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The Hybrid Self-tuning PID Regulator and Its Application to pH Control

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Abstract

The hybrid design of self-tuning PID regulator combines the advantage of phase margin design with the advantage of pole placement design. Experimental studies and field tests show that it is probably one of the most feasible design for the general purpose self-tuning PID regulator.

I. Introduction

The PID regulators are very popular but they need laborious tuning for best performance. Thus a self-tuning algorithm is required.

In this paper, an algorithm proposed by L. Keviczky et al. is reviewed, then some extensions are made, and a general purpose HYBRID SELF-TUNING REGULATOR is developed. Finally, a practical example shows its robustness and effectiveness.

II. Fundamental Algorithms

1. Algorithm based on desired phase margin (DPM) for closed loop stability

The algorithm proposed by L. Keviczky et al. is now briefly reviewed. Consider a second order process model with dead time

$$\frac{y(t)}{u(t)}=\frac{b_0+b_1z^{-1}}{1+a_1z^{-1}+a_2z^{-2}}z^{-k}=\frac{B(z^{-1})}{A(z^{-1})}z^{-k} \tag{1}$$

where $t=0, 1, 2, \cdots$ denote the discrete time instants, u and y stand for process input and output respectively, z^{-1} is the backward snift operator, and $k>0$ is the discrete time delay. The control algorithm with PID structure is

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$$\frac{u(t)}{e(t)}=\frac{q_0(1+\hat{a}_1 z^{-1}+\hat{a}_2 z^{-2})}{1-z^{-1}}=\frac{q_0\hat{A}(z^{-1})}{1-z^{-1}} \tag{2}$$

where $e(t)=w(t)-y(t)$, and $w(t)$ is the system set point; while the circumflex (^) represents estimate.

Based on 60° DPM, q_0 in (2) is determined for the following cases:

$$1)\quad q_0=\frac{1}{b_0(2k-1)}=\frac{q}{b_0} \qquad \text{for} \qquad b_0\gg b_1 \tag{3}$$

In this case, it can be shown that the relative overshoot for step response is less than 5%.

2) In general,

$$q_0=\frac{q}{B(z^{-1})} \qquad \text{for } \left|\frac{b_1}{b_0}\right|<1 \tag{4}$$

and

$$q_0=\frac{q}{B(1)(1+fz^{-1})} \qquad \text{for } \left|\frac{b_1}{b_0}\right|\geq 1 \tag{5}$$

where $f=qb_1/(b_0+b_1)$, and

$$q=\frac{1}{2k-1}, \qquad k>1 \tag{6}$$

2. Extensions of the original algorithms

1) Sometimes, a shorter rising time is desired and more overshoot is tolerable. Based on 45° DPM, we get

$$q'=\frac{3}{2(2k-1)}, \qquad k>1 \tag{7}$$

instead of q in (3), (4) and (5). Simulation studies show that in any case the relative overshoot for step response is less than 26%, while the damping ratio is greater than 10 to 1.

2) when $k=1$ in (6), we suggest the choice

$$q=\frac{1}{3} \qquad q'=\frac{1}{2} \tag{8}$$

for 60° and 45° DPM respectively. Later on, we will discuss in detail when $k=1$ in (3) and (4).

3) For an precise first order process model with dead time, it is better to use PI algorithm.

$$\frac{u(t)}{e(t)}=\frac{q_0(1+\hat{a}z^{-1})}{1-z^{-1}} \tag{9}$$

And, choose (6) or (7) for q as mentioned above.

3. Algorithm based on simple pole placement approach

It is important to note that when $k=1$ in (3) and (4), the closed loop transfer function with 60° DPM reduces to

$$\frac{y(t)}{w(t)}=\frac{z^{-k}}{(2k-1)(1-z^{-1})+z^{-k}}=z^{-1} \tag{10}$$

Obviously, a drastic change on the regulator output will be resulted, and this is not always desirable for practical use. In this case, we turn to pole placement approach proposed by K. J. Astrom et al.

For a second order process model without dead time, $k=1$, if the desired closed loop transfer function is defined as

$$\frac{(1+p_1+p_2)z^{-1}}{1+p_1z^{-1}+p_2z^{-2}}=\frac{P(1)z^{-1}}{P(z^{-1})} \tag{11}$$

then the self-tuning PID algorithm can be obtained

$$\frac{u(t)}{e(t)}=\frac{P(1)w(t)-(s_0+s_1z^{-1}+s_2z^{-2})y(t)}{B(z^{-1})(1-z^{-1})} \tag{12}$$

where $s_0=p_1+1-a_1$, $s_1=p_2+a_1-a_2$, and $s_2=a_2$, while p_1 and p_2 are set by the user.

III. The Hybrid Self-Tuning PID Regulator

We now propose a hybrid self-tuning PID regulator, in which the DPM and the simple pole placement approaches are combined. The latter is used only for minimum phase process without dead time. The algorithms concerned are as follows:

1. In case of first or second order minimum phase process model with dead time, $k>1$, the DPM algorithm (9) or (2) with (3) or (4) can be employed. In addition, either (6) or (7) for q can be selected depending on the concrete situation. And, we suggest to choose (6) when the process is more uncertain.

2. In case of second order nonminimum phase process model with dead time, $k>1$, choose the algorithm (2) with (5). Similarly, either (6) or (7) can be chosen.

Moreover, for nonminimum phase process without dead time, $k=1$, either expression in (8) is available.

3. In case of second order minimum phase process model without dead time, $k=1$, choose algorithm (12). The desired rising rate and the tolerant overshoot of the system response can be defined by the user.

IV. Application of Hybrid Self-Tuning PID Regulator to pH Control of Cane Juice Neutralization

1. Technological character and control scheme

In sugar factories, pH value of cane juice exerts a critical influence on both quality and quantity of the products.

The industrial pH control problem is rather complex in general. However, field tests show that the hybrid self-tuning PID regulator is generally successful in cane juice pH control.

The pH value of the mixed juice at the outlet is measured by the Sb-electrode transducer. From the technological point of view, the pH value should be within the range of 7.0-7.2. Disturbances might include flowrate change, pH variation of the mixed juice input and density fluctuation of the lime milk.

The control system scheme is shown in Fig.1.

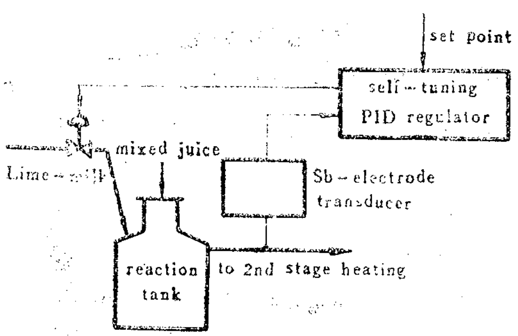

Fig. 1

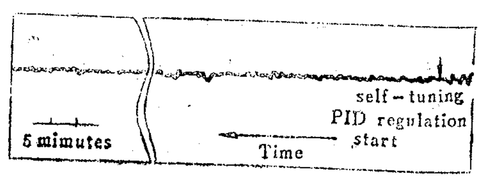

Fig. 2

2. Modelling and algorithm

According to the process step response, the process can be described by a first order model with dead time

$$\frac{y(t)}{u(t)} = \frac{bz^{-k}}{1+az^{-1}} = G(z^{-1}) \tag{13}$$

where $y(t)$ is the controlled signal coming from the Sb-electrode transducer, $u(t)$ the output of the regulator sending to the control valve, and k the discrete time delay, corresponding to sampling period $T=5''$, $k=3$.

Thus, the PI algorithm (9) is applicable. Considering the field conditions, we use (6) for q and set the forgetting factor $\lambda=0.99$ for parameter estimation.

3. Results

we began with fixed PI control, and then switched into self-tuning control after a period of identification and a set of convincible model parameter was obtained.

The estimated process model ranges from

$$G(z^{-1}) = \frac{0.05472z^{-3}}{1-0.1297z^{-1}} \quad \text{to} \quad G(z^{-1}) = \frac{0.08430z^{-3}}{1-0.2929z^{-1}}$$

The corresponding chart record is shown in Fig.2. Although there exist disturbances, the self-tuning eontrol still performs very well. The pH value of cane juice at the outlet holds around 7.1 as technologically required.

V. Conclusion

we have proposed a class of general purpose hybrid self-tuning PID regulator so far. It is easy to implement on a microprocessor system, and easy to operate too. In general, the regulator proposed here is available for a broad range of process.

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综合式自校正PID调节器及其在pH控制中的应用

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摘 要

综合式自校正PID调节器兼有相位裕度和极点配置两种设计方法的优点。实验室和工厂现场的经验表明，它是通用型自校正PID调节器的一种可行方案。