Comparison of Two Identification Methods for PID Controller Tuning

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Proportional integral and derivative (PID) controllers are still used widely in industry. For automatic tuning of the PID controllers, simple methods, instead of elaborate adaptive methods, are usually used. Significant efforts have been lately devoted to easy testing and better tuning.

Yuwana and Seborg (1982) identified the first-order plus time-delay model from closed-loop testing with a P controller. Their method has been refined by Rodriguez and Jutan (1984) and Lee (1989). Because the gain of a P controller is not known in advance, some trial tests are required. Second-order plus time-delay model can be also obtained with this method (Lee et al., 1990).

Astrom and Hagglund (1984) proposed a relay feedback method to determine the ultimate period and the ultimate gain for Ziegler-Nichols-type tuning. The method, however, inherits fundamental limitations of the Ziegler-Nichols tuning mainly because it is based on only one Nyquist point data about the process. Another Nyquist point may be extracted from the relay feedback by inserting an artificial dynamics such as dead time or by using a relay with hysteresis. Parametric models were also obtained with two relay feedback testings by Li et al. (1991). But their model is usually high-order and uses the true time delay of process. High-order models make next tuning steps difficult.

In this work, compare these two identification methods. For comparison, the first-order plus time-delay models are identified with both methods. In fact, the first-order plus time-delay model has many correlation rules for the PID controller tuning, and its efficiency for many processes has been proved for a long time. For the relay feedback method, new equations exact for the first-order plus time-delay process are derived with the steady-state gain information of process in addition to the relay feedback information. The steady-state gain can be obtained stably with closed-loop testing. For the P control method, the gain of a testing P controller is obtained from the ultimate gain of the relay feedback method. These two identification methods require similarly small efforts for testing and can be used for automatic tuning of the PID controllers. Tuning performances are compared.

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Relay Feedback Method

For most processes, stable oscillation can be obtained with the relay feedback. From the amplitude and period of oscillation, the approximate ultimate gain and period can be extracted. Here, instead of ultimate data, we determine the first-order plus time-delay model with one additional information of the process steady-state gain as

$$\tau = p/\ln\left[\left(1+\frac{a}{kd}\right)\Big/\left(1-\frac{a}{kd}\right)\right]$$

$$\theta = \tau \ln\left[\frac{1+\exp(p/\tau)}{2}\right]$$

where

d = amplitude of the relay
a = amplitude of the oscillation
p = half period of the oscillation
k = steady-state gain of the process
τ, θ = time constant and time delay of the model

Above expressions can be derived from that $y(Np)=0$ and $y(Np+\theta)=a$ for large N, where $y(t)$ is the solution of the model equation with a square wave input of period $2p$:

$$Y(s) = \frac{k\exp(-\theta s)}{\tau s+1}\frac{d}{s}[1-2\exp(-ps)+2\exp(-2ps)-\cdots]$$

Hence, they are exact for the first-order plus time-delay process.

The steady-state gain is obtained from the step set point change with a P controller of:

$$Kc = 0.6\frac{4d}{\pi a}$$

This controller gain is used for the P control identification method, too. The P control method was described in detail by Lee (1989).

Comparisons

Tuning results are compared with the process:

Table 1. Models and Tuning Results for the Process of Eq. 1

(n, θ)	Method	τ	θ	K_{cu}	ω_u	K_c	T_I	T_D	M_p	ω_b
2, 0.2	Exact			10.7	3.11					
	Relay	4.084	0.555	12.2	2.98	6.29	4.36	0.260	1.33	4.58
	P-cntl	3.101	0.630	8.39	2.69	4.34	3.42	0.286	1.09	3.31
	Open-loop	1.472	0.729	3.84	2.52					
2, 1.0	Exact			2.71	1.31					
	Relay	2.182	1.505	2.95	1.27	1.560	2.93	0.560	1.27	2.00
	P-cntl	1.824	1.591	2.49	1.25	1.317	2.62	0.554	1.00	1.71
	Open-loop	1.472	1.529	2.21	1.34					
2, 5.0	Exact			1.21	0.457					
	Relay	1.442	5.686	1.19	0.451	0.603	4.29	0.957	1.09	0.56
	P-cntl	1.258	5.526	1.16	0.472	0.582	4.02	0.864	1.11	0.53
	Open-loop	1.472	5.529	1.21	0.461					
3, 0.2	Exact			5.15	1.41					
	Relay	4.342	1.276	6.00	1.36	3.12	4.98	0.556	1.34	1.93
	P-cntl	3.155	1.413	4.17	1.28	2.19	3.86	0.577	1.01	1.50
	Open-loop	1.827	1.373	2.77	1.41					
3, 1.0	Exact			2.50	0.916					
	Relay	2.922	2.183	2.78	0.888	1.471	4.01	0.795	1.32	1.33
	P-cntl	2.327	2.338	2.25	0.867	1.196	3.50	0.778	1.00	1.12
	Open-loop	1.827	2.173	2.02	0.961					
3, 5.0	Exact			1.25	0.400					
	Relay	1.870	6.400	1.24	0.392	0.634	5.07	1.180	1.10	0.50
	P-cntl	1.656	6.326	1.20	0.403	0.610	4.82	1.087	1.08	0.48
	Open-loop	1.827	6.173	1.25	0.410					

$$G(s) = \frac{\exp(-\theta s)}{(s+1)^n} \quad (1)$$

Models obtained by the above relay feedback method, the P control method (Lee, 1989), and the open-loop characteristic area method (Astrom and Hagglund, 1988) are shown in Table 1. Popular IMC-PID rule (Morari and Zafiriou, 1989) with $\lambda = 0.25\theta$ was used for the final tuning of PID controllers. For both models of the relay feedback method and the P control method, the IMC-PID tunings provide PID parameters with moderate peak amplitude ratios (Mp) and similar bandwidths (ω_b).

Best estimates of the ultimate data are obtained with the relay feedback method. However, since the estimates of the ultimate gain with the relay feedback method are larger than the actual ones, we are concerned that control responses might be oscillatory when less conservative tuning rules are used. Models and tuning results of the process,

$$G(s) = \frac{1}{(s+1)^5}, \quad (2)$$

are shown in Table 2, and control responses for load change with the load dynamics, which are the same as the process, are shown in Figure 1. As expected, load response with the relay feedback identification and the ITAE (load) tuning (Seborg et al., 1989) were somewhat oscillatory.

Table 2. Models and Tuning Results for the Process of Eq. 2

Method	τ	θ	Kc	T_I	T_D
Relay/IMC	4.449	2.684	1.726	5.79	1.031
Relay/ITAE (load)			2.190	3.64	1.025
P-cntl/IMC	3.301	2.880	1.317	4.74	1.003
P-cnt/ITAE (load)			1.544	3.54	1.098

Table 3 shows the identification and tuning (IMC) results for an underdamped process and a process with inverse response as:

$$G(s) = \frac{\exp(-s)}{9s^2 + 2.4s + 1} \quad (3)$$

$$G(s) = \frac{(-3s+1)\exp(-s)}{(s+1)(5s+1)} \quad (4)$$

which are difficult to approximate very well with the first-order plus time-delay model. The relay feedback method provides good and conservative estimates of ultimate data and may be used as a PID controller tuning method for these unusual processes. But for the process with inverse response, the P control method provides a larger ultimate gain than the actual one. We should be careful in using the P control identification method for processes with inverse response.

In summary, for the overdamped processes, the relay feedback identification method provided better ultimate data. Conservative IMC-PID tuning rule, however, is recommended for

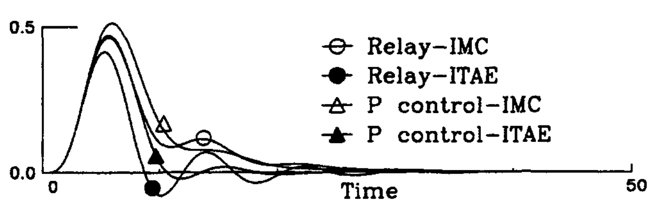

Figure 1. Control responses for a load change of the process of Eq. 2.

Table 3. Models and Tuning Results for the Processes of Eqs. 3 and 4

Process	Method	τ	θ	K_{cu}	ω_u	K_c	T_I	T_D	M_p	ω_b
Eq. 3	Exact			2.54	0.587					
	Relay	4.591	3.506	2.19	0.555	1.448	6.344	1.269	1.62	0.725
	P-cntl	2.678	4.401	1.67	0.502	0.887	4.879	1.208	1.28	0.542
Eq. 4	Exact			1.67	0.501					
	Relay	2.230	5.320	1.41	0.444	0.735	4.89	1.213	1.13	1.06
	P-cntl	3.595	4.297	2.02	0.487	1.069	5.744	1.345	2.17	1.74

the final tuning of the PID controllers, since the ultimate gain of the model by the relay feedback method is larger than the actual ones.

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