Electromechanical Systems ASE 375

Lecture 15: Dynamic Measurements, Accelerometers - 2

Classes of Acceleration

- There are three main classes of motion we can define
- **Motion**
  - Motion is defined as "slow" changes in position or velocity. Some examples include human motion, orientation tracking, waves, and sustained accelerations like rocket takeoffs.
- **Vibration**
  - Vibration is defined as oscillating motion about a position of equilibrium. Some examples include an electric motor, turbine or bearing monitoring, health monitoring, and resonance detection.
- **Shock**
  - Shock is defined as a sudden change in acceleration that generally excites a structure's resonance. A few examples include drop testing, automotive crash testing, and dampeners/shock absorbers testing.

Accelerometer - Applications

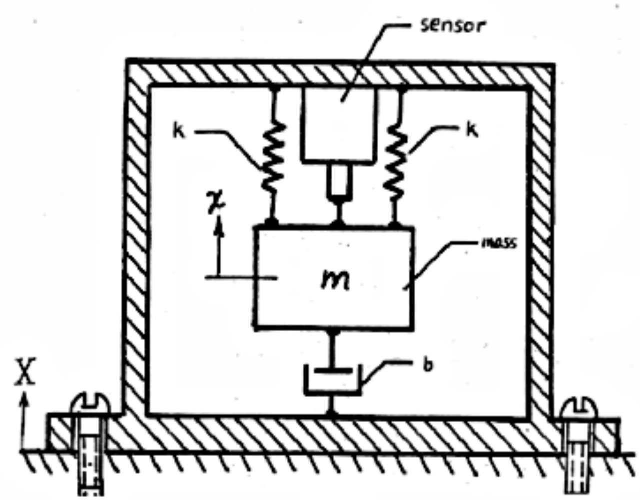
- There are so many applications of accelerometers, its impossible to list them all on one slide
  - Video games
  - Hard drive protection
  - Vehicle crash detection
  - Earthquake sensors
  - Machinery health monitoring
  - Construction work – driving piles, demolition, drilling and excavating
  - Moving loads on bridges
  - Impact loads – falling debris
  - Concussion loads – internal and external explosions
  - Collapse of structural elements
  - Wind loads and wind gusts
  - Air blast pressure
  - Loss of support because of ground failure
  - Earthquakes and aftershocks
  - Image stabilization
  - Inertial navigation

Accelerometers - Fundamentals

- Accelerometers are based on a spring-mass-damper system.
- Acceleration causes displacement of a ”proof mass" proportional to the acceleration experienced.

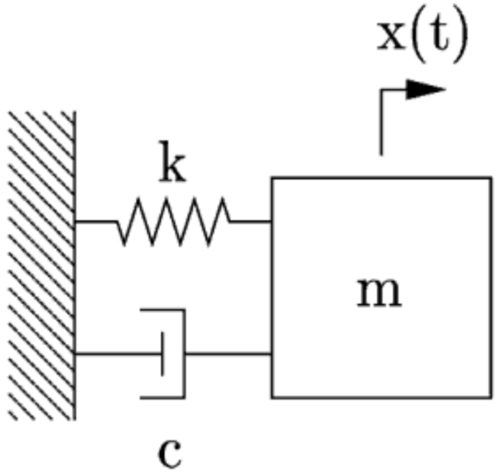
Acceleration is expressed in g force:

- This room = your weight = 1g
- Bugatti Veyron, 0 to 60mph in 2.4s= 1.55g
- Space Shuttle reentry & launch = 3g
- F-1 car cornering = 5g to 6g
- Max for fighter jet pilots = 11g to 12g
- Max experienced by a human* = 46.2g
- Death or extensive & severe injuries= +50g



Modern accelerometers are small microelectromechanical systems (MEMS) consisting of a cantilever beam with a proof mass. Thus they sense acceleration in only one direction.

Basic Spring-Mass-Damper System



Spring Force

Damping Fource

Applied Force

Movement of Mass

$$F(t) = kx(t) + m\,\frac{d^2x(t)}{dt^2} + c\cdot\frac{dx(t)}{dt}$$

Oscillatory motion $\omega = 2\pi f$

- Position $x(t) = x_0 e^{j\omega t}, \quad x_0 \cos(\omega t)$
- Velocity $v(t) = \frac{d}{dt} x_0 e^{j\omega t} = j\omega x_0 e^{j\omega t} \quad , \quad -x_0 \omega \sin(\omega t)$
- Acceleration $a(t) = \frac{d^2}{dt^2} x_0 e^{j\omega t} = -\omega^2 x_0 e^{j\omega t} \quad , -\omega^2 x_0 \cos(\omega t)$

Accelerometer approaches

$$ma = F$$

Stress/force based

Measure F
- Compression
- Bending

Piezoelectric

Piezoresistive

$$F = kx$$

Measure x

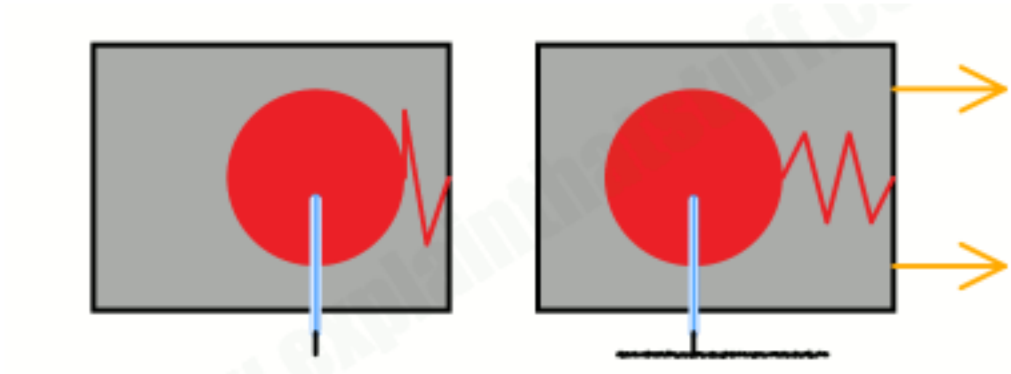
Capacitive

Optical

Magnetic

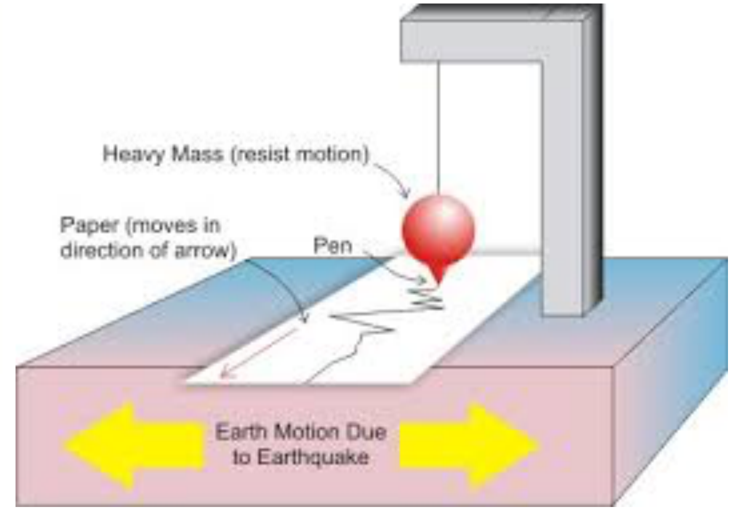
Thermal

Mechanical Accelerometers



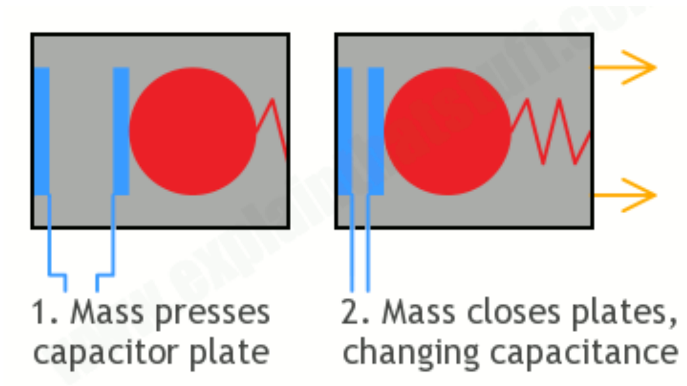
Stationary mass in a structure

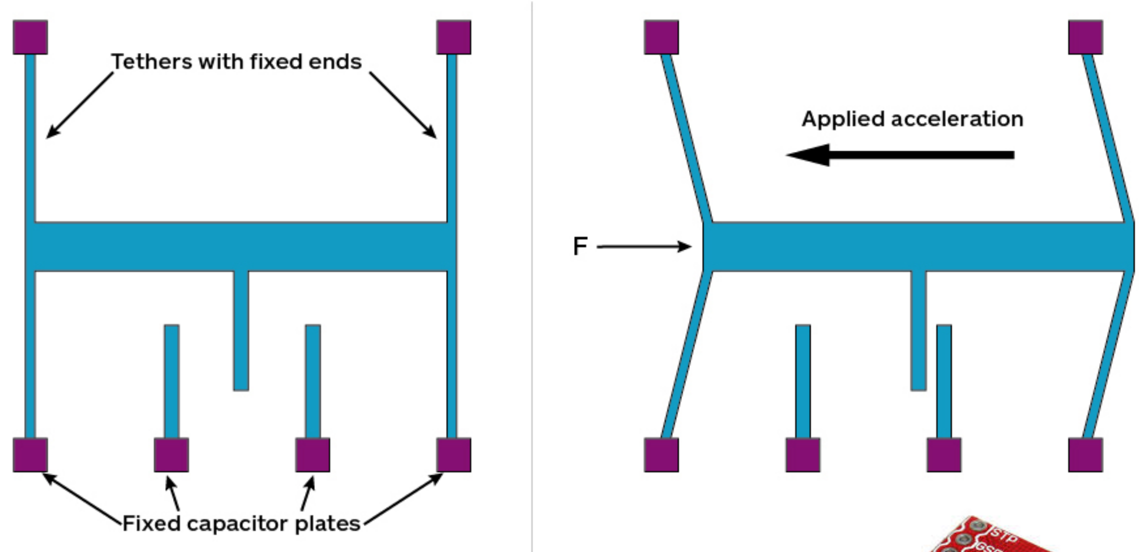
When structure moves, mass stays in place

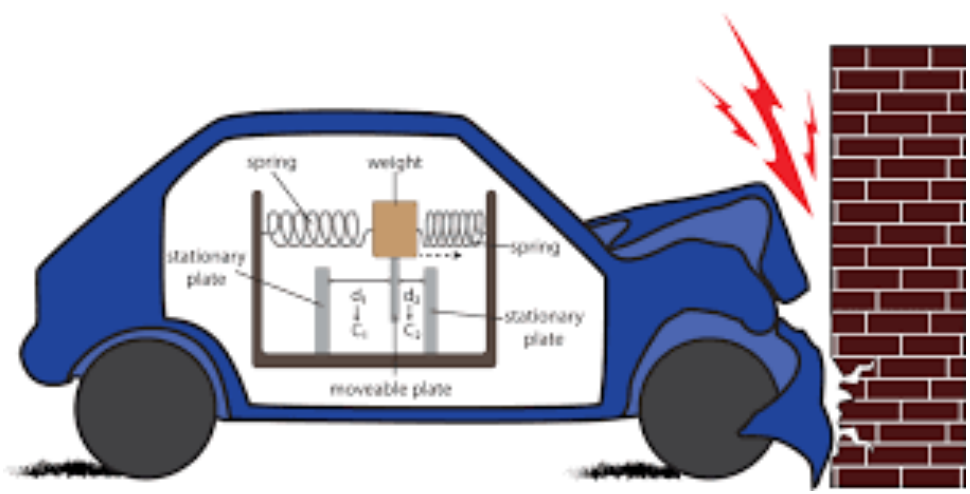


- Mechanical motion is converted into a graphical output
- A stationary mass suspended in a structure with a responsive spring
- When the structure experiences a vibration, the mass doesn’t know of it until the information is communicated by the spring.
- The motion of the structure is the input to the spring-mass system
- Seismometers use this principle

Capacitive Accelerometers (MEMs)

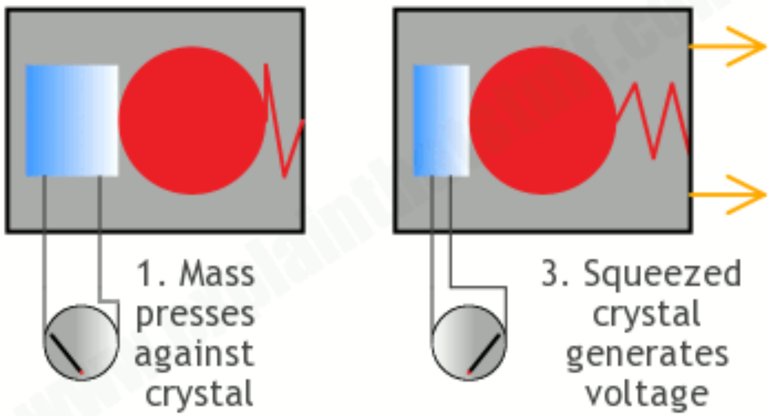


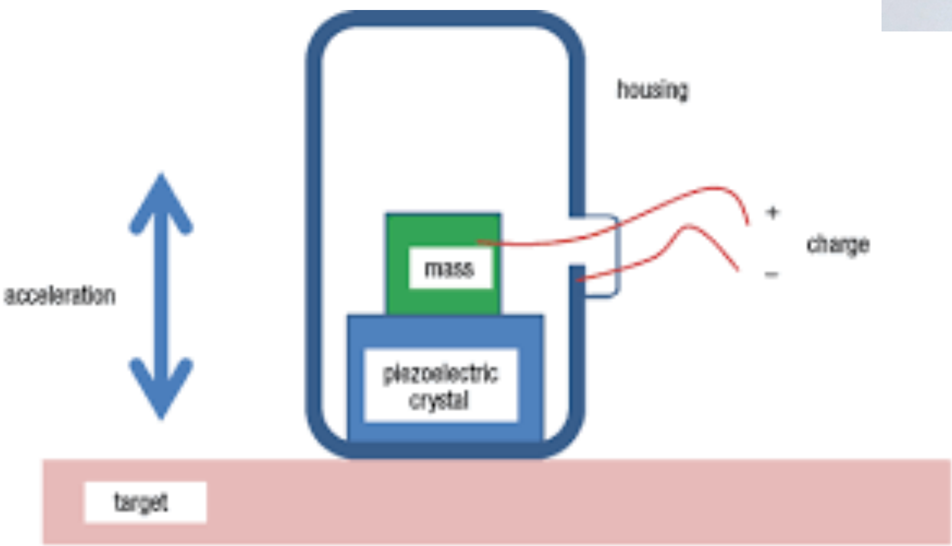




- Mechanical motion is converted into a change in capacitance
- Capacitance changes quickly with distance, resulting in an unsteady output
- Easy to make MEMS devices based on this principle
- Common uses: Airbag deployment sensors in automobiles, human computer interaction (HCI) devices and smartphones
- Need external power
- Small sizes, typically PCB surface mount

Piezoelectric Accelerometers



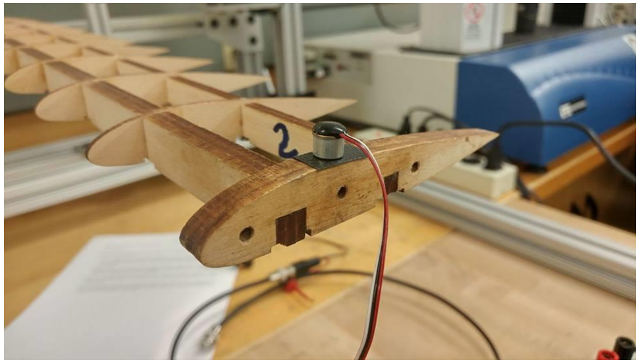


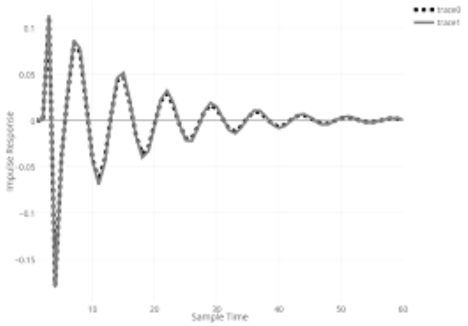
- Mechanical motion is converted into a change in capacitance
- Capacitance changes quickly with distance, resulting in an unsteady output
- Easy to make MEMS devices based on this principle
- Common uses: Engine testing, ballistics, manufacturing, aerospace (ejection, rocketry)
- No external power needed

Comparison of Use Conditions

Application	Piezoelectric	Capacitive MEMS
Static Acceleration (0 Hz, 1 g) Gravity, Sensor Orientation		✓
G- Force (0 Hz, <25 g) Rocket, Centrifugal, Aircraft		✓
Seismic (<1 Hz, <1 g) Earthquake, Waves, Bridges	✓	
Low Frequency Vibration (<5 Hz, <25 g) Human Motion, Robotics	✓	✓
General Vibration (5 Hz to 500 Hz, <25 g) Electric Motor, Car Suspension	✓	✓
High Frequency Vibration (>500 Hz, <25 g) Gear Noise Analysis, Turbine Monitoring	✓	
General Shock (<100 Hz, <200 g) General Testing, Shock Absorber Testing	✓	✓
High Impact Shock (<250 Hz, >200 g) Drop Testing	✓	

Lab 6: Impulse Response





In this lab, you will explore the dynamic response of a built-up wing. You measured the static response of this wing in Lab 3.

1. Attach the piezoelectric accelerometer (IMI 660) to the tip of the wing (use a small piece of wax). Gently tap the wing and record the output of the accelerometer over 3 seconds. Use a sampling frequency of 1 kHz. Do this for several taps so that you can average the measurements.

2. Repeat the above experiment using the MEMS accelerometer (MMA 7361L). In this case, tap the wing at an angle so that you excite both the out-of-plane and in-plane bending vibration. Measure the accelerations in both these directions.

3. Plot the measured accelerations and compare the two sensors. Use the acceleration to calculate the tip displacement as a function of time. Describe the errors inherent in these measurements.

4. Plot the power spectrum of the measured acceleration using (a) 3 seconds of data (b) the last 1 second of data. Identify the natural frequencies of the wing. What are the differences between the power spectrum of (a) and (b) ?