INDIAN INSTITUTE OF TECHNOLOGY–KHARAGPUR

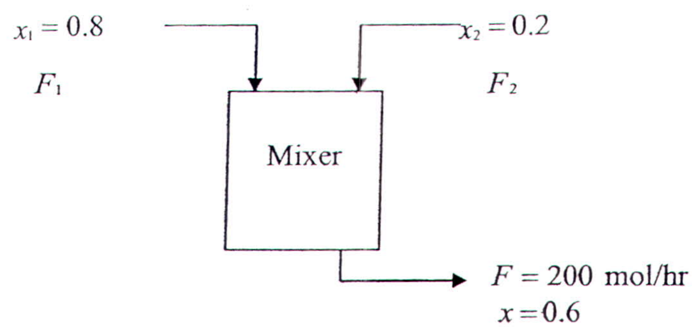
End-Spring Semester 2017-18 (Closed Book)

Course No.: CH 61016 | Max. Time: 3 hrs
Course Title: Process Dynamics and Control | Total Marks: 50

Answer all questions

Q1. (a) Derive the estimator-based inferential control scheme and develop its closed-loop block diagram with representing each block in terms of transfer function (G).

(b) Consider a mixer as shown below **[(2+2)+3+(2+2)+3=14]**



Two streams with flow rates (mol/hr) F_1 and F_2, and compositions (mole fraction) x_1 and x_2 in a chemical A are mixed in a vessel. Find the best control pairs by performing RGA analysis.

(c) A closed-loop process consists of the following four elements:

Process: $G_p = G\,e^{-t_d s}$ Controller: G_c

Measuring device: $G_m = 1$ Final control element: $G_f = 1$

Derive the smith predictor and develop its block diagram in the closed-loop system.

(d) Consider a feedback loop having the following transfer functions:

$$G_p = G\,e^{-t_d s} = \frac{e^{-0.5s}}{0.5s+1} \qquad G_m = G_f = 1$$

Although the model is perfectly known (i.e., $G = G'$), the dead-time (t_d) value is wrongly determined as 0.4 min. Discuss the impact of dead-time on the effectiveness of smith predictor when the process operates under P-only controller with $K_c = 5$.

Q2. (a) Consider a *gain-plus-dead time* process having the following transfer function:

$$\overline{G}_p(s) = \overline{k}\exp(-\theta s)$$ **[(2+3)+(2+2)+(1+1)=11]**

(i) Derive the expression for the IMC controller based on simple factorization and using second-order Pade approximation.

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(ii) Find the expressions for tunable parameters (i.e., K_c, τ_I, τ_D and τ_F) comparing the feedback controller (G_c) with a real PID controller in the form of:

$$(\text{Transfer function})_{PID} = K_c\left(1+\frac{1}{\tau_I s}+\tau_D s\right)\left(\frac{1}{\tau_F s+1}\right)$$

(b) Formulate the projected error of DMC and derive the final control expression in terms of control sequence. Mention the dimension of all matrices involved.

(c) What constraints are involved in DMC and how to handle them?

Q3. Consider the following model of a bioreactor

$$\frac{dx_1}{dt} = (\mu - 0.3)\, x_1$$

$$\frac{dx_2}{dt} = 0.3\,(4 - x_2) - \frac{\mu\, x_1}{0.4}$$

$$\mu = \frac{0.53\, x_2}{0.12 + x_2 + 0.45\, x_2^2}$$

a) Find the number of steady states and their values.

b) Calculate eigenvalues and eigenvectors and sketch Phase Portrait of system for the steady state where $0.5 < x_{1s} < 1$

[2+4]

Q4. The transfer function of a process is given by $\frac{y(s)}{u(s)} = \frac{5}{s(s+3)}$

a) Realize state space model for the system

b) Calculate state feedback controller gains **K** for the system using Bass-Gura approach for the desired closed loop system poles at $\frac{\sqrt{2}}{2} \pm \frac{\sqrt{2}}{2}j$

c) Find the reduced order observer gain $\mathbf{K_e}$ to place the observer poles at -5 and write the reduced order observer equation for this system.

d) Derive the observer-controller transfer function.

The general equation for reduced order observer is given below with usual notations (as mentioned in class)

$$\dot{\tilde{\eta}} = (\mathbf{A}_{bb} - \mathbf{K}_e\mathbf{A}_{ab})\tilde{\eta} + \left[(\mathbf{A}_{bb} - \mathbf{K}_e\mathbf{A}_{ab})\mathbf{K}_e + \mathbf{A}_{ba} - \mathbf{K}_e A_{aa}\right]y + (\mathbf{B}_b - \mathbf{K}_e B_a)u$$

where

$$\tilde{\eta} = \tilde{\mathbf{x}}_b - \mathbf{K}_e y = \tilde{\mathbf{x}}_b - \mathbf{K}_e x_1$$

[1+3+2+3]

Q5. a) State and explain Pontryagin's minimum principle

b) Derive infinite time linear quadratic regulator using pontryagin's minimization technique for a general linear state space model of a process. [5+5]

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