Electronic Instrumentation

Project 2

Velocity Measurement
Cantilever Beam Sensors

- Position Measurement – obtained from the strain gauge
- Velocity Measurement – previously obtained from the magnetic pickup coil (not available since Fall of 2006)
- Acceleration Measurement – obtained from the Analog Devices accelerometer
Sensor Signals

- The 2 signals
  - Position
    \[ x = x_0 e^{-\frac{t}{\tau}} \cos \omega t \]
  - Acceleration
    \[ a = \frac{d^2 x}{dt^2} \]
Basic Steps for Project

• Mount an accelerometer close to the end of the beam
  • Wire +2.5V, -2.5V, and signal between IOBoard and Circuit
    (Note that this cannot be done directly. Follow the circuit diagram in the
    Project write-up and in slide 7 of this presentation.)
  • Record acceleration signal
• Reconnect strain gauge circuit
  • Calibrate the stain gauge
  • Record position signal
• Compare accelerometer and strain gauge signals
• Build an integrator circuit to get velocity from the accelerometer sensor
• Build a differentiator circuit to get velocity from the strain gauge sensor
• Include all calibration and gain constants and compare measurements of velocity
Building the Accelerometer Circuit
The Analog Device Accelerometer

- The AD Accelerometer is an excellent example of a MEMS device in which a large number of very, very small cantilever beams are used to measure acceleration. A simplified view of a beam is shown here.
Accelerometer Circuit

- The Analog Device chip produces a very accurate signal proportional to acceleration
- Voltage between pins 7 and 14 must be about 5V
- Only 3 wires need to be connected, +4V, -4V and the signal $v_{out}$. Once you have the circuit connected correctly, measure the voltages on pins 7 and 14 to be sure they are -2.5V and +2.5V, respectively
Accelerometer Circuit

- The ADXL150 is surface mounted, so we must use a surfboard to connect it to a protoboard
Caution

• Please be very careful with the accelerometers. While they can stand quite large g forces, they are electrically fragile. If you apply the wrong voltages to them, they will be ruined. AD is generous with these devices (you can obtain samples too), but we receive a limited number each year.

• Note: this model is obsolete, so you can’t get this one. Others are available.
Extra Protoboard

• You will be given a small protoboard on which you will insert your accelerometer circuit.

• Keep your circuit intact until you complete the project.

• We have enough accelerometer surfboards that you can keep it until the end of project 2.
Mounting the Accelerometer
Mount the Accelerometer Near the End of the Beam

- Place the small protoboard as close to the end as practical
- The axis of the accelerometer needs to be vertical
Accelerometer Signal

- The output from the accelerometer circuit is 38mV per $g$, where $g$ is the acceleration of gravity.
- The equation below includes the units in brackets

$$a(t)[m/s^2] = \frac{V_a(t)[mV]}{38[mV]} \rightarrow a(t)[m/s^2] = -\frac{9.8[m/s^2] \cdot V_a(t)[V]}{0.038[V]}$$
Amplified Strain Gauge Circuit

\[ V_{out} = \left( \frac{R_b}{R_a} \right) (V_{left} - V_{right}) \]
Position Measurement Using the Strain Gauge

- Set up the amplified strain gauge circuit
- Place a ruler near the end of the beam
- Make several measurements of bridge output voltage and beam position
- Find a simple linear relationship between voltage and beam position \((k_1)\) in V/m.

\[ x_b(t) = C_{sg} V_{sg}(t) = \frac{V_{sg}(t)}{k_1} \]
Comparing the accelerometer measurements with the strain gauge measurements

\[ x(t) = Ce^{-\alpha t} \sin \omega t \]

\[ v = \frac{\partial x}{\partial t} \approx C \omega e^{-\alpha t} \cos \omega t \quad \text{for} \ \alpha \ \text{small compared to} \ \omega \]

\[ a = \frac{\partial v}{\partial t} \approx -C \omega^2 e^{-\alpha t} \sin \omega t = -\omega^2 x(t) \]

- The position, \( x \), is calculated from the strain gauge signal.
- The acceleration is calculated from the accelerometer signal.
- The two signals can be compared, approximately, by measuring \( \omega \).
Velocity

• The velocity is the desired quantity, in this case.
• One option – integrate the acceleration signal
  • Build a Miller integrator circuit - exp. 4
  • Need a corner frequency below the beam oscillation frequency
  • Avoid saturation of the op-amp – gain isn’t too big
  • Good strong signal – gain isn’t too small
• Another option – differentiate the strain gauge signal.
  • Build an op-amp differentiator – exp. 4
  • Corner frequency higher than the beam oscillation frequency
  • Avoid saturation but keep the signal strong.
Velocity

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Remember that a feedback capacitor is probably necessary to reduce noise on the signal. See troubleshooting guide.
Velocity

• Be careful to include all gain constants when calculating the velocity.
  • For the accelerometer
    • Constant of sensor (.038V/g) \([g = 9.8\text{m/s}^2]\)
    • Constant for the op-amp integrator \((-1/RC)\)
  • For the strain gauge
    • The strain gauge sensitivity constant, \(k_1\)
    • Constant for the op-amp differentiator \((-RC)\)
MATLAB

• Save the data to a file
  • Open the file with MATLAB
    • faster
    • Handles 65,000 points better than Excel
  • Basic instructions are in the project write up
Some Questions

• How would you use some of the accelerometer signals in your car to enhance your driving experience?

• If there are so many accelerometers in present day cars, why is acceleration not displayed for the driver? (If you find a car with one, let us know.)

• If you had a portable accelerometer, what would you do with it?
Passive Differentiator

\[ V_{out} = V_R = RC \frac{dV_C}{dt} \approx RC \frac{dV_{in}}{dt} \text{ at low frequencies} \]

\[ H(j\omega) = \frac{j\omega RC}{1 + j\omega RC} \]

\[ H_{LO}(j\omega) = j\omega RC \]
Active Differentiator

\[ H(j\omega) = -j\omega R_f C_{in} \]

\[ V_{out} = -R_f C_{in} \frac{dV_{in}}{dt} \]

\[ f << \frac{1}{2\pi R_{in} C_{in}} \]
Typical Acceleration

- Compare your results with typical acceleration values you can experience.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Acceleration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevator (fast service)</td>
<td>0.3 g</td>
</tr>
<tr>
<td>Automobile (take off)</td>
<td>0.1-0.5 g</td>
</tr>
<tr>
<td>Automobile (brake or corner)</td>
<td>0.6-1 g</td>
</tr>
<tr>
<td>Automobile (racing)</td>
<td>1-2.5 g</td>
</tr>
<tr>
<td>Aircraft take off</td>
<td>0.5 g</td>
</tr>
<tr>
<td>Earth (free-fall)</td>
<td>1 g</td>
</tr>
<tr>
<td>Space Shuttle (take off)</td>
<td>3 g</td>
</tr>
<tr>
<td>Parachute landing</td>
<td>3.5 g</td>
</tr>
<tr>
<td>Plop down in chair</td>
<td>10 g</td>
</tr>
<tr>
<td>30 mph car crash w airbag</td>
<td>60 g</td>
</tr>
<tr>
<td>Football tackle</td>
<td>40 g</td>
</tr>
<tr>
<td>Seat ejection (jet)</td>
<td>100 g</td>
</tr>
<tr>
<td>Jumping flea</td>
<td>200 g</td>
</tr>
<tr>
<td>High speed car crash</td>
<td>700 g</td>
</tr>
</tbody>
</table>
Crash Test Data

- Head on crash at 56.6 mph

Ballpark Calc:
56.6 mph = 25.3 m/s
Stopping in 0.1 s
Acceleration is about
-253 m/s² = -25.8 g
Crash Test Data

- Head on crash at 112.1 mph

Ballpark Calc:
- 112.1 mph = 50.1 m/s
- Stopping in 0.1 s
- Acceleration is about
  -501 m/s² = -51.1 g
Crash Test Analysis Software

• Software can be downloaded from NHTSA website

Airbags

• Several types of accelerometers are used & at least 2 must sense excessive acceleration to trigger the airbag.