# CONTROL I

**ELEN3016**

## Closed-Loop Control Systems

(Lecture 9)

# Overview

- First Things First!
- PID Control - Revision
- Ziegler-Nichols Tuning Methods
- Other Tuning Methods
- PD Control
- Tutorial Exercises & Homework

- Next Attraction!

# First Things First!

- Miss prints & corrections
  - p 57: In item (b) in Sec. (3.7.2) $1 < \zeta > 0.06$ should read $1 > \zeta > 0.06$
  - p 67: 3rd block diagram, top right of Table 4.1 misses a division line.
  - p 83: the sentence above Eq (4.66) should read "The closed-loop time-constant for equation (4.64) is"
  - p 84: 2nd term in the numerator of Eq (4.71) needs to be divided by $K_1$.

# PID Control - Revision

- Proportional control
  - Most important part of the PID control.
- Integral control
  - Reduces steady-state errors.
  - Introduces sluggishness: response lag & overshoot.
- Derivative control
  - Introduces anticipatory action – reduces sluggishness (i.e. improve responsiveness) and reduces as overshoot.

# PID Control

- Midnight Callout to the Plant
  - Late-night boredom and curiosity led the plant operator to tamper with the PID controller causing an alarm and eventual plant shutdown due to the risk of plant operation becoming unsafe.
  - You, the *control engineer*, are called out well after midnight since production loss necessitates <u>immediate</u> action.
  - To minimise plant downtime there is no time to perform the standard painstaking setup procedure. So, how would you swiftly restore production?

# PID Control

- Midnight Callout to the Plant (cont'd)
  - Your options are:
    - Some experimental tuning procedure.
    - Some simple tuning method such as one of the Ziegler-Nichols method.

# Ziegler-Nichols Tuning Methods

- Process Reaction Method (PRM)
  - Open-loop step response of most systems has an S-shape called the *process reaction curve*.
  - Process reaction curve can be approximated by a time delay D (*transportation lag*) and a 1$^{st}$-order system of maximum tangential slope R.
  - PRM assumes optimal response of the closed-loop system to occur for a ratio of success peaks of 4:1 which translates to a closed-loop damping ratio of $\zeta = 0.21$ using Burns' Eq. (3.71).
  - PRM not suitable for O/L systems with overshoot.

# Ziegler-Nichols Tuning Methods

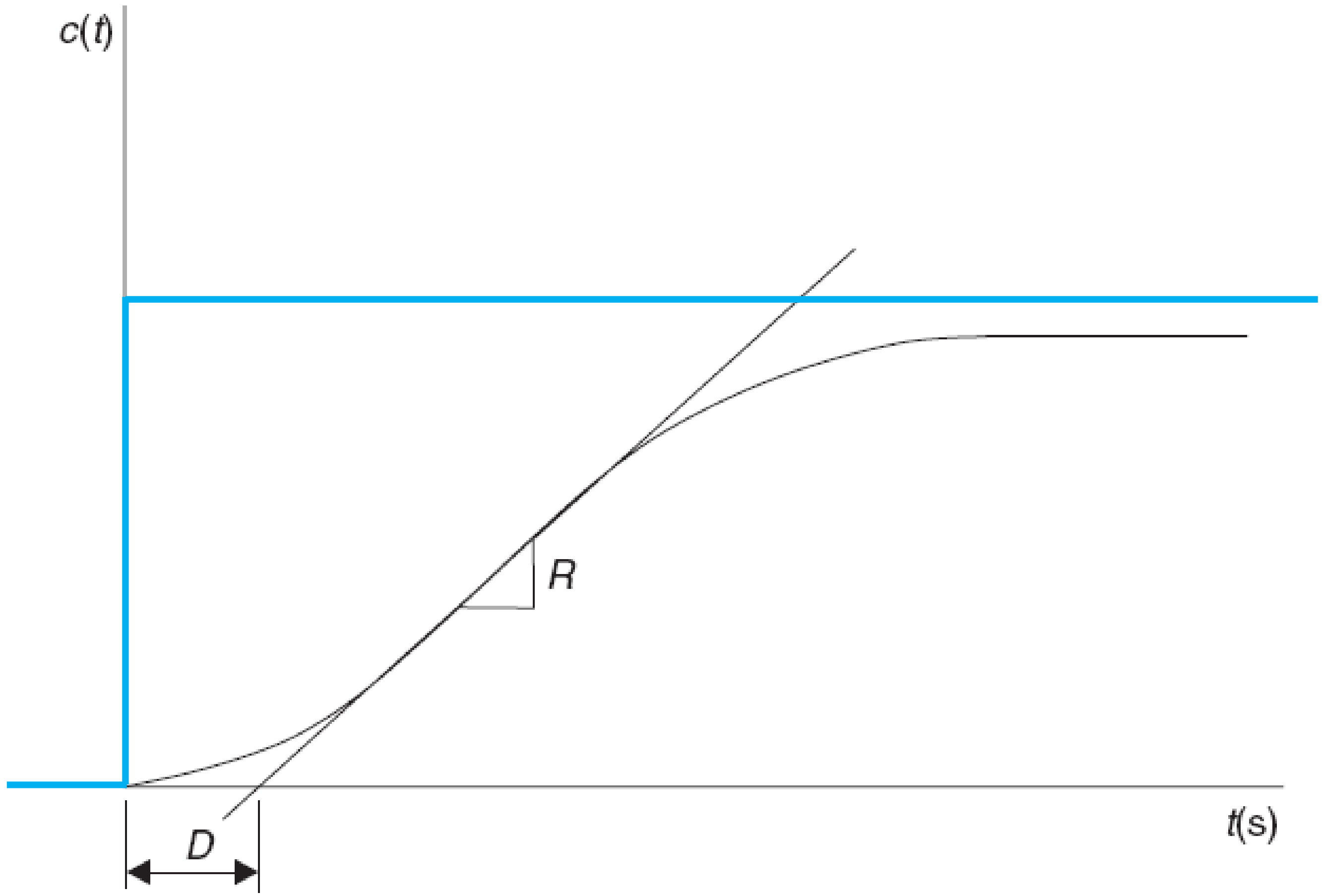


**Fig. 4.29** Process reaction curve.

# Ziegler-Nichols Tuning Methods

$$U(s) = K_1\left(1 + \frac{1}{T_i s} + T_d s\right)E(s)$$

**Table 4.2** Ziegler–Nichols PID parameters using the Process Reaction Method

| *Controller type* | $K_1$ | $T_i$ | $T_d$ |
|---|---|---|---|
| P | $1/RD$ | – | – |
| PI | $0.9/RD$ | $D/0.3$ | – |
| PID | $1.2/RD$ | $2D$ | $0.5D$ |

# Ziegler-Nichols Tuning Methods

- Continuous Cycling Method (CCM)
  - Closed-loop response method using P-control.
  - Adjust $K_1$ (proportional gain) until system O/P becomes marginally stable (oscillate w/o damping).
  - This value of $K_1$ is called the *ultimate gain* $K_u$ .
  - The period of the oscillation at the ultimate gain is called the *ultimate period* $T_u$.

# Ziegler-Nichols Tuning Methods

$$U(s) = K_1\left(1 + \frac{1}{T_i s} + T_d s\right)E(s)$$

**Table 4.3** Ziegler–Nichols PID parameters using the Continuous Cycling Method

| *Controller type* | $K_1$ | $T_\mathrm{i}$ | $T_\mathrm{d}$ |
|---|---|---|---|
| P | $K_\mathrm{u}/2$ | – | – |
| PI | $K_\mathrm{u}/2.2$ | $T_\mathrm{u}/1.2$ | – |
| PID | $K_\mathrm{u}/1.7$ | $T_\mathrm{u}/2$ | $T_\mathrm{u}/8$ |

# PID Control

- PID tuning methods abound!
  - Classical approaches to PID controller tuning [1–3].
  - Intelligent PID controller tuning [4].
  - Computational intelligence-based PID controller tuning:
    - Immune algorithm [5, 6].
    - Genetic algorithm [7].

# PID Control

- Literature Survey


1. A. O'Dwyer, *Handbook of PI and PID Controller Tuning Rules*, Imperial College Press, 1st edition, 2003.
2. A. O'Dwyer, "PI and PID Controller Tuning Rules: An Overview and Personal Perspective," *ISSC* 2006, June 28-30, pp. 161–166, 2006.
3. J.C. Basilio, SR Matos, "Design of PI and PID Controllers with Transient Performance Specification," *IEEE Trans. Educ.*, vol. 45, no. 4, pp. 364–370, November 2002.
4. D.H. Kim, "Intelligent Tuning of the 2-DOF PID Controller On the DCS for Steam Temperature Control of Thermal Power Plant," *IEEE Industrial Application Society* (*I&CPS* 2002), May 5-8, 2002.

# PID Control

- Literature Survey (cont'd)


5. D.H. Kim, JH Cho, "Design of Robust PID Controller with Disturbance Rejection for Motor using Immune Algorithm," Proceedings of the 4th *International Conference on Hybrid Intelligent Systems* (*HIS'*04), 2004.

6. D.H. Kim, "Intelligent tuning of a PID Controller using an Immune Algorithm," *Trans. KIEE*, vol. 51-D, no.1, pp. 8–16, 2002.

7. R.A. Krohling, J.P. Rey, "Design of Optimal Disturbance Rejection PID Controllers using Genetic Algorithms," *IEEE Trans. Evolutionary and Computation*, vol. 5, no. 1, February 2001

# PD Control

- For sluggish plants – use PD control

Proportional plus Derivative control action is expressed as

$$u(t) = K_1 e(t) + K_3 \frac{\mathrm{d}e}{\mathrm{d}t} \tag{4.93}$$

Taking Laplace transforms

$$U(s) = K_1\left(1 + \frac{K_3}{K_1}\right)E(s)$$

$$= K_1(1 + T_\mathrm{d}s)E(s) \tag{4.94}$$

The inclusion of a derivative term in the controller generally gives improved damping and stability. This is discussed in more detail in Chapters 5 and 6.

# Tutorial Exercises & Homework

- Tutorial Exercises
  - For the PD controller repeat the complete steady-state analysis performed for P, PI and PID control in Lecture 8.
- Homework
  - Example 4.6.1 (Burns, p. 92)
  - Example 4.6.3 (Burns, p. 100)

# Conclusion

- PID Control – Revision
- Ziegler-Nichols Tuning Methods
- Other Tuning Methods
- PD Control
- Example 4.6.1 (p. 92) (Self-study!)
- Example 4.6.2 (p. 97) (Discard!)
- Example 4.6.3 (p. 100) (Self-study!)
- Tutorial Exercises & Homework

# Next Attraction! – Miss It & You'll Miss Out!

- Case Study, Burns Sec. 4.6

…

**Thank you!**

**Any Questions?**