Exercise Questions for Chapter 7: Complex Control Schemes

1. Consider the cascade control system in Fig. Q1.

   (a) Specify K_{c2} so that the gain margin $\geq$ 1.7 and phase margin $\geq 30^o$ for the slave loop.

   (b) Then specify K_{c1} and τ_I for the master loop using the Ziegler-Nichols tuning relation.

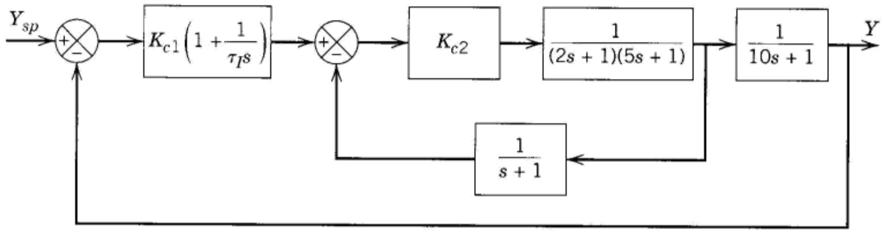

Fig. Q1 Cascade control system

2. A cascade control configuration is sometimes used to separate different objectives of feedback control. For instance, first an inner loop can be used to stabilize the process, and then an outer loop can be used to control the output to track set-point changes and reject disturbances. An example of a cascade control system is shown in Fig. Q2. The process transfer function

$$G_p = \frac{s+1}{s-3}$$

   is unstable.

   (a) Determine the maximum range of K_{c2} values for which the inner loop will be stable.

   (b) Now assume K_{c2} = 6 and G_{c1} is a PI controller with gain K_{c1} and τ_{I1}. Find values of K_{c1} and τ_1 such that the closed-loop poles of the transfer function from Y_{sp} to Y(s) are at $s = -0.5 \pm 0.2j$.

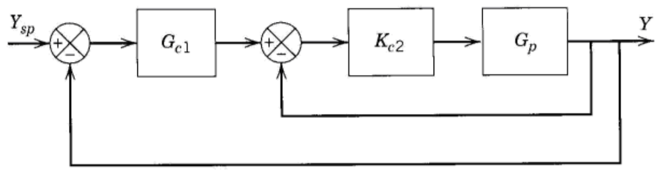

Fig. Q2. Cascade control for unstable process

3. It is desired to control liquid level h_2 in the storage tank system shown in Figure Q3 by manipulating flow rate q_3. Disturbance variable q_1 can be measured. Use the information available to do the following:

   (a) Draw a block diagram for a feedforward-feedback control system.

   (b) Derive an ideal feedforward controller based on a steady-state analysis.

(c) Suppose that the flow-head relation for the hand valve is $q_2 = \sqrt{h_1 - h_2}$. Does the ideal feedforward controller of part (b) change?

Available Information

(i) The two tanks have uniform cross-sectional areas, A_1 and A_2, respectively.

(ii) The valve on the exit line of Tank 1 acts as a linear resistance with a flow-head relation,

$$q_2 = (h_1 - h_2)/R.$$

(iii) The transmitters and control valve are pneumatic instruments that have negligible dynamics.

(iv) The pump operates so that flow rate q_3 is independent of h_2 when the control valve stem position is maintained constant.

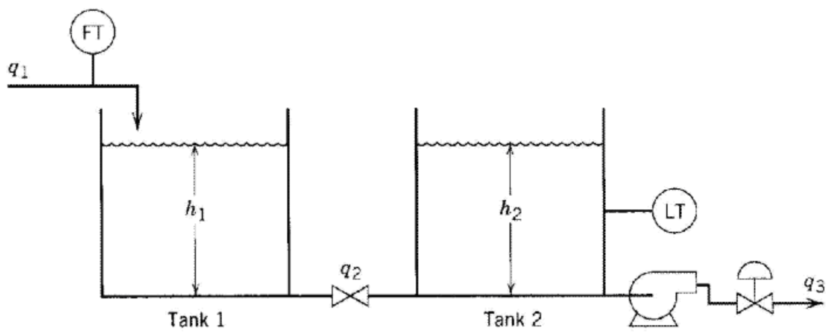

Figure Q3. Storage tank system

4. For the liquid storage system shown in Figure Q4, the control objective is to regulate liquid level h_2 despite disturbances in flow rates, q_1 and q_4. Flow rate q_2 can be manipulated. The two hand valves have the following flow-head relations:

$$q_3 = C_1\sqrt{h_1} \qquad\qquad q_5 = C_2\sqrt{h_2}$$

Do the following, assuming that the flow transmitters and the control valve have negligible dynamics:

(a) Draw a block diagram for a feedforward control system for the case where q_1 can be measured and variations in q_4 are neglected.

(b) Design a feedforward control law for case (a) based on a steady-state analysis.

(c) Repeat part (b) but consider dynamic behavior.

(d) Repeat parts (a) through (c) for the situation where q_4 can be measured and variations in q_1 are neglected.

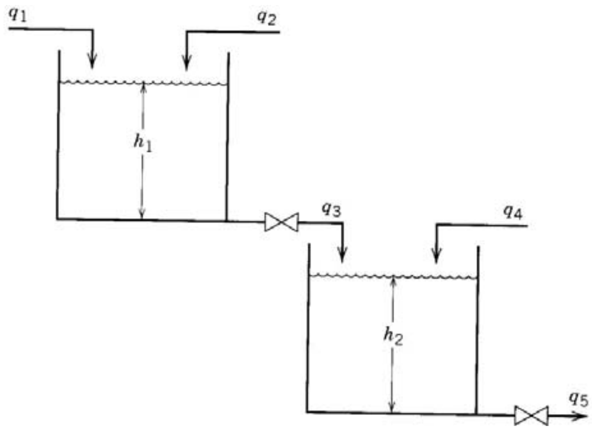

Figure Q4. Liquid storage system

5. A feedforward control system is to be designed for the two-tank heating system shown in Figure Q5. The design objective is to regulate temperature T_4, despite variations in disturbance variables T_1 and w. The voltage signal to the heater p is the manipulated variable. Only T_1 and w are measured. Also, it can be assumed that the heater and transmitter dynamics are negligible and that the heat duty is linearly related to voltage signal p.

   (a) Design a feedforward controller based on a steady-state analysis. This control law should relate p to T_{1m} and w_m .

   (b) Is dynamic compensation desirable? Justify your answer.

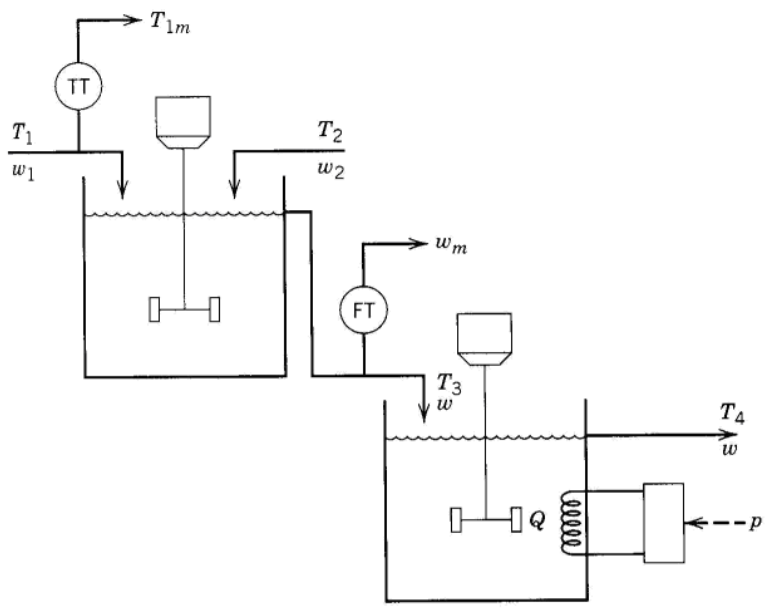

Figure Q5. Two-tank heating system

6. It is desired to design a feedforward control scheme in order to control the exit composition x_4, of the two tank blending system shown in Figure Q13. Flow rate q_2 can be manipulated, while disturbance variables, q_5 and x_5, can be measured. Assume that controlled variable x_4, cannot be measured and that each process stream has the same density. Also, assume that the volume of liquid in each tank is kept constant by using an overflow line. The transmitters and control valve have negligible dynamics.

   (a) Using the steady-state data given below, design an ideal feedforward control law based on steady-state considerations. State any additional assumptions that you make.

   (b) Do you recommend that dynamic compensation be used in conjunction with this feedforward controller? Justify your answer.

Steady-State Data

Stream	Flow (*gpm*)	Mass Fraction
1	1900	0.000
2	1000	0.990
3	2400	0.167
4	3400	0.409
5	500	0.800

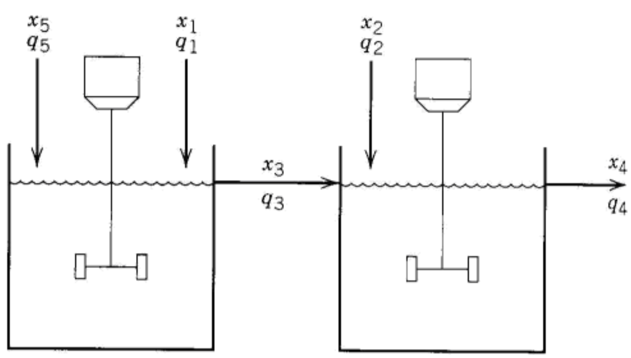

Figure Q6. Two tank blending system

7.

   (a) Figure Q7a shows a feedback control scheme for a blending process that is subject to significant disturbances. It is desired to augment this scheme with feedforward control. Of the four potential locations for the feedforward measurement indicated in the diagram, A, B, C, or D, which would be the best? The θ values noted in the diagram correspond to the average residence time in the indicated hollow pipes.) Justify your answer briefly.

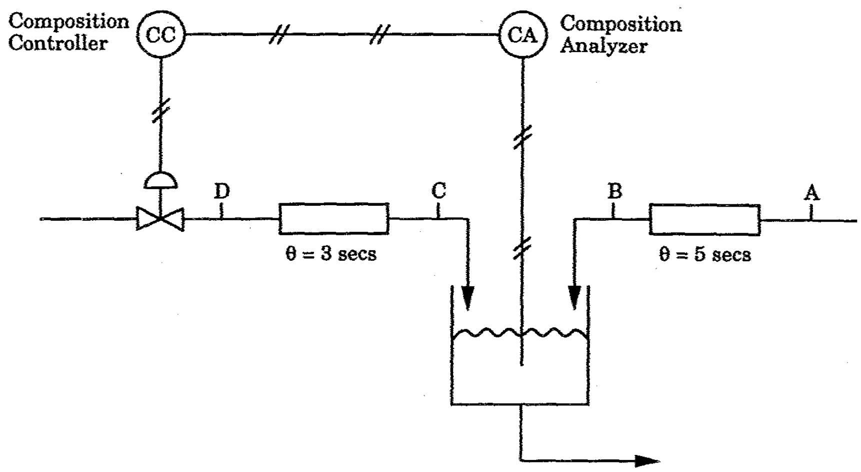

Figure Q7. A feedback control scheme for a blending process

(b) Figure Q7b shows a schematic diagram for a heat exchanger exit temperature control problem. The exit temperature of the process stream is influenced by the steam flowrate into the heat exchanger shell, and by the erratically varying inlet temperature of the process stream. The steam flowrate itself is also subject to erratic fluctuations induced by unsteady, unpredictable, and unmeasured steam supply pressure. Temperature measurements are provided by two temperature sensors and accompanying transmitters indicated as TTI and TT2 in the diagram; and steam flow measurements are provided by a flowmeter and the accompanying flow transmitter; FT, also indicated in the diagram.

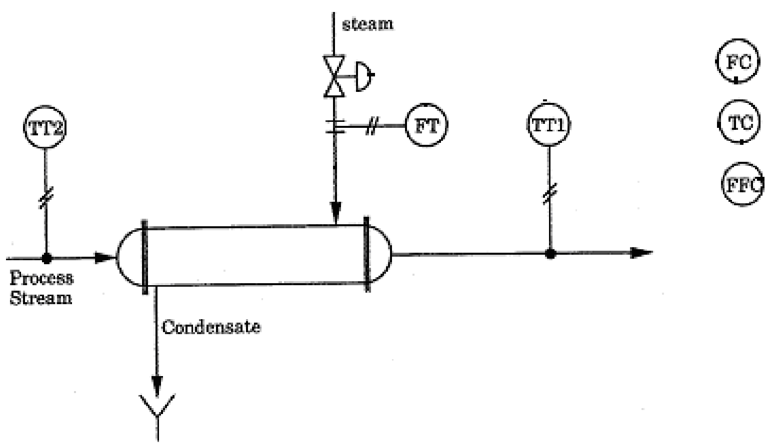

Figure Q7b Schematic diagram of heat exchanger exit temperature control

8. Consider the stirred-tank heating system shown in Fig. Q85. It is desired to control temperature T_1 by adjusting the heating rate Q_1 (Btu/h) via voltage signal V_1 to the SCR. It has been suggested that measurements of T_1 and T_0, as well as T_2, could provide improved control of T_2.

   (a) Briefly describe how such a control system might operate and sketch a schematic diagram. State any assumptions that you make.

(b) Indicate how you would classify your control scheme, for example, feedback, cascade, or feed-forward. Briefly justify your answer.

(c) Draw a block diagram for the control system.

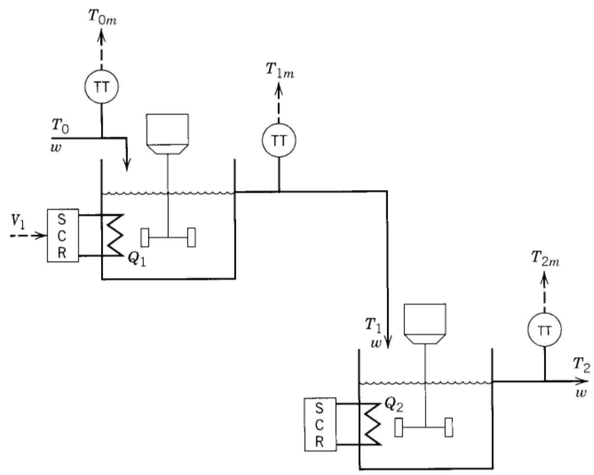

Fig. Q8 The stirred-tank heating system

9. Shinskey (1994) has proposed a delay-time compensator of the form,

$$G_c = K_c \left(\frac{1+\tau_1 s}{1+\tau_1 s - e^{-\theta s}} \right)$$

for a FOPTD process, with $K_c = \dfrac{1}{K_p}$ and $\tau_1 = \tau$.

(a) Derive the closed-loop transfer function and show that the time delay is eliminated from the characteristic equation.

(b) Will the closed-loop response exhibit overshoot?

10. Applepolscher has designed a Smith predictor with proportional control for a control loop that regulates blood glucose concentration with insulin flow. Based on simulation results for a FOPTD model, he tuned the controller so that it will not oscillate. However, when the controller was implemented, severe oscillations occurred. He has verified through numerous step tests that the process model is linear. What explanations can be offered for this anomalous behavior?

11 A Smith predictor is to be used with an integrator-plus-time-delay process, $G(s) = \dfrac{2}{s} e^{-3s}$.

For a unit step disturbance and $G_d = G$, show that PI control will not eliminate offset even when the model is known perfectly. Use equation

$$\frac{Y(s)}{D(s)} = \frac{G_d\left(1+G_cG^*(1-e^{-\theta s})\right)}{1+G_cG^*}$$

as the starting point for your analysis.

12. In Chapter 5, we introduced the Direct Synthesis design method in which the closed-loop servo response is specified and the controller transfer functions are calculated algebraically. For an IMC controller, show that setting $G_+ = e^{-\theta s}$ leads to a Smith predictor controller structure when G=$\tilde{G}$ for a FOPTD process.