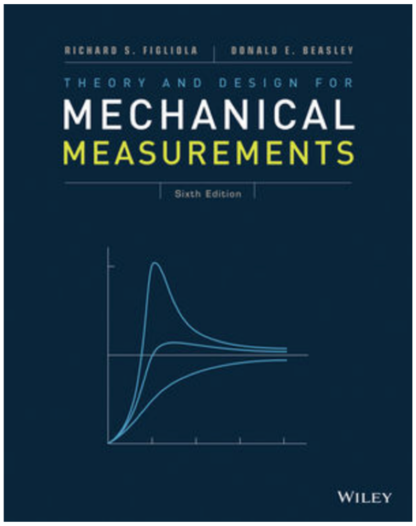


Acceleration

Engr325

Instrumentation

Dr Curtis Nelson

Accelerometers - Applications

- Automotive: monitor vehicle tilt, roll, skid, impact, vibration, for the purpose of deploying safety devices like stability control, anti-lock breaking system, airbags, and to ensure a comfortable ride (active suspension).
- Aerospace: inertial navigation, smart munitions, unmanned vehicles.
- Sports/Gaming: monitor athlete performance and injury, joystick, tilt.
- Personal electronics: cell phones, digital devices.
- Security: motion and vibration detection.
- Robotics: self-balancing.

Helmet: Impact Detection

2 axis joystick

WII Nunchuk: 3 axis accelerometer

Segway

Types of Accelerometers

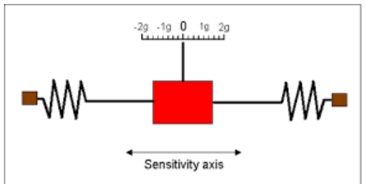
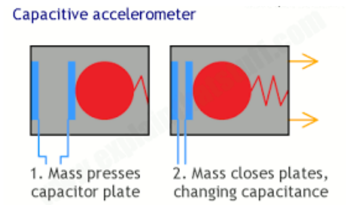
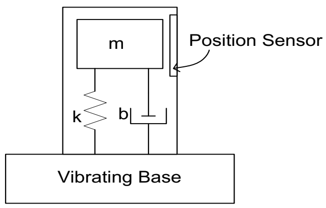
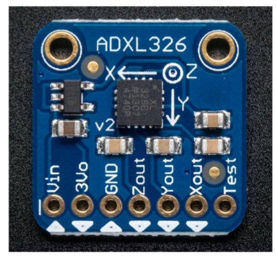


Fig. 1. Schematic structure of an accelerometer

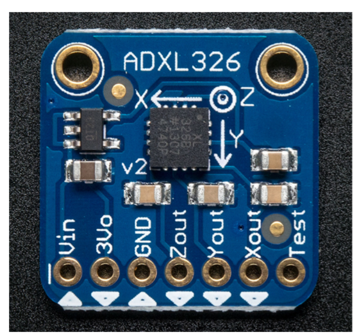






Commercial Integrated Circuit Accelerometer

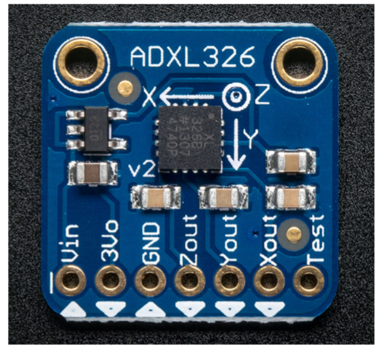
The ADXL326 is a small, low power, complete 3-axis accelerometer with signal conditioned voltage outputs. The product measures acceleration with a minimum full-scale range of $\pm 16\ g$. It can measure the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration.



The user selects the bandwidth of the accelerometer using the C_X, C_Y, and C_Z capacitors at the X_{OUT}, Y_{OUT}, and Z_{OUT} pins. Bandwidths can be selected to suit the application with a range of 0.5 Hz to 1600 Hz for X and Y axes and a range of 0.5 Hz to 550 Hz for the Z axis.

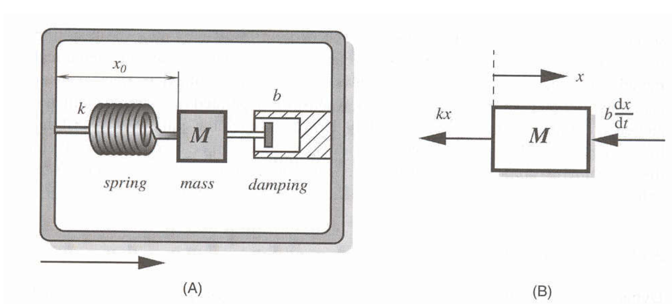
Accelerometer Board

This breakout board comes with 3 analog outputs for X, Y and Z axis measurements. The ADXL326 is the latest and greatest from Analog Devices, known for their exceptional quality MEMS (Micro-Electro-Mechanical Systems) Micro-devices. The Vin input takes up to 5V and regulates it to 3.3V. The analog outputs are ratiometric: that means that 0g measurement output is always at half of the 3.3V output (1.65V), -16g is at 0v and 16g is at 3.3V with linear scaling in between.



Accelerometers - Principles

- Methods of acceleration sensing start with the mechanical model of a spring, mass, and damper system.
- The mass moves under the influence of forces and has a restoring force (spring) and a damping force which essentially prevents it from oscillating.
- The distance between the mass and a fixed surface, which depends on acceleration, can be measured and converted to acceleration.

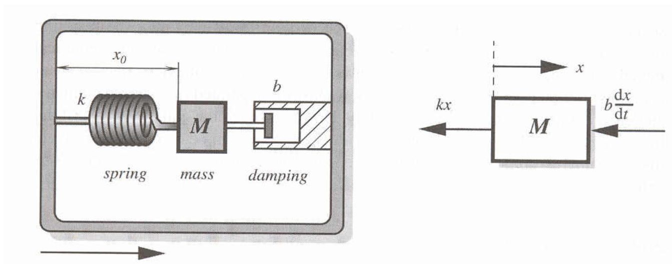


Accelerometers - Principles

- Under these conditions, and assuming the mass can only move in one direction along the horizontal axis, Newton's second law may be written as:

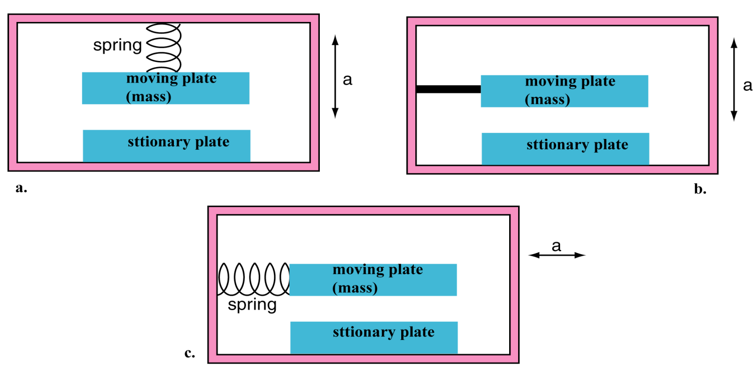
$$ma = -kx - b\frac{dx}{dt}$$

- This equation assumes that the mass has moved a distance x under the influence of acceleration, k is the restoring (spring) constant and b is the damping coefficient.
- Given the mass m and the constants k and b, a measurement of x gives an indication of the acceleration a.



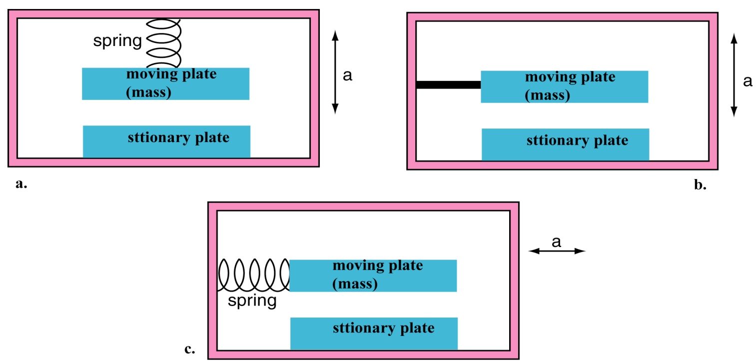
Accelerometers - Capacitive

- One plate of a small capacitor is fixed and connected physically to the body of the sensor.
- A second plate serves as the inertial mass of the sensor and is free to move, and is connected to a restoring spring.
- Three basic configurations are shown below.
- In Figures a and b, the distance between the plates change with acceleration.
- In Figure c, the effective area of the plates changes while the distance between the plates stays constant.



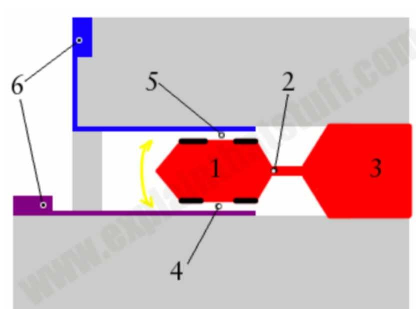
Accelerometers - Capacitive

- In either case, acceleration will either increase or decrease the capacitance, depending on the direction of motion.
- In a practical accelerator, the plates are prevented from touching by stoppers.
- Some kind of damping mechanism must be added to prevent the springs or the beam from oscillating.
- Capacitance can then be measured and is proportional to vertical acceleration:
  - Changes in capacitance are very, very small (micro, nano, or pico farads).
  - Indirect methods, such as using the capacitor in an LC oscillator are used and the frequency of oscillation is a derived measure of acceleration.



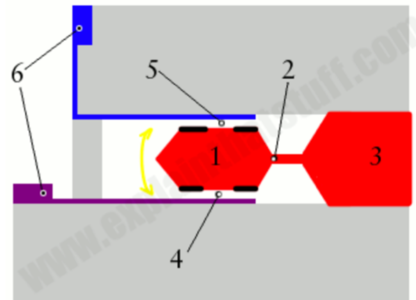
Integrated Circuit Accelerometers

1. The red electrode is an electrical terminal that has enough mass to move up and down very slightly when you move or tilt the accelerometer.
2. The electrode is supported by a tiny cantilever beam that's rigid enough to hold it but flexible enough to allow it to move.
3. There's an electrical connection from the cantilever and electrode to the outside of the integrated circuit so the signal can be measured and analyzed.



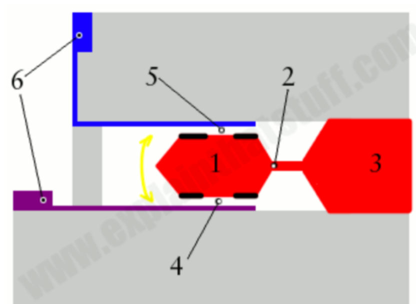
Integrated Circuit Accelerometers

4. Below the red electrode, and separated from it by an air gap, is a second purple electrode. The air gap between the two electrodes means the red and purple electrodes work together as a capacitor. As you move the accelerometer and the red electrode moves up and down, the distance between the red and purple electrodes changes, and so does the capacitance between them. We're talking about extremely tiny distances here of a few millionths of a meter (µm), or less. Small bits of insulation, shown as black lines, prevent the red electrode from making direct electrical contact with the purple line.



Integrated Circuit Accelerometers

5. In exactly the same way, there's a blue electrode above the red electrode and another air gap making a second capacitor. As before, the distance between the blue and red electrodes (and the capacitance between them) changes as you move the accelerometer.
6. The electrodes are connected to electrical terminals at the edges of the integrated circuit so the signal can be measured and analyzed.



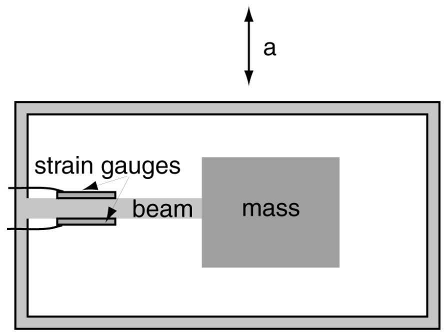
$$C = \varepsilon_r \varepsilon_0 \frac{A}{d}$$

where

C is the capacitance, in farads;
A is the area of overlap of the two plates, in square meters;
ε_r is the relative static permittivity (sometimes called the dielectric constant) of the material between the plates (for a vacuum, $\varepsilon_r = 1$);
ε_0 is the electric constant ($\varepsilon_0 \approx 8.854 \times 10^{-12}$ F·m^{-1}); and
d is the separation between the plates, in meters;

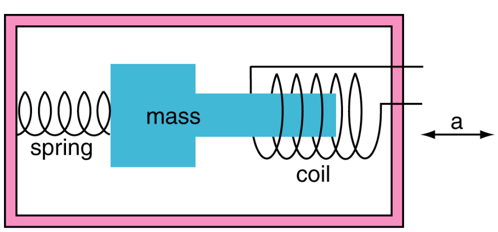
Strain Gauge Accelerometers

- The mass is suspended on a cantilever beam.
- A strain gauge senses the bending of the beam.



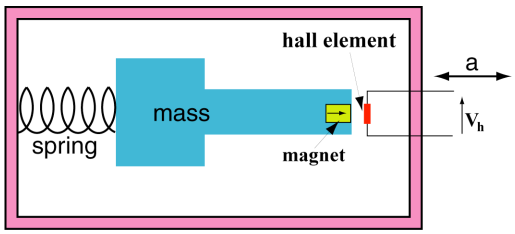
Variable Inductance Accelerometers

- A mass is attached to a spring and oscillates inside a coil. The inductance of the coil is proportional to the position of the mass.
- An LVDT (Linear-Variable-Differential-Transformer) is used as an inductor.
- A circuit is then constructed to calculate the acceleration based on the change in inductance.



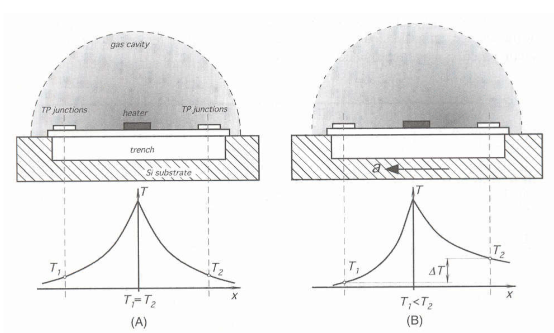
Hall-Effect Magnetic Accelerometers

- Acceleration changes distance to hall element.
- Hall element output is calibrated to calculate acceleration.



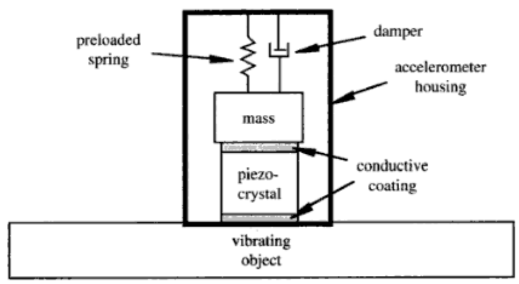
The Heated Gas Accelerometer

- Gas in a cavity is heated to an equilibrium temperature.
- Two (or more) thermocouples are provided equidistant from the heater.
- Under rest conditions, the two thermocouples are at the same temperature. One thermocouple is the sense thermocouple, the second is the reference thermocouple.
- Under acceleration, the gas shifts to the direction opposite the motion (the gas is the inertial mass) causing a temperature gradient which is calibrated in terms of acceleration.



Piezo- Accelerometers

- Piezoelectric accelerometers - a microscopic crystal structure is mounted on a mass undergoing acceleration; the piezo crystal is stressed by acceleration forces thus producing a voltage.
- Piezoresistive accelerometer - consists of a beam or micro-machined feature whose resistance changes with acceleration.



Accelerometers - Summary

- Mechanisms
  - Spring, mass, damper
  - Capacitive
    - Integrated Circuits
    - MEMS (Micro-Electro-Mechanical Systems)
  - Strain gauge
  - Variable inductance
  - Hall effect
  - Piezoelectric
  - Piezoresistive
  - Heated gas