458.308 Process Control & Design

Lecture 10: Enhancements to Basic Feedback Control

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Objective

- To learn popular control strategies that add on to the basic feedback control
  - Feedback control does not take corrective action until after a deviation in the controlled variable occurs.
  - Feedback control does not provide predictive control action to compensate for the effects of known or measurable disturbances.
  - ...
- Relevant Chapters: 15, 16
- Topics
  - Feedforward control
  - Cascade control
  - Time delay compensation

Complementary Nature of Feedforward and Feedback Control

- In practice, feedforward control is combined with feedback control.
- Feedforward control
  - Enables early compensation to a sensed disturbance (important for processes with delays or slow dynamics).
  - Sensitive to model error
  - Disturbance must be ``sensed".
- Feedback control
  - Continuously correct for error due to other unmeasured disturbances and model/plant mismatch.
- The two controllers can be designed independently and put together.
  - No adverse interaction between the two. (Eq. 15-28).

Feedforward Controller Design based on Steady-State Model

- Immediately change the MV value when changes in the disturbance variables are sensed.
- Use steady-state mass, energy, momentum balances.

Example: Distillation Column

- CV: y, MV: D
- Measured disturbances: F, z

Steady-state mass balances:

$$F = D + B \qquad Fz = Dy + Bx$$

The feedforward control law is given by

$$D = \frac{F(z - x_{sp})}{y_{sp} - x_{sp}}$$

Feedforward Controller Design based on Dynamic Models

$$\frac{Y(s)}{D(s)} = \frac{G_d + G_t G_f G_v G_p}{1 + G_c G_v G_p G_m}$$

Ideal feedforward controller

$$G_f = -\frac{G_d}{G_t G_v G_p}$$

However, with model error, $G_d + G_t G_f G_v G_p \neq 0$ in general.

If we make the simplifying assumption that the disturbance measurement and control valve have no dynamics

$$G_f = -\frac{G_d(s)}{G_p(s)}$$

Examples

- 1^{st} order process and disturbance transfer functions

$$G_p(s) = \frac{K_p}{\tau_p s + 1}, \quad G_d(s) = \frac{K_d}{\tau_d s + 1}$$

$$G_f = -\left(\frac{K_d}{K_p}\right)\frac{\tau_p s + 1}{\tau_d s + 1}$$

  - A lead-lag controller: a typical form of most feedforward controllers
- FODT process and disturbance transfer functions

$$G_p(s) = \frac{K_p e^{-\theta_p s}}{\tau_p s + 1}, \quad G_d(s) = \frac{K_d e^{-\theta_d s}}{\tau_d s + 1}$$

$$G_f = -\left(\frac{K_d}{K_p}\right)\frac{\tau_p s + 1}{\tau_d s + 1} e^{-(\theta_d - \theta_p)}$$

  - $\theta_d \geq \theta_p$ is required for the controller to be realizable.
  - $\theta_d < \theta_p$: we cannot have perfect feedforward control, even if the models are perfect.

Cascade Control

- This control scheme also concerns ``disturbance rejection.": practical problem
- Involves the use of multiple output measurements and a single manipulated input.
    - Note: FF control: disturbance measurement
- Objective: To improve the response of the most important (primary) output to a disturbance.

Cascade Control

- Why?
  - Reject disturbance in the slave loop before it affects the main process variable
  - ``Linearize" the slave process
  - Improve the dynamics of the slave process
- Tips for Implementation
  - Slave process should be at least 3 times as fast as the master process in terms of response time.
  - I-mode in the slave controller is seldom necessary. P-mode suffices in most cases.
    - Small offsets in the slave loop can be compensated by the master loop.
  - The most common cascade-control loop involves a flow controller as the inner loop. This type of loop easily rejects disturbances in fluid stream pressure, either upstream or downstream of the valve.
  - The inner loop should be tuned before the outer loop. After inner loop is tuned, and closed, the outer loop should be tuned using knowledge of the dynamics of the inner loop.

Time Delay Compensation

- Delays introduce ``phase lag."
  - The larger the delay, the faster phase angle drops with frequency.
- Large delays make PID tuning very difficult.
  - Severely limits the size of gain one can use (Bode stability criterion).
  - Ziegler-Nichols or Cohen-Coon tuning rules advise that they be used only when $\theta/\tau < 1.0$.
  - In IMC tuning rules, delays are approximated. The approximation gets worse with larger delays and hence necessitate a use of a larger τ_c.