

TWO DEGREES OF FREEDOM PID AUTO-TUNING CONTROLLER

Takashi Shigemasa* Yutaka Iino* Masae Kanda**

* Toshiba R & D Center
Toshiba Corporation
Kawasaki Japan

** Instrument & Automation Development Dept.
Toshiba Corporation
Tokyo Japan

ABSTRACT: Recently, two degrees of freedom PID control systems have attracted attention, because of their better process control quality for both set point variable tracking and disturbance resistivity than that of conventional PID control systems. This paper describes a new auto-tuning method for the two degrees of freedom PID control system based on a newly developed model matching method in the frequency domain. This new method has been introduced into a two degrees of freedom PID auto-tuning controller, named AdTune TOSDIC-211D8. The superior features of the controller and the results of field tests are presented.

1. INTRODUCTION

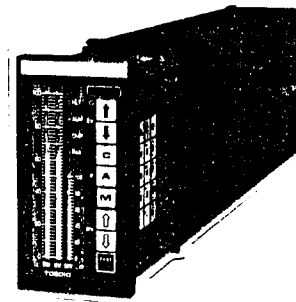
From operational and economical points of view, every process control loop should be tuned optimally in accordance with the process dynamic characteristics and the operational conditions. Recently, in order to save time for the tuning work of field engineers and to improve control performance, auto-tuning PID (proportional, integral, derivative) controllers have been developed.⁴⁾⁵⁾

Conventional PID auto-tuning controllers have the following problems to be improved;

- (a) weak disturbance resistivity when optimal PID control parameters are used for set point variable tracking.
- (b) large overshoot response in set point variable tracking when optimal PID control parameters are used for disturbance rejection, and
- (c) application restriction to particular characteristics.

In order to overcome the above problems, the authors have developed a new auto-tuning method for the two degrees of freedom PID control system. The new auto-tuning method is mainly based on a newly developed model matching method using the process characteristics in the cut-off frequency region. The new model matching method described here opens up wide application areas to such processes including not only time delay and dead time but also overshooting, reverse-shooting and oscillating characteristics. Applying this auto-tuning method, a two degrees of freedom PID auto-tuning controller, named AdTune TOSDIC 211D8 (Picture 1), has been produced.

This paper describes the auto-tuning method for a two degrees of freedom PID control system. The superior features of the controller and the results of field tests are presented later.



Picture 1 TOSDIC 211D8, a two degrees of freedom PID auto-tuning controller.

2. CONFIGURATION OF THE TWO DEGREES OF FREEDOM PID AUTO-TUNING CONTROLLER

The basic scheme of the two degrees of freedom PID auto-tuning control system consists of the following five functions, as shown in Figure 1:

- (1) two degrees of freedom PID control function,
- (2) two degrees of freedom PID control parameter calculation function,
- (3) process parameter estimation function,
- (4) perturbation signal generation function, and
- (5) Z-jw conversion function.

2.1 TWO DEGREES OF FREEDOM PID CONTROL FUNCTION

There are several control schemes in two degrees of freedom PID control systems.¹⁾ The most typical two degrees of freedom PID control system

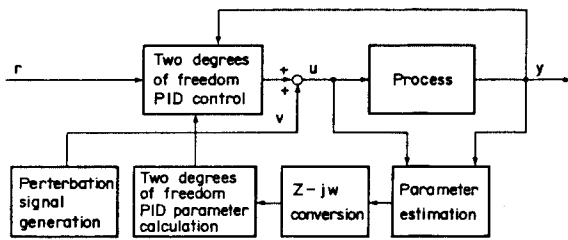


Figure 1 Scheme for two degrees of freedom PID auto-tuning system.

is shown in Figure 2, and the block diagram of the system in Figure 2(A) becomes the same as that of Figure 2(B) by the following equations;

$$K = K_p / T_I \quad , \quad (1a)$$

$$f_0 = K_p \quad , \quad (1b)$$

$$f_1 = K_p \cdot T_D \quad , \quad (1c)$$

$$f_f = \alpha \cdot K_p \quad , \quad (1d)$$

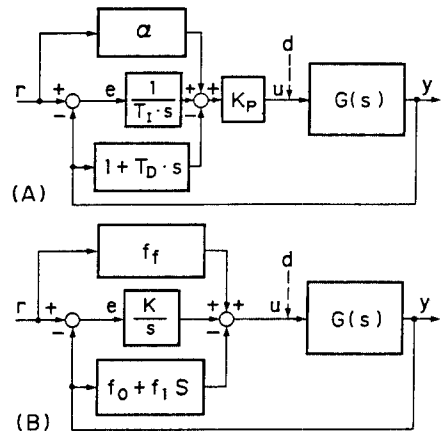
The control system works best when the control parameters K , f_0 , f_1 are tuned optimally for disturbance rejection and the control parameter f_f is tuned optimally for set point value tracking.

2.2 TWO DEGREES OF FREEDOM PID PARAMETER CALCULATION FUNCTION

In order to calculate the control parameters, the authors developed a new model matching method in the cut-off frequency region by extending the conventional model matching method in the s domain. The basic idea of this new model matching method is to make the cut-off frequency characteristics of the control system equal to that of the reference model.⁷⁾ Considering the structure of Kitamori's reference model³⁾, the following open loop reference model $\tilde{G}_m(s)$ from e to y is used.

$$\tilde{G}_m(s) = [\sigma s + \sigma_2(\sigma s)^2 + \sigma_3(\sigma s)^3 + \sigma_4(\sigma s)^4]^{-1}, \quad (2)$$

where σ is a time constant and α_i ($i=2, 3, 4$) are dumping coefficients. Figure 3 shows the vector locus of $\tilde{G}_m(j\omega)$. The phase margin ϕ_M and the gain margin G_M of the reference model are determined by points P and G, respectively. The dumping coefficients, the phase margins and the gain margins of well-known reference models, for example, the Butterworth model, the ITAE minimum model, the Bessel model and the Binomial model,



r : set point variable
 e : deviation signal
 u : manipulated variable
 y : process variable
 d : disturbance

Figure 2 Two degrees of freedom PID(FF-I-PD) control system.

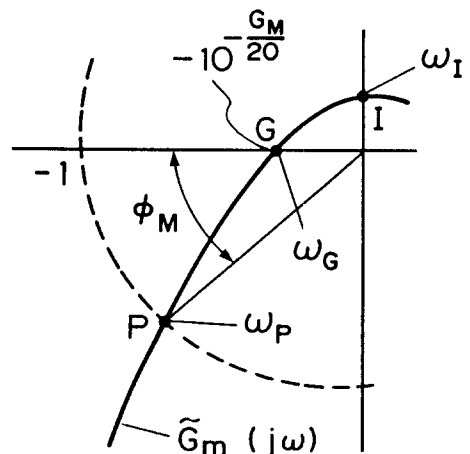


Fig. 3 Vector locus of $\tilde{G}_m(j\omega)$.

are given in Table 1. The step response curves of these reference models are shown in Figure 4. A desired reference model is chosen from these response curves and the desired specification of the control system. The open transfer function $Gey(s)$ from e to y in Figure 2(B) can be expressed as

$$Gey(s) = \frac{K}{s[f_0 + f_1s + G(s)^{-1}]}, \quad (3)$$

where $G(s)$ is the transfer function of the process, as shown in Figure 2. By matching the cut-off frequency characteristics of $Gey(j\omega)$ with that of $\tilde{G}_m(j\omega)$, the control parameters K , f_0 and f_1 can be determined easily and the feed-forward gain f_f can be determined by matching the closed loop transfer function with the loop reference model.

2.3 PROCESS PARAMETER ESTIMATION FUNCTION

The frequency characteristics of the process are necessary for designing the control system by the new model matching method. In this auto-tuning system, the well-known recursive least squares (RLS) algorithm for the auto-regressive moving average (ARMA) model is used.

$$A(z^{-1})y(k) = B(z^{-1})u(k), \quad (4a)$$

$$A(z^{-1}) = 1 + a_1z^{-1} + a_2z^{-2} + \dots + a_{na}z^{-na}, \quad (4b)$$

Table 1 Phase Margin-Gain Margin of Reference Models.

NO.	Ref. Model	n	DUMPING COEFFICIENTS			$\phi_M(\text{deg})$	$G_M(\text{dB})$	$ G(j\omega_1) $
			α_2	α_3	α_4			
1	Butterworth	3	0.5	0.125	-	60.5	12.04	0.0
		4	0.5030	0.1479	0.02188	59.8	7.61	0.0869
2	ITAE minimum	3	0.3786	0.1006	-	66.5	11.51	0.0
		4	0.4664	0.1067	0.01882	63.4	8.69	0.1222
3	Bessel	3	0.4	0.0667	-	67.2	15.56	0.0
		4	0.4268	0.09524	0.009524	65.1	10.71	0.0457
4	Binomial	3	0.3333	0.03704	-	71.3	19.08	0.0
		4	0.3750	0.0625	0.003906	68.6	13.98	0.0204

$$B(z^{-1}) = b_1z^{-1} + b_2z^{-2} + \dots + b_{nb}z^{-nb}, \quad (4c)$$

where $y(k)$ is the process variable, $u(k)$ is the manipulated variable, k is discrete time with sampling period τ , z^{-1} is the backward shift operator, n_a and n_b are the order of $A(z^{-1})$ and $B(z^{-1})$, respectively.

2.4 PERTURBATION SIGNAL GENERATION FUNCTION

In order to satisfy the identifiability conditions²⁾ for any process under a closed loop PID operation, it is necessary to add a perturbation signal, including many frequency components, to the manipulated variable. The maximum period sequence signal is used as the perturbation signal because of its simple generation algorithm.

2.5 Z-j ω CONVERSION FUNCTION

The frequency characteristics of the process $G(j\omega)$ is converted from the identified pulse transfer function $G(z^{-1})$

$$G(z^{-1}) = \frac{b_1z^{-1} + b_2z^{-2} + \dots + b_{nb}z^{-nb}}{1 + a_1z^{-1} + a_2z^{-2} + \dots + a_{na}z^{-na}} \quad (5)$$

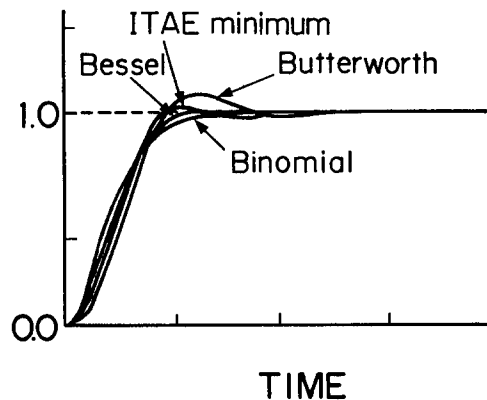


Figure 4 Response curves for reference models.

3. FIELD TEST

Several field tests were carried out to verify the auto-tuning performance of the two degrees of freedom PID auto-tuning controller AdTune TOSD1C 211D8. A typical example performed at CHIYODA CHEMICAL ENGINEERING & CONSTRUCTION CO., LTD. is presented here. Figure 5 shows the gas flow process of a pilot plant with a gas flow control loop (FIC) and a gas pressure control loop (PIC).

Figure 6 shows an example of the process response in a tuning test for the PIC loop. The process characteristics were identified within about 10.5 minutes using the perturbation signal of 3 percent. The two degrees of the PI control parameter were calculated from the identified process characteristics, and were set into the control part, automatically. The set point value was suddenly increased and decreased by 10 kg/cm² at 15.7 minutes and 20 minutes, respectively; fine gas pressure (PV) response was obtained. The PIC loop was intensively interacted from the FIC loop, however, and the disturbance caused by a change in the set point variable for the FIC loop was well rejected from the PIC loop.

The control parameters were tuned optimally within a short period and were almost the same as the parameters manually tuned by expert engineers. These results show the effectiveness of the two degrees of freedom PID auto-tuning controller.

4. CONCLUSIONS

The authors developed a new auto-tuning method by combining the process parameter estimation method in the z domain, the precise z-jw conversion method and the newly developed model matching method in the cut-off frequency region. The two degrees of freedom PID auto-tuning controller, AdTune TOSD1C 211D8, was developed using this method.

The superior features of the auto-tuning controller are summarized as follows;

- (1) the two degrees of freedom PID control system brings excellent process control quality for both set point variable tracking and disturbance resistivity,
- (2) an auto-tuning method under closed loop operation,

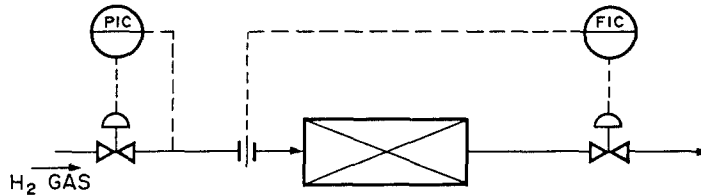


Figure 5 H₂ Gas flow process of pilot plant.

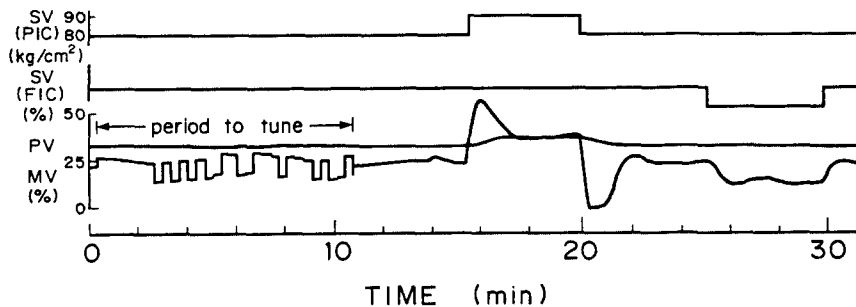


Figure 6 Tuning experiment for PIC Loop.

- (3) wide application to processes including not only time delay and dead time but also overshooting, reverse-shooting and oscillating characteristics, based on the newly developed model matching method in the cut-off frequency region.
- (4) capability of choosing the desired reference model function suiting the control system specification.
- (5) short tuning period with a small perturbation signal.

Several tuning tests showed the effectiveness of the auto-tuning scheme for the two degrees of freedom PID control system.

REFERENCES

- (1) Araki, M. (1985)
2-degrees of freedom controller part 1, Japan Associ. of Auto. Cont. Eng. (Japan), 29, 649.
- (2) Gustavsson, I., L. Ljung and T. Soderstrom (1977)
Identification of Process in Closed Loop (Survey), Automatica, 13, 59.
- (3) Kitamori, T. (1979)
A method of control system design based upon partial knowledge about controlled processes, Trans. Soc. Instrum. & Control Eng. (Japan), 15, 549.
- (4) Kraus, T. (1984)
Self-tuning control: an expert system approach, ISA preprint, 605.
- (5) Nagakawa, K., T. Shigemasa and Y. Hanakuma (1982)
An auto-tuning PID controller, ISA preprint, 1353.
- (6) Shigemasa, T. and Y. Ichikawa (1984)
A closed loop auto-tuning method for a digital process control system, Trans. Soc. Instrum. & Control Eng. (Japan), 20, 592.
- (7) Shigemasa, T. and Y. Iino (1986)
A design method for control system based on model matching in cut off frequency region, 29th Joint Conference of Automatic Control (Japan), preprint, 1041.
- (8) Shigemasa, T. and Y. Ichikawa and S. Sumida (1985)
An Interactive online tuning system for process control - Applications to control system of BWR power plant, 7th IFAC Symposium on Identification and system parameter estimation, proceedings, 993.
- (9) Shigemasa, T., Y. Iino and M. Kanda (1987)
Two Degrees of Freedom PID Auto-Tuning Controller, Proceedings of ISA/87, International Conference and Exhibit (Anaheim, USA)