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UNIVERSITI KUALA LUMPUR
Malaysia France Institute

FINAL EXAMINATION
JANUARY 2014 SESSION

SUBJECT CODE	:	**FAB40803**
SUBJECT TITLE	:	**CONTROL SYSTEMS 2**
LEVEL	:	**BACHELOR**
TIME / DURATION	:	**(3 HOURS)**
DATE	:	

INSTRUCTIONS TO CANDIDATES

1. **Please read the instructions given in the question paper CAREFULLY.**
2. **This question paper is printed on both sides of the paper.**
3. **Please write your answers on the answer booklet provided.**
4. **Answer should be written in blue or black ink except for sketching, graphic and illustration.**
5. **This question paper consists of FIVE (5) questions. Answer FOUR (4) questions only.**
6. **Answer all questions in English.**
7. **The semi-log paper, graph paper and formula are appended.**

THERE ARE 5 PAGES OF QUESTIONS AND 3 PAGES OF APPENDIX, EXCLUDING THIS PAGE.

Question 1

A unity feedback system with the following open loop transfer function is operating at 32 % overshoot, %OS and 0.5681 seconds peak time, T_p.

$$G(s) = \frac{K}{(s+15)(s^2+6s+13)}$$

a) Sketch the root locus of the closed loop system as K varies from zero to infinities, in the s-plane and indicate the asymptotes, break points on the real axis, cross-over points at the imaginary axis, angle of departure or arrival, where appropriate.

(8 marks)

b) Determine the dominant closed loop poles when the system is operating at 32% overshoot.

(2 marks)

c) Design a suitable compensator to improve the settling time, T_s by a factor of 2 with the same overshoot.

(10 marks)

d) Determine the open loop transfer function of the compensated system with the associated overall gain, KK_c.

(5 marks)

Question 2

The block diagram of a positioning servomechanism is shown in **Figure 2**:

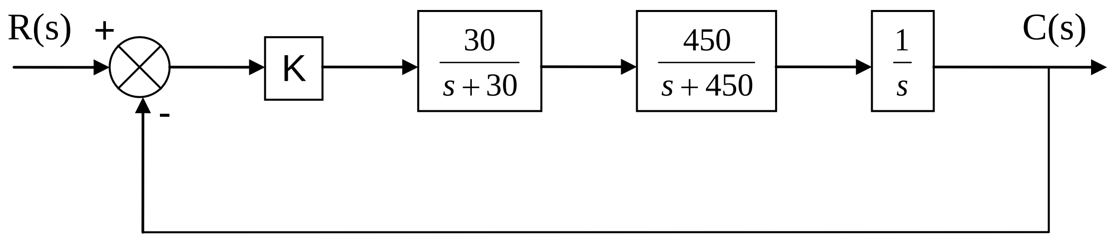

Figure 2: Positioning servomechanism

a) Sketch the asymptotic Bode plot (magnitude and phase) on a semi-log paper for controller gain $\boldsymbol{K}$ = 100.

(10 marks)

b) From the Bode plot, find the phase margin, gain margin, frequency of phase and gain margin.

(2 Marks)

c) It is desired to have velocity error constant $\boldsymbol{K_v}$ = 100 and phase margin of 52°. Is it possible to achieve this requirement with a gain adjustment alone? Justify your answer.

(3 Marks)

d) Design a phase-lead compensator to meet the following specifications:

i. Velocity error constant $\boldsymbol{K_v}$ = 100.

ii. Phase margin is more than 52°.

(10 marks)

Question 3

A telescopic pointing device can be represented in state-space as follow:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -6 & -5 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u$$
$$y = \begin{bmatrix} -1 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

a) Use Ackerman's formula to find the state feedback gain ***K*** required to place the poles at $s_1 = -1$ and $s_2 = -1$.

(10 marks)

b) Calculate the closed-loop poles of the system.

(5 marks)

c) As the values of the states cannot be directly measured, a state observers need to be introduced in order to implement the state feedback controller. Design a state observer by choosing the poles observer **10** times faster than the slowest pole of the controlled system.

(10 marks)

Question 4

The position control of an antenna of a telescope is using a drive shaft actuated by a DC motor. The system is modeled by a transfer function $G(s)$. The control system is composed of a set point (desired angle in radians), a comparator, a pre-amplifier gain ***K***, a power amplifier transfer function $G_p(s)$, a controlled voltage source, and two position sensors (potentiometer at input and output) whose gain is $1/\pi$. The closed-loop system is represented by the block diagram as shown in **Figure 3**.

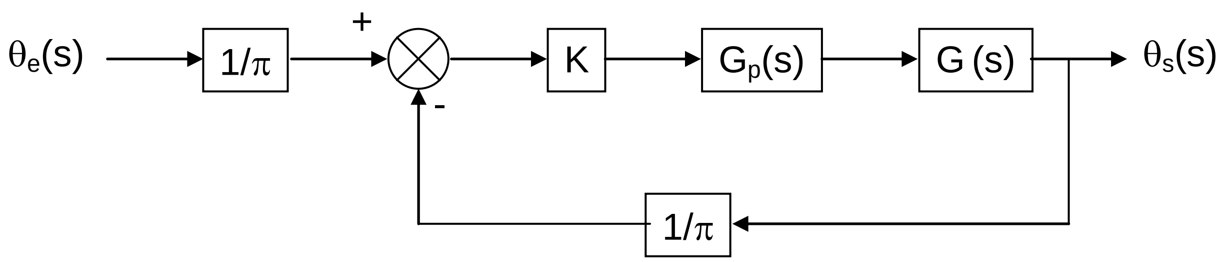

Figure 3: Block diagram of antenna position control

Given the transfer function: $G(s) = \dfrac{0.2083}{s(s+1.71)}, \quad G_p(s) = \dfrac{100}{s+100}$

a) Sketch the physical implementation of the system. Show the basic components and the interconnection among them.

(5 marks)

b) Sketch the Bode plot of the system for ***K = 1*** and find the range of ***K*** to ensure stability.

(10 marks)

c) Adjust the magnitude plot for ***K* = 50.7** and estimate the closed-loop bandwidth and the steady state error to ramp input from the Bode plot.

(5 marks)

d) Name two (2) types of controller that can improve steady state error of the system and describe how to implement those controllers.

(5 marks)

Question 5

Consider a block diagram of a sampled-data system as shown **Figure 4**.

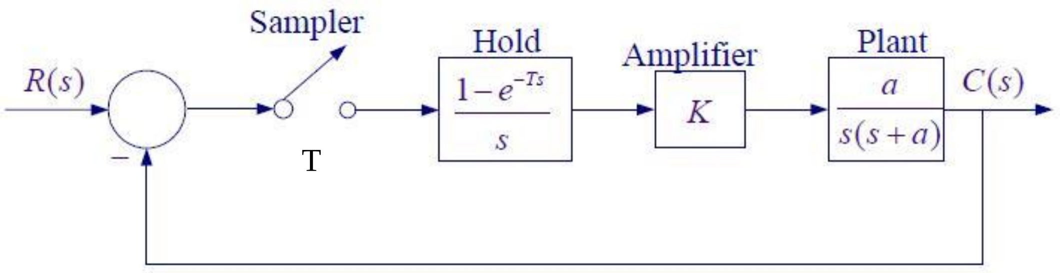

Figure 4: Block diagram of a sampled-data system.

a) Find the sampled-data transfer function $G(z)=\dfrac{C(z)}{R(z)}$ when ***a*** = 25 and the sampling time is ***T*** = 0.1 second.

(10 marks)

b) Find the closed-loop transfer function *T(z)* for a unity feedback system.

(5 marks)

c) State the stability condition of the unity feedback closed-loop system, *T(z)* in z-plane.

(3 marks)

d) List three (3) advantages of using digital computer in the loop.

(3 marks)

e) Explain how to implement a dc motor position control system using digital control technique. Describe the instruments required and draw the block diagram indicating the point of sampling and conversion.

(4 marks)

END OF QUESTION

Appendix

Time Response:

Underdamped Second Order Systems

Settling Time (within 2% of steady state value	$T_s = \frac{4}{\zeta w_n}$
Peak Time	$T_p = \frac{\pi}{w_d}$
Damped Frequency	$w_d = w_n\sqrt{1-\zeta^2}$
Damping Ratio	$\varsigma = \frac{-\ln(\%OS/100)}{\sqrt{\pi^2 + \ln^2(\%OS/100)}}$
Closed-Loop Transfer Function	$G(s) = \frac{w_n^2}{s^2 + 2\zeta w_n s + w_n^2}$
Percent overshoot, %OS	$e^{\frac{-\varsigma\pi}{\sqrt{1-\varsigma^2}}} \times 100\%$

Frequency Response:

Closed-Loop Bandwidth	$w_{BW} = \frac{4}{T_S\zeta}\sqrt{(1-2\zeta^2) + \sqrt{4\zeta^4 - 4\zeta^2 + 2}}$ $= \frac{\pi}{T_p\sqrt{1-\zeta^2}}\sqrt{(1-2\zeta^2) + \sqrt{4\zeta^4 - 4\zeta^2 + 2}}$ $= w_n\sqrt{(1-2\zeta^2) + \sqrt{4\zeta^4 - 4\zeta^2 + 2}}$
Phase Margin	$\phi_m = \tan^{-1}\frac{2\varsigma}{\sqrt{-2\varsigma^2 + \sqrt{1+4\varsigma^4}}}$
Maximum Phase Shift of Compensator	$\phi_{\max} = \sin^{-1}\left(\frac{1-\beta}{1+\beta}\right)$
Magnitude at w_{max}	$M_{\max} = \frac{1}{\sqrt{\beta}}$

The State Model

For linear time-invariant system:

$$\dot{X} = AX(t) + BU(t)$$
$$Y(t) = CX(t) + DU(t)$$

where $A \in \Re^{nXn}$, $B \in \Re^{nXn_i}$, $C \in \Re^{n_oXn}$, $D \in \Re^{nXn_i}$.

The solution $X(t)$	$e^{At}X(0) + \int_0^t e^{A(t-\tau)}Bu(\tau)d\tau$
The matrix exponential e^{At}	$e^{At} = I + \frac{At}{1!} + \frac{A^2t^2}{2!} + \cdots$ $e^{At} = \mathcal{L}^{-1}((sI - A)^{-1})$
Eigenvalues	$\det(\lambda I - A) = 0$
Transfer function	$G(s) = \frac{Y(s)}{U(s)} = C(sI - A)^{-1}B + D$
Controllability matrix	$C = [B \quad AB \quad A^2B \quad \cdots \quad A^{n-1}B]$
Observability matrix	$O = [C \quad CA \quad CA^2 \quad \cdots \quad CA^{n-1}]^T$
Ackermann's formula	Controller: $K = [0 \quad 0 \quad \cdots \quad 0 \quad 1][B \quad AB \quad \cdots \quad A^{n-2}B \quad A^{n-1}B]^{-1}\alpha_c(A)$ Estimator: $G = \alpha_e(A)([C \quad CA \quad \cdots \quad CA^{n-1}]^T)^{-1}[0 \quad 0 \quad \cdots \quad 0 \quad 1]^T$

Table 13.1 Partial table of z- and s-transforms

	f(t)	F(s)	F(z)	f(kT)
1.	$u(t)$	$\frac{1}{s}$	$\frac{z}{z-1}$	$u(kT)$
2.	t	$\frac{1}{s^2}$	$\frac{Tz}{(z-1)^2}$	kT
3.	t^n	$\frac{n!}{s^{n+1}}$	$\lim_{a\to 0}(-1)^n \frac{d^n}{da^n}\left[\frac{z}{z-e^{-aT}}\right]$	$(kT)^n$
4.	e^{-at}	$\frac{1}{s+a}$	$\frac{z}{z-e^{-aT}}$	e^{-akT}
5.	$t^n e^{-at}$	$\frac{n!}{(s+a)^{n+1}}$	$(-1)^n \frac{d^n}{da^n}\left[\frac{z}{z-e^{-aT}}\right]$	$(kT)^n e^{-akT}$
6.	$\sin \omega t$	$\frac{\omega}{s^2+\omega^2}$	$\frac{z \sin \omega T}{z^2 - 2z\cos \omega T + 1}$	$\sin \omega kT$
7.	$\cos \omega t$	$\frac{s}{s^2+\omega^2}$	$\frac{z(z - \cos \omega T)}{z^2 - 2z\cos \omega T + 1}$	$\cos \omega kT$
8.	$e^{-at}\sin \omega t$	$\frac{\omega}{(s+a)^2+\omega^2}$	$\frac{ze^{-aT}\sin \omega T}{z^2 - 2ze^{-aT}\cos \omega T + e^{-2aT}}$	$e^{-akT}\sin \omega kT$
9.	$e^{-at}\cos \omega t$	$\frac{s+a}{(s+a)^2+\omega^2}$	$\frac{z^2 - ze^{-aT}\cos \omega T}{z^2 - 2ze^{-aT}\cos \omega T + e^{-2aT}}$	$e^{-akT}\cos \omega kT$