Predictive Two-Degree-of-Freedom Control for Cavity-Temperature System

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Abstract. By analyzing the operating principle of rotor dryer, the cavity temperature system is approximatively abstracted as a second-order plant with time-lag. To aim at efficient control for the cavity-temperature system, two-degree-of-freedom controller with predictive control is designed. The simulations demonstrate that, two-degree-of-freedom control makes both tracking and anti-disturbance performances well synchronously and separately. The combination of two-degree-of-freedom control and predictive control is effective to eliminate time-delay effect in temperature control system.

Keywords: rotor dryer, cavity-temperature system, temperature control, two-degree-of-freedom control, predictive control.

1 Introduction

With the developments of control theories and industrial control system, improving control structure has become an effective method for refining control performance. To aim at the shortage of one-degree-of-freedom in regulating tracking performance and anti-disturbance capacity synchronously and separately, Horowitz proposed Two-Degree-of-Freedom Control (2DF control) in his book, titled *Synthesis of Feedback System*, in 1963 [1, 2]. As a rudiment of active-disturbance-rejection control, 2DF control structure could regulate and optimize the tracking performance and anti-disturbance of system's control capacity synchronously and separately. It has been widely used in industrial control system. For example, by combining fuzzy theory and 2DF control, Cheng *et al*. designed a 2DF bi-fuzzy self-tuning PID controller for linear motor. The simulations demonstrated that both the dynamic performance and response speed were advanced more comparing with classical PID control and fuzzy self-tuning PID control [3]. Liu *et al*. designed and employed a 2DF-PID controller in a higher-order hydraulic system to improve system's robustness and reduce energy consumption [4]. With combining 2DF control and internal model control, Li *et al*. employed the designed controller in level control system and implemented completed decoupling of the control parameters [5]. Wu *et al*. designed 2DF-model-driven PID controller for bed temperature system of boiler circulating fluidized bed [6].

In these applications mentioned above, 2DF controller performed well anti-disturbance performance. But its regulating capacity for time-lag system is constrained. For time-lag system, Smith predictive controller could eliminate the response delay effectively. It is an efficient method to combine 2DF control and Smith predictive control for keep good anti-disturbance, tracking and response performances. For instance, Xin *et al*. proposed a 2DF Smith controller for typical industrial process [7]. Lei *et al*. designed a 2DF Smith predictive controller aiming at the problem of time-delay multivariable processes which commonly exist in industrial systems. The simulations proved that the designed controller was simple in design convenient in parameter tuning, and possessed excellent tracking performance, anti-disturbance capability, and robustness [8]. These investigations proved that 2DF control structure could be combined with Smith predictive control in time-lag systems.

Rotor dryer cavity-temperature system is a typical time-lag system. In this article, to address the problems of tracking setting smoothly, rejecting disturbances effectively, and responsing rapidly, a 2DF PID controller based on Smith predictive control is designed and employed in cavity-temperature system. The simulations show that the designed controller could shorten the response time delay and reject the pulse disturbance effectively. It also makes the system to track the setting temperature with smaller overshoot than pure 2DF PID controller. There is no steady state error in the system with Smith-2DF PID controller.

2 Operating Principle of Rotor Dryer

Rotor dryer consists of hull, rotor, power transmission unit, heated air system, cooling unit of main axis, rotary feeder, dehumidifying system, thermal medium pipeline, and so on (as shown in Fig. 1) [9], in which the rotor is driven by power transmission unit, and consists of main axis and tube bundle. The tube bundle includes many horizontal and vertical tubes. The one end of tube bundle is fixed to main axis, and the other end extends along main axis to eliminate the stress which is caused by thermal extension.

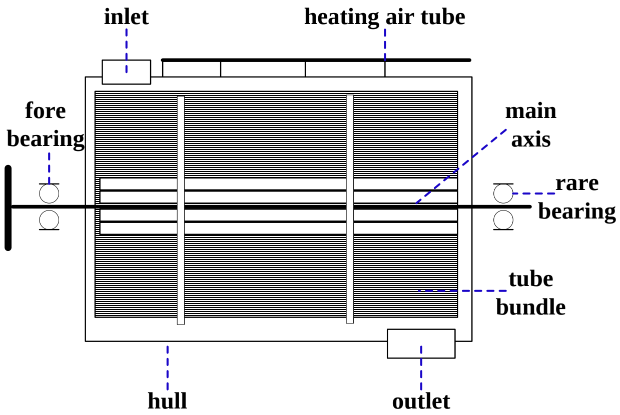

Figure 1. Structure of rotor dryer

The thermal medium enters each tube through sealed connector of main axis and exchanges heat, and cycles back to the sealed connector. After cycling, some of thermal medium flows to the heated air unit, and some to the heating furnace. The thermal medium could be steam or thermal oil.
The heated air intake which is on the side of the dryer is connected with the heated air system. The outlet on the top is connected with dehumidifying system. The wet materials are fed to the dryer through the rotary feeder, and are scattered to the tube bundle surface. The heating surface and heated air evaporate moisture of the wet materials. And then, the materials are transmitted to exit of the dryer. The heated air enters into the hull through the lateral pipe, and is used to supply the heat and air.
The temperature measurement device in dryer cavity inputs a signal to temperature control system when the temperature is changed. The temperature control system will output signal to regulate the thermal medium main valve. Then the thermal medium flow could be controlled by main valve, and the cavity temperature could be regulated.
In the dryer cavity, temperature is controlled by thermal medium heat in the tube bundle. The thermal medium (could be steam or thermal oil) is heated by the electrically heated boiler. Thus the cavity temperature system could be described as a second-order plant with time-lag:

$$P(s)=\frac{Ke^{-\tau s}}{(T_1 s+1)(T_2 s+1)} \tag{1}$$

3 2DF PID Controller Based on Predictive Control for Cavity-Temperature System

The goals to control dryer cavity temperature are:

a. to track the setting temperature accurately.
b. to reject various disturbances so as to keep the robustness of system.
c. to eliminate the time-lag which is ubiquitous for temperature control system.

To aim at the control goals *a* and *b*, employ 2DF control structure in cavity-temperature system, which could enable the system to eliminate disturbance well and track reference setting accurately synchronously and separately as shown in Fig. 2. $P(s)$ denotes the plant. $N_1(s)$ and $N_2(s)$ denote disturbances. $R(s)$ is reference input.

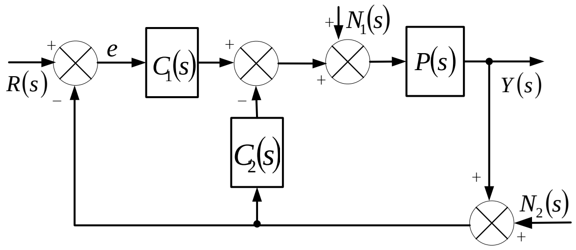

Figure 2. 2DF control structure for cavity-temperature system

The transfer functions are as Eq. (2) and (3). The closed-loop transfer functions G_{yr} and G_{yn2} are independent of each other.

$$\begin{cases} G_{yr} = \dfrac{Y(s)}{R(s)} = \dfrac{C_1 P}{1+(C_1+C_2)P} \\ G_{yn1} = \dfrac{Y(s)}{N_1(s)} = \dfrac{P}{1+(C_1+C_2)P} \\ G_{yn2} = \dfrac{Y(s)}{N_2(s)} = \dfrac{(C_1+C_2)P}{1+(C_1+C_2)P} \end{cases} \tag{2}$$

$$\begin{cases} G_{yr} = C_1 G_{yn1} \\ G_{yn2} = \dfrac{P - G_{yn1}}{P} \end{cases} \tag{3}$$

For the second-order plant as Eq. (1), the 2DF controller could be designed as Fig. 3.

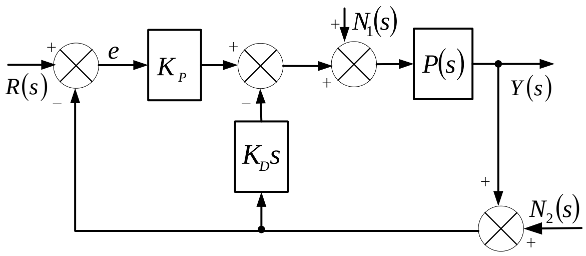

Figure 3. 2DF PID control for cavity-temperature system

To aim at the control goal *c*, introduce Smith predictive control method in 2DF PID control structure as Fig. 4. Smith predictive control was proposed by Smith in 1957 to solve control delay [10, 11], which predicts the possible response to uncertain disturbances and carries compensations to system through predictive model so as to eliminate the time delay.

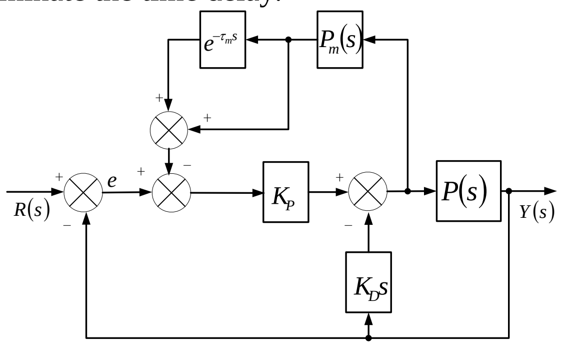

Figure 4. 2DF PID control with predictive control for cavity-temperature system

Because Smith predictive control is independent with control structure, and the predictive control parameters only relate to the dynamic characteristics of plant, the setting of control parameters is easy to implement.

4 Performance Evaluation

Simulate the cavity temperature system in Matlab/Simulink. Let the plant $P(s)$ be $P(s)=\dfrac{e^{-40s}}{5s^2+3s+4}$. Set the control parameters as $K_P=10$ and $K_D=7$. Simulation time is 80s. Set unit step signal as the reference input meaning to set cavity temperature at 45℃. The initial condition (cavity temperature at the beginning of work) is 20℃. The disturbance is a pulse signal which is one tenth of the reference input and occurs at the 40ths.

Fig. 5 shows the system output. With 2DF PID controller, system reaches steady state at the 61ths and the maximum overshoot is about 8℃, which is presents steady state at the 48ths and the maximal overshoot is about 2.5℃ with Smith-2DF PID controller. The disturbance results no effect to the control system. Fig. 6 shows the error. With 2DF PID controller, the steady state error is obvious which is about 0.5℃. But with Smith-2DF PID controller, there is no steady state error.

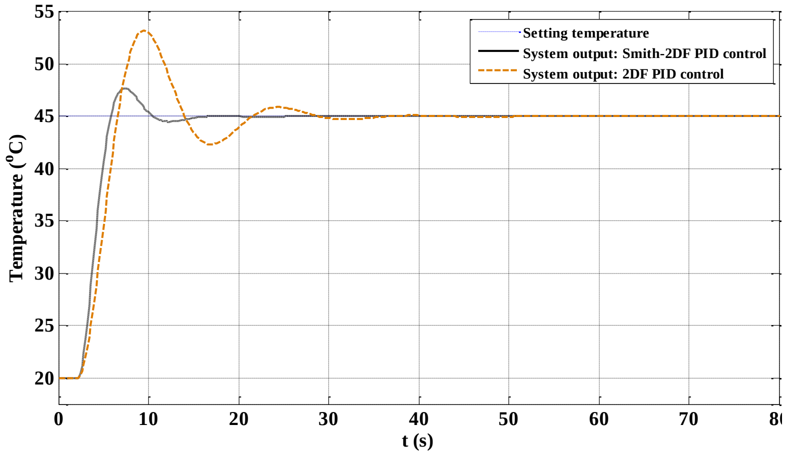

Figure 5. System outputs

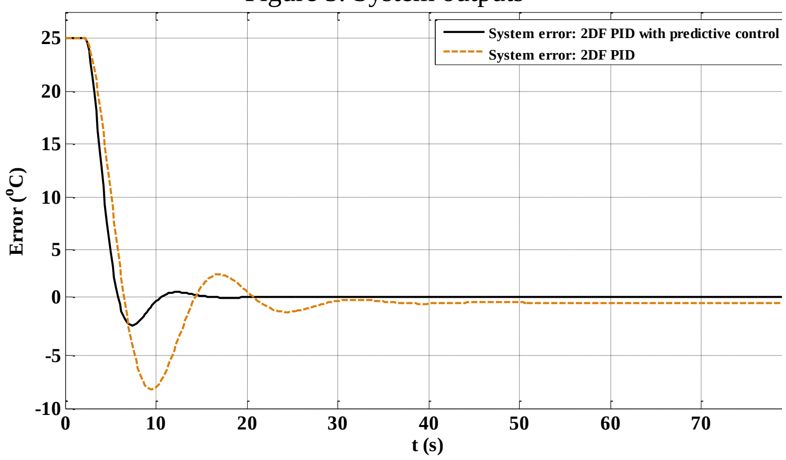

Fig. 6. System errors

5 Summary

By analyzing the operating principle and system organization, cavity-temperature system has been abstracted as a second-order time-lag system. A designed 2DF PID controller has been employed in the cavity-temperature system so as to enable system good tracking and anti-disturbance performances. And then Smith predictive control has been introduced in 2DF PID control structure for eliminating time-lag. The simulations demonstrate that 2DF PID controller is effective in rejecting pulse disturbance. And predictive 2DF PID controller reserves the advantages of pure 2DF PID control structure, and predictive control could shorten the time cost for system reaches steady state. In addition, the overshoot has been reduced because of Smith predictive control.

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