Spring 2021

控制系統
Control Systems

Unit 7C
Control System Design:
Engine, Hard Disk, Wafer, E-coli

Feng-Li Lian
NTU-EE

Feb – Jun, 2021

▪ Examples of Control Systems Design

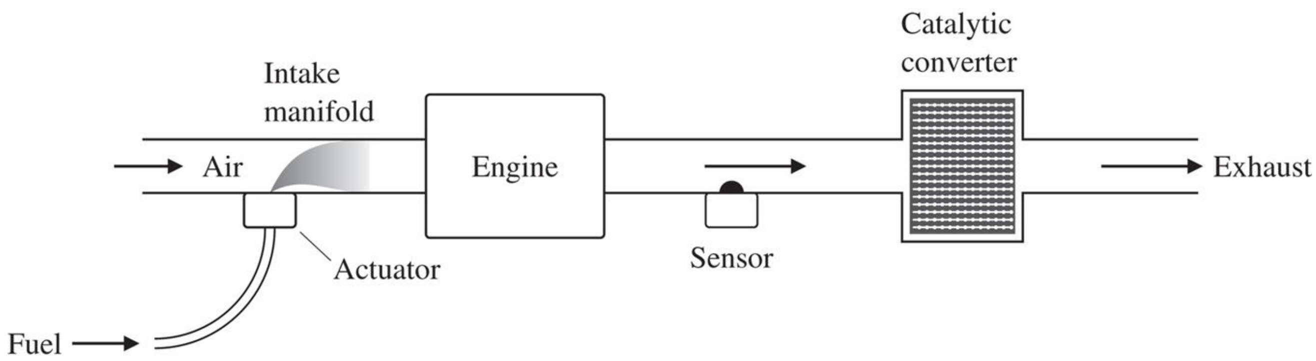
- Outline of Control Systems Design
- Satellite's Attitude Control
- Fuel–Air Ratio in an Automotive Engine
- Read Write Head of a Hard Disk
- RTP Systems in Wafer Manufacturing
- Chemotaxis Swims Away from Trouble

Control Tutorials Website

- Cruise Control
- Motor Speed
- Motor Position
- Suspension
- Inverted Pendulum
- Aircraft Pitch
- Ball & Beam

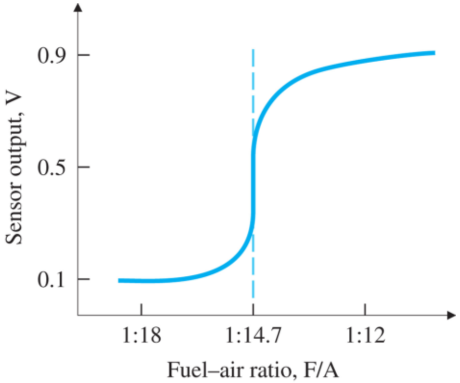
Example 10.4 Fuel–Air Ratio in an Automotive Engine

- The ratio of gasoline-mass flow to air-mass flow, (fuel-to-air ratio (F/A)), remained in 1:15



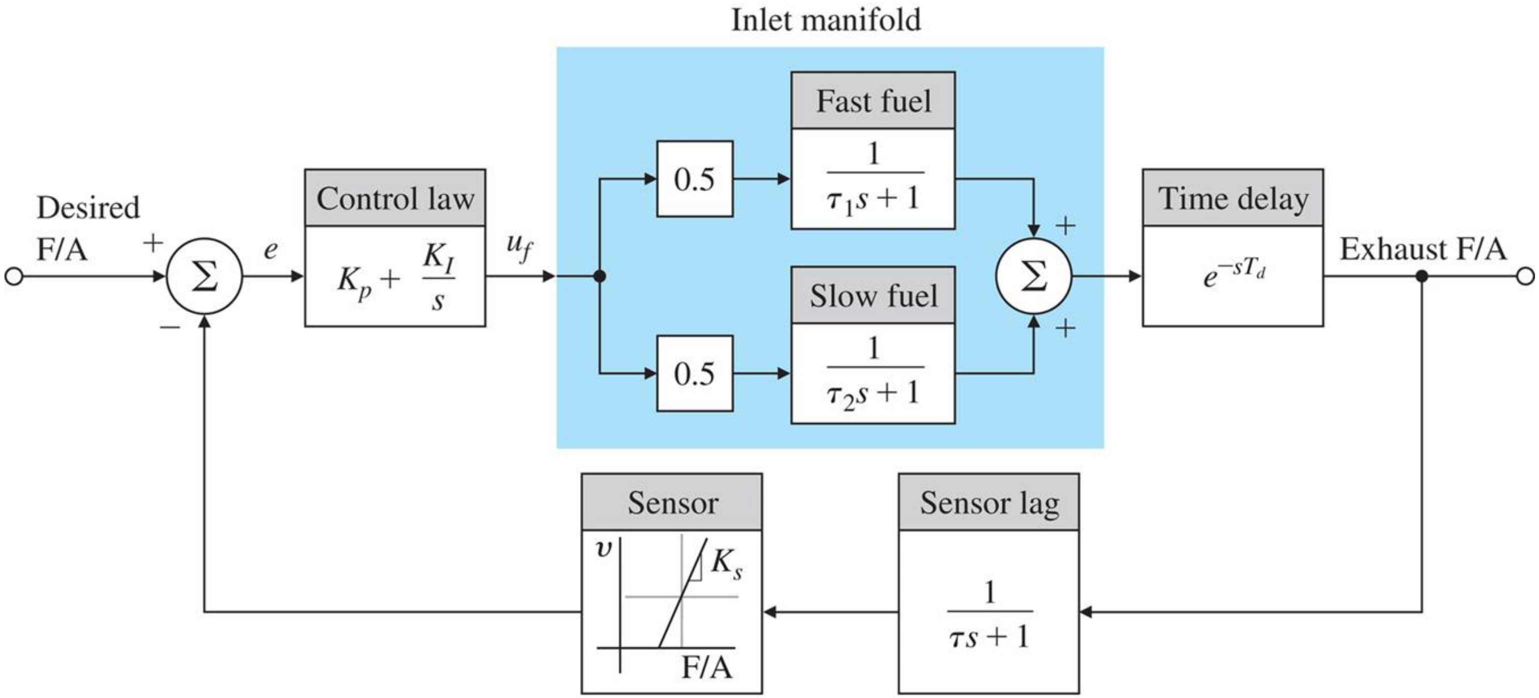
- (STEP 1) Understand the process and its performance specifications
  - A feedback control system is required to maintain the F/A within 1% of the desired level

- (STEP 2) Select sensors
  - exhaust sensor



Example 10.4 Fuel–Air Ratio in an Automotive Engine

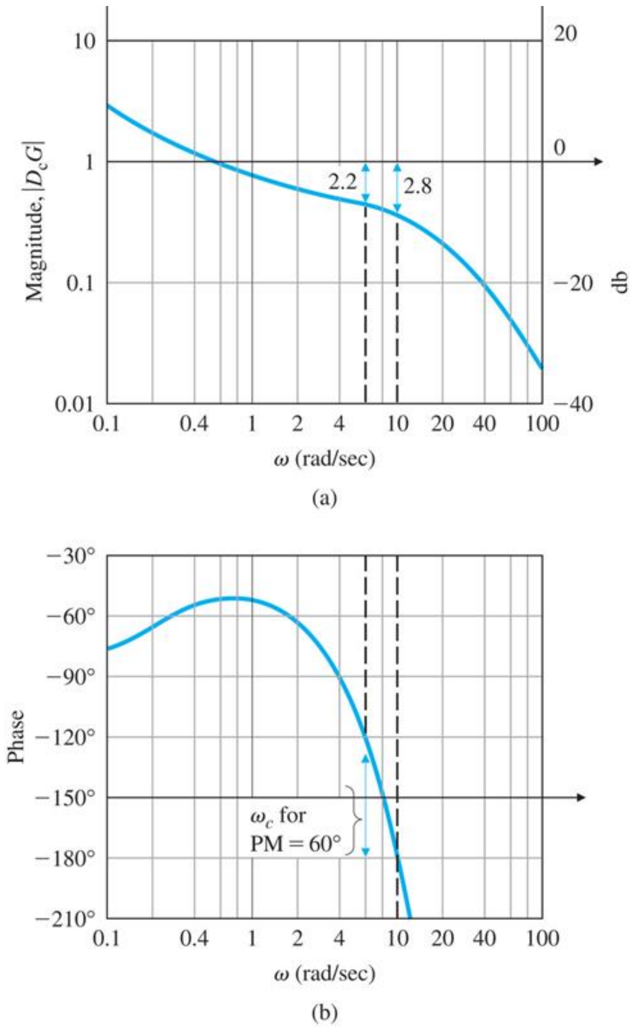
- (STEP 4) Make a linear model

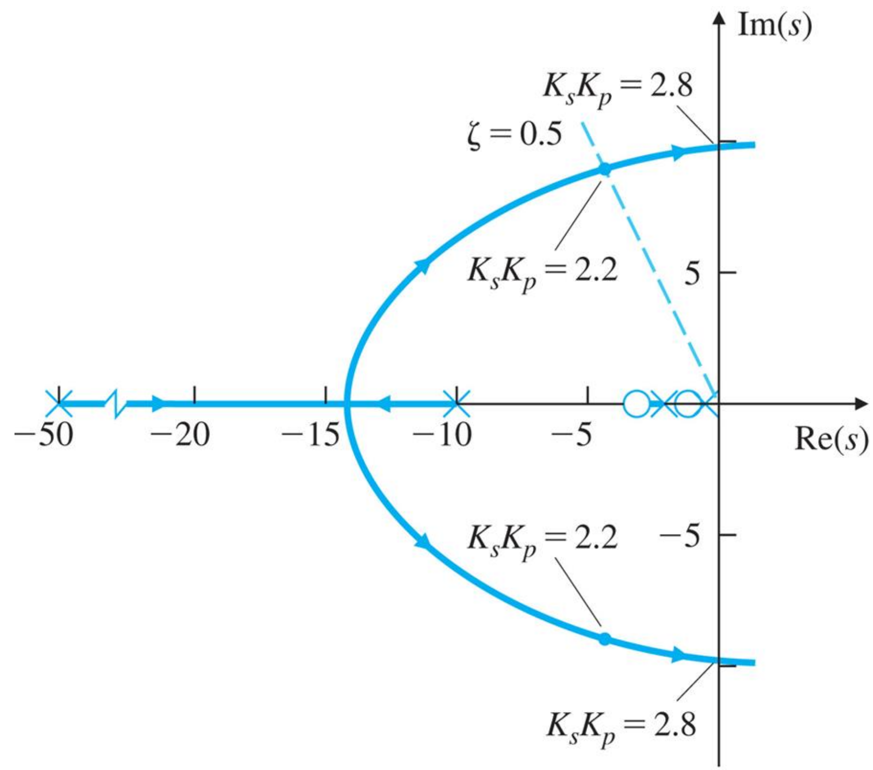


$$D_c(s) = K_p + \frac{K_I}{s} = \frac{K_p}{s}(s+z), \quad z = \frac{K_I}{K_p}$$

Example 10.4 Fuel–Air Ratio in an Automotive Engine

- (STEP 5) Try a lead-lag or P/D controller
  - $K_s K_p = 1.0, \quad z = 0.3$



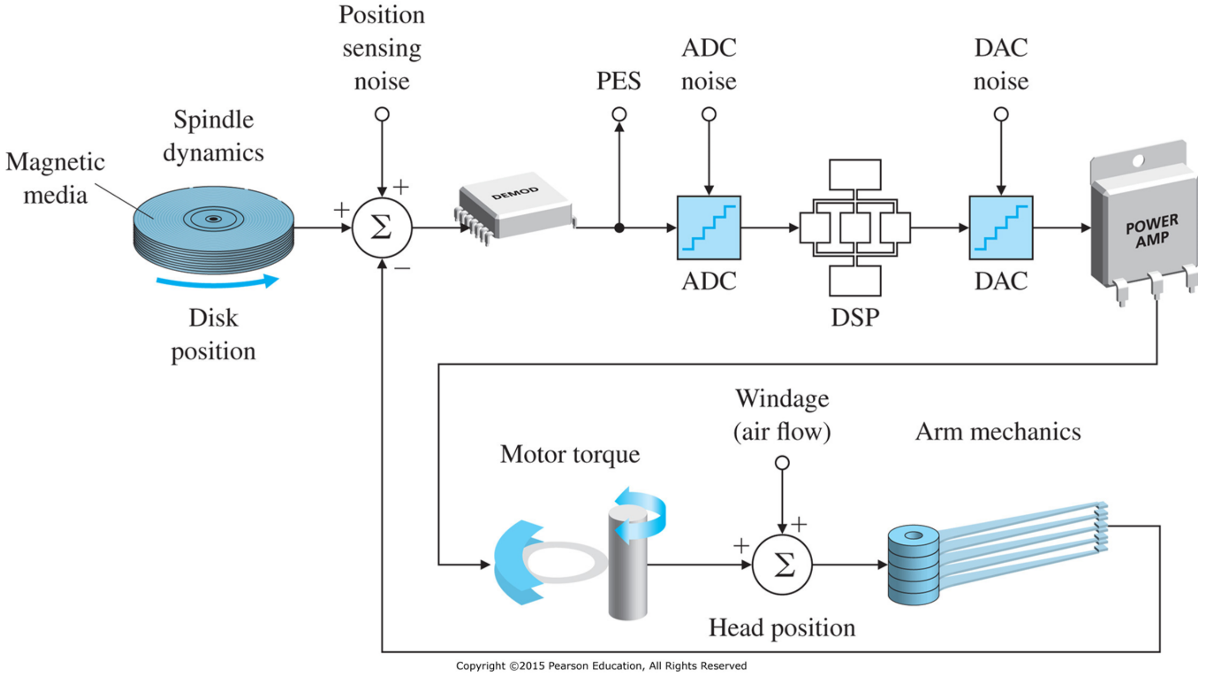


Example 10.5 Read Write Head of a Hard Disk

Motion control:

To seek motion to move the head from track to track

To maintain the hedads over the center of the selected track



Example 10.5 Read Write Head of a Hard Disk

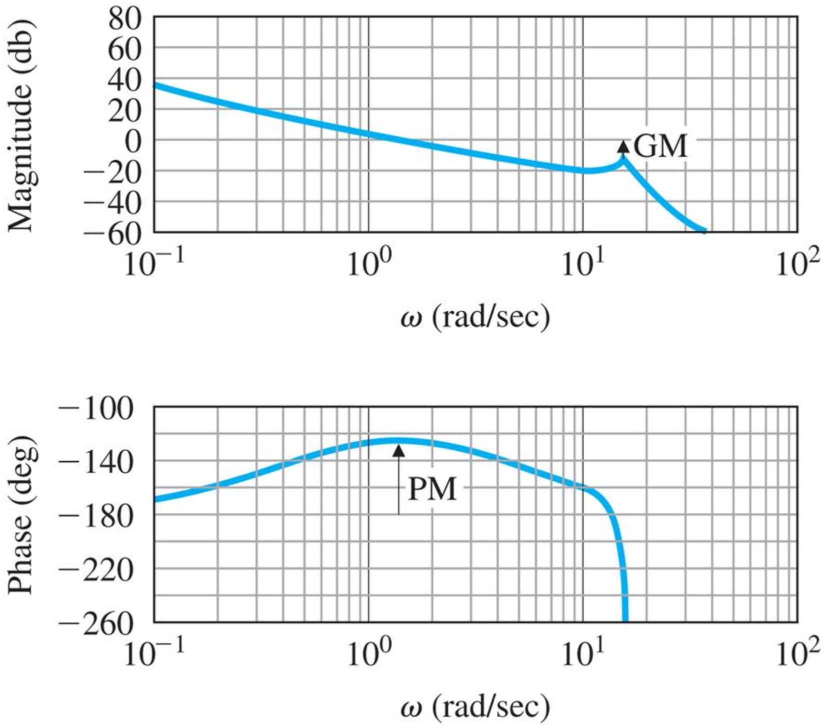
- (STEP 1) Understand the process and its performance specifications
  - A feedback control system is required to maintain the F/A within 1% of the desired level
- (STEP 2) Select sensors
  - Track position
- (STEP 3) Select actuators
  - Motor
- (STEP 4) Make a linear model

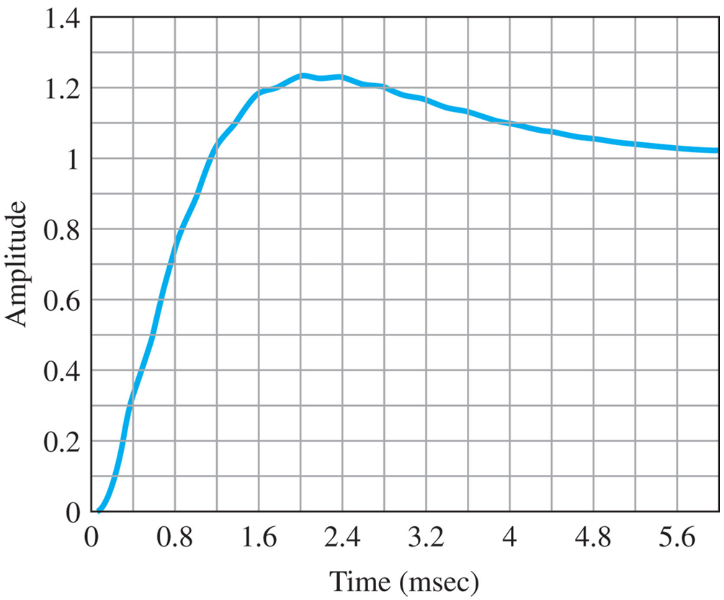
$$G(s) = \frac{1}{s^2} \frac{(2\zeta s/\omega_1 + 1)}{(\frac{s^2}{\omega_1} + 2\zeta \frac{s}{\omega_1} + 1)} \qquad \zeta = 0.05, \quad \omega_1 = 2.5$$

Example 10.5 Read Write Head of a Hard Disk

- (STEP 5) Try a lead-lag or P/D controller
  - Leadcompensation to have 50° phase margin, factor of 4 gain margin

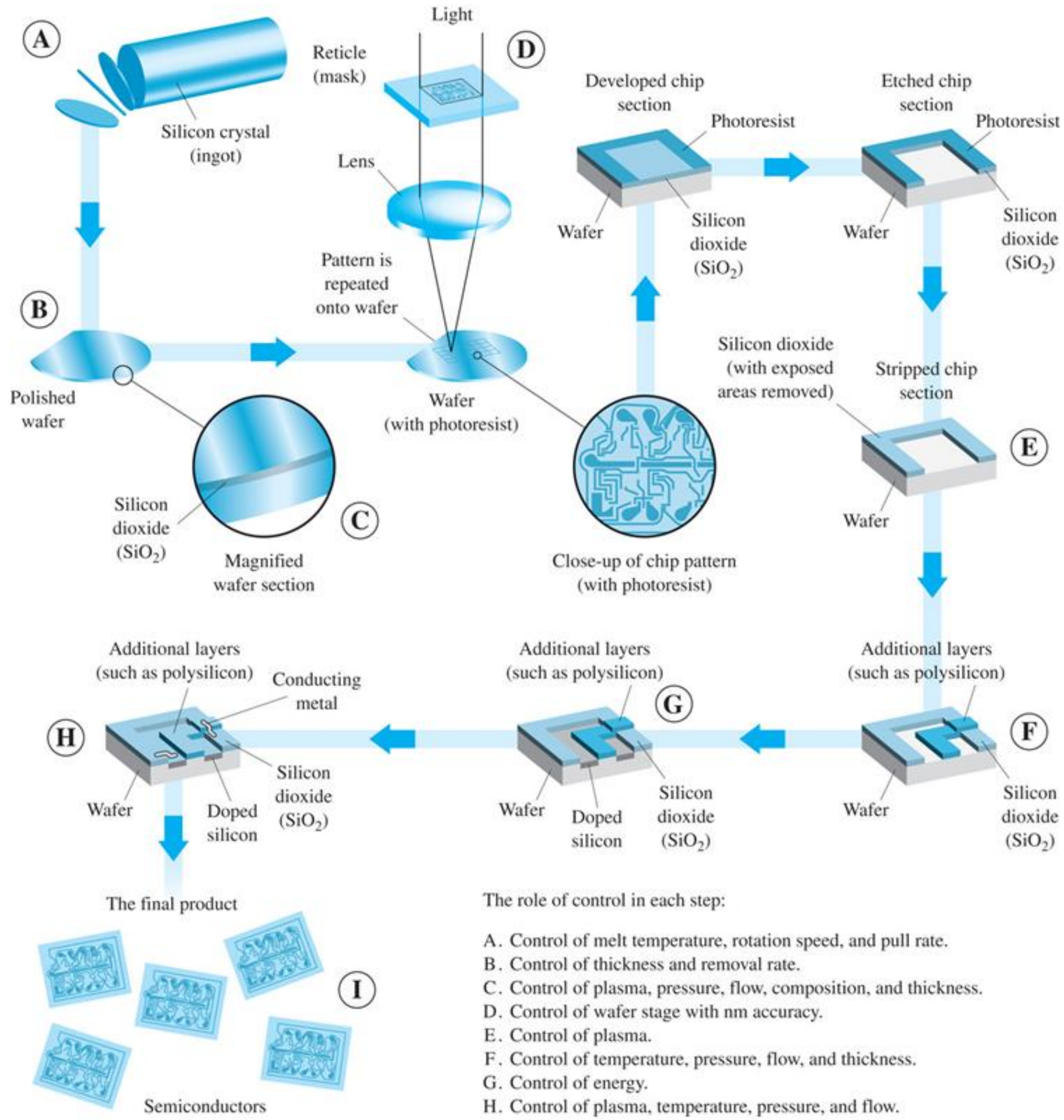
$$D_c(s) = 0.617\frac{(2.22s+1)}{(0.222s+1)}$$





Example 10.6 RTP Systems in Wafer Manufacturing

- Rapid Thermal Processing (RTP)

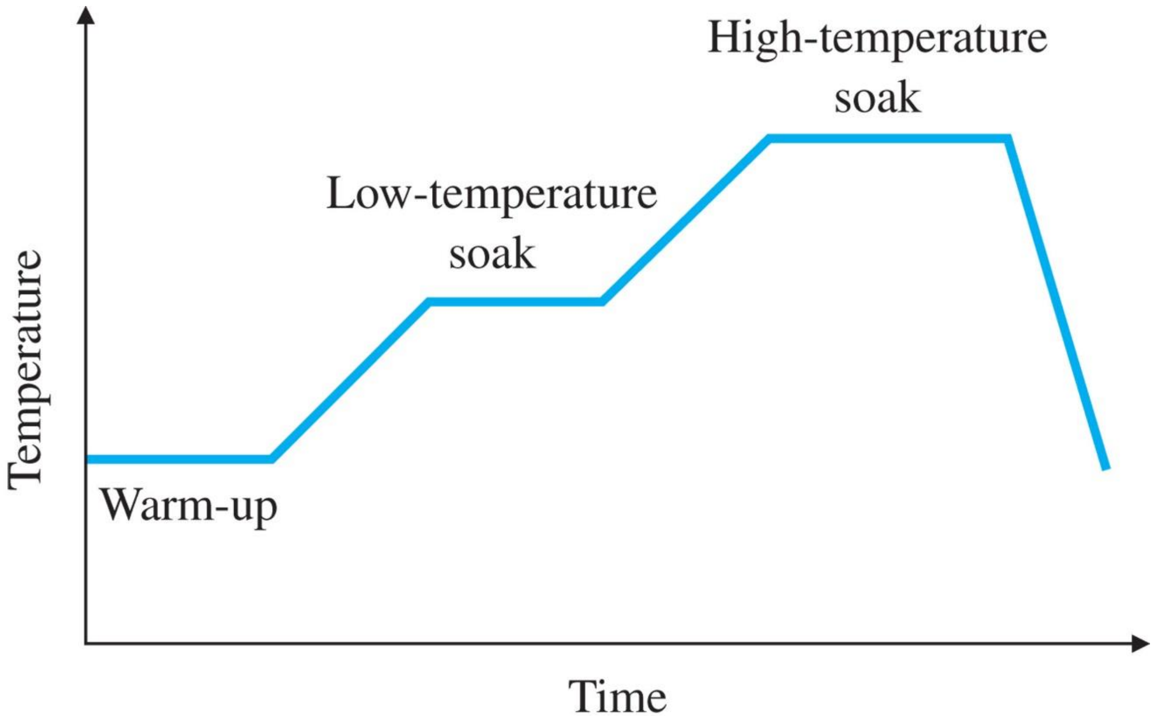


The role of control in each step:

A. Control of melt temperature, rotation speed, and pull rate.
B. Control of thickness and removal rate.
C. Control of plasma, pressure, flow, composition, and thickness.
D. Control of wafer stage with nm accuracy.
E. Control of plasma.
F. Control of temperature, pressure, flow, and thickness.
G. Control of energy.
H. Control of plasma, temperature, pressure, and flow.

Example 10.6 RTP Systems in Wafer Manufacturing

- (STEP 1) Understand the process and its performance specifications
  - The temperature of the wafer needs to be rapidly increased or decreased by the profile



Example 10.6 RTP Systems in Wafer Manufacturing

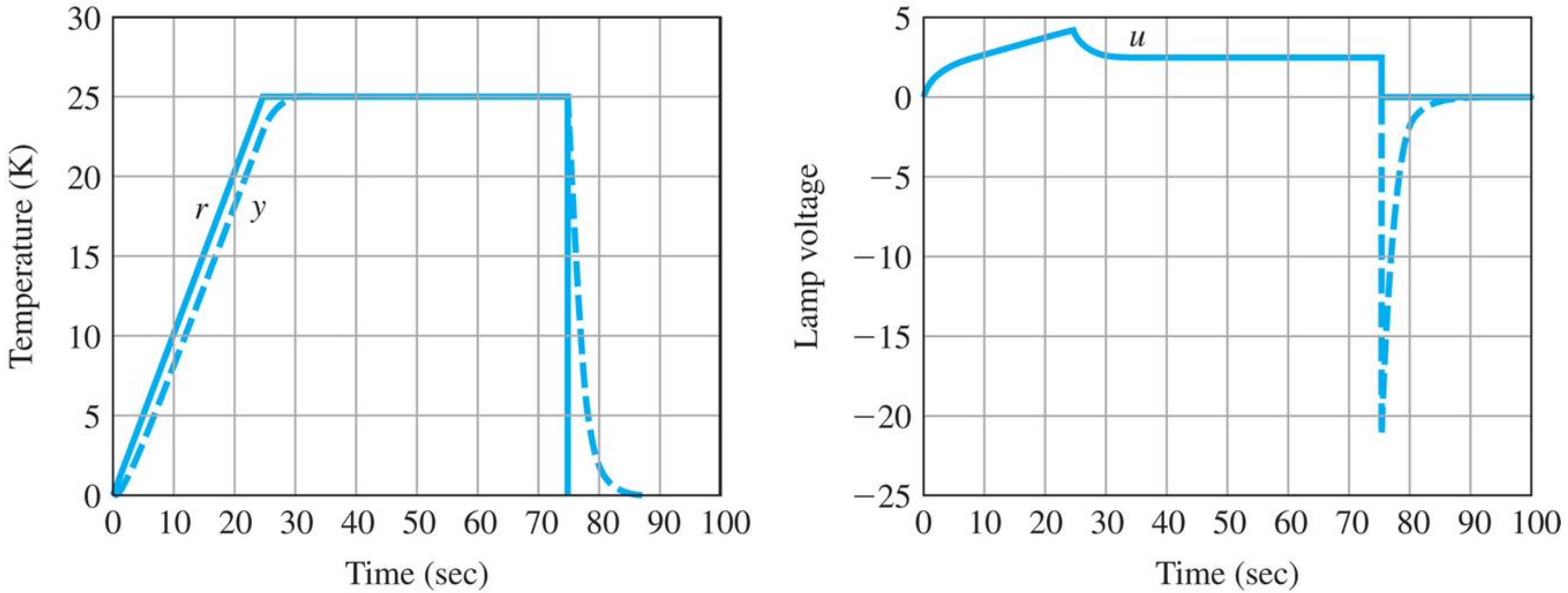
- (STEP 1) Understand the process and its performance specifications
  - A feedback control system is required to maintain the F/A within 1% of the desired level
- (STEP 2) Select sensors
  - Temperature measurement
- (STEP 3) Select actuators
  - Heating (lamp)
- (STEP 4) Make a linear model

$$G(s) = \frac{T_{y_2}(s)}{V_{cmd}(s)} = \frac{0.5226(s+0.0876)(s+0.1438)}{(s+0.1482)(s+0.0527)(s+0.0863)}$$

Example 10.6 RTP Systems in Wafer Manufacturing

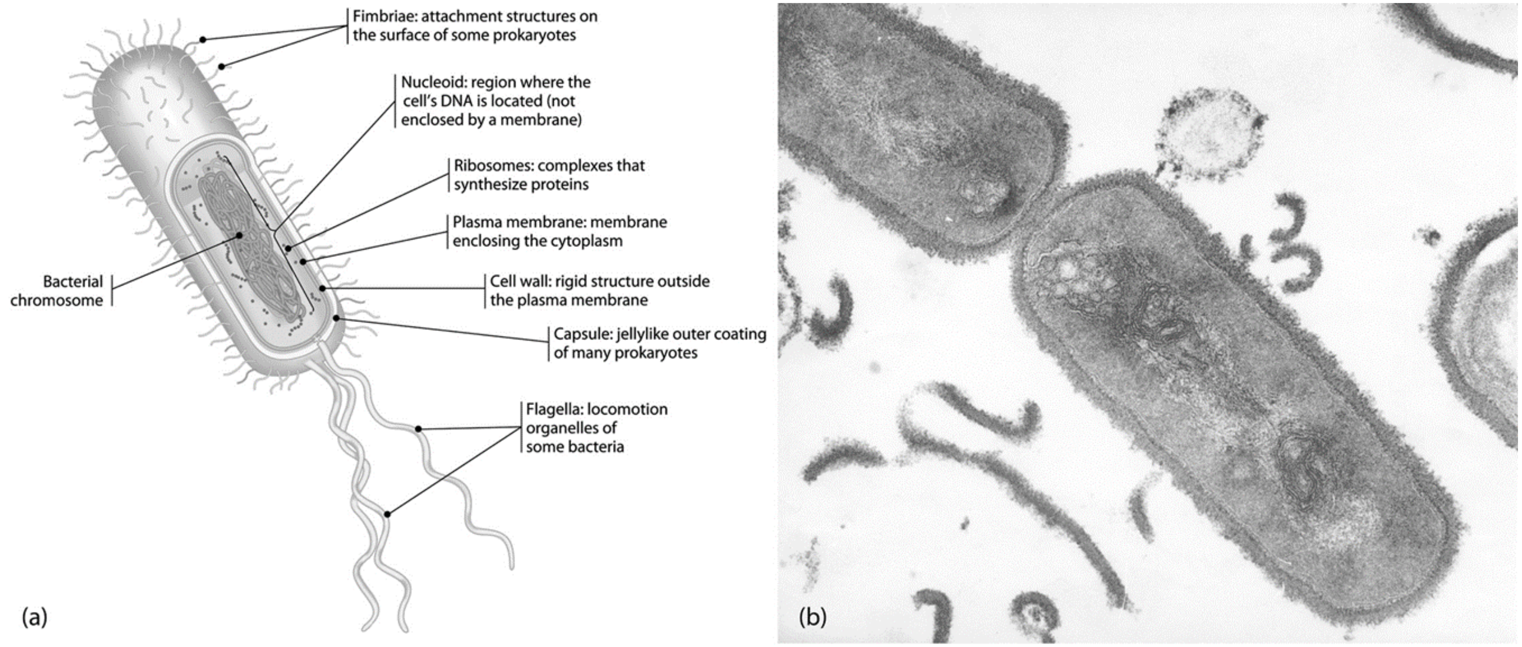
- (STEP 5) Try a lead-lag or P/D controller
  - PI Control

$$D_c(s) = \frac{(s + 0.0527)}{s}$$



(a) Temperature tracking response (b) Control effort

- System Biology
  - How shifting variables in one part impact the whole



(a) A typical bacterium;

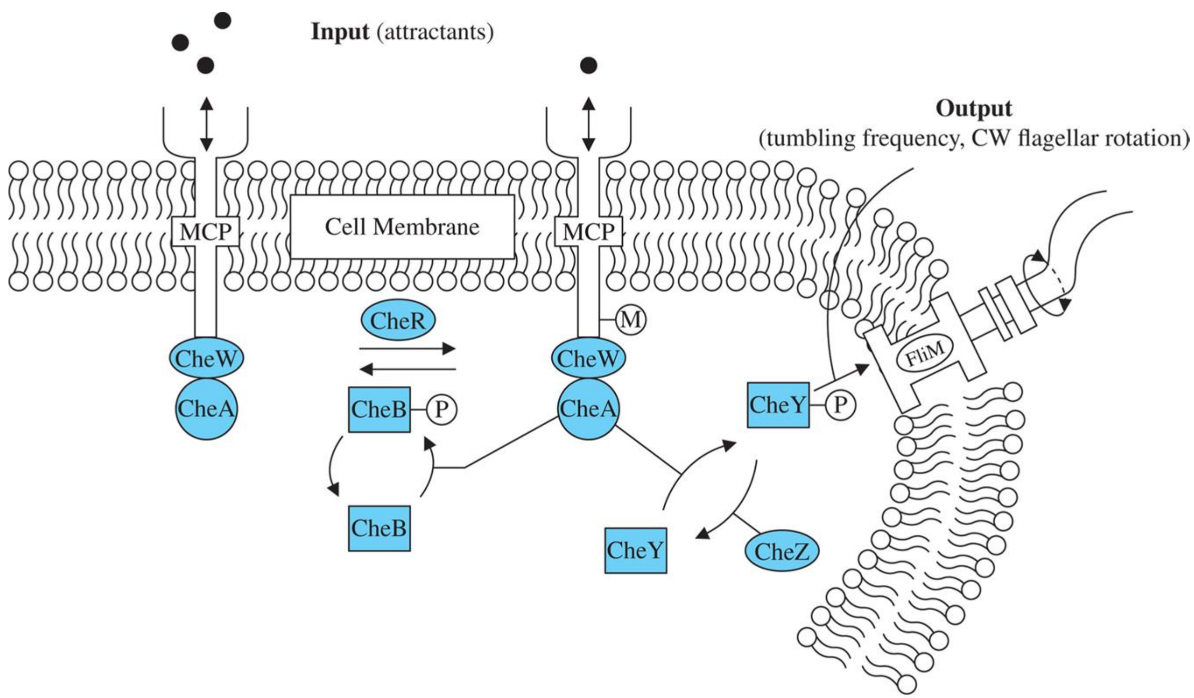
(b) TEM of bacterium Bacillus coagulans

Source: (a) Campbell and Reece, page 98, 2008. (b) © 2014 Stanley C. Holt/Biological Photo Service.

Example 10.7 Chemotaxis Swims Away from Trouble

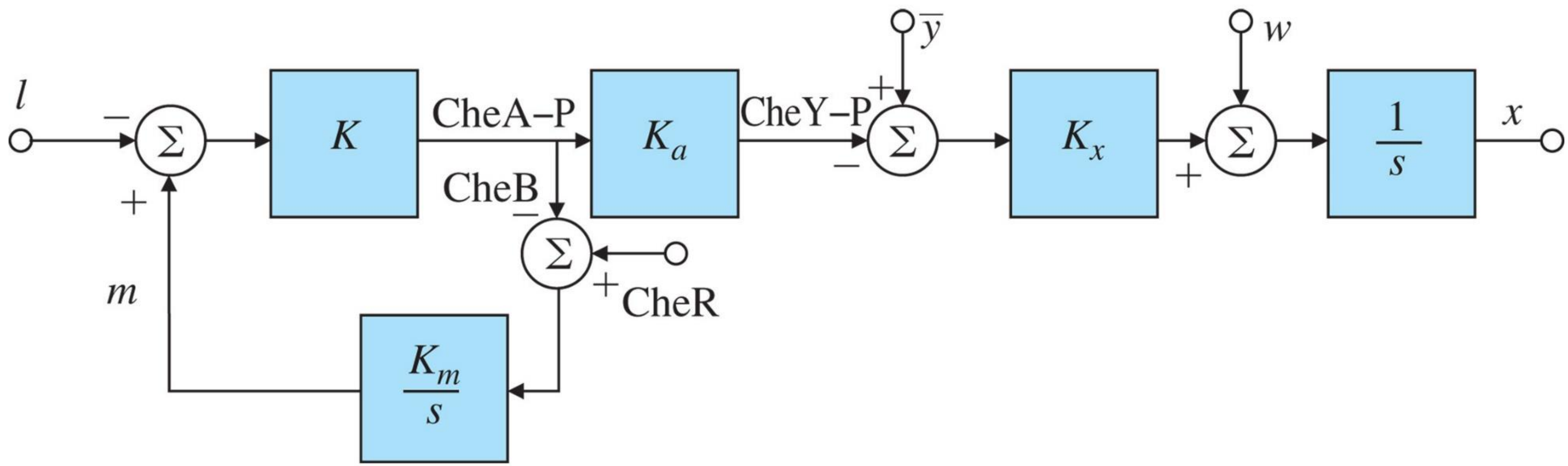
- Understand the process and its performance specifications
  - Chemotaxis is the name given to the process by which a motile bacterium senses the changes in its environment and moves toward places with a more favorable environment.
  - The dynamics of this chemotaxis are the subject of case study.

- Model

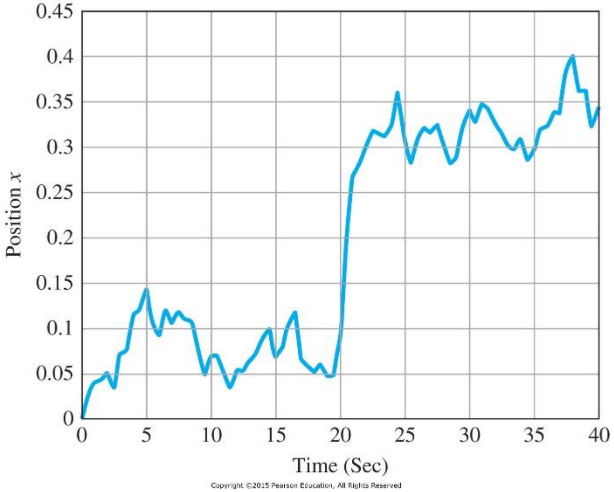


Example 10.7 Chemotaxis Swims Away from Trouble

- Simplified block diagram of E.coli chemotaxis. l represents ligand, m the methylation, CheR the steady-state rate of methylation, y the steady-state activity, and w the steady-state random walk motion



- Motion response of the chemotaxis model following insertion of attractant at t = 20 sec



Summary: Control System Design Principles

- Make a system model and determine the required performance specifications.
  - The purpose of this step is to answer the question. What is the system, and what is it supposed to do?
- Select sensors (measurement output)
  - A basic rule of control is that if you can't observe it, you can't control it.
- Select actuators.
  - The actuators must be capable of driving the system so as to meet the required performance specifications.
- Make a linear model.
  - All our design methods are based on linear models. Both small-signal perturbation models and feedback linearization methods can be used.
- Try a simple P/D controller.
  - An effort to meet the specifications with a PIO or its cousin. the lead-lag compensator, may succeed; in any case such an effort will expose the nature of the control problem.

- Evaluate/modify plant.
  - Evaluate whether plant modifications enhance closed-loop performance; if so. return to Step I or 4. Make a system model and determine the required performance specifications.
- Simulate the design, and verify its performance.
  - All the tools of analysis should be used here. induding the ro'-1t locus. the frequency response. G< and PM measurements, and transient responses.
  - Also. the performance of the design can be tested in simulation against changes in model parameters and the effects of approximating the compensator with a discrete model if digital control is to be used.
- Build a prototype and measure their performance with typical input signals