Georgia Tech
ChE 4400, Spring 2001
Midterm Exam 1, February 23, 2001
Closed Book, Closed Notes
60 minutes

1. Which of the following control mode is needed to eliminate offset?
   a. P-mode b. I-mode c. D-mode d. All of the above.
   (b) I-mode

2. Which of the following control mode is responsible for "windup"?
   a. P-mode b. I-mode c. D-mode d. All of the above
   (b) I-mode

3. Which of the following about feedback control is NOT true?
   a. It can stabilize an unstable system.
   b. It can destabilize a stable system.
   c. It can change overdamped dynamics into underdamped dynamics.
   d. It is particularly effective when the process has a large time delay or shows an inverse response.

   (d) It is particularly effective when the process has a large time delay or shows an inverse response.

4. Which of the following control strategy is effective for eliminating steam pressure line disturbances or (steam) valve errors in the temperature control of a jacketed reactor?
   a. Feedback control b. Feedforward control c. Combined feedback/feedforward control d. Cascade control
   (d) Cascade Control

5. Which of the following is NOT true in sizing a valve?
   a. Smaller size implies increased pumping requirement.
   b. Smaller size means less controllability and more nonlinear behavior.
   c. Larger valve size causes less pressure drop for a given flowrate.
   d. Rule of thumb is that the pressure drop across the valve at a nominal flowrate should be about ¼ - 1/3 of the total pressure drop.

   (b) Smaller size means less controllability and more nonlinear behavior.

6. You are controlling a reactor temperature by a steam flow valve. The valve is Air-To-Open type. You should be using
   a. Direct-Acting Mode
   b. Indirect-Acting Mode
   c. Reverse-Acting Mode
   d. Straight-Acting Mode

   (c) Reverse Acting Mode

7. Which of the following is true about Distributed Control System (DCS)?
    a. It’s a single centralized computer system that performs control for the entire plant.
    b. It’s a modularized controller that can handle only a single PID loop.
    c. Each unit can handle tens of analog and digital inputs and outputs and can be networked with other units and computers.
    d. It performs high-level functions such as process scheduling, optimization, and advanced control.

    (c) Each unit can handle tens of analog and digital inputs and outputs and can be networked with other units and computers.

8. “Transfer function” is
    a. Laplace transform of a step response curve.
    b. Laplace transform of a differential equation with a general forcing term (input).
    c. Laplace transform of a differential equation with a particular forcing term.
    d. Laplace transform of the time signal of the output.

    (b) Laplace transform of a differential equation with a general forcing term (input).

9. Which of the following is NOT true about impulse?
    a. It is an ideal signal that has infinite height and infinitesimal width.
    b. It is used to approximate a pulse of a very short duration.
    c. It is measured by height, which should be set equal to the height of the pulse it is approximating.
    d. It can be used to approximate forcing functions like tracer injection or (very fast) pouring a beaker of liquid into a tank.

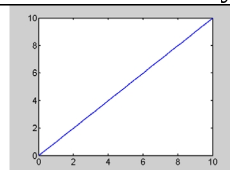
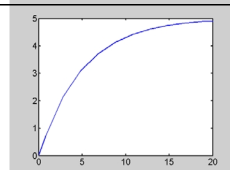
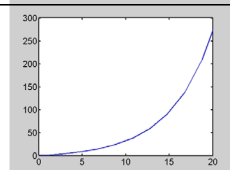
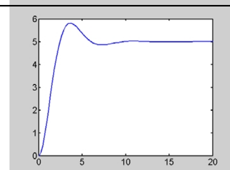
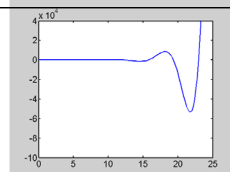
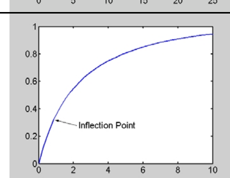
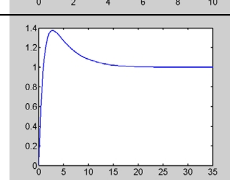
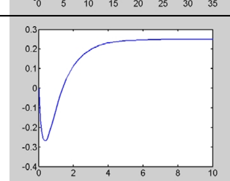
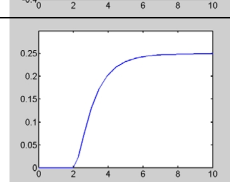
    (c) It is measured by height, which should be set equal to the height of the pulse it is approximating.

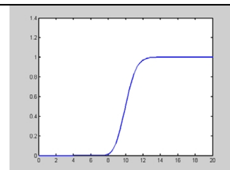
10. Which of the following is NOT true about linearization?
    a. It is an approximation that is valid around a particular equilibrium.
    b. Once linearized, the model can be converted to a transfer function form via Laplace transform.
    c. Linearization involves taking partial derivatives of nonlinear functions.
    d. It is an approximation that is globally valid and can be used to predict the output response far away from the reference equilibrium.

    (d) It is an approximation that is globally valid and can be used to predict the output response far away from the reference equilibrium.

11. Match the following transfer functions with step responses.

Note: Column 2 contains the behavior of the system (i.e. the “matched” answer)

$\frac{k}{s}$		Ramp function
$\frac{5}{5s+1}$		First order stable system
$\frac{5}{5s-1}$		First order unstable (divergent) system **Unstable pole**
$\frac{5}{s^2+s+1}$		Second order underdamped system
$\frac{5}{s^2-s+1}$		Unstable second order system
$\frac{2s+1}{4s^2+5s+1}$		Poles at –0.25 and –1 Zeros at –0.5 “Relative order” = 1, stable system
$\frac{7s+1}{4s^2+5s+1}$		Relative order = 1 Zero = -0.14 < poles
$\frac{-2s+1}{s^2+5s+4}$		Right half plane zero “Inverse Response” a.k.a. **non-minimum phase dynamics**
$\frac{e^{-2s}}{s^2+5s+4}$		Overdamped second order system with a transport lag of 2 units.

$\dfrac{1}{(0.1s+1)^{100}}$		Kind of act as a system with a lag of 0.1*100 = 10 time units. Not exactly e^{-10s}… it's a series of first order systems

12. Consider an arrangement of a heat exchanger and a control valve in series. At nominal flowrate 220 gal/min, it was measured that pressure drop across the heat exchanger to be 60psi.
    a. Calculate the pumping requirement in order to make the pressure drop across the control valve to be 1/4 of the total pressure drop at the nominal flowrate.
    b. Size an equal percentage valve (R=50) for the maximum flow rate of 250 gal/min.
    c. Write the equation for the installed characteristic curve and plot the curve. You can leave the equation in implicit form.
    d. Calculate the flowrate that results when the valve is half-open. Is it half of the maximum flowrate?

    Hint: The valve equation for equal percentage valve is

$$q = C_v R^{\ell-1}\sqrt{\frac{\Delta P_v}{g_s}}$$

a. $\Delta P_{total} = \Delta P_{HE} + \Delta P_E = 60 + \tfrac{1}{4}\Delta P_{total} \Rightarrow \tfrac{3}{4}\Delta P_{total} = 60$

Hence $\Delta P_{total} = 80\,psi$ and $\Delta P_v = 20\,psi$

b. $\Delta P_{HE} = kq^2$; with $\Delta P_{HE} = 60$ at $q = 220\ gal/min$

Hence $k = \dfrac{60\ psi}{(220\,gal/min)^2} = 1.24\times10^{-3}\ psi\,min^2/gal^2$

$$q_{\max} = 250\,gal/min$$

$$C_v = \frac{q}{k^{l-1}\sqrt{\dfrac{\Delta P_v}{g_s}}}$$

Design of C_v should be such that when $l = 1$, $q = q_{\max}$

$$C_v = \frac{250}{k^{1-1} \times \sqrt{\Delta P_{total} - kq^2}} = \frac{250}{1 \times \sqrt{80 - 1.24 \times 10^{-3} \times 250^2}} = 158.1\, gal/min.psi^{1/2}$$

c.

Based on the equations we had above, we can write the installed valve characteristics as:

$$q = 158.1 \times 50^{l-1} \sqrt{\frac{80 - 1.24 \times 10^{-3} q^2}{1}}$$

d. $l = 0.5$

Substituting in the above equation and solving for q, we get

$$(1 + 0.6199)q^2 = 39993$$
$$\therefore q = 157.1\, gal/min > 125$$

13. A can of beer with the initial temperature of 90ºF (the room temperature) is put into a freezer of temperature –10 ºF at t=0. Calculate the transient response of the beer as a function of time. The entire beer (including the can) can be though of as having a uniform temperature at any given moment. The heat capacity of the beer is 1.5 Btu/lb ºF and weighs 0.8 lb. The heat transfer coefficient between the beer and the outside temperature is 2.0 Btu/hr ºF ft^3. The heat transfer surface area is 0.3 ft^3.

You may realize in this problem that the system under consideration is a closed system. There is no exchange of matter with the surroundings, but the system interacts thermally.

Rate of change of heat content = Heat Out through walls

$$\frac{d\left[m_b c_b (T_b - T_{ref})\right]}{dt} = UA(T_0 - T_b)$$

It is convenient to choose them both equal to the initial value of 90^{o}F.

$$m_b c_b \frac{d[T_b]}{dt} - \frac{d[\overline{T}_b]}{dt} = UA\left[(T_0 - \overline{T}_0) - (T_b - \overline{T}_b)\right]$$

Note that we have chosen $\overline{T}_b$ and $\overline{T}_o$ equal to each other (equal 90^{o}F). This simplifies our analysis, as the initial value of the deviation variables is 0. For other choices of the variables, a constant term appears in the laplace transform. Denoting deviation variables with a prime (‘), we get

$$1.2\frac{dT_b'}{dt} = 0.6(T_0' - T_b')$$
$$1.2\left[s\hat{T}_b(s)\right] = 0.6\left[\hat{T}_0(s) - \hat{T}_b(s)\right]$$
$$(2s+1)\hat{T}_b(s) = \hat{T}_0(s)$$
$$\hat{T}_0(s) = \frac{1}{2s+1}\hat{T}_0(s)$$

$\hat{T}_0(s)$ is a step function of size –100 (from 90^{o}F to -10^{o}F)

Hence $\quad \hat{T}_b(s) = \dfrac{-100}{s(2s+1)}$

Laplace Inverse: $\quad T_b'(t) = 100(e^{-0.5t} - 1)$

Hence the solution is $\quad T_b(t) = 90 + 100(e^{-0.5t} - 1) = -10 + 100e^{-0.5t}$