ChEn 436 – Process Dynamics and Control

Final Exam

Closed Book, 4 Pages Personal Notes

College Lecture Attendance

I attended _____ college lecture(s) or equivalent lectures this semester. (2 required)

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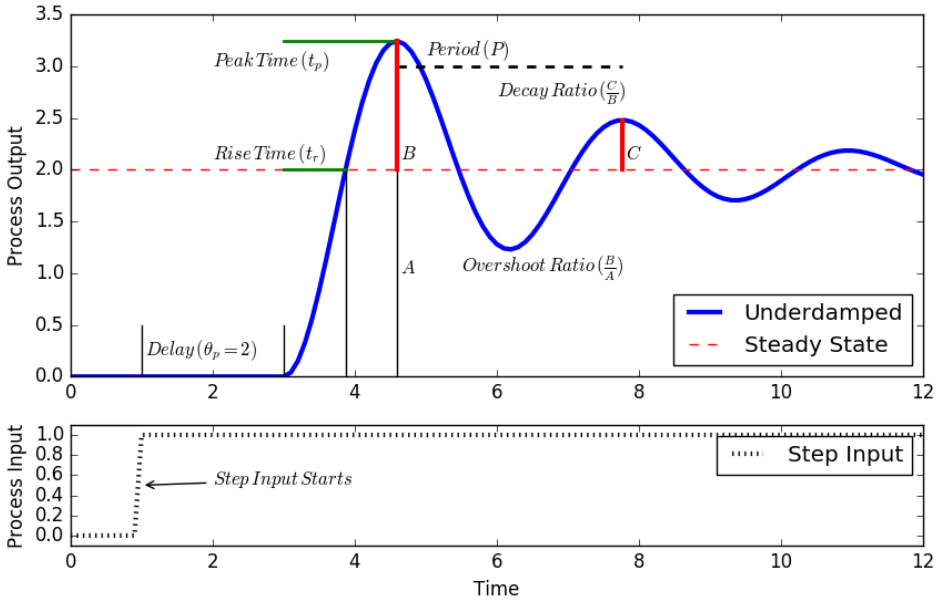
f(t) in Time Domain	*F(s)* in Laplace Domain
$\delta(t)$ unit impulse	1
$S(t)$ unit step	$\frac{1}{s}$
t ramp with slope $= 1$	$\frac{1}{s^2}$
t^{n-1}	$\frac{(n-1)!}{s^n}$
$e^{-b\,t}$	$\frac{1}{s+b}$
$1-e^{-t/\tau}$	$\frac{1}{s(\tau s+1)}$
$\sin(\omega t)$	$\frac{\omega}{s^2+\omega^2}$
$\cos(\omega t)$	$\frac{s}{s^2+\omega^2}$
$\frac{1}{\tau_1-\tau_2}\left(\exp\left(-t/\tau_1\right)-\exp\left(-t/\tau_2\right)\right)$	$\frac{1}{\left(\tau_1 s+1\right)\left(\tau_2 s+1\right)}$
$\frac{1}{\tau^n\,(n-1)!}t^{n-1}\exp\left(-\frac{t}{\tau}\right)$	$\frac{1}{(\tau s+1)^n}$
$\frac{1}{\tau\sqrt{1-\zeta^2}}\exp\left(-\frac{\zeta\,t}{\tau}\right)\sin\left(\sqrt{1-\zeta^2}\frac{t}{\tau}\right)$	$\frac{1}{\tau^2 s^2+2\zeta\tau s+1}$
$\frac{df}{dt}$	$sF(s)-f(0)$
$\frac{d^n f}{dt^n}$	$s^nF(s)-s^{n-1}f(0)-s^{n-2}f^{(1)}(0)-\ldots$ $-sf^{(n-2)}(0)-f^{(n-1)}(0)$
$\int f(t)$	$\frac{F(s)}{s}$
$f\left(t-t_0\right)S\left(t-t_0\right)$	$e^{-t_0 s}F(s)$



- Rise time t_r: amount of time to first cross the steady state level (after accounting for dead time).

$$t_r = \frac{\tau_s}{\sqrt{1-\zeta^2}}\left(\pi - cos^{-1}\zeta\right)$$

- Peak time t_p: amount of time to reach the first peak (after accounting for dead time).

$$t_p = \frac{\pi\tau_s}{\sqrt{1-\zeta^2}}$$

- Overshoot ratio OS: amount that first oscillation surpasses the steady state level relative to the steady state change

$$OS = \exp\left(-\frac{\pi\zeta}{\sqrt{1-\zeta^2}}\right) \qquad \zeta = \sqrt{\frac{(\ln(OS))^2}{\pi^2 + (\ln(OS))^2}}$$

- Decay ratio DR: fractional size of successive peaks

$$DR = OS^2 = \exp\left(-\frac{2\pi\zeta}{\sqrt{1-\zeta^2}}\right)$$

- Period P: the length of time for an oscillation from peak to peak

$$P = \frac{2\pi\tau_s}{\sqrt{1-\zeta^2}} \qquad \tau_s = \frac{\sqrt{1-\zeta^2}}{2\pi}P$$

1. Short Answer Questions

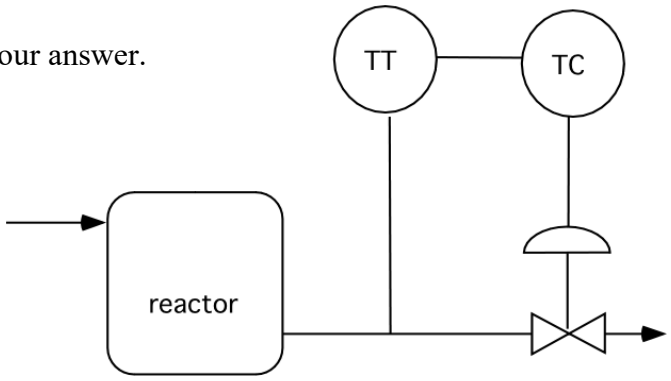
a. Sketch the response of a second order system that is underdamped. Please indicate on your sketch how to calculate rise time, overshoot ratio, decay ratio, and settling time.

b. Give three similarities of (i) cascade control and (ii) feed-forward control with feedback trim.

c. Which is better, a shorter rise time or a smaller overshoot ratio?

d. What does it mean to "tune" a controller?

e. Is the following system feedforward? Explain your answer.



2. For a system where the transfer function is:

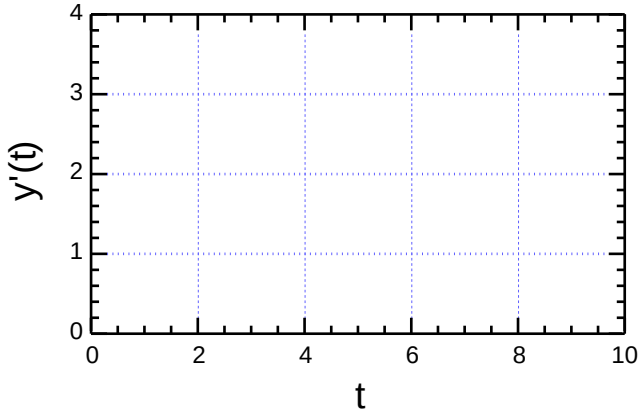
$$\frac{Y'(s)}{X'(s)} = \frac{-2}{5s+1}$$

and the input function is

$$X'(s) = \frac{1}{s^2} - \frac{2e^{-2s}}{s^2} + \frac{e^{-5s}}{s^2}$$

(a) Please sketch the shape of the input function X'(s) in the time domain.

(b) Please derive the final expression for y'(t).

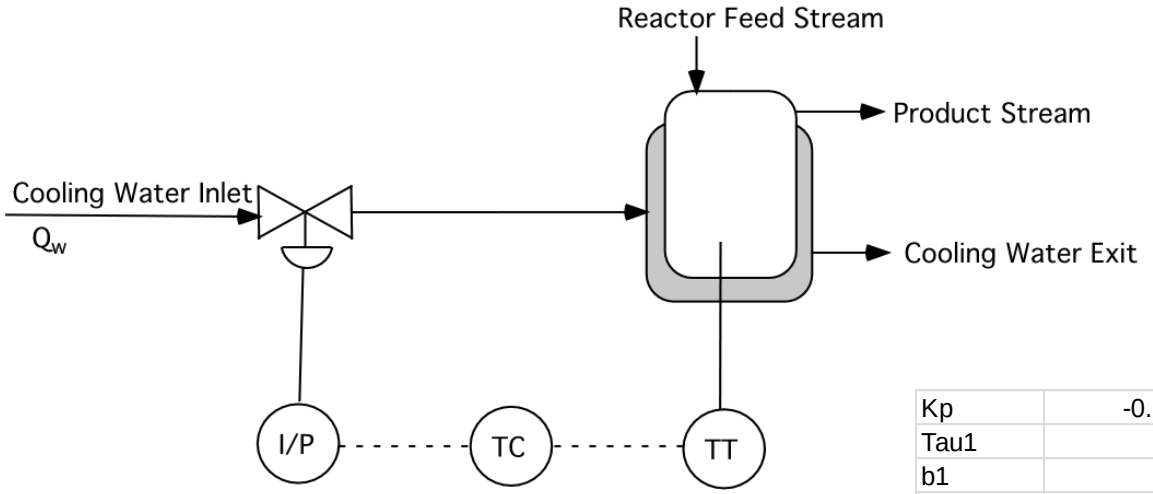


3. Cooling water flows through a jacket to control the temperature of a reactor, as shown below. The transfer function relating the reactor temperature T to the flow rate of cooling water through the jacket (Q_w) is:

$$\frac{T'(s)}{Q_w'(s)} = \frac{-0.7}{(s+1)(2s-1)} \quad °\text{F/gpm}$$

where the time constants are in minutes. The valve on the cooling water inlet fails in the open position (air-to-close), and passes 360 gpm of water when completely open. You may assume that the pressure drop across the valve is constant, that valve dynamics are negligible, and that the valve is linear. The temperature transmitter has a range of 200-400°F and requires about 0.5 minutes for a reading to reach its final value (5τ). The output from the transmitter is a 4-20 mA signal to the reverse-acting controller. The proportional-only controller outputs a current signal, which is converted to pressure in a standard I/P transducer (4-20 mA, 3-15 psig). Sketch a block diagram for the system and determine the transfer function for each of the blocks, including units.

Mario Diaz notices that the process is unstable, but claims that stable operation can be achieved with the feedback control loop shown and a proportional-only controller. What range of values of K_c (if any) will make this process stable?



Kp	-0.7
Tau1	1
b1	1
Tau2	2
b2	-1
Km	0.08
Taum	0.1
K_I-P	0.75
Kv	-30
a4	0.2
a3	2.1
a2	0.9
a1_KC	1.26
a1_b	-1
Kc>	0.793651
KC<	8.293651

Multiple Choice (Circle One)

a) $1.23 < K_c < 6.52$

b) $-10.2 < K_c < 10.2$

c) $0.79 < K_c < 8.29$