Fall 2022 (111-1)

控制系統
Control Systems

Unit 4D
Ziegler–Nichols Tuning

Feng-Li Lian

NTU-EE

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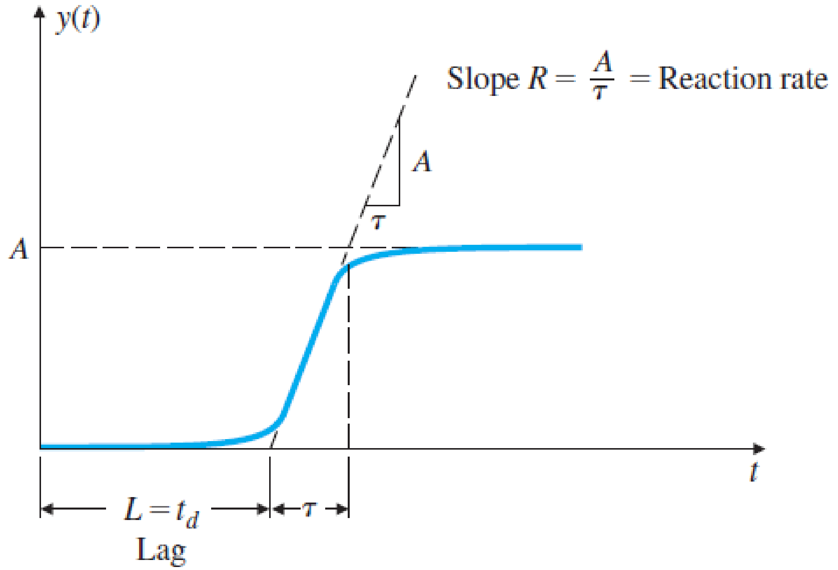
Ziegler–Nichols Tuning of the PID Controller

- Callender, Hartree, Porter (1936) proposed a design for PID controllers
  by specifying satisfactory values for the terms
  based on estimates of the plant parameters
  that an operating engineer could make from experiments on the process.
- Extended by Ziegler and Nichols (1942, 1943) who recognized that
  the step response of a large number of process control systems
  exhibit a **process reaction curve**,
  generated from experimental step response data.



$$\frac{Y(s)}{U(s)} = \frac{A\, e^{-s\, t_d}}{\tau\, s + 1}$$

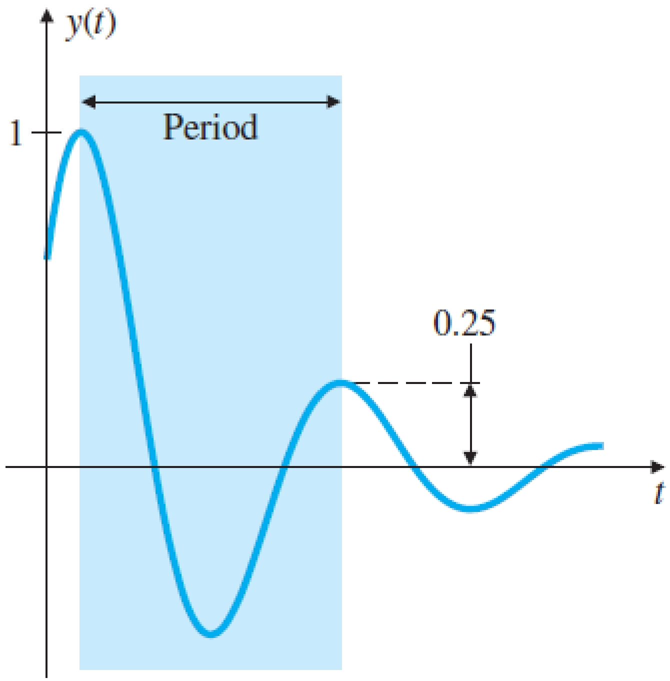
- A first-order system
  with a time delay (lag)

Method 1: Quarter Decay Ratio

In a closed-loop step response transient with a decay ratio of 0.25

$$D_c(s) = k_P \left(1 + \frac{1}{T_I\, s} + T_D\, s \right)$$

- Quarter decay ratio



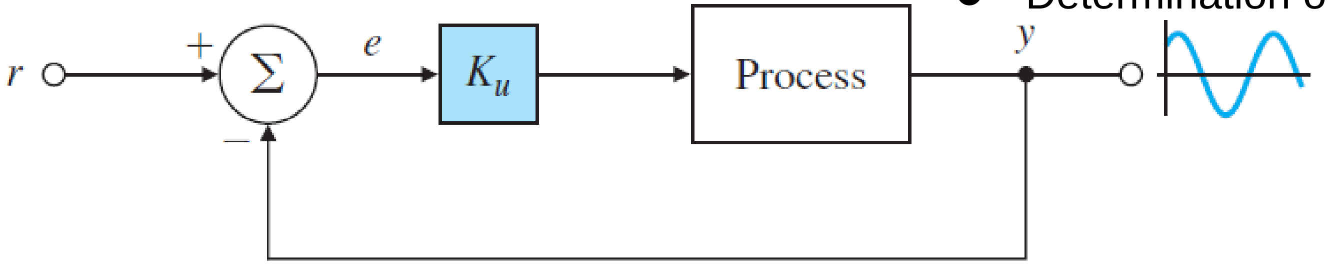
Ziegler–Nichols Tuning for the Regulator $D_c(s) = k_P(1 + 1/T_I s + T_D s)$, for a Decay Ratio of 0.25

Type of Controller	Optimum Gain
P	$k_P = 1/RL$
PI	$\begin{cases} k_P = 0.9/RL \\ T_I = L/0.3 \end{cases}$
PID	$\begin{cases} k_P = 1.2/RL \\ T_I = 2L \\ T_D = 0.5L \end{cases}$

- **Method 2: Ultimate Sensitivity Method:**

  Based on evaluating the amplitude and frequency of the oscillations of the system at the limit of stability rather than on taking a step response.

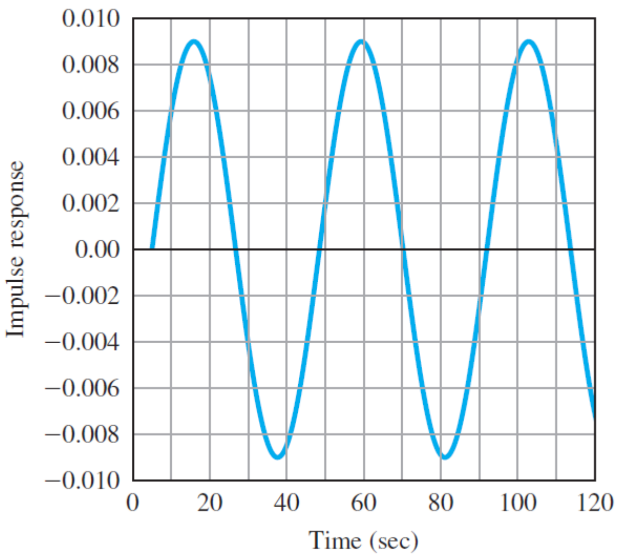
  - Determination of ultimate gain and period



- K_u : Ultimate Gain
- P_u : Ultimate Period

Ziegler-Nichols Tuning for the Regulator $D_c(s) = k_P(1 + 1/T_I s + T_D s)$, Based on the Ultimate Sensitivity Method

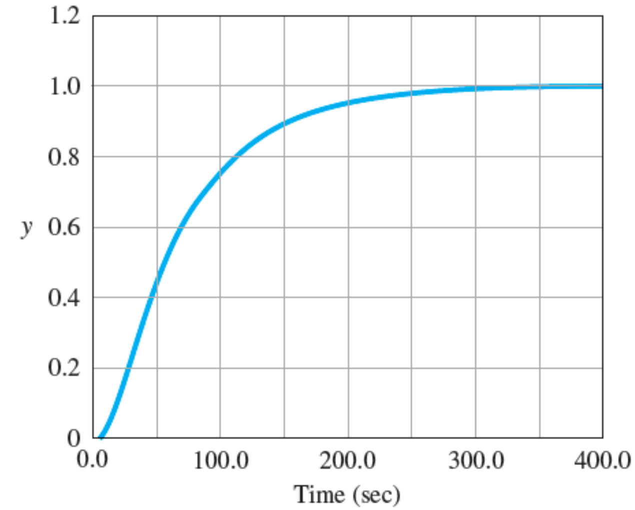
Type of Controller	Optimum Gain
P	$k_P = 0.5K_u$
PI	$k_P = 0.45K_u$, $T_I = \frac{P_u}{1.2}$
PID	$k_P = 0.6K_u$, $T_I = 0.5P_u$, $T_D = 0.125P_u$



Examples

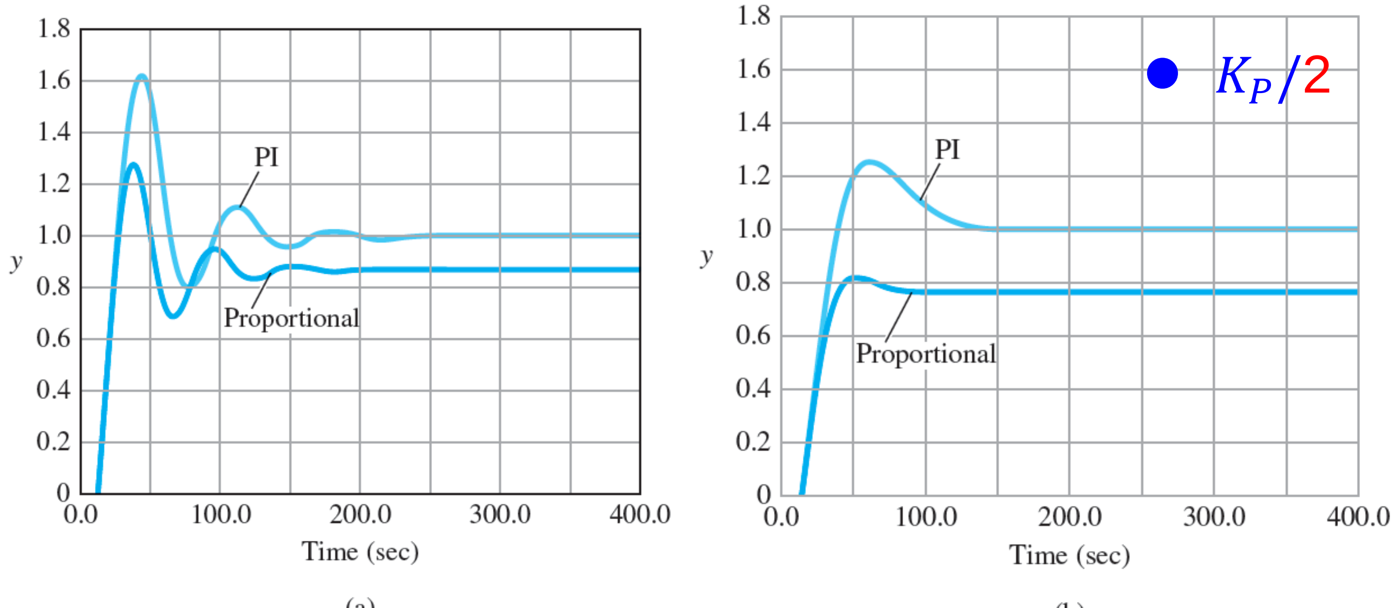
- Example 4.8: Tuning of a Heat Exchanger: Quarter Decay Ratio

- The measured process reaction curve



- Maximum slope: R = 1/90
- Time delay: L = 13 sec

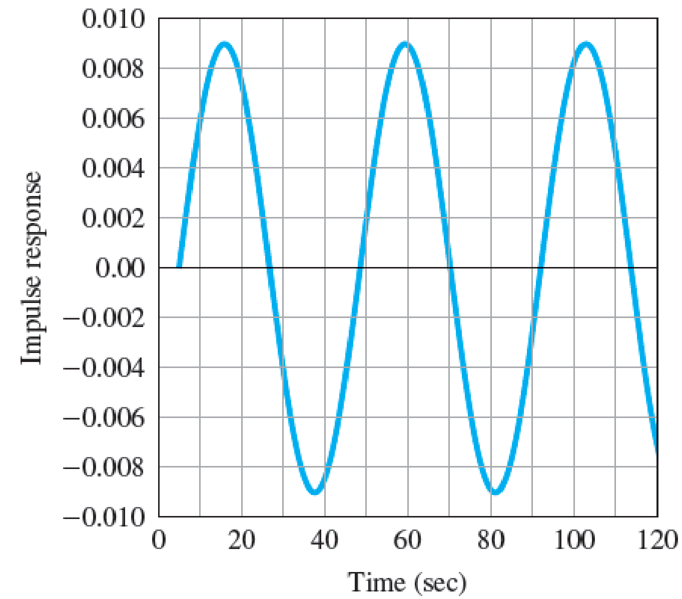
- P: K_P = 1/RL = 90/13 = 6.92
- PI: K_P = 0.9/RL = 6.22
- and T_I = L/0.3 = 13/0.3 = 43.3

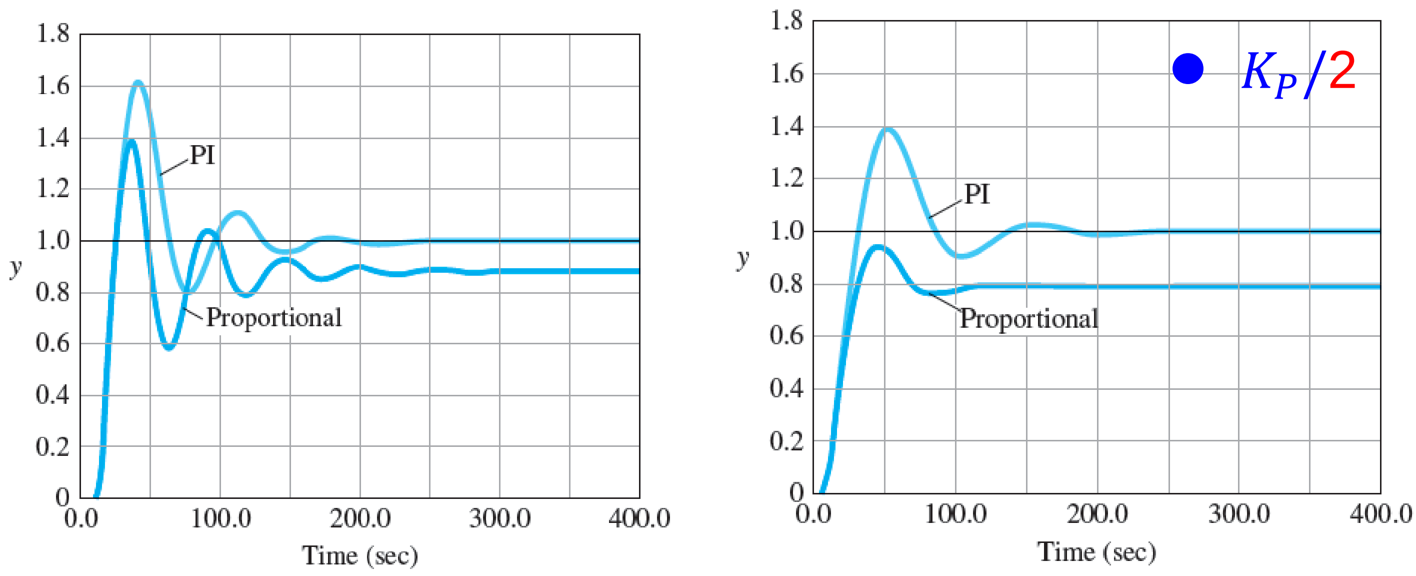


Example 4.9: Tuning of a Heat Exchanger: Oscillatory Behavior

- Non-decaying oscillation
- K_u = 15.3
- P_u = 42 sec

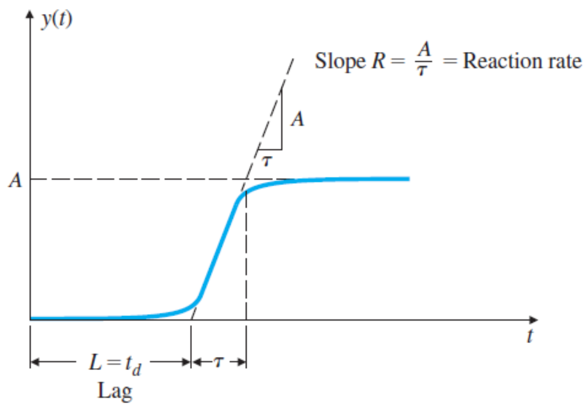
- P: K_P = 0.5 K_u = 7.65
- PI: K_P = 0.45 K_u = 6.885
- and T_I = 1/1.2 P_u = 35





(a) (b)

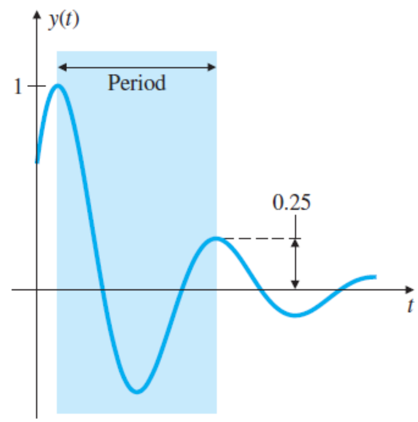
Summary: Ziegler–Nichols Tuning of the PID Controller



$$\frac{Y(s)}{U(s)} = \frac{A\, e^{-s\, t_d}}{\tau\, s + 1}$$

- A first-order system with a time delay (lag)

- Method 1: Quarter Decay Ratio



Ziegler–Nichols Tuning for the Regulator $D_c(s) = k_P(1 + 1/T_I s + T_D s)$, for a Decay Ratio of 0.25	
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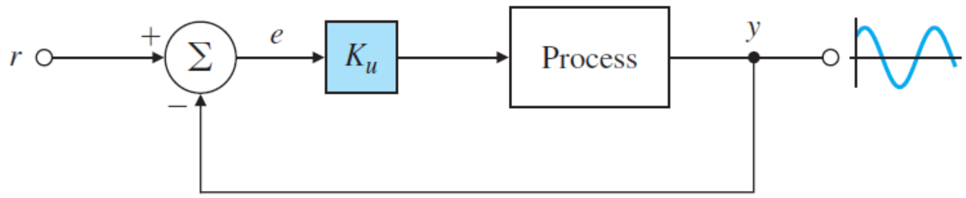
- Method 2: Ultimate Sensitivity Method:



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