공정모델링과 비례-적분-미분 제어기의 자동튜닝

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On-line Identification and Automatic Tuning of PID Controller

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Introduction

A major controller which has been used in industry is a Proportional-Integral-Derivative (PID) type controller. The PID controller has been recognized as a simple and robust controller and this is familiar to the field operator. Until now, many methods have been proposed to tune PID controllers automatically.

Åström and Hägglund (1984) identified the ultimate process information from a relay feedback test to tune the PID controller automatically. Li et al. (1991) obtained parametric models from two relay feedback tests. Lee and Sung (1993) obtained the first order plus time delay model from a relay feedback test combined with a proportional (P) controller. Their method provides the exact model for the first order plus time delay process. Sung et al. (1995) proposed a new identification method using the second order plus time delay model to identify the process more accurately and a simple tuning rule for the second order plus time delay model. Shen and Yu (1994) and Loh et al. (1993) applied these automatic tuning concept to the multi-input and multi-output(MIMO) case using the sequential loop closing concept. Lee et al. (1993) proposed an on-line identification method using Åström and Hägglund's (1984) concept to control the pH processes.

Yuwana and Seborg(1982) proposed a P control method to obtain the first order plus time delay model using a few transient data points. The method was improved by Jutan and Rodrigez (1984), Lee (1989), Chen (1989) and Sung et al. (1994). Lee et al. (1990) suggested a P control method to identify the process using the second order plus time delay model. To estimate the parameters of the PID controller, a frequency domain method based on the methods of Edgar et al.(1981) and Harris and Mellichamp (1985) is applied, yielding a good controller setting. Sung and Lee (1995a) applied Yuwana and Seborg's (1982) autotuning concept to obtain the titration curve of the pH process automatically .

However, all the previous methods should use a separated test signal generator such as P controller or relay. Therefore, the PID controller can't control the process continuously and it is difficult to determine the magnitude of the relay feedback and the initial proportional gain of the P controller. Moreover, the identified models of previous methods are confined to the first order plus time delay or the second order plus time delay model. We propose a new identification method to automatically tune the PID controller. The proposed identification method doesn't need a separated test signal generator such as P controller or relay because only the controller output and the measured process output are sufficient to identify the process.

Proposed On-line Identification Method

Consider the following Laplace transform.

$$y(s) = \int_0^{\infty} \{ \exp(-st)y(t) \}dt \qquad (1)$$

$$u(s) = \int_0^{\infty} \{ \exp(-st)u(t) \}dt \qquad (2)$$

$$G(s) = \frac{y(s)}{u(s)} \qquad (3)$$

where, y(s),u(s) and G(s) denote Laplace transforms of the process output, controller output and transfer function, respectively. Assume that the initial state and the final state are steady state and the set point is changed at $t = 0$. The underlying identification concept is very simple. (1) and (2) are estimated by numerical integration technique for several s values and the G(s)'s are estimated and finally, G(s)'s are used to obtain the specified model by using a least squares method. To obtain the tuning parameters of the PID controller, this obtained model can be reduced to low order plus time delay model(Sung and Lee(1995b)). That is,

$$y(s_i) = \sum_{t=0}^{\infty} \{ \exp(-s_i t)y(t) \}\Delta t \qquad (4)$$

$$u(s_i) = \sum_{t=0}^{\infty} \{ \exp(-s_i t)u(t) \}\Delta t \qquad (5)$$

$$G(s_i) = \frac{y(s_i)}{u(s_i)} \qquad (6)$$

$$0 < s_0 < s_1 < \cdots < s_i < \cdots < s_{n_s} < \text{about } \omega_u \text{ , } i = 0, 1, \cdots, n_s \qquad (7)$$

where, n_s, ω_u and Δt denote the number of s_i, ultimate frequency and sampling time, respectively and s_i should be determined by user. (7) represents the recommended the upper and lower boundary values of s_i. In the viewpoint of the accuracy of the model, the upper value of s_i should be chosen as a very small value (Sung and Lee (1995b)). However, the identification time may increases. It should be noted that $t = \infty$ means a large value of t. That is, if $\exp(-s_0 t)y(t)$ and $\exp(-s_0 t)u(t)$ almost go to zero, the integration can be complete. If the state of the controller and process outputs already reach the steady state before $\exp(-s_0 t)y(t)$ goes to zero, after this point, the integrations of $\exp(s_i t)y(t)$ and $\exp(s_i t)u(t)$ can be estimated directly without future measurement because y(t) and u(t) are constant. To obtain a continuous model from $G(s_i)$'s, the following model can be used.

$$G_m(s) = \frac{k(n_m s^m + n_{m-1} s^{m-1} + \cdots + n_1 s^1 + 1)}{d_n s^n + d_{n-1} s^{n-1} + \cdots + d_1 s^1 + 1} \qquad (8)$$

Then, a least squares method minimizing the following objective function can be used to obtain the coefficients of (8) from the estimated $G(s_i)$.

$$d,n = \arg\underset{d,n}{\mathrm{MIN}} \left[\sum_{i=0}^{n_s} \{d_n G(s_i)s_i^n + d_{n-1}G(s_i)s_i^{n-1} + \cdots + d_1 G(s_i)s_i^1 - n_m k s_i^m - n_{m-1} k s_i^{m-1} - \cdots - n_1 k s_i^1 - k + G(s_i)\}^2\right] \quad (9)$$

$$k = \frac{y_\infty}{u_\infty} \quad (10)$$

where, d and n denote vectors composed of the coefficients of denominator and numerator, respectively and u_∞ and y_∞ denote the steady state controller output and process output, respectively. We recommend $n_s = 2(n+m)$ with equal interval between s_i's. Here, k can be also included as the arguments of the optimization problem (9) with d, n. We consider only d, n because we can estimate the exact static gain from (10). In summary, from the controller output and the measured process output data, (4), (5) and (6) can be calculated and then we can estimate the coefficients of (8) using a least squares method satisfying (9), (10). Next, the model (8) can be reduced to the second order plus time delay or the first order plus time delay model. However, if the tuning rule for a high order model is available, (8) can be reduced easily to that model (Sung and Lee(1995b)).

Model Reduction and On-line Tuning Method

From (8), we can obtain the second order plus time delay model or the first order plus time delay model easily from Sung and Lee's(1995b) method. Then many tuning rules such as ITAE, IMC, Cohen-Coon tuning methods,Sung et al.'s(1995) tuning method can be used to estimate the parameters of the PID controller.

Simulation Study

To show the performances of the proposed identification method for the PID controller autotuning, consider the following examples.

Third order plus time delay process controlled by the ideal PID controller without measurement noise or with measurement noise of ±0.3

$$G(s) = \frac{\exp(-0.2s)}{(s+1)^3}$$

Bode plot of the process G(s) and the model $G_m(s)$ shows the proposed method provides very accurate model. We compared the control performance of the proposed method using Sung et al.'s(1995) tuning method with that of the continuous cycling method with Zeigler-Nichols tuning rule. From the simulation results, we recognize that the proposed method provides acceptable model parameters and shows the robustness to the measurement noise.

Conclusions

We proposed a new on-line identification method for the automatic tuning of the PID controller to overcome the disadvantages of the previous identification methods. The proposed method doesn't need a separated test signal generator. The proposed method shows a good model accuracy and robustness to the measurement noise. Because the proposed method uses a numerical integration technique, the sampling time should be small during the identification work

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