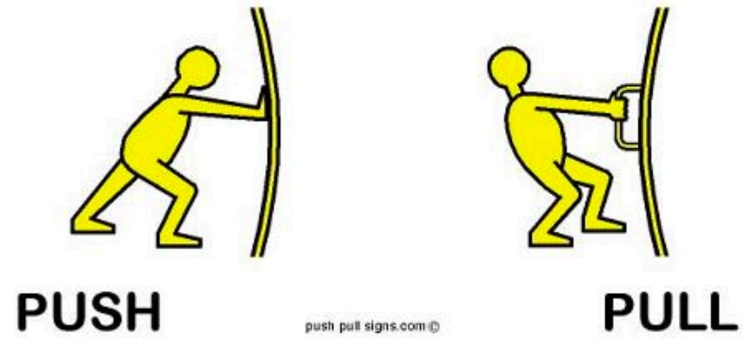
ROCO222: Intro to sensors and actuators

Lecture 1

Measuring force

Definition of force



- A push or a pull
- The ability to do work

- Is is a vector quantity
- Has magnitude and direction

- Measured in Newtons (N)

- **Newton's Second Law**
- A force acting on a mass will accelerate or decelerate it
- $F = ma$

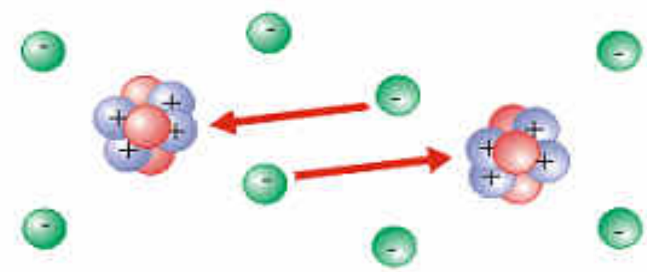
where F is Force (N), m is mass (Kg), a is acceleration (ms^{-2})

Four fundamental forces in nature

1. Gravity
Dominates at large distances

2. Electromagnetic forces

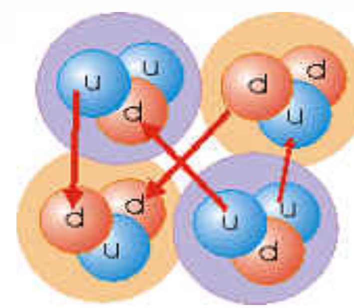
Observed in the interactions between atoms



3 . & 4. Nuclear forces

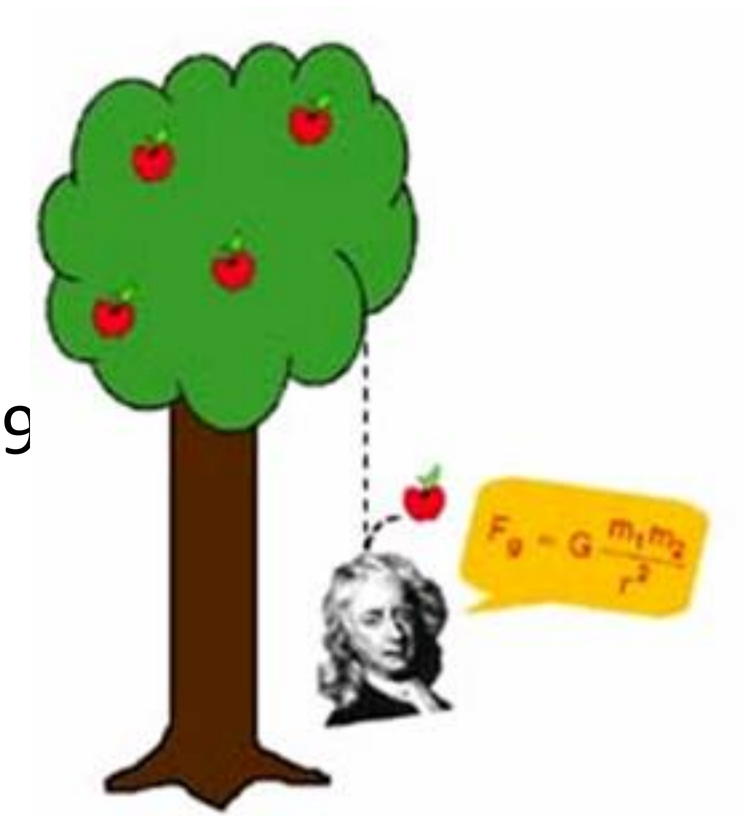
Strong & weak

Both very short range



Force arises from gravity acting on a mass

- Force arises from gravity acting on a mass
- $F = mg$
  - where F is Force (N),
  - m is mass (Kg),
  - g is acceleration due to gravity ≈ 9



Measuring force by balancing known force

- Use gravity acting on a known mass as source of known force

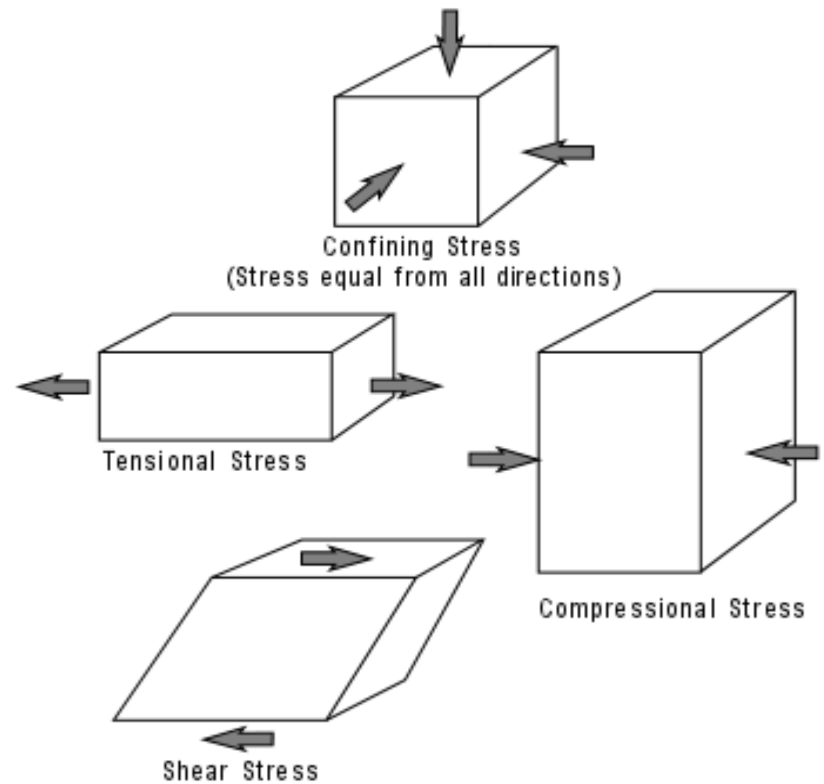
- Search for equilibrium position to find gravitational mass of test object

Measuring force by measuring strain

- Stress defined as "force per area"
- Strain is defined as: "deformation of a solid due to stress”
- When we apply force
- Induced **stress** results in a **strain**

$E = stress\ /\ strain = (F\ /\ \mathrm{A}_0)\ /\ (\Delta \mathrm{L}\ /\ \mathrm{L}_0)$

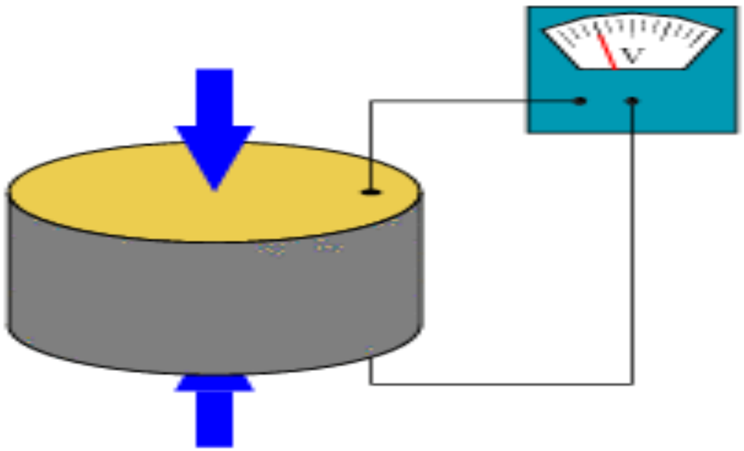
Where
E is the Young's modulus (modulus of elasticity)
F is the force exerted on an object under tension
A_0 is the cross-sectional area
ΔL is the amount by which object length changes
L_0 is the original length of the object

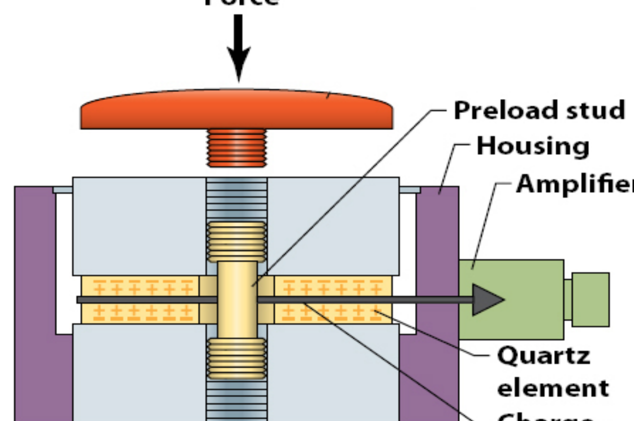


- By measuring strain of a material of known properties can estimate force

Piezo-electric effect

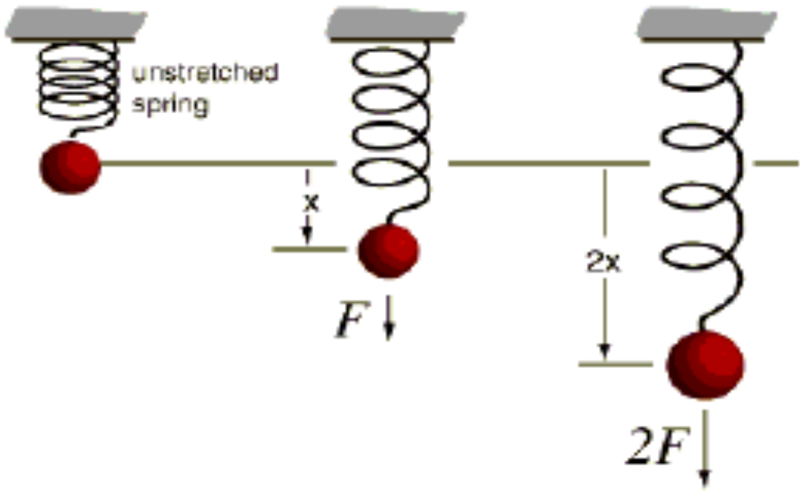
- Some materials generate electric charge under mechanical stress



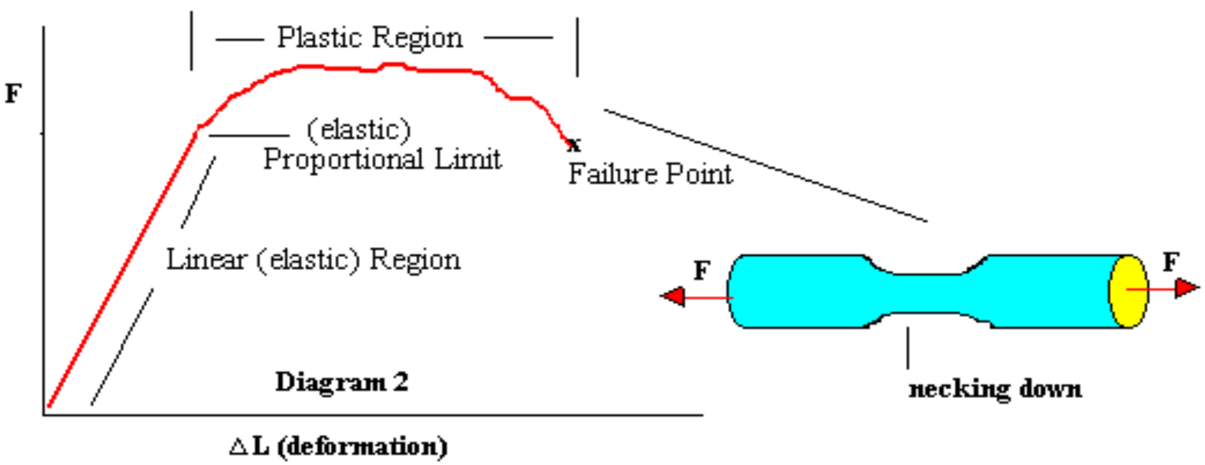


- Force results in a separation of charges with in structure
- Capacitive effect generates output voltage.
- Leakage causes charge dissipation and voltage decay over time
- Suitable for dynamic measurements

Measurement of elastic deformation



Hooke’s law: $F = -kx$



Hooke’s law only holds over the elastic region

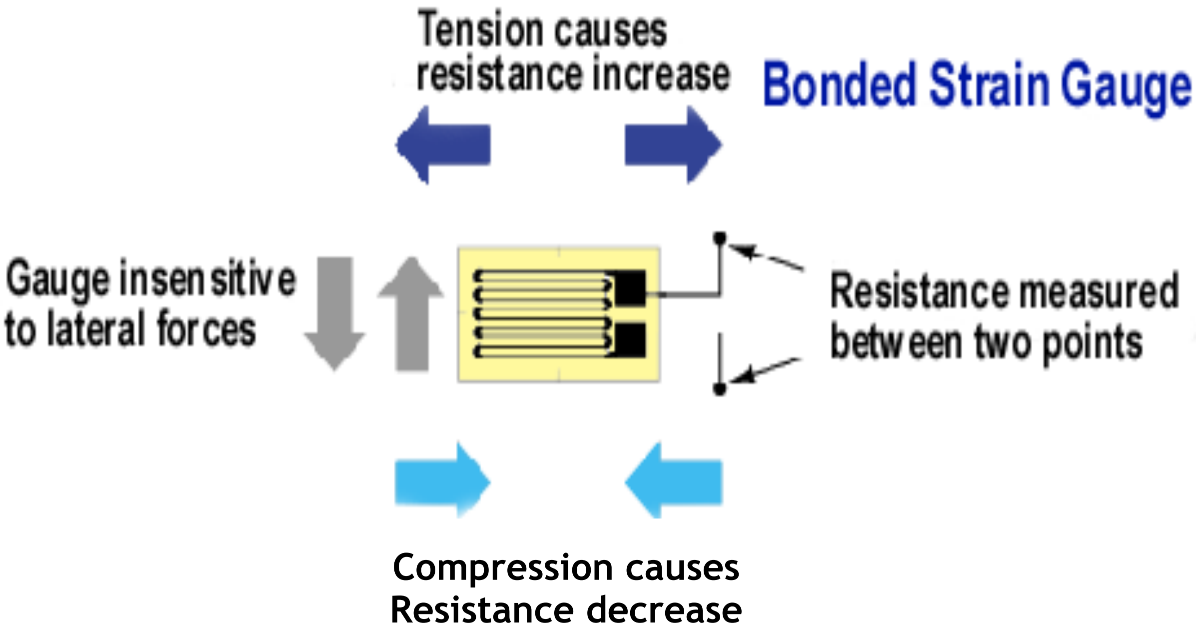
Direct measurement of elastic deformation

Can simply observe extension to estimate force

+

Other mechanical methods
Proving ring - Displacement measured directly using micrometer or dial gauge

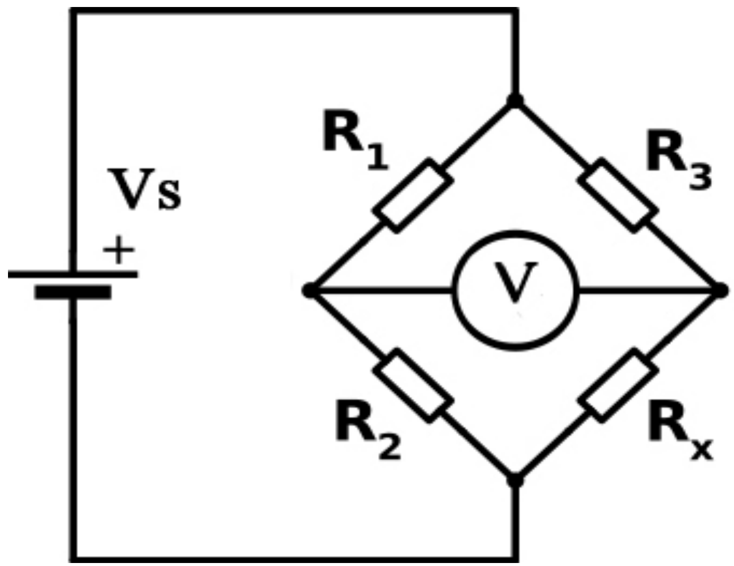
Strain gauge



- This is an electrical method of force measurement
- The gauge measures strain of substrate to which it is attached
- Provided substrate load operated in elastic region of the material, this is linearly relates to the applied force by Young's modulus

- Strain gauge measures strain because when film stretches it becomes narrower and longer and this increases its resistance
- Gauge is much more sensitive to strain is direction along the longer thin regions
- Overall during use such a sensor delivers only a fraction of percent change in resistance
- Resistance change is usually measured using a Wheatstone bridge

Wheatstone bridge circuit



$$I_{LeftBranch} = \frac{V_s}{R_1 + R_2}$$

$$V_{R2} = \frac{V_s R_2}{R_1 + R_2}$$

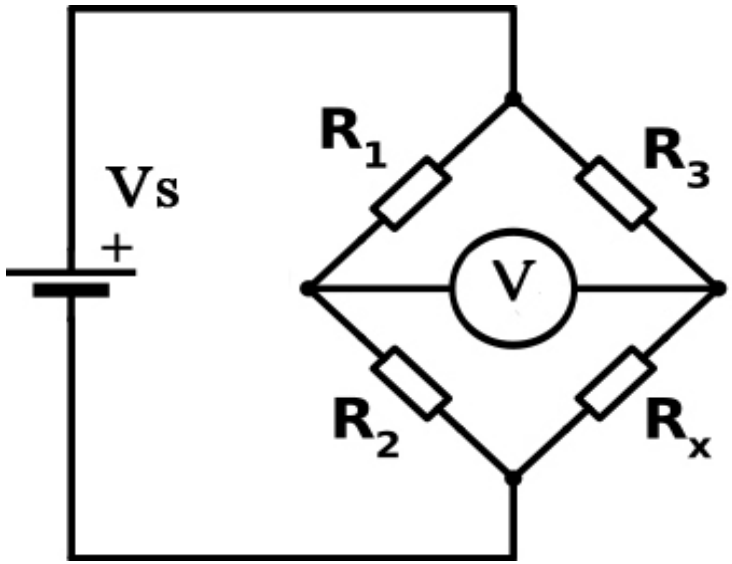
$$I_{RightBranch} = \frac{V_s}{R_3 + R_x}$$

$$V_{Rx} = \frac{V_s R_x}{R_3 + R_x}$$

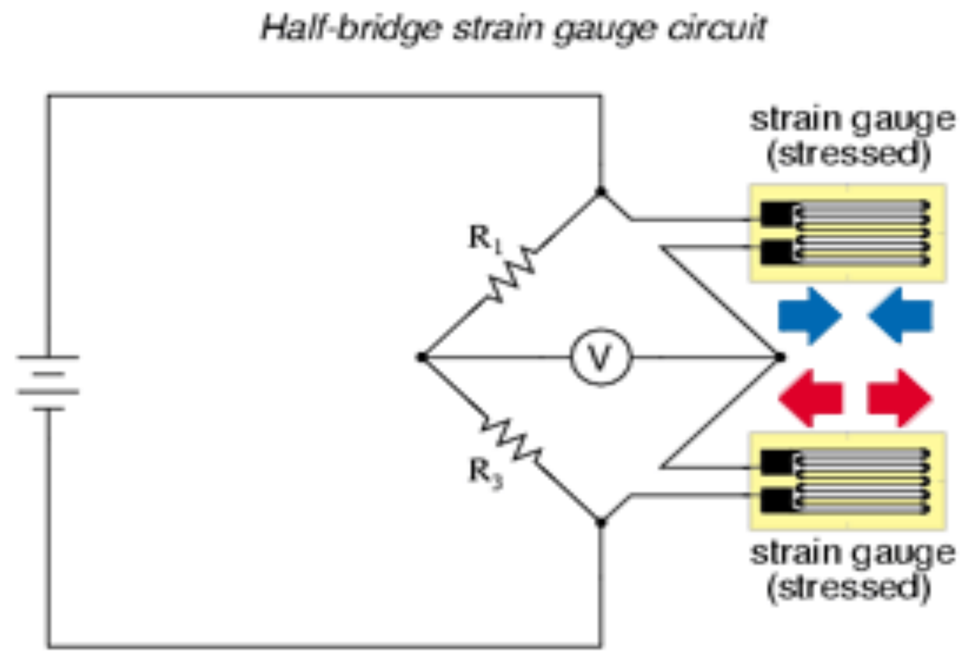
- Wheatstone bridge converts change in resistance to change in voltage

$$V = \left(\frac{R_x}{R_3 + R_x} - \frac{R_2}{R_1 + R_2} \right) V_s$$

Wheatstone bridge circuit



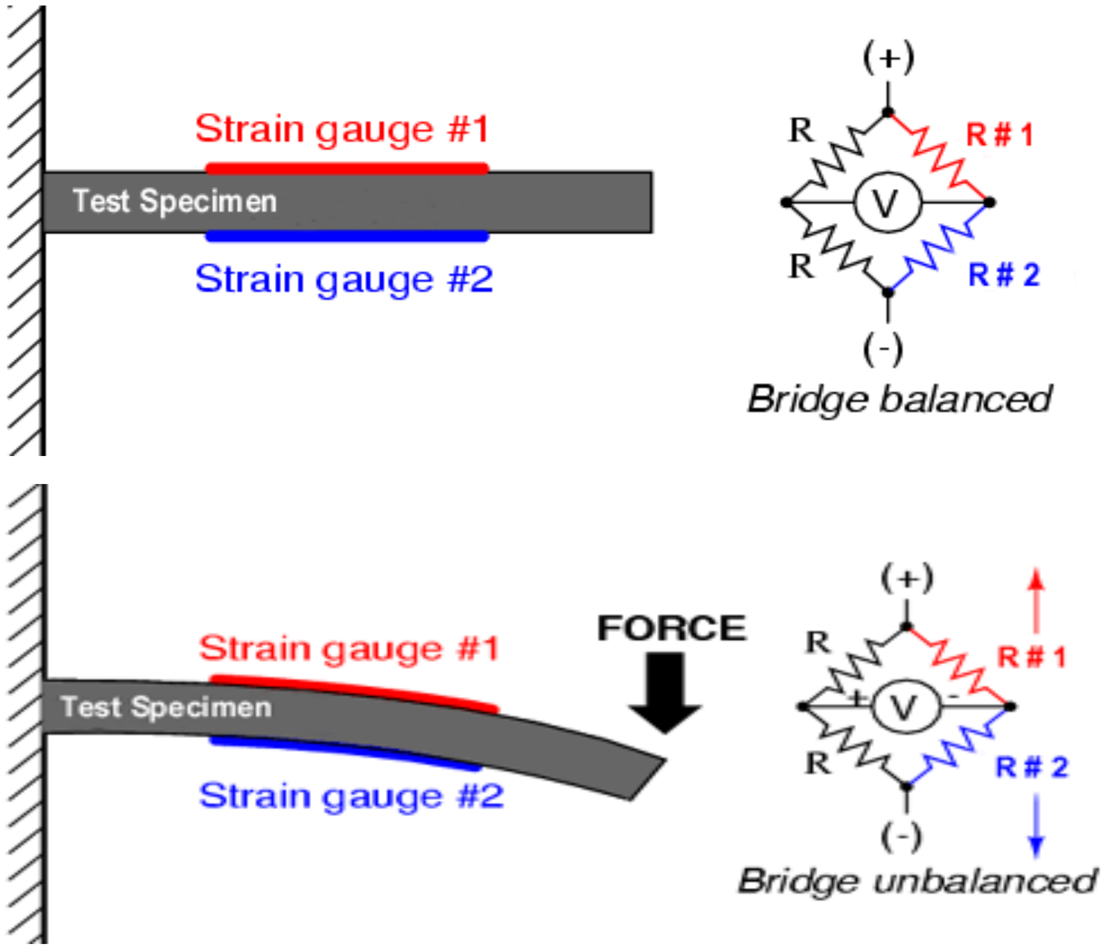
$$V = \left(\frac{R_x}{R_3 + R_x} - \frac{R_2}{R_1 + R_2}\right) V_s$$



- By placing strain gauges into the bridge, changes in their resistance resulting from the strain in the substrate gives rise to changes in voltage that can be measured

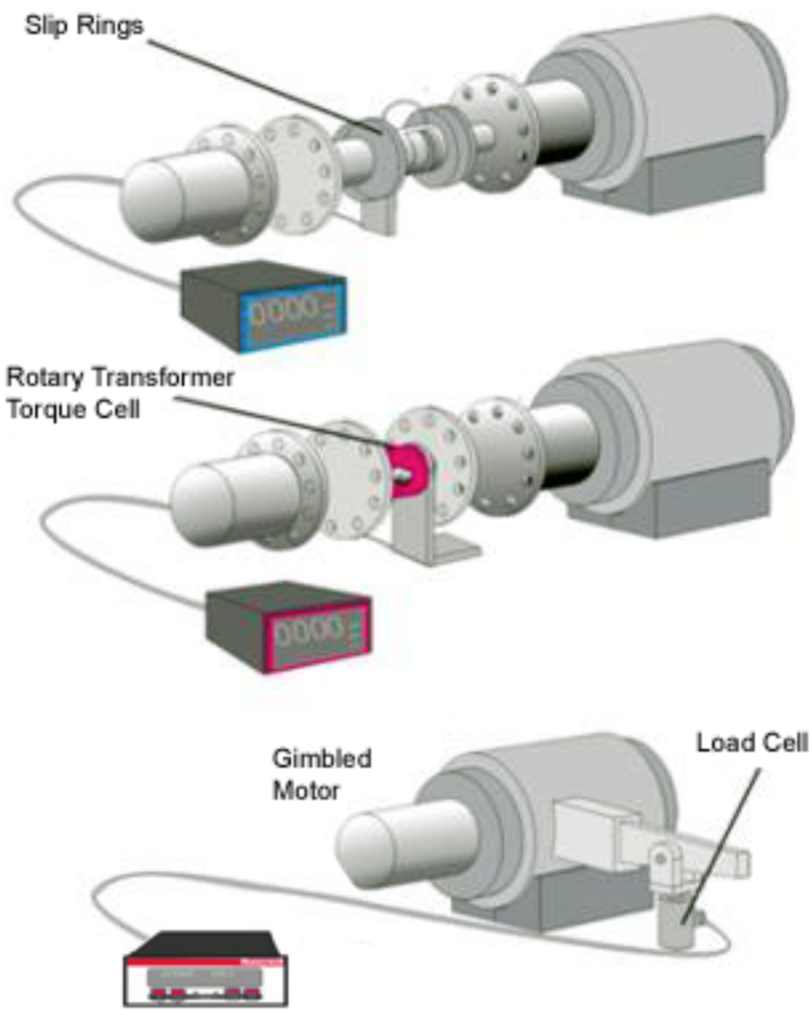
- Bridge arrangement cancels out changes that occur in all the resistive elements
- This compensates for resistance changes due to changes on temperature and also for strains in unwanted directions

Simple cantilever load cell



- If gauges are centrally mounted then
- no change in output voltage due to a side load

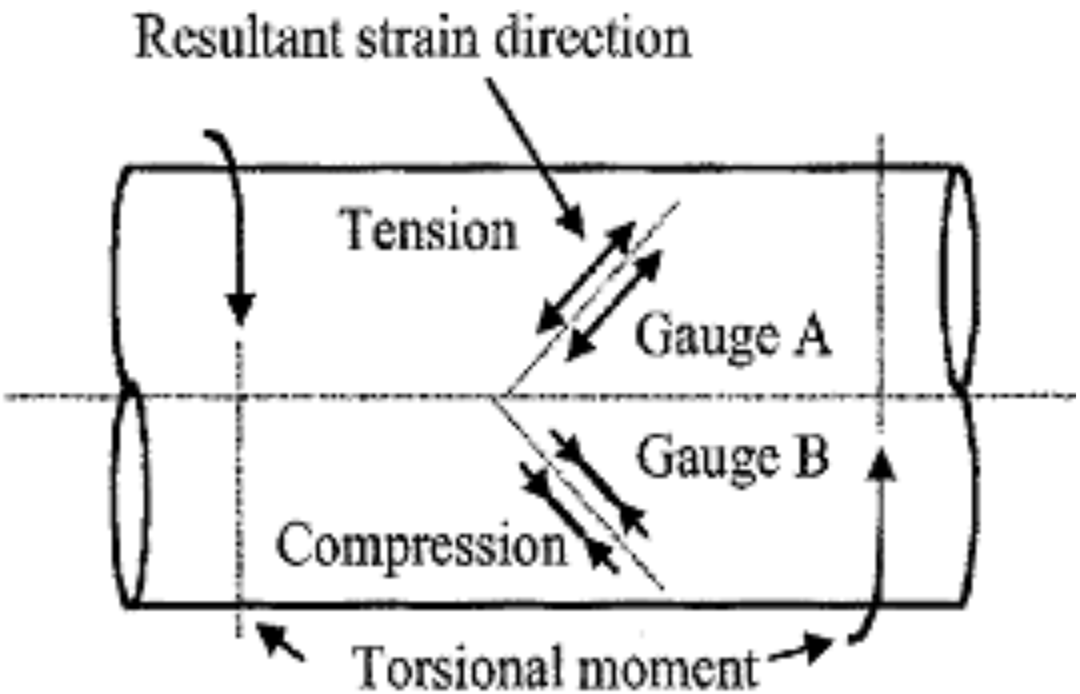
Measuring torque



- Two common ways to obtain torque measurements are by strain-gauging the shaft and by using in-line torque cells.

- Both have two technical obstacles: getting power to the gauges over the stationary/rotating gap and getting the signal back.

Measuring torque using gauge on shaft



- The gauges lie perpendicular to one another at 45 deg to the plane about which the tensional moment is applied.

1- 6 DOF load cells

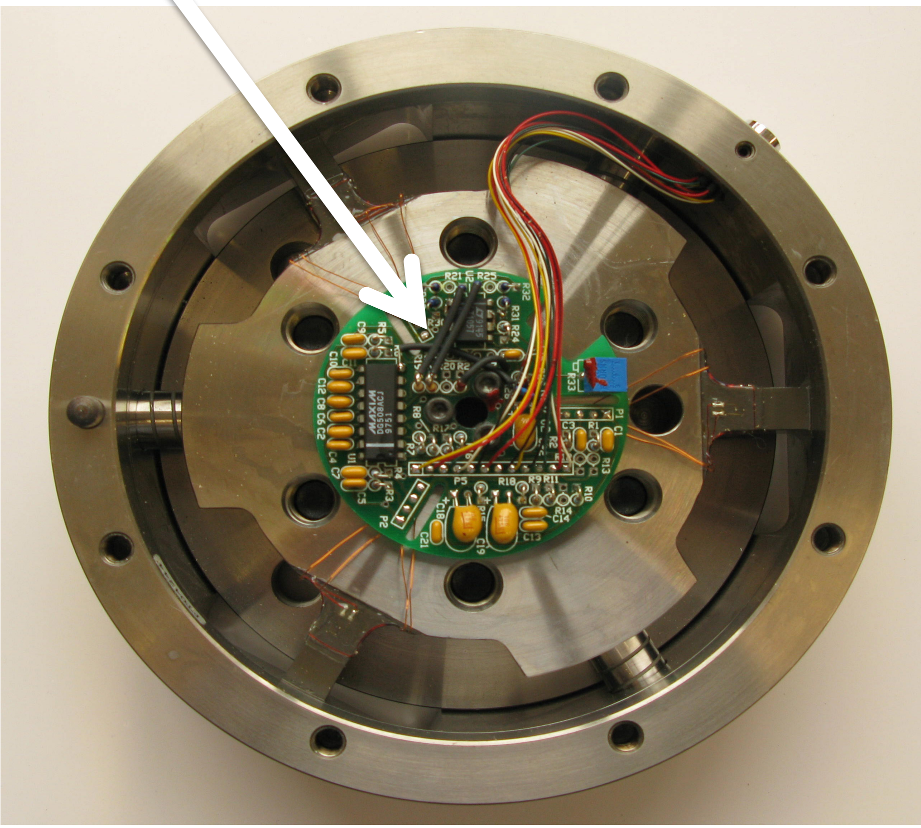
1 translational DOF

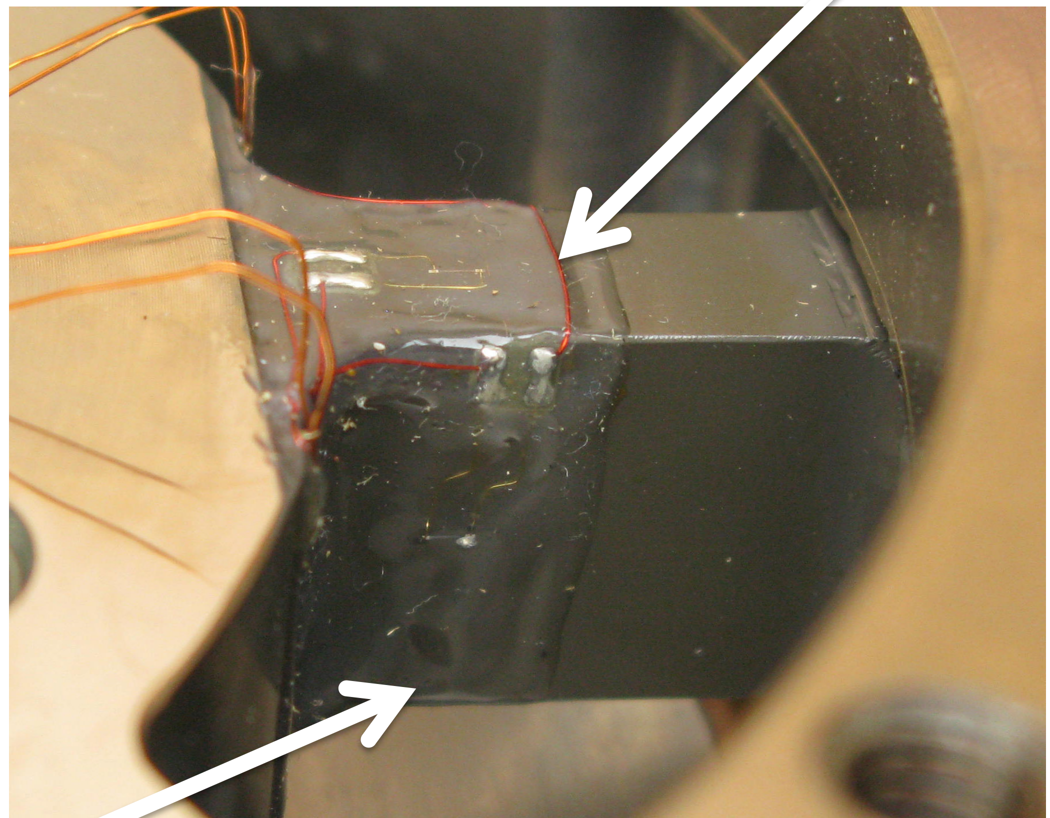
3 translational & 3 rotational DOFs

Inside a large 6DOF FT

Signal conditioning circuitry

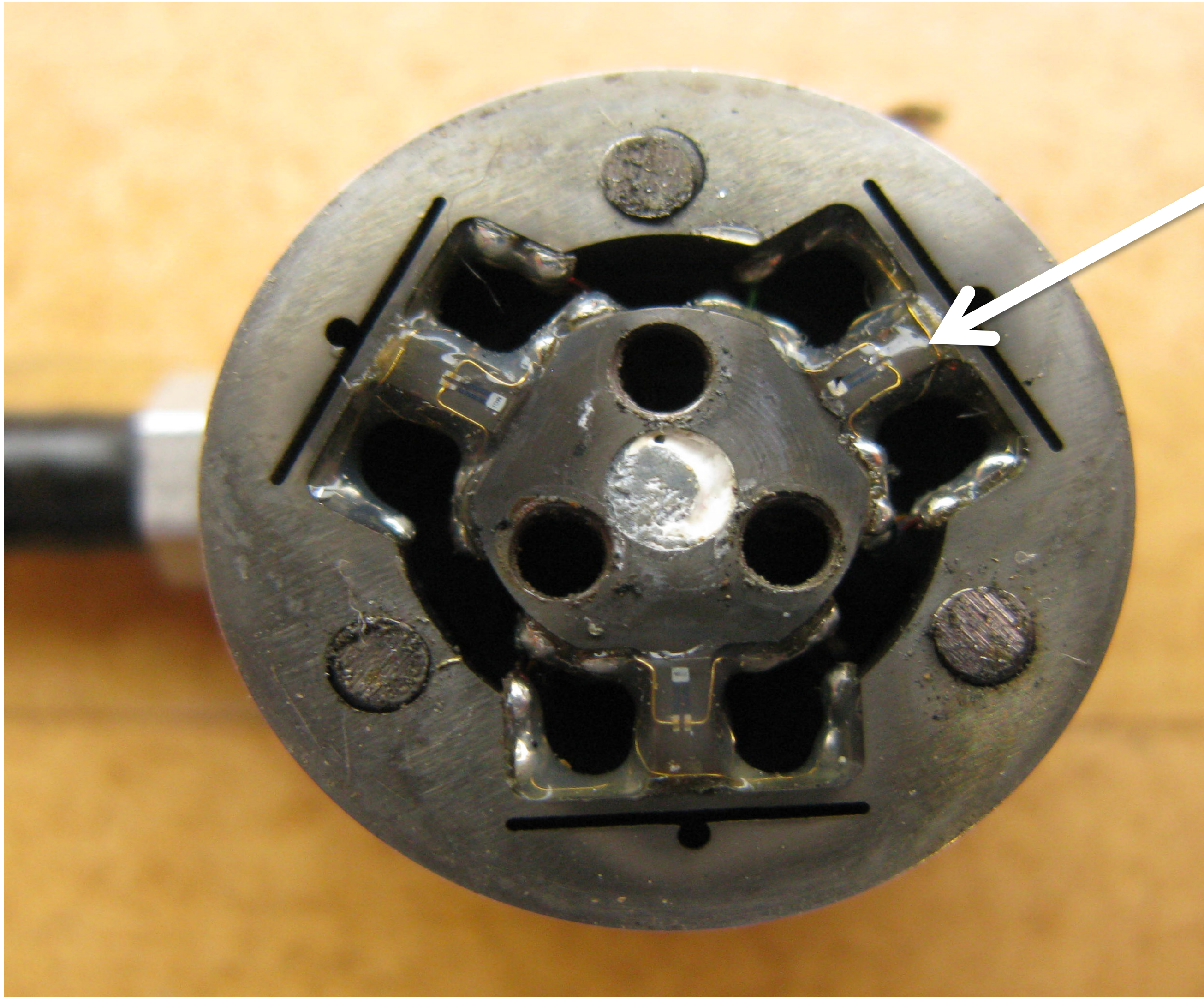
Silicon strain gauges





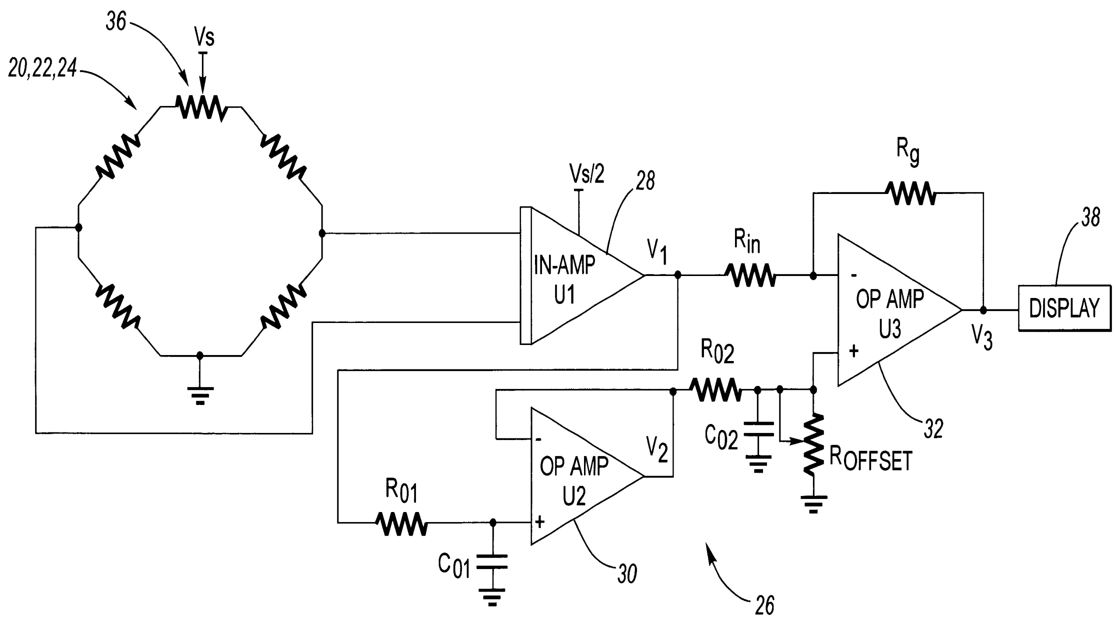
Massive structure which deforms under stress

Inside a small 6DOF FT



Silicon strain gauges

A signal conditioning amplifier is needed



- The amplifier needed because voltage changes generates by Wheatstone bridge are small
- Need differential input to cancel interference
- Also it can filter unwanted signal outside the bandwidth of interest