UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2008/2009 Academic Session
Peperiksaan Semester Kedua
Sidang Akademik 2008/2009

April/Mei 2009

ESA 251/3 – Control System Theory
Teori Sistem Kawalan

Duration : 3 hours
[Masa : 3 jam]

INSTRUCTION TO CANDIDATES
ARAHAN KEPADA CALON

Please ensure that this paper contains **TEN (10)** printed pages and **FIVE (5)** questions before you begin examination.
*Sila pastikan bahawa kertas soalan ini mengandungi **SEPULUH (10)** mukasurat bercetak dan **LIMA (5)** soalan sebelum anda memulakan peperiksaan.*

Answer any **TWO (2)** questions in Part A and **ALL** questions in Part B.

*Jawab mana-mana **DUA (2)** soalan pada Bahagian A dan **SEMUA** soalan pada Bahagian B.*

Student may answer the questions either in English or Bahasa Malaysia.
Pelajar boleh menjawab soalan dalam Bahasa Inggeris atau Bahasa Malaysia.

APPENDIX/*LAMPIRAN*

1.	Appendix A/*Lampiran A*	(1 page/*mukasurat*)
2.	Appendix B/*Lampiran B*	(1 page/*mukasurat*)

Each questions must begin from a new page.
Setiap soalan mestilah dimulakan pada mukasurat yang baru.

PART A/*BAHAGIAN A*

Answer TWO (2) questions only/*Jawab DUA (2) soalan sahaja.*

1. (a) **Figure 1(a)** shows a ground receiving station for tracking a weather satellite. The figure shows the control system used for positioning the antenna dish along the azimuth axis. An optical encoder measures the actual azimuth angle of the antenna dish and sends the measured signal to the tracking receiver where it is compared with the desired azimuth angle. The angular difference is amplified by a power amplifier which produces the control action to the motor so as to turn the antenna dish to the desired angle.

__Gambarajah 1(a)__ menunjukkan stesyen penerima bumi untuk menjejak satelit cuaca. Rajah tersebut menunjukkan sistem kawalan yang digunakan untuk menetapkan kedudukan piring antena pada paksi azimut. Satu pengekod optik mengukur sudut azimut sebenar dan menghantar isyarat yang diukur ke penerima jejakan di mana isyarat ini dibandingkan dengan sudut azimut yang diingini. Perbezaan sudut di perkuatkan oleh penguatkuasa yang menghasilkan tindakan kawalan kepada motor supaya memutarkan piring antena ke sudut yang dikehendaki.

(i) Draw a block diagram of the system.

Lukiskan gambarajah blok bagi sistem.

(3 marks/*markah*)

(ii) Identify all the components of the block diagram.

Kenalpasti semua komponen gambarajah blok.

(2 marks/*markah*)

(iii) State the type of the system.

Nyatakan jenis sistem.

(2 marks/*markah*)

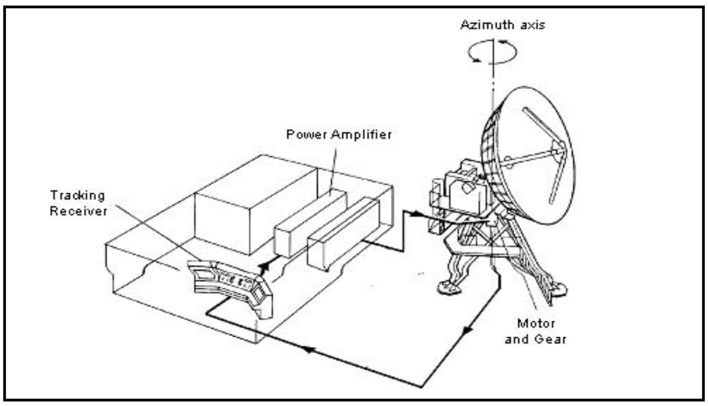

Figure 1(a)/ *Gambarajah 1(a)*

(b) **Figure 1(b)** shows a model for the wheel and its suspensions system for a car. Based on the model.

Gambarajah 1(b) *menunjukkan model sistem tayar dan ampaian bagi sebuah kereta. Merujuk kepada model tersebut.*

(i) Draw a free body diagram to represent the system.

Lukiskan gambarajah badan bebas untuk mewakili sistem.

(6 marks/*markah*)

(ii) Find the transfer function relating the output $X_2(s)$ to the input $F(s)$.

Dapatkan rangkap pindah menghubungkan keluaran $X_2(s)$ dengan masukan $F(s)$.

(6 marks/*markah*)

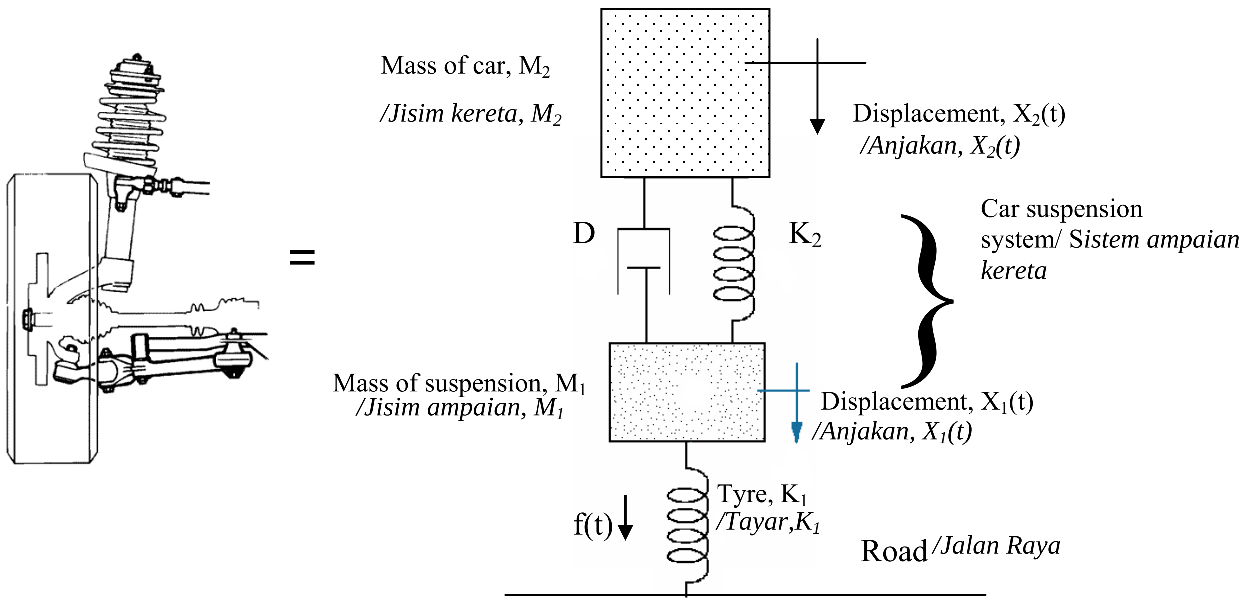

Figure 1(b)/*Gambarajah 1(b)*

(c) Find the transfer function relating the output T(s) to the input θ2(s) for the mechanical bearing system in **Figure 1(c).**

Dapatkan rangkap pindah yang menghubungkan keluaran Tm(s) terhadap masukan θm(s) bagi sistem mekanikal dalam ***Gambarajah 1(c).***

(6 marks/*markah*)

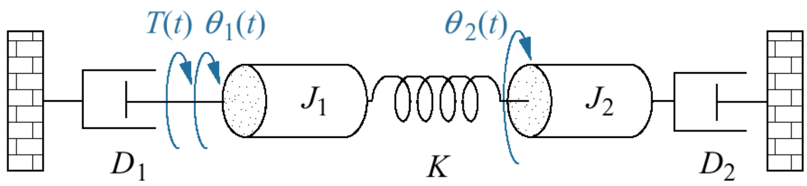

Figure 1(c)/*Gambarajah 1(c)*

2. (a) Reduce the system described by **Figure 2(a)** to a single block and determine the transfer function of the block.

*Ringkaskan sistem bagi **Gambarajah 2(a)** kepada blok sistem paling ringkas dan dapatkan rangkap pindah bagi blok sistem tersebut.*

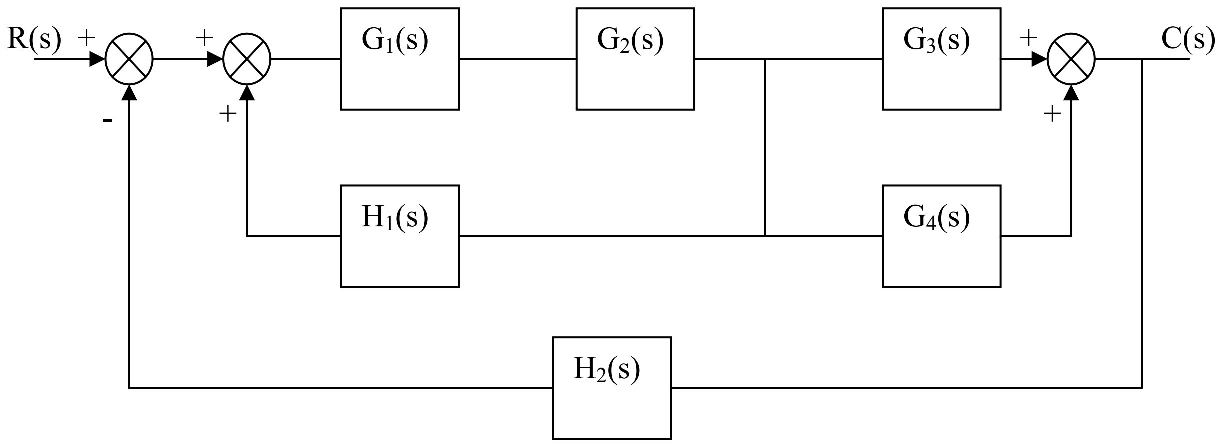

Figure 2(a)/*Gambarajah 2(a)*

(12 marks/*markah*)

(b) Find the transfer function for the system shown in **Figure 2(b)** by Mason gain Formula.

*Dapatkan rangkap pindah bagi sistem dalam **Gambarajah 2(b)** dengan menggunakan formula Mason.*

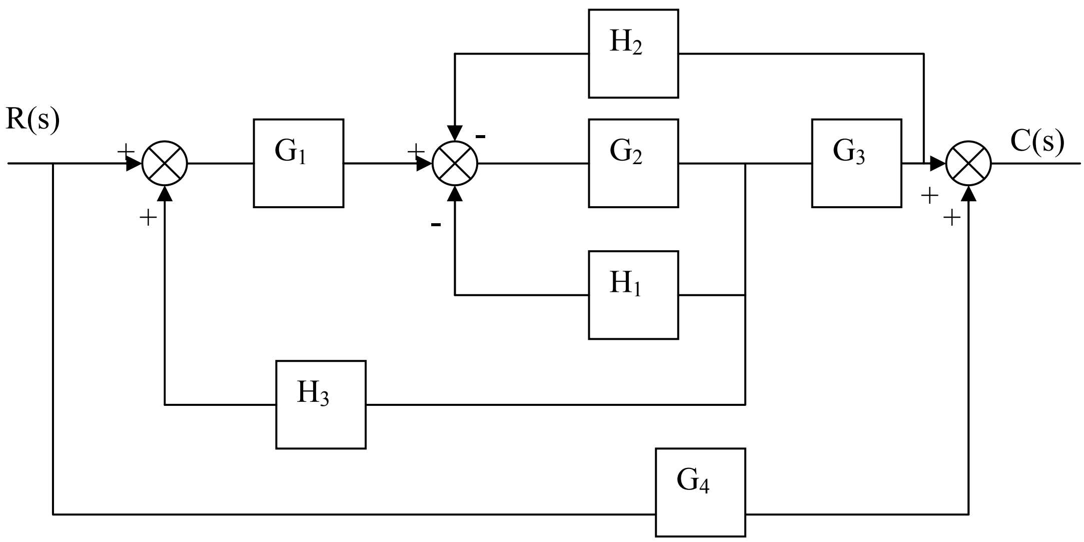

Figure 2(b)/*Gambarajah 2(b)*

(13 marks/*markah*)

3. **Figure 3** represents the block diagram of a process control system with gain K_P and K_T.

Gambarajah 3 *mewakili sistem kawalan proses dengan gandaan* K_P *dan* K_T.

(a) Find the system closed loop transfer function.

Dapatkan rangkap pindah gelung tutup sistem.

(5 marks/*markah*)

(b) Given that

Gain, $K_P = 40$

Steady-state error for a unit ramp input, $e_{ss} = 0.08$

Diberi

gandaan, $K_P = 40$

ralat keadaan mantap terhadap masukan unit tanjakan, $e_{ss} = 0.08$

Determine the required value of:

Dapatkan nilai:

(i) K_T

(2 marks/*markah*)

(ii) undamped natural frequency, ω_n.

frekuensi tabii tanpa redam, ω_n.

(2 marks/*markah*)

(iii) damping ratio, ζ.

nisbah redaman, ζ.

(2 marks/*markah*)

Using the values of gain K_P and K_T obtained above, calculate the values of:

Menggunakan nilai K_P *dan* K_T *diperolehi di atas, kirakan nilai:*

(iv) percentage of maximum overshoot, $\% c_p$.

peratus lajakan maksimum, $\% c_p$.

(2 marks/*markah*)

(v) settling time, t_s (2% criteria)

masa pengenapan, t_s *(2% kriteria)*

(2 marks/*markah*)

(c) If a unit step input is applied to the system with gain $K_P = 9$ and $K_T = 2$,

Sekiranya sistem dikenakan masukan unit langkah dengan nilai gandaan K_P *= 9 dan* K_T *= 2,*

(i) find the output system response and sketch the response.

dapatkan dan lakarkan sambutan keluaran sistem.

(5 marks/*markah*)

(ii) determine whether the following specification can be met.

peak time, $t_p < 0.5$ seconds.
Show your workings.

tentukan samada spesifikasi berikut boleh dipenuhi atau tidak.

masa puncak, t_p *< 0.5 saat.*
Tunjukkan jalankerja anda.

(5 marks/*markah*)

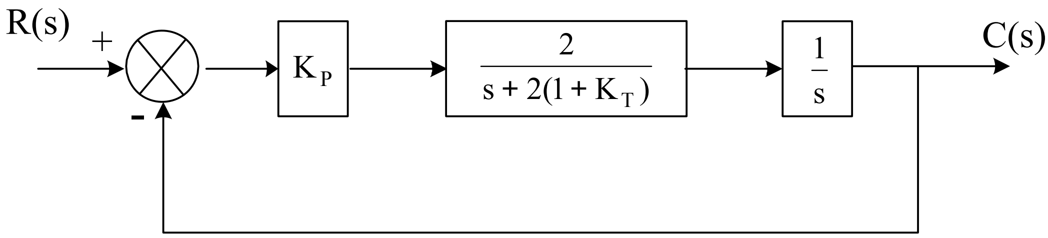

Figure 3/*Gambarajah 3*

PART B/*BAHAGIAN B*

Answer ALL questions/*Jawab SEMUA soalan.*

4. The open-loop transfer function of a feedback control system is given as follows:

Rangkap pindah gelung buka satu sistem kawalan suapbalik diberi seperti berikut:

$$G(s)H(s) = \frac{K(s+4)}{(s-1)(s^2+4s+8)}$$

(a) Using the rules for plotting the root locus, sketch the root locus plot on the graph paper provided, as K varies from 0 to infinite.
(For the real axis, use a scale of 1 cm = 0.5 with a maximum value of 4 and a minimum value of –6. For the imaginary axis, use a scale of 1 cm = 0.5 with a maximum value of j7 and a minimum value of –j7).

Dengan menggunakan peraturan binaan londar punca, lakarkan plot londar punca sistem di atas kertas graf yang disediakan, untuk gandaan K yang berubah dari sifar ke infiniti.
(Untuk paksi nyata, gunakan skala 1 cm = 0.5 dengan nilai maksimum 4 dan nilai minimum -6. Untuk paksi khayal, gunakan skala 1 cm = 0.5 dengan nilai maksimum j7 dan nilai minimum -j7).

(15 marks/*markah*)

(b) Determine and show on the root locus plot,

Dapatkan dan tunjukkan di atas plot,

(i) the angle of departure from the complex poles.

sudut berlepas londar punca dari kutub kompleks.

(3 marks/*markah*)

(ii) the point of intersection on the imaginary axis and the value of gain K.

titik persilangan londar punca di paksi khayal serta nilai gandaan K.

(3 marks/*markah*)

(c) Determine the range of gain K for the closed-loop system to be stable.

Tentukan julat gandaan K supaya sistem gelung tutup adalah stabil.

(4 marks/*markah*)

5. The open - loop transfer function of a certain unity feedback system is,

$$G(s) = \frac{K}{S(S+2)(S+20)}$$

Rangkap pindah gelung-buka untuk sistem suapbalik uniti ialah,

$$G(s) = \frac{K}{S(S+2)(S+20)}$$

Please construct Bode Plots.

Sila bina Plot Bode.

(9 marks/*markah*)

From the Bode Plots, find:-

Daripada Bode Plot, carikan:-

(a) gain margin and phase margin if K=40.

jidar gandaan dan jidar fasa jika K=40.

(4 marks/*markah*)

(b) limiting value of K for system to be stable.

nilai penghad K supaya sistem stabil.

(4 marks/*markah*)

(c) value of K for gain margin to be 10 dB.

nilai K untuk jidar fasa 10 dB.

(4 marks/*markah*)

(d) value of K for phase margin to be 50^0

nilai K untuk jidar fasa 50^0.

(4 marks/*markah*)

- oooOooo -

APPENDIX A/ *LAMPIRAN A*

Laplace transform	*Time function*	*Description of time function*
1		A unit impulse
$\frac{1}{s}$		A unit step function
$\frac{e^{-st}}{s}$		A delayed unit step function
$\frac{1-e^{-st}}{s}$		A rectangular pulse of duratic
$\frac{1}{s^2}$	t	A unit slope ramp function
$\frac{1}{s^3}$	$\frac{t^2}{2}$	
$\frac{1}{s+a}$	e^{-at}	Exponential decay
$\frac{1}{(s+a)^2}$	te^{-at}	
$\frac{2}{(s+a)^3}$	t^2e^{-at}	
$\frac{a}{s(s+a)}$	$1-e^{-at}$	Exponential growth
$\frac{a}{s^2(s+a)}$	$t-\frac{(1-e^{-at})}{a}$	
$\frac{a^2}{s(s+a)^2}$	$1-e^{-at}-ate^{-at}$	
$\frac{s}{(s+a)^2}$	$(1-at)e^{-at}$	
$\frac{1}{(s+a)(s+b)}$	$\frac{e^{-at}-e^{-bt}}{b-a}$	
$\frac{ab}{s(s+a)(s+b)}$	$1-\frac{b}{b-a}e^{-at}+\frac{a}{b-a}e^{-bt}$	
$\frac{1}{(s+a)(s+b)(s+c)}$	$\frac{e^{-at}}{(b-a)(c-a)}+\frac{e^{-bt}}{(c-a)(a-b)}+\frac{e^{-ct}}{(a-c)(b-c)}$	
$\frac{\omega}{s^2+\omega^2}$	$\sin \omega t$	Sine wave
$\frac{s}{s^2+\omega^2}$	$\cos \omega t$	Cosine wave
$\frac{\omega}{(s+a)^2+\omega^2}$	$e^{-at}\sin \omega t$	Damped sine wave
$\frac{s+a}{(s+a)^2+\omega^2}$	$e^{-at}\cos \omega t$	Damped cosine wave
$\frac{\omega^2}{s(s^2+\omega^2)}$	$1-\cos \omega t$	
$\frac{\omega^2}{s^2+2\zeta\omega s+\omega^2}$	$\frac{\omega}{\sqrt{(1-\zeta^2)}}e^{-\zeta\omega t}\sin[\omega\sqrt{(1-\zeta^2)}t]$	
$\frac{\omega^2}{s(s^2+2\zeta\omega s+\omega^2)}$ with $\zeta < 1$	$1-\frac{1}{\sqrt{(1-\zeta^2)}}e^{-\zeta\omega t}\sin[\omega\sqrt{(1-\zeta^2)}t+\phi]$ with $\zeta = \cos\phi$	

APPENDIX B/ *LAMPIRAN B*

SECOND ORDER TIME DOMAIN SPECIFICATION
(SPESIFIKASI DOMAIN MASA SISTEM TERTIB KEDUA)

% Overshoot, $\%C_P = 100e^{-\left[\frac{\zeta\pi}{\sqrt{1-\zeta^2}}\right]}$
(%Lanjakan Maksimum)

Peak Time, *Masa puncak,* $t_p = \dfrac{\pi}{\omega_n\sqrt{1-\zeta^2}}$

Rise time, *Masa menaik*, $t_r = \dfrac{\pi - \cos^{-1}\zeta}{\omega_n\sqrt{1-\zeta^2}}$

Settling time, *Masa pengenapan*, $t_s = \dfrac{4}{\zeta\omega_n}$ (for 2% criteria/*kriteria 2%*)

Error Steady State, *Ralat keadaan mantap*, $e_{ss} = \lim_{s\to 0} \dfrac{sR(s)}{1 + G(s)H(s)}$