The Elimination of Overshoot Curve Response of Closed Loop in Proportional Integral (PI) Controller

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Abstract - Most operators in industry use trial and error method in determining the parameter in PID controller. This way is quite dangerous because it cannot predict what will happen in the next process. For this, we need a method that can adjust the changing of parameter in process, and simultaneously retune the parameter of controller automatically. Ziegler-Nichols method, a method for setting parameter of PID controller, can be use for eliminating the oscillation and reducing overshoot curve in a process. This method is common yet, but it offers simple procedure but produce quick and accurate result. This method analyzes the curve of a process. It is done when oscillation and overshoot projected onto x-axis (time) occurred. The parameters resulted from this analysis among others are: critical gain (Kpu), time/period oscillation (T_{osc}), static gain (K), proportional gain (K_P), integral time T_i, and differential time T_d. These parameters will be tuned to PID controller using Ziegler-Nichols method. The overshoot (Mp) curve response of closed loop in this simulation is 0 %. It will save energy and time beside that the stability of system can be maintained.

Keywords: heat exchanger, overshoot, proportional gain K_p, integral time T_i, and differential time T_d

I.   INTRODUCTION

Heat exchanger is the secondary process which is commonly needed in chemical industry process. Even though heat exchanger is only a part of process but the stability of this unit must be maintained for the sustainability of all process and also determine the quality of end product in chemical industry [1-2].

This equipment is used for exchanging the heat of two kinds of fluid of different temperature and it is expected that the output fluid temperature is constant. The occurrence of physical events changes the characteristics of process and cause instability in the system. These changes must be controlled.

This paper discusses about method to eliminate overshoot curve in closed loop. Overshoot will waste time and energy in reaching stability point. Most operators determine the parameter of PID controller in industry by rule of thumb [1], trial and error. This way is quite dangerous because it is guessing only and it cannot predict what is going on in the next process. Besides that retuning the controller takes time and disturbs the process. We need a method that can adapt the changing of parameter process

and retune controller parameter automatically for eliminating curve overshoot in a process. Finding out method which is not commonly used yet and can show fast and accurate result is not easy. It is not easy because retuning the controller parameter takes time and disturbs the process. This article introduces Ziegler-Nichols method, a method which employs simple, effective and efficient transient curve [3-7]. This method can show result fast.

This method employs curve analysis in process. We analyze the curve when overshoot projected onto x-axis (time) occurred. Based on this analysis the parameters found: proportional gain K_p, integral time T_i, and differential time T_d. These parameters will be tuned to PID controller by using Ziegler-Nichols method.

II.   The Analysis of Overshoot Curve Response of Closed Loop

Curve response which has overshoot in first order system with delay time can be eliminated by PI [2] controller setting given by:

$$G(s)H(s) = K_p\left(1+\frac{1}{T_i s}\right)\left(\frac{K_s}{\tau s+1}e^{-toS}\right) \quad (1)$$

Where $s = j\omega$, form (1) then

$$G(j\omega)H(j\omega) = K_p\left(\frac{j\omega T_i+1}{j\omega T_i}\right)\left(\frac{K_s}{j\omega\tau+1}\right)e^{-j\omega to} \quad (2)$$

where $T_i = \tau$,   form   (2)   then

$$G(j\omega)H(j\omega) = \frac{K_p.K_s}{j\omega\tau}e^{-j\omega to} \quad (3)$$

Magnitude of form (3) then $|GH| = \dfrac{K_p.K_s}{\omega.\tau}$

where $\omega = \omega_c$, form (4) then $|GH| = \dfrac{K_p.K_s}{\omega_c.\tau} \le 0,5 \quad (5)$

Angle of form (5) then $\angle GH = -\dfrac{\pi}{2} - \omega.t_o$

where $\omega = \omega_c$, form (6) then $\angle GH = -\dfrac{\pi}{2} - \omega_c.t_o$ (7)

form (7) then $-\dfrac{\pi}{2} - \omega_c.t_o = -\pi$

or $\omega_c = \dfrac{\pi}{2.t_o}$ (9)

so $K_p \leq 0,5.\omega_c.\tau$ (10)

$K_p \leq 0,5.\dfrac{\pi}{2}.\dfrac{\tau}{t_o}.\dfrac{1}{K_s}$ (11)

$K_p \leq 0,8.\dfrac{\tau}{t_o}.\dfrac{1}{K_s}$ (12)

for P controller $K_p \leq \dfrac{0,5}{K}$ (13)

or $K_p < 0,8.\dfrac{\tau}{t_o}.\dfrac{1}{K_s}$ (14)

Magnitude of $\left| G(j\omega)H(j\omega) \right|$ then

$\left| G(j\omega)H(j\omega) \right| = \dfrac{K_p.K_s\sqrt{(\omega T_i)^2 + 1}}{\omega T_i\sqrt{(\omega \tau)^2 + 1}}$ (15)

Characteristic equation $1 + G(s)H(s) = 0$ (16)

or $1 + K_p\left(1 + \dfrac{1}{T_i s}\right)\left(\dfrac{K}{\tau_s + 1}\right) = 0$ (17)

or $(T_i s)(\tau s + 1) + K_p.K_s(T_i s + 1) = 0$ (18)

or $T_i \tau s^2 + T_i s(1 + K_p.K_s) + K_p.K_s = 0$ (19)

Where $GB = K_p.K_s$ and the system will not oscillate, equation (19) then $T_i^2(1 + K_p.K_s)^2 - 4T_i.\tau.K_pK_s \geq 0$ (20)

or

$$T_i \geq \dfrac{4\tau\, GB}{(1 + GB)^2}$$

Fig. 1 shows the relationship of GB and T_i, domain for system respons with osillation and domain for system no oscillation.
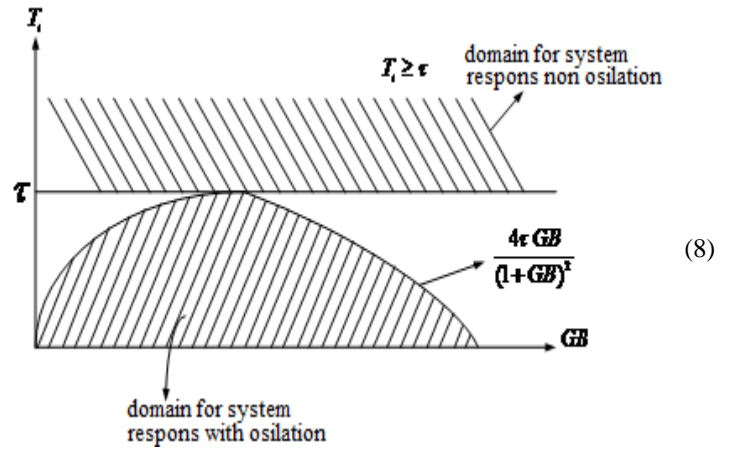

Figure 1. The Relation GB and T_i Domain for System Respons with Osillation and domain for System No Oscillation.

III.   Tuning for PID Controller

The value of proporsional gain (K_p), integral time (T_i), and differential time (T_d) is determined by using Ziegler-Nichols method. Determining parameters of PID controller is called tuning. Tuning of PID controller can be done by getting mathematical model of process which represents the whole dynamic process.

One way to get the mathematical model is by experiment. Getting mathematical model and determining optimum parameter of process by experiment is called identification [1].

The result of identification will show us curve characteristics: static gain (K_s), delay time (t_0) and time constant (τ). Based on the curve characteristics we can get proportional gain (K_p), integral time (T_i), and differential time (T_d) by using Ziegler-Nichols method as described in Table 1.

Tabel 1. Ziegler-Nichols Tuning Based on Step Response.

Controller Type	K_p	T_i	T_d
P	$\dfrac{1}{K_s}\left(\dfrac{t_0}{\tau}\right)^{-1}$	∞	0
PI	$\dfrac{0,9}{K_s}\left(\dfrac{t_0}{\tau}\right)^{-1}$	$3,33t_0$	0
PID	$\dfrac{1,2}{K_s}\left(\dfrac{t_0}{\tau}\right)^{-1}$	$2t_0$	$\dfrac{1}{2}t_0$

IV.   SIMULATION & RESULT

Figure 2 describes the simulation of curve response in heat exchanger closed loop with PI controller setting.
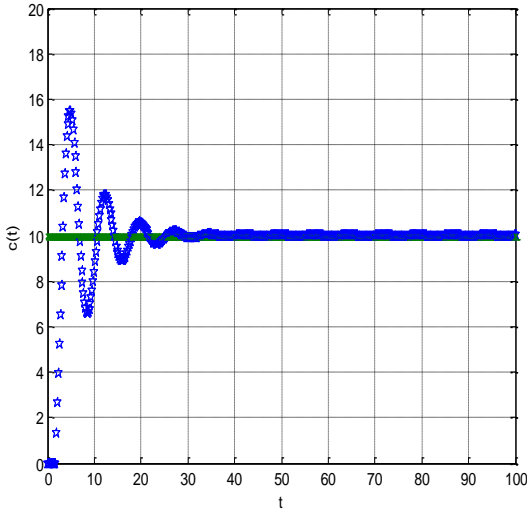

Figure 2. Curve Response of heat exchanger Closed Loop with PI Controller Setting.

Eliminating the overshoot in Figure 2 is by determining the value of K_p, T_i and $T_d = 0$. Equation (13) and Equation (21) are for determining the value of K_p and T_i. With static gain $K = 1,34$, $\tau = 4,2$ minutes. The value of K_p as follows

$$K_p \leq \frac{0,5}{K}$$

$$K_p \leq \frac{0,5}{1,34}$$

$$K_p \leq 0,373$$

The value of $K_p = 0,3$. The value of T_i then

$$T_i \geq \frac{4\tau.K_p.K}{(1+K_p.K)^2}$$

Then

$$T_i \geq \frac{4 . 4,2 . 0,3 . 1,34}{(1 + 0,3 . 1,34)^2}$$

$$T_i \geq 3,436$$

or

$$3,436 \leq T_i$$

The value of $T_i = 3$ minutes.

Based on this simulation the value of $K_p = 0,3$, $T_i = 3$ minutes, and $T_d = 0$. Figure 3 describes curve responses of overshoot and non overshoot.
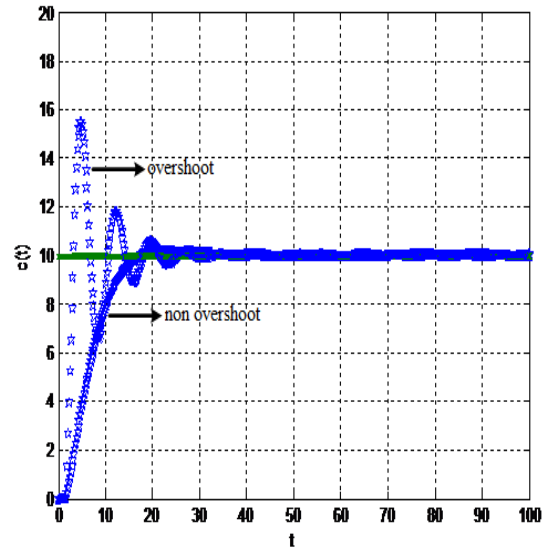

Figure 3. Curve Responses of Overshoot and Non Overshot

V.   CONCLUSION

Based on this simulation *overshoot* (M_p) = 0%. By analyzing this reduction, we can save energy and time and maintain the stability of the system.

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