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UNIVERSITY COLLEGE TATI

UNIVERSITY COLLEGE TATI (UC TATI)

FINAL EXAMINATION QUESTION BOOKLET

COURSE CODE	: BCE 3234
COURSE	: PROCESS CONTROL
SEMESTER/SESSION	: 1-2023/2024
DURATION	: 3 HOURS

Instructions:

1. This booklet contains 4 questions. Answer **ALL** questions.
2. All answers should be written in answer booklet.
3. Write legibly and draw sketches wherever required.
4. If in doubt, raise your hands and ask the invigilator.

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO
YOU ARE ALLOWED TO BRING ONE (1) A4 PAPER

THIS BOOKLET CONTAINS 8 PRINTED PAGES INCLUDING COVER PAGE

QUESTION 1

a) Classify TRUE or FALSE of the following statement:

i) A measured variable is essential for both feedback and feedforward control.

ii) In feedback control, the measured variable is the process variable to be controlled.

iii) In theory, feedforward control can achieve perfection as the controller can act through the manipulated variable even when the controlled variable stays at its desired value.

iv) Feedforward control has the capability to achieve perfect control, that is the output can be maintained at its desired value even when using an imperfect process model.

v) Feedback control will consistently take corrective action, irrespective of the precision of the employed process model or the origin of a disturbance.

(5 marks)

b)

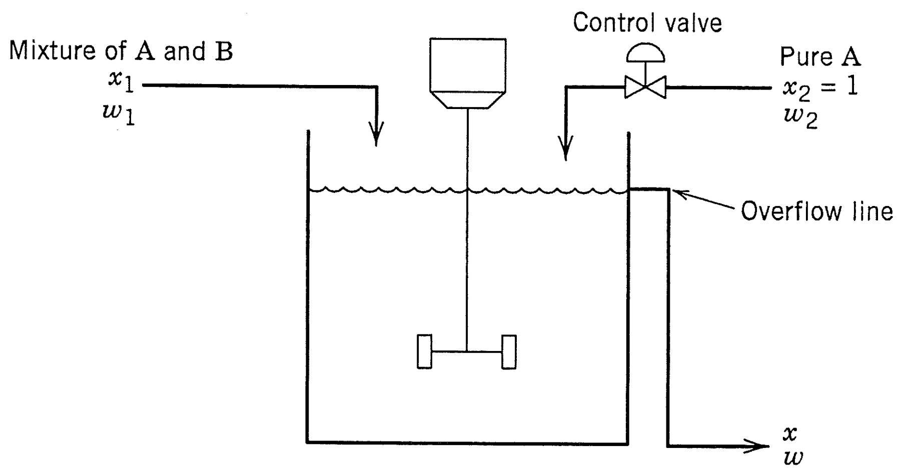

Figure 1

In Figure 1, a continuous stirred-tank blending system is depicted. It is assumed that the mass flow rate, w_1, remains constant, while the mass fraction of component

A, denoted as x_1, undergoes variations over time. Stream 2 contains pure A, resulting in x_2 being equal to 1. The mass flow rate of Stream 2 is represented by w_2. The fraction of A in the exit stream is indicated by x, and the desired value, or set point, is denoted as X_{sp}.

i) Diagnose:

a. Manipulated variable.
b. Control objective
c. Disturbance
d. How is the composition of the tank measured?
e. How is the conversion of the controller output (an electrical signal ranging from 4 to 20 mA) to an equivalent pneumatic signal P_t (3 to 15 psig) achieved?
f. How does the utilization of the transducer output signal contribute to the adjustment of the valve in the system?

(10 marks)

ii) Illustrate how the composition control system is employed in Figure 1 (Hint: Include electrical signal and pneumatic signal)

(5 marks)

iii) Illustrate complete qualitative block diagram for the process in (ii)

(5 marks)

QUESTION 2

a) Consider the stirred-tank blending process in Figure 1 (Page 2). If the nominal steady-state conditions are w_1 = 600 kg/min, w_2 = 2 kg/min, x_1 = 0.050, and x_2 = 1 (for pure solute). Also, the liquid volume and density are constant: V = 2 m^3 and ρ = 900 kg/m^3, respectively. Given:

$$\frac{X'(s)}{X_1'(s)} = G(s) = \frac{K_1}{\tau s+1} \text{ where } K_1 = \frac{w_1}{w} \text{ and } \tau = \frac{\rho V}{w}$$

i) Calculate the exit flowrate, *w*. (2 marks)

ii) Calculate the exit concentration, *x*. (2 marks)

iii) Compute K_1 and τ. (4 marks)

iv) Produce transfer function for $\frac{X'(s)}{X_1'(s)}$ (2 marks)

v) Build a mathematical equation for the response, *x(t)*, to a sudden change in x_1 from 0.050 to 0.075 that occurs at time, t = 0. (8 marks)

b) Solve the differential equation below using Laplace Transform. (7 marks)

$$5\frac{dy}{dt} + 4y = 2 \qquad y(0) = 1$$

QUESTION 3

a) A stirred tank reactor incorporates an internal cooling coil to eliminate heat generated during the reaction. The regulation of coolant flow rate is managed by a proportional controller to maintain a reasonably constant reactor temperature. The controller is designed to exhibit typical underdamped second-order temperature response characteristics when disturbed, whether by changes in feed flow rate or coolant temperature. In response to a sudden change in feed flow rate from 0.5 to 0.6 kg/s, the reactor contents, initially at 110°C, eventually reach temperatures of 112°C and 111.5°C at 1000 s and 3050 s, respectively, after the initiation of the change.

i) Illustrate the characteristics of the step response of this process. (4 marks)

ii) Determine gain of the transfer function (with units), τ and ξ (8 marks)

iii) Elucidate the transfer function in: (3 marks)

$$G(s) = \frac{Kp}{\tau^2 s^2 + 2\xi\tau s + 1}$$

b) Figure 2 shows the standard notations contains in quantitative block diagram of feedback control for stirred-tank blending system. Analyse and define the notations: Y, U, D, P, E, Y_m, Y_{sp}, $\tilde{Y}_{sp}$, Y_u, Y_d. (10 marks)

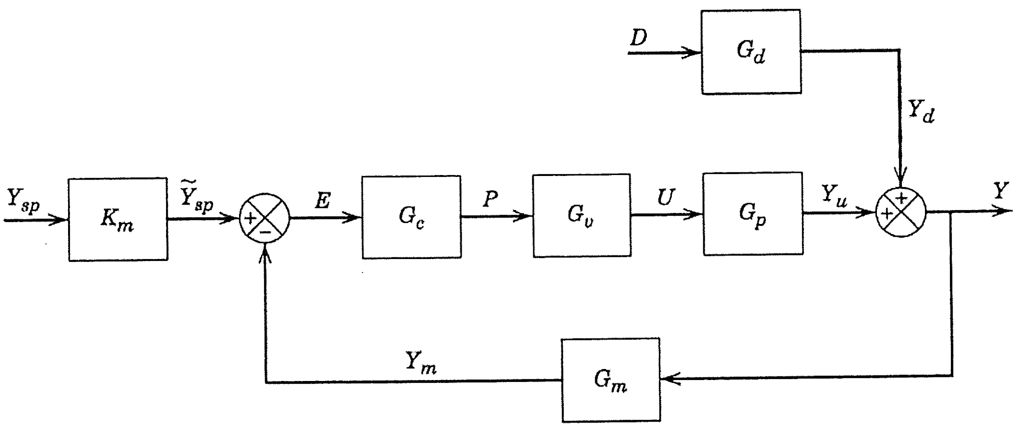

Figure 2

QUESTION 4

a) Considering a liquid-level P control system with given parameter values such as A = 3 ft², R = 1.0 min/ft², K_v = 0.2 ft³/min psi, K_m = 4 mA/ft, K_c = 5.33, K_{Ip} = 0.75 psi/mA, and τ_I= 3 min, and assuming the system is initially at the nominal steady state with a liquid level of 2 ft. If the set point is changed from 2 to 4 ft, calculate the time required for the system to reach 3 ft.

(15 marks)

b) Given the characteristics equation:

$$s^3 + 6s^2 + 11s + (6 + 4K_c) = 0$$

Determine the values of the controller gain, K_c, to ensure the stability of the feedback control system using Routh Array.

(10 marks)

--**End of question**--

ATTACHMENTS

Table 1: Laplace transform for various time domain function

$f(t)$	$F(s)$
1. $\delta(t)$ (unit impulse)	1
2. $S(t)$ (unit step)	$\frac{1}{s}$
3. t (ramp)	$\frac{1}{s^2}$
4. t^{n-1}	$\frac{(n-1)!}{s^n}$
5. e^{-bt}	$\frac{1}{s+b}$
6. $\frac{1}{\tau}e^{-t/\tau}$	$\frac{1}{\tau s+1}$
7. $\frac{t^{n-1}e^{-bt}}{(n-1)!}\ (n>0)$	$\frac{1}{(s+b)^n}$
8. $\frac{1}{\tau^n(n-1)!}t^{n-1}e^{-t/\tau}$	$\frac{1}{(\tau s+1)^n}$
9. $\frac{1}{b_1-b_2}(e^{-b_2t}-e^{-b_1t})$	$\frac{1}{(s+b_1)(s+b_2)}$
10. $\frac{1}{\tau_1-\tau_2}(e^{-t/\tau_1}-e^{-t/\tau_2})$	$\frac{1}{(\tau_1 s+1)(\tau_2 s+1)}$
11. $\frac{b_3-b_1}{b_2-b_1}e^{-b_1t}+\frac{b_3-b_2}{b_1-b_2}e^{-b_2t}$	$\frac{s+b_3}{(s+b_1)(s+b_2)}$
12. $\frac{1}{\tau_1}\frac{\tau_1-\tau_3}{\tau_1-\tau_2}e^{-t/\tau_1}+\frac{1}{\tau_2}\frac{\tau_2-\tau_3}{\tau_2-\tau_1}e^{-t/\tau_2}$	$\frac{\tau_3 s+1}{(\tau_1 s+1)(\tau_2 s+1)}$
13. $1-e^{-t/\tau}$	$\frac{1}{s(\tau s+1)}$
14. $\sin \omega t$	$\frac{\omega}{s^2+\omega^2}$

15. $\cos \omega t$		$\dfrac{s}{s^2 + \omega^2}$
16. $\sin(\omega t + \phi)$		$\dfrac{\omega \cos \phi + s \sin \phi}{s^2 + \omega^2}$
17. $e^{-bt} \sin \omega t$	b, ω real	$\dfrac{\omega}{(s + b)^2 + \omega^2}$
18. $e^{-bt} \cos \omega t$	b, ω real	$\dfrac{s + b}{(s + b)^2 + \omega^2}$
19. $\dfrac{1}{\tau\sqrt{1 - \zeta^2}} e^{-\zeta t/\tau} \sin(\sqrt{1 - \zeta^2}\, t/\tau)$ $(0 \le \lvert\zeta\rvert < 1)$		$\dfrac{1}{\tau^2 s^2 + 2\zeta\tau s + 1}$
20. $1 + \dfrac{1}{\tau_2 - \tau_1}(\tau_1 e^{-t/\tau_1} - \tau_2 e^{-t/\tau_2})$ $(\tau_1 \neq \tau_2)$		$\dfrac{1}{s(\tau_1 s + 1)(\tau_2 s + 1)}$
21. $1 - \dfrac{1}{\sqrt{1 - \zeta^2}} e^{-\zeta t/\tau} \sin[\sqrt{1 - \zeta^2}\, t/\tau + \psi]$ $\psi = \tan^{-1}\dfrac{\sqrt{1 - \zeta^2}}{\zeta}$, $(0 \le \lvert\zeta\rvert < 1)$		$\dfrac{1}{s(\tau^2 s^2 + 2\zeta\tau s + 1)}$
22. $1 - e^{-\zeta t/\tau}[\cos(\sqrt{1 - \zeta^2}\, t/\tau) + \dfrac{\zeta}{\sqrt{1 - \zeta^2}} \sin(\sqrt{1 - \zeta^2}\, t/\tau)]$ $(0 \le \lvert\zeta\rvert < 1)$		$\dfrac{1}{s(\tau^2 s^2 + 2\zeta\tau s + 1)}$
23. $1 + \dfrac{\tau_3 - \tau_1}{\tau_1 - \tau_2} e^{-t/\tau_1} + \dfrac{\tau_3 - \tau_2}{\tau_2 - \tau_1} e^{-t/\tau_2}$ $(\tau_1 \neq \tau_2)$		$\dfrac{\tau_3 s + 1}{s(\tau_1 s + 1)(\tau_2 s + 1)}$
24. $\dfrac{df}{dt}$		$sF(s) - f(0)$
25. $\dfrac{d^n f}{dt^n}$		$s^n F(s) - s^{n-1} f(0) - s^{n-2} f^{(1)}(0) - \cdots - s f^{(n-2)}(0) - f^{(n-1)}(0)$
26. $f(t - t_0)S(t - t_0)$		$e^{-t_0 s} F(s)$

[a]Note that $f(t)$ and $F(s)$ are defined for $t \ge 0$ only.

Time to first peak: $t_p = \pi\tau/\sqrt{1 - \zeta^2}$

Overshoot: $\text{OS} = \exp\left(-\pi\zeta/\sqrt{1 - \zeta^2}\right)$ $\text{OS} = a/b$ (% overshoot is 100 a/b).

Decay ratio: $\text{DR} = (\text{OS})^2 = \exp(-2\pi\zeta/\sqrt{1 - \zeta^2})$

Period: $P = \dfrac{2\pi\tau}{\sqrt{1 - \zeta^2}}$

$$\frac{H'(s)}{H'_{sp}(s)} = \frac{K_c K_{IP} K_v K_m/(\tau s + 1)}{1 + K_c K_{IP} K_v K_m/(\tau s + 1)} \qquad \frac{H'(s)}{H'_{sp}(s)} = \frac{K_1}{\tau_1 s + 1}$$

$$K_1 = \frac{K_{OL}}{1 + K_{OL}} \qquad \tau_1 = \frac{\tau}{1 + K_{OL}}$$

$$K_{OL} = K_c K_{IP} K_v K_P K_m$$