Process Control, 3P4

Written midterm 2, 13 March 2014

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Note:

- You may bring in any printed materials to the midterm; any textbooks, any papers, *etc*.
- You may use any calculator during the midterm.
- **To help us with grading, please start each question on a new page, but use both sides of each page in your booklet**.
- You may answer the questions in any order on all pages of the answer booklet.
- This exam requires that you apply the material you have learned here in 3P to new, unfamiliar situations, which is the level of thinking we start to require from students that will be graduating or working in co-ops in a year from now.
- Any ambiguity or lack of clarity in a question may be resolved by making a suitable and justifiable assumption, and continuing to answer the question with that assumption(s).
- **Total marks**: 54 marks, 12.5% of course grade.
- Total time: 2 hours. There are 4 pages on the exam, please ensure your copy is complete.

Question 1 [6 x 2 = 12]

The questions below are related to a PID controller, with control law given in the time-domain. This is the form recommended for implementation.

$$\text{MV}(t) = K_c \left(E(t) + \frac{1}{T_I} \int_0^t E(t^*)\, dt^* - T_D \frac{d\,\text{CV}}{dt} \right)$$

1. Clearly describe in one sentence what the purpose of the integral mode is, i.e. the T_I term.
2. We learnt in class that the last term is derived in textbooks as

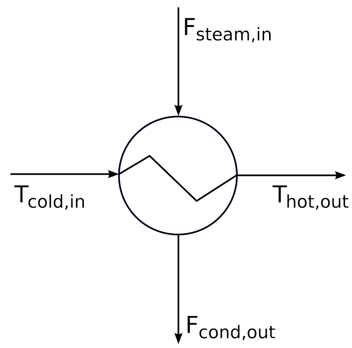
   $$+T_D \frac{d\,\text{E}}{dt}$$

   Why is the recommended form, shown at the start of this question, preferred over this form?
3. Under which condition is the derivative mode often set to zero?
4. Should the integral mode ever be turned off? Explain your answer in a single sentence.
5. We learnt about the Ciancone tuning rules (*see last page of this test*) to find initial values of K_c, T_I and T_D. What main criterion is these Ciancone rules optimizing to provide tuning values for a first-order plus time delay (FOPTD) process?
6. If you were setting the tuning for a FOPTD process and did not have a copy of the Ciancone rules with you, what single value of $\dfrac{T_I}{\theta + \tau}$ would you remember for the rest of your career that would be a good enough guess for T_I? Justify why.

Question 2 [18 = 5 + 4 + 5 + 4]

1. Describe what the time-domain response to a step input for the following heat exchanger system would be, given by the transfer function below. Show all calculations. **[5]**

$$\frac{T_{\text{hot,out}}(s)}{F_{\text{steam,in}}(s)} = \frac{2}{15s^2 + 8s + 1}$$

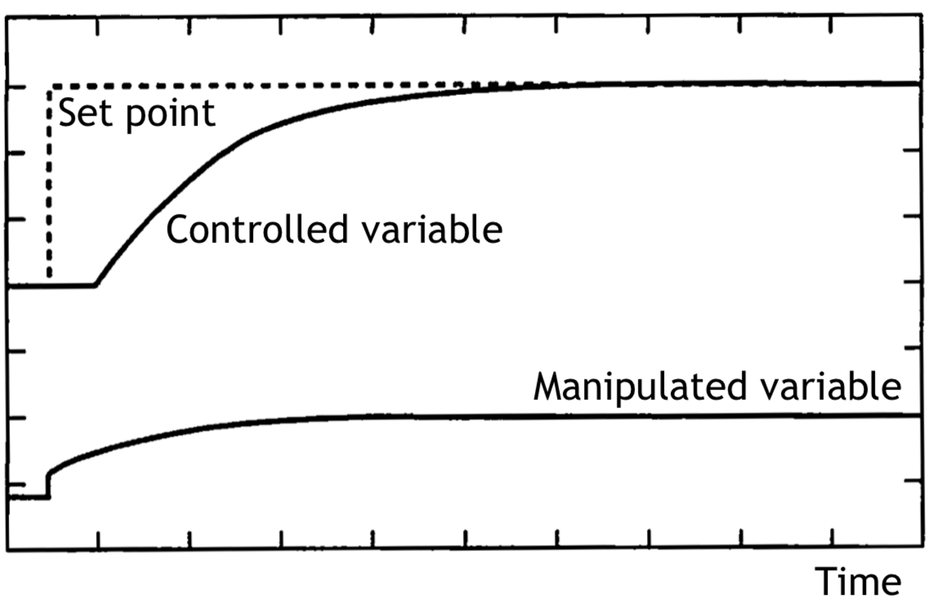


2. For the above heat-exchanger system, the objective is to control the outlet temperature $T_{\text{hot,out}}$ by manipulating the $F_{\text{steam,in}}$. Give two complete and specific examples of disturbances that will upset the process if there is no feedback control. **[4]**

3. You are responsible for operating the primary reactor in your plant. It is a CSTR with volume $5.6\,\text{m}^3$. The current flow rate into the tank is $0.4\,\text{m}^3$.min^{-1}.

   You increase the feed concentration by 20% to alter the reaction kinetics and product purity. Approximately how long before the tank stabilizes again? **[5]**

4. The following output is from a process that is controlled by a PI controller.

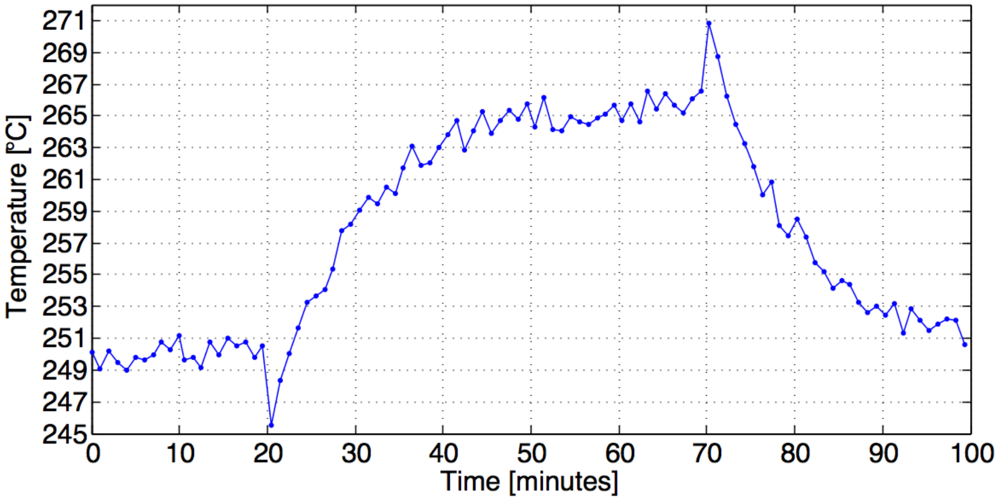


   (a) What two things can you change to reduce the IAE? **[2]**

   (b) What will happen to the manipulated variable when you make those changes? **[2]**

Question 3 [10]

The operator made a mistake! He increased the pressure to the gas-phase reactor, which shifted the equilibrium, changed the kinetics, and altered the heat released by the exothermic reaction.



He made the increase of 200 kPa at 10 minutes; at time 60 minutes he realized the mistake and dropped the pressure back down by 200 kPa again. Although this disrupted the production, your company got a free experiment out of this. Use the above data to estimate the parameters of a suitable transfer function model that relates the input (pressure) to the output (temperature). Provide units for all parameters and justify all your work with suitable reasons.

Question 4 [14]

You are a new employee at a continuous (not batch) chemical plant and the area you are responsible for contains an important feedback control loop that controls product purity.

Customers require your product to have consistent purity throughout the 8 hours that it takes to continuously produce the product. Every 8 hours the company switches production schedules to new settings for the next customer's product, so about 3 switches are made per day.

Purity, $P(t)$, is affected by many factors, but the one factor most easily changed is the current, $I(t)$, that is supplied to the electrical heating coil in the reactor. Your electrical engineering colleague provides you with the following relationship that the previous engineer in your position derived:

$$P(t) = \left[-2.4 + 2.4e^{-(t-5)/15}\right] \mathcal{S}\left(t-5\right)$$

This is the time-domain response to a 1.0 amp step increase in $I(t)$; the t represents time in minutes.

Your boss wants you retune the control loop; you have one chance to set either the PI or PID controller tuning. Clearly describe your process that you will follow, explaining your thinking.

In your answer draw a transfer function block diagram for the entire system.

The end.

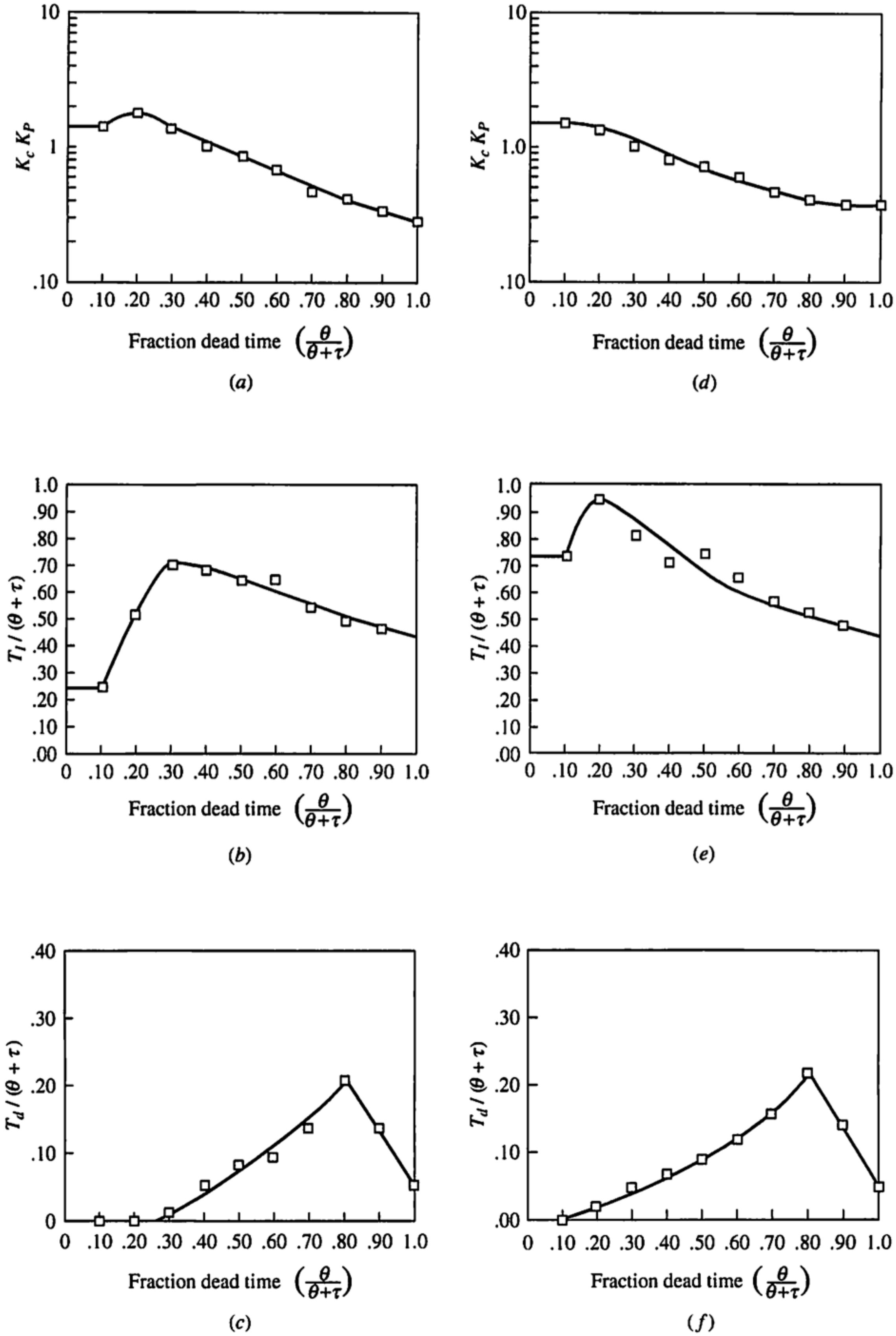


FIGURE 9.5

Ciancone correlations for dimensionless tuning constants, PID algorithm. For disturbance response: (*a*) control system gain, (*b*) integral time, (*c*) derivative time. For set point response: (*d*) gain, (*e*) integral time, (*f*) derivative time.

1. Ensure that the performance goals and assumptions are appropriate.
2. Determine the dynamic model using an empirical method (e.g., the process reaction curve), giving K_p, θ, and τ.
3. Calculate the fraction dead time, $\theta/(\theta+\tau)$.
4. Select the appropriate correlation, disturbance, or set point; use the disturbance if not sure.
5. Determine the dimensionless tuning values from the graphs for $K_c K_p$, $T_I/(\theta+\tau)$, and $T_d/(\theta+\tau)$.
6. Calculate the dimensional controller tuning, e.g., $K_c = (K_c K_p)/K_p$.
7. Implement and fine-tune as required (see Section 9.5).