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Frequency Response Analysis and Optimum Tuning for Temperature Control System

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Abstract

The paper presents frequency responce analysis of temperature control system through Bode Diagram. From the open loop manual test, First Order Plus Dead Time model reflects open loop process behavior. SISOTOOL function in Matlab is utilized for designing the Proportional and Integral Controller. Besides, this paper proposes Routh-Hurwitz stability criterion to calculate stability margin and Compensator Ratio for obtaining optimized controller settings and the analysis were justified through Process Control Simulator, SE-201. It was found that Compensator ratio of 0.095 is the optimized tuning, which gives proportional gain of 16.2% and time constant is 65s for both servo and regulatory control.

Key-word: - Bode Diagram, Frequency, Stability and Simulator.

1.0 Introduction

This paper reports the frequency response analysis using SISOTOOL function in in Matlab in designing Proportional plus Integral (PI) control settings for Process Simulator, SE-201 (SOLTEQ,2015). Routh-Hurwitz stability criterion is proposed for setting limit of tuned parameters as well as Compensator (*C*) ratio is recommended for obtaining optimized tuning for both servo and regulatory control. Meanwhile, Proportional, Integral plus Derivative (PID) control is widely applied to many industries (Astrom & Hagglund, 2001). It was first introduced by Ziegler-Nichols (1942), the frequency domain analysis was used for both open loop and closed-loop tuning methods for determining PID settings. Thereafter, a lot of tunings methodology such as Cohen-Coon (1953), Astrom and Hagglund (2001) and Marlin (1995) calculate PID settings by direct implying parameters to the developed formulas of each method **(**Luyben & Luyben, 1997). However, the study on frequency domain in designing PID controller is still popular because the all generated figures of Bode Diagram is easily interpreted.

1.**1** BODE DIAGRAM AND ROUTH-HURWITZ STABILITY

Bode diagram reflects two quantitative measurements that determine the quality of performance known as Gain Margin (*GM)* and Phase Margin (*PM)* through measuring the Amplitude Ratio (A_r) and Phase Angle (∅) versus the logarithm of frequency, ω (Ogata, 2010). *GM* is the difference between a amplitude value corresponding to Phase Crossover frequency (W_{pc}) angle of 180^0, which is reciprocal to A_r. The Bode plot clarifies the stability criterion by stating that a stable open-loop system would have *GM* > 1 or reciprocally A_r < 1. Upon the requirement, the closed-loop response is stable. An identical value for *GM* is approximated to 2.0 (Tavakoli & Fleming, 2003).vv*PM* is the difference between a phase angle corresponding to when A_r is 1.0 and the phase angle of 180^0 (Marlin, 1995). When *PM* > 0, the system is stable, and when *PM* = 0, the system operates under sustained oscillations. The ω_{gc} is the frequency that correspond to A_r = 1. Typical system design would have phase margin of 30^0 to 60^0. Figure 1 illustrates block diagram of feedback control system, comprises process and PI controller.

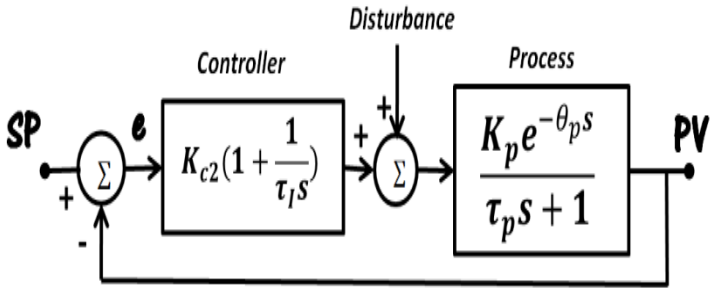


Figure 1. Block Diagram of feedback control system.

Apply Taylor's approximation in stability analysis, solving of Characteristic Equation (CE) is shown in (1), which produces both upper and lower limit as in (2) and (3) :

$$1+\left\{K_{c2}(1+\frac{1}{\tau_I s})\right\}\left\{\frac{K_p(1-0.5\theta_p s)}{(\tau_p s+1)}\right\} = 0 \quad (1)$$

For term s^2 , $\left(\tau_p\tau_I - \tau_I K_c K_p\right) > 0$

$$K_c < \frac{\tau_p}{K_p\theta_p} \quad \text{(upper limit)} \quad (2)$$

For s , $\left(\tau_I + \tau_I K_c K_p - K_c K_p \theta_p\right) > 0$

$$\tau_I > \frac{\theta_p K_c K_p}{1+K_c K_p} \quad \text{(Lower Limit)} \quad (3)$$

Compared with the tuning method of Hassan (2014), this paper proposes Compensator (*C)* ratio tuning in designing PI controller as shown in (4) :

$$K_2 = C * \left[K_c(1+\frac{1}{\tau_I}s)\right] \quad (4)$$

Tan et al.(2008) explained SISOTOOL function in Maltab is able to tune *C* for generating graphical interactions of controlled system, which is displayed by Bode diagram.

2.0 ANALYSIS AND RESULT

2.1 FIRST ORDER PLUS DEAD TIME AND CLOSED LOOP STABILITY

Determining FOPDT is preliminary stages towards analysis of process dynamic for stable process control (Tavakoli & Fleming, 2003). The stages of determining FOPDT is well-presented in literature Chew et al. (2017). From experimental studies, the developed First Order plus Dead Time (FOPDT) is shown in (5) :

$$G(s) = \frac{0.68e^{-15s}}{150s+1} \quad (5)$$

Substituting, τ_p = 150, θ_p = 15 and K_p = 0.68 into (2)
$K_c <$ 14.7 or PB > 6.8%
Also refer to integral time constant, τ_I as in (3).
Taking, K_c = 14 (<14.7), substitute, θ_p = 15 and K_p = 0.68 gives
$\tau_I > 13.57$

Therefore, the applied tuning limits for PI controller are PB > 6.8% and $\tau_I > 13.57$.

2.2 FREQUENCY RESPONSE AND TUNING OF COMPENSATOR,C

The view of Bode diagram for the applied *Cs* are shown by Figure 2 below.

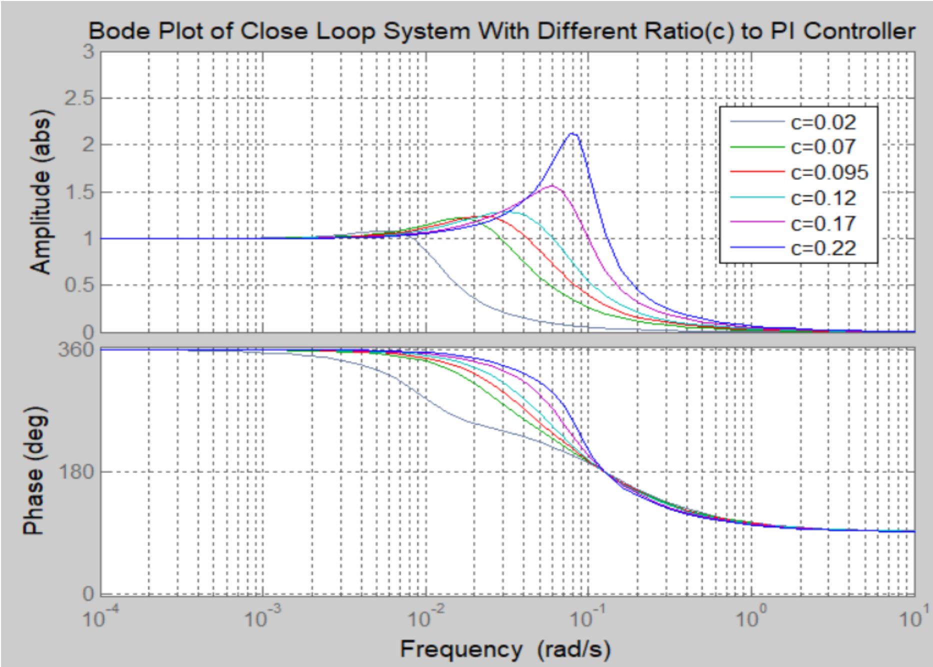


Figure 2. Bode diagram of various compensator ratio, C.

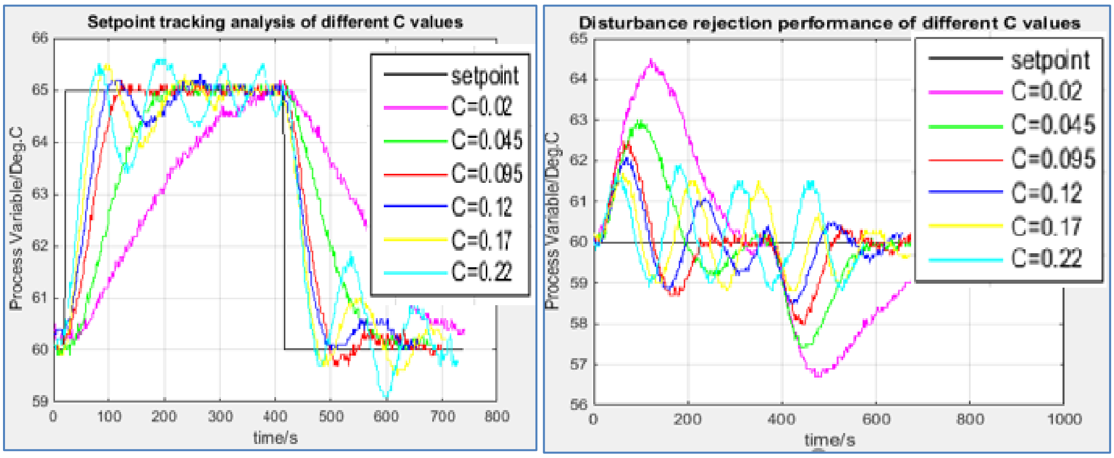
From the SISOTOOL, acquisition of *GM* and *PM* from Figure 2 were tabulated in Table 1. It is also noted that tunings of *C* in SISOTOOL were tested up to *C*=0.22 as *PB* is approximated to 7%. Thereby, *C* tunings until 0.22 are used to obtain K_c and τ_I of PI controller.

Table 1: Gain Margin and Phase Margin

Compensator ratio, *C*	Frequency Responce *GM*	*PM*	PI Controller Setting K_c	*PB* (%)	K_i	τ_i
c=0.02	23.205	120.025	1.13	88.5	0.0173	56.5
c=0.07	4.977	101.073	4.56	21.9	0.07	65
c=0.095	3.404	87.216	6.19	16.2	0.095	65
c=0.12	2.487	65.897	7.82	12.8	0.12	65
c=0.17	1.461	23.364	11.1	9.0	0.17	65
c=0.22	0.902	-5.227	14.3	7.0	0.22	65

2.3 RELATIVE PERFORMANCE FOR SERVO AND REGULATORY CONTROL

Response of servo and regulatory control are shown in Figure 3 (a) and (b).



(a) (b)

Figure 3. Servo and Regulatory response of various compensator ratios.

Table 2 depicts *C* = 0.12 till 0.22 caused unstable response. As *C* = 0.095 is comparatively settles fast that other tunings, it is preferably selected as optimal tuning for PI controller.

Table 2: Process Similator performance for servo and regulatory control

Compensator	Setpoint Tracking Analysis		Disturbance Rejection Performance	
	Rise Time (s)	Settling Time (s)	Overshoot (Deg.C)	Settling Time (s)
C=0.02	386	386	4.3	352
C=0.045	203	203	2.9	315
C=0.095	116	116	2.2	221
C=0.12	94	197	2.0	unstable
C=0.17	79	191	1.6	unstable
C=0.22	67	unstable	1.5	unstable

It is clear to denote that *C* = 0.095 is choosen as optimal tuning for the temperature control system of Process Control Simulator, SE201 which is resulted by satisfactory response for both servo and regulatory control.

3.0 CONCLUSION

Frequency Response Analysis provides innovative tuning approach for determining PI controller based on the displayed figures in the Bode diagram. Applying the SISOTOOL function in Matlab had reduced mathematic calculations in analyzing response of varies PI controller settings to Process Control Simulator, SE-201. It is concluded that compensator ratio of *C* = 0.095 is the best ratio fixed to both servo and regulatory control. The produced overshoots were less with fast setting time when compared to the other settings. In balancing the servo and regulatory control for SE-201, the optimum tunings PI controller is PB = 16.2% and τ_i = 65s.

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