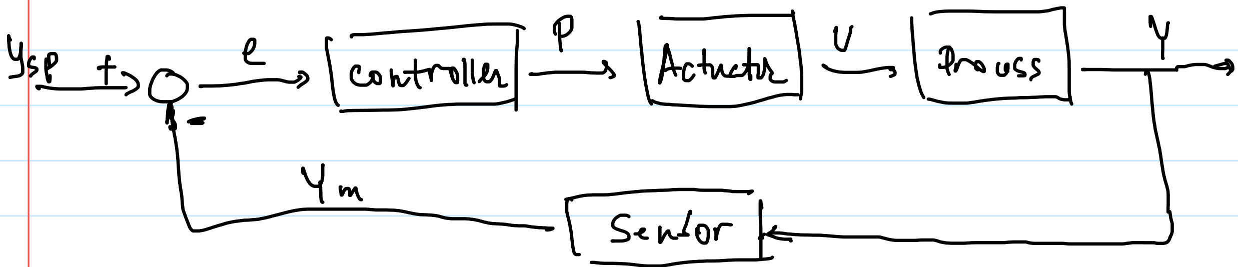
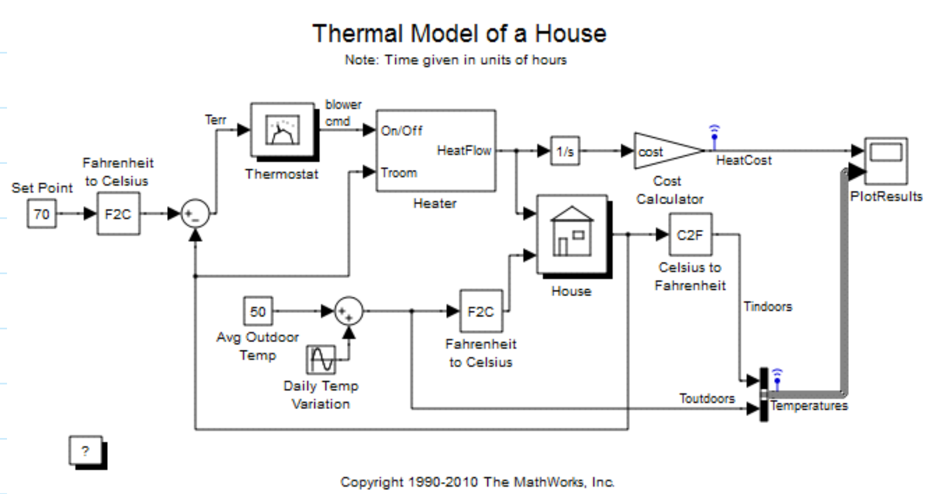
Thursday, February 14, 2013
9:01 AM



Role of controller: Reduce the error e (deviation of measured output y_m from its setpoint y_{sp}) to zero (0)

Control modes: define relationship between the controller output p and the error e

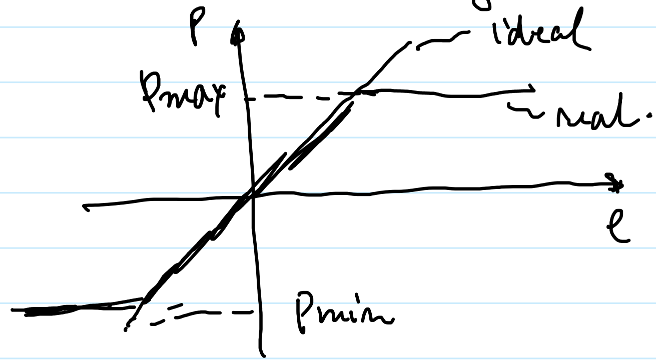
1) on-off control (discussed last lecture)



2) Proportional control: → output of the controller is proportional to the error.

$$p(t) = \bar{p} + \bar{K_c}\, e(t) \qquad e(t) = y_{sp} - y_m(t)$$

$\bar{p}$ = "bias" = the steady state value of the controller output.



Due to ~~ac~~ actuator saturation (inherent limitations in actuator capacity - e.g. a valve can only open to 100% close to 0%), the response is not continuous in real systems, it will "plateau" @ min, max values dictated by the actuator capacity

Sign of the gain K_c? dictated by the gain of the system to be controlled:

A controller is called

- Direct acting: if it is desired that its output increase ~~to~~ when y_m increases output ↑ if y_m ↑ $K_c < 0$

- Reverse acting

output ↑ when y_m ↓ $K_c > 0$

The output p of a proportional controller only depends on the <u>current</u> value of the measured output y_m. This results in <u>steady-state offset</u>: the value of y will never be equal to y_m, or, equivalently, the control error e will never be zero.

③ Proportional - Integral control:

- Implemented to eliminate steady-state offset.

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

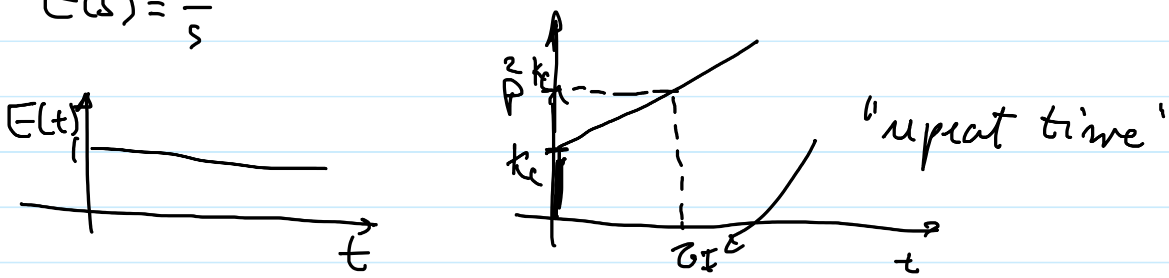
→ operating principle: the controller output will keep changing as long as the error $e(t)$ has not reached zero.

Transfer fcn:

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

Response of PI controller to step change in error?

$E(s) = \frac{1}{s}$



If actuator /controller saturation occurs, the error integral computed by the PI controller will continue to grow. Likewise, the output of the controller, p, will continue to change. However, b/c actuator saturation, these changes will not affect the operation of the process.

The continued increase in the error integral, which occurs in the presence of saturation is referred to as "integral windup" or "reset windup"

Solution: implement an "anti-windup" mechanism: take the integral component of the controller off-line (i.e., stop integrating the error) when saturation occurs.

Typical situations when windup can occur:
- startup (e.g., empty tank under PI level control)
- large, sudden disturbances (e.g., changes in operating point/ changes in product grade)

(2) Derivative control:

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

τ_D = derivative time ct.
units = time.

concept: Anticipate (vs. using memory effect that is provided by ∫ action) the future behavior of the error signal by considering its rate of change

P control : acts on current deviation of y_m from y_{sp}

I : based on past history.

(D) -control: valuable when sudden changes in a controlled variable occur.

Q: Does D-control by itself lead to zero offset? No : the output of a derivative controller does not change unless the error $e(t)$ changes in time.

→ D-control is never used by itself, only in combination with P, PI control.

→ Potential issue: if data are noisy, derivative of the error is difficult to calculate

→ need data smoothing

→ Transfer function of the ideal PD controller.

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

$$\frac{\tilde{P}(s)}{E(s)} = K_c(1 + \tau_D s) \leftarrow \text{Not physically realizable.}$$

Transformed version:

$$\frac{\tilde{P}(s)}{E(s)} = K_c\left(1 + \underbrace{\frac{\tau_D s}{\alpha \tau_D s + 1}}_{\text{derivative filter form}}\right)$$

$\alpha = 0.05 \ldots 0.2$

③ Proportional - Integral - Derivative (PID) Control

- Vast proportion of industrial controllers
- Combination of P, I, D control modes.
- Can take several functional forms:

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

T.F.: $$\frac{\tilde{P}(s)}{E(s)} = K_c\left[1 + \frac{1}{\tau_I s} + \tau_D s\right]$$

↑ parallel form

Series form: — w/ derivative

series form:

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

w/ derivative filter,

↳ implemented in ~~the~~ analog controllers.