Control Strategy: (In-class exercise)

1. Control objective?
2. Input variables
3. Output variables
4. Constraints
5. Operation
6. Safety, environmental, economic
7. Control Structure

Controller Tuning,
- fast or slow response?
  \( \Rightarrow \) depends on the process!

Analog vs. Digital
- Most modern plants have switched to digital controls. Analog signals transmitted via pneumatic signals (3 \( \Rightarrow \) 15 psig) and denoted as \( P_i \).
- show overhead visual representation.

\( \text{digital: } 4 \Rightarrow 20 \text{ mA} \) (usually)

PRACTICE QUIZ: FF/FB, gain, fail-open, fail-closed
Control Valve Placement (Show Fig. 1-12)

"Fail-Safe" Values

Objective: In the case of a signal loss, the default setting of the
valve should be "safe" → free of environmental, health concerns.
The "worst case scenario" should be identified & the control
strategy should be designed to avoid it.

- Valves have two possible settings:

  (a) fail-closed: if signal is lost, the valve completely closes. This
      is also called "air-to-open", since a pneumatic
      signal is often used. A continuous signal (air pressure)
      is required to keep the valve open. If the air
      signal is lost, the valve closes.

  (b) fail-open: if signal is lost, the valve completely opens. This is
      also called "air-to-close", since a pneumatic signal
      is often used. A continuous signal (air pressure)
      is required to keep the valve closed. If the air
      signal is lost, the valve completely opens.

Example: Surge Tank (Scenario I)

Fail-open or Fail-closed?
Surge Tank (Scenario II)

Fail-open or fail-closed?

Heater

Fail-open or fail-closed?

WCS: Overheat

Question: What is the process gain ($K_p$) of the previous 3 examples?

$$K_p = \frac{\Delta \text{output variable}}{\Delta \text{controlled input variable}}$$

Output variable is $h$ or $T$

1. $F_1 \uparrow$, $h \uparrow$ (positive)
2. $F_2 \uparrow$, $h \downarrow$ (negative)
3. $F \uparrow$, $T \uparrow$ (positive)

Quantitative Example: Heater

1. What is the gain? 
   positive/negative

2. What is the value of the gain?
   (a) $\Delta F_2 = 10$ gallons/min
   (b) $\Delta T_2 = 5^\circ C$
   gain ($k$) = 0.5 gallons/min

$h_2O$ $F_1$ $T_1$

heating oil $F_2$ $F_2$ $T_2$
**Process Models: Dynamic**

- First step to analyze and control a process is to develop an accurate model. Why?
  
  (a) How does process behave with respect to system parameters?
  
  (b) How will the process respond to a disturbance?
  
  (c) How will the process respond to a change in
      a setpoint?

**Dynamic Model for Holding Tank**

![Diagram of a holding tank with flow rates](Image)

- **Objective:** Develop a dynamic model for the height of the fluid in the tank.

- **Solution:** Apply a conservation law to the system (mass/energy)

**Mass Balance:**

\[
\dot{m}_{acc} = \dot{m}_{in} - \dot{m}_{out}
\]

\[
\dot{m}_{acc} = \frac{dM}{dt} \quad [\text{kg/h}]
\]

\[
\dot{m}_{in} = F_1 \cdot \rho \quad \left[ \frac{m^3}{h} \cdot \text{kg/m}^3 \right]
\]

\[
\dot{m}_{out} = F_2 \cdot \rho \quad \left[ \frac{m^3}{h} \cdot \text{kg/m}^3 \right]
\]

\[
\frac{dM}{dt} = F_1 \cdot \rho - F_2 \cdot \rho \]

\[
m = \rho V = \rho Ah
\]

\[
\frac{\rho A}{\text{dt}} = \rho (F_1 - F_2)
\]

\[
\frac{\text{dh}}{\text{dt}} = \frac{F_1 - F_2}{A}
\]

\[
\int_{h_1}^{h_2} dh = \int_{t_1}^{t_2} \left( \frac{F_1 - F_2}{A} \right) dt
\]

\[
h_2(t_2) = h_1(t_1) + \left( \frac{F_1 - F_2}{A} \right) (t_2 - t_1)
\]

*This is an example of an integrating process.*
Dynamic Model for Holding Tank

\[ \frac{dh}{dt} = \text{?} \quad h(t) = \text{?} \]

\[
\dot{m}_{\text{in}} = \frac{dM}{dt} = \frac{d(eV)}{dt} = \frac{d(e \frac{1}{3} \pi h^3)}{dt}
\]

\[
\dot{m}_{\text{out}} = F_1 e + F_2 e
\]

\[
\frac{d}{dt} \left( \frac{1}{3} \pi h^3 \right) = (F_1 + F_2 - F_3)
\]

\[
\left[ \frac{dh}{dt} = \frac{(F_1 + F_2 - F_3)}{\pi h^2} \right] \rightarrow \text{are the units consistent?}
\]

\[
\left[ \int_{h_1}^{h_2} \frac{d}{dt} \left( \frac{1}{3} \pi h^3 \right) = \int_{t_1}^{t_2} (F_1 + F_2 - F_3) \, dt \right]
\]

\[
\frac{1}{3} \pi h_2^3 - \frac{1}{3} \pi h_1^3 = (F_1 + F_2 - F_3)(t_2 - t_1)
\]

\[
h_2 = \sqrt[3]{h_1^3 + \frac{3}{\pi} (F_1 + F_2 - F_3)(t_2 - t_1)} \rightarrow \text{are the units consistent?}
\]

Comment: You should be able to develop similar models to other processes, simply by performing a mass balance. (Regardless of the geometry, # of input/output streams)
2. In the process below, a liquid enters a holding tank with a flowrate of \( F_i \). A feed-forward controller is used to control the flowrate \( F \) of the liquid leaving the tank. Since disturbances may exist in the inlet flowrate, the tank has been built using flexible materials. The tank may expand up to twice its normal volume before rupturing.

(a) Is the control strategy reasonable (circle answer)?

\[ \text{YES or NO} \]

(b) Explain your answer.
1. A CSTR is used to eliminate a waste component (w) from a process stream through the reaction: \( W \rightarrow P \).
   - The conversion of the reaction increases with respect to the reactor temperature and increases with respect to reactor residence time.
   - Higher temperatures require more heat to be added to the system.
   - **Main objective**: maintain the concentration of (w) below a threshold value.

For each system shown below:

(i) State whether the process gain (relating manipulated flow rate and measured concentration) is positive or negative.
(ii) Should the control valve be fail-open or fail-closed?

**KEY:**
- \( C_{wi} \) = concentration of (w) in the inlet stream
- \( C_w \) = Concentration of (w) in the outlet stream

(a)

\[ \text{Cw}_{i} \rightarrow \text{CSTR} \rightarrow \text{Cw} \]

Fuel \[ \rightarrow \text{furnace} \]

controller \[ \rightarrow \text{measurement} \]

(iii) \( \text{FF/FB} \)?

(b)

\[ \text{Cwi} \rightarrow \text{CSTR} \rightarrow \text{Cw} \]

Recycle stream \[ \rightarrow \text{CSTR} \rightarrow \text{measurement} \]

controller

(iii)
1. A CSTR is used to eliminate a waste component \((w)\) from a process stream through the reaction: \(W \rightarrow P\).
- The \textbf{conversion} of the reaction increases with respect to the reactor temperature and increases with respect to reactor residence time.
- Higher temperatures require more heat to be added to the system.
- \textbf{Main objective:} maintain the concentration of \((w)\) below a threshold value.

For each system shown below:

(i) State whether the process gain (relating manipulated flow rate and measured concentration) is \textbf{positive} or \textbf{negative}.
(ii) Should the control valve be fail-open or fail-closed?

\textbf{KEY:} \(C_{wi} = \text{concentration of } (w) \text{ in the inlet stream}
\)
\(C_{w} = \text{Concentration of } (w) \text{ in the outlet stream}\)

(a)

(i) \textbf{negative}.
(ii) \textbf{fail-open}.
(iii) \textbf{FB}.

(b)

(i) \textbf{negative}.
(ii) \textbf{fail-open}.
(iii) \textbf{FB}.
2. In the process below, a liquid enters a holding tank with a flowrate of \( F_i \). A feed-forward controller is used to control the flowrate \( F \) of the liquid leaving the tank. Since disturbances may exist in the inlet flowrate, the tank has been built using flexible materials. The tank may expand up to twice its normal volume before rupturing.

(a) Is the control strategy reasonable (circle answer)?

YES or NO

(b) Explain your answer.

(i) Positive

(ii) fail-closed

(iii) FF