458.308 Process Control & Design

Lecture 1: Introduction to Process Control

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What Is Control (System)?

- Generally speaking, it is a system that is used to realize a desired output or objective.
- Control systems are everywhere.
  - homes, cars, industry, labs, hospital,...
- It is multidisciplinary.
  - process + control + math + computer ...
- Team work is essential. (consulting business)

Why an engineer should know control

- Practically all engineers will use control
- Essential element of almost all engineering systems
- Control can give designers extra degrees of freedom
- Control has beautiful theoretical results and really neat devices

Wilbur Wright 1901

We know how to construct airplanes.
Men also know how to build engines.
Inability to balance and steer still confronts students of the flying problem.
When this one feature has been worked out, the age of flying will have arrived, for all other difficulties are of minor importance.

A Quiz!

Robot Piloted Plane makes safe crossing of the Atlantic.
No hands on controls from Newfoundland to Oxforshire.
Take-off, flight, and landing are fully automatic.

New York Times 19??

Let's see some video clips!

- Water heater
  - www.youtube.com/watch?v=JmJoyuUJj2Q
- BP Explosion
  - www.chemsafety.gov/index.cfm?folder=current_investigations&page=info&IN
- Better car with better control
  - www.youtube.com/watch?v=Q23HpNkM8gs

Control is not confined to engineering

Feedback control is a central feature of life: All organisms share the ability to sense how they are doing to make changes in `mid-flight' if necessary. The process of feedback governs how we grow, respond to stress and challenge, and regulate factors such as body temperature, blood pressure and cholesterol level. This apparent purposefulness, largely unconscious, operates at every level -- from the interaction of proteins in cells to the interaction of organisms in complex ecologies."

Way Life Works by M. Hoagland and B. Dodson

Basic Principles of Process Operation

- Operate safely
- Meet the product quality specifications
- Meet the required production rate (or maximize)
- Minimize operating costs (energy, raw materials, etc.)

Example: Refinery

1. No explosion, other accidents, or long shutdowns
2. Meet the composition spec's for each stream
3. Meet the intended production rate for each stream
4. Minimize energy consumption

What's Process Control? (in detail)

- Measure and monitor the process variables
- Adjust the process's (dynamic) degrees-of-freedom (e.g., valve positions, pump speeds)
  - To maintain the relevant variables within acceptable ranges or close to their desired values (setpoints)
  - To move the process to a new operating condition fast but smoothly without violating constraints (as in startup, shutdowns, and grade transitions)

Example: A Blending Process

- $x,\ x_1,\ x_2$: mass fraction of A
- $w,\ w_1,\ w_2$: mass flow rate
- Stream 1: w_1 is constant. x_1 varies with time.
- Stream 2: $x_2 = 1$. We can manipulate w_2.
- Stream 3: We want x to be x_{sp}.

Classification of Variables

*"Shallow men believe in luck. Strong men believe in **cause and effect**."* -- R. W. Emerson

- Input variables (independent variables)
  1. Manipulated Variables (MV): u
  2. Disturbances (measured or unmeasured) : d
- Output variables (dependent variables)
  - Controlled Variables (CV) (measured or unmeasured): y
- State variables: $x \supseteq$ output variables
  - Variables determining the internal dynamic condition

Input-Output Relationship? Build a model

Steady state model

$$\begin{aligned} 0 &= \bar{w}_1 + \bar{w}_2 - \bar{w} \\ 0 &= \bar{w}_1 \bar{x}_1 + \bar{w}_2 \bar{x}_2 - \bar{w}\bar{x} \end{aligned}$$

What do you want to determine?

$$\bar{w}_2 = \bar{w}_1 \frac{x_{sp} - \bar{x}_1}{1 - x_{sp}}$$

Q. How can we ensure that x remains at or near its desired value if x_1 changes?
A. Control!

Types of Control Strategies

- Manual vs. Automatic
- Open-loop vs. Closed-loop
- Strategies
  - Feedback Control
  - Feedforward Control
  - Cascade Control
- Linear vs. Nonlinear

Power of Feedback

- Feedback is very important in control!
- With feedback, you can control despite substantial uncertainty and incomplete knowledge about the process.
  - Imperfect knowledge of disturbances
  - Imperfect knowledge of the dynamic effect of MVs on CVs
- Open-loop control or just feedforward control alone seldom works well in an uncertain plant environment.
- Feedback Error: Setpoint - Measured CV value

Control Methods: Blending system

Feedback control

$$w_2(t) = \bar{w}_2 + K_c[x_{sp} - x(t)]$$

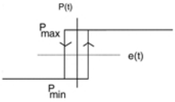
K_c: Controller Gain

Feedforward Control

$$w_2(t) = \bar{w}_1 \frac{x_{sp} - x_1(t)}{1 - x_{sp}}$$

Types of Control Algorithm

- On-Off Control



- Proportional Control

$$p(t) = \bar{p} + K_c[r_m(t) - y_m(t)] \Rightarrow p'(t) = K_c e(t)$$

- Proportional-Integral Control

$$p(t) = \bar{p} + K_c \left[e(t) + \frac{1}{\tau_I} \int_0^t e(t^*)\, dt^* \right]$$

- Proportional-Integral-Derivative (PID) Control

$$p(t) = \bar{p} + K_c \left[e(t) + \frac{1}{\tau_I} \int_0^t e(t^*)\, dt^* + \tau_d \frac{de}{dt} \right]$$

- Model-Based Control

Computer Integrated Process Management