PID 제어기의 자동튜닝을 위한 이차 시간 지연 모델의 식별법

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Identification Method using Second Order plus Time Delay Model for Automatic Tuning of PID Controller

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Introduction

The PID(Proportional, Integral and Derivative) controller is widely used due to its simple structure and robustness in the majority of chemical processes. To achieve a high control performance, it is very important to approximate accurately the actual process and automatically determine the parameters of controller.

Many reseachers have proposed the on-line identification methods and tuning rules. For example, Astrom(1984) used the relay feedback method to identify the ultimate data of the process. Lee and Sung(1993) obtained the analytic solution for the closed-loop response of the first-order plus time delay process controlled by relay feedback and they proposed a technique to obtain the first-order plus time dealy model using the derived equation. Yuwana and Seborg(1982) used the P-controller as an identification method and Lee(1989) improved the P-controller method using the dominant pole matching technique. Also, Chen(1989) proposed an identification method using the critical data of closed-loop response under P-controller and Sung(1994) derived the expression of the closed-loop response of the first-order plus time delay model without any approximation.

However, all of the previous methods used first-order plus time delay model which has a structural limitation in the approximation of the process output in overall frequency region.

In this study, we propose a new identification method for the automatic tuning of the PID controller using the second-order plus time delay model. The proposed method utilizes the transient response for the step set point change to get the process parameters such as time constant, damping factor and time delay. The process model can be estimated by a simple least squares technique based on the fitted closed-loop response using second-order plus time delay model. We simulated the performance of the obtained model with PID tuning rule proposed by Sung et al.(1995) for the second-order plus time delay model.

We recognize that the proposed method shows a better performance for several simulated processes than the previous on-line identification methods.

Theoretical Development

A simple closed-loop system can be illustrated as shown in figure 1. It is assumed that the controller is a P-controller, that is, $G_c(s) = K_c$ and the proportional gain is large enough to give a oscillatory response. Second-order plus time delay model is used to approximate the closed-loop response of the step set point change as eq(1).

$$G(s) = \frac{C(s)}{R(s)} = \frac{Ke^{-\theta s}}{\tau^2 s^2 + 2\tau\xi s + 1} \tag{1}$$

As the first step, the steady state gain of model(K) can be obtained from the measured steady state value of the process output and the magnitude of the input change.

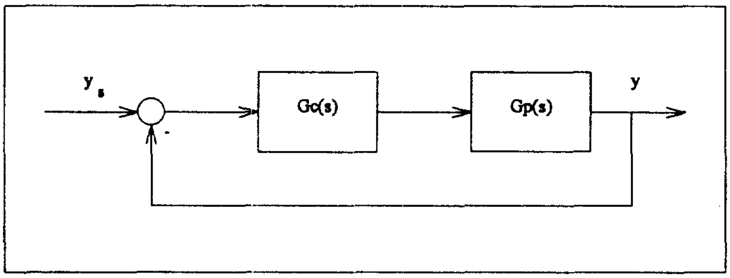

Figure 1. Block diagram of a simple closed-loop system

The typical response of the closed-loop to a step set point change can be illustrated as figure 2. Time delay(θ_c) can be calculated using eq(2) using the measured first peak time(t_{p1}) and the first valley time(t_{m1})(Chen(1989)). Damping factor(ξ_c) and time constant(τ_c) can be obtained by eq(3) and eq(4) respectively(Yuwana and Seborg (1982)).

$$\theta_c = 2t_{p1} - t_{m1} \tag{2}$$

$$\xi_c = -\ln\left(\frac{c_\infty - c_{m1}}{c_{p1} - c_\infty}\right) \Bigg/ \sqrt{\pi^2 + \left[\ln\left(\frac{c_\infty - c_{m1}}{c_{p1} - c_\infty}\right)\right]^2} \tag{3}$$

$$\tau_c = \Delta t\sqrt{1 - \xi_c^2}\Big/\pi \tag{4}$$

where c_{p1}, c_{m1} denotes the first peak and first valley of the closed-loop response respectively. c_∞ represents the steady state value of the system. Δt is the measured half-period of oscillation. Based on the calculated parameters, the closed-loop response $y_c(t)$ of the set point change can be estimated as follows.

$$y_c(t) = KM\left\{1 - e^{-\xi_c(t-\theta_c)/\tau_c}\left[\cos\left(\frac{\sqrt{1-\xi_c^2}}{\tau_c}(t-\theta_c)\right) + \frac{\xi_c}{\sqrt{1-\xi_c^2}}\sin\left(\frac{\sqrt{1-\xi_c^2}}{\tau_c}(t-\theta_c)\right)\right]\right\} \tag{5}$$

where $0 < \xi_c < 1$ and M represents the magnitude of the step set point change.

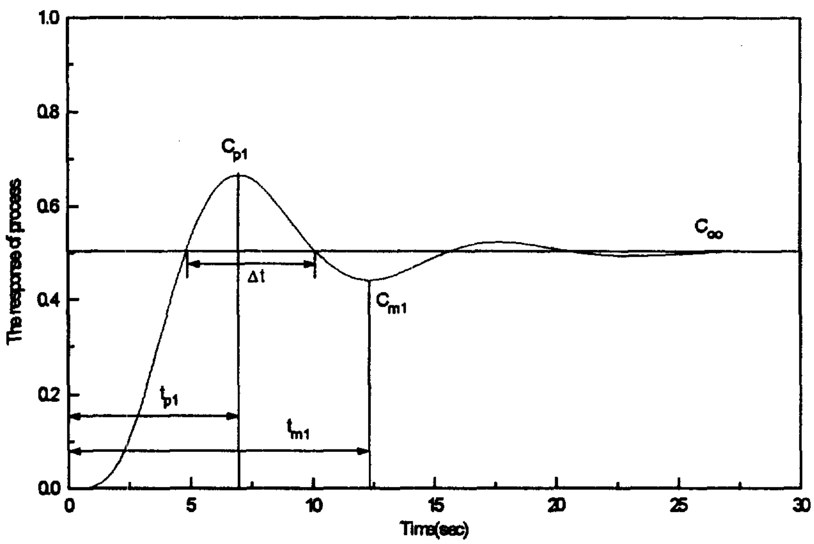

Figure 2. Typical response of the closed-loop to a step set point change

If the second-order plus time delay process is controlled by a P-controller, the following equation should be satisfied.

$$\tau^2 \frac{d^2 y_c}{d^2 t} + 2\xi\tau \frac{dy_c}{dt} + y_c = KK_c(y_s - y_c(t-\theta_c)) \tag{6}$$

Then, time constant(τ) and damping factor(ξ) can be obtained easily by a least squares method from eq(6). By a simple calculation, we can estimate the parameters of the process as follows.

$$\tau^2 = \frac{\sum \beta_i^2 \sum \alpha_i \gamma_i - \sum \alpha_i \beta_i \sum \beta_i \gamma_i}{\sum \alpha_i^2 \sum \beta_i^2 - (\sum \alpha_i \beta_i)^2} \tag{7}$$

$$2\xi\tau = \frac{\sum \alpha_i^2 \sum \beta_i \gamma_i - \sum \alpha_i \beta \sum \alpha_i \gamma_i}{\sum \alpha_i^2 \sum \beta_i^2 - (\sum \alpha_i \beta_i)^2} \tag{8}$$

where $\alpha_i = \frac{d^2 y_{ci}}{d^2 t}$, $\beta_i = \frac{dy_{ci}}{dt}$, $\gamma_i = KK_c(y_s - y_{ci}(t-\theta_c)) - y_{ci}$, $i = 1,2,\ldots,n$

The subscript i denotes the index to the sampled data of the closed-loop response. We recommend n should be a large number so that the closed-loop response can almost reach the steady state.

The rule proposed by Sung et al.(1995) is used as the PID tuning rule for second-order plus time delay model. The method fitted the optimal controller parameters obtained by solving the ITAE minimizing problem.

Simulation Study and Results

The proposed identification method is illustrated with several examples. The comparion with some previous methods is supplied. The result of one of them is provided in fgure 3. From several simulation results, we can recognize that the proposed method outperforms other methods and the limit of the first-order plus time delay model can be overcome by the proposed method. The least squares technique applied to the proposed method can approximate the closed-loop response for the overall frequency.

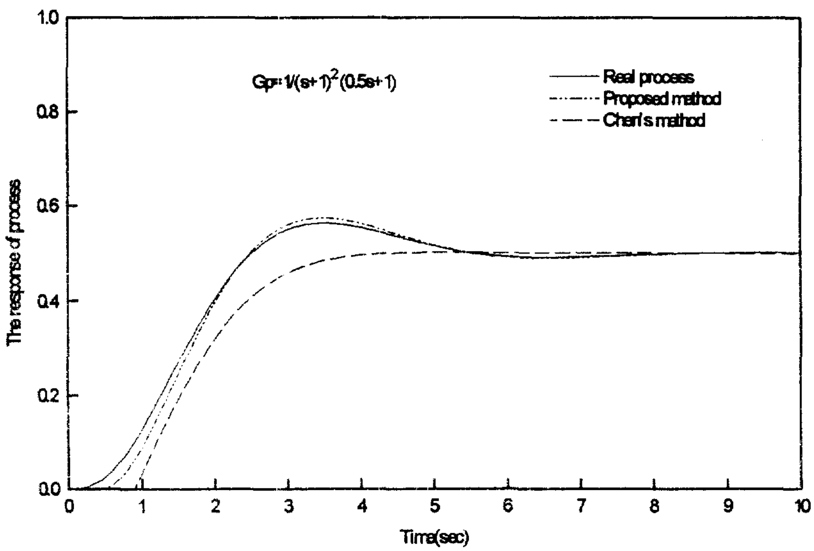

Figure 3. Identification results of the proposed method and Chen's method for an example process

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