향상된 릴레이 피드백 방법

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Improved Relay Feedback Method

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Introduction

Although many advanced controllers have been proposed, the PID controller has been widely used in chemical industries because it has a simple structure and is robust to the modeling error and easy to operate.

Åström and Hägglund (1984) proposed a relay feedback method which is one of the easiest identification methods to obtain the ultimate information of the process. Their method used a square wave (relay output) signal to obtain a oscillatory response and then, the ultimate data sets of the process can be obtained very easily. In theoretical development, they approximated the square wave and oscillatory process output as the sinusoidal signals by using the Fourier series expansion. From this approximation, they derived very simple equations to identify the ultimate data sets of the process. Their method can guarantee stable oscillatory closed-loop responses for a stable process and is very simple so that it has been widely applied to tune the PID controller automatically in industries.

This method has been also improved and applied in many areas. For example, Luyben (1987) proposed Autotune Variation (ATV) method using the relay feedback method to get the transfer function of the process model and the ATV method was improved by Li et al. (1991). Lee et al. (1993) used the relay feedback method to tune a nonlinear pH controller automatically and Lin and Yu (1993) used the relay feedback method to obtain the titration curve and tuning parameters in the pH process. Lee and Sung (1993) used the relay feedback method to obtain the first order plus time delay model for the automatic tuning of the PID controller. Friman and Waller (1994) proposed an identification method to obtain the integrator plus time delay model by using one relay feedback experiment and Friman and Waller (1995) suggested a more accurate estimator for the ultimate gain and the ultimate period by use of single-valued nonlinearities. Sung et al. (1995) suggested a modified relay feedback method to get the more accurate ultimate information of the process. The modified relay feedback method uses a six-step signal instead of two-step signal (original relay feedback method (Åström and Hägglund, 1984) to reduce the high harmonic terms. Hang et al. (1993) proposed a new relay feedback method and identified the ultimate data sets in the presence of static load disturbance. However, this method needs a prior appropriate information for the static gain of the process. Moreover, if there is no prior information of the static gain of the process, this method requires several relay tests to get the accurate ultimate data and the static gain of the process.

In this paper, we propose a new improved relay feedback method to get more accurate ultimate information in the presence of static load disturbance. The proposed relay feedback method shifts the relay output automatically to guarantee the symmetric process output. The proposed method does not need any prior information of the static gain of the process and shows a good performance. Also, the static gain of the process as well as the ultimate information can be obtained from one relay experiment simultaneously.

Improved Relay Feedback Method considering static load disturbance

Static load disturbances are quite common in process control and then it is essential to eliminate the effect of unexpected static load disturbance in order to get the accurate ultimate data sets in relay feedback experiment. It should be recognized that the unknown static load disturbance can be exactly removed by shifting the relay output to the inverse direction of the disturbance then the process output is the same as that of no disturbance case. Here, the total magnitude of the relay is fixed as $2d$. That is, by the comparison of the values of peak (p_{k-1}) and valley (v_{k-1}) at the previous period, we can determine the amount of the relay output which should be shifted. The amount of relay output to be shifted can be determined by the following equation.

$$\Delta u = -k_{\omega} \times \Delta y \tag{1}$$

where, $\Delta y = \dfrac{p_{k-1} + v_{k-1}}{2}$, $\Delta u = h_{max,k} - h_{max,k-1}$, and $k_{\omega} = \dfrac{|p_{k-1}| + |v_{k-1}|}{2d}$ respectively.

Here, Δy denotes the magnitude to be shifted to guarantee the symmetric response of the process output and Δu is the corresponding amount to be shifted and k_{ω} represents the gain at the frequency of the relay feedback and $h_{max,k}$ denotes the maximum value of the relay output as shown in Figure 1. That is, the larger is the difference between the values of peak (p_{k-1}) and valley (v_{k-1}), the more shifting of the relay output is achieved.

Considering equation (1), we can derive the following equation (2).

$$h_{max,k} = h_{max,k-1} - \lambda \times d \times \left(\frac{p_{k-1} + v_{k-1}}{|p_{k-1}| + |v_{k-1}|} \right) \tag{2}$$

where, $h_{max,k}$, $h_{max,k-1}$ = the positive maximum value of the relay at step k and $k-1$

λ = the tuning parameter

d = the magnitude of relay feedback signal

p_{k-1}, v_{k-1} = the values of peak and valley at step $k-1$, respectively

$|p_{k-1}|$, $|v_{k-1}|$ = the absolute values of peak and valley at step $k-1$, respectively

The proposed relay feedback signal is shown in Figure 1 and the procedure is as follows. Here, the magnitude of relay (d) should be chosen as a larger one than the magnitude of the static load disturbance. First, $h_{max,k}$ is applied to deviate the process output from the initial value 0. Second, $h_{min,k}$ and the following $h_{max,k}$ are applied to obtain the oscillatory process output ($h_{max,k}$ is the same as d at the starting period). Here, the minimum value of the relay output is determined by the following equation.

$$h_{min,k} = h_{max,k} - 2d \tag{3}$$

Third, by using the measured p_k and v_k, the next relay output ($h_{max,k+1}$) is calculated from (2) and the relay produces the $(k+1)th$ peak and valley values. Finally the procedures from the second step to the third step are repeated until the following steady-state is obtained.

$$h_{max,k} = h_{max,k-1} = h_x = constant \quad (4)$$

Here, as the tuning parameter λ increases, $h_{max,k}$ shows oscillatory behavior to the h_x value and as λ decreases a slower convergence rate is achieved. From extensive simulation results we recommend $\lambda = 0.5$. If a steady-state is obtained, we can calculate the ultimate gain and the ultimate period directly by using equation (5).

$$k_{cu} = \frac{4d}{\pi a}, \quad \omega_u = \frac{2\pi}{P_r} \quad (5)$$

where, k_{cu}, ω_u denote the ultimate gain and the ultimate frequency, respectively and a represents the amplitude of the process output in the steady-state and P_r denotes the period of relay feedback in the steady-state. The proposed method shows a good convergence rate for various processes, that is, the response almost converge to the final value after two or three times period in almost cases and the obtained data are the same as those of no disturbance case.

The proposed method can also be applied to obtain the static gain of the process. That is , by simply adding an artificial output disturbance to the process output, we can estimate the static gain of the process. If we added an artificial output disturbance to the process output, and then the proposed relay feedback method would achieve symmetric responses by shifting the relay output as much as $\Delta u_t = \Delta y_t / k_p$ value. Here k_p denotes the static gain of the process. Therefore, we can estimate the static gain of the process by considering total amount of the process output change (Δy_t) and total amount of the shifted relay output (Δu_t).

This strategy is very useful to many identification methods with the static gain of the process. For example, Lee and Sung (1993) proposed a relay feedback method combined with an additional proportional controller to obtain the first order plus time delay model, and they used the proportional controller to estimate the static gain of the process. However, the first order plus time delay model can be obtained directly with only one relay feedback test by using the proposed method. This proposed method can also improve and simplify ATV methods (Luyben (1987) and Li et al. (1991)) by providing the accurate static gain of the process and the ultimate data simultaneously. That is, the proposed method can save relay tests for the static gain of the process to the previous process identification methods. Therefore, the identification time of the proposed method is much shorter than the previous methods. Moreover, the operation would be simpler and less affected by the disturbance.

Conclusions

We proposed a new improved relay feedback method to eliminate the effect of the static load disturbance. The ultimate data sets estimated by the proposed method in the presence of the static load disturbance is the same as those of no disturbance. If there is no disturbance, the autotuning of the PID controller can be complete more simply and accurately than the previous methods because the static gain and ultimate data sets can be obtained simultaneously. Contrarily, the previous identification methods use an additional test for the static gain of the process.

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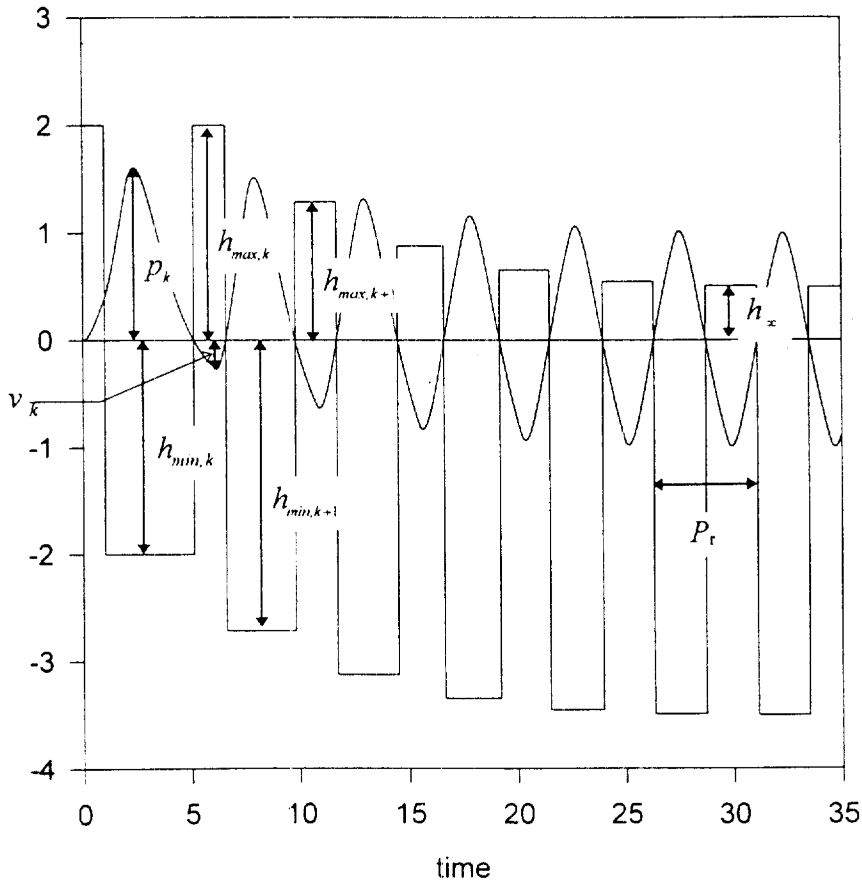

Figure 1. Test signal generation of the proposed relay feedback method