UNIVERSITI TEKNOLOGI PETRONAS

FINAL EXAMINATION
MAY 2024 SEMESTER

COURSE : **CEB2083 - PROCESS INSTRUMENTATION AND CONTROL**

DATE : **13 AUGUST 2024 (TUESDAY)**

TIME : **2.30 PM - 5.30 PM (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **NINE (9)** pages in this Question Booklet including the cover page and appendices.

ii. **DOUBLE-SIDED** Question Booklet.

1. A stirred tank heater system shown in **FIGURE Q1** is used to heat up the process liquid. F_i, F and F_{st} are the volumetric flow rates for inlet, outlet and steam streams, respectively. While, T_i and T are the temperatures for inlet and outlet streams, respectively.

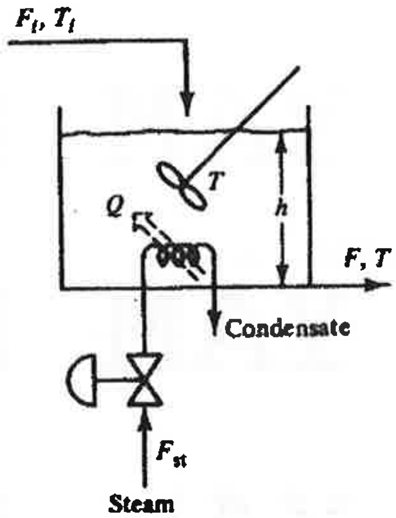

FIGURE Q1: A Stirred tank heater system

a. Identify the controlled, manipulated and disturbance variables in the system.

[6 marks]

b. Develop the dynamic models for the controlled variables identified in **part (a)**.

[10 marks]

c. Develop the transfer function model that relates h to F_i. Given $F = \alpha\sqrt{h}$ and the steady state value of h is 3.5 m. All initial conditions are zero.

[9 marks]

2. a. Derive the response of the process as a function of time for a unit step change in input.

i. $G(s) = \frac{(s+2)}{(s+3)}$

[4 marks]

ii. $G(s) = \frac{s(s+1)}{(s+2)(s+3)(s+4)}$

[6 marks]

b. Determine whether the processes are stable with appropriate justification.

i. $G(s) = \frac{2(s+1)}{s(s+2)(s+3)}$

[4 marks]

ii. $G(s) = \frac{2(s-1)}{(2s+1)(s^2-4s+12)}$

[4 marks]

c. For a step change of size 5 in the input, using final value theorem, determine the final change in the output.

a. $G(s) = \frac{2(s-1)}{(s+2)(s^2+8s+20)}$

[4 marks]

b. $G(s) = \frac{2}{(s^2+4)}$

[3 marks]

3. A feedback control is used to control a process as shown in **FIGURE Q3**. A unit step change in the set-point is introduced.

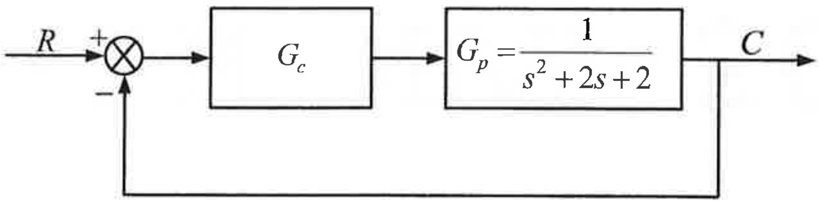

FIGURE Q3: A feedback control system

a. Sketch the output responses, $C(t)$, if proportional (P) and proportional-integral (PI) controllers are used.

[5 marks]

b. If PI controller with $\tau_I = 0.1$ is employed, determine the controller gain (K_c) value for a stable closed-loop system.

[12 marks]

c. Estimate the offset of the closed-loop response if a proportional controller with $K_c = 2$ is used.

[8 marks]

4. a. The operating conditions of a control valve is given in **TABLE Q4a**.

TABLE Q4a: Control valve operating conditions

Upstream pressure	75 psi
Downstream pressure	50 psi
Vena contracta pressure	45 psi
Fluid specific gravity	0.75
Normal flow rate	70 gpm
Normal opening range	50% - 70%

i. Select the appropriate size of a full port control valve with flow characteristics as given in **TABLE Q4b** in **APPENDIX IV**.

[7 marks]

ii. Determine the maximum liquid flowrate of the selected valve in **part (i)**.

[5 marks]

iii. Identify whether choked flow will occur or not.

[7 marks]

b. Propose the appropriate fail position of the control valve in the following services. Justify your answer.

i. A steam flow to a distillation reboiler.

[3 marks]

ii. A cooling water flow to a highly exothermic polymer reactor.

[3 marks]

-END OF PAPER-

TABLE A1: Laplace transforms for various time-domain functions

1	$f(t)$	F(s)
2	$\delta(t)$ (*unit impulse*)	1
3	$\begin{cases} 0 & t<0 \\ a & t \geq 0 \end{cases}$ (*step*)	$\frac{a}{s}$
4	at (*ramp*)	$\frac{a}{s^2}$
5	t^n	$\frac{n!}{s^{n+1}}$
6	e^{-at} (*Exponential*)	$\frac{1}{s+a}$
7	$\sin(\omega t)$	$\frac{\omega}{s^2+\omega^2}$
8	$\cos(\omega t)$	$\frac{s}{s^2+\omega^2}$
9	$e^{-at}\sin(\omega t)$	$\frac{\omega}{(s+a)^2+\omega^2}$
10	$e^{-at}\cos(\omega t)$	$\frac{s+a}{(s+a)^2+\omega^2}$
11	$e^{-at}f(t)$	$F(s+a)$
12	$f(t-t_0)$ *time delay*	$e^{-t_0 s}F(s)$
13	$\frac{df}{dt}$	$sF(s)-f(0)$
14	$\frac{d^n f}{dt^n}$	$s^n F(s)-s^{n-1}f(0)-s^{n-2}f^{(1)}(0)-\ldots-sf^{(n-2)}-f^{(n-1)}(0)$
15	$\int_0^t f(t)dt$	$\frac{F(s)}{s}$
16	$\lim_{t\to\infty} f(t)$ [final value theorem]	$\lim_{s\to 0}[sF(s)]$
17	$\lim_{t\to 0} f(t)$ [Initial vale theorem]	$\lim_{s\to\infty}[sF(s)]$

TABLE A2: Inverse Laplace transforms for various Laplace-domain functions

	$F(s)$	$f(t)$
1	1	$\delta(t)$ (unit impulse)
2	$\frac{1}{s}$	$S(t)$ (unit step)
3	$\frac{1}{s^2}$	t (ramp)
4	$\frac{1}{s^n}$	$\frac{t^{n-1}}{(n-1)!}$
5	$\frac{1}{s+a}$	e^{-at}
6	$\frac{1}{(s+a_1)(s+a_2)}$	$\frac{1}{a_1-a_2}\left(e^{-a_2 t}-e^{-a_1 t}\right)$
7	$\frac{s+a_3}{(s+a_1)(s+a_2)}$	$\frac{a_3-a_1}{a_2-a_1}e^{-a_1 t}+\frac{a_3-a_2}{a_1-a_2}e^{-a_2 t}$
8	$\frac{1}{(s+a)^n}$	$\frac{t^{n-1}e^{-at}}{(n-1)!}$ $(n>0)$
9	$\frac{1}{\tau s+1}$	$\frac{1}{\tau}e^{-t/\tau}$
10	$\frac{1}{s(\tau s+1)}$	$1-e^{-t/\tau}$
11	$\frac{1}{(\tau_1 s+1)(\tau_2 s+1)}$	$\frac{1}{\tau_1-\tau_2}(e^{-t/\tau_1}-e^{-t/\tau_2})$
12	$\frac{\tau_3 s+1}{(\tau_1 s+1)(\tau_2 s+1)}$	$\frac{1}{\tau_1}\frac{\tau_1-\tau_3}{\tau_1-\tau_2}e^{-t/\tau_1}+\frac{1}{\tau_2}\frac{\tau_2-\tau_3}{\tau_2-\tau_1}e^{-t/\tau_2}$
13	$\frac{1}{(\tau s+1)^n}$	$\frac{1}{\tau^n(n-1)!}t^{n-1}e^{-t/\tau}$
14	$\frac{1}{s(\tau^2 s^2+2\zeta\tau s+1)}$	$1-e^{-\zeta t/\tau}\left[\cos\left(\frac{\sqrt{1-\zeta^2}}{\tau}t\right)+\frac{\zeta}{\sqrt{1-\zeta^2}}\sin\left(\frac{\sqrt{1-\zeta^2}}{\tau}t\right)\right]$

EQUATIONS

1. **Liquid flow across control valve**

$$Q = Cv\sqrt{\frac{\Delta P}{SG}}$$ where

Cv = flow characteristic coefficient

ΔP = pressure drop across the valve (psi)

SG = specific gravity

2. **Chocked Equation**

$$K_m = \frac{\Delta P_a}{P_1 - P_{vc}}$$ where

ΔP_a = the allowable pressure drop (psi)

K_m = valve-recovery coefficient

P_1 = uptsream pressure (psi)

P_{vc} = vena-contracta pressure (psi)

3. **Routh Array**

$$a_n s^n + a_{n-1}s^{n-1} + \ldots + a_1 s + a_0 = 0$$

a_n	a_{n-2}	a_{n-4}
a_{n-1}	a_{n-3}	a_{n-5}
b_1	b_2	b_3
c_1	c_2	

$$b_1 = \frac{a_{n-1}a_{n-2} - a_n a_{n-3}}{a_{n-1}} \qquad c_1 = \frac{b_1 a_{n-3} - a_{n-1}b_2}{b_1}$$

$$b_2 = \frac{a_{n-1}a_{n-4} - a_n a_{n-5}}{a_{n-1}} \qquad c_2 = \frac{b_1 a_{n-5} - a_{n-1}b_3}{b_1}$$

$$\vdots \qquad\qquad \vdots$$

TABLE Q4b: Flow characteristics of a control valve

Equal Percentage

Equal Percentage Characteristic

Coefficients	Body Size, In.	Port Diameter, In.	Total Travel, In.	Valve Opening—Percent of Total Travel 10	20	30	40	50	60	70	80	90	100	K_m* and C_l
C_v (Liquid)	1	1	3/4	.834	1.22	1.79	2.54	3.60	5.46	8.04	10.4	11.3	12.0	.92
	1-1/2	1-1/2	3/4	1.18	1.76	2.63	3.58	5.17	7.63	10.5	17.0	22.8	28.9	.85
	2	2	1-1/8	2.18	3.35	4.55	6.40	9.10	13.5	22.0	34.6	44.5	50.0	.94
	3	3	1-1/2	4.13	7.07	10.6	15.8	23.6	39.0	62.4	92.4	112	120	.83
	4	4	2	5.54	9.39	14.4	20.5	29.1	41.0	61.9	108	155	183	.86
	1*	3/4	3/4	.361	.597	.878	1.38	1.98	3.02	4.51	6.30	7.37	7.84	.97
	1-1/2*	3/4	3/4	.354	.559	.874	1.34	2.02	3.01	4.61	6.78	8.54	9.71	.96
		1	3/4	.803	1.13	1.61	2.50	3.58	4.95	8.20	12.3	15.7	16.9	.93
	2*	1	3/4	.772	1.17	1.65	2.47	3.53	5.38	8.20	11.2	13.7	14.9	.93
		1-1/2	3/4	1.11	1.64	2.42	3.46	4.86	7.22	12.0	17.4	24.0	29.1	.83
	3*	1-1/2	3/4	1.17	1.75	2.46	3.62	4.66	7.06	11.0	17.9	25.4	31.5	.79
		2	1-1/8	2.01	3.14	4.57	6.39	9.01	12.8	22.0	37.1	51.8	60.9	.84
	4*	2	1-1/8	2.18	3.27	4.61	6.28	8.78	12.8	23.1	40.2	53.8	64.1	.83
		3	1-1/2	3.47	6.12	9.66	14.8	22.6	37.1	62.2	92.5	117	136	.84