UNIVERSITI SAINS MALAYSIA

First Semester Examination
2010/2011 Academic Session

November 2010

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

Duration : 3 hours
[Masa : 3 jam]

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

[Sila pastikan bahawa kertas peperiksaan ini mengandungi SEBELAS muka surat yang bercetak dan DUA 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.]

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Answer <u>ALL</u> questions.
Jawab <u>SEMUA</u> soalan.

1. [a] Briefly define the following terms:
Takrifkan secara ringkas istilah-istilah berikut:

[i] Rise Time
Masa naik

[ii] Time to First Peak
Masa untuk puncak pertama

[iii] Settling Time
Masa pengenapan

[iv] Overshoot
Terlajak

[v] Decay Ratio
Nisbah susut

[vi] Period of Oscillation
Tempoh ayunan

[3 marks/markah]

[b] Consider the temperature sensor sketched in Figure Q.1.[b]. The bulb and its surrounding thermowell are at a uniform temperature, $T_b(t)$, and the surroundings are at a uniform temperature, $T_s(t)$.

Pertimbangkan penderia suhu seperti yang dilakarkan dalam Rajah S.1[b]. Bebuli dan telaga haba sekelilingnya adalah pada suhu seragam, $T_b(t)$, dan persekitarannya adalah pada suhu seragam, $T_s(t)$.

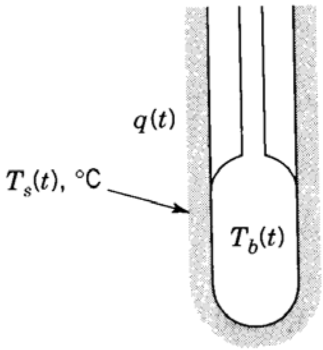

Figure Q.1.[b]: Temperature Sensor
Rajah S.1.[b]: Penderia Suhu

The exchange of heat between the surroundings and the bulb is given by:
Pertukaran haba antara persekitaran dan bebuli diberi sebagai:

$$q(t) = hA[T_s(t) - T_b(t)]$$

where
q(t) = heat transfer rate, J/s
h = film coefficient of heat transfer, J/s-m^2-°C
A = contact area between the bulb and its surroundings, m^2

di mana
q(t) = kadar pemindahan haba, J/s
h = pekali saput bagi pemindahan haba, J/s-m^2-°C
A = luas sentuhan antara bebuli dan persekitarannya, m^2

Let M, kg, be the mass of the bulb and thermowell and C_v, J/kg-°C, its heat capacity. Obtain the transfer function that describes the response of the temperature of the bulb when the surrounding temperature changes. List all assumptions and draw the block diagram for the bulb. Express the time constant and the gain in terms of the bulb parameters.

Biarkan M, kg, sebagai jisim bagi bebuli dan telaga sekelilingnya dan C_v, J/kg-°C, muatan habanya. Dapatkan rangkap pindah yang menggambarkan sambutan bagi suhu bebuli apabila suhu persekitarannya berubah. Senaraikan semua anggapan dan lukiskan gambarajah blok bagi bebuli tersebut. Ungkapkan masa malar dan gandaan dalam sebutan parameter-parameter bebuli.

[10 marks/markah]

[c] The dynamic response of a stirred-tank bioreactor can be represented by the transfer function

Sambutan dinamik bagi bioreaktor tangki teraduk boleh diwakili oleh rangkap pindah

$$\frac{C'(s)}{C'_F(s)} = \frac{4}{2s+1}$$

where C' is the exit substrate concentration, mol/L and C'_F is the feed substrate concentration, mol/L.

di mana C' merupakan kepekatan substrat yang keluar, mol/L dan C'_F merupakan kepekatan substrat yang disuap, mol/L.

[i] Derive an expression for c'(t) if c'_F (t) is a rectangular pulse with the following characteristics:
Terbitkan ungkapan bagi c'(t) jika c'_F (t) adalah denyut segi empat tepat dengan ciri-ciri berikut:

$$c_F(t) = \begin{cases} 2 & t < 0 \\ 4 & 0 \le t < 2 \\ 2 & 2 \le t < \infty \end{cases}$$

[ii] What is the maximum value of c'(t)? When does it occur? What is the final value of c'(t)?

Apakah nilai maksima bagi c'(t)? Bilakah ia berlaku? Apakah nilai akhir bagi c'(t)?

[iii] If the initial value is c(0) = 1, how long does it take for c(t) to return to a value of 1.05 after it has reached its maximum value?

Sekiranya nilai awal bagi c(0) = 1, berapa lama masa yang diperlukan bagi c(t) untuk kembali kepada nilai 1.05 selepas ia sampai kepada nilai maksimanya?

[12 marks/markah]

2. [a] The caustic concentration of the mixing tank shown in Figure Q.2.[a] is measured using a conductivity cell. The total volume of solution in the tank is constant at 7 ft^3 and the density (ρ = 70 lb/ft^3) can be considered to be independent of concentration. Let c_m denote the caustic concentration measured by the conductivity cell. The dynamic response of the conductivity cell to a step change (at t = 0) of 3 lb/ft^3 in the actual concentration (passing through the cell) is also shown in Figure Q.2.[a].

Kepekatan kaustik bagi tangki pencampur yang ditunjukkan dalam Rajah S.2.[a] diukur menggunakan sel keberaliran. Jumlah isipadu larutan di dalam tangki tersebut adalah malar pada 7 $kaki^3$ dan ketumpatannya (ρ = 70 $lb/kaki^3$) boleh dianggap tidak bergantung kepada kepekatan. Biarkan c_m sebagai kepekatan kaustik yang diukur oleh sel keberaliran. Sambutan dinamik bagi sel keberaliran dalam kepekatan sebenar (yang melepasi sel tersebut) terhadap satu perubahan langkah (pada t = 0) sebanyak 3 $lb/kaki^3$ juga ditunjukkan dalam Rajah S.2.[a].

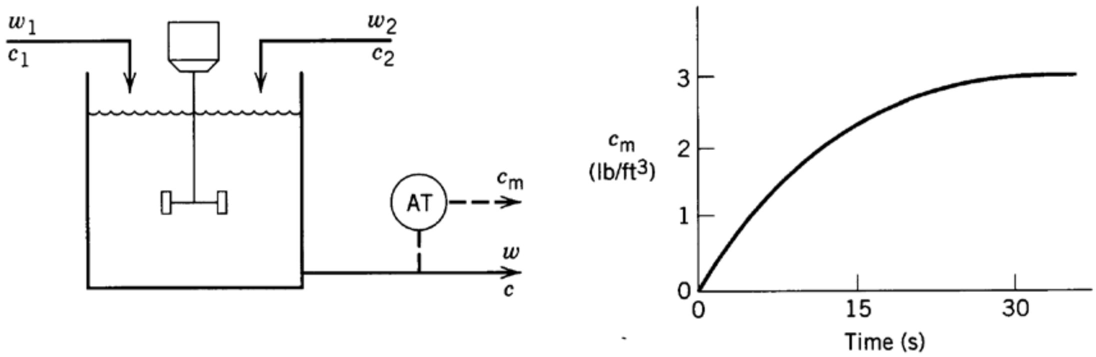

Figure Q.2.[a]: Mixing Tank
Rajah S.2.[a]: Tangki Pencampur

[i] Determine the transfer function $C_m(s)/C_1(s)$ assuming the flow rates are equal and constant: ($w_1 = w_2$ = 5 lb/min).

Tentukan rangkap pindah $C_m(s)/C_1(s)$ dengan menganggap kadar-kadar aliran adalah sama dan malar: ($w_1 = w_2$ = 5 lb/min).

[ii] Find the response for a step change in c_1 from 14 to 17 lb/ft^3.

Carikan sambutan bagi satu perubahan langkah pindah dalam c_1 dari 14 ke 17 $lb/kaki^3$.

[iii] If the transfer function $C'_m(s)/C'(s)$ were approximated by 1 (unity), what would be the step response of the system for the same input change?

Jika rangkap pindah $C'_m(s)/C'(s)$ dianggarkan bersamaan dengan 1, apakah sambutan langkah bagi sistem tersebut bagi perubahan masukan yang sama?

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[iv] By comparison of [ii] and [iii], what can you say about the dynamics of the conductivity cell? Plot both responses if necessary.

Dengan membandingkan [ii] dan [iii], apakah yang anda dapat katakan berkaitan dengan dinamik bagi sel keberaliran tersebut? Plotkan kedua-dua sambutan jika perlu.

[18 marks/markah]

[b] If the input Y_m to PI controller changes stepwise (Y_m (s) = 2/s) and the controller output changes initially as in Figure Q.2.[b], what are the values of the controller gain and integral time?

Jika masukan Y_m kepada pengawal PI berubah secara langkah (Y_m (s) = 2/s) dan keluaran pengawal berubah pada awalnya seperti dalam Rajah S.2.[b], apakah nilai-nilai gandaan pengawal dan masa kamiran?

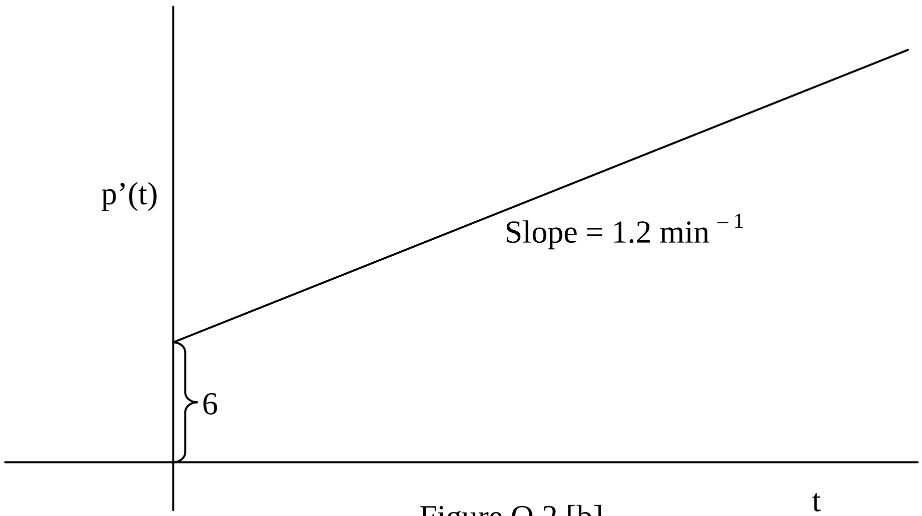

Figure Q.2.[b].
Rajah S.2.[b].

[7 marks/markah]

3. [a] A student was asked to determine the controller tuning for air pressure system as shown in Figure Q.3.[a]. Figure Q.3.[b] shows several responses using the continuous cycling method (CCM) and step test method.

Seorang pelajar telah diminta untuk menentukan penalaan pengawal bagi sistem tekanan udara seperti yang ditunjukkan dalam rajah S.3.[a]. Rajah S.3.[b] menunjukkan beberapa respon yang menggunakan kaedah kitaran berterusan (CCM) dan kaedah ujian langkah.

[i] Outline the process of obtaining the trial and error procedure of CCM method.
Rangkakan proses cubajaya kaedah CCM.

[5 marks/markah]

[ii] Obtain the PID controller setting based on this method with aid of Ziegler-Nichol closed loop tuning. You may pick any one of six cases Figure Q.3.[b] for your basis of calculation and justify.

Dapatkan set pengawal PID berdasarkan kaedah ini dengan bantuan penalaan gelung tertutup Ziegler-Nichol. Anda boleh memilih mana-mana enam kes dalam Rajah S.3.[b] bagi tujuan pengiraan dan justifikasikannya.

[5 marks/markah]

[iii] List three disadvantages of continuous cycling method.
Senaraikan tiga kekurangan kaedah kitaran berterusan.

[3 marks/markah]

[iv] Some of the disadvantages of the CCM can be avoided using either the relay auto-tuning method or the step test method. Case 7 and 8 give two different direction of step change. Comment on these cases.

Sesetengah kelemahan CCM boleh dielakkan sama ada menggunakan kaedah penalaan automatik geganti atau kaedah ujian langkah. Kes 7 dan 8 memberi dua arah berlainan bagi tukaran langkah. Komen kes-kes ini.

[2 marks/markah]

[v] Determine the PID controller setting with the assistance of Ziegler Nichol open loop tuning.
Tentukan set pengawal PID dengan bantuan penalaan gegelung terbuka Ziegler Nichol.

[7 marks/markah]

[vi] Compare the performance of both controllers setting in term of the process responses when servo control is tested in [ii] and [v].
Bandingkan prestasi set kedua-dua pengawal dari sudut sambutan proses apabila kawalan servo diuji dalam [ii] dan [v].

[3 marks/markah]

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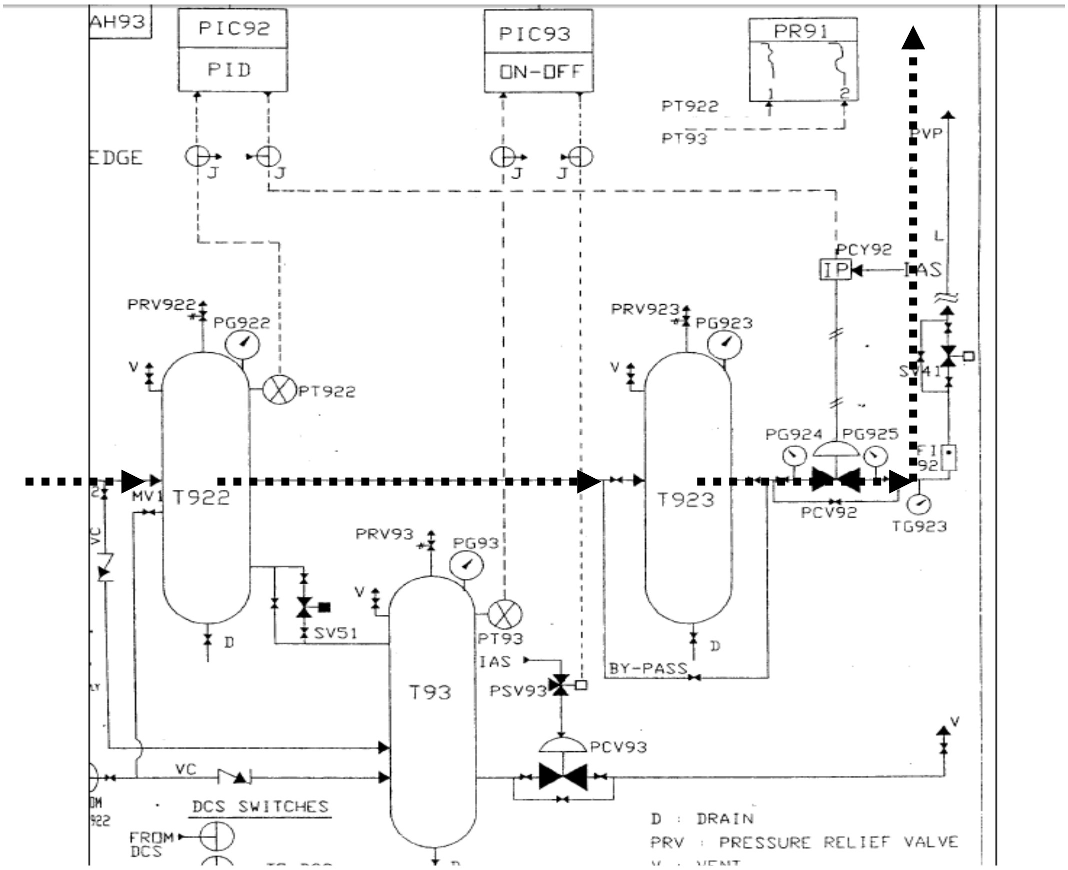


Figure Q.3.[a] Schematic PI & D of the air pressure system (▪▪▪► air flow direction)
Rajah S.3.[a] PI & D Skematik bagi sistem tekanan udara (▪▪▪► arah aliran udara)

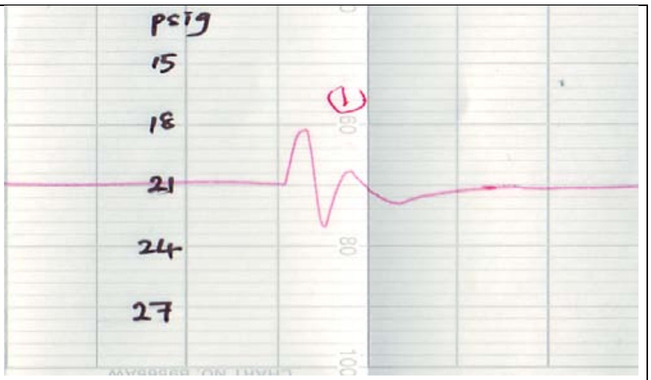
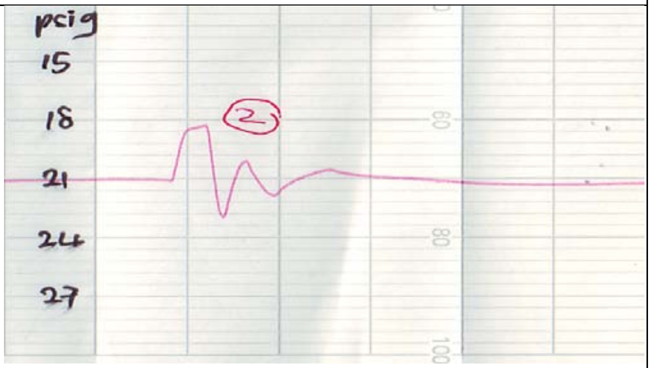
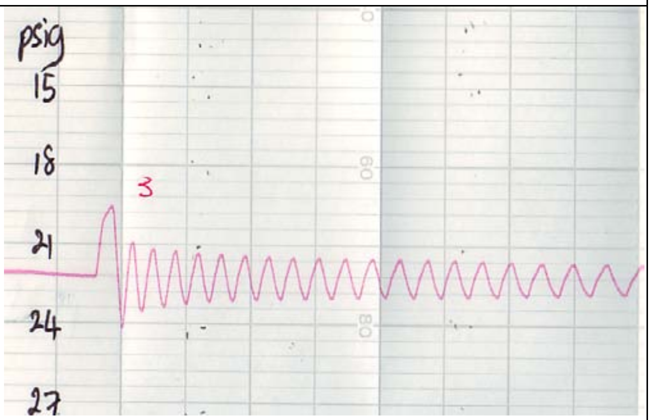
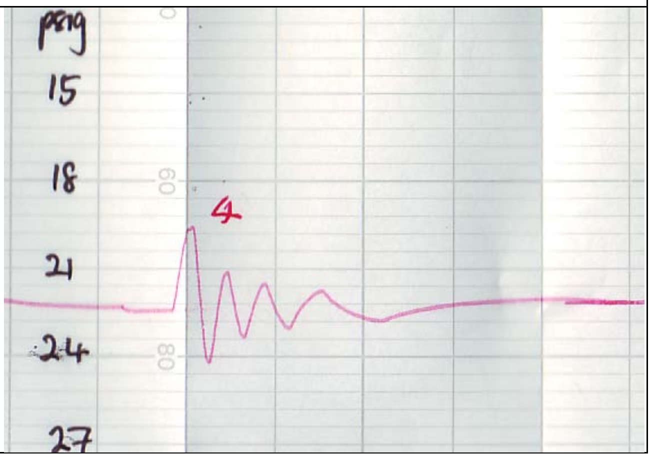
Case 1: Proportional Band = 30 Integral = infinity Derivative = Zero Manipulated Variable: Oscillation between 32 to 60% *Kes 1:* *Jalur berkadaran = 30* *Kamiran = ketakterhinggaan* *Terbitan = Sifar* *Pembolehubah olahan = Ayunan antara 32 dan 60%*	
Case 2: Proportional Band = 25 Integral = infinity Derivative = Zero Manipulated Variable: Oscillation between 30 to 63% *Kes 2:* *Jalur berkadaran = 25* *Kamiran = ketakterhinggaan* *Terbitan = Sifar* *Pembolehubah olahan = Ayunan antara 30 dan 63%*	
Case 3: Proportional Band = 15 Integral = infinity Derivative = Zero Manipulated Variable: Oscillation between 20 to 87% *Kes 3:* *Jalur berkadaran = 15* *Kamiran = ketakterhinggaan* *Terbitan = Sifar* *Pembolehubah olahan = Ayunan antara 20 dan 87%*	
Case 4: Proportional Band = 20 Integral = infinity Derivative = Zero Manipulated Variable: Oscillation between 30 to 76% *Kes 4:* *Jalur berkadaran = 20* *Kamiran = ketakterhinggaan* *Terbitan = Sifar* *Pembolehubah olahan = Ayunan antara 30 dan 76%*	

Figure Q.3.[b]: Response Curves
Rajah S.3.[b] : Lengkung Sambutan

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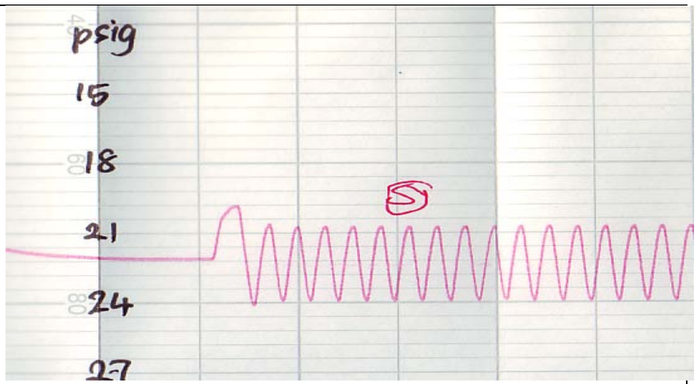
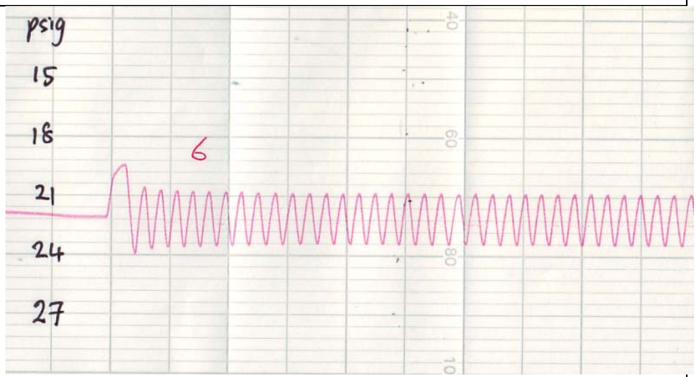
Case 5:
Proportional Band = 10
Integral = infinity
Derivative = Zero
Manipulated Variable: Oscillation between 4 to 100%

Kes 5:
Jalur berkadaran = 10
Kamiran = ketakterhinggaan
Terbitan = Sifar
Pembolehubah olahan = Ayunan antara 4 dan 100%



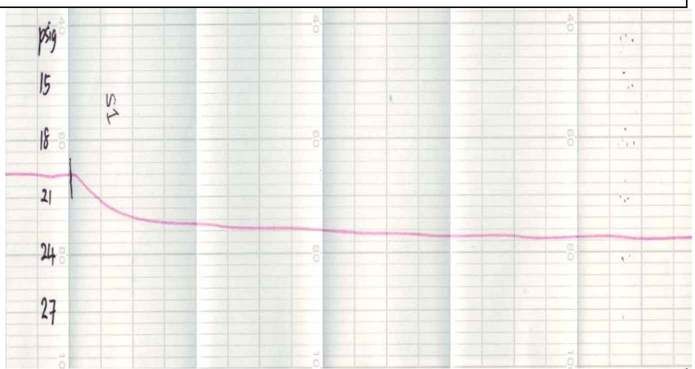
Case 6:
Proportional Band = 12
Integral = infinity
Derivative = Zero
Manipulated Variable: Oscillation between 16 to 93%

Kes 6:
Jalur berkadaran = 12
Kamiran = ketakterhinggaan
Terbitan = Sifar
Pembolehubah olahan = Ayunan antara 16 dan 93%



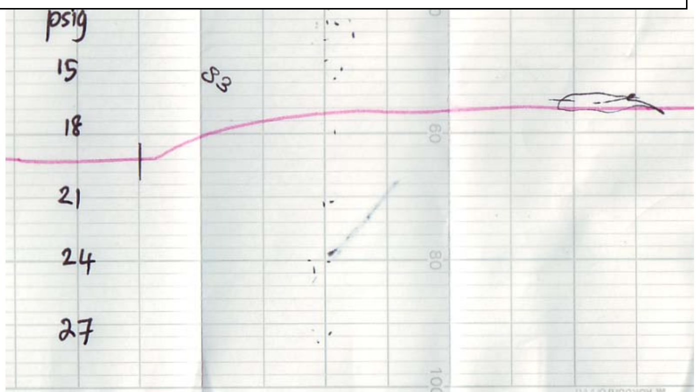
Case 7:
No controller action
The response resulted from a step change from 50 to 65% after two trial of changes from 50 to 55% and 50 to 60% consecutively

Kes 7:
Tiada tindakan pengawal
Sambutan adalah hasil daripada penukaran langkah dari 50 ke 65% selepas dua percubaan perubahan dari 50 ke 55% dan 50 ke 60% secara berturutan.



Case 8:
No controller action
The response resulted from a step change from 50 to 45%

Kes 8:
Tiada tindakan pengawal
Sambutan adalah hasil daripada penukaran langkah dari 50 ke 45%



Note: All figures are not in standard scale.
The paper speed is 2000 mm/h.
The axes: The actual distance between bolder marked axes is 10 mm.

Nota: Semua gambarajah tidak dalam skala piawai.
Kelajuan kertas graf adalah 2000 mm/jam.
Paksi-paksi: Jarak sebenar antara paksi-paksi x adalah 10 mm.

Figure Q.3.[b]…continued
Rajah S.3.[b]… sambungan

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4. Illustration of feedback control system is shown in Figure Q.4. with the associated transfer functions.

Ilustrasi sistem kawalan suapbalik adalah ditunjukkan dalam Rajah S.4. bersama dengan fungsi-fungsi pemindahan yang berkaitan.

[a] Plot a Bode diagram for the open-loop transfer function.
Plot gambarajah Bode bagi fungsi pemindahan gegelung terbuka.
[10 marks/markah]

[b] Calculate the value of K_c that provides a phase margin of 30^o.
Kirakan nilai K_c yang menghasilkan jidar fasa 30°.
[5 marks/markah]

[c] What is the gain margin when $K_c = 10$?
Apakah jidar gandaan apabila $K_c = 10$?
[10 marks/markah]

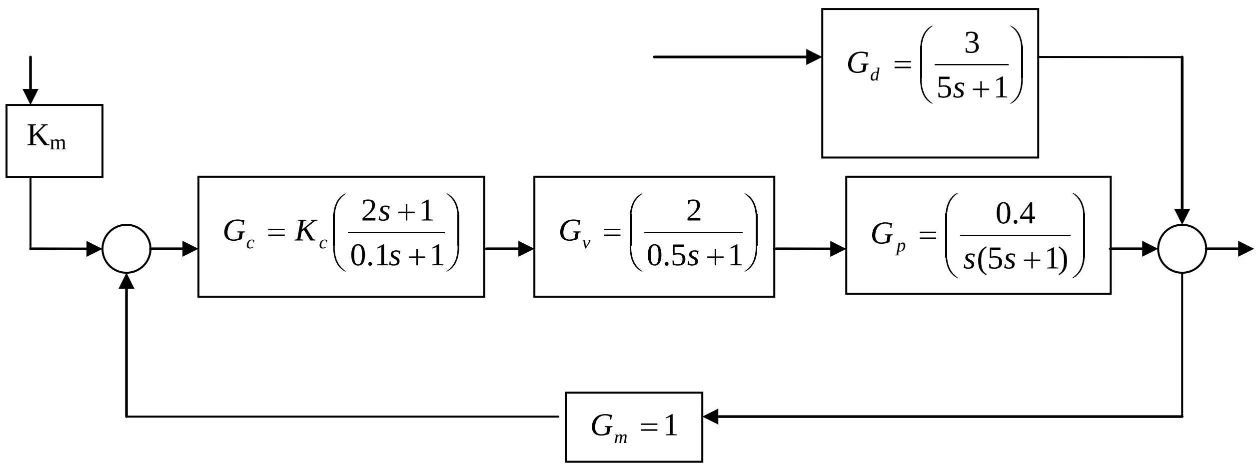

Figure Q.4.
Rajah S.4.

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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. $\frac{1}{\tau\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin(\sqrt{1-\zeta^2}\,t/\tau)$ $(0\le\|\zeta\|<1)$	$\frac{1}{\tau^2s^2+2\zeta\tau s+1}$
20. $1+\frac{1}{\tau_2-\tau_1}(\tau_1e^{-t/\tau_1}-\tau_2e^{-t/\tau_2})$ $(\tau_1\ne\tau_2)$	$\frac{1}{s(\tau_1 s+1)(\tau_2 s+1)}$
21. $1-\frac{1}{\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin[\sqrt{1-\zeta^2}\,t/\tau+\psi]$ $\psi=\tan^{-1}\frac{\sqrt{1-\zeta^2}}{\zeta}$, $(0\le\|\zeta\|<1)$	$\frac{1}{s(\tau^2s^2+2\zeta\tau s+1)}$
22. $1-e^{-\zeta t/\tau}[\cos(\sqrt{1-\zeta^2}\,t/\tau)+\frac{\zeta}{\sqrt{1-\zeta^2}}\sin(\sqrt{1-\zeta^2}\,t/\tau)]$ $(0\le\|\zeta\|<1)$	$\frac{1}{s(\tau^2s^2+2\zeta\tau s+1)}$
23. $1+\frac{\tau_3-\tau_1}{\tau_1-\tau_2}e^{-t/\tau_1}+\frac{\tau_3-\tau_2}{\tau_2-\tau_1}e^{-t/\tau_2}$ $(\tau_1\ne\tau_2)$	$\frac{\tau_3 s+1}{s(\tau_1 s+1)(\tau_2 s+1)}$
24. $\frac{df}{dt}$	$sF(s)-f(0)$
25. $\frac{d^nf}{dt^n}$	$s^nF(s)-s^{n-1}f(0)-s^{n-2}f^{(1)}(0)-\cdots-sf^{(n-2)}(0)-f^{(n-1)}(0)$
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.

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**