Lecture 12—Auto-tuning and Gain Scheduling

1. Introduction
2. Tuning Techniques
3. Relay tuning
4. Applications
5. Gain Scheduling
6. How to find schedules
7. Applications
8. Conclusions

Introduction

- Tuning and adaptation
- Prior knowledge
- Initialization of adaptive controllers
- PID Control
- Operational aspects
- Operator interface
- Views from the field

Views from the Field

Canadian mill audit. Average paper mill has 2000 loops, 97% use PI the remaining 3% are PID, adaptive etc. Bill Bialkowski CCA'93.

- Default settings
- Poor control performance due to bad tuning
- Poor control performance due to valves, actuators or positioner problems

Process Performance is not as good as you think. D. Ender, Control Engineering 1993.

- More than 30% of installed controllers operate in manual
- More than 30% of the loops actually increase short term variability
- About 25% of the loops use default settings
- About 30% of the loops have equipment problems

Auto-tuning Techniques

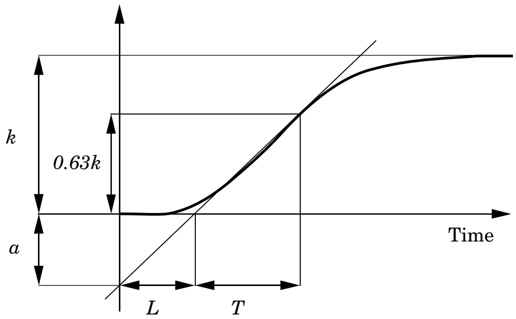
- The Ziegler-Nichols method
- Transient response methods
- Frequency response methods

Transient Response Methods

The three parameter model

$$G(s) = \frac{k}{1+sT}e^{-sL}$$

Step response methods



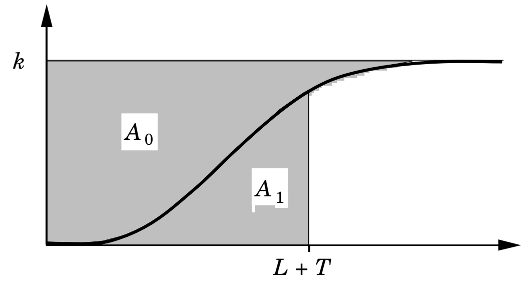
The Ziegler-Nichols method

Controller	aK_c	T_i/L	T_d/L	T_p/L
P	1			4
PI	0.9	3		5.7
PID	1.2	2	0.5	3.4

Difficulties with Ziegler-Nichols

- Difficult to determine parameters
- Too low damping
- Two parameters not enough

Area methods



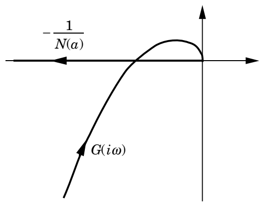
Parameters are given by

$$T + L = \frac{A_0}{k}$$
$$T = \frac{eA_1}{k}$$

Ziegler-Nichols Frequency Response Method

Idea: Run a proportional controller, increase gain until the system starts to oscillate. Observe "ultimate gain K_u, and "ultimate period T_u.

Interpretation: Find features of frequency response

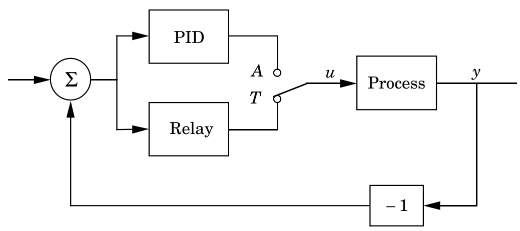


Controller parameters

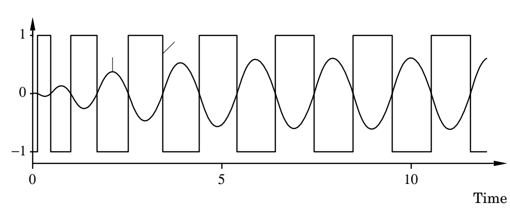
Controller	K_c/K_u	T_i/T_u	T_d/T_u	T_p/T_u
P	0.5			1
PI	0.4	0.8		1.4
PID	0.6	0.5	0.12	0.85

Relay Tuning

The experiment



The results



- Closed loop experiment
- Stable limit cycle for large class of processes
- Much control energy close to ω_{180}

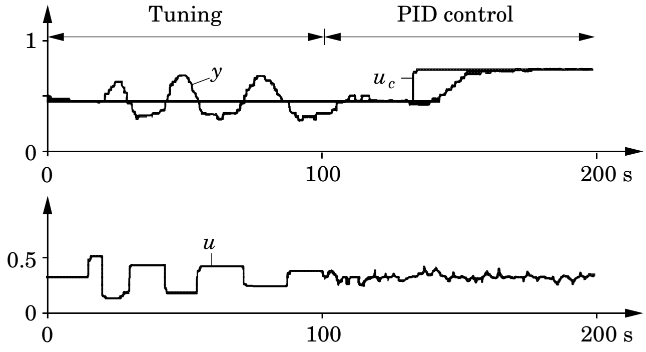
Practical Issues

- Prior information?
- How to start the experiments
- Feedback to limit the amplitiude of the oscillation
- Modified Ziegler-Nichols rules
  - Change values in the tables
  - Use three parameters k_u, T_u and K_p
- How to cope with disturbances
  - Load disturbances
  - Measurement noise
  - Hysteresis

Automatic Tuning of the Double Tank

Consider the double tank used in our laboratory experiments.

Here is the results obtained with one of our earliest auto-tuners.



Flow Control

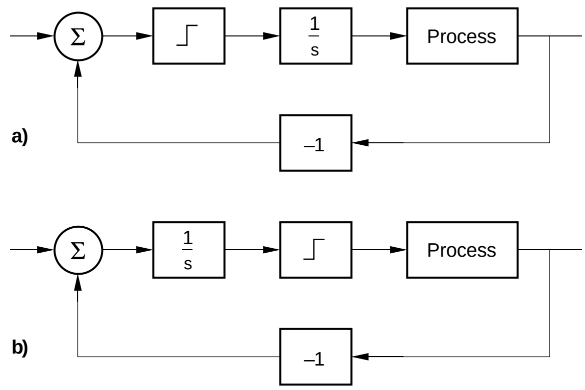
Temperature Control

Composition Control

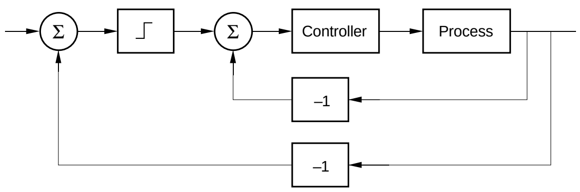
Adding Dynamics in the Feedback Loop

Other information can be obtained by introducing dynamics in the feedback loop

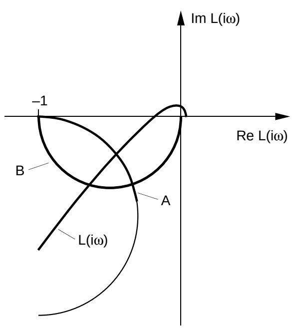
- An integrator gives ω_{90}
- A differentiator gives ω_{270}



Closed Loop Experiments



An integrator can also be added

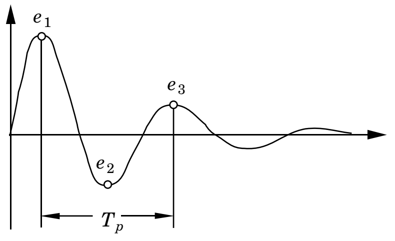


Summary of Relay Feedback

- Close to industrial operation
- Easy to use
- One-button tuning
- Easy to explain to users
- Works well for standard loops
- Little prior information
- Very robust
- Generates automatically a perturbation signal with a lot of energy at ω_{180}
- Many possibilities not exploited

On-line Iteration

Idea: Find features of the online response due to set point or load disturbances. Modify controller settings based on the observed features.



Features: damping d and overshoot o

$$d = \frac{e_3 - e_2}{e_1 - e_2} \quad o = -\frac{e_2}{e_1}$$

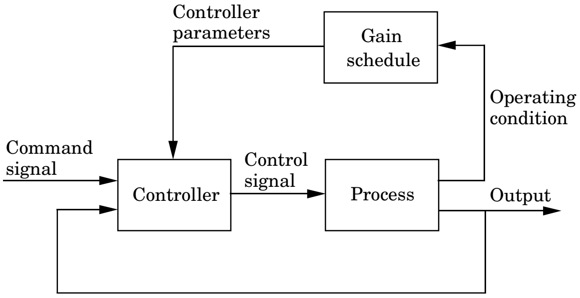
Controller modified based on heuristic rules. Easy for PI more difficult for PID.

- Prior information
- Pre-tuning

Gain Scheduling

1. What is it?
2. How to find schedules?
3. Applications
4. Conclusions

Gain Scheduling



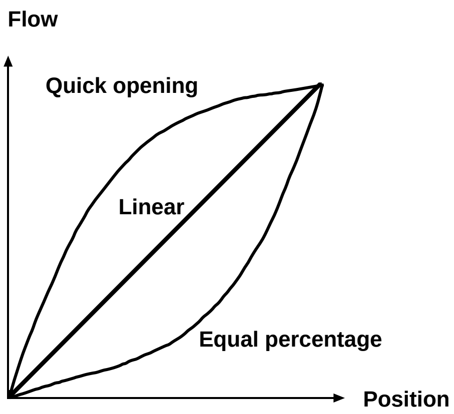
Example of scheduling variables

- Production rate
- Machine speed
- Mach number and dynamic pressure

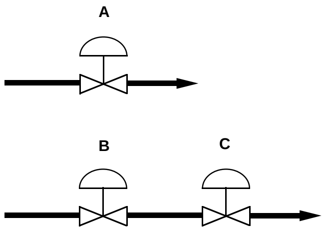
How to Find Schedules?

- Select scheduling variables
- Make control design for different operating conditions
- Use automatic tuning
- Transformations

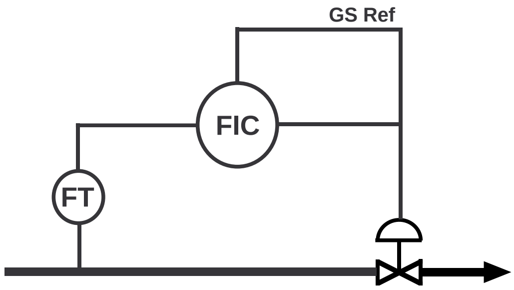
Valve Characteristics



The valve characteristics depend on the installation

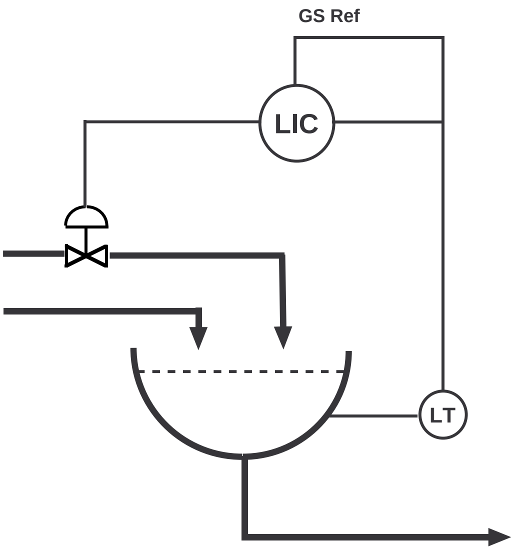


Schedule on Controller Output



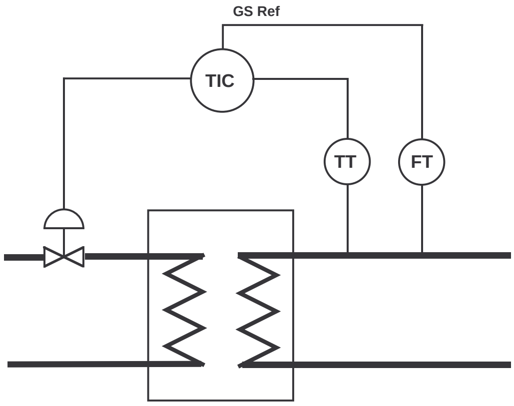
Discuss when this is appropriate

Schedule on Process Variable



Discuss when this is appropriate

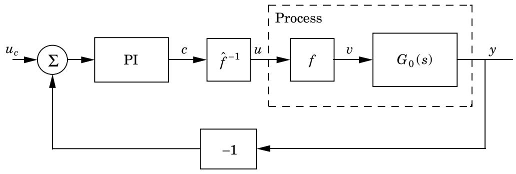
Schedule on External Variable



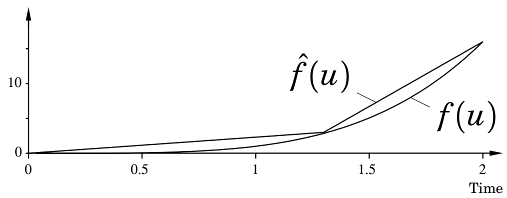
Discuss when this is appropriate

Nonlinear Valve

A typical process control loop



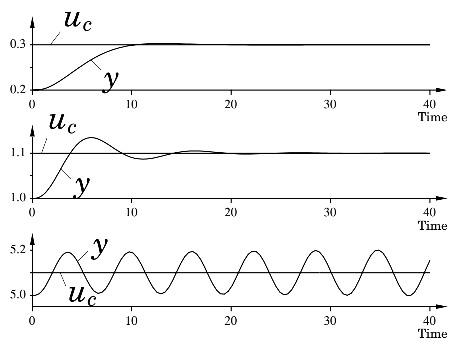
Valve characteristics



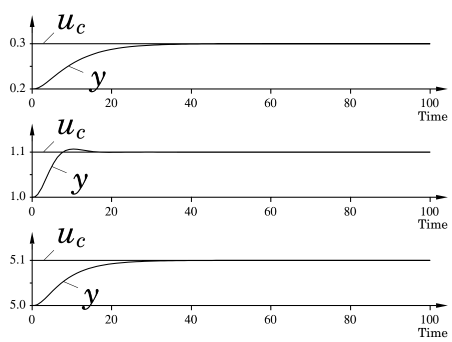
A crude approximation!

Results

Without gain scheduling

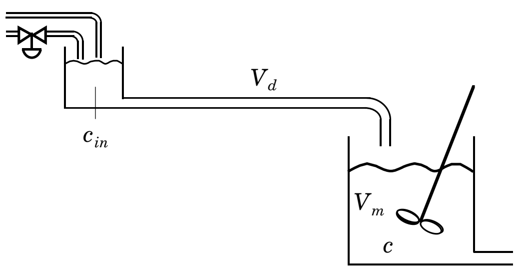


With gain scheduling

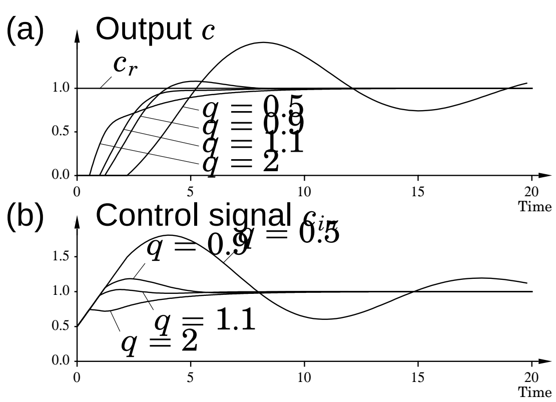


Concentration Control

System



Performance with changing flow



Variable Sampling Rate

Process model

$$G(s) = \frac{1}{1 + sT} e^{-s\tau}$$

where

$$T = \frac{V_m}{q} \qquad \tau = \frac{V_d}{q}$$

Sample the system with period

$$h = \frac{V_d}{nq}$$

The sampled model becomes

$$c(kh + h) = a\,c(kh) + (1 - a)u(kh - nh)$$

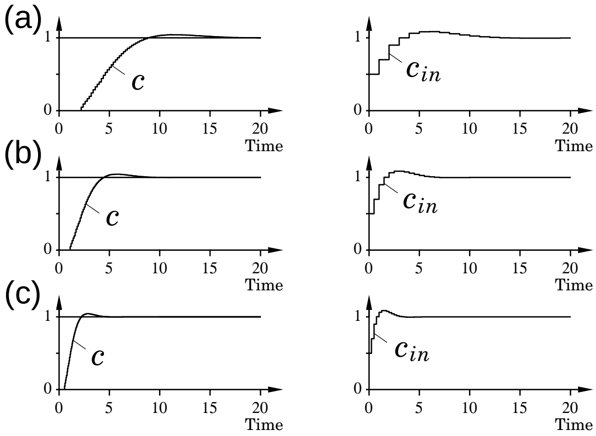
where

$$a = e^{-qh/V_m} = e^{-V-d/(nV_m)}$$

Notice that the sampled equation does not depend on q!!!

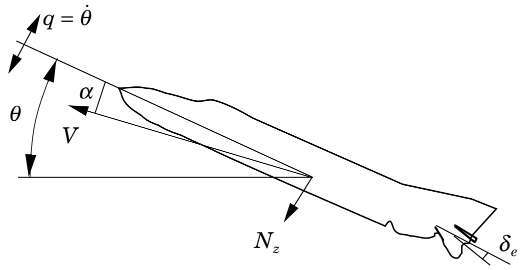
Results

Digital control with $h = 1/(2q)$. The flows are: (a) $q = 0.5$; (b) $q = 1$; (c) $q = 2$

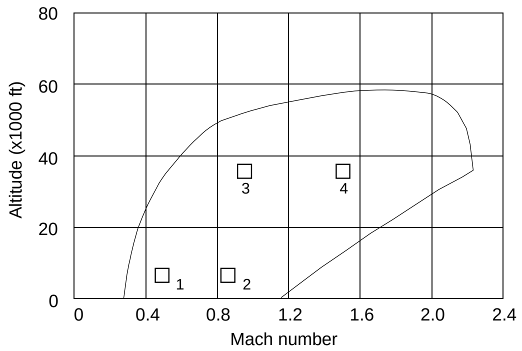


Flight Control

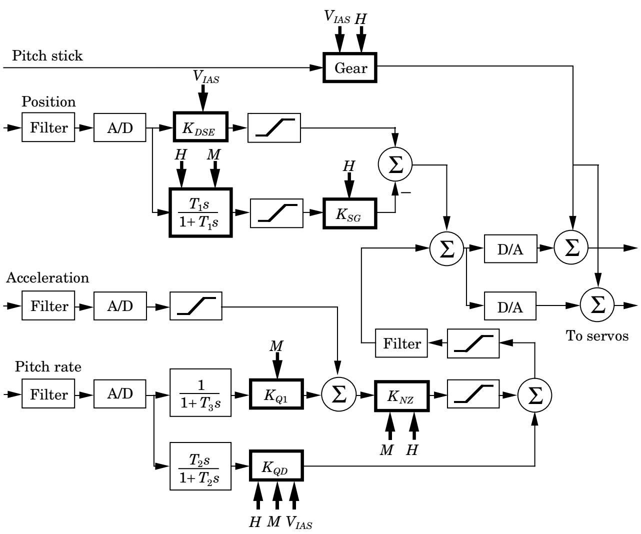
Pitch dynamics



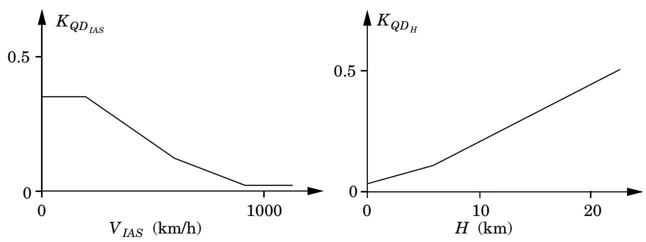
Operating conditions



The Pitch Control Channel

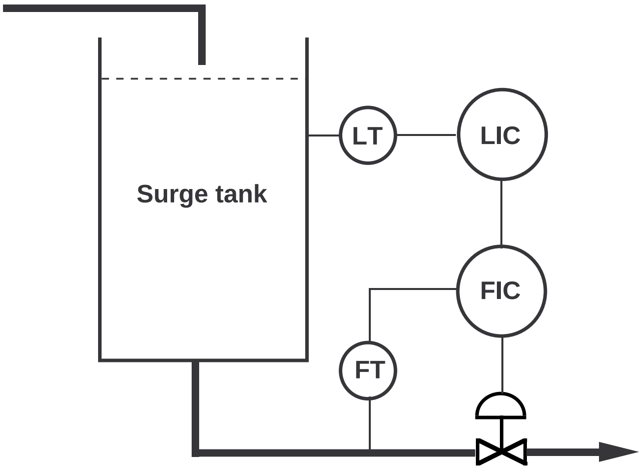


Schedule of K_Q with Respect to Indicated Airspeed (IAS) and Height (H)



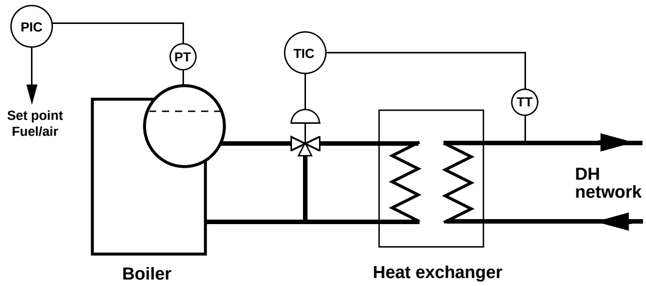
Surge Tank Control

A surge tank is used to smooth flow variations. The is allowed will fluctuate substantially but it is important that the tank does not become empty or that it overflows.

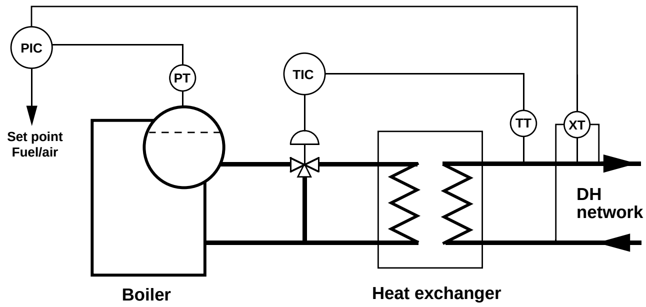


The Igelsta Power Station

Controller structure before modification



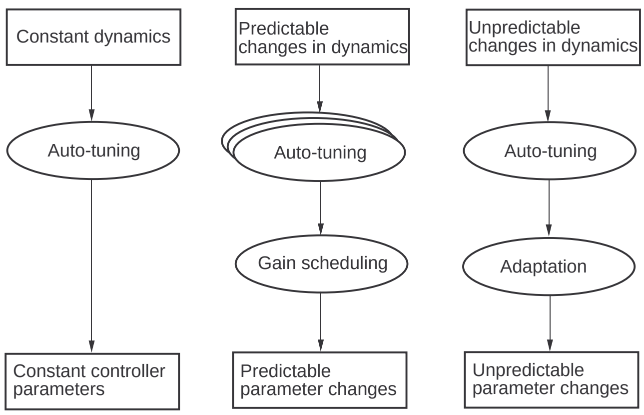
Modified controller structure



Schedule

Valve Position	K_c	T_i	T_d
0.00-0.15	1.7	95	23
0.15-0.22	2.0	89	22
0.22-0.35	2.9	82	21
0.35-1.00	4.4	68	17

When to Use Different Techniques?



Conclusions

- Very useful technique
  - Linearization of nonlinear actuators
  - Surge tank control
  - Control over wide operating ranges
- Requires good models
- Easy to use when combined with auto-tuning
- Good operational experience
- Issues to be considered
  - Choice of scheduling variables
  - Granularity of scheduling tables
  - Interpolation
  - Bumpless parameter changes
  - Operator interfaces