Feedback controllers

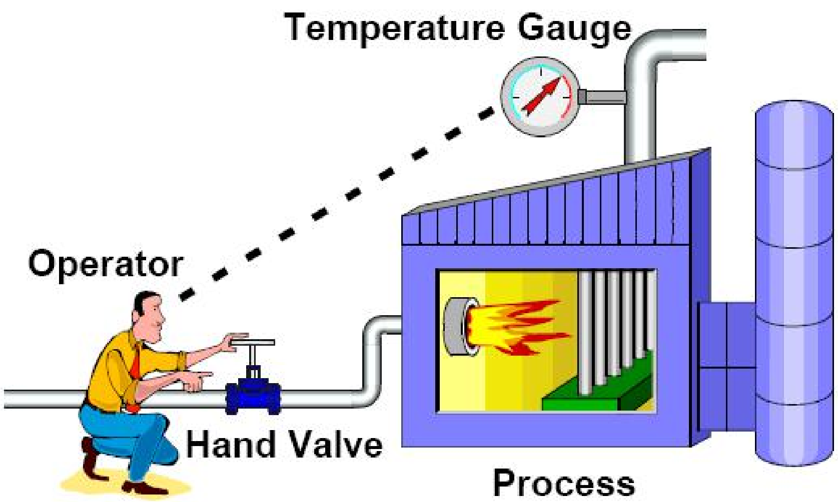
1 Introduction

2 Basic control modes

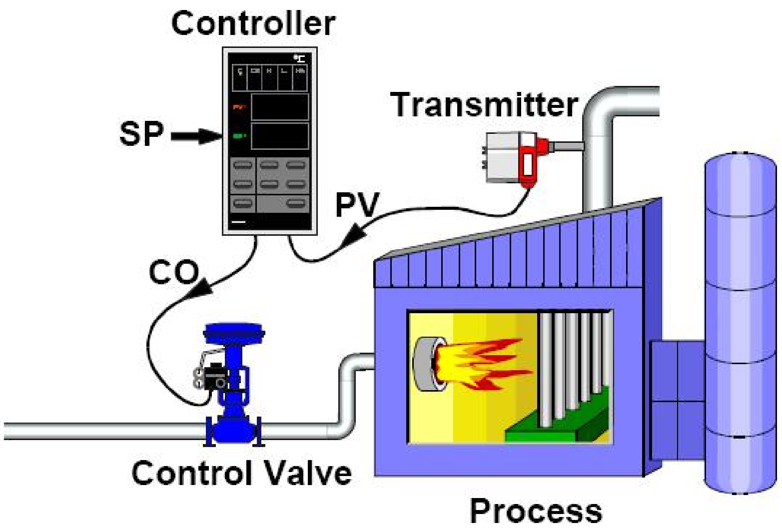
3 Features of PID controllers

4 Typical response of feedback control systems

Feedback Control system

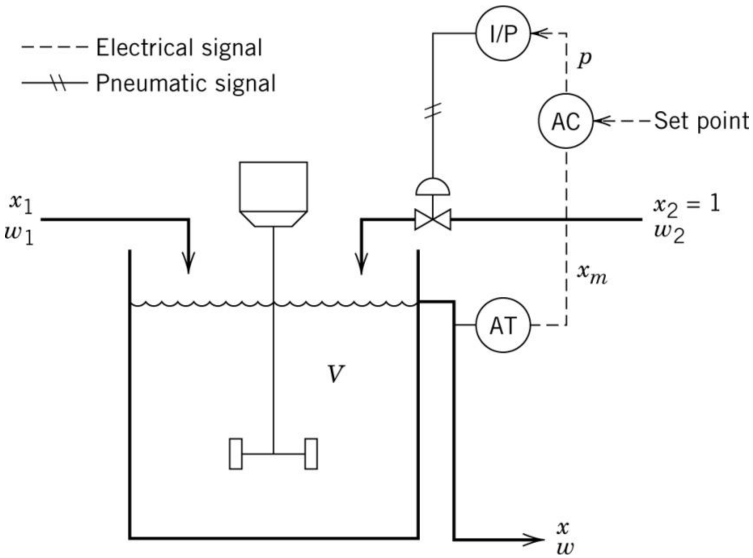


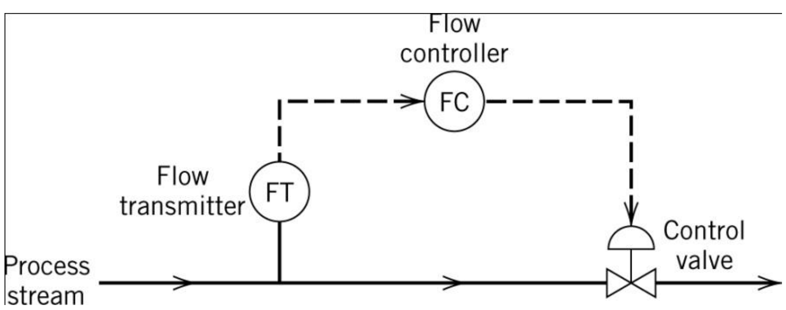
Manual control



Automatic control

Feedback Control system





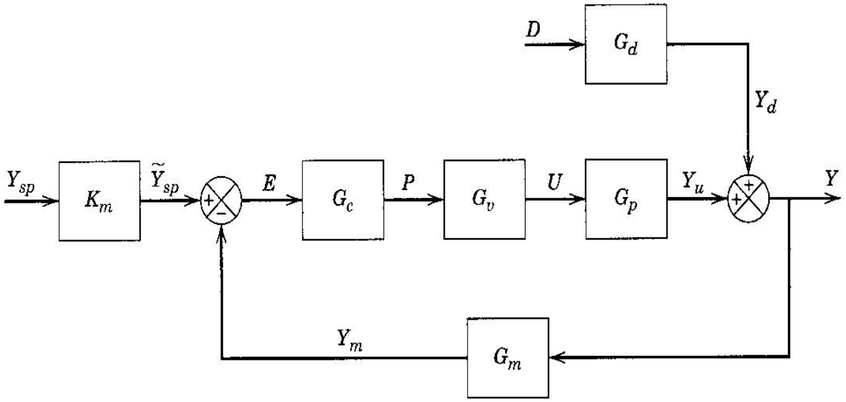
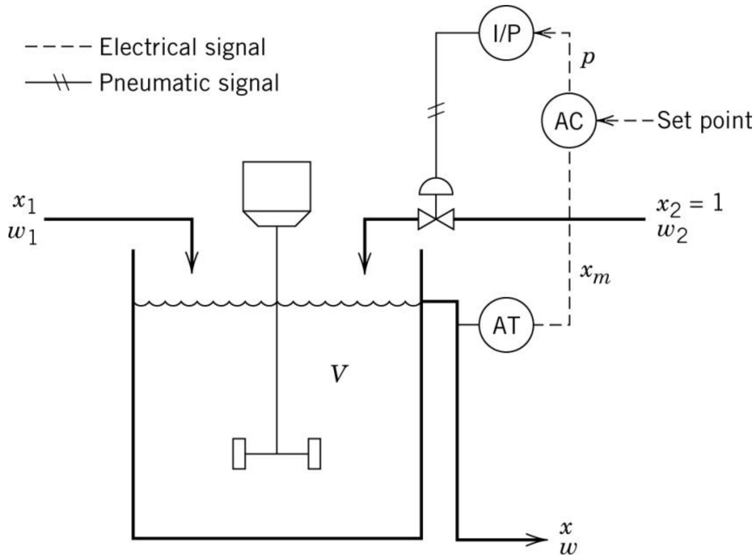


Figure 11.8 Standard block diagram of a feedback control system.

Basic Components in a feedback control loop



(1) Process being controlled

(2) Sensor-transmitter combination

(3) Feedback controller

(4) Current to pressure transducer

(5) Final control element (control valve)

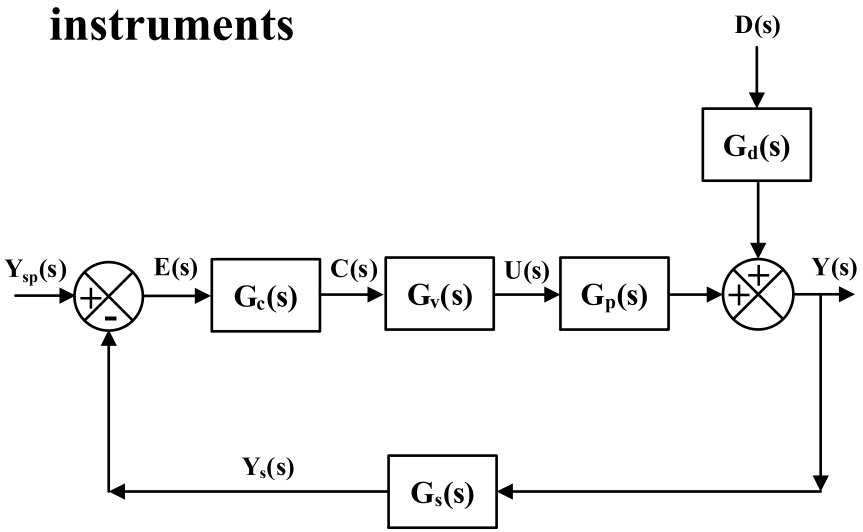
(6) Transmission lines between instruments

Analog instrumentation:

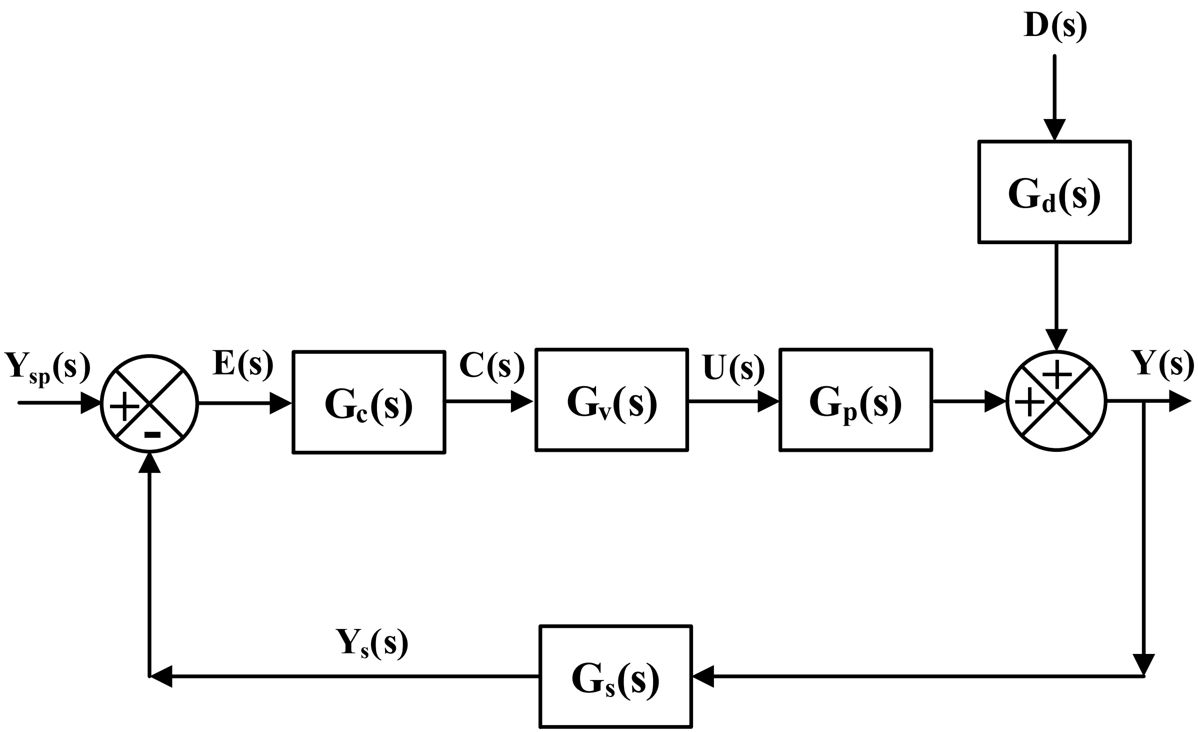
Electronic device : 4-20MA,1-5v

Pneumatic device: 3-15 psig

Digital technology



General Feedback Control Loop



Closed Loop Transfer Functions

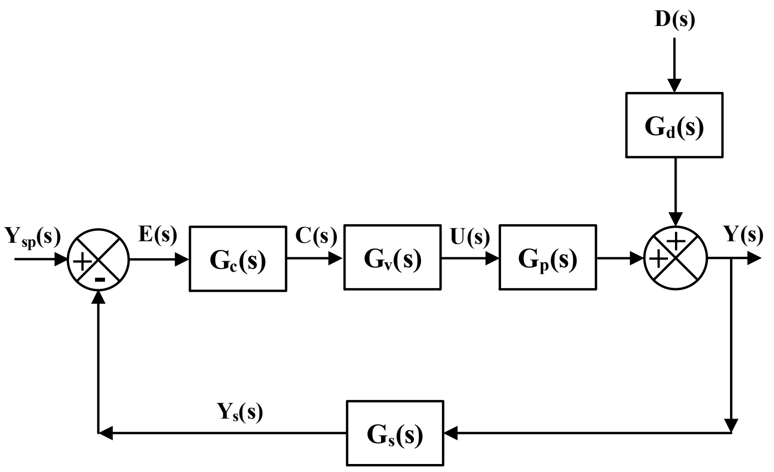
Y(s)=Gp(s)U(s)+Gd(s)D(s)

U(s)=Gv(s)C(s)

C(s)=Gc(s)E(s)

E(s)=Ysp(s)-Ys(s)

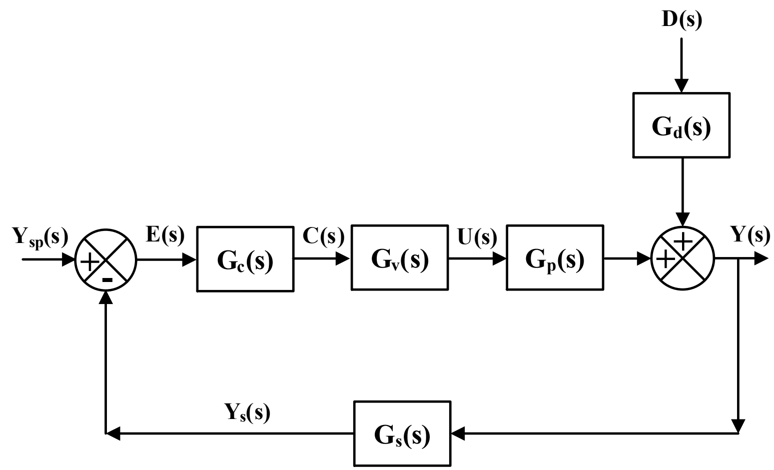
Ys(s)=Gs(s)Y(s)



$$\frac{Y(s)}{Y_{sp}(s)} = \frac{G_p(s)\ G_v(s)\ G_c(s)}{G_p(s)\ G_v(s)\ G_c(s)\ G_s(s) + 1}$$

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

Closed Loop Transfer Functions



Servo problem:

$$\frac{Y(s)}{Y_{sp}(s)} = \frac{G_p(s)\ G_v(s)\ G_c(s)}{G_p(s)\ G_v(s)\ G_c(s)\ G_s(s) + 1}$$

Regulatory problem:

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

Feedback controller

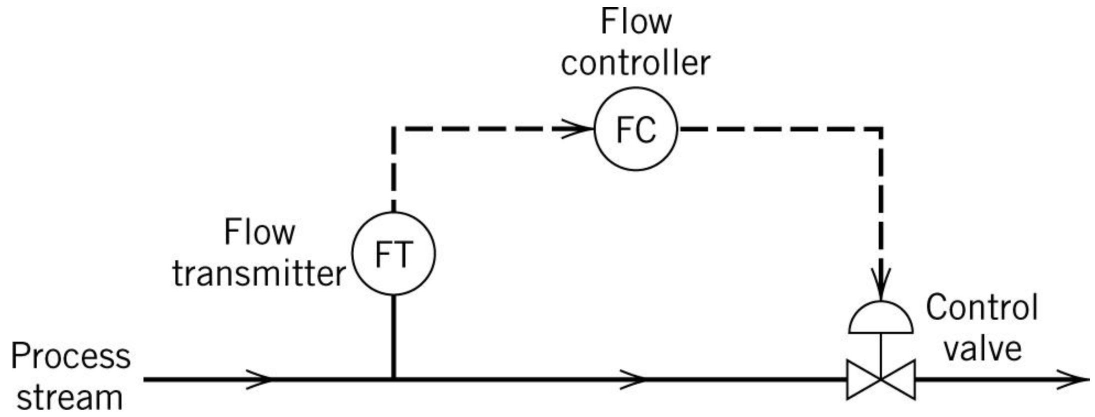


Figure 7.2 Flow control system

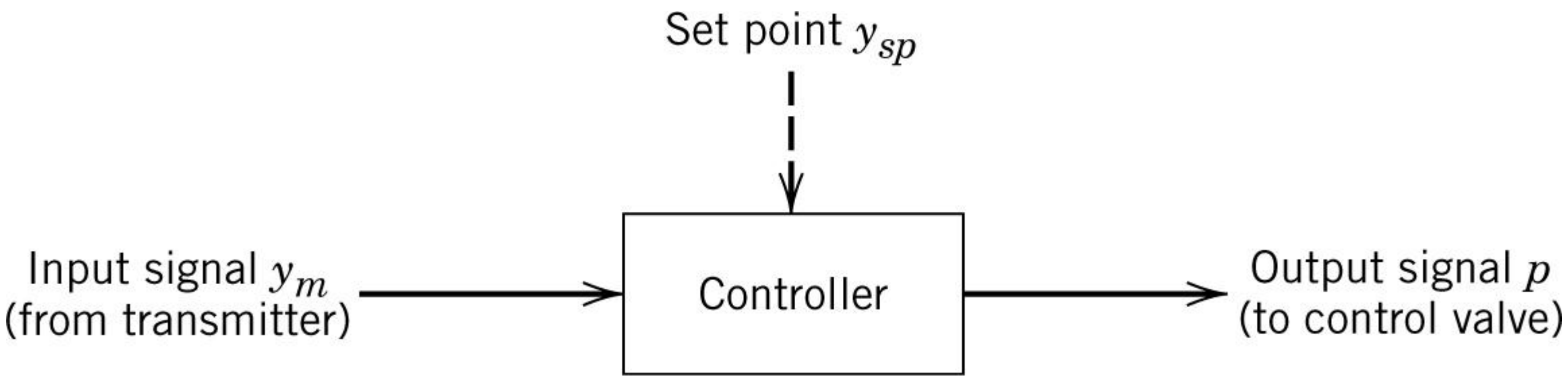


Figure 7.3 Simple diagram of a feedback controller

Three Mode (PID) Controller

- Proportional
- Integral
- Derivative

Proportional Control

- Define an error signal, e, by $e = Y_{sp} - Y_m$

  where

  Y_{sp} = set point

  Y_m = measured value of the controlled variable (or equivalent signal from transmitter)

Since signals are time varying,

$e(t) = Y_{sp}(t) - Y_m(t)$

- For proportional control: $p(t) = \bar{p} + K_c e(t) \qquad p' = p - \bar{p}$

  where,

  $p(t)$ = controller output

  $\bar{p}$ = bias value (adjustable)

  K_c = controller gain (dimensionless, adjustable)

Some important issues of proportional controllers

1 Proportional Band, PB

$$PB \equiv \frac{100\%}{K_c}$$

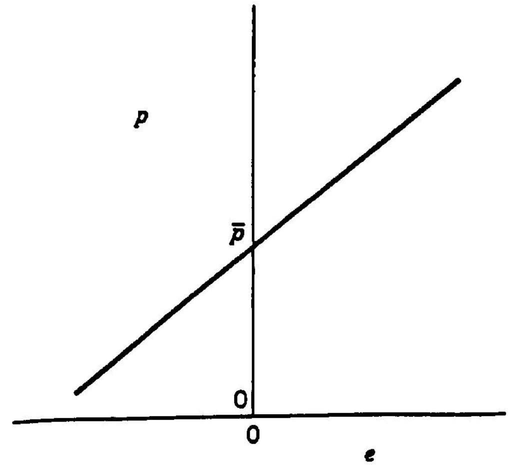


Figure 8.4. Proportional control: ideal behavior (slope of line = K_c).

<u>Standards</u> (ISO/ISA)

3 – 15 psi
4 - 20 mA
0 – 10 VDC

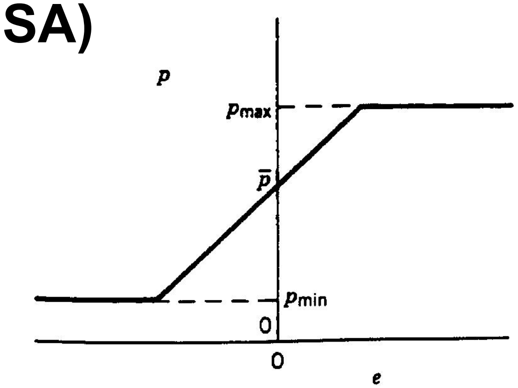


Figure 8.5. Proportional control: actual behavior.

Some important issues of proportional controllers

2 Reverse or Direct Acting Controller

- K_c can be made positive or negative
- Recall for proportional FB control:

$$p(t) = \bar{p} + K_c e(t)$$

or

$$p(t) = \bar{p} + K_c \left[Y_{sp}(t) - Y_m(t) \right]$$

- **Direct-Acting** ($K_c < 0$)

  "output increases as input increases"

  p(t) $Y_m(t)$

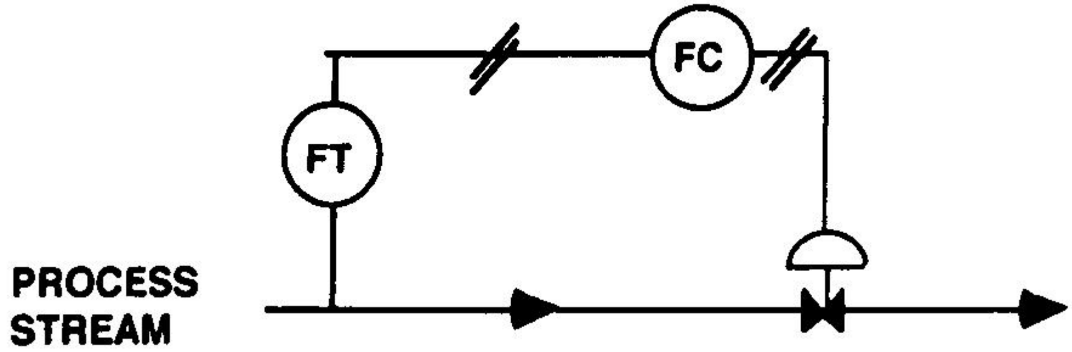
- **Reverse-Acting** ($K_c > 0$)

  "output increases as input decreases"

Feedback Control Analysis

- The loop gain ($K_c K_v K_p K_M$) should be positive for stable feedback control.
- An open-loop unstable process can be made stable by applying the proper level of feedback control.

- ***Example 2:*** Flow Control Loop



Assume FT is direct-acting. Select sign of K_c so that $K_c K_v > 0$

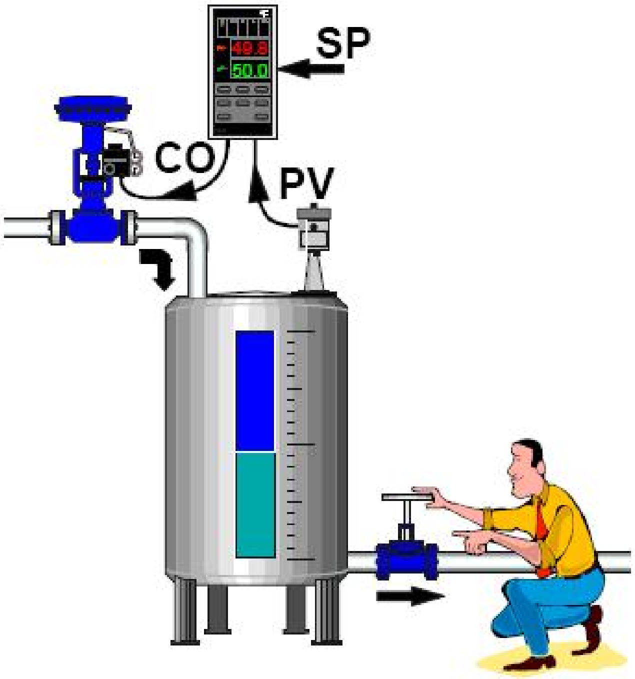
1.) Air-to-open (fail close) valve ==> ?
2.) Air-to-close (fail open) valve ==> ?

- Consequences of wrong controller action??

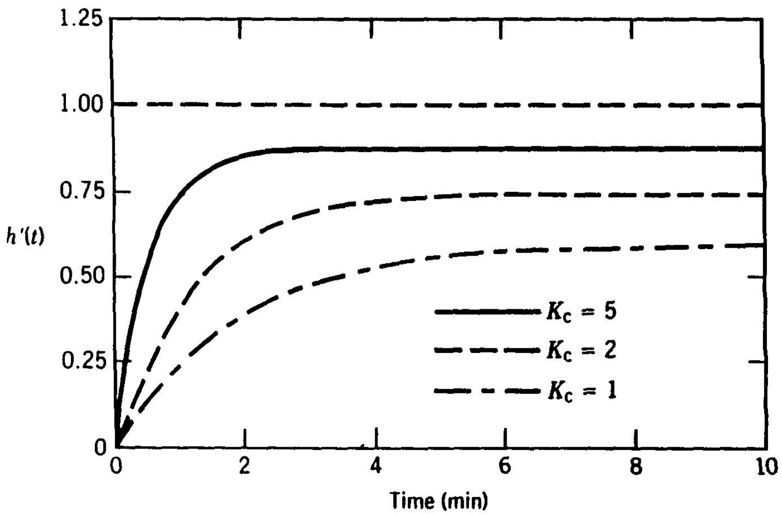
Some important issues of proportional controllers

- What is the steady state?

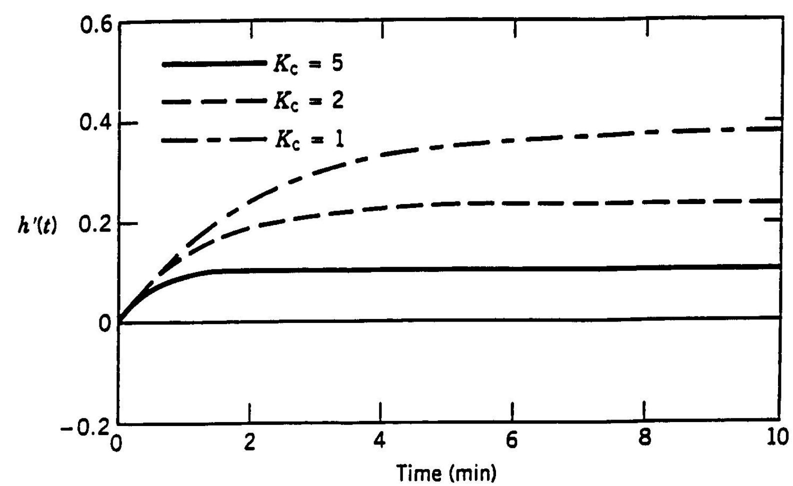
- Offset can not be eliminated by P-only control !



Offset Resulting from P-only Control



Set-point responses



load responses

- **Transfer Function for Proportional Control:**

Let $$p'(t) \equiv p(t) - \overline{p}$$

Then controller input/output relation can be written as

$$p'(t) \equiv K_c e(t)$$

Take Laplace transform of each side,

$$P'(s) \equiv K_c E(s)$$

or

$$\frac{P'(s)}{E(s)} \equiv K_c$$

P-only control sumary

- **Advantage** : immediate corrective action.
- **Disadvantage** : **steady-state error(offset)**.
- **Usage** : when the steady-state error is tolerable(ex. level control which wants to prevent the system from overflowing or drying), proportional-only controller is attractive because of its simplicity ← seldom used only.
- **B** To remove the steady-state error(offset), the **integral control action** should be included in the feedback controller.

INTEGRAL CONTROL ACTION

$$p(t) = \overline{p} + \frac{1}{\tau_I}\int_0^t e(t^*)dt^* \qquad \frac{P'(s)}{E(s)} = \frac{1}{\tau_I s}$$

$\tau_I \equiv$ reset time (or integral time) - adjustable

Proportional-Integral (PI) Control

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

integral provides memory of e
most popular controller

- Response to unit step change in e:

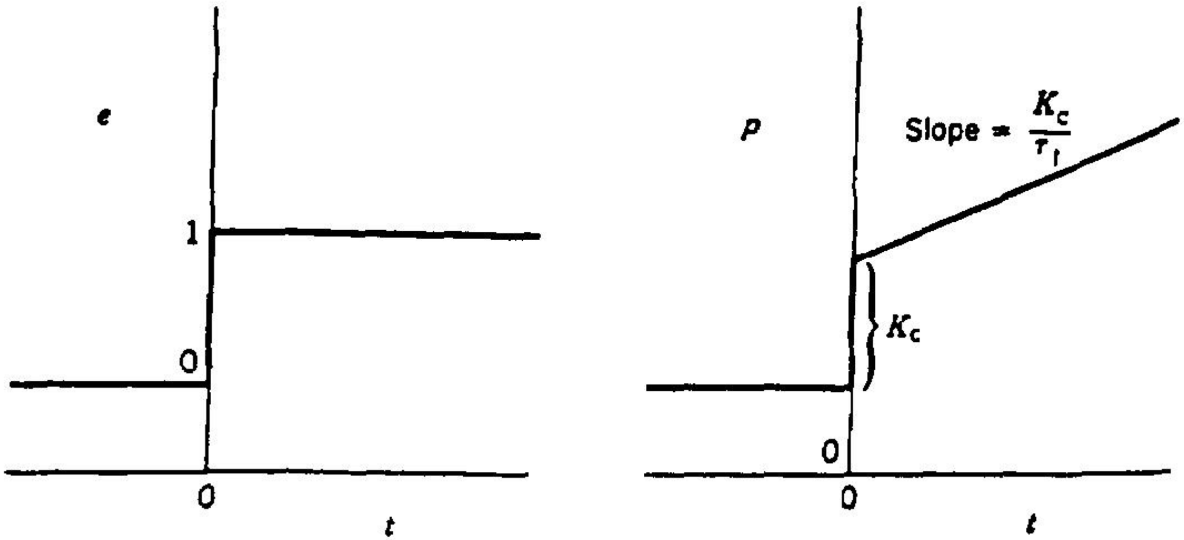


Figure 8.6. Response of proportional-integral controller to unit step change in $e(t)$.

- Transfer function for PI control

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

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

Derivative Control

The function of derivative control action is to anticipate the future behavior of the error signal by considering its rate of change.

- The anticipatory strategy used by the experienced operator can be incorporated in automatic controllers by making the controller output proportional to the rate of change of the error signal or the controlled variable.

- *Ideal* derivative action,

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

where τ_D, the derivative time, has units of time.

Transfer function of PD control:

$$\frac{P'(s)}{E(s)} = K_c\left(1 + \tau_D s\right) \qquad (8-11)$$

- By providing anticipatory control action, the derivative mode tends to stabilize the controlled process.
- Unfortunately, the ideal proportional-derivative control algorithm is *physically unrealizable* because it cannot be implemented exactly.

- For analog controllers, the transfer function in (8-11) can be approximated by

derivative filter

$$\frac{P'(s)}{E(s)} = K_c\left(1 + \frac{\tau_D s}{\alpha\tau_D s + 1}\right) \qquad (8\text{-}12)$$

where the constant α typically has a value between 0.05 and 0.2, with 0.1 being a common choice.

- In Eq. 8-12 the derivative term includes a *derivative mode filter* (also called a *derivative filter*) that reduces the sensitivity of the control calculations to high-frequency noise in the measurement.

Proportional-Integral-Derivative (PID) Control

Now we consider the combination of the proportional, integral, and derivative control modes as a PID controller.

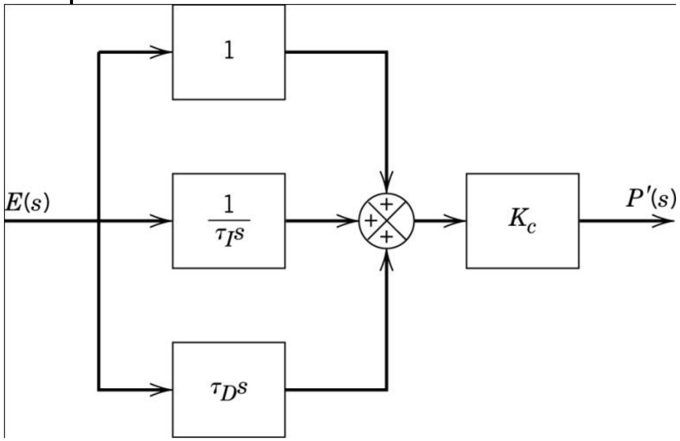
- Many variations of PID control are used in practice.
- We consider the three most common forms.

Parallel Form of PID Control

The *parallel form* of the PID control algorithm (without a derivative filter) is given by

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

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



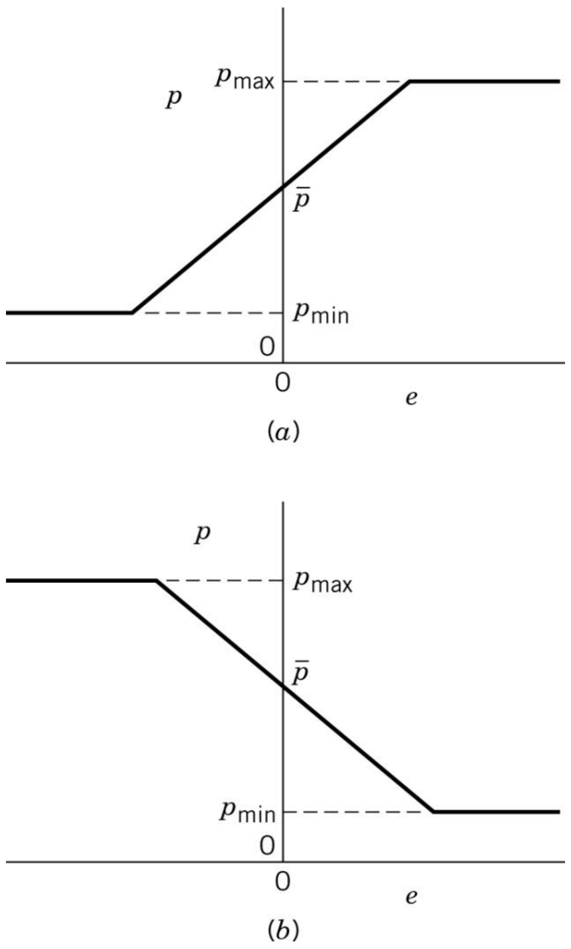
Expanded Form of PID Control

In addition to the well-known series and parallel forms, the *expanded form* of PID control in Eq. 8-16 is sometimes used:

$$p(t) = \bar{p} + K_c e(t) + K_I \int_0^t e(t^*)\,dt^* + K_D \frac{de(t)}{dt} \qquad (8\text{-}16)$$

PID Controller Features

- **Reverse and direct action**
  - Reverse action ($K_c > 0$) – controller output increases with increasing error
  - Direct action ($K_c < 0$) – controller output decreases with increasing error
  - Proper action determine by sign of the steady-state process gain (K) such that $KK_c > 0$



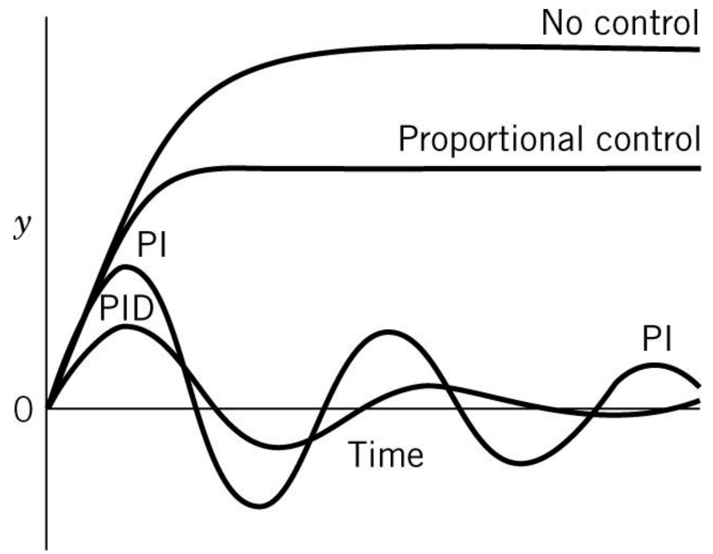
PID Controller Features

Automatic and Manual Control Modes

- Automatic Mode
  Controller output, p(t), depends on *e(t),* controller constants, and type of controller used.
  (PI *vs.* PID etc.)
- Manual Mode
  Controller output, p(t), is adjusted manually.
- Manual Mode is very useful when unusual conditions exist:
  plant start-up
  plant shut-down
  emergencies
- Percentage of controllers "on manual" ??

(30% in 2001, Honeywell survey)

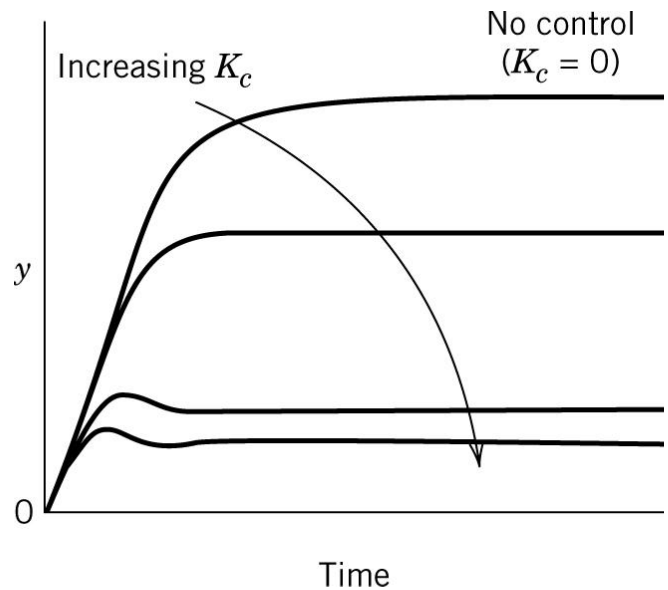
Typical Response of Feedback Control Systems



Typical process response with feedback control.

- **No feedback control** make the process slowly reach a new steady-state.
- **Proportional control** speeds up the process response and reduces the offset.
- **Integral control** eliminates offset but tends to make the response oscillatory.
- **Derivative control** reduces both the degree of oscillation and response time.

Effect of controller gain k_c .



Process response with proportional control.

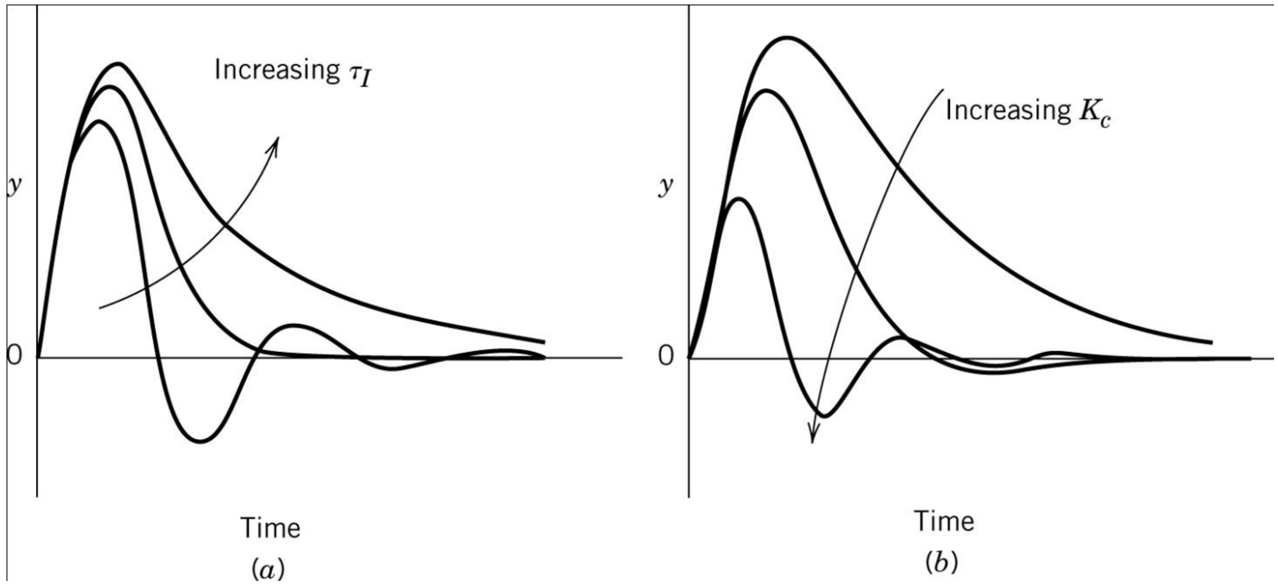
- Increasing the controller gain.

  🡐 less sluggish process response.
- Too large controller gain.

  🡐 undesirable degree of oscillation or even unstable response.
- An intermediate value of the controller gain

  🡐 best control result.

Effect of integral time τ_I .



PI control: (a) effect of integral time (b) effect of controller gain.

- Increasing the integral time.

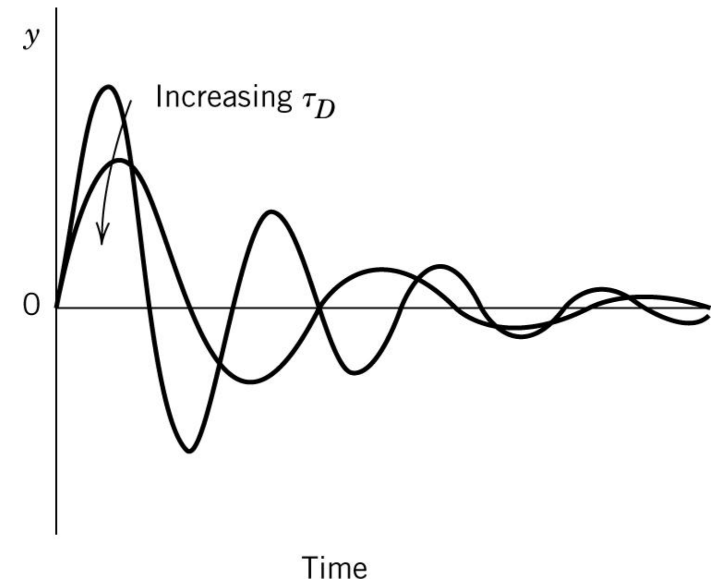
  🡐 more conservative(sluggish) process response.

- Too large integral time.

  🡐 too long time to reach to the set point after load upset or set-point change occurs.

- Theoretically, offset will be eliminated for all values of τ_I .

Effect of derivative time τ_D .



PID control: effect of derivative time.

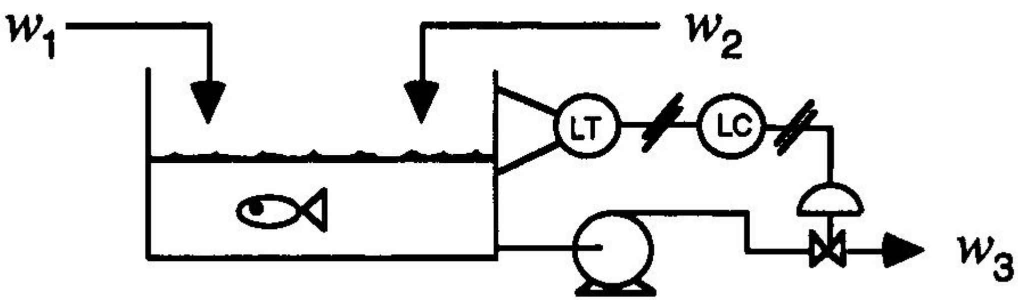
- Increasing the derivative time.

  🡐 improved response by reducing the maximum deviation, response time and the degree of oscillation.
- Too large derivative time.

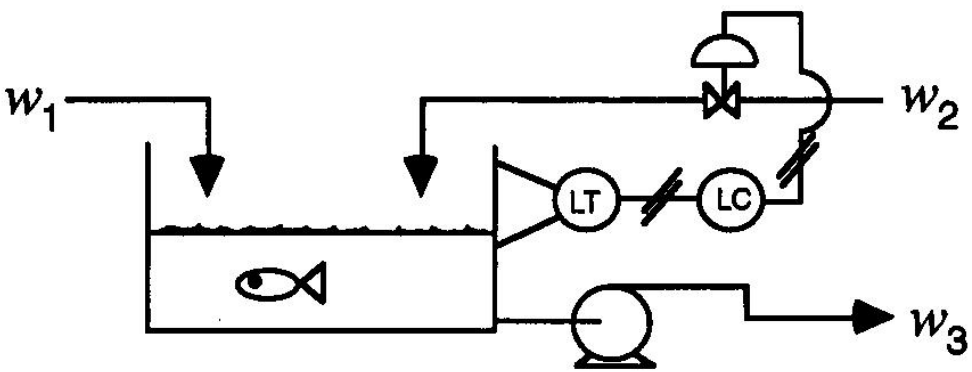
  🡐 measurement noise tends to be amplified and the response may be oscillatory.
- Intermediate value of τ_D is desirable.

Example 3: Liquid Level Control

- Control valves are air-to-open
- Level transmitters are direct acting



System I



System II

Question:

1. Type of controller action? Select K_c so that

$$K_c K_v K_p > 0$$

(a) air-to-open valve: sign of K_v?
(b) sign of process gain?