Charles Darwin University

Final Examination

Family Name	
Given Name/s	
Student Number	
Teaching Period	Semester 2, 2018

ENG445 – Process Control and Simulation	DURATION	
	Reading Time:	10 minutes
	Writing Time:	180 minutes

INSTRUCTIONS TO CANDIDATES

1. Read all questions carefully.
2. Answer ALL questions.
3. Show all working (calculations and sketches).
4. This exam constitutes 50% of the total marks for this Unit.
5. Total marks available on this exam = 100.
6. Use dark blue or black ink.

EXAM CONDITIONS

<u>You may begin writing from the commencement of the examination session.</u> The reading time indicated above is provided as a guide only.

This is a RESTRICTED OPEN BOOK examination

Any non-programmable calculator is permitted

One A4 sheet of handwritten double-sided notes permitted

No dictionaries are permitted

ADDITIONAL AUTHORISED MATERIALS	EXAMINATION MATERIALS TO BE SUPPLIED
No additional printed material is permitted	1 x 20 Page Book Reference Information

THIS EXAMINATION IS PRINTED DOUBLE-SIDED.

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Question 1

A group of engineers have developed a new process that follows the transfer function $\frac{Y_{(s)}}{U_{(s)}} = \frac{1}{1-\tau s}$, where $\tau > 0$. One of the engineers suggested that the process can be controlled by using a proportional only controller.

1. Develop the block diagram for the controlled process. (5 marks)
2. Find the range for Kc values that yield a stable response (5 marks)
3. If $\tau = 20$ find the value of Kc that yields a pole at $s = -0.1$. what is the offset at that condition? (10 marks)

20 marks

Question 2

A theoretical force balance for a control valve as the one shown below is described by a differential equation as follows $PA_D + M\frac{g}{g_c} - Kx - P_f A_P - R\frac{dx}{dt} = \frac{M}{g_c}\frac{d^2x}{dt^2}$, where

M= mass of the movable stem = $10\ lb_m$

P = valve air pressure input

A_D = diaphragm area

A_P = valve plug area

g, q_c = gravity and conversion constant = 32.17 $^{ft}/_{s^2}$, 32.17 $\frac{lb_f}{^{ft}/_{s^2}}$

K = spring constant = $3600\ ^{lb_f}/_{ft}$

P_f = fluid pressure

R = coefficient of friction = $15000\ ^{lb_f}/_{ft/s}$

x = valve position

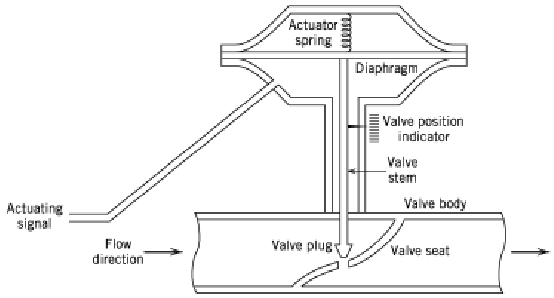

Figure 1. Control valve. Taken from Seborg, D. (2011). *Process dynamics and control* (3rd ed.). Hoboken, N.J.: John

If we assume that the equation is linear (all coefficients are constants),

1. find values of the coefficients of the equation (in deviation variables form) (5 marks)
2. determine whether the valve dynamic behaviour is overdamped or underdamped. (5 marks)
3. Use the eigenvalues to evaluate the stability of the valve. (10 marks)

Hint: The roots of a second order equation are given by

$$root = \frac{-b \pm \sqrt[2]{b^2 - 4ac}}{2a}$$

20 marks

Question 3

It is desired to control the exit temperature T_3 of the tank shown in the figure below.

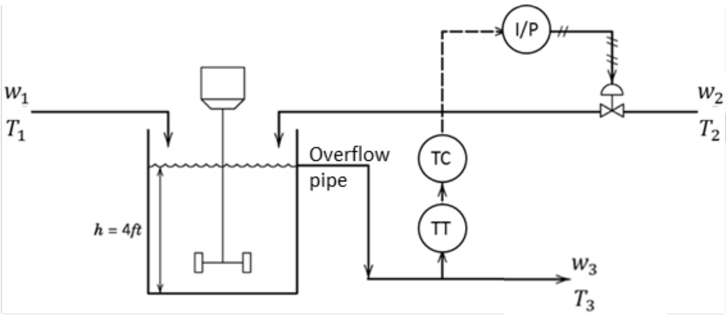

Figure 2. stirred tank. Modified from Seborg, D. (2011). *Process dynamics and control* (3rd ed.). Hoboken, N.J.: John

The following is the available information of the process.

1. The tank is perfectly mixed.
2. An overflow pipe is used to keep the mixture height at 4ft. $w_3 = w_1 + w_2$
3. The mass flow rate and the temperatures of stream 2, w_2 and T_2, vary with time, whereas those of stream 1 are constant.
4. The density and heat capacities of all three streams are identical and do not vary with time.
5. There is a 1-minute delay associated with the temperature measurement. The transmission output signal varies linearly from 4 to 20 mA as T_3 varies from $158°\text{F}$ to $194°\text{F}$.
6. The pneumatic control valve has negligible dynamics ($\tau_{valve} = 0$). Its steady-state behaviour is summarized below where $P_t(Psi)$ is the air pressure signal to the control valve from the I/P transducer.

$P_t(Psi)$	$w_2\left({lbm}/{min}\right)$
6	166.0
9	124.5
12	83.0

7. An electronic, direct-acting PI controller is used.
8. The current-to-pressure transducer has negligible dynamics ($\tau_{IP} = 0$) and a gain of $K_{IP} = 0.3\ {psi}/{mA}$.
9. The nominal operating conditions are:

$$\rho = 75\frac{lbm}{ft^3}; C_p = 1.0\frac{BTU}{lb_m\text{°F}};\ \bar{T}_3 = 176\ \text{°F}$$

$$\bar{w}_1 = \bar{w}_2 = 75\frac{lbm}{min};\ \bar{T}_1 = 158\ \text{°F}; \bar{T}_2 = 194\ \text{°F}$$

The tank is cylindrical with a diameter of $4ft$.

1. Demonstrate that the transfer functions of the process $\frac{T'_{3(s)}}{W'_{2(s)}}$ and $\frac{T'_{3(s)}}{T'_{2(s)}}$ are given by

$$\frac{T'_{3(s)}}{W'_{2(s)}} = \frac{\frac{1}{\bar{w}_2}(\bar{T}_2 - \bar{T}_3)}{\left(\frac{m}{\bar{w}_2}s + 1\right)} \quad ; \quad \frac{T'_{3(s)}}{T'_{2(s)}} = \frac{1}{\left(\frac{m}{\bar{w}_2}s + 1\right)}$$

(10 marks)

2. Derive an expression for each transfer function and substitute numerical values when possible. Assume that there is an PI controller. (20 marks)
3. Draw a block diagram for the temperature control scheme, using the symbols in the figure. Indicate the units in all signals. (5 marks)

35 marks

Question 4

Use the Routh array method to proof that the following characteristic equation is stable

$$s^4 + 3s^3 + 5s^2 + 4s + 2 = 0$$

10 marks

Question 5

The block diagram below shows a control system for two stirred tanks heated. Calculate the values of K_c for which the control system proposed is stable. Assume that the time constant values are $\tau_1 = 1, \tau_2 = {}^1/_2$ *and* $\tau_3 = {}^1/_3$

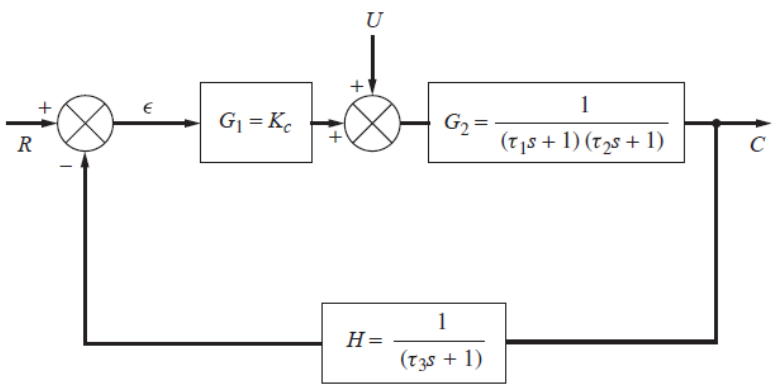

Figure 3. Control valve. Taken from Coughanowr, D. (1991). Process Systems Analysis and Control. McGraw-Hill.

15 marks