Review past lectures & Continuation of PID Controller Design

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Today’s Quote:

“Good, better, best. Never let it rest. Til your good is better and your better is best.”

— St. Jerome

Classical Controller-
PID Controller

Introduction

Design PID control

- Know mathematical model 👉 various design techniques
- Plant is complicated, can’t obtain mathematical model 👉 experimental approaches to the tuning of PID controllers

PID Control

- A closed loop (feedback) control system, generally with Single Input-Single Output (SISO)
- A portion of the signal being fed back is:
  - Proportional to the signal (**P**)
  - Proportional to integral of the signal (**I**)
  - Proportional to the derivative of the signal (**D**)

Output equation of PID controller in time domain

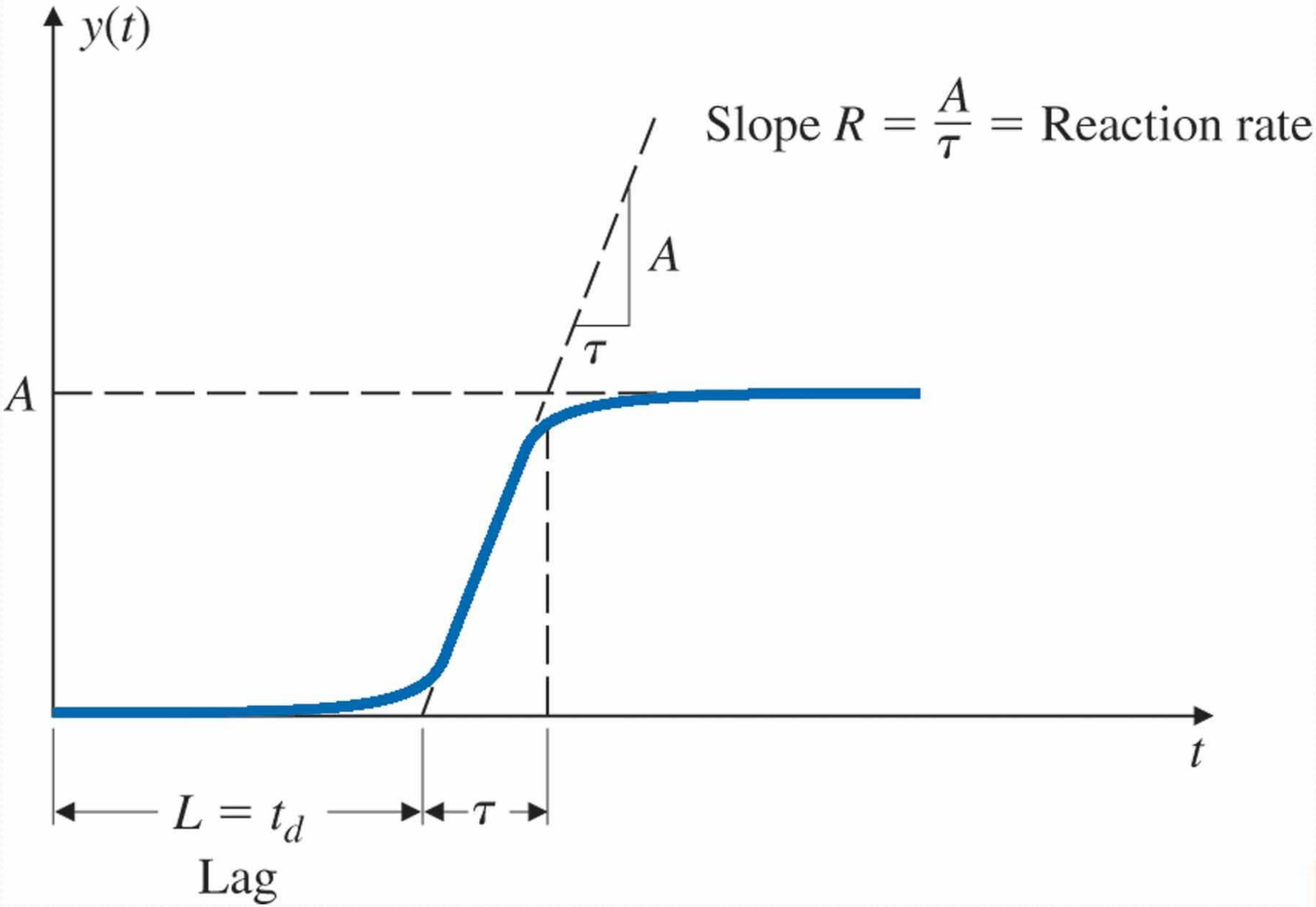
$$u(t) = K_p e(t) + K_I \int e(t)\,dt + K_D \frac{de(t)}{dt}$$

The Characteristics of P, I, and D controllers

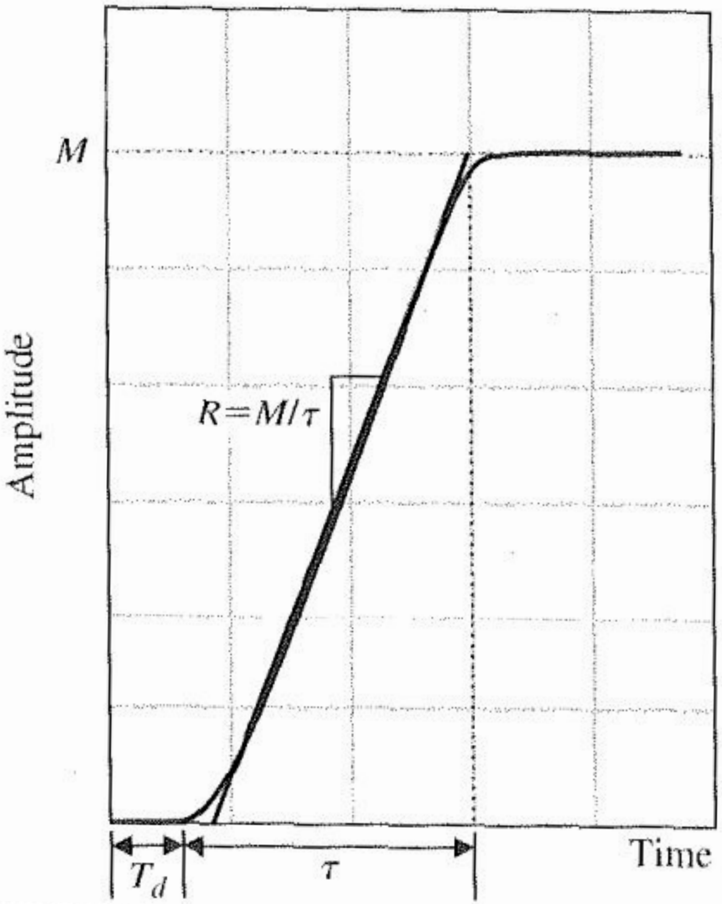
CL RESPONSE	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
Kp	Decrease	Increase	Small Change	Decrease
Ki	Decrease	Increase	Increase	Eliminate
Kd	Small Change	Decrease	Decrease	Small Change

PID Controller- Ziegler Method #1

Figure 4.11 Process reaction curve



PID Controller- Ziegler Method #1



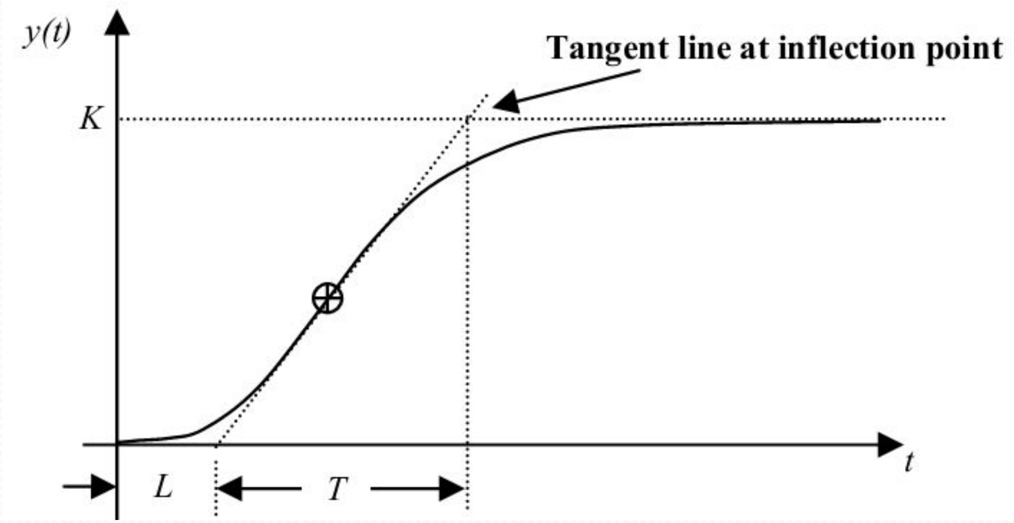


Figure 4.11 Process reaction curves (R.C.Dorf et.al and Others)

PID Controller- Ziegler Method #1

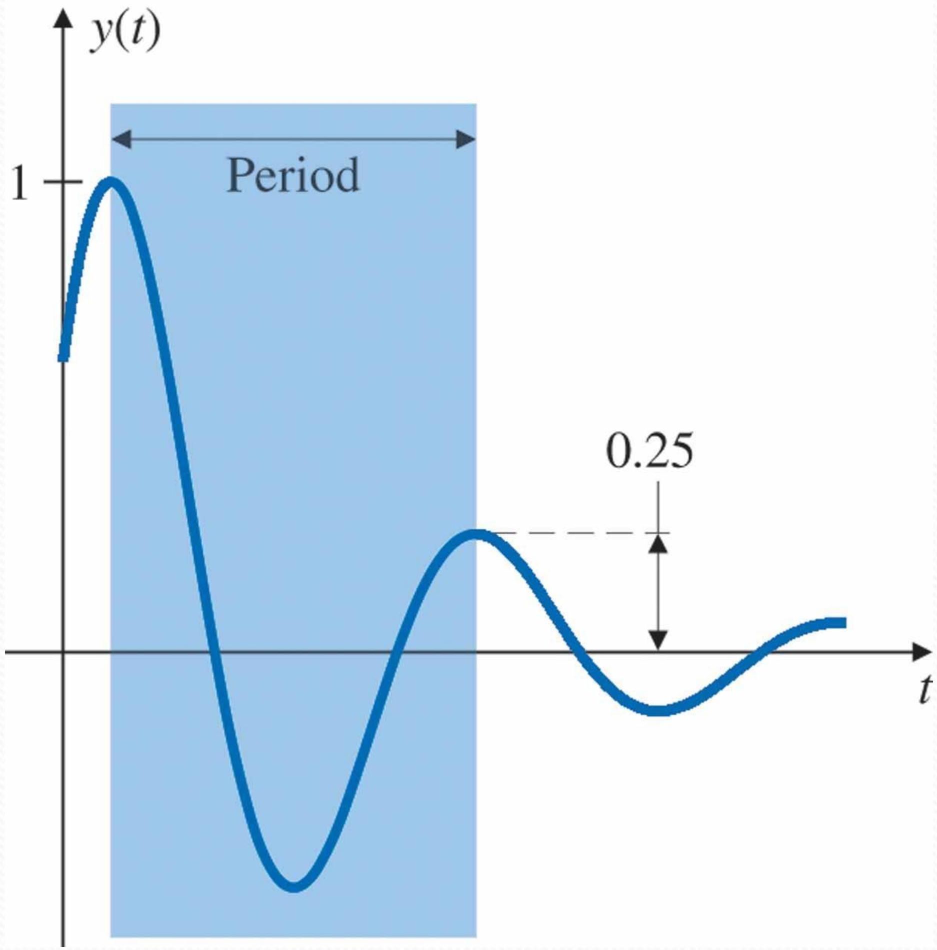


Figure 4.12 Quarter decay ratio

PID Controller- Ziegler Method #1

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

Type of Controller	Optimum Gain
P	$k_p = 1/RL$
PI	$k_p = 0.9/RL$, $T_I = L/0.3$
PID	$k_p = 1.2/RL$, $T_I = 2L$, $T_D = 0.5L$

PID Controller- Ziegler Method #2

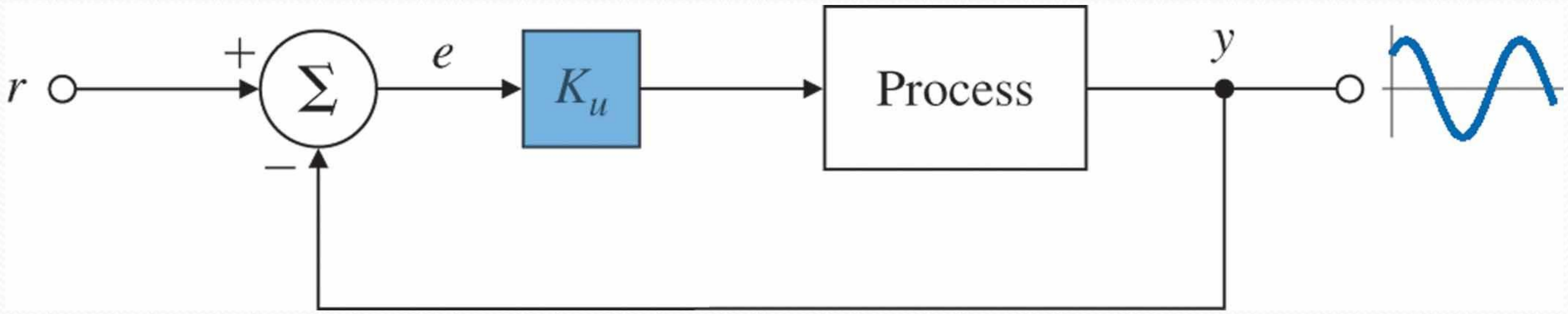


Figure 4.13 Determination of ultimate gain and period

PID Controller- Ziegler Method #2

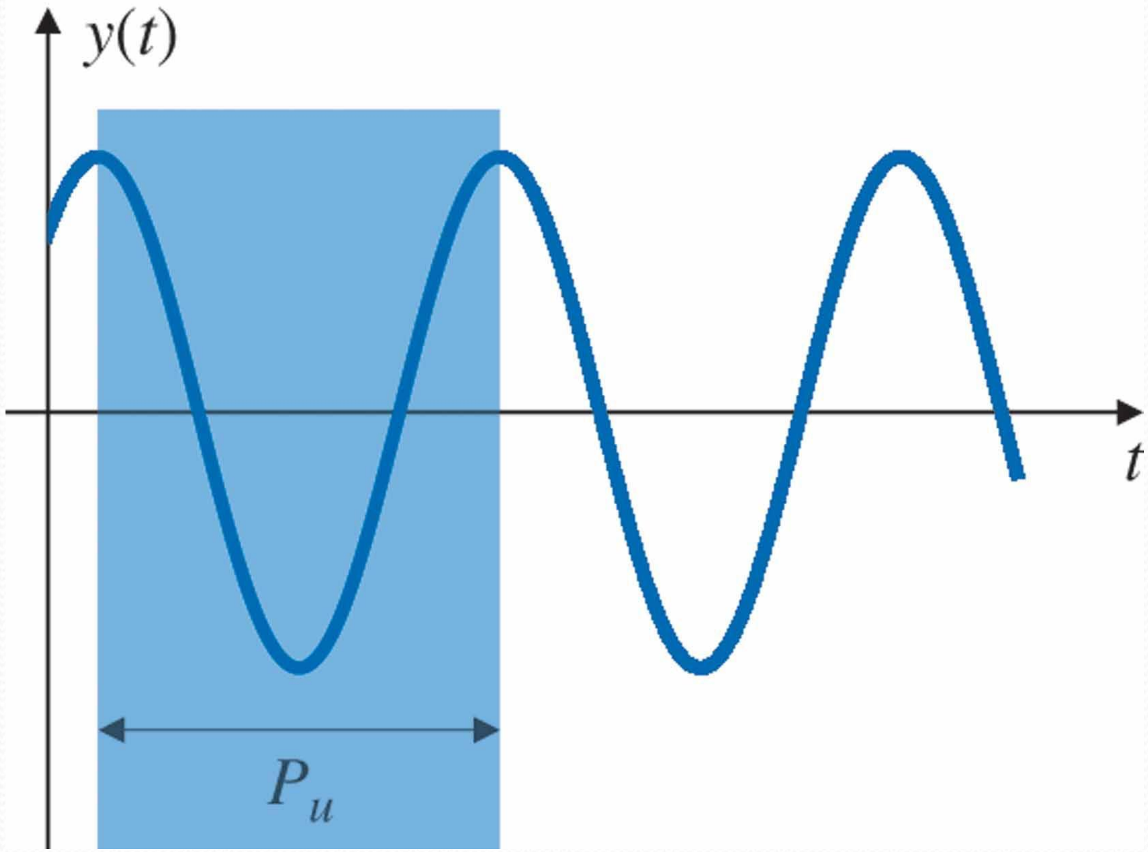


Figure 4.14 Neutrally stable system

PID Controller- Ziegler Method #2

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	$\begin{cases} k_p = 0.45K_u \\ T_I = \dfrac{P_u}{1.2} \end{cases}$
PID	$\begin{cases} k_p = 1.6K_u \\ T_I = 0.5P_u \\ T_D = 0.125P_u \end{cases}$

Ti - the controller's integrator time constant

Td - the controller's derivative time constant

Example: Method # 1

Tuning of a Heat Exchanger: Quarter Decay Ratio

Consider the heat exchanger discussed in Chapter 2. The process reaction curve of this system is shown in Fig. 4.15. Determine proportional and PI regulator gains for the system using the Zeigler–Nichols rules to achieve a quarter decay ratio. Plot the corresponding step responses.

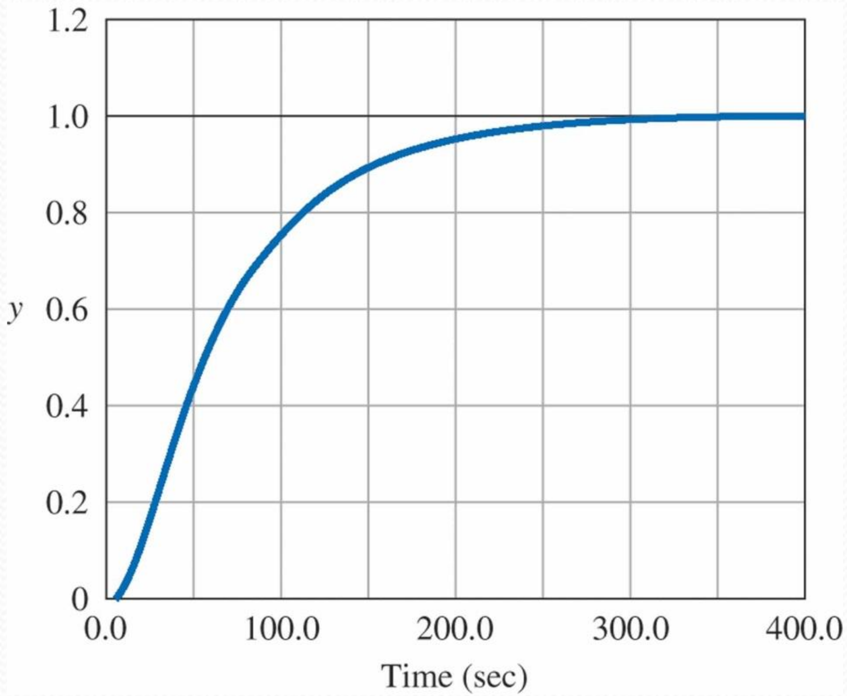


Figure 4.15 A measured process reaction curve

Example: Method # 2

Tuning of a Heat Exchanger: Oscillatory Behavior

Proportional feedback was applied to the heat exchanger in the previous example until the system showed nondecaying oscillations in response to a short pulse (impulse) input, as shown in Fig. 4.17. The ultimate gain is measured to be $K_u = 15.3$, and the period was measured at $P_u = 42\ sec$. Determine the proportional and PI regulators according to the Zeigler–Nichols rules based on the ultimate sensitivity method. Plot the corresponding step responses.

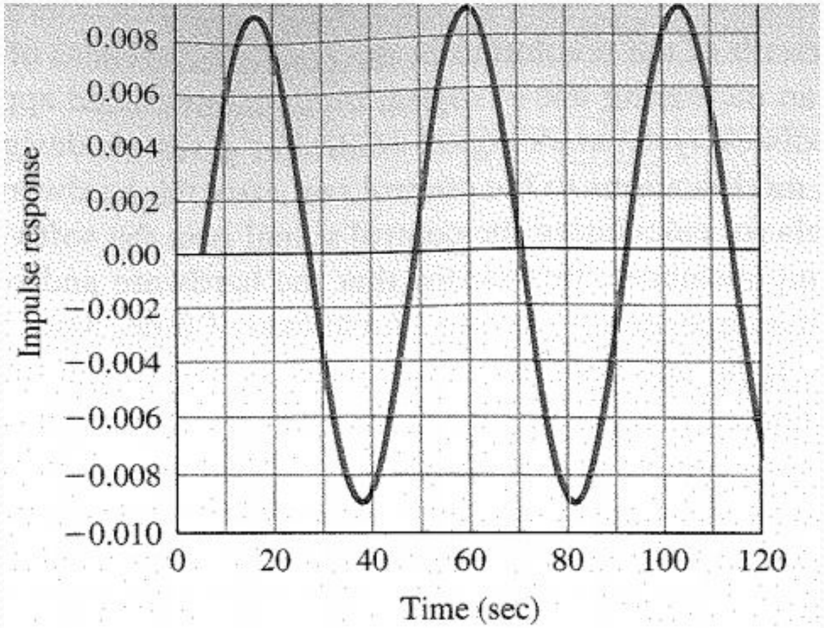


Figure 4.17 Ultimate period of heat exchanger

Exercise # 1-PID Controller

32. The unit-step response of a paper machine is shown in Fig. 4.43(a) where the input into the system is stock flow onto the wire and the output is basis weight (thickness). The time delay and slope of the transient response may be determined from the figure.

   (a) Find the proportional, PI, and PID-controller parameters using the Zeigler–Nichols transient-response method.

   (b) Using proportional feedback control, control designers have obtained a closed-loop system with the unit impulse response shown in Fig. 4.43(b). When the gain $K_u = 8.556$, the system is on the verge of instability. Determine the proportional-, PI-, and PID-controller parameters according to the Zeigler–Nichols ultimate sensitivity method.

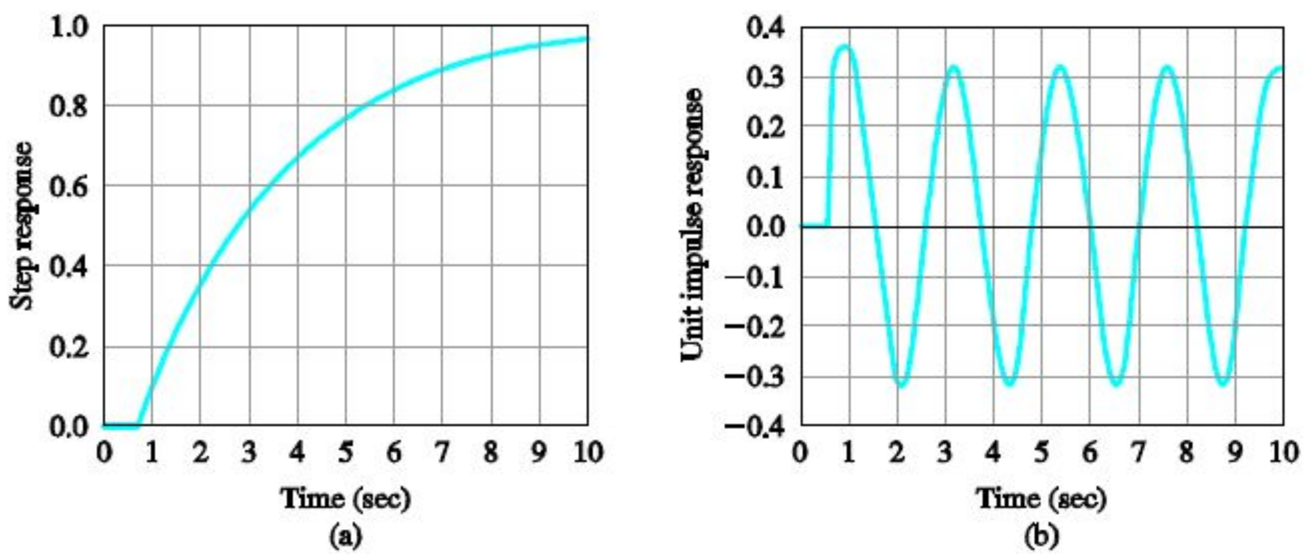
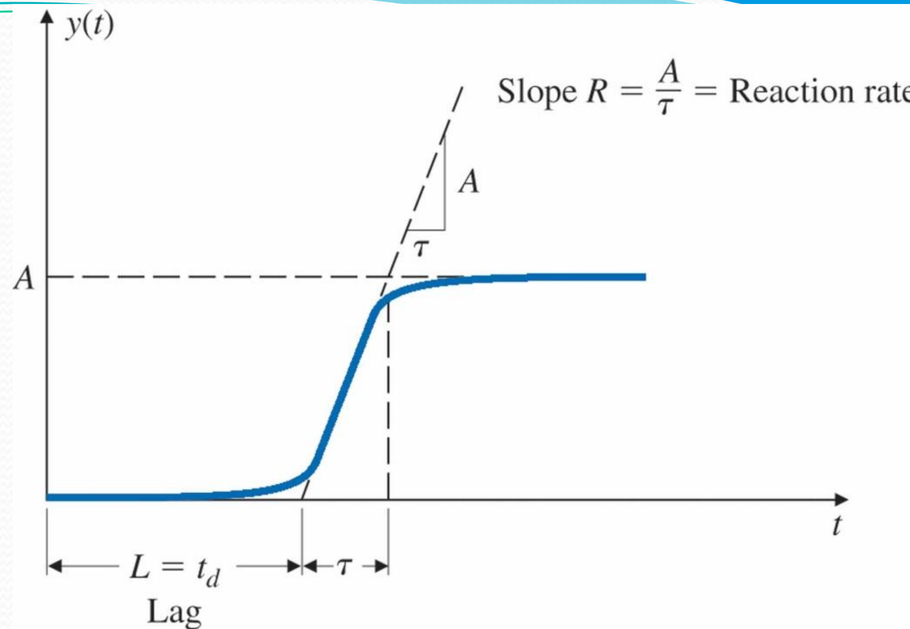


Figure 4.43: Paper-machine response data



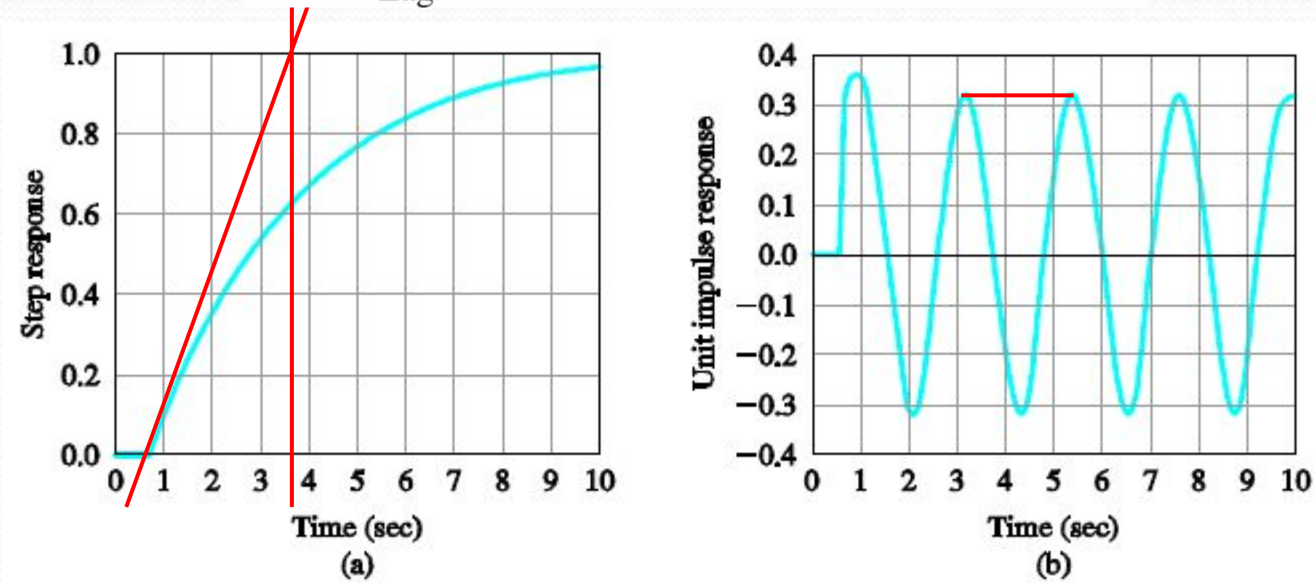


Figure 4.43: Paper-machine response data

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

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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

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PID	$\begin{cases} k_p = 1.6K_u \\ T_I = 0.5P_u \\ T_D = 0.125P_u \end{cases}$

Practice-Exercise

A paper machine has the transfer function

$$G(s) = \frac{e^{-2s}}{3s+1},$$

where the input is stock flow onto the wire and the output is basis weight or thickness.

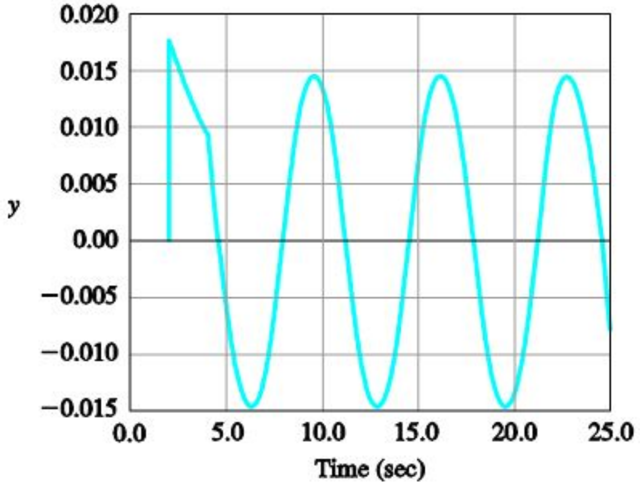

Figure 4.44: Unit impulse response for paper-machine in Problem 33

(a) Find the PID-controller parameters using the Zeigler–Nichols tuning rules.

(b) The system becomes marginally stable for a proportional gain of $K_u = 3.044$ as shown by the unit impulse response in Fig. 4.44. Find the optimal PID-controller parameters according to the Zeigler–Nichols tuning rules.

Further Reading

- Franklin, et. al., Chapter 4
  - Section 4.3

- Richard C. Dorf et.al, Chapter 6,
  Chapter 6.2