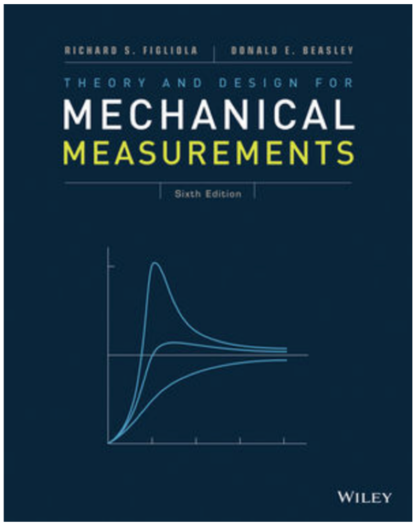


Strain Measuremment

Engr325

Instrumentation

Dr. Curtis Nelson

Applications

[Strain guage overview from Omega Corporation]

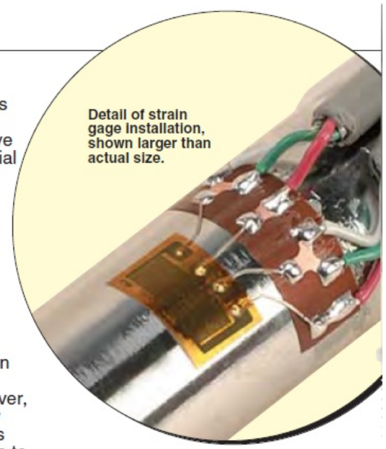
Applications

PIPE PRESSURE APPLICATIONS

Pressure application, using a ½ male NPT by 101.6 mm (4"), chrome plated brass pipe nipple. Application used a tee rosette. One carrier piece has 2 electrically independent strain gages which are perpendicular to each other. The installation will have two separate strain gages, to measure hoop and axial strain, here wired using three-wire method. This method compensates for the effect of temperature on thelead wires.

Strain Gage: SGT-4/350-XY13, page 36
Bondable Terminal Pad: BTPC-4, page 66
Adhesive: SG496, page 71
Cable: TX4-100, page 73

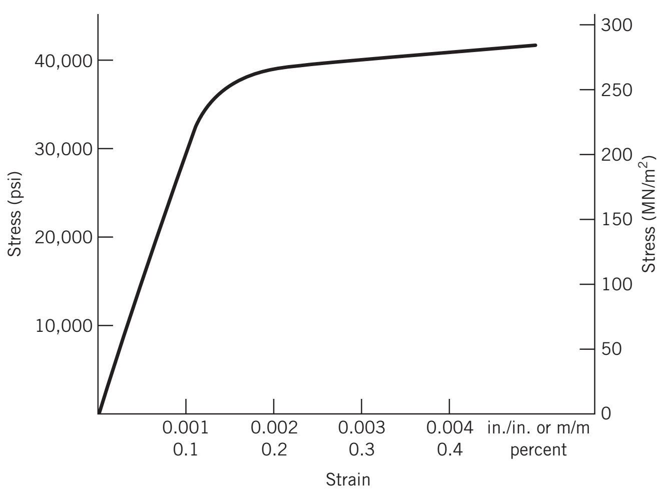
Installation using standard surface preparation per page 70. The strain gage selected has temperature characteristics matched to aluminum, and has ribbon leads. The bondable terminal pad has been placed close by, and the ribbon leads have been brought over, leaving small flex loops, and soldered in place. Any excess lead has been trimmed away. TX4 cable has been used, and 3-leads have been soldered in place to bring the two ¼ bridge strain gages out to instrumentation. The BCM-1 page 74 can be used to complete the Wheatstone bridge.



Chrome plated brass pipe with SGT-4/350-XY13, strain gage, $49 per pack of 5, shown actual si

Stress vs. Strain

- A typical stress-strain curve for mild steel.

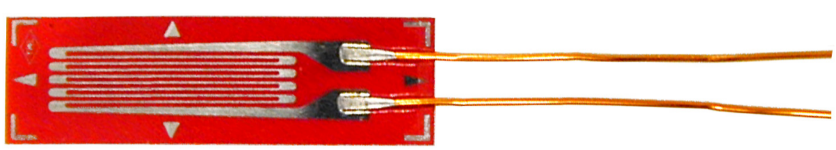


Stress vs. Strain

- When a force is applied to a structure, the components of the structure change slightly in their dimensions and are said to be strained. Devices that measure these small changes in dimensions are called **strain gauges**.
- Strain (ε) is a measure of displacement, usually in terms of micro-strain such as micro-inches of elongation for each inch of specimen length.
- Stress (σ) is a measure of loading in terms of load per unit cross-sectional area.
- Using Hooke's Law, stress and strain are related by a material property known as the Young's modulus, or modulus of elasticity, E:

$$\sigma = \varepsilon E$$

Measuring Strain



Strain has units of inches per inch or millimeters per millimeter and hence is dimensionless. In most structures, the values of strain are usually very small. For example, a low-strength steel will yield (take a permanent deformation) at a strain of only about 0.0014. As a result, it is common to talk about strain in units of micro-strain. Thus, a strain of 1400 μstrain is an actual strain of 0.0014

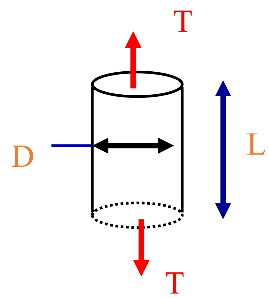
Types of Strain

Strain is defined as relative elongation in a particular direction.

e_a= dL/L (axial strain)

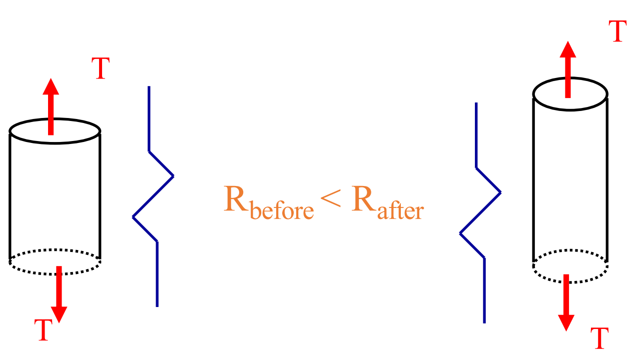
e_t= dD/D (transverse strain)

u = e_t / e_a (Poisson's ratio)



How Strain Gauges Work

The electrical resistance of a conductor changes when it is subjected to a mechanical deformation.



Strain Gauge Resistance Changes

R= r* L/A

- Electrical Resistance (R) is a function of:

  r   the resistivity of the material (Ohms·m)
  L   the length of the conductor (m)
  A   the cross-sectional area of the conductor (m^2)

- R increases with:
  - Increased material resistivity.
  - Increased length of conductor.
  - Decreased cross-sectional area.
  - Increased temperatures (can bias results if not accounted for).

Gauge Factor (GF) - Summary

- **Gauge factor** (GF) is the ratio of relative change in electrical resistance R, to the mechanical strain ε_a:

$$\varepsilon_a = \frac{1}{GF}\frac{\Delta R}{R}$$

- It is also calculated using Poisson's ratio μ

$$GF = 1 + 2\mu$$

- GF is a number provided to you by those who manufacturer strain gauges.

Strain Gauges

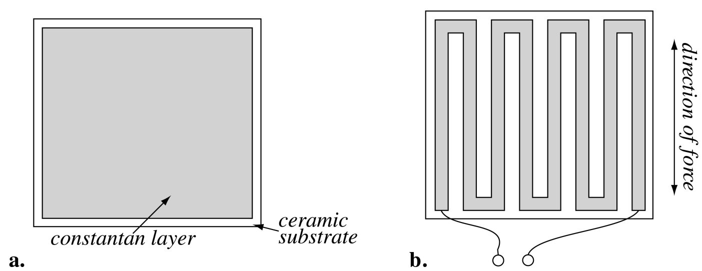
- Strain gauges come in many forms and types.
- Any material, combination of materials, or physical configuration that changes its resistance due to strain constitutes a strain gauge.
- We will restrict our discussion to two types that account for most of the strain gauges in use today:
  - Wire (or metal) strain gauges – resistive.
  - Semiconductor strain gauges.

Common Strain Gauge Materials

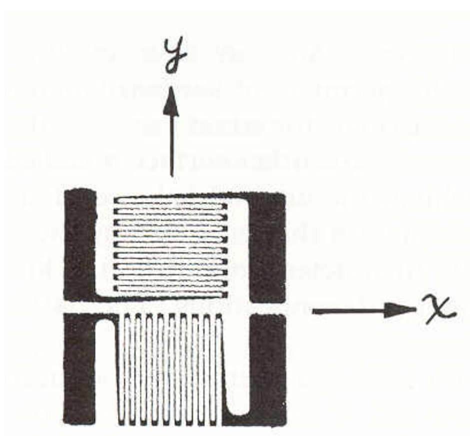
Grid Material	Composition	Appprox. Gage Factor, F	Approximate Resistivity Micro-ohm · cm	Approximate Resistivity Ohms per mil · foot	Approximate Temperature Coefficient of Resistance, ppm/°C	Maximum Operating Temp., °C (approx.)
Nichrome V*	80% Ni; 20% Cr	2.0	108	650	400	1100
Constantan*, Copel*, Advance*	45% Ni; 55% Cu	2.0	49	290	11	480
Isoelastic*	36% Ni; 8% Cr; 0.5% Mo; Fe remainder	3.5	112	680	470	—
Karma*	74% Ni; 20% Cr; 3% Al; 3% Fe	2.4	130	800	18	815
Manganin*	4% Ni; 12% Mn; 84% Cu	0.47	48	260	11	—
Platinum-Iridium	95% Pt; 5% Ir	5.1	24	137	1250	1100
Monel*	67% Ni; 33% Cu	1.9	42	240	2000	—
Nickel		-12†	7.8	45	6000	—
Platinum		4.8	10	60	3000	—

Resistive Strain Gauges

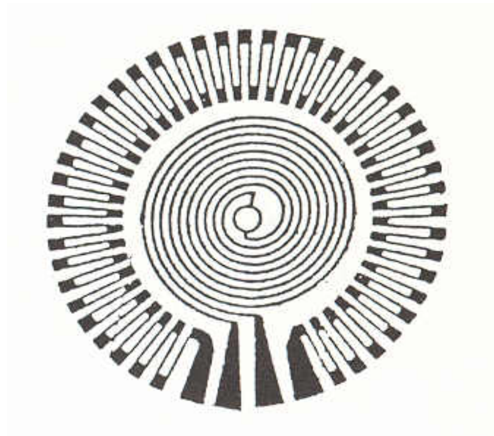
- Built out of a thin layer of conducting material.
- Deposited on an insulating substrate (plastic, ceramic, etc.).
- Etched to form a long, meandering wire.
- Constantan (60% copper, 40% nickel) is the most common material.
- Negligible temperature coefficient of resistance.



Two-Axis Strain Gauge

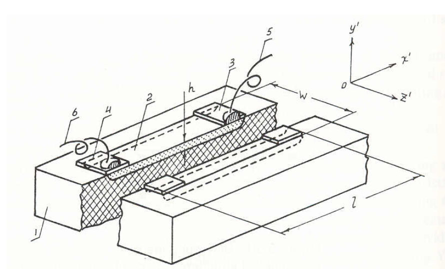


Membrane Rosette Strain Gauge



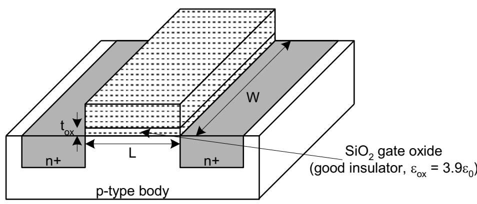
Semiconductor Strain Gauges

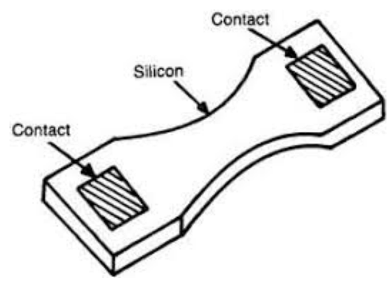
- Operate like resistive strain gauges.
- Construction and properties are different.
- The gauge factor for semiconductors is much higher than for metals.
- Semiconductor strain gauges are much smaller than metal types.
- Often more sensitive to temperature variations, requiring temperature compensation.



Semiconductor Strain Gauges

- The most common material is silicon because of its inert properties and ease of production.
- The substrate provides the means of straining the silicon chip and connections are provided by deposition of metal at the ends of the device.
- One of the important differences between conductor and semiconductor strain gauges is that semiconductor strain gauges are essentially nonlinear devices with a quadratic transfer function.



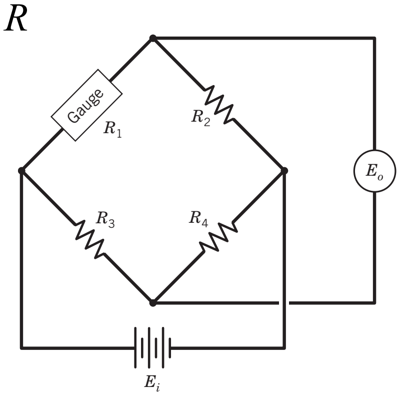


Measuring Strain With a Wheatstone Bridge

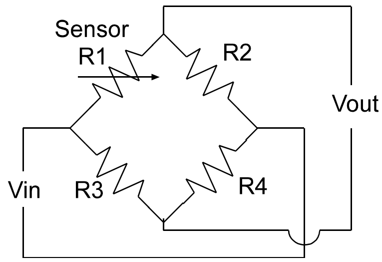
- The **Wheatstone Bridge Circuit** is a means of transforming resistance change to voltage change. This will give us the strain calculated directly from:

$$\varepsilon_a = \frac{1}{GF}\frac{\Delta R}{R}$$

- When the bridge is balanced, $E_0 = 0$



Wheatstone Bridge Circuit



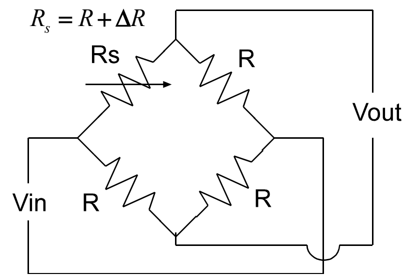
$$V_{out} = \left(\frac{R_2}{R_1 + R_2} - \frac{R_4}{R_3 + R_4} \right) V_{in}$$

$$V_{out} = \left(\frac{R}{R + (R + \Delta R)} - \frac{R}{2R} \right) V_{in} =$$

$$\left(\frac{R}{2R + \Delta R} - \frac{1}{2} \right) V_{in} = \left(\frac{R}{2R + \Delta R} - \frac{(R + \frac{\Delta R}{2})}{2(R + \frac{\Delta R}{2})} \right) V_{in}$$

Common configuration.

$R_s = R + \Delta R$

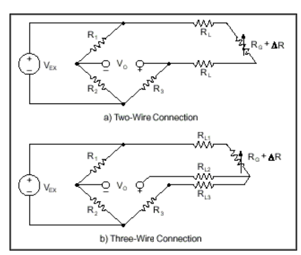


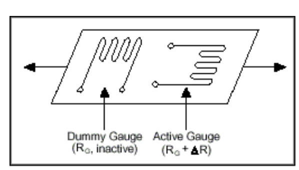
$$V_{out} = \left(\frac{-\Delta R / 2}{2R + \Delta R} \right) V_{in}$$

Temperature in-sensitive.

Strain Gauge Bridge Enhancements

- 3-wire configuration addresses lead wire resistance issues.
- Half-bridge configuration – with a dummy gauge mounted transversely addresses gauge sensitivity to surface temperature.





Loaded Cantilever Beam Example

You must either know the load P or the displacement, v(x).

Determine displacement (v) at x = a

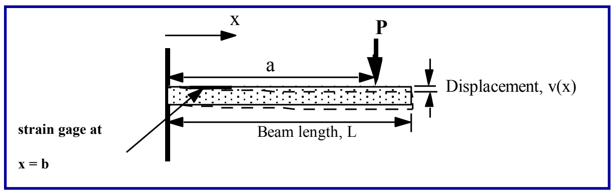
Knowing beam dimensions and material (and hence EI) estimate the load.

$$v = \frac{-Px^2(3a-x)}{6EI}, \text{so} \quad P = 3\frac{vEI}{a^3}$$

Calculate stress at location of gauge

$$\sigma = \frac{My}{I} = \frac{P*b*h/2}{I} \text{, where h = beam thickness}$$

Calculate e from s = eE



Cantilever Beam Application

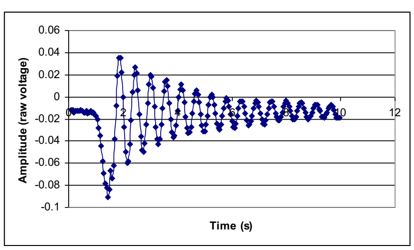
- When the cantilever beam is "plucked" it will respond as a damped 2nd order system. The amplitude of vibration has the general form:

$$Y(t) = Ce^{-\zeta\omega_n t}\sin(\omega_d t)$$

- Where the damped frequency (what you measure) is related to the natural frequency (w_n) by:

$$\omega_d = \omega_n\sqrt{1-\zeta^2}$$

- The damping ratio (zeta) can be determined by curve-fitting the plot.

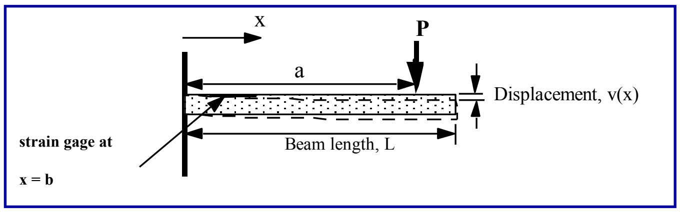


Natural Frequency of Plucked Beams

The natural frequency of a uniform beam is given by:

$$\omega_n = (1.875)^2 \sqrt{\frac{EI}{m' L^4}}$$

E is the modulus of elasticity, I is the moment of inertia about the centroid of the beam cross-section ($bh^3/12$), m' is the mass per unit length of the beam (ie kg/m), and L is the cantilevered beam length.



Summary

- Stress and strain are related through **Hooke's law**.
- Axial and transverse strain are related by **Poisson's ratio**.
- **Gauge factor** (GF) is the ratio of relative change in electrical resistance, R, to the mechanical strain ε.
- Looked at resistive and semiconductor strain gauges.
- Wheatstone bridges are used for converting strain to voltage.
- Temperature compensation.