in the temperature control system, based on the conventional Smith predictive control, a feedback increment adaptive Smith predictive control scheme is adopted, and the control algorithm is implemented through S7 PLC 1500. Semi-physical simulation. The simulation results shows that the improved scheme has certain adaptability to the model parameters. Before and after its gain change, the system overshoot and adjustment time can meet the control requirements. The overall control effect is relatively ideal, and it has good generalization in practical applications value.

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