The Open University of Sri Lanka
Faculty of Engineering Technology
Department of Mechanical Engineering

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Study Programme	: Bachelor of Technology Honours in Engineering
Name of the Examination	: Final Examination
Course Code and Title	: **DMX5403 Control Systems Engineering**
Academic Year	: 2021/22
Date	: 16^{th} February 2023
Time	: 09:30 – 12:30 hrs.
Duration	: **3 hours**

General Instructions

1. Read all instructions carefully before answering the questions.
2. This question paper consists of **eight (8)** questions in **five (05)** pages.
3. Write the answers for the **Section A** and **Section B** in separate answer books.
4. Answer **Q1**, which is **compulsory** and **FOUR** other questions, selecting at least **ONE** from **SECTION A** and **TWO (2)** from **SECTION B**. Answer for each question should commence from a new page.
5. Relevant charts/codes are provided.
6. This is a **Closed Book Test** (CBT).
7. Answers should be in clear handwriting and do not use Red colour pen.
8. Clearly state your assumptions, if any.

SECTION A

Q1 An electric hot-water heater is illustrated in Figure Q1. In order to maintain a desired temperature, the heating element is turned on/off by a switch.

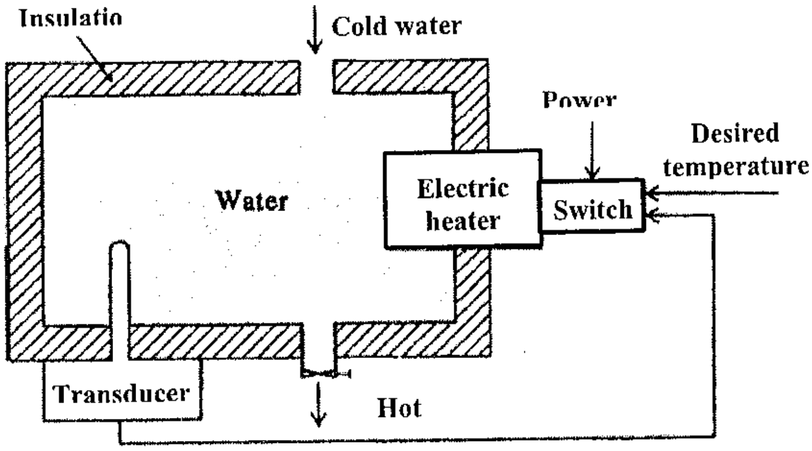

Figure Q1

(a) How can you measure the system output and what type of transducer would you propose to use? [03]

(b) What is the Actuator of the system? [02]

(c) Qualitatively explain how the system operates if the desired temperature is changed. [04]

(d) Draw a complete functional block diagram for this closed-loop control system shown in Figure Q1 and identify each block with its function. [08]

(e) Explain how the system operates if the ambient temperature surrounding the tank suddenly changes. [03]

Q2 Consider the feedback control system shown in Figure Q2 below.

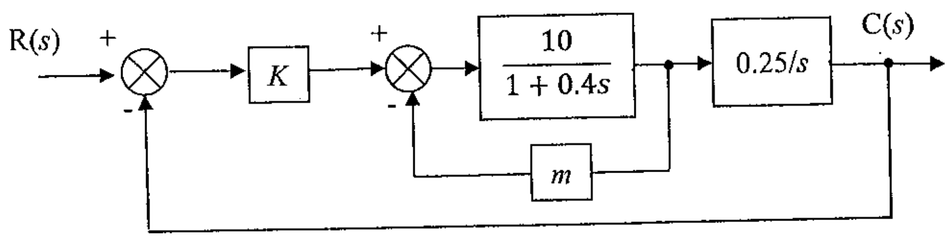

Figure Q2

(a) Obtain the closed loop transfer function for the given system. [08]

(b) Determine the following parameters when the damping ratio and settling time of the unit step of the system are 0.5 and 0.2 seconds, respectively.

i) m ii) K [08]

(c) Explain briefly, the influence of damping ratio and settling time on the stability of any control system. [04]

Q3 Figure Q3 shows the block diagram of a feedback control system.

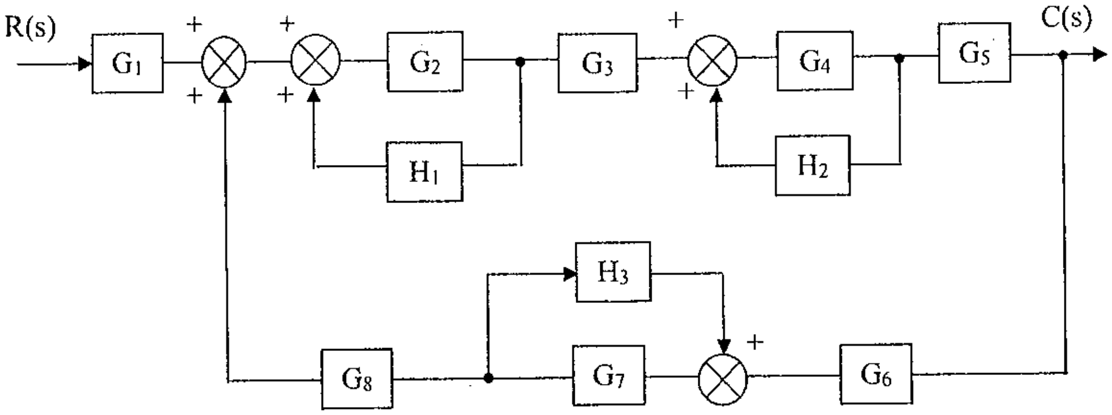

Figure Q3

(a) Draw the signal flow graph for the given system. [04]

(b) State the Mason's Gain formula and explain each parameter. [04]

(c) Use Mason's Gain Formula to obtain the closed loop transfer function C(s)/R(s) of the system. **You must clearly show all steps.** [12]

Q4 Figure Q4 shows a potential tracking problem with a reference input R(s) and disturbance input D(s).

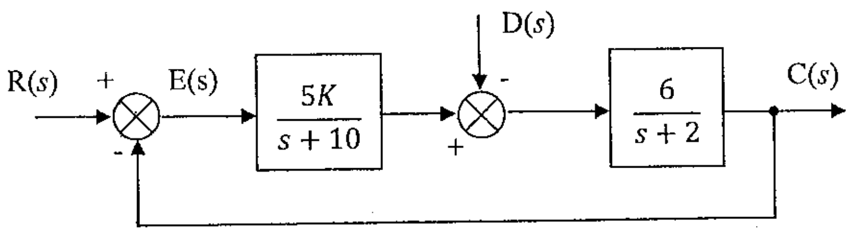

Figure Q4

(a) Determine the following: [15]

i) The steady-state error for a unit step input, $r(t) = U(t)$ with $K = 10$.

ii) The steady-state error for a unit disturbance step input, $d(t) = U(t)$ with $K = 10$.

iii) The value of K so that the steady-state error due to a disturbance step input, $d(t) = U(t)$ equals 5% of the disturbance step input value.

(b) What is meant by *sensitivity* of a system? Explain briefly. [02]

(c) Determine the sensitivity of the above system to variation in the parameter K by ignoring the disturbance input. [03]

SECTION B

Q5

(a) A unity feedback system is characterized by the open- loop transfer function.

$$G(s) = \frac{K(s+10)}{s(s+2)(s+7)}$$

Using the Routh criterion, calculate the range of values of K for the system to be stable.
[06]

(b) A feedback system has an open loop transfer function of

$$G(s)H(s) = \frac{Ke^{-s}}{s(s^2+6s+9)}$$

Determine, by using the Routh criterion, the maximum value of K for the closed loop system to be stable.
[06]

(c) Define following terminologies:

i) Gain margin
ii) Phase margin
iii) Gain crossover point
iv) Phase crossover point

[04]

(d) The bode plot of a control system is shown in figure Q5. Determine the gain Margin and Phase Margin of the system.
[04]

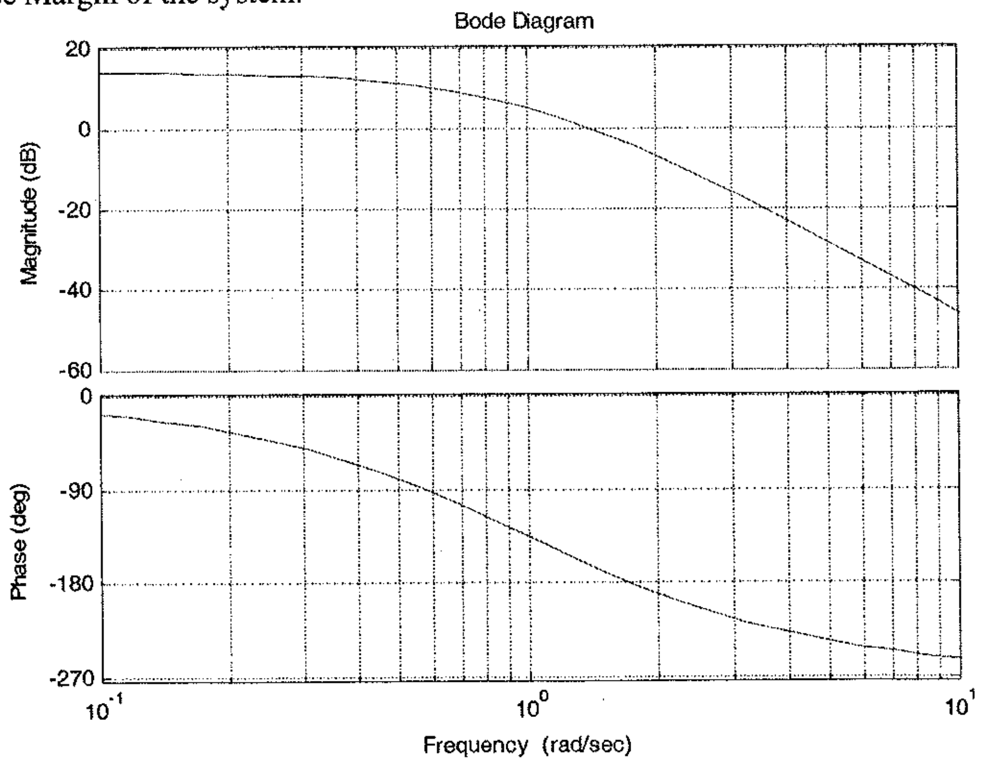

Figure Q5

Q6

(a) Define following terms.
   i) Root Loci (RL)
   ii) Complementary Root Loci (CRL)
   iii) Root Contours (RC)
   iv) Complete Root Loci

[04]

(b) A feedback control system has an open-loop transfer function.

$$G(s)H(s) = \frac{K}{s(s+3)(s^2+2s+2)}$$

Find the root locus as K is varied from 0 to ∞.

[14]

(c)Hence find the range of ***K*** to keep the system stable.

[02]

Q7

a) Describe and compare the characteristics of
   (i) Proportional Controller.
   (ii) Proportional plus Integral Controller.
   (iii)Proportional plus Integral plus Derivative Controller.

[06]

b) The closed loop transfer function of a control system is given by

$$G(s) = \frac{16}{s^2+1.6s+16}$$

Determine the derivative feedback constant K_t and compare the rise time, peak time, maximum overshoot and steady state error for an unit ramp input with and without derivative feedback control, if it is desired to have the damping ratio of 0.8.

[14]

Q8

(a) Briefly explain how digital control systems differ with classical control systems.

[05]

(b) For each of the following difference equations, determine the order of the equation. Is the equation (a) linear, (b) time invariant, or (c) homogeneous?

   (i) $y(k+4) + \sin(0.4k)y(k+1) + 0.3y(k) = 0$
   (ii) $y(k+1) = -0.1y^2(k)$

[05]

(c) Derive the state space equation for following transfer functions.

i) $\dddot{y} + 7\ddot{y} + 14\dot{y} + 8y = 8u(t)$ [05]

ii)

$$\frac{Y(s)}{U(s)} = \frac{8}{(s+1)(s+2)(s+4)}$$

[05]

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