INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

End-Spring Semester 2023-2024 (Closed Book)

Course No.: CH 61016 | *Duration:* 3 hrs
Course Title: Process Dynamics and Control | *Total Marks*: 50
Department: Chemical Engineering
Instructions: 1. No need of graph paper, logbook 2. Assume any missing data

Answer all questions

Q1. (a) Configure the override controller with a boiler system for steam pressure control showing all relevant elements.
(b) Find the action (direct/reverse) of the involved controllers when the control valve is in air-to-open mode.
(c) Perform the RGA analysis (with finding relative gain and relative gain array) for a chemical process example that involves one-way interaction. Does the RGA analysis truly show one-way/both-way/no interaction?
(d) The transfer function of a deethanizer is given as:

$$G_p(s) = \begin{bmatrix} \dfrac{1.318e^{-2.4s}}{(18s+1)} & -\dfrac{e^{-4.2s}}{3s} \\ \dfrac{0.038(180s+1)}{(25s+1)(12s+1)(7s+1)} & \dfrac{0.36}{s} \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix}$$

Obtain the RGA for this system and use it to recommend loop pairing.

[2+1+(3+1)+3=10]

Q2. (a) Considering both measured disturbance d_1 and unmeasured disturbance d_2, one can have $d(s) = g_d(s)d_1(s) + d_2(s)$

Derive the IMC control action in terms of $u(s)$.

(b) Consider the following *gain plus dead time* process:

$$\bar{g} = \bar{k}\, e^{-\theta s}$$

(i) Design the IMC controller, using Pade approximation and simple factorization.
(ii) Develop the conventional feedback controller (g_c) that is equivalent to PID connected with a first-order filter in series
(iii) Find the simplified expressions for PID parameters (k_c, τ_I, τ_D) and filter time constant (τ_F)

(c) Derive the DMC control scheme for a CSTR (2×2 system) highlighting the computer-assisted sequential steps in details. Discuss the tuning heuristics of the multivariable DMC controller.

[2+(2+3+2)+(4+2)=15]

[Please Turn Over]

Q3. a) What is dual system and why is it important in state-space control system design?
b) Consider the following dynamic model of biochemical reactor

$$\frac{dC_b}{dt} = (\mu - F_d)C_b$$

$$\frac{dC_s}{dt} = F_d(C_{sf} - C_s) - \frac{\mu C_b}{P}$$

$$\mu = \frac{\mu_m C_s}{k_m + C_s + k_1 C_s^2}$$

Where, C_b and C_s are the biomass and substrate concentration respectively.

I. Derive linear state space model for the system to control C_b by manipulating F_d

II. Show that this reactor is not fully state controllable irrespective of parameter and steady state values.

[2+4=6]

Q4. Consider the following system

$$\frac{dx_1}{dt} = a_{11}x_1 + a_{12}x_2$$
$$\frac{dx_2}{dt} = a_{21}x_1 + a_{22}x_2 + bu$$
$$y = x_2$$

a) Derive reduced order state observer equation and corresponding error dynamics equation for the following system

b) Show that the reduced order observer controller system obeys separation principle

c) Derive the transfer function of reduced order observer – controller system.

[5+2+3=10]

Q5. Consider the design of regulator system for the following process

$$\frac{dx_1}{dt} = x_2$$
$$\frac{dx_2}{dt} = 20.6\, x_1 + 2u$$
$$y = x_1$$

a) Find the state feedback controller gain in terms of desired pole location at μ_1 and μ_2 using Bass-Gura method.

b) Determine optimal state feedback controller gain by minimizing the following performance index $J = \int_0^\infty (X^T X + u^2)dt$

c) Determine the μ_1 and μ_2 based on the results obtained from a) and b)
[$Algebraic\ Riccati\ Eqn\ is\ \ A^T P + PA - PBR^{-1}B^T P + Q = 0$]

[3+5+1=9]

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