INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Mid-Spring Semester 2022-23 (closed book)

Course No.: CH21208 **Max. Time**: 2 hrs
Course Title: Instrumentation and Process Control **Total Marks**: 30

Answer all questions

Q1. Consider an isothermal stirred-tank blending system shown in Figure 1. Here, V denotes the liquid volume. The mass fraction of component A in the two inlet streams are x_1 and x_2, and that in the exit stream is x. The respective mass flow rates are F_1, F_2 and F.

(a) Stating suitable assumptions, develop the dynamic model.

(b) Supposing constant V, F_1, F_2 and F, develop the transfer function model in terms of gain K_p and time constant τ_p:

(i) When x_1 varies and x_2 remains constant,

(ii) When both x_1 and x_2 vary. **[2+(2+2)+(3+2)=11]**

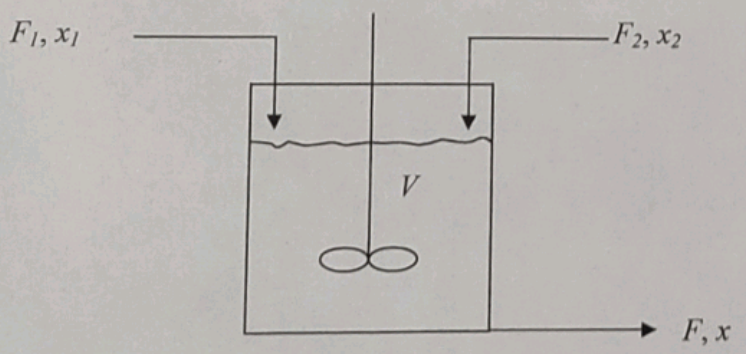

Fig. 1: A stirred-tank blending system.

(c) Consider a constant liquid holdup of 2 m^3 maintained to blend the said two streams whose densities are both approximately 900 kg/m^3. The density does not change during mixing.

(i) Assume that the process has been operating for a long period of time with flow rates of $F_1 = 500$ kg/min and $F_2 = 200$ kg/min, and the feed compositions (mass fractions) of $x_1 = 0.4$ and $x_2 = 0.75$. What is the steady state value of x?

(ii) Suppose that F_1 changes suddenly from 500 to 400 kg/min and remains at the new value. Determine an expression for $x(t)$.

Q2. (a) Why do we need to develop the mathematical model of a process we want to control?

(b) Derive the standard expression of decay ratio for an underdamped response.

(c) With an example of first-order system, show how the time constant is correlated with storage capacitance and resistance to heat flow. **[2+3+3+3+8=19]**

(d) How the system responds when the real part of its complex poles is zero? Mathematically prove it.

(e) Two noninteracting liquid tanks having the following transfer functions are connected in series (see Figure 2):

$$G_1(s) = \frac{K_1}{\tau_1 s + 1} \text{ (for Tank 1)} \qquad G_2(s) = \frac{K_2}{\tau_2 s + 1} \text{ (for Tank 2)}$$

Consider $K_1 = K_2 = 1$ and $\tau_1 = \tau_2 = 1$.

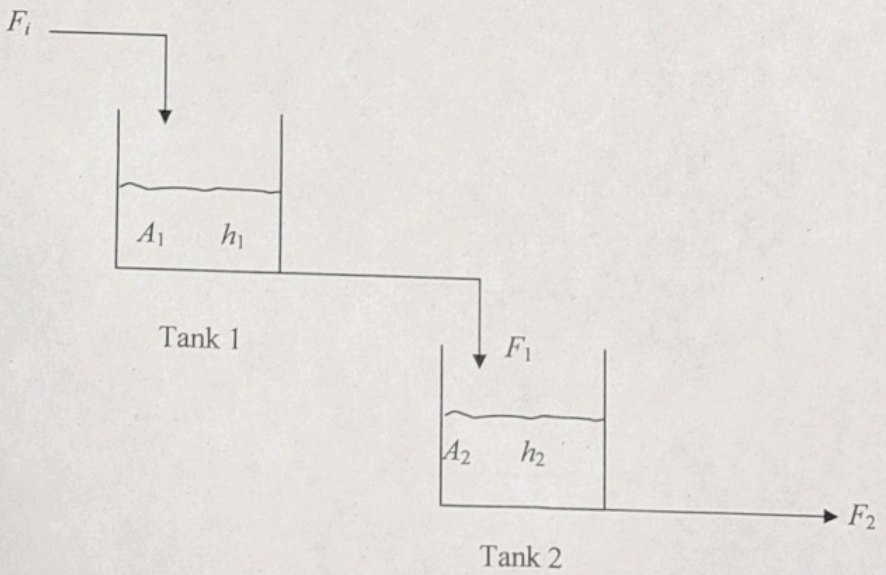

Fig. 2: Two noninteracting tanks in series.

Obtain an expression for the response of $h_2'(t)$ (the level in the second tank as a deviation from its initial steady state value) to a unit step change in the inlet flow rate to Tank 1.

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INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

End-Spring Semester 2022-23 (closed book)

Max. Time: 3 hrs
Total Marks: 50

Course No.: CH21208
Course Title: Instrumentation and Process Control

Answer all questions

Q1. (a) What is derivative kick? Is there any way to overcome this problem in the feedback controller? **[2+2+2+(2+2+2)=12]**

(b) Find the amplitude ratio (AR) and phase angle (ϕ) for the PID controller.

(c) What are the major limitations of Ziegler-Nichols tuning method?

(d) Consider a closed-loop process shown in Fig. 1, in which a PID controller is used to control the system.

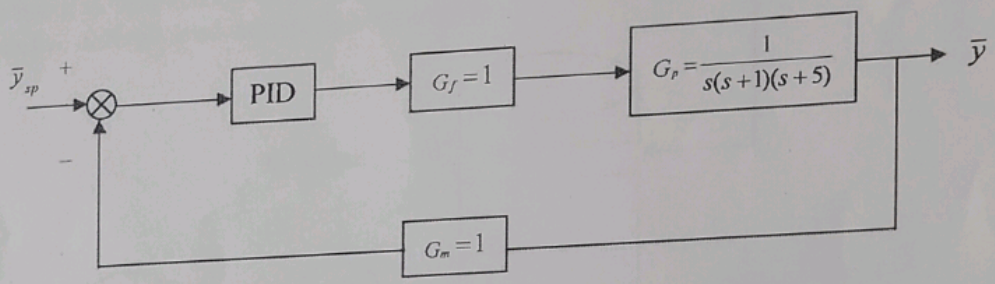

Fig. 1. A closed-loop process with PID controller.

(i) Find the ultimate gain (K_u) and ultimate period (P_u).

(ii) Use the Tyreus – Luyben recommended settings and tune the PID controller.

(iii) Find the pole(s) and zero(s) of the PID controller.

Q2 (a) Show for the following system that the AR of $G_{OL}(s)$ equals unity at cross over frequency provides oscillations in output (y) with constant amplitude: **[3+3+1+3=10]**

$$G_p(s) = \frac{e^{-0.123s}}{0.1s+1} \qquad G_c = K_c \qquad G_f = G_m = 1$$

(b) Investigate the stability of a closed-loop system whose characteristic equation has the following form:

$$8s^3 + 6s + 3 = 0$$

(c) What is the basic difference between the cascade and the feedforward-feedback combined control scheme in terms of their application?

(d) The transfer functions of a process with respect to manipulated variable and disturbance are given, respectively, as:

$$G_P = \frac{K_P}{(\tau_1 s+1)(\tau_2 s+1)} \qquad G_d = \frac{K_d}{(\tau_3 s+1)}$$

Design the feedforward controller that is physically realizable.

Q3. (a) Consider a liquid tank system shown in Fig. 2. The liquid level should be maintained above height h_2 to avoid cavitation at the pump.

(i) Develop the override control scheme.

(ii) Mention the action (direct/reverse) of the controllers. **[(2+2+2)+2 = 8]**

(iii) Explain how the override controller works when the level is at h_1.

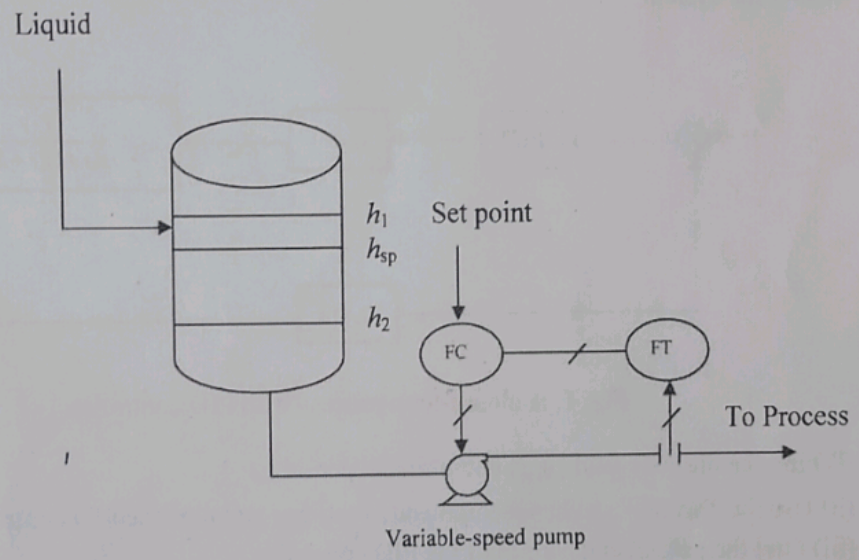

Fig. 2. The liquid tank under flow control.

(b) Discuss a suitable control scheme used to keep the ratio of fuel/air fed to a combustion chamber at its optimum value.

Q4 (a) What is the difference between a variable conversion element and variable manipulation element? Give examples. **[1.5]**

(b) What is the difference between an active and passive transducer? Give example for both kind. **[1.5]**

(c) What is the difference between null and deflection mode of measurement? Discuss the relative merits and demerits of these two methods with examples. **[1.5]**

(d) What are spurious inputs? What are different kinds of spurious inputs usually present? Give examples. **[1.5]**

Q5 (a) Sketch a flapper nozzle system and explain how it converts a displacement signal into a pneumatic signal. **[2]**

(b) Sketch a control valve and identify various parts of the control valve and actuator. **[1.5]**

(c) What is the difference between a fail open and a fail close control valve? Describe a situation where you will use a fail open control valve and another situation where you will use a fail close control valve. **[1.5]**

(d) What is inherent control valve characteristics and installed characteristics? Sketch various commonly encountered inherent control valve characteristics. **[2]**

Q6 (a) Crude oil is flowing through a pipeline of 1 m dia. What type of flowmeter is most suitable here? Justify your answer. **[1]**

(b) A highly viscous polymeric fluid which has large number of small trapped gas bubbles is flowing through a circular tube at a very low rate. How to obtain the flow rate of such a flow? **[1]**

(c) What is reference junction correction? Discuss relative merits and demerits of thermocouple and thermistors. **[2]**

(d) Draw symbols for process lines, pneumatic lines, safety relief valve and needle valve. How to determine if an instrument is field mounted, panel mounted or DCS display? **[2]**

(e) Discuss two different level monitoring methods. **[1]**

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