CONTROLLERS:

P, PI, PD

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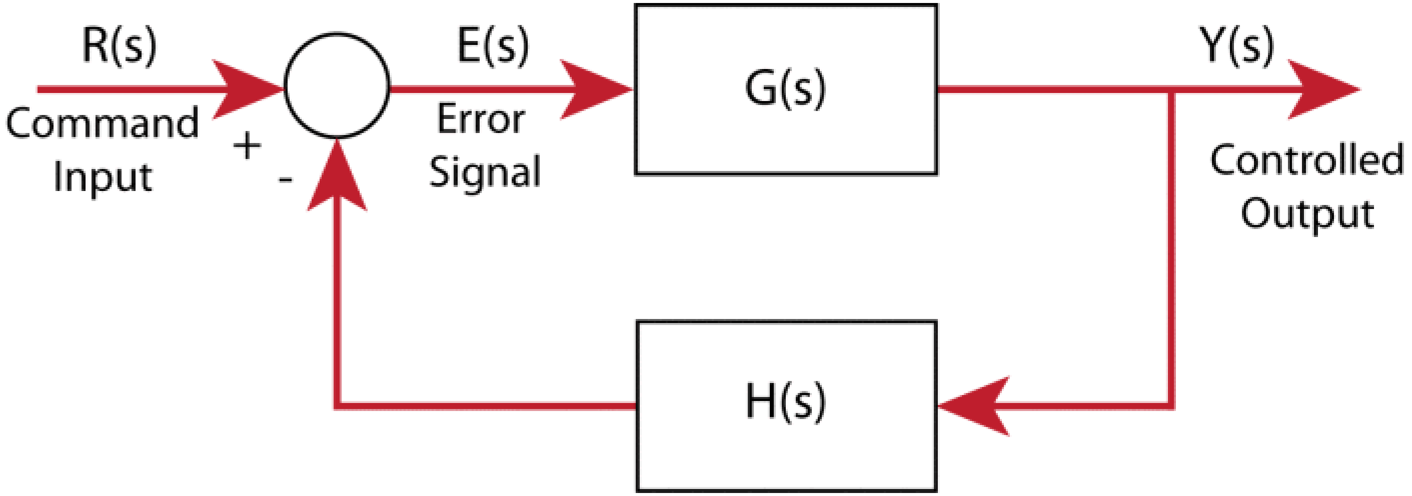
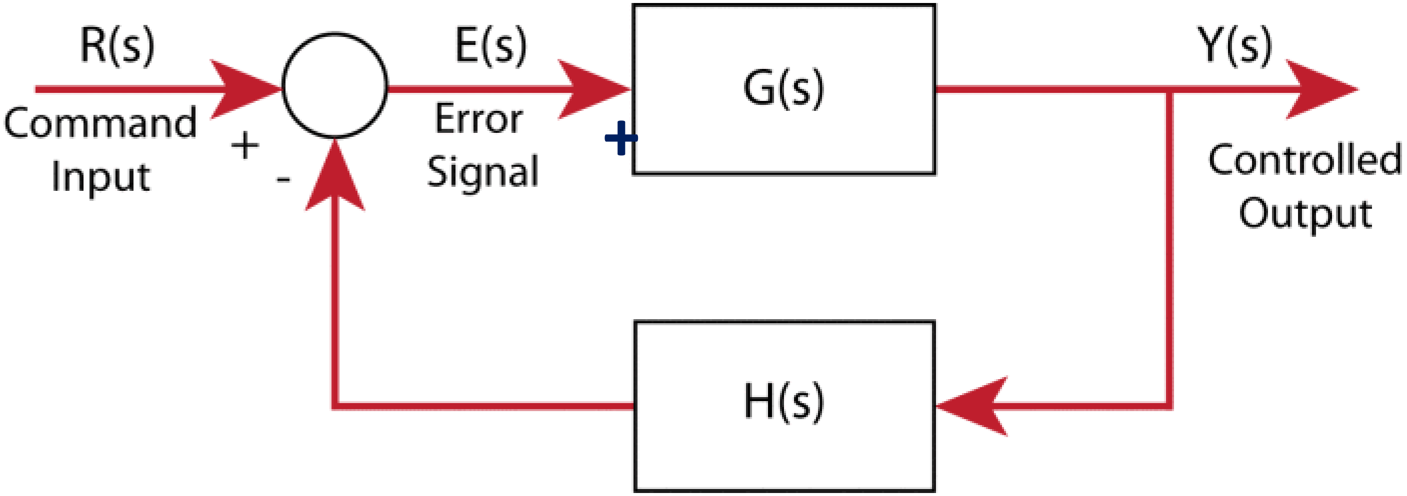
Transfer function- Negative feedback



$$C(s)/R(s) = G(s)/(1+G(s)H(s))$$

Transfer function- Positive feedback



C(s)/R(s)= G(s)/(1-G(s)H(s))

Negative vs. Positive Feedback

- N**egative feedback** is almost always the most useful type of feedback.
- When we subtract the value of the output from the value of the input (our desired value), we get a value called the **error signal**.
- The error signal shows us how far off our output is from our desired input.
- **Positive feedback** has the property that signals tend to reinforce themselves, and grow larger.
- In a positive feedback system, noise from the system is added back to the input, and that in turn produces more noise.
- As an example of a positive feedback system, **consider an audio amplification system with a speaker and a microphone.** Placing the microphone near the speaker creates a positive feedback loop, and the result is a sound that grows louder and louder. Because the majority of noise in an electrical system is high-frequency, the sound output of the system becomes high-pitched.

Feedback and feed forward control system?

Feedback:

- ✓ The output of the process is measured with the help of a **sensor** and the **sensor value is given to the controller to take a proper controlling action**.

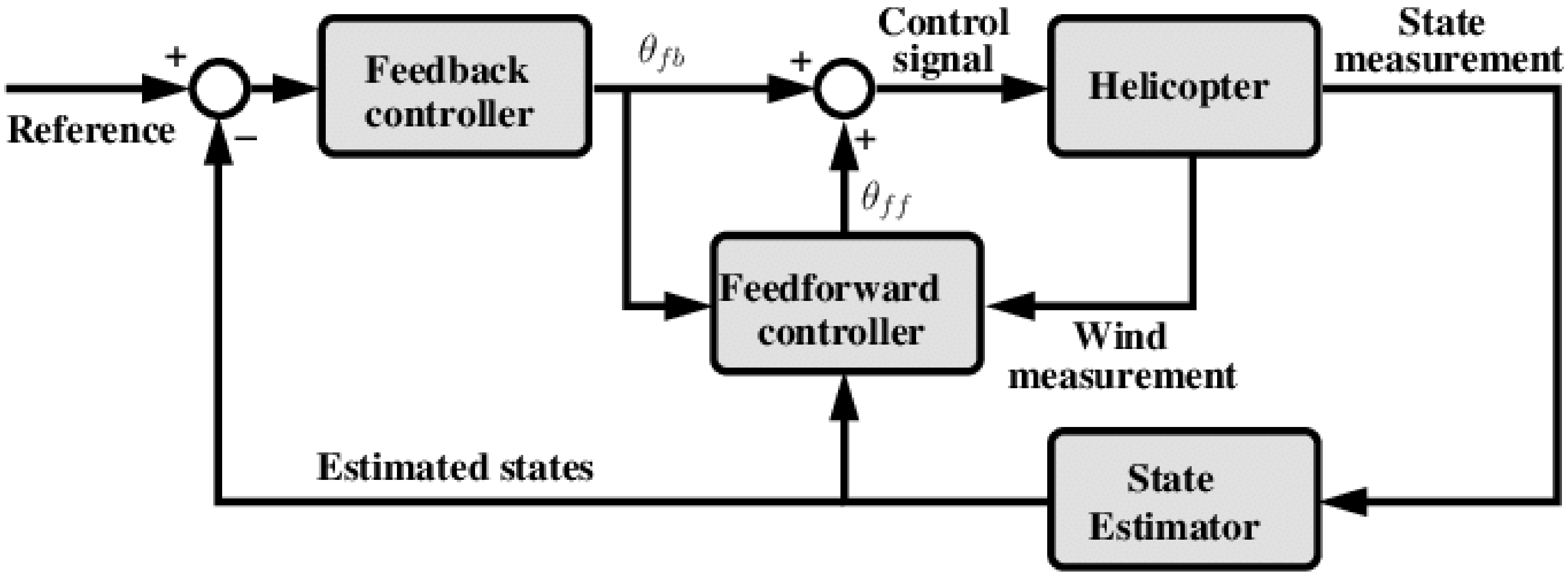
Feedback:

- ✓ Correcting perturbations after the fact.
- ✓ Controller takes control action **only after** the process variables and disturbance effects the process and the control action is also given to the process directly.
- ✓ **For example** a thermostat will counteract a drop in temperature by switching on the heating.

Feed Forward (FF)

- ✓ A feed forward system will **proactively** turn on the furnace to prevent system change.
- ✓ **For example:** Feed forward control might be applied to the thermostatically controlled room by installing a temperature sensor outside of the room, which would warn the thermostat about a drop in the outside temperature, so that it could start heating before this would affect the inside temperature.

Combination between feedback and feed forward

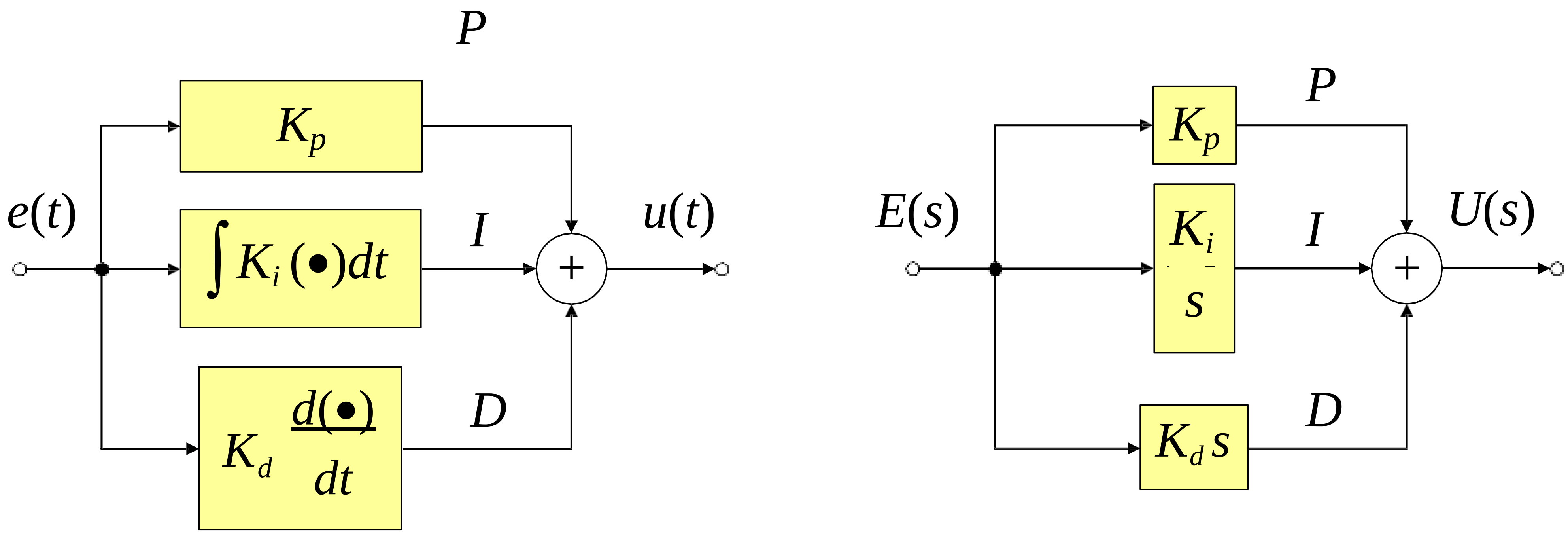


Rationale (Physical Sense)

- How to determine the control action?
  - based on the error (the difference between the set-point and the actual output value)
- PID = Proportional + Integral + Derivative
- Proportional mode
  - reacts to the present error
- Integral mode
  - reacts to the past history of the error signal
- Derivative mode
  - reacts to the expected future of the error signal (rate)

Block Diagram

- PID = Proportional + Integral + Derivative
- Also known as: Three-term controller



PID Time Domain Representation

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt}$$

$$= K_p \left\{ e(t) + \frac{1}{T_i} \int_0^t e(t)dt + T_d \frac{de(t)}{dt} \right\}$$

integral time constant **derivative time constant**

$$\text{where} \quad T_i = \frac{K_p}{K_i}, \qquad T_d = \frac{K_d}{K_p}$$

derivative gain

proportional gain integral gain

Steady state error equation

Steady-State Error for Unity Feedback Systems

$$E(s) = R(s) - C(s)$$

Steady-State Error in Terms of $G(s)$

$$E(s) = R(s) - C(s)$$

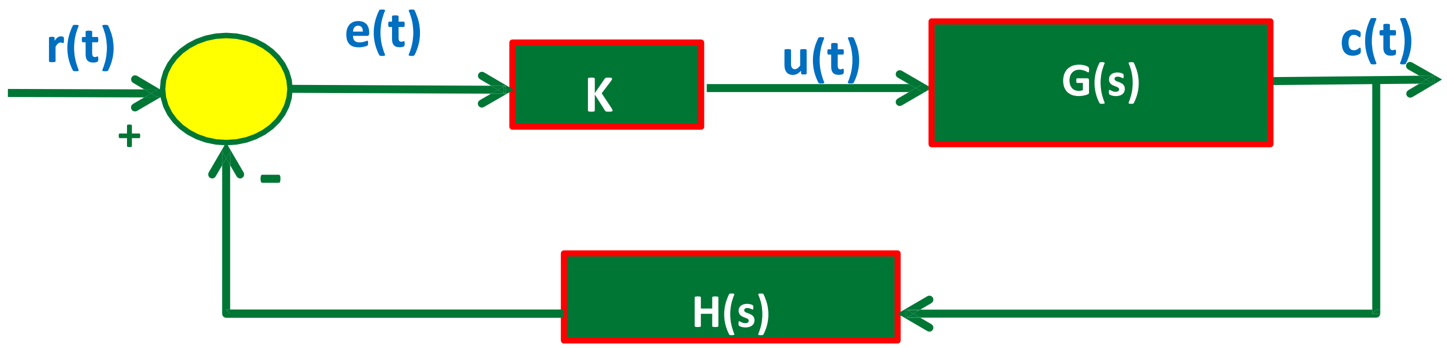
$$C(s) = E(s)G(s)$$

$$E(s) = \frac{R(s)}{1 + G(s)}$$

$$e(\infty) = \lim_{s \to 0} \frac{sR(s)}{1 + G(s)}$$

Note: *$G(s)$ is called the forward-path transfer function, which is different from the closed-loop transfer function*

Proportional control (P control)

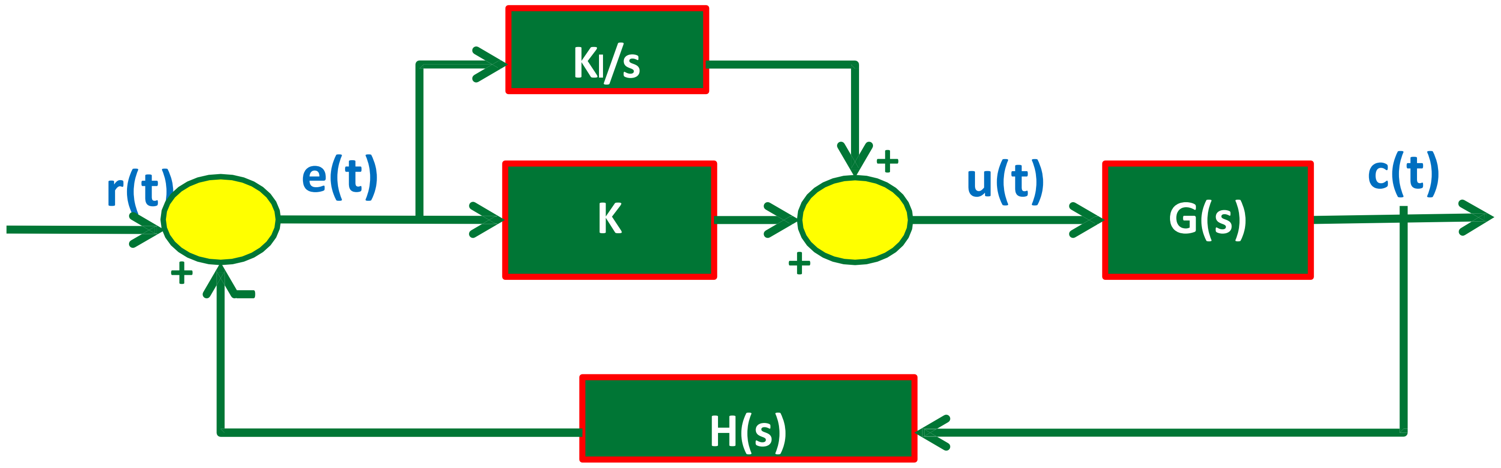


- Control action:- u(t)=Ke(t)
- Effect on Steady State Response:- Reduces the steady state error

$$ess = \lim_{s \to 0} sE(s) = \lim_{s \to 0} \frac{sR(s)}{1 + KG(s)H(s)}$$

- Effect on Transient Response:- Increases the speed of response.
- Limitations and shortcomings:- Saturation, noise and instability.
- Hence new control schemes (PI, PD) are conceived.

Proportional and Integral (PI) control



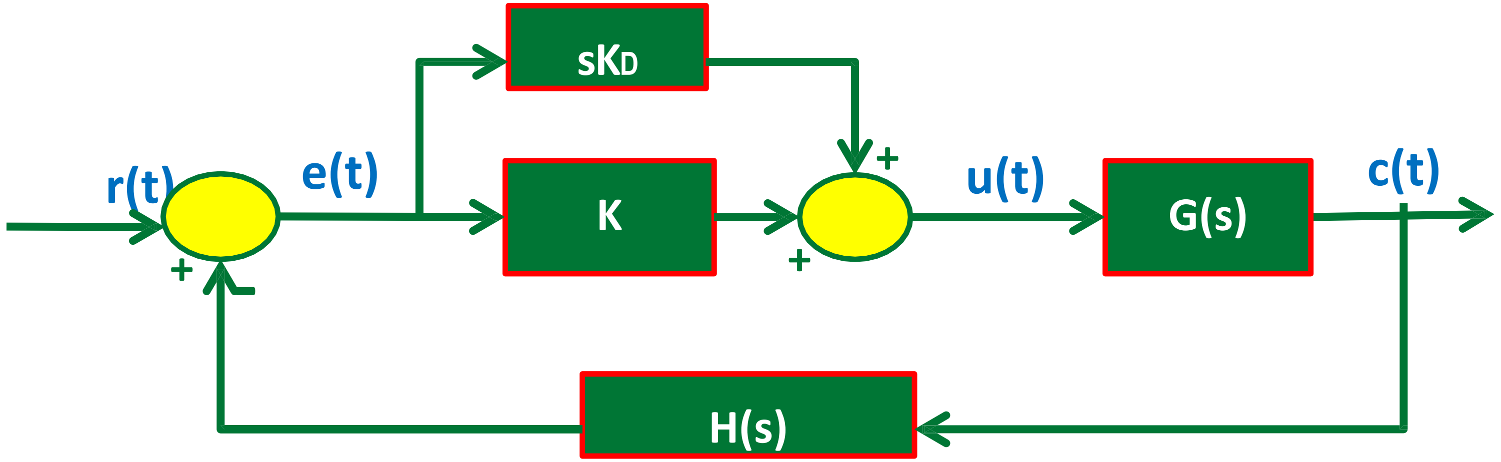
- ✓ Control action:- $u(t)=K_e(t)+K_I\int e(t)dt$

  $U(s)=(K+ K_I/s)E(s)$

  where $K_I=1/T_I$, T_I=Integral or reset time

- ✓ Effect on Steady State Response:- steady state error can be reduced to zero exactly.
- ✓ Effect on Transient Response:-Increases peak overshoot & reduces the speed of response.
- ✓ Limitations and shortcomings:- Reduces the stability margin of the system.

Proportional and Derivative (PD) control

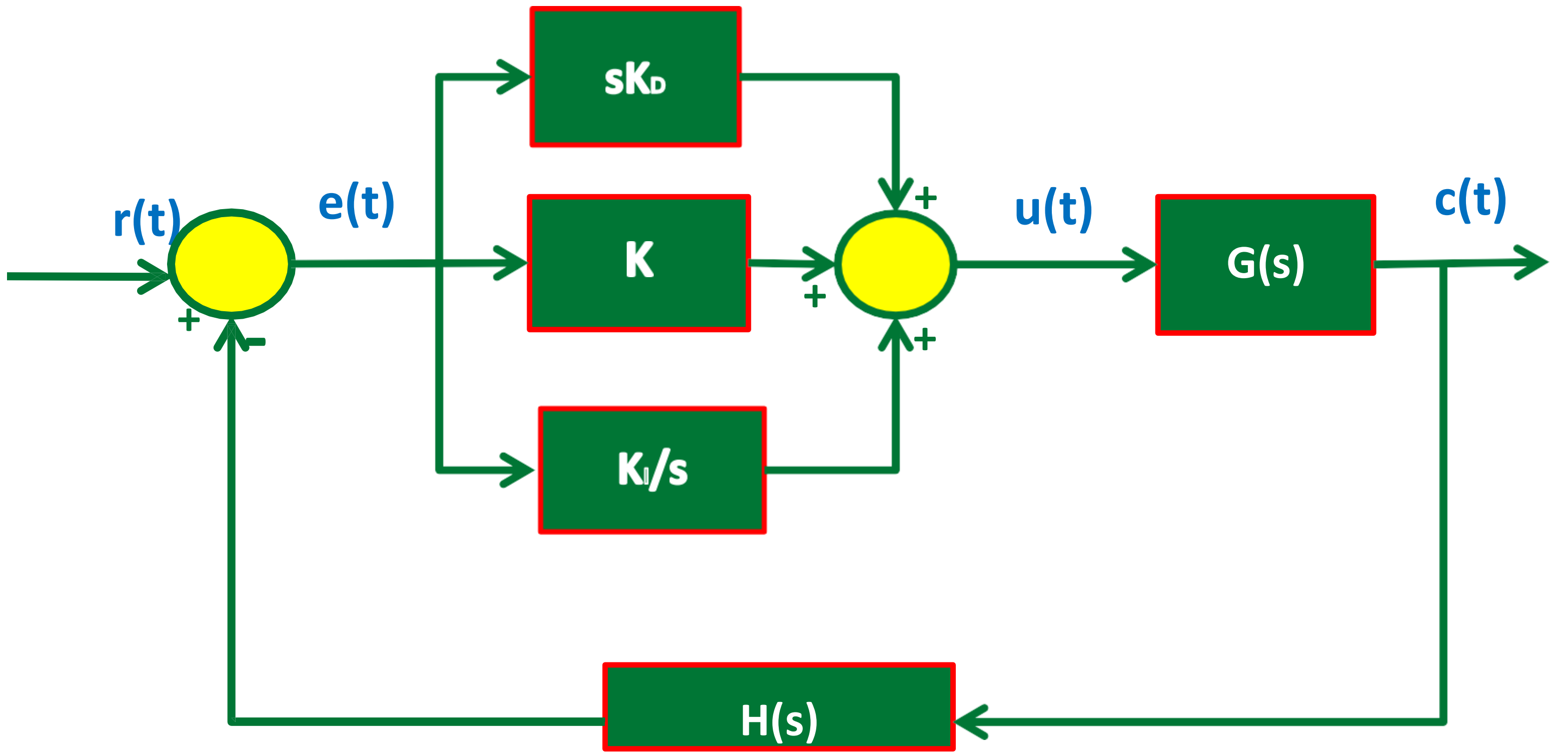


- ✓ Control action:- $u(t)=K_e(t)+K_D(d_e/d_t)$

  $U(s)=(K+ sK_D)E(s)$

  where $K_D=K_cT_D$, T_D=Derivative or rate time.
- ✓ Effect on Steady State Response:- Almost no effect.
- ✓ Effect on Transient Response:- Decreases the peak overshoot by improving the effective damping of the system.
- ✓ Limitations and shortcomings:-Amplifies the high frequency noise signals.

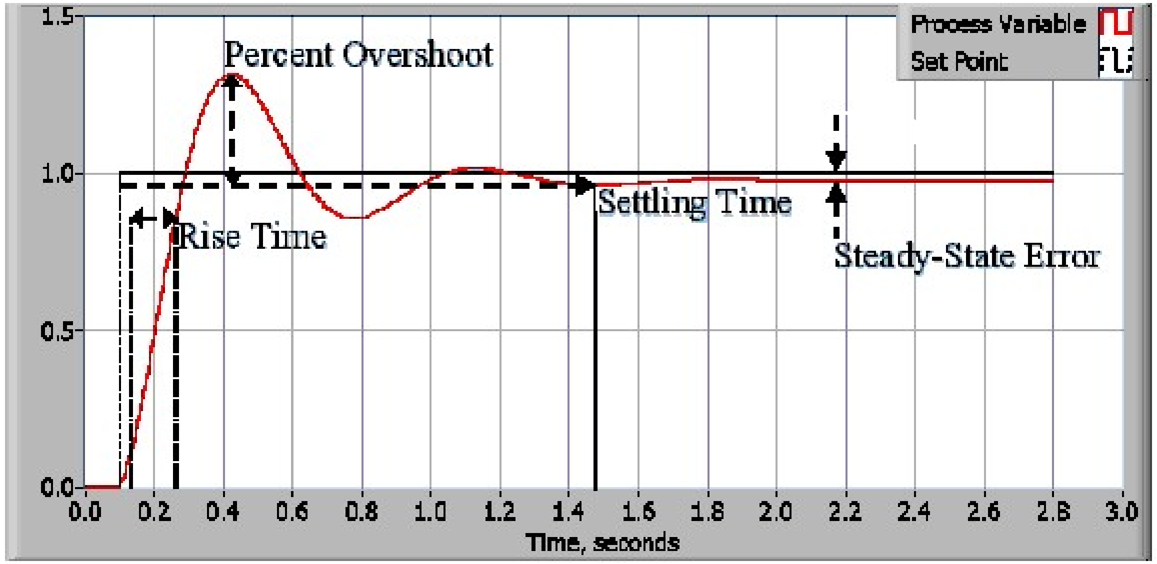
Proportional ,Integral & Derivative (PID) control



- ✓ Control action:- By proper adjustment of K, K_D,K_I the transient and dynamic responses are properly shaped.
- ✓ Problems:-Tuning of PID controller is a difficult job.

P-Term

$$A(t) = K_p \times e(t)$$

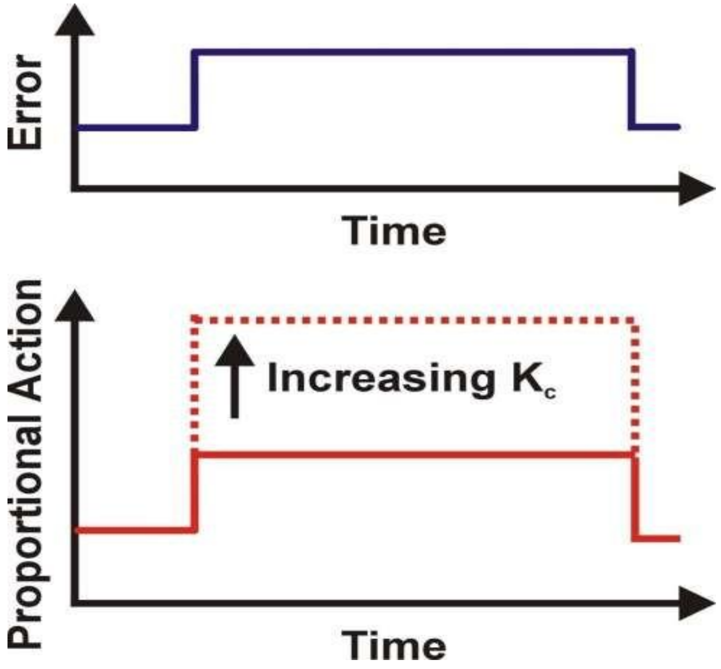


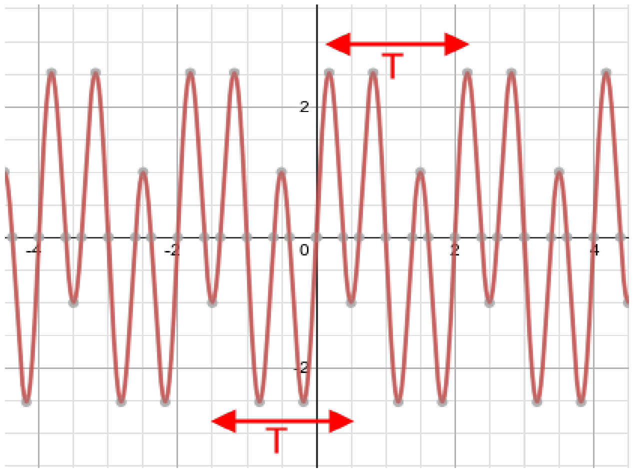
Advantages

- Immediate corrective action, Minimize rise time.
- Simple to implement.

Disadvantages

- It **leaves a steady state error** in some cases (when the error is zero action is zero steady state error reproduced)
- Proportional controllers also **increases the maximum overshoot** of the system
- High values of proportional gain reduces the stability of the system which can lead to **oscillation.**

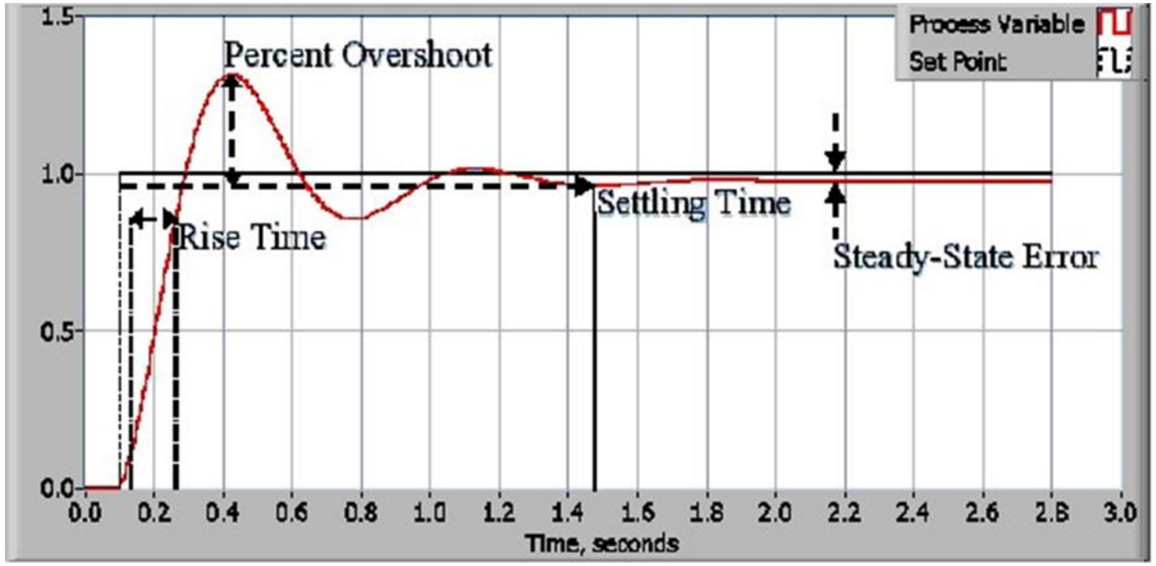




I-Term

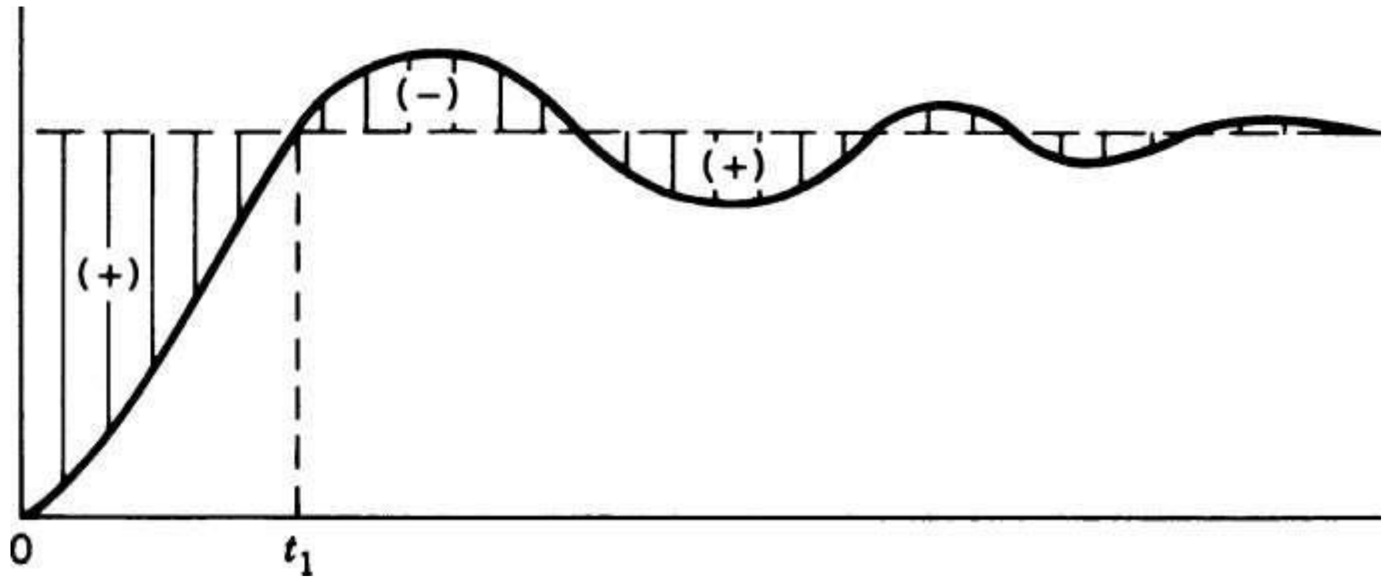
- ✓ Unlike proportional control, which looks at the present error, integral control looks at past errors.
- ✓ it looks at the history of the error signal.

$$A(t) = K_i \times \int_0^t e(t)dt$$



Disadvantages

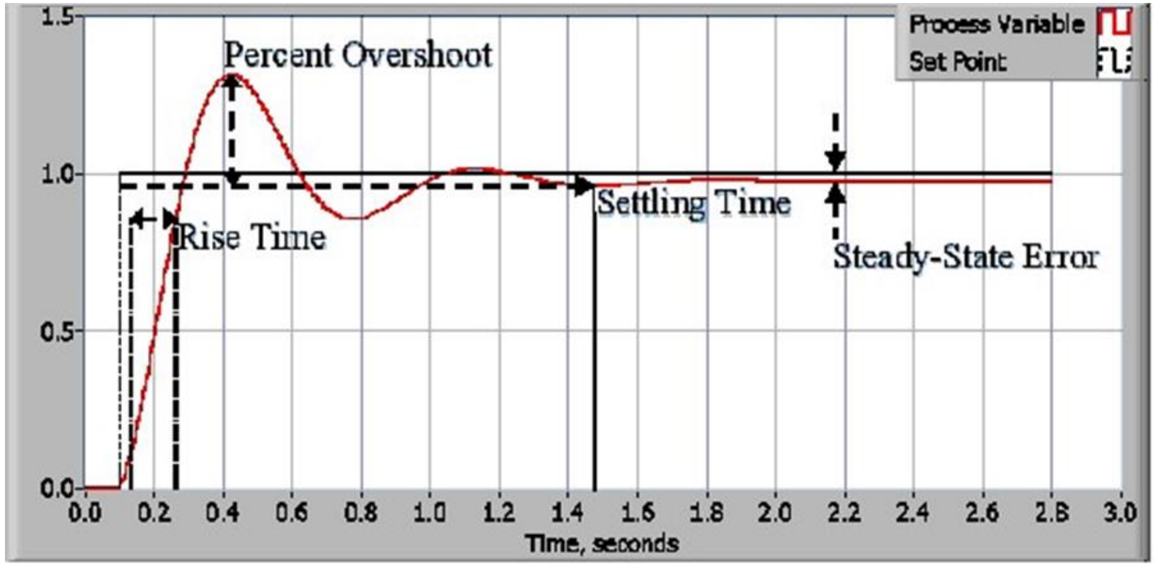
- Unstable because it **responds slowly** towards the produced error
- **More oscillatory** response & overshoot
- Can cause **serious overshoots** the system response becomes more oscillatory

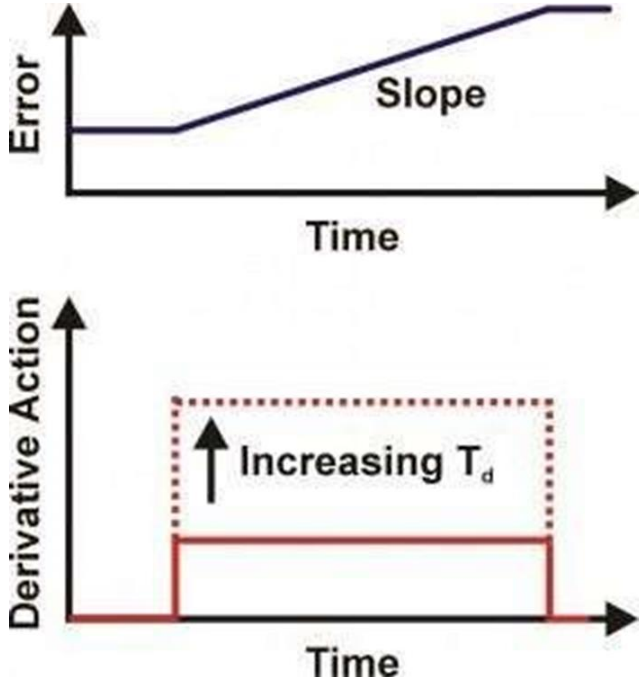


D-Term

- ✓ Expected future of the error signal
- ✓ While the proportional control reacts only to the present error and the integral control reacts to the past history of the error signal the derivative control reacts to the expected future of the error signal.
- ✓ Tendency of the error signal
- ✓ It uses the present and past errors to forecast/ anticipate the future behavior of the error signal and reacts according to the tendency of the error signal with the appropriate action

$$A(t) = K_d \times \frac{de(t)}{dt}$$





Advantages

- Reduces system oscillations

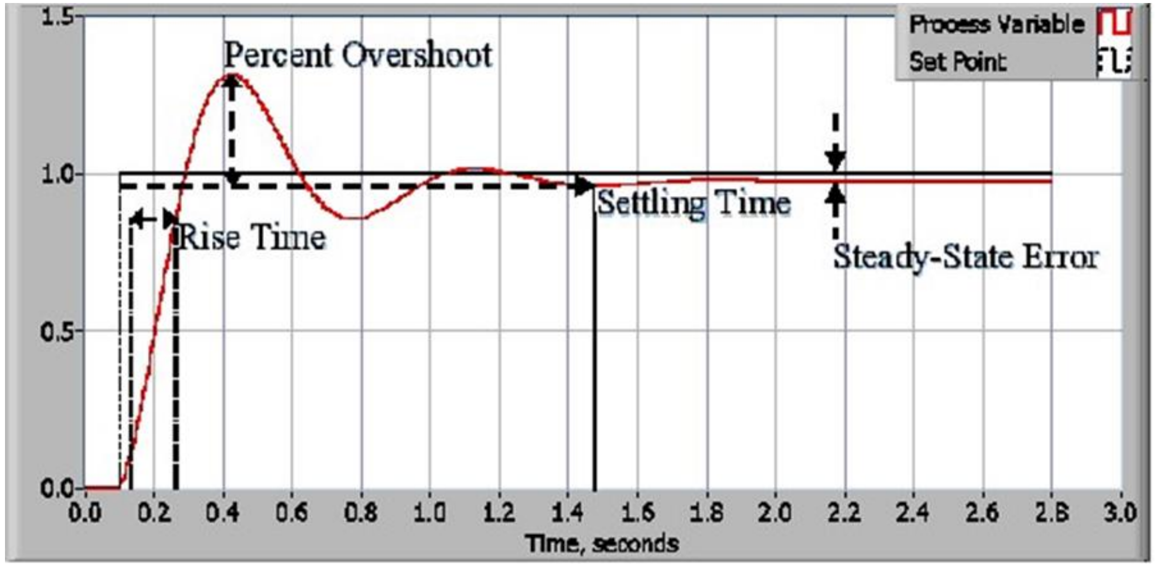
  Main advantage: **reduces system oscillations by braking the response** (braking here will not slow the system, it will increase the rise time … On the other hand reducing oscillations will reduce the settling time)

- It improves the transient response of the system.

Disadvantages

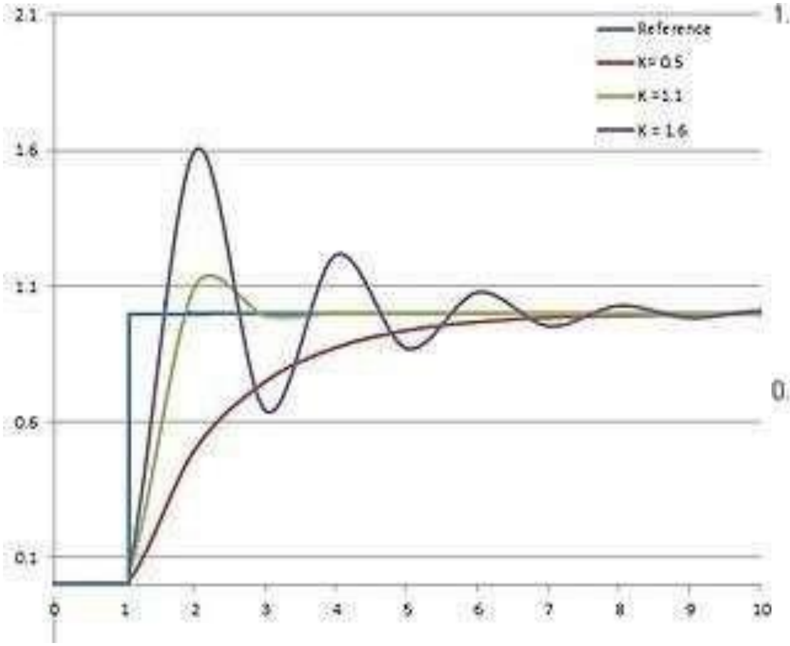
- The derivative action amplifies noise

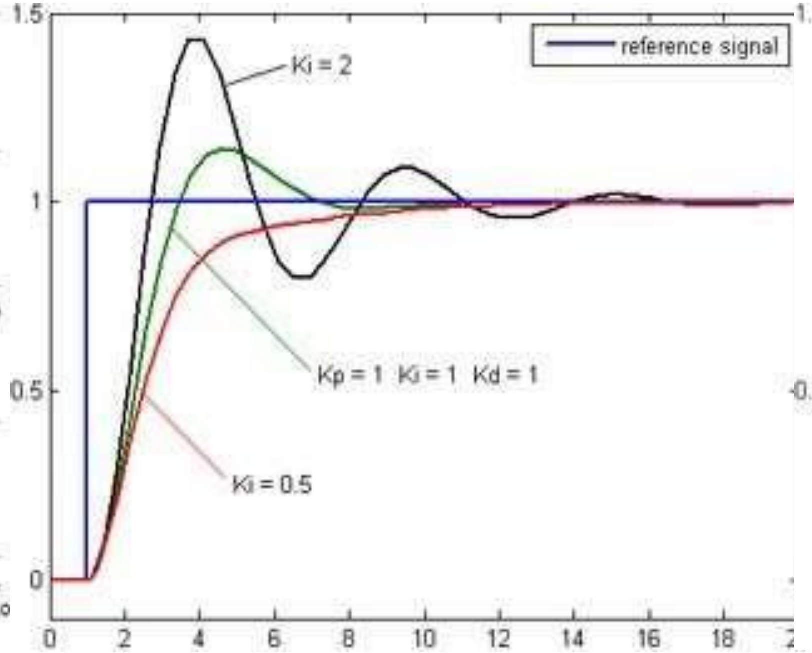
PID Controller Effects

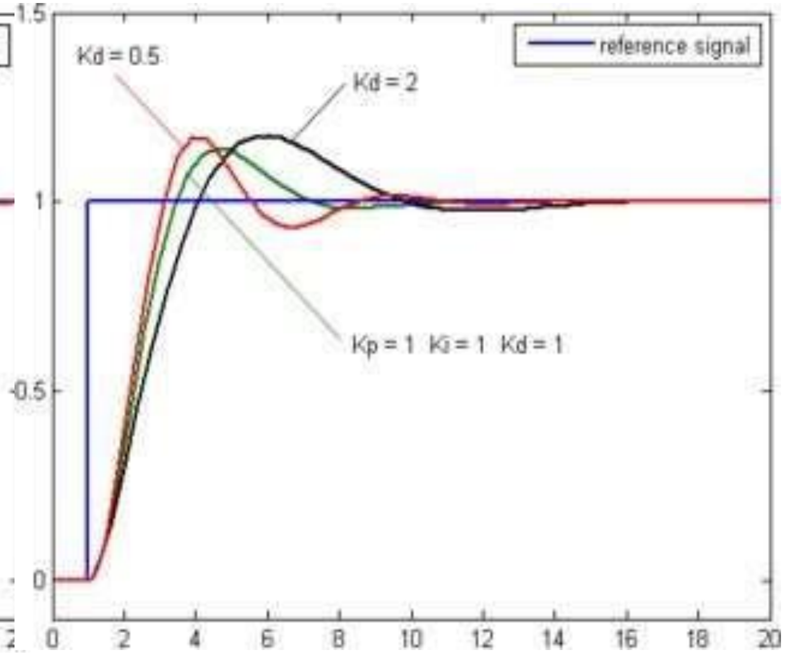


Closed-loop Response

	Rise time	Maximum overshoot	Settling time	Steady-state error
P	Decrease	Increase	Small change	Decrease
I	Decrease	Increase	Increase	Eliminate
D	Small change	Decrease	Decrease	No Change







Controller Effects

- Proportional controller (P)
  - reduces error responses to disturbances,
  - speeds up the process response
  - but still allows a steady-state error.
- Integral controller (I)
  - When the controller includes a term proportional to the integral of the error (I), then the **steady state error to a constant input is eliminated**.
- Derivative controller (D)
  - typically makes the system **better damped and more stable.**

Variations of PID Controller

- P
- P+D (Lead) Compensation
- P+I (Lag) Compensation
  - Is generally adequate when plant/process dynamics are essentially of 1st order
- P+I+D (Lead-Lag) Compensation
  - Is generally ok if dominant plant dynamics are of 2nd order

Combinations pros and cons

Advantages:

1. **Proportional (P)** : Speed controlled (Increase gain)
2. **Proportional - Integrated (PI)** : Good damping, No steady state error
3. **Proportional - Differential (PD)** : Maximum overshoot, decreases Rise time, settling time is reduced , Bandwidth is increased.
4. **Proportional - Integrated - Differential (PID)** : Decreases rise time (Kp), Eliminates steady state error (Ki), Decreases overshoot and settling time (Kd).

Disadvantages:

1. **Proportional (P)** : Steady state error.
2. **Proportional - Integrated (PI)** : Slow Response, Stability
3. **Proportional - Differential (PD)** : Steady state error

Design Guidelines

- ✓ Liquid level
  - ✓ Integrating process
  - ✓ Use P or PI controller with high gain
  - ✓ D-mode is not suitable since level signal is usually noisy due to the splashing and turbulence of the liquid entering the tank
- ✓ Flow control
  - ✓ Use PI controller with intermediate gain
  - ✓ No D-mode because of high frequency noise
  - ✓ Fast response, no time delay

Design Guidelines

- ✓ Temperature
  - ✓ Various characteristics with time delay.
  - ✓ Use PID or PI controller
  - ✓ (D-mode can accelerate the response)

General Tips for Designing a PID Controller

1. Obtain an open-loop response and determine what needs tobe improved
2. Add a proportional control to improve the risetime
3. Add an integral control to eliminate the steady-stateerror
4. Add a derivative control to improve theovershoot
5. Adjust each of Kp, Ki, and Kd until you obtain a desiredoverall response