First Semester Examination
2022/2023 Academic Session

February 2023

EEE350 – Control Systems
(Sistem Kawalan)

Duration : 3 hours
(Masa : 3 jam)

Please check that this examination paper consists of **EIGHT (8)** pages of printed material including appendix before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi **LAPAN (8)** muka surat yang bercetak termasuk lampiran sebelum anda memulakan peperiksaan ini.]*

Instructions : This paper consists of **THREE (3)** questions. Answer **ALL** questions.

*[**Arahan** : Kertas ini mengandungi **TIGA (3)** soalan. Jawab **SEMUA** soalan.]*

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

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

1. a) A system is presented by the following differential equations. By assuming zero initial conditions, deduce $x(t)$. Identify its forced and natural responses.

Suatu sistem dipersembahkan oleh persamaan kebezaan berikut. Dengan mengandaikan bahawa keadaan awalan adalah sifar, dapatkan $x(t)$. Kenalpasti sambutan paksaan dan asli sistem tersebut.

$$\frac{d^2x}{dt^2}+8\frac{dx}{dt}+25x=10u(t)$$

(40 marks/*markah*)

b) Find the transfer function, $G(s)=X_2(s)/F(s)$ for the mass, spring and damper system shown in Figure 1. Given $f_{v1}=f_{v2}=f_{v3}=f_{v4}=4\ \text{Ns/m}$; $M_1=M_2=4\ \text{kg}$; $K=5\ \text{N/m}$.

Cari fungsi pindah, $G(s)=X_2(s)/F(s)$ bagi sistem jisim, spring dan peredam seperti yang ditunjukkan dalam Rajah 1. Diberi $f_{v1}=f_{v2}=f_{v3}=f_{v4}=4\ Ns/m$; $M_1=M_2=4\ kg$; $K=5\ N/m$.

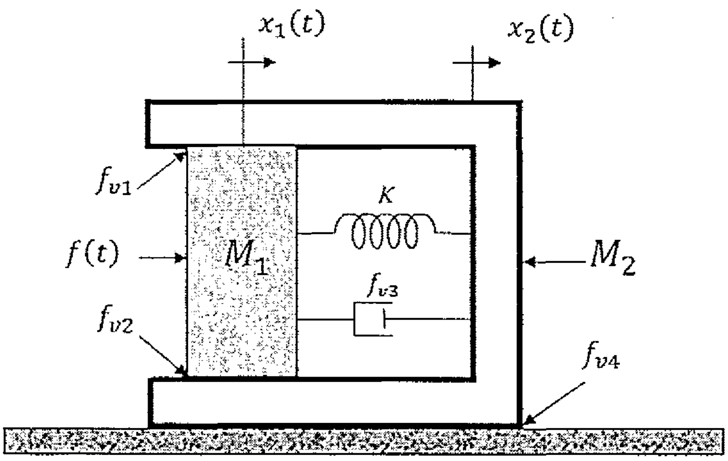

Figure 1
Rajah 1

(40 marks/*markah*)

c) A second order system has a damping ratio of 0.5, a natural frequency of 100 rad/s, and a dc gain of 1. Determine the response of the system to a unit step input.

Satu sistem tertib kedua mempunyai nisbah redaman 0.5, frekuensi asli 100 rad/s dan gandaan dc 1. Tentukan sambutan sistem tersebut terhadap masukan unit langkah.

(20 marks/*markah*)

2. A closed-loop system subject to reference input, r, and a step input disturbance, d_i is shown in Figure 2. The open-loop system and the controller are given by $P(s)$ and $C(s)$ respectively.

Sebuah sistem gelung tertutup dengan masukan rujukan, r dan gangguan langkah masukan, d_i, ditunjukkan di dalam Rajah 2. Sistem gelung terbuka dan pengawal masing-masing diberikan sebagai $P(s)$ dan $C(s)$.

$$P(s) = \frac{1}{s(s+5)}$$

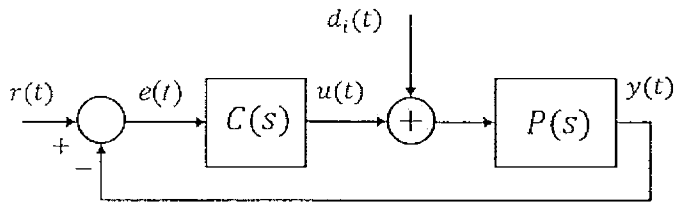

Figure 2: Closed-loop system with an input disturbance
Rajah 2: Sistem gelung tertutup dengan gangguan masukan

a) Assume $r(t)$ is a ramp input, and $C(s) = k_p$ where k_p is a positive constant. Find suitable values of k_p such that the steady-state error due to a ramp input is less than 10%. Assume there is no input disturbance in this case.

Andaikan $r(t)$ ialah masukan tanjakan, dan $C(s) = k_p$ di mana k_p ialah pemalar positif. Carikan nilai-nilai yang sesuai untuk k_p supaya ralat keadaan mantap disebabkan masukan tanjakan adalah kurang daripada 10%. Andaikan tiada gangguan masukan bagi kes ini.

(40 marks/*markah*)

b) Assume $r(t)$ is a unit step input, and $C(s) = k_p$ where k_p is a positive constant. Evaluate the range of k_p that can ensure the step response of the closed-loop system satisfies the following specifications:

Andaikan $r(t)$ ialah satu unit langkah masukan, dan $C(s) = k_p$ di mana k_p ialah pemalar positif. Nilaikan julat k_p yang dapat memastikan sambutan langkah sistem gelung tertutup tersebut menepati spesifikasi-spesifikasi di bawah:

i. The magnitude of the steady-state error with respect to a step input disturbance is less than 10%.

Magnitud ralat keadaan mantap disebabkan oleh gangguan langkah masukan kurang daripada 10%.

ii. The damping ratio, ζ, for the closed-loop system is greater than 0.7.

Nisbah redaman, ζ, untuk sistem gelung tertutup tersebut lebih daripada 0.7.

(60 marks/*markah*)

3. Consider the plant in a feedback loop with a gain K > 0.

Pertimbangkan satu loji di dalam gelung suapbalik dengan gandaan K > 0.

$$P(s) = \frac{s-2}{(s+3)(s^2+2s+17)}$$

a) Sketch the root locus.

Lakarkan londar punca.

(10 marks/*markah*)

b) By applying Routh's criterion to the system, find the range of K > 0 such that the system is asymptotically stable.

Dengan menggunakan kriteria Routh kepada system tersebut, tentukan julat K > 0 agar sistem adalah stabil secara asimtot.

(20 marks/*markah*)

c) Sketch the approximate Bode plot for the plant, *P(s)*.

Lakar anggaran plot Bode kepada loji, P(s) tersebut.

(25 marks/*markah*)

...5/-

d) Sketch the Nyquist plot for the plant, *P(s)*. (Make sure to calculate the intersections with the axes and to clearly indicate the angle of arrival for $\omega \to \infty$)

Lakar plot Nyquist kepada loji, P(s). (Pastikan anda mengira rentasan dengan paksi-paksi dan menunjukkan dengan jelas sudut ketibaan untuk $\omega \to \infty$*)*

(25 marks/*markah*)

e) Add the phase-lead compensator

Tambah pemampas mendulu fasa

$$C(s) = \frac{s+6}{s+20}$$

to the feedback system. Find the root locus.

kepada sistem suapbalik. Tentukan londar punca.

(20 marks/*markah*)

APPENDIX
LAMPIRAN

Laplace Transform Table

Item no.	f(t)	F(s)
1.	$\delta(t)$	1
2.	$u(t)$	$\frac{1}{s}$
3.	$tu(t)$	$\frac{1}{s^2}$
4.	$t^n u(t)$	$\frac{n!}{s^{n+1}}$
5.	$e^{-at}u(t)$	$\frac{1}{s+a}$
6.	$\sin \omega t u(t)$	$\frac{\omega}{s^2+\omega^2}$
7.	$\cos \omega t u(t)$	$\frac{s}{s^2+\omega^2}$

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Laplace Transfrom Theorems

Item no.	Theorem	Name
1.	$\mathcal{L}[f(t)] = F(s) = \int_{0-}^{\infty} f(t)e^{-st}dt$	Definition
2.	$\mathcal{L}[kf(t)] = kF(s)$	Linearity theorem
3.	$\mathcal{L}[f_1(t) + f_2(t)] = F_1(s) + F_2(s)$	Linearity theorem
4.	$\mathcal{L}[e^{-at}f(t)] = F(s+a)$	Frequency shift theorem
5.	$\mathcal{L}[f(t-T)] = e^{-sT}F(s)$	Time shift theorem
6.	$\mathcal{L}[f(at)] = \frac{1}{a}F\left(\frac{s}{a}\right)$	Scaling theorem
7.	$\mathcal{L}\left[\frac{df}{dt}\right] = sF(s) - f(0-)$	Differentiation theorem
8.	$\mathcal{L}\left[\frac{d^2f}{dt^2}\right] = s^2F(s) - sf(0-) - \dot{f}(0-)$	Differentiation theorem
9.	$\mathcal{L}\left[\frac{d^nf}{dt^n}\right] = s^nF(s) - \sum_{k=1}^{n} s^{n-k}f^{k-1}(0-)$	Differentiation theorem
10.	$\mathcal{L}\left[\int_{0-}^{t} f(\tau)\,d\tau\right] = \frac{F(s)}{s}$	Integration theorem
11.	$f(\infty) = \lim_{s \to 0} sF(s)$	Final value theorem[1]
12.	$f(0+) = \lim_{s \to \infty} sF(s)$	Initial value theorem[2]

[1] For this theorem to yield correct finite results, all roots of the denominator of $F(s)$ must have negative real parts and no more than one can be at the origin.
[2] For this theorem to be valid, $f(t)$ must be continuous or have a step discontinuity at $t = 0$ (i.e., no impulses or their derivatives at $t = 0$).

APPENDIX
LAMPIRAN

Question	Course Outcome (CO)	Programme Outcome (PO)
1	1	PO2
2	2	PO4
3	3	PO4

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