# PROCESS DYNAMICS AND CONTROL

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## RECAP

- Elements of feedback control
- On/off controller
- Proportional controller

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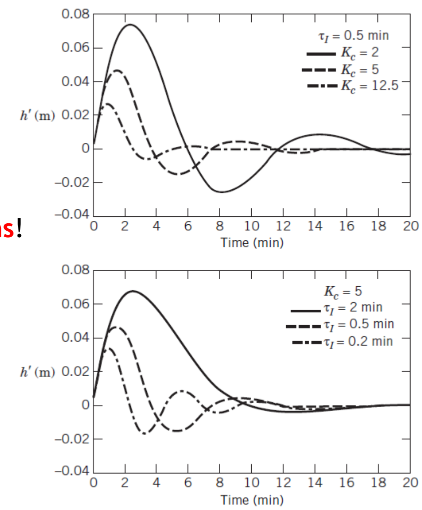
## PI CONTROL: RESET TIME/GAIN AND OSCILLATIONS

- **First-order** process

Integral action introduces **oscillations**!
•**Why?**




Seborg et al. Process Dynamics and Control

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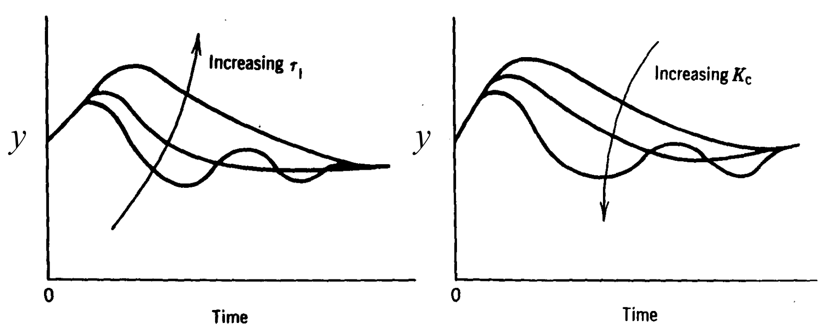
## TYPICAL RESPONSES OF PI: HIGH-ORDER PROCESSES

- Regulatory control




(a) Seborg et al. Process Dynamics and Control (b)

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# DERIVATIVE MODE

- Improve controller response through prediction

$$p(t) = \overline{p} + \tau_D \frac{de}{dt}$$

- Can it be used alone? Why?
- Combine with proportional (PD)
  - Ideal form

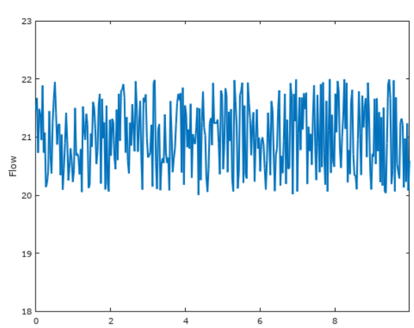
$$p(t) = \overline{p} + K_c(e(t) + \tau_D \frac{de}{dt})$$

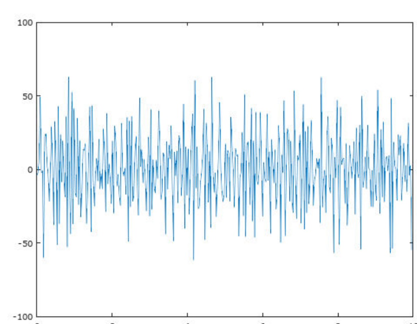
  - Transfer function $\dfrac{P'(s)}{E(s)} = K_c(1 + \tau_D s)$



# PD CONTROL: DISADVANTAGES

- Ideal PD is not physically realizable (why?)
- Derivative action is sensitive to noise
  - Amplifying control action
  - Examples?



## APPROXIMATE DERIVATIVE MODE

- Approximate D-action using a filter

$$\frac{P'(s)}{E(s)} = K_c\left(1+\frac{\tau_D s}{\alpha\tau_D s+1}\right)$$

$$\alpha \in [0.05, 0.2]$$

- Filter (first-order lag) eliminates high-frequency noise
- Low-pass filter (recall the surge tank!)

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## PROPORTIONAL-INTEGRAL-DERIVATIVE CONTROL

- Combine all three actions
  - Can be done in different ways

- Parallel form of PID

$$p(t) = \bar{p} + K_c\left[e(t) + \frac{1}{\tau_I}\int_0^t e(t')dt' + \tau_D\frac{de}{dt}\right]$$

$$\frac{P'(s)}{E(s)} = K_c\left(1+\frac{1}{\tau_I s}+\tau_D s\right)$$

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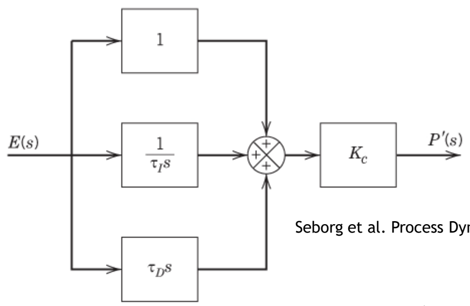
# PARALLEL FORM OF PID (CONT'D)

- Block diagram (the three actions work in parallel)

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- Parallel form with filter $\frac{P'(s)}{E(s)} = K_c\left(1 + \frac{1}{\tau_I s} + \frac{\tau_D s}{\alpha \tau_D s + 1}\right)$

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# EXPANDED FORM OF PID

$$p(t) = \bar{p} + K_c e(t) + K_I \int_0^t e(t')dt' + K_D \frac{de}{dt}$$

- Three independent tuning parameters
  - Easier to tune

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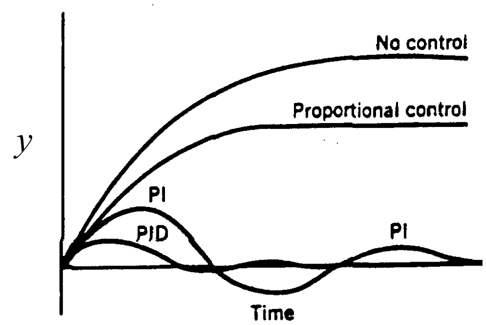
# TYPICAL REPONSES OF PID

- Regulatory control

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# PRACTICAL ISSUE WITH PIDS

- **Instantaneous (step) or fast set point changes**
  - **Derivative kick**: derivative action becomes infinity or very large (de/dt=d($\mathbf{y_{sp}}$-$y_m$)/dt→∞)
    - **Solution**: Remove set point from derivative term

$$p(t) = \overline{p} + K_c \left[ e(t) + \frac{1}{\tau_I} \int_0^t e(t^*)\,dt^* - \tau_D \frac{dy_m(t)}{dt} \right] \tag{8-17}$$

  - **Proportional kick**: Proportional action becomes very large (Kc*e=Kc($\mathbf{y_{sp}}$-$y_m$)→very large)
    - **Solution**: Remove set point from proportional term (Kc*(-$y_m$))

## TWO-DEGREES OF FREEDOM PID

- Allow user to eliminate from or keep set point in the proportional and derivative terms.
  - Use **weight factors**

$$p(t) = \overline{p} + K_c \left( e_P(t) + \frac{1}{\tau_I} \int_0^t e(t^*)\, dt^* + \tau_D \frac{de_D(t)}{dt} \right)$$

$$e_P(t) \triangleq \beta y_{sp}(t) - y_m(t) \qquad e(t) \triangleq y_{sp}(t) - y_m(t)$$

$$e_D(t) \triangleq \gamma y_{sp}(t) - y_m(t)$$

  - alpha and beta between [0,1]

- Error for integral term must always be the actual error (why?)

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