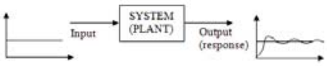
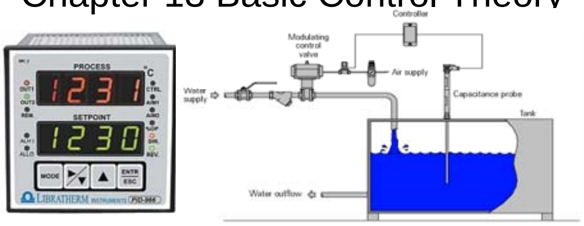


Lecture 11
Chapter 13 Basic Control Theory



By Hung Nguyen
Maritime Engineering and Hydrodynamics

Chapter 13

- Learning outcomes
  - Pp 13-3
- Contents
  - System responses
  - Proportional control
  - Integral control
  - P+I control
  - P+D control
  - P+I+D control

Chapter 13

- Importance of automatic control
  - Product quality
  - Production economy
  - Security
  - Environmental care
  - Feasibility and automation
- Marine and offshore: temp, liquid level and pressure in boilers, fuel flow rate, etc.

Chapter 13

- Open tank level system – control strategies

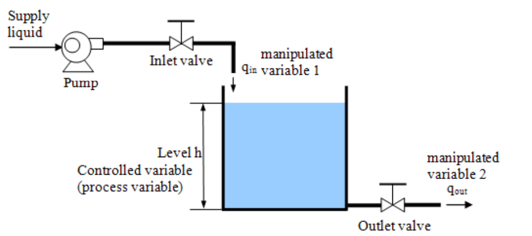
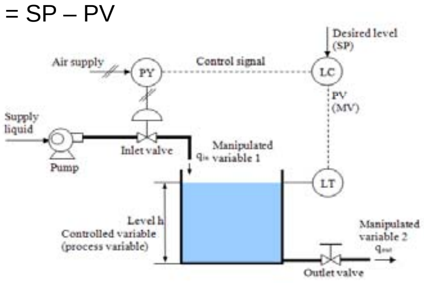


Figure 1 Tank level system

Chapter 13

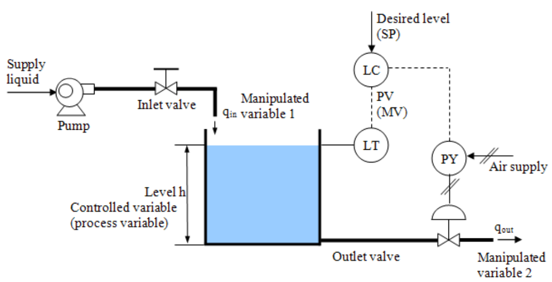
- Tank level system: control strategy 1
  - E = SP – PV



(a) Control strategy 1 – adjustment of inflow

Chapter 13

- Tank level system: control strategy 2



(a) Control strategy 2 – adjustment of outflow

Chapter 13

- Block diagram of a feedback control sys

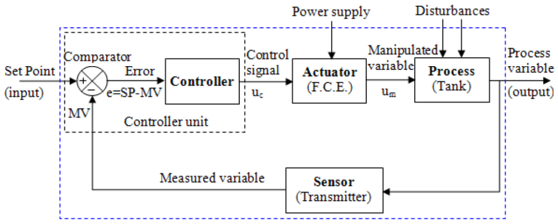
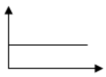


Figure 3 Block diagram of a feedback control system (with 4 basic components)

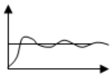
Chapter 13

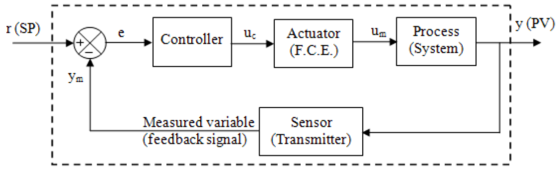
- 3. Control loop responses



step

step response





Chapter 13

- 3. Control loop responses
  - Transient
  - Steady-state

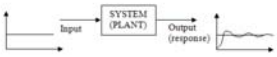


Figure 5 A system (plant) with an input and an output

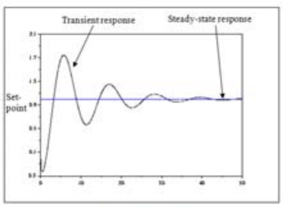
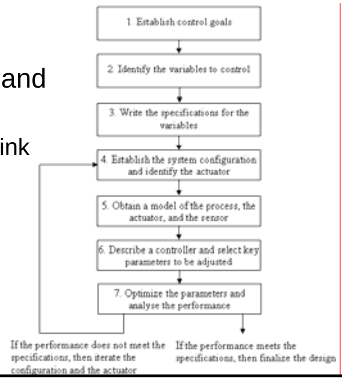


Figure 6 Control loop responses

Chapter 13

- Control system design process and software tools
  - MATLAB/Simulink
  - LabVIEW



Chapter 13

- Case study examples: temperature control

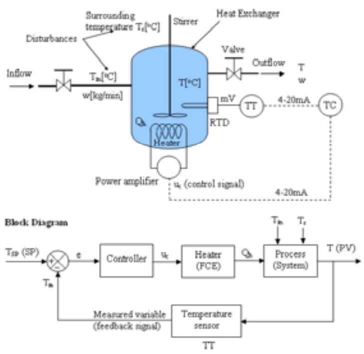


Figure 8 Temperature control

Chapter 13

- Case study
  - Motor speed control

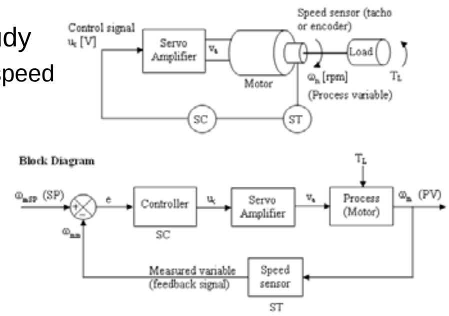


Figure 9 Motor speed control

Chapter 13

- Dynamic characteristics
  - Test input signals
  - Transfer function
- Examples of transfer function
  - Zero-order system
  - First-order system (*example 1*)
  - Second-order system (*example 2*)

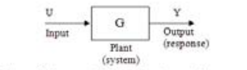


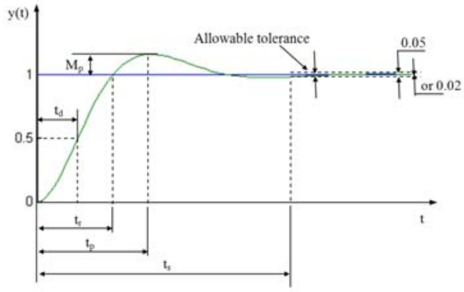
Figure 11 A system (plant) with an input and an output

Chapter 13

- 6.3 Examples of step responses
  - Zero-order systems (gain or sensitivity): linear temperature system
  - First-order systems (time constant, sensitivity): storage tank (level and inlet flow rate), RC circuit (input voltage and output voltage)
  - Second-order systems (damping ratio, natural frequency and sensitivity): mass-spring-damper, RLC circuit

Chapter 13

- 6.3.4 Step response specifications



Chapter 13

- 6.4 Process lags, dead time and control lag

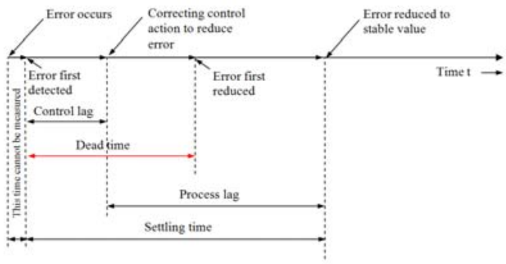


Figure 17 Time lags in control systems

Chapter 13

- Examples of control systems with time delays

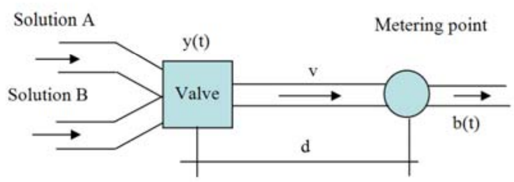
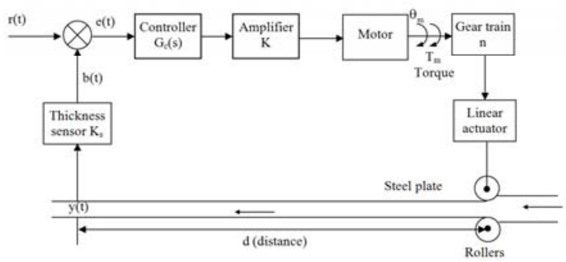


Figure 18 A fluid mixing system

Chapter 13

- Examples of control system with time delays



Chapter 13 Controller Actions

- 7. Direct and Reverse control actions

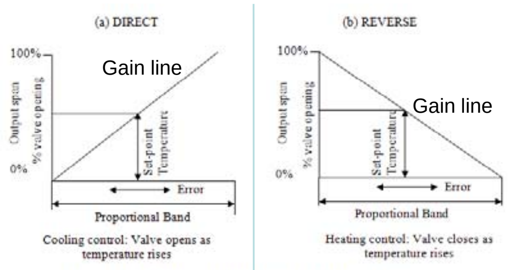


Figure 20 An illustration of DIRECT and REVERSE control actions

Chapter 13

- 8. Error calculations:
  - Error is calculated by a comparator (in software control program)
  - E = SP – PV or E = PV – SP
  - % Span Error = (SP – PV)*100%/Span
- Example 1: % span error?
- Example 2: Possible range of PV?

Chapter 13

- 9. Types of control actions
  - On-Off control (two or 3 steps)
  - Continuous control:
    - Proportional (P) control
    - Integral (I) control
    - Proportional and integral (PI) control
    - Proportional and derivative control (PD) control
    - Three-term (proportional, integral and derivative, PID) control

Chapter 13

- 10. On-Off control

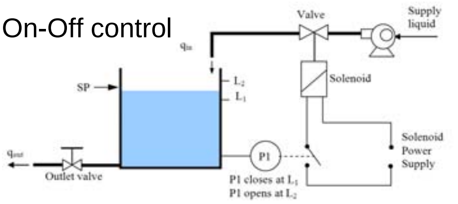
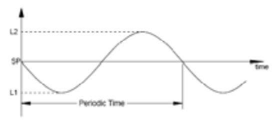
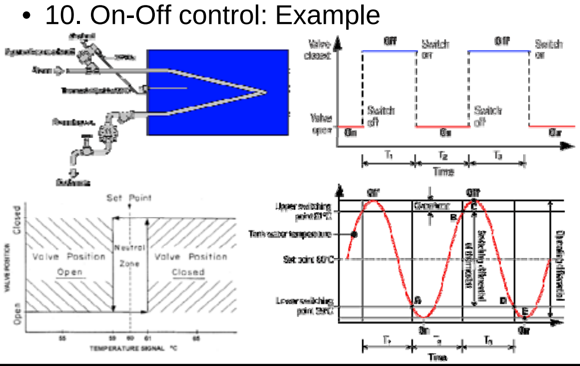


Figure 22 On/Off control scheme for tank level control



Chapter 13

- 10. On-Off control: Example



Chapter 13

- 10. On-Off control: summary
  - On/off control - control signal is either 0% or 100%
  - Control at set point not achievable, a deadband must be incorporated.
  - Useful for large, sluggish systems particularly those incorporating electric heaters.
  - On-Off control algorithm:

Error (E) = SP – PV

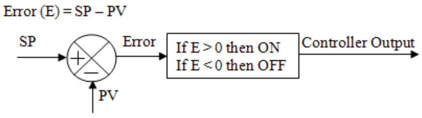


Figure 28 On/Off control algorithm

Chapter 13

- Proportional control action

$$PB = \frac{100\%}{K_p}$$

$$u(t) = K_p e(t) \qquad \frac{U(s)}{E(s)} = K_P \qquad K_p = \frac{100\%}{PB}$$

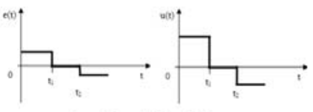


Figure 29 Proportional control action

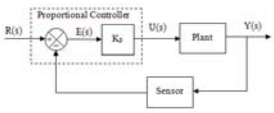
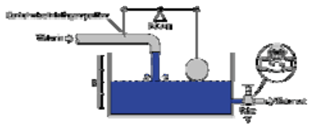


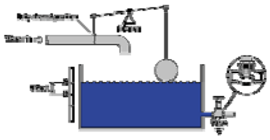
Figure 30 Block diagram of a proportional controller

Chapter 13

- Proportional control action
  - Tank level control with a float



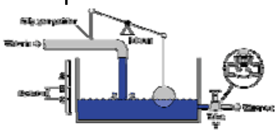
Valve 50% open



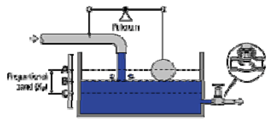
Valve closed

Chapter 13

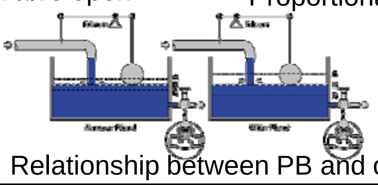
- Proportional control action



Valve open



Proportional band



Relationship between PB and offset

Chapter 13

- Proportional control action
  - Proportional band
  - Gain

$$u = K_p \times \%\text{span error} + u_0$$

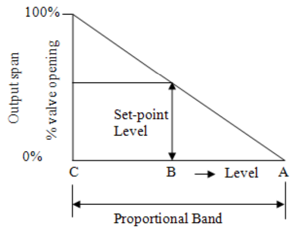


Figure 33 Proportional band diagram

Chapter 13

- Proportional control
  - Example (pp 27

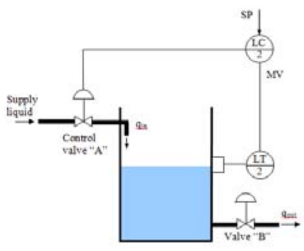
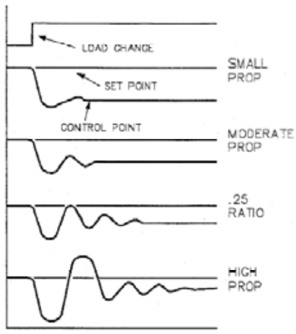


Figure 34 Tank level system for Example

Chapter 13

- Proportional control
  - Effects of proportional gain on system response

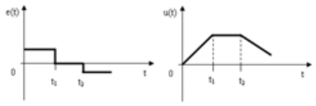
•A wide proportional band (small gain) will provide a less sensitive response, but a greater stability.
•A narrow proportional band (large gain) will provide a more sensitive response, but there is a practical limit to how narrow the PB can be set.
•Too narrow a proportional band (too much gain) will result in oscillation and unstable control.

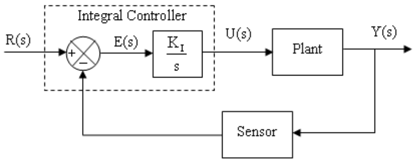


Chapter 13

- Proportional and integral control
  - Integral control

$$u_I(t) = K_I \int_0^t e(t)dt$$

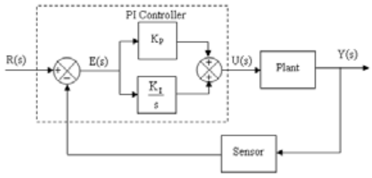


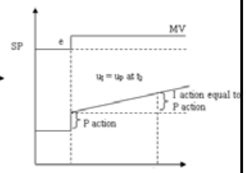


Chapter 13

- PI control
  - P and I control

$$u_{PI}(t) = \underbrace{K_P e(t)}_{P} + \underbrace{K_I \int_0^t e(t)\,dt}_{I}$$

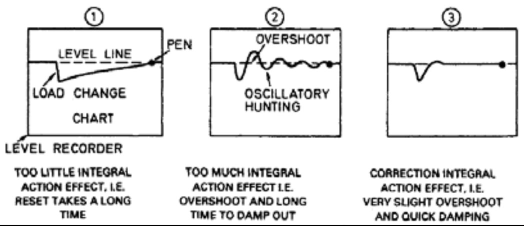




Chapter 13

- PI control
  - Integral time
  - Effect of Integral time

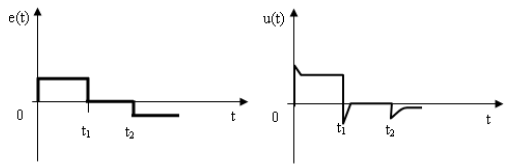
$$V_{PI} = K_P \times \left(e + \frac{1}{T_I} \times \int edt \right)$$



Chapter 13

- Proportional and Derivative control
  - Derivative control

$$u_D(t) = K_D \frac{de(t)}{dt}$$

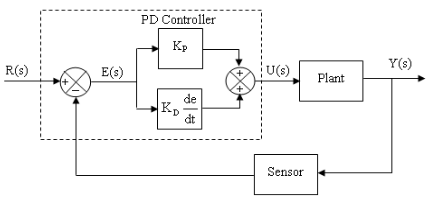


Controller actions

- Proportional and Derivative control

$$u_{PD} = \text{Proportional} + \text{Derivative}$$

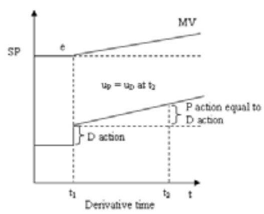
$$u_{PD} = K_P \times e + K_D \frac{de}{dt}$$



Controller actions

- Proportional and Derivative control:
  - Derivative time

$$u_{PD} = K_P \times \left(e + T_D \frac{de}{dt} \right)$$



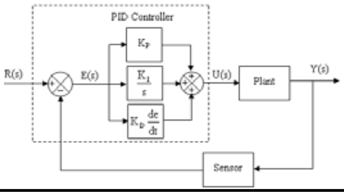
- Derivative control action is never used alone, it is often with the Proportional control action

Controller actions

- Proportional, Integral (Reset) and Derivative (Rate) control

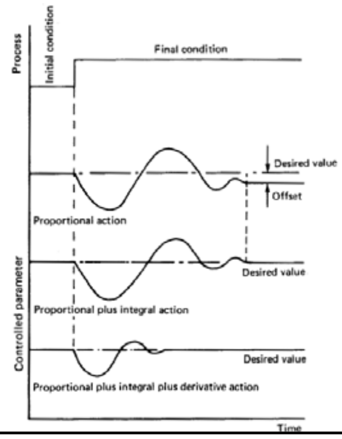
$$u_{PID} = \text{Proportional} + \text{Integral} + \text{Derivative}$$

$$u_{PID} = K_P \times e + K_I \times \int edt + K_D \times \frac{de}{dt}$$



Chapter 13

- PID controller action response



Chapter 13

- 11.5 PID controller configuration

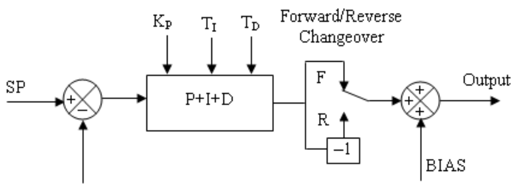


Figure 40 A PID controller with Forward/Reverse changeover switch

Chapter 13

- 11.6 Auto/Man transfer

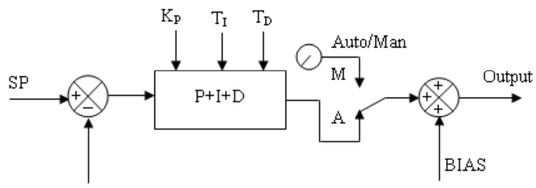


Figure 41 A PID controller with Auto/Man changeover switch

Chapter 13

- PID controllers in market:
  - Microprocessor-based PID controllers

Chapter 13

- Summary (Basic control theory)
  - System responses
  - Proportional (P) control
  - Integral (I) control
  - P+I control
  - P+D control
  - P+I+D control

Any Questions?

Further reading

- Basic control theory:
  - http://www.spiraxsarco.com/resources/steam-engineering-tutorials/basic-control-theory/basic-control-theory.asp