PLCs: Part 2

Rajesh Rajamani
Department of Mechanical Engineering
University of Minnesota

OVERVIEW

• Importance of PID Control
• Importance of Bode Plots
• Video on PLCs
• Lab 11: Simulating a Washing Machine Cycle
• Final Exam
IMPORTANCE OF PID CONTROL

- PID Control with the Ziegler-Nichols Criterion
  - Most commonly used industrial control tool

\[ y_{des} + e \rightarrow C \rightarrow u \rightarrow P \rightarrow y \]

\[ C(s) = K_p \left( 1 + \frac{T_i}{s} + T_d s \right) \]

<table>
<thead>
<tr>
<th>Controller</th>
<th>( K_p )</th>
<th>( T_i )</th>
<th>( T_d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>( 0.5K_{cr} )</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PI</td>
<td>( 0.45K_{cr} )</td>
<td>( P_{cr}/1.2 )</td>
<td>-</td>
</tr>
<tr>
<td>PID</td>
<td>( 0.6K_{cr} )</td>
<td>( 0.5P_{cr} )</td>
<td>( 0.125P_{cr} )</td>
</tr>
</tbody>
</table>

IMPORTANCE OF BODE PLOTS

- Experimentally determining the dynamic model for a system
- Design of vibration isolation mounts
- Design of sensors
- Design of actuators
- Signal processing filters
- Control system design
- Countless other applications ……. 
VIBRATION ISOLATION

Designing vibration isolation mounts for a machine

\[ F - \text{mean } 5000 \text{ N and sinusoidal } 1000 \text{ N at } 25\text{Hz} \]

Objective
• Motion of the machine should be less than \( \pm 1 \text{ mm} \) from equilibrium
• At 25 Hz, less than 250 N of force should be transmitted to the structure

\[ m\ddot{x} + c\dot{x} + kx = F \]

\[ F_t = c\dot{x} + kx \]

Motion of machine
\[ G(s) = \frac{X(s)}{F(s)} = \frac{1}{ms^2 + cs + k} \]

Force transmitted to structure
\[ H(s) = \frac{F_t(s)}{F(s)} = \frac{cs + k}{ms^2 + cs + k} \]
**VIBRATION ISOLATION**

Motion of machine

\[ G(s) = \frac{X(s)}{F(s)} = \frac{1}{ms^2 + cs + k} = \frac{1}{k} \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} \]

\[ m\ddot{x} + c\dot{x} + kx = F \]

Force Transmitted

\[ H(s) = \frac{F_t(s)}{F(s)} = \frac{cs + k}{ms^2 + cs + k} = \frac{\omega_n^2 \left( \frac{c}{k} s + 1 \right)}{s^2 + 2\xi\omega_n s + \omega_n^2} \]
VIBRATION ISOLATION

Designing vibration isolation mounts for a machine

Conclusions

• A very hard spring can restrain motion to be less than ±1 mm
• But a hard spring increases the high frequency forces transmitted to the structure

SENSOR DESIGN

Design an accelerometer to measure inertial acceleration

Objective

• Estimate acceleration of the casing: \( A = \dot{y} \)
• Use the physically measured variable:
  – Relative position \( z = x - y \)
SENSOR DESIGN

Proof mass \( m \)  

\[ H(s) = \frac{Z(s)}{Y(s)} = \frac{cs + k}{ms^2 + cs + k} - 1 \]

\[ = -\frac{ms^2}{ms^2 + cs + k} \]

\[ Z(s) = \frac{-s^2}{s^2 + 2\xi \omega_n s + \omega_n^2} \]

\[ A(s) = \frac{-1}{s^2 + 2\xi \omega_n s + \omega_n^2} \]

MEMS ACCELEROMETER

Solid model of a two-axis MEMS accelerometer
IMPORTANCE OF BODE PLOTS

• Experimentally determining the dynamic model for a system
• Design of vibration isolation mounts
• Design of sensors
• Design of actuators
• Signal processing filters
• Control system design
• Countless other applications ……

PLCs

• Video of UPS Automated Sortation Facility at Maple Grove, MN

• All machinery shown in the video are controlled by PLCs

• Video recorded by Jason Quinn
COUNTERS

If the enable input is ON and the input In 1 transitions from OFF to ON, then the variable “accum” is increased by 1.

When accum become equal to preset, the output out becomes HIGH.

If Enable goes OFF, accum is reset to zero.

REAL-TIME CLOCK

Y1 10 T 0.1 Y1 seconds

Y1 60 CTR Y2 minutes

Y2 60 CTR Y3 hours

Y3 24 CTR Y4 days
REAL-TIME CLOCK

LAB 11

- Washing Machine
WASHING MACHINE

- **Wash**
  - Open water valve until high level switch is ON
  - Run agitator motor for 12 minutes
  - Drain until low level switch is OFF
- **Rinse**
  - Open water valve until high level switch is ON
  - Run agitator motor for 6 minutes
  - Drain until low level switch is OFF
- **Spin**
  - Run spin motor for 4 minutes

WASHING MACHINE

- **Finish flags**
  - Fill 1
  - Wash 1
  - Drain 1
  - Fill 2
  - Wash 2
  - Drain 2
  - Spin
  - Total Cycle

- **Sensors**
  - Start switch
  - High level switch
  - Low level switch

- **Actuators**
  - Agitator motor
  - Spin motor
  - Water valve
  - Drain motor
WASHING MACHINE

Using OR logic to set finish flags

- High level switch
- Start
- Total cycle
- Fill 1

WASHING MACHINE

Using OR logic to set finish flags

- Fill 1
- 720
- T1
- Start
- Total cycle
- Wash 1
WASHING MACHINE

Outputs are determined from the finish flags

FINAL EXAM

- Approximately 25% of grade
- 25 questions, multiple choice
- Total time: 2 hours 0 minutes
  (~5 minutes per question)
- Cheat sheet: One 8.5” x 11” sheet, both sides
- Exam time (1:30 pm – 3:30 pm):
  - Tuesday, Dec 16, Room 54 Rapson Hall
- Special office hours: Mornings, 9:00-11:00, week of 12/8
Sample question

Q1. If the input range of a 12-bit A/D converter is –5V~+5V, its resolution is approximately: (Notice that $2^{12}=4096$)

A. 0.1V.
B. 0.01V.
C. 0.001V.
D. 0.0025V.

Sample question

Q. Given the frequency response function

$$H(j\omega) = \frac{1}{j\omega + 3}$$

The magnitude of $H(j\omega)$ at $\omega = 2$ rad/sec is

A. –11.1 db
B. +11.1 db
C. –9.5 db
D. +9.5 db
Sample question

Q. A Bode plot is given as below. The approximate bandwidth of the system is closest to

A. 1 rad/sec.
B. 1.4 rad/sec.
C. 10 rad/sec.
D. None of the above.