CONFIDENTIAL

UTHM
Universiti Tun Hussein Onn Malaysia

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER 2
SESSION 2022/2023

COURSE NAME	:	CONTROL ENGINEERING
COURSE CODE	:	BDA 30703
PROGRAMME CODE	:	BDD
EXAMINATION DATE	:	JULY/AUGUST 2023
DURATION	:	3 HOURS
INSTRUCTION		1. ANSWER **ALL** QUESTIONS IN PART A AND ONLY **ONE (1)** QUESTION IN PART B. 2. THIS FINAL EXAMINATION IS CONDUCTED VIA CLOSED BOOK. 3. STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK.

THIS QUESTION PAPER CONSISTS OF **NINE (9)** PAGES

CONFIDENTIAL

PART A: ANSWER ALL QUESTION

Q1 (a) As a newly hired engineer, you are requested to setup a measurement system for measuring liquid temperature in a tank.

i. Draw a block diagram describing all the elements of the measurement system.

ii. List at least four factors that must be taken into consideration in choosing the most suitable instrument for the measurement system.

iii. Propose a suitable temperature sensor to be used in the measurement system and describe its working principle with the help of an appropriate illustration.

(12 marks)

(b) **Figure Q1(b)** shows e.m.f. temperature characteristic for some standard thermocouple materials. Note that the generated e.m.f. of the thermocouple is too small to be directly used as an input to a data acquisition card which accepts an analog signal of 0 to 24 volt.

i. Sketch a suitable signal conditioning circuit that can be used to condition the generated e.m.f. of the thermocouple, so that it can be read by the data acquisition card.

ii. Derive a general equation relating the input and output of the proposed signal conditioning circuit above.

(8 marks)

Q2 **Figure Q2** shows a liquid storage tank system that are commonly used in industries.

(a) Write all four governing equations of tank 1(two equations) and tank 2 (two equations) in time-domain.

(4 marks)

(b) Use Laplace transform and converts each governing equations obtained in **Q2(a)** into s-domain.

(4 marks)

(c) Draw block diagram for each s-domain governing equations obtained in **Q2(b)**.

(4 marks)

(d) Create block diagram of the entire system by combining each individual block diagram obtained in **Q2(c)**.

(4 marks)

(e) Reduce the block diagram obtain in **Q2(d)** to obtain transfer function of the entire system relating the volumetric flow rate, q_i to liquid level h_2 in the second tank.

(4 marks)

Q3 Simplified equations describing the dynamics of a DC motor rotating a disk are given below:

$$T(t) = K_t i_a(t) \quad (1)$$

$$e_b(t) = K_b \omega(t) \quad (2)$$

$$T(t) - T_d(t) = J\frac{d\omega(t)}{dt} + c\omega(t) \quad (3)$$

$$e_a(t) - e_b(t) = R_a i_a(t) \quad (4)$$

where

$\omega(t)$	motor speed
$i_a(t)$	motor current
$T(t)$	motor torque
$T_d(t)$	disturbing torque
$e_d(t)$	back emf voltage
$e_a(t)$	input voltage to motor
R_a	motor resistance
J	combined inertia of motor and disk
c	viscous damping coefficient
K_t	motor constant
K_b	motor constant

(a) Derive the transfer function that relates the motor motor speed, $\Omega(s)$, to both the input voltage, $E_a(s)$, and the disturbing torque, $T_d(s)$.

(8 marks)

(b) Assume R_a=1, K_t=2, K_b=1, J=5, c=2, and that all units of measure are consistent. Show that motor speed increases with the input voltage and reduces with the disturbing torque. Assume unit steps for both the input voltage and the disturbing torque.

(4 marks)

(c) Assume R_a=1, K_t=2, K_b=1, J=5, and in this part c=0 and $T_d(t)$=0, i.e. no viscous friction nor disturbing torque. Show how the motor current changes with time if a constant input voltage, $e_a(t)$=1, is applied to the system. Here you need to find and sketch the time response. Be sure to specify the steady-state motor current on the plot.

(8 marks)

Q4 A company has hired you to study an existing control system designed by a previous control engineer. The control system consists of a second-order system and a proportional controller as shown in **Figure Q4**. Your job is to improve the control system so that the output, *c(t)*, follows the input, *r(t)*, with no overshoot and no steady-state error. However, the previous engineer forgot to document her/his work, so you don't know the system parameters or the controller gain. So, the first step is to familiarize yourself with the performance of the current system. You apply a step input to the closed-loop system, i.e., $r(t) = 1$. The actual response, *c(t)*, is shown in **Figure Q4**. Using the information in the figure:

(a) Estimate the system parameters, ζ and ω_n as well as the controller gain, K_p.

(10 marks)

(b) Sketch the root locus plot as the controller gain is increased from $K_p = 0$ till $K_p = \infty$.

(5 marks)

(c) Determine the range of K_p to keep the closed-loop system stable.

(5 marks)

PART B : ANSWER **ONE(1)** QUESTION ONLY

Q5 (a) Transfer function of an electric regulator system is given by;

$$G(s) = \frac{200{,}000s - 2{,}000{,}000}{(s^2 + 20s)(s^2 + 20s + 10{,}000)}$$

Rewrite the transfer function in constituent elementary factors form

(2 marks)

(b) Calculate the magnitude values (dB) and phase values (Degrees) for each constituent element at frequency between 0.01 and 10,000 rad/s.

(5 marks)

(c) Sketch on a semilog graph paper the Bode diagram for the system by using straight line asymptote methods.

(10 marks)

(d) Determine the gain margin (GM) and phase margin (PM) from the Bode plot and relate these values with the stability of the system.

(3 marks)

Q6 (a) Considering a typical feedback control system, explain ONE advantage of a (P+I) controller as compared to a purely proportional (P) controller.

(3 marks)

(b) Illustrate the compensation characteristics of cascade PI and PD compensators.

(7 marks)

(c) Consider the control system shown in **Figure Q6.** Examine a Ziegler-Nichols tuning rule for the determination of the values of parameters K_p, T_i and T_d.

(10 marks)

-END OF QUESTIONS-

FINAL EXAMINATION

SEMESTER / SESSION : SEM II / 2022/2023 PROGRAMME : BDD
COURSE NAME : CONTROL ENGINEERING COURSE CODE : BDA 30703

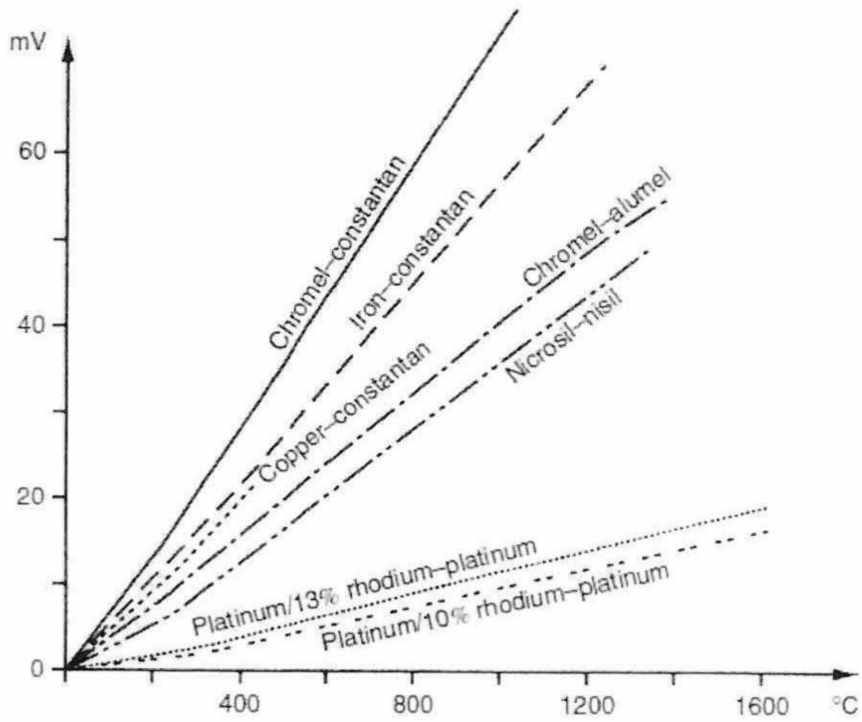
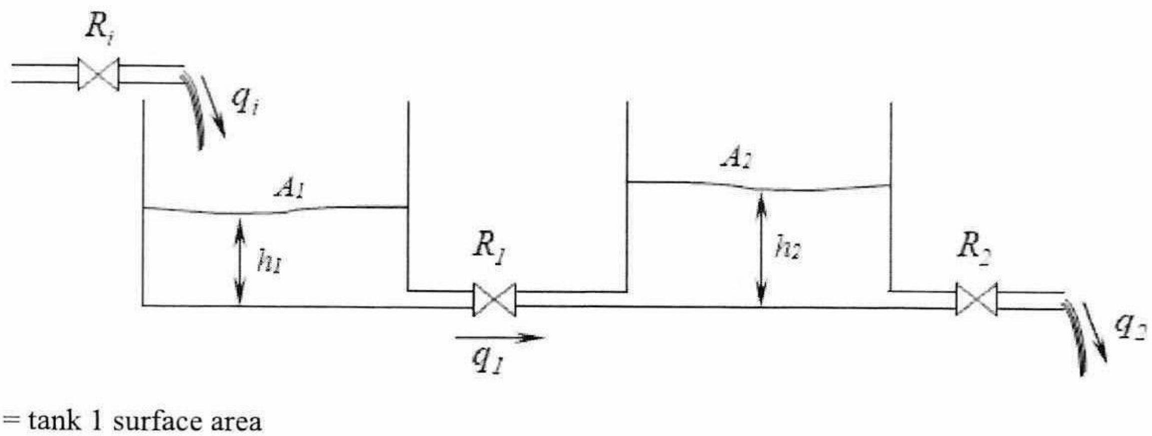


Figure Q1(b)



A_1 = tank 1 surface area
A_2 = tank 2 surface area
R_i = input valve resistance
R_1 = connecting valve resistance
R_2 = output valve resistance

Figure Q2

FINAL EXAMINATION

SEMESTER / SESSION : SEM II / 2022/2023 PROGRAMME CODE : BDD
COURSE NAME : CONTROL ENGINEERING COURSE CODE : BDA 30703

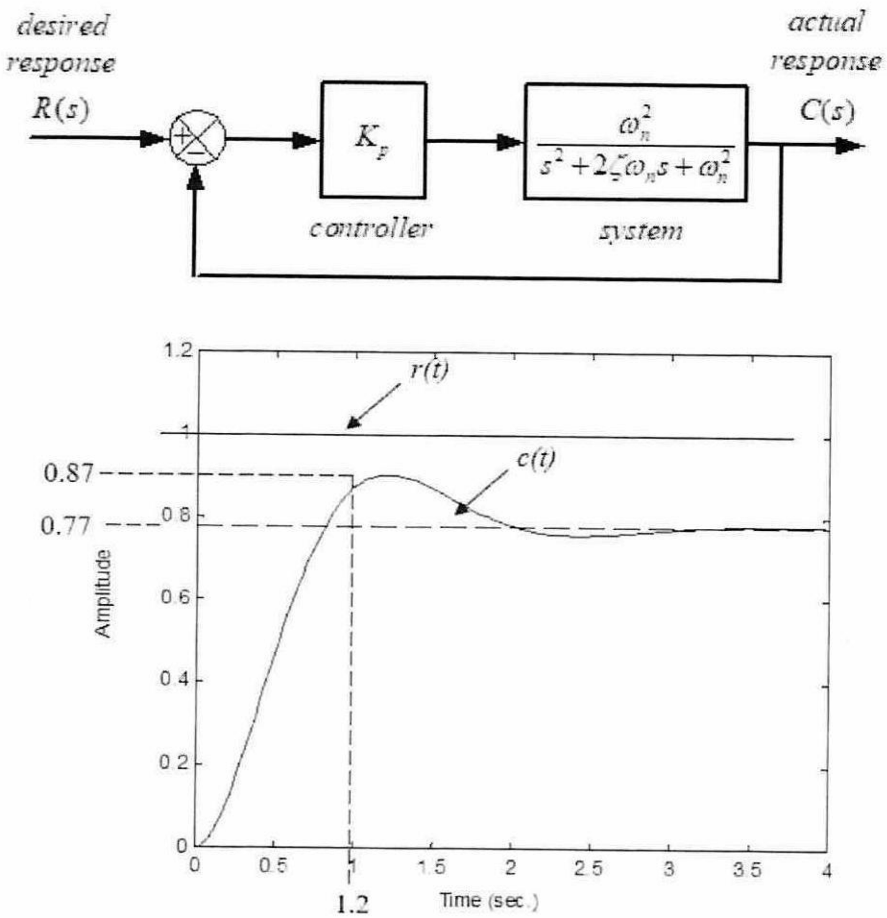


Figure Q4

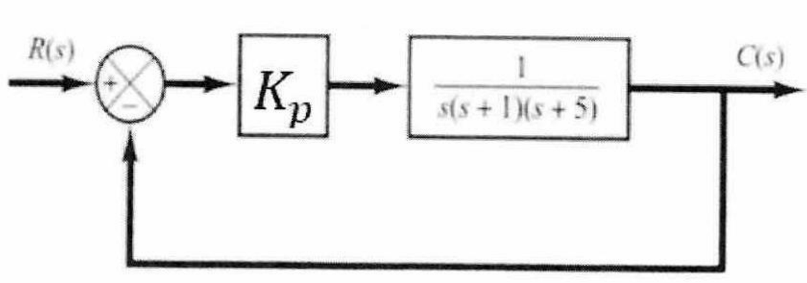


Figure Q6

FINAL EXAMINATION

SEMESTER / SESSION : SEM II / 2022/2023 PROGRAMME CODE : BDD
COURSE NAME : CONTROL ENGINEERING COURSE CODE : BDA 30703

References:

Original	Image
a	$\frac{a}{s}$
t	$\frac{1}{s^2}$
t^2	$\frac{2}{s^3}$
$t^n, n \in N$	$\frac{n!}{s^{n+1}}$
e^{at}	$\frac{1}{s-a}$
te^{at}	$\frac{1}{(s-a)^2}$
t^2e^{at}	$\frac{2}{(s-a)^3}$
$t^ne^{at}, n \in N$	$\frac{n!}{(s-a)^{n+1}}$

Original	Image
$\sin(\omega t)$	$\frac{\omega}{s^2+\omega^2}$
$\cos(\omega t)$	$\frac{s}{s^2+\omega^2}$
$\sinh(\omega t)$	$\frac{\omega}{s^2-\omega^2}$
$\cosh(\omega t)$	$\frac{s}{s^2-\omega^2}$
$t\sin(\omega t)$	$\frac{2s\omega}{(s^2+\omega^2)^2}$
$t\cos(\omega t)$	$\frac{s^2-\omega}{(s^2+\omega^2)^2}$
$e^{at}\sin(\omega t)$	$\frac{\omega}{(s-a)^2+\omega^2}$
$e^{at}\cos(\omega t)$	$\frac{s-a}{(s-a)^2+\omega^2}$

$$C(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \qquad \zeta = \frac{-\ln(\%OS/100)}{\sqrt{\pi^2 + \ln^2(\%OS/100)}} \qquad \%OS = 100e^{-\left(\frac{\zeta\pi}{\sqrt{1-\zeta^2}}\right)}$$

$$T_p = \frac{\pi}{\omega_n\sqrt{1-\zeta^2}} = \frac{\pi}{\omega_d} \qquad T_s = \frac{4}{\zeta\omega_n} = \frac{4}{\sigma_d}$$