UNIVERSITI SAINS MALAYSIA

First Semester Examination
2016/2017 Academic Session

December 2016 / January 2017

EEE 350/3 – CONTROL SYSTEMS
[SISTEM KAWALAN]

Duration : 3 hours
[Masa : 3 jam]

Please check that this examinantion paper consists of **FIFTHTEEN (15)** pages of printed material and **ONE (1)** page of Appendix before you begin the examination. English version from page **TWO (2)** to page **EIGHT (8)** and Malay version from page **NINE (9)** to page **FIFTHTEEN (15)**.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi ***LIMA BELAS (15)*** *muka surat beserta* ***SATU (1)*** *mukasurat lampiran bercetak sebelum anda memulakan peperiksaan ini. Versi Bahasa Inggeris daripada muka surat* ***DUA (2)*** *sehingga muka surat* ***LAPAN (8)*** *dan versi Bahasa Melayu daripada muka surat* ***SEMBILAN (9)*** *sehingga muka surat* ***LIMA BELAS (15)****.]*

Instructions: This question paper consists of **SIX (6)** questions. Answer **FIVE (5)** questions. All questions carry the same marks.

[Arahan: *Kertas soalan ini mengandungi* ***ENAM (6)*** *soalan. Jawab* ***LIMA (5)*** *soalan. Semua soalan membawa jumlah markah yang sama]*

Answer to any question must start on a new page.
[Mulakan jawapan anda untuk setiap soalan pada muka surat yang baharu].

"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].

ENGLISH VERSION :-

1. (a) Figure 1(a) shows an operational amplifier circuit which serves as a controller/filter where V_{in} is the input and V_o is the output. Via Kirchoff's law, we have

$$i_{a1}(t) + i_{a2}(t) = 0$$
$$i_{b1}(t) = i_{b2}(t)$$

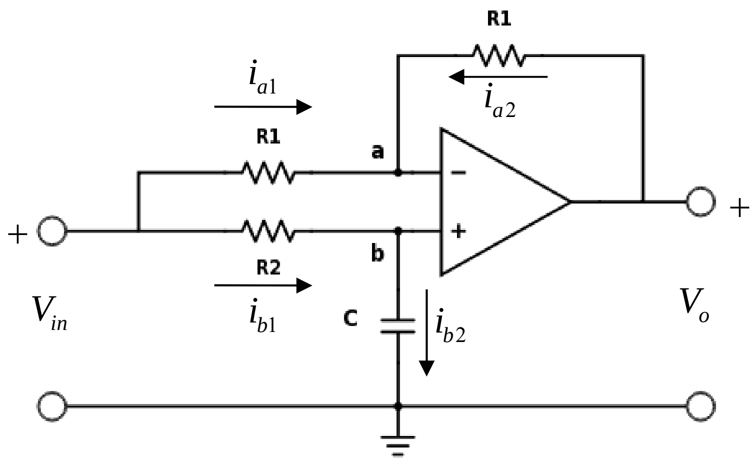

Figure.1(a) : Operational amplifier circuit.

Assuming an ideal op-amp (nodes *a* and *b* are connected), find the transfer function between the input and the output in terms of R_1, R_2, and C.

(35 marks)

(b) Determine the poles and zeros of the transfer function obtained in part (a).

(10 marks)

(c) Let $R_2C = 2,$ find $V_o(t)$ when the input $V_{in}(t) = 2,\ t \geq 0.$

(20 marks)

(d) From your answer in (c), sketch the corresponding time response.

(10 marks)

(e) Now let $V_{in}(t) = t,\ t \geq 0,$ find $V_o(t)$.

(25 marks)

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2. The dynamics of a high speed train is represented by the transfer function:

$$G(s) = \frac{15}{(s+5)(s+7)}$$

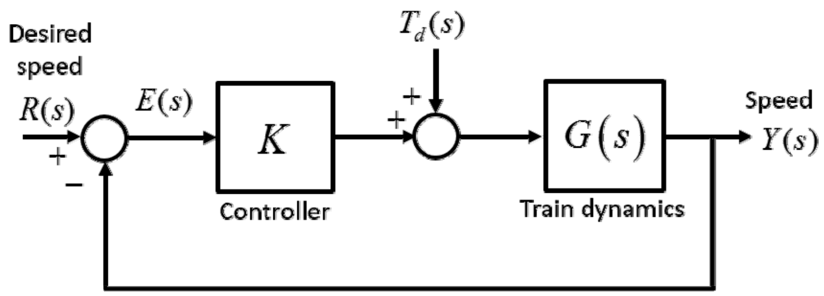

Figure 2 : Control system of a high speed train

The corresponding closed-loop system with controller K and input disturbance $T_d(s)$ is shown as in Figure 2.

(a) If K is a positive gain, determine whether the closed-loop system is stable when subject to both step input $R(s)$ and step input disturbance $T_d(s)$. (Hint: you may need to find the transfer functions from $R(s)$ to $Y(s)$ and $T_d(s)$ to $Y(s)$ first)

(40 marks)

(b) In terms of K, what is the steady-state error with respect to a unit step input $R(s)$?

(15 marks)

(c) Supposed that the design specification is such that

(i) The steady-state error due to a unit step input $R(s)$ is less than 20%.

(ii) The steady-state error due to a unit step input disturbance $T_d(s)$ is less than 10% (i.e $|y/T_d|_{\max} < 0.1.$)

(iii) The maximum peak overshoot with respect to the step input is 22%. Using the approximations

$$M_p = e^{-\frac{\zeta\pi}{\sqrt{1-\zeta^2}}}$$

where is the peak overshoot and ζ is the damping ratio, find the suitable range of K such that all the specifications can be satisfied at once.

(45 marks)

3. A closed-loop system is shown in Figure 3.1 where $C(s)$ is the controller and $G(s)$ is the plant.

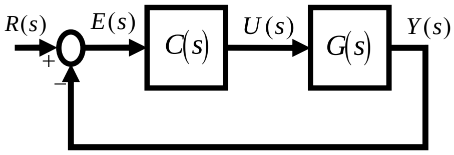

Figure 3.1: Closed-loop system

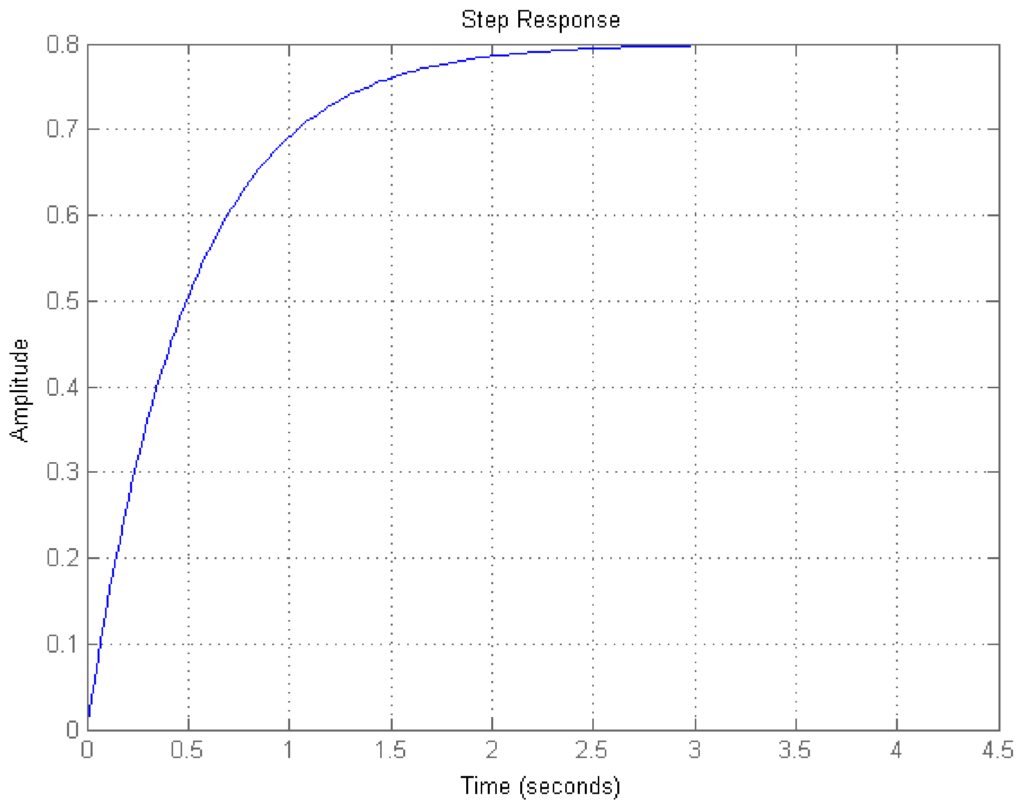

Figure 3.2 : Step response of the closed-loop system in Figure 3.1

(a) The response of the system to a unit step when $C(s)=1$ is shown in Figure 3.2. From the step response, estimate the time constant of the closed-loop system.

(15 marks)

(b) With the time constant obtained from (a), derive the corresponding transfer function of the closed-loop system.

(20 marks)

(c) From the answer in (b), find the open-loop transfer function $G(s)$.

(10 marks)

(d) Supposed that $C(s)$ is an integral action with transfer function

$$C(s) = \frac{K_I}{s}$$

where K_I is a positive constant. How does this controller improve the response of the system in general?

(5 marks)

(e) Suggest the values of K_I such that the step response of the closed-loop system satisfies the following specifications:

(i) The peak overshoot is less than 20%.
(ii) The peak time, t_p is less than 2s

Use the approximations

- $M_p = e^{-\frac{\zeta\pi}{\sqrt{1-\zeta^2}}}$ (peak overshoot)
- $t_p \approx \frac{\pi}{\omega_n\sqrt{1-\zeta^2}}$ (peak time)

where ζ is the damping ratio and ω_n is the natural frequency.

(50 marks)

4. (a) Given a unity feedback system that has the forward transfer function

(i) Using the root-loans method, calculate the angle of *G(s)* at the point by finding the algebraic sum of angles of the vectors drawn from the zeros and poles of *G(s)* to the given point.

(ii) Determine if the point specified in (i) is on the root locus.

(iii) If the point specified in (i) is on the root locus, find the gain *K*, using the lenghts of the vectors.

(40 marks)

(b) Given a unity feedback system that has the forward transfer function of

(i) Sketch the root locus

(ii) Find the imaginary-axis crossing

(iii) Find the gain, K, at the axis crossing

(iv) Find the break-in point.

(v) Find the angle of departure from the complex poles.

(60 marks)

5. (a) Consider the mechanical system shown in Figure 5(a). It consists of a spring and two dashpots.

(i) Obtain the transfer function of the system. The displacement x_i is the input, and the displacement x_o is the output.

(60 marks)

(ii) Is this system a mechanical lead network or lag network? Explain the reason of your answer.

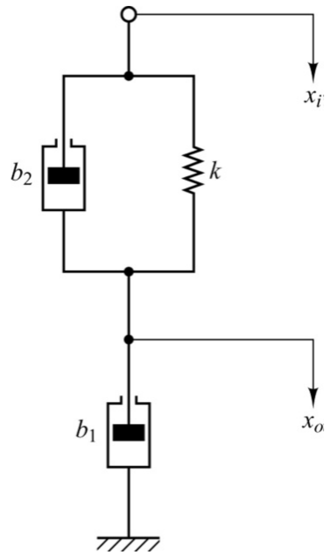

Figure 5(a)

(40 marks)

6. (a) A bode diagram of an open-loop transfer function *G(s)* of a unity-feedback control system is shown in Figure 6(a). It is known that the open-loop transfer function is minimum phase. From the Bode diagram, it can be seen that there is a pair of complex-conjugate poles at = 2 rad/sec.

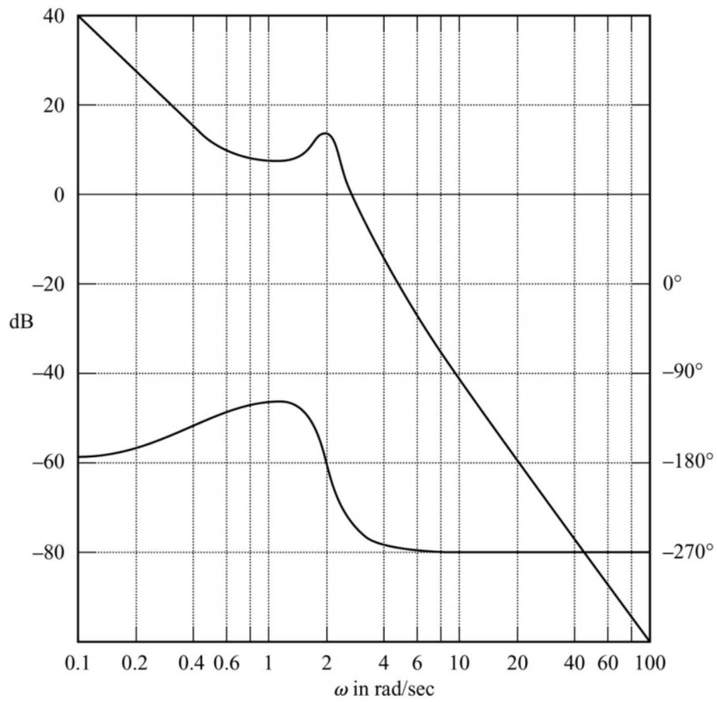

Figure 6(a)

(i) Determine the damping ratio of the quadratic term involving these complex-conjugate poles.

(ii) Determine the transfer function *G(s)*

(40 marks)

(b) Given a system with an open-loop transfer function of

(i) Sketch a Nyquist locus for the system.

(ii) Using Nyquist stability criterion, determine *K* for stability of the system.

(30 marks)

(c) Consider the system shown in Figure 6(c) above.

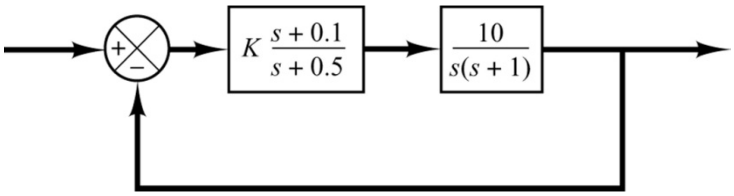

Figure 6(c)

(i) Draw the Bode diagram for the open-loop transfer function,

(ii) Determine the value of the gain *K* such that the phase margin is 50°.

(iii) What is the gain margin of the system with this gain *K*

(30 marks)

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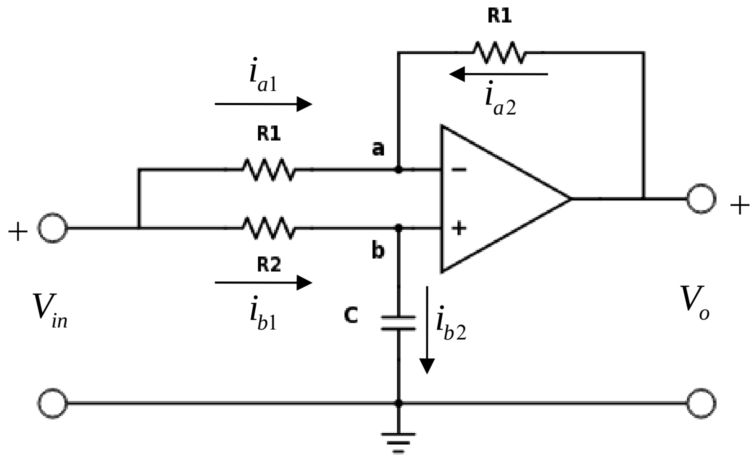
VERSI BAHASA MELAYU :-

1. (a) Rajah 1(a) menunjukkan sebuah litar penguat kendalian bertindak sebagai pengawal/penapis di mana V_{in} ialah masukan dan V_o ialah keluaran. Melalui peraturan Kirchoff, diberi,

$$i_{a1}(t) + i_{a2}(t) = 0$$
$$i_{b1}(t) = i_{b2}(t)$$



Rajah 1(a) : Litar penguat kendalian.

Andaikan litar penguat kendalian yang ideal (nod *a* dan *b* bersambung), carikan rangkap pindah di antara masukan dan keluaran dalam pemboleh ubah R_1, R_2, and C.

(35 markah)

(b) Tentukan kutub dan sifar rangkap pindah yang diperolehi dari bahagian (a).

(10 markah)

(c) Biarkan $R_2C = 2,$ carikan $V_o(t)$ jika masukan $V_{in}(t) = 2,\ t \geq 0.$

(20 markah)

(d) Daripada jawapan anda di (c), lakarkan sambutan masa yang berkaitan.

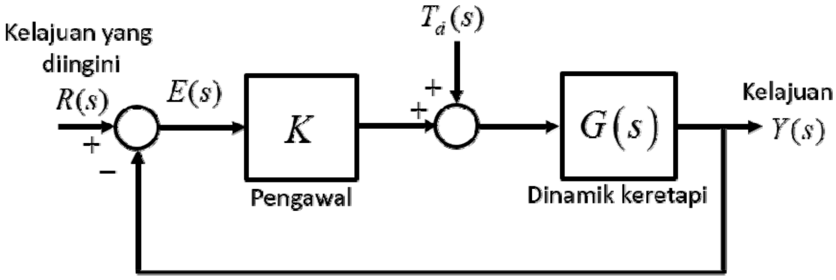
(10 markah)

(e) Sekarang diberi masukan $V_{in}(t) = t,\ t \geq 0,$ carikan $V_o(t)$.

(25 markah)

2. Dinamik sebuah keretapi berkelajuan tinggi diwakilkan oleh rangkap pindah:

$$G(s)=\frac{15}{(s+5)(s+7)}$$



Rajah 2 : Sistem pengawal keretapi berkelajuan tinggi

Sistem gelung tertutup yang berkaitan bersama pengawal K dan gangguan masukan $T_d(s)$ digambarkan di dalam Rajah 2.

(a) Jika K ialah gandaan positif, tentukan sama ada sistem gelung tertutup tersebut stabil jika tertakluk kepada kedua-dua masukan langkap $R(s)$ dan gangguan langkah $T_d(s)$. (Petunjuk: anda mungkin perlu mencari rangkap-rangkap pindah dari $R(s)$ ke $Y(s)$ dan dari $T_d(s)$ ke $Y(s)$ dahulu)

(40 markah)

(b) Dalam K, apakah ralat keadaan mantap berkenaan dengan langkah satu unit masukan $R(s)$?

(15 markah)

(c) Andaikan spesifikasi rekabentuk ialah

(i) Ralat keadaan mantap bagi langkah satu unit masukan $R(s)$ ialah kurang daripada 20%.

(ii) Ralat keadaan mantap bagi langkah satu unit gangguan $T_d(s)$ ialah kurang daripada 10% (iaitu $|y/T_d|_{\max} < 0.1.$)

(iii) Maksimum puncak tersasar bagi langkah masukan ialah 22%. Dengan menggunakan anggaran

$$M_p = e^{-\frac{\zeta\pi}{\sqrt{1-\zeta^2}}}$$

di mana ialah puncak tersasar dan ζ ialah nisbah redaman, carikan nilai-nilai K yang sesuai supaya kesemua spesifikasi boleh dipenuhi secara serentak.

(45 markah)

3. Sebuah sistem gelung tertutup digambarkan di dalam Rajah 3.1 di mana $C(s)$ ialah pengawal dan $G(s)$ is loji.

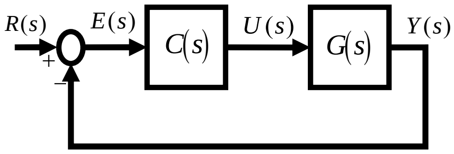
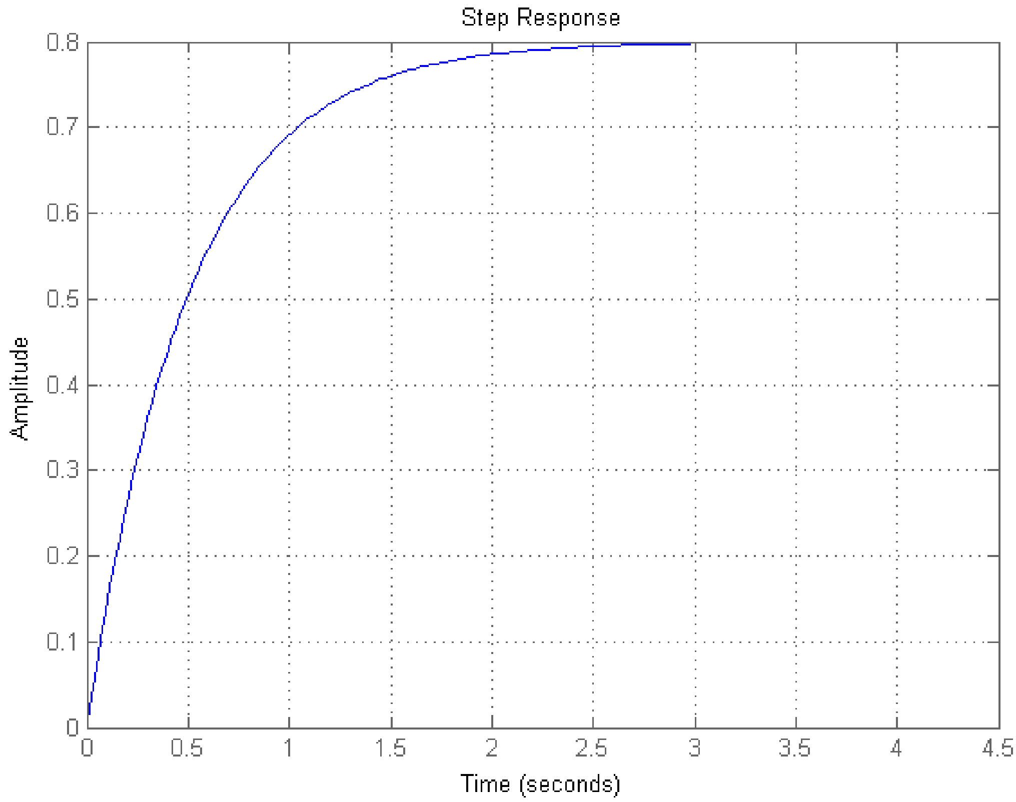


Figure 31 : Sistem gelung tertutup



Rajah 3.2: Sambutan langkah bagi sistem gelung tertutup di Rajah 3.1.

(a) Sambutan bagi sistem untuk satu unit langkah jika $C(s)=1$ digambarkan di dalam Rajah 3.2. Daripada sambutan langkah tersebut, anggarkan pemalar masa bagi sistem gelung tertutup tersebut.

(15 markah)

(b) Dengan pemalar masa yang anda perolehi dari (a), bina rangkap pindah berkaitan untuk sistem gelung tertutup tersebut.

(20 markah)

(c) Daripada jawapan anda di (b), carikan rangkap pindah gelung terbuka $G(s)$.

(10 markah)

(d) Andaikan $C(s)$ ialah tindakan integral dengan rangkap pindah

$$C(s) = \frac{K_I}{s}$$

di mana K_I ialah pemalar positif. Bagaimana pengawal tersebut membaiki sambutan sistem tersebut secara umum?

(5 markah)

(e) Cadangkan nilai-nilai K_I supaya sambutan langkah sistem gelung tertutup tersebut menepati spesifikasi-spesifikasi di bawah:

(i) Puncak tersasar kurang daripada 20%.
(ii) Puncak masa t_p is kurang daripada 2s

Gunakan anggaran

- $M_p = e^{-\frac{\zeta\pi}{\sqrt{1-\zeta^2}}}$ (puncak tersasar)
- $t_p \approx \dfrac{\pi}{\omega_n\sqrt{1-\zeta^2}}$ (puncak masa)

di mana ζ ialah nisbah redaman dan ω_n ialah frekuensi tabii.

(50 markah)

4. (a) Diberi suatu sistem suap-balik uniti yang mempunyai rangkap pindah ke hadapan . (i) Kirakan sudut *G (s)* pada titik dengan mencari jumlah sudut algebra sudut vektor diambil daripada sifar dan kutub *G (s)* ke titik yang diberikan. (ii) Tentukan sama ada titik yang dinyatakan dalam (i) adalah pada londar punca. (iii) Jika titik yang dinyatakan dalam (i) adalah pada londar punca, cari gandaan *K*, dengan menggunakan panjang vektor.

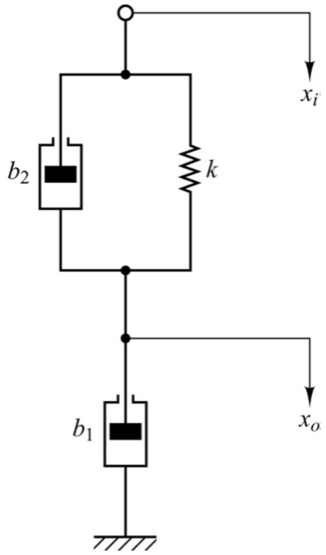
(40 markah)

(b) Diberi suatu sistem suap-balik ke yang mempunyai rangkap pindah ke hadapan .

(i) Lakarkan londar punca
(ii) Cari lintasan khayalan paksi
(iii) Cari gandaan, *K*, di persimpangan paksi
(iv) Dapatkan titik pulang dalam.
(v) Cari sudut berlepas dari kutub kompleks.

(60 markah)

5. Pertimbangkan sistem mekanikal yang ditunjukkan dalam Rajah 5. Ia terdiri daripada satu spring dan dua peredam.



Rajah 5

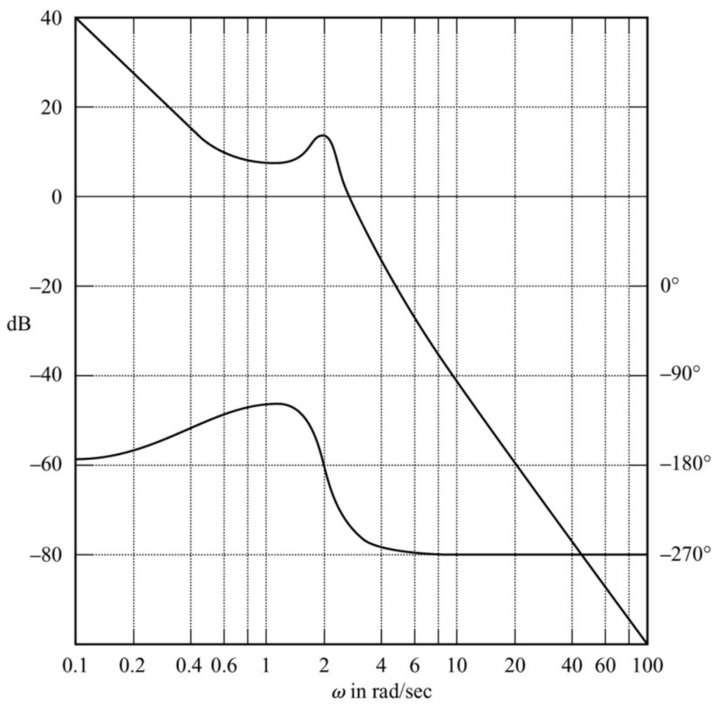
(i) Dapatkan rangkap pindah sistem tersebut. Anjakan x_i adalah masukan, dan anjakan x_o adalah keluaran.

(60 markah)

(ii) Adakah sistem ini rangkaian mendahulu atau rangkaian mengekor? Terangkan jawapan anda.

(40 markah)

6. (a) Gambar rajah Bode daripada rangkap pindah gelung-buka *G (s)* untuk suatu sistem suap balik unit i ditunjukkan dalam Rajah 6(a). Telah diketahui bahawa rangkap pindah gelung buka adalah pada fasa minimum. Daripada gambar rajah Bode tersebut, ia boleh dilihat bahawa terdapat sepasang kutub kompleks konjugat di = 2 rad / saat.



Rajah 6(a)

(i) Tentukan nisbah redaman kuadratik yang melibatkan kutub kompleks konjugat tersebut.

(ii) Tentukan rangkap pindah *G (s)*

(40 markah)

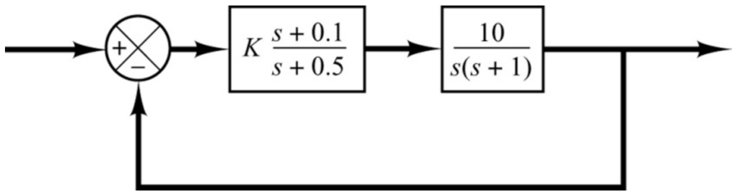
(b) Diberikan suatu sistem dengan fungsi pindah gelung terbuka daripada

(i) Lakarkan londar Nyquist untuk sistem tersebut.

(ii) Dengan menggunakan kriteria kestabilan Nyquist, tentukan *K* untuk kestabilan.

(30 markah)

(c) Pertimbangkan sistem yang ditunjukkan di Rajah 6(c) atas.



Rajah 6(c)

(i) Lakar gambarajah Bode bagi rangkap pindah gelung terbuka tersebut,
(ii) Tentukan nilai gandaan *K* supaya margin fasa ialah 50°.
(iii) Apakah margin jidan gandaan bagi jidar masa dengan *K* ini

(30 markah)

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