UNIVERSITI SAINS MALAYSIA

First Semester Examination
2011/2012 Academic Session

January 2012

EKC 361 – Process Dynamics and Control
[Proses Dinamik dan Kawalan]

Duration : 3 hours
[Masa : 3 jam]

Please check that this examination paper consists of NINE pages of printed material and FOUR pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi SEMBILAN muka surat yang bercetak dan EMPAT muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instruction: Answer **ALL** (4) questions.

*[**Arahan:** Jawab **SEMUA** (4) soalan.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai.]

Answer ALL questions.
Jawab SEMUA soalan.

1. [a] For the steam-heated tank shown in Figure Q.1.[a], identify manipulated, controlled, and disturbance variables. What disturbances are measured for feedforward control? How would the control system react to an increase in feed temperature in order to keep the tank temperature at its setpoint?

Bagi tangki terpanas stim yang ditunjukkan dalam Rajah S.1.[a], kenal pasti pembolehubah olahan, pembolehubah terkawal dan pembolehubah gangguan. Apakah gangguan-gangguan yang diukur untuk pengawal suap-depan? Bagaimanakah sistem kawalan bertindak terhadap peningkatan dalam suhu suapan untuk mengekalkan suhu tangki pada titik setnya?

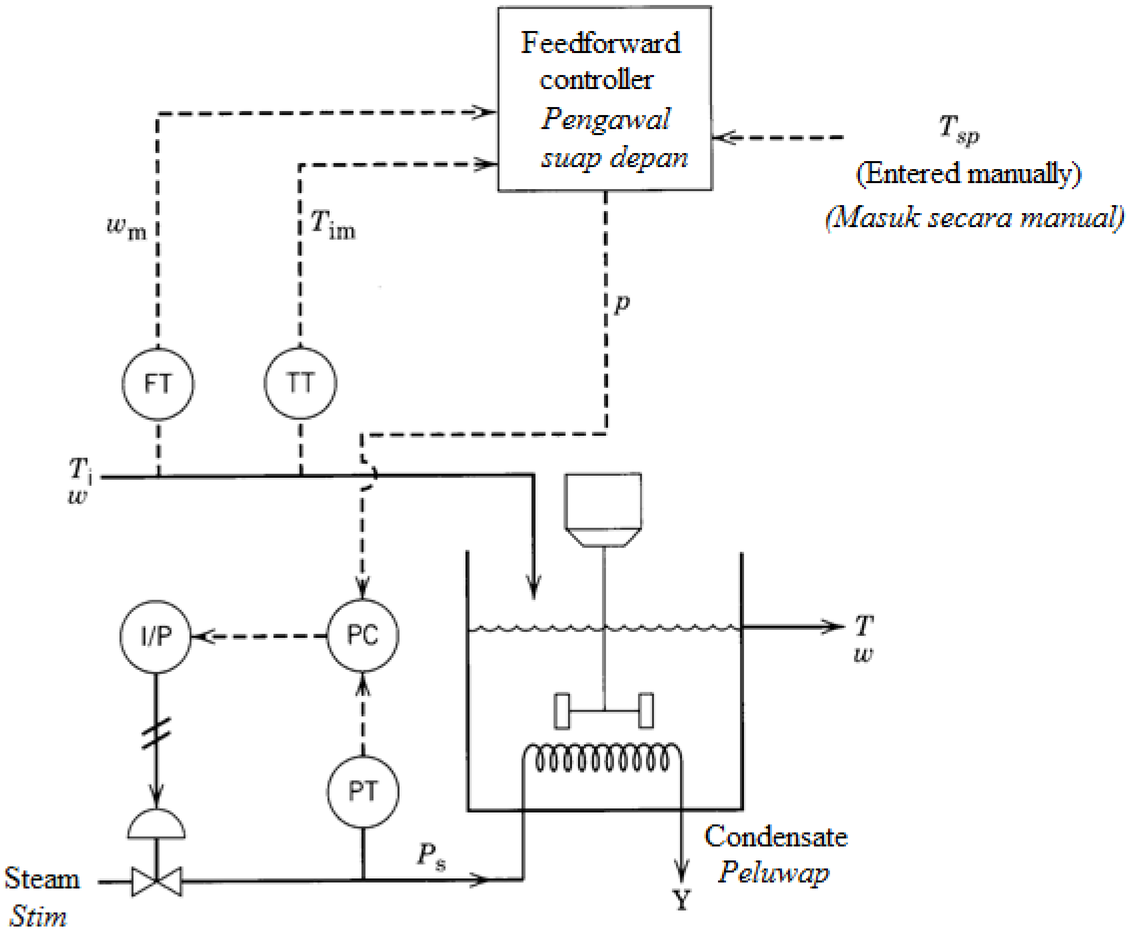

Figure Q.l.[a]. Feedforward control with a feedback control loop for outlet temperature
Rajah S.1.[a]. Pengawal suap depan bersama pengawal suap balik bagi suhu keluaran

[5 marks/markah]

[b] Consider the heated mixing tank example, which had the modeling equations:
Pertimbangkan contoh tangki pencampur terpanas yang mempunyai persamaan-persamaan model:

$$\frac{dV}{dt} = F_i - F$$
$$\frac{dT}{dt} = \frac{F_i}{V}(T_i - T) + Q$$

For steady-state inlet and outlet flow rates of l00 liters/minute, a liquid volume of 500 liters and inlet and outlet temperatures of 20°C and 40°C, respectively:

Bagi aliran masukan dan aliran keluaran yang mantap 100 liter/minit, isipadu cecair 500 liter dan suhu masukan dan suhu keluaran yang masing-masing 20°C dan 40°C:

[i] Find the steady-state heating rate, Q.
Cari kadar pemanasan pada keadaan mantap, Q.

[ii] Consider a step inlet temperature change from 20°C to 22°C, find the vessel temperature response for the first 2 minutes.

Pertimbangkan satu perubahan langkah suhu masukan dari 20°C ke 22°C, cari sambutan suhu bekas untuk 2 minit pertama.

[10 marks/markah]

[c] The output response data *y* shown in Table Q.1.[c] were generated from a step change in input *u* from 2 to 4 at time t = 0. Develop a transfer function model of the form:

Data sambutan keluaran, y*, ditunjukkan dalam Jadual S.1.[c] telah dihasilkan daripada satu perubahan langkah dalam masukan* u *dari 2 ke 4 pada masa t = 0. Binakan satu model rangkap pindah dalam bentuk:*

$$\frac{Y(s)}{U(s)} = \frac{Ke^{-\theta s}}{(\tau_1 s + 1)(\tau_2 s + 1)}$$

Table Q.l.[c].
Jadual S.1.[c].

t	0	1	2	3	4	5	6	7	8	9	10	11	12	13
y	0	0	0	0.3	0.6	0.9	1.3	1.8	2.4	2.7	2.8	2.9	3.0	3.0

[10 marks/markah]

2. [a] Match the transfer functions with the responses to a unit step input, shown in Figure Q.2.[a].

Padankan rangkap-rangkap pindah dengan sambutan-sambutan terhadap satu unit langkah masukan seperti ditunjukkan dalan Rajah S.2.[a].

[i] $\frac{3(-2s+1)}{s^2+0.5s+1}$

[ii] $\frac{-2e^{-3s}}{3s+1}$

[iii] $\frac{2}{-5s+1}$

[iv] $\frac{1}{s(5s+1)}$

[v] $\frac{4s+1}{2s+1}$

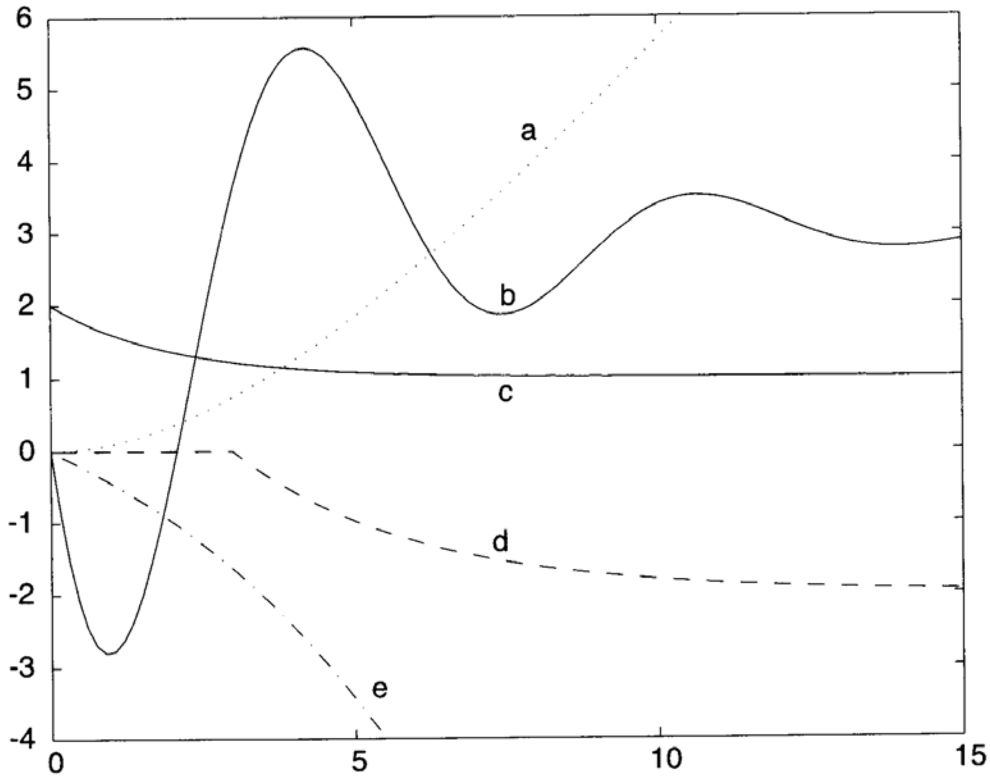

Figure Q.2.[a].
Rajah S.2.[a].

[5 marks/markah]

[b] Your company is having problems with the feed stream to a reactor. The feed must be kept at a constant mass flow rate (w) even though the supply from the upstream process unit varies with time, $w_i(t)$. Your boss feels that an available tank can be modified to serve as a surge unit, with the tank level expected to vary up and down somewhat as the supply fluctuates around the desired feed rate. He wants you to consider whether (1) the available tank should be used, or (2) the tank should be modified by inserting an interior wall, thus effectively providing two tanks in series to smoothen the flow fluctuations.

Syarikat anda mempunyai masalah dengan alur suapan ke suatu reaktor. Suapan tersebut mesti ditetapkan pada suatu kadar aliran jisim yang malar (w) walaupun bekalan dari unit proses huluan berubah dengan masa, $w_i(t)$. *Ketua anda merasakan yang tangki sedia ada boleh diubahsuai untuk bertindak sebagai suatu unit pusuan, dengan paras tangki dijangka berubah naik dan turun sebagaimana turun naiknya bekalan di sekitar kadar suapan yang diinginkan. Dia meminta anda untuk mempertimbangkan sama ada (1) tangki sedia ada perlu digunakan, atau (2) tangki tersebut perlu diubahsuai dengan memasukkan dinding dalaman, yang akan menjadikan dua tangki secara bersiri untuk melancarkan turun naiknya aliran.*

The available tank would be piped as shown in Figure Q.2.[b].[i].
Tangki sedia ada akan disambungkan seperti dalam Rajah S.2.[b].[i].

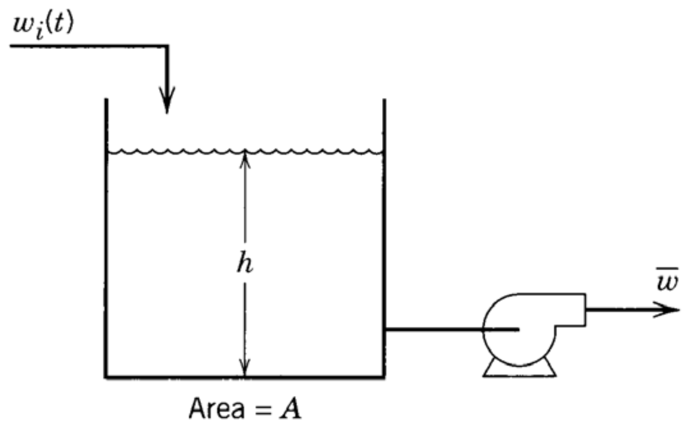

Figure Q.2.[b].[i].
Rajah S.2.[b].[i].

In the second proposed scheme, the process would be modified as shown in Figure Q.2.[b].[ii].

Dalam skim cadangan kedua, proses tersebut akan diubahsuai seperti yang ditunjukkan seperti dalam Rajah S.2.[b].[ii].

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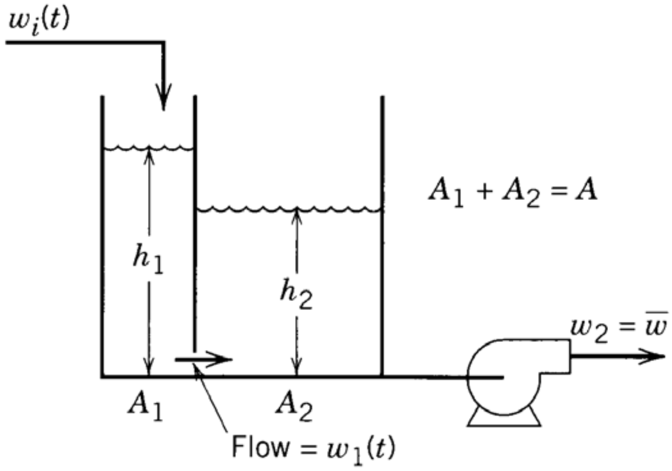

Figure Q.2.[b].[ii].
Rajah S.2.[b].[ii].

In this case, an opening placed at the bottom of the interior wall permits flow between the two partitions. You may assume that the resistance to flow $w_i(t)$ is linear and constant (R).
Dalam kes ini, satu bukaan terletak pada dasar dinding dalaman yang membenarkan aliran antara dua sekatan. Anda boleh mengandaikan yang rintangan kepada aliran $w_i(t)$ adalah lelurus dan pemalar (R).

Derive a transfer function model for the two-tank process [H_2'(s)/W_i'(s)] and compare it to the one-tank process [H'(s)/W_i'(s)]. In particular, for each transfer function indicate its order, presence of any zeros, gain, time constants, presence or absence of an integrating element and whether it is interacting or noninteracting.

Terbitkan satu model rangkap pindah bagi proses dua tangki [H_2'(s)/W_i'(s)] dan bandingkannya dengan proses satu tangki [H'(s)/W_i'(s)]. Secara khususnya, bagi setiap rangkap pindah nyatakan tertibnya, kewujudan sifar, gandaan, kewujudan atau ketiadaan elemen kamiran dan sama ada saling tindak atau tidak saling tindak.

[20 marks/markah]

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3. A process stream is heated using a shell and tube heat exchanger. The exit temperature is controlled by adjusting the steam control valve shown in the Figure Q.3. During an open loop experimental test, the steam pressure P_S was suddenly changed from 18 to 20 psig and the temperature data shown in Table Q.3. below were obtained. At the normal condition, the control valve and current-to-pressure tranducers have gains of K_V = 0.9 psi/psi and K_{IP} = 0.75 psi/mA, respectively.

Satu aliran proses telah dipanaskan dengan menggunakan penukar haba kelompang dan tiub. Suhu yang keluar dikawal dengan pelaras injap kawalan stim seperti yang ditunjukkan dalam Gambarajah S.3. Semasa ujian eksperimen gelung terbuka, tekanan stim P_S tiba-tiba diubah dari 18 ke 20 psig dan data suhu adalah seperti yang ditunjukkan dalam Jadual S.3. Pada keadaan biasa, injap kawalan dan penukar arus tekanan masing-masing mempunyai gandaan K_v=0.9 psi/psi dan K_{IP} = 0.75 psi/mA.

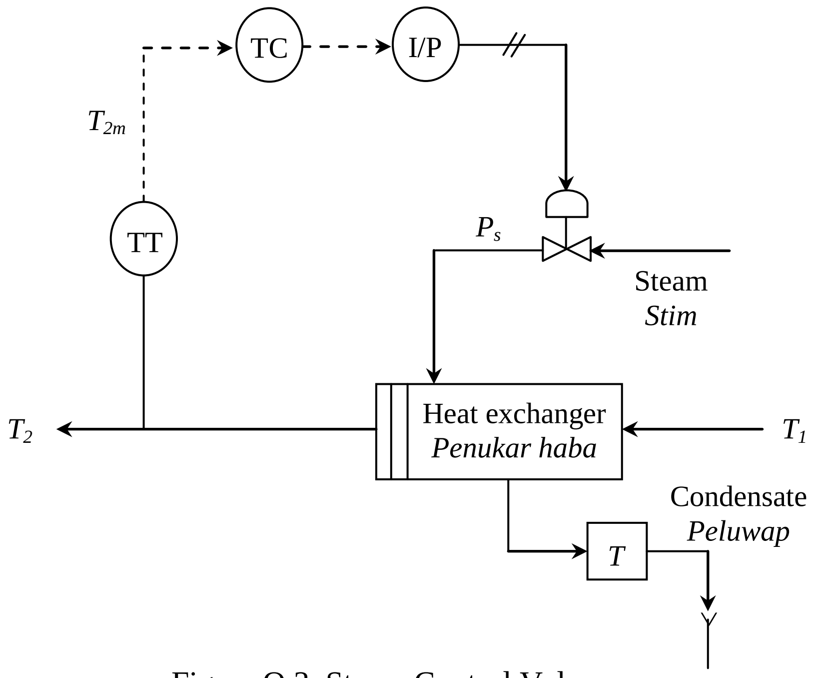

Figure Q.3. Steam Control Valve
Gambarajah S.3. Injap Kawalan Stim

Table Q.3. Temperature Data
Jadual S.3. Data Suhu

t (min)	0	1	2	3	4	5	6	7	8	9	10	11	12
T_{2m} (mA)	12.0	12.0	12.5	13.1	14.0	14.8	15.4	16.1	16.4	16.8	16.9	17.0	16.9

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[a] State the variables associated with this case.
Nyatakan pembolehubah-pembolehubah bagi kes ini. *[3 marks/markah]*

[b] Draw a standard block diagram of a feedback control system.
Lukiskan gambarajah blok umum bagi sistem kawalan suapan berbalik.
[2 marks/markah]

[c] Determine an appropriate process model for the system.
Tentukan satu model proses yang sesuai bagi sistem ini. *[5 marks/markah]*

[d] Determine appropriate PID controller settings using any available approaches using available data, relation or setting. State the reasons you chose the approach.

Tentukan set-set pengawal PID yang sesuai dengan menggunakan sebarang pendekatan-pendekatan yang ada dengan menggunakan data hubungkait atau set yang sedia ada. Nyatakan alasan-alasan pendekatan yang dipilih.
[5 marks/markah]

[e] The control loop can be either unstable or sluggish. Please diagnose the reasons behind this situation based on this case.
Gelung kawalan boleh menjadi sama ada tidak stabil atau lambat bergerak. Diagnoskan atau selidiki antara alasan-alasan di sebalik situasi ini, berasaskan kes ini. *[3 marks/markah]*

[f] The feedforward control scheme can be used for this case. Suggest the control configuration and then draw a block diagram for this. Besides the measured variable you suggested, propose other measured disturbance variable.

Keadaan kawalan suap depan boleh digunakan bagi kes ini. Cadangkan tatarajah kawalannya dan kemudian lukiskan gambarajah bloknya. Selain daripada mengukur pembolehubah yang telah anda cadangkan, cadangkan ukuran pembolehubah gangguan yang lain. *[3 marks/markah]*

[g] This case is based on empirical experimental tests where the model and controller setting can later be determined. If you are to design the control system from scratch conceptually, what would you do?

Kes ini berasaskan ujian eksperimen empirikal di mana model dan set kawalan boleh ditentukan. Jika anda dikehendaki untuk merekabentuk sistem kawalan daripada awal secara konsep, apakah yang akan anda lakukan?
[4 marks/markah]

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4. [a] An analyser measures the pH of a wastewater treatment plant every 15 minutes. During normal process operation, the mean and standard deviation for the pH measurement are $\bar{x}$ = 5.76 and s = 0.05 respectively. When the process is operating normally, what is the probability that a pH measurement will exceed 5.9?

Satu pengukur pH loji rawatan air sisa mengukur pada setiap 15 minit. Semasa proses operasi biasa, purata dan sisihan piawai bagi ukuran pH adalah masing-masing $\bar{x}$ *= 5.76 dan* s *= 0.05. Apabila proses beroperasi secara biasa, apakah kebarangkalian ukuran pH akan melebihi 5.9?*

[10 marks/markah]

[b] Two thermocouples, one of them a known standard, are placed in an air which the temperature is varying sinusoidally. The temperature responses of the two thermocouples are recorded at a various of frequencies, with the phase angle between the two measured as shown in Table Q.4. The standard is known to follow first-order dynamics and with a time constant of 0.15 min when operating in the air stream. From the data, show that the unknown thermocouple also is first-order and find its time constant.

Dua unit pengganding suhu, salah satu daripadanya diketahui piawainya, ditempatkan di udara di mana suhu berubah-ubah berbentuk sinus. Suhu respon kedua-dua pengganding suhu direkodkan pada frekuensi yang berubah-ubah, dengan sudut fasa di antara kedua-dua ukuran seperti yang ditunjukkan dalan Jadual S.4. Keadaan piawai yang diketahui mengikut dinamik tertib pertama dan masa malar 0.15 minit apabila operasi dalam aliran udara. Daripada data, tunjukkan bahawa pengganding suhu yang tidak diketahui juga adalah tertib pertama dan diketahui masanya malar.

[15 marks/markah]

Table Q.4.
Jadual S.4.

Frequency (cycles/min) *Frekuensi (kitaran/min)*	Phase difference (deg) *Perbezaan fasa (darjah)*
0.05	4.5
0.1	8.7
0.2	16.0
0.4	24.5
0.8	26.5
1.0	25.0
2.0	16.0
4.0	9.2

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Appendix

Table Laplace Transforms for Various Time-Domain Functions[a]

$f(t)$		$F(s)$
1. $\delta(t)$ (unit impulse)		1
2. $S(t)$ (unit step)		$\frac{1}{s}$
3. t (ramp)		$\frac{1}{s^2}$
4. t^{n-1}		$\frac{(n-1)!}{s^n}$
5. e^{-bt}		$\frac{1}{s+b}$
6. $\frac{1}{\tau}e^{-t/\tau}$		$\frac{1}{\tau s+1}$
7. $\frac{t^{n-1}e^{-bt}}{(n-1)!}$ $(n>0)$		$\frac{1}{(s+b)^n}$
8. $\frac{1}{\tau^n(n-1)!}t^{n-1}e^{-t/\tau}$		$\frac{1}{(\tau s+1)^n}$
9. $\frac{1}{b_1-b_2}(e^{-b_2t}-e^{-b_1t})$		$\frac{1}{(s+b_1)(s+b_2)}$
10. $\frac{1}{\tau_1-\tau_2}(e^{-t/\tau_1}-e^{-t/\tau_2})$		$\frac{1}{(\tau_1 s+1)(\tau_2 s+1)}$
11. $\frac{b_3-b_1}{b_2-b_1}e^{-b_1t}+\frac{b_3-b_2}{b_1-b_2}e^{-b_2t}$		$\frac{s+b_3}{(s+b_1)(s+b_2)}$
12. $\frac{1}{\tau_1}\frac{\tau_1-\tau_3}{\tau_1-\tau_2}e^{-t/\tau_1}+\frac{1}{\tau_2}\frac{\tau_2-\tau_3}{\tau_2-\tau_1}e^{-t/\tau_2}$		$\frac{\tau_3 s+1}{(\tau_1 s+1)(\tau_2 s+1)}$
13. $1-e^{-t/\tau}$		$\frac{1}{s(\tau s+1)}$
14. $\sin \omega t$		$\frac{\omega}{s^2+\omega^2}$
15. $\cos \omega t$		$\frac{s}{s^2+\omega^2}$
16. $\sin(\omega t+\phi)$		$\frac{\omega\cos\phi+s\sin\phi}{s^2+\omega^2}$
17. $e^{-bt}\sin \omega t$	b, ω real	$\frac{\omega}{(s+b)^2+\omega^2}$
18. $e^{-bt}\cos \omega t$	b, ω real	$\frac{s+b}{(s+b)^2+\omega^2}$
19. $\frac{1}{\tau\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin(\sqrt{1-\zeta^2}\,t/\tau)$ $(0 \le \lvert\zeta\rvert < 1)$		$\frac{1}{\tau^2 s^2+2\zeta\tau s+1}$
20. $1+\frac{1}{\tau_2-\tau_1}(\tau_1 e^{-t/\tau_1}-\tau_2 e^{-t/\tau_2})$ $(\tau_1 \neq \tau_2)$		$\frac{1}{s(\tau_1 s+1)(\tau_2 s+1)}$
21. $1-\frac{1}{\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin[\sqrt{1-\zeta^2}\,t/\tau+\psi]$, $\psi=\tan^{-1}\frac{\sqrt{1-\zeta^2}}{\zeta}$, $(0 \le \lvert\zeta\rvert < 1)$		$\frac{1}{s(\tau^2 s^2+2\zeta\tau s+1)}$
22. $1-e^{-\zeta t/\tau}[\cos(\sqrt{1-\zeta^2}\,t/\tau)+\frac{\zeta}{\sqrt{1-\zeta^2}}\sin(\sqrt{1-\zeta^2}\,t/\tau)]$ $(0 \le \lvert\zeta\rvert < 1)$		$\frac{1}{s(\tau^2 s^2+2\zeta\tau s+1)}$
23. $1+\frac{\tau_3-\tau_1}{\tau_1-\tau_2}e^{-t/\tau_1}+\frac{\tau_3-\tau_2}{\tau_2-\tau_1}e^{-t/\tau_2}$ $(\tau_1 \neq \tau_2)$		$\frac{\tau_3 s+1}{s(\tau_1 s+1)(\tau_2 s+1)}$
24. $\frac{df}{dt}$		$sF(s)-f(0)$
25. $\frac{d^n f}{dt^n}$		$s^nF(s)-s^{n-1}f(0)-s^{n-2}f^{(1)}(0)-\cdots-sf^{(n-2)}(0)-f^{(n-1)}(0)$
26. $f(t-t_0)S(t-t_0)$		$e^{-t_0 s}F(s)$

[a]Note that $f(t)$ and $F(s)$ are defined for $t \ge 0$ only.

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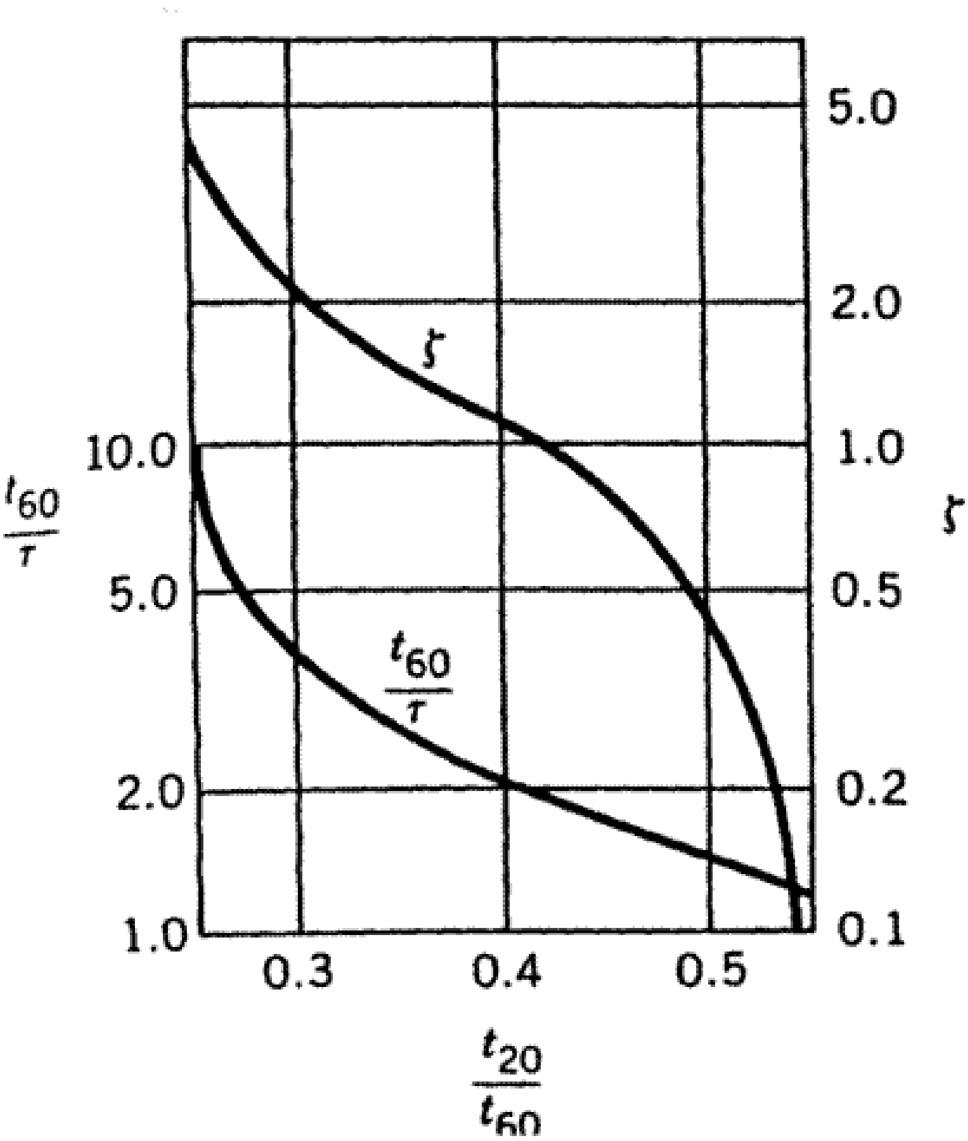

Figure: Smith's method: relationship of ζ and τ to τ_{20} and τ_{60}

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Table 1: Ziegler-Nichols closed loop tuning rule

	K_c	τ_I	τ_D
P	$0.5K_{cu}$	-	-
PI	$0.45K_{cu}$	$P_u/1.2$	-
PID	$0.6K_{cu}$	$P_u/2$	$P_u/8$

Table 2: Ziegler-Nichols open loop tuning rule

MODE	PB, %	K_c	I, time	D, time
P-only	100 RR T_d	$\frac{1}{RR \cdot T_d}$		
PI	111.1 RR T_d	$\frac{0.9}{RR \cdot T_d}$	3.33 T_d	
PID	83.3 RR T_d	$\frac{1.2}{RR \cdot T_d}$	2 T_d	0.5 T_d

Table 3: Controller Design Relation Based on the ITAE Performance Index and a First Order Plus Time Delay Model

Type of Input	Type of Controller	Mode	A	B
Disturbance	PI	P	0.859	−0.977
		I	0.674	−0.680
Disturbance	PID	P	1.357	−0.947
		I	0.842	−0.738
		D	0.381	0.995
Set point	PI	P	0.586	−0.916
		I	1.03[b]	−0.165[b]
Set point	PID	P	0.965	−0.85
		I	0.796[b]	−0.1465[b]
		D	0.308	0.929

[a] Design relation: $Y = A(\theta/\tau)^B$ where $Y = KK_c$ for the proportional mode, τ/τ_I for the integral mode, and τ_D/τ for the derivative mode.

[b] For set-point changes, the design relation for the integral mode is $\tau/\tau_I = A + B(\theta/\tau)$.

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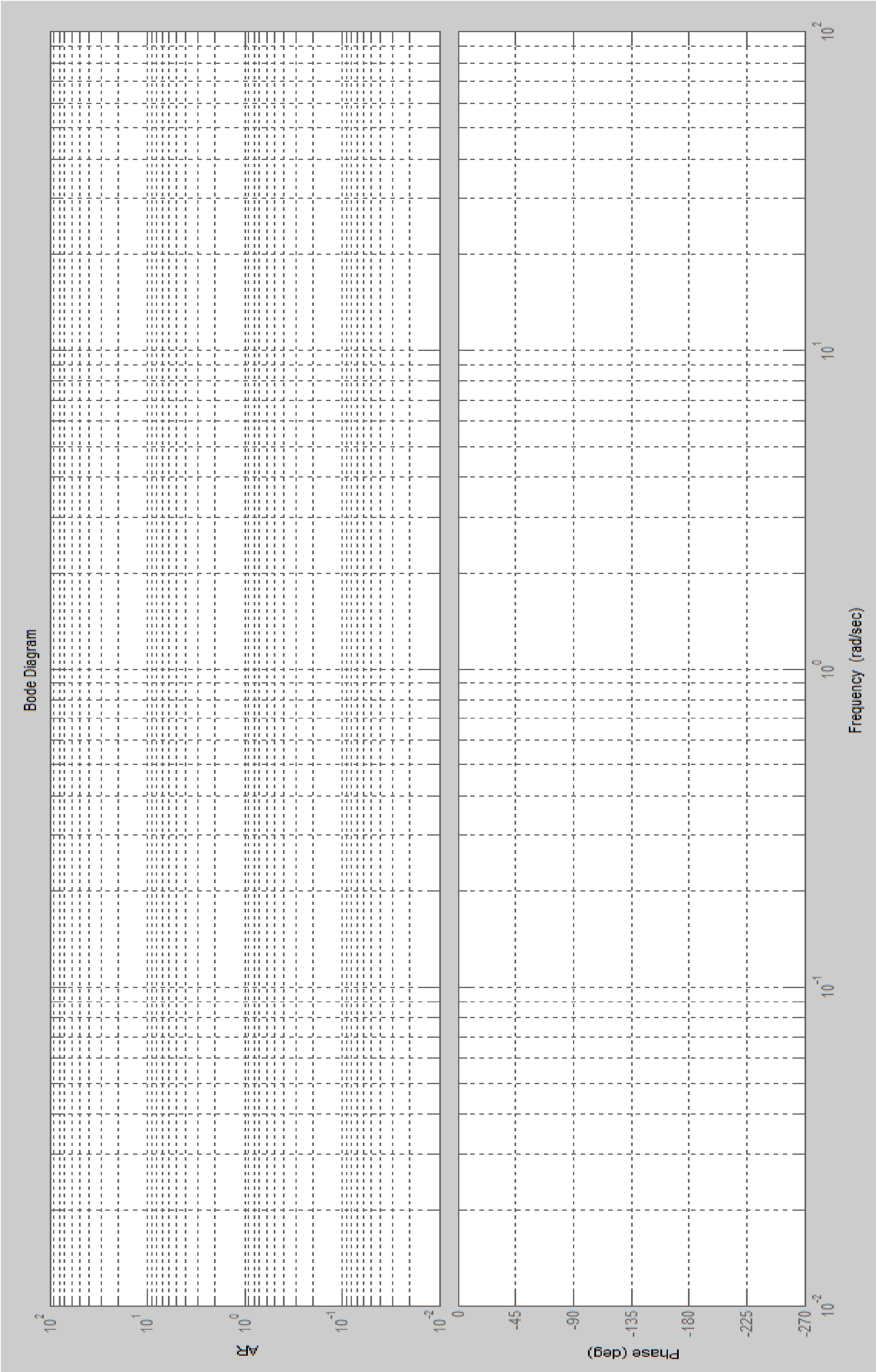
Bode Diagram
AR
Phase (deg)
Frequency (rad/sec)
0
-45
-90
-135
-180
-225
-270