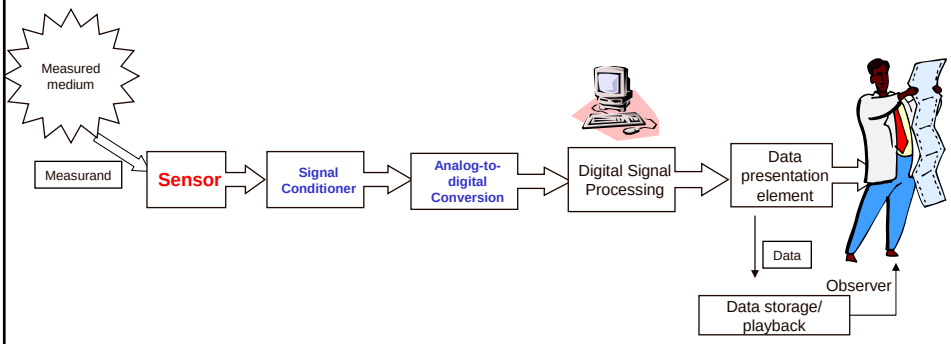
Lecture 12 & 13

Strain Sensor and Wheatstone Bridge

Announcements

- Reading assignment: p425-p437, p200-207, P441-443, P288-292

Elements of a measurement system

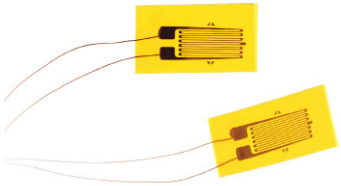


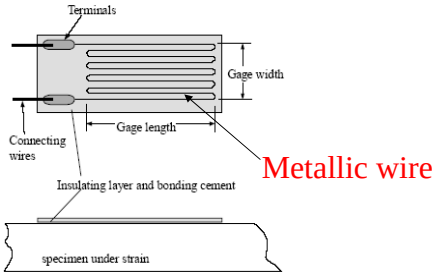
Strain Sensor

- Stress evaluation provides the fundamental understanding of the behavior of load-carrying components
- Experimental measurements are required to verify mechanical design
- Stress can only be measured *indirectly* from strain measurement $\sigma_a = E_m \varepsilon_a$
- Strain definition: $\varepsilon_a = \delta L/L$, $\varepsilon_L = -\upsilon_p \varepsilon_a$
- Most common strain sensor – Metallic resistance strain gauge

Requirements for Strain Sensor

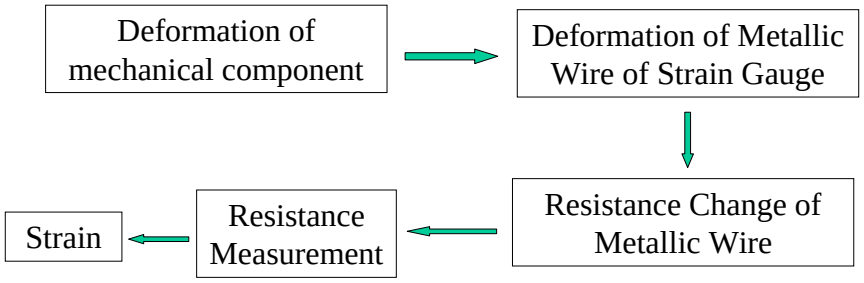
- Good spatial resolution
- Unaffected by changes in ambient conditions (temperature, pressure, etc.)
- High-frequency response for dynamic strain measurement





Working Principle of Resistance Strain Gauge

- **Measure resistance change of a metallic wire**



What is the relationship between strain and resistance change?

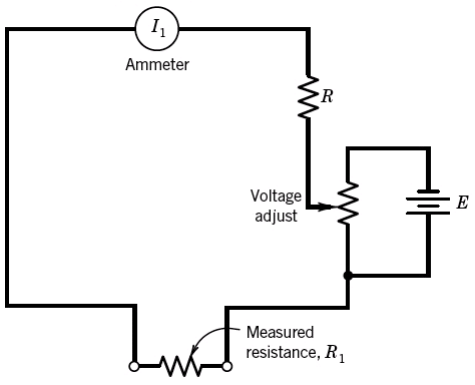
Strain-Resistance Relationship

$$\delta R/R = (1+2\upsilon_p+\pi_1 E_m)\varepsilon_a = GF*\varepsilon_a$$

GF: Gauge factor

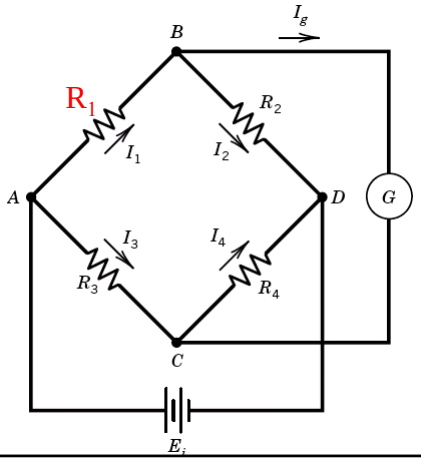
Resistance Measurement

- Ohm's Law: R=U/I
  - U: voltage
  - I: Current



Wheatstone Bridge

- Measure small resistance changes
- R_1: resistance that changes



Balance conditions:

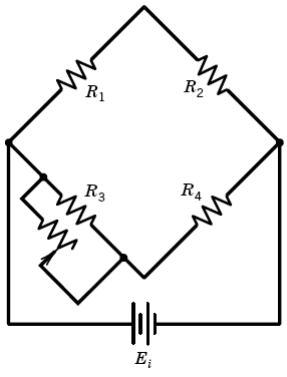
$I_g=0$ ➔ $I_1=I_2$ and $I_3=I_4$

➔ $R_2/R_1 = R_4/R_3$

Measuring Methods:

- Null method: adjust one of the resistor to balance the circuit
- Deflection method: measure voltage or current between B and C

Null Method-Strain Gauge



Circuit with a shunt balance

- adjust R_3 to balance the circuit

$R_2/R_1 = R_4/R_3$

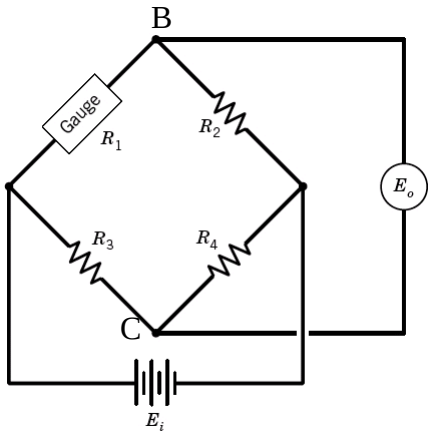
➔ $R_1 = R_2*R_3/R_4$

R_3 must be calibrated

$\delta R_1/R_1 = GF*\varepsilon$

GF: Gauge Factor

Deflection Method



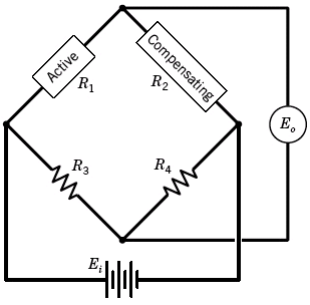
Measure the current or voltage across B and C

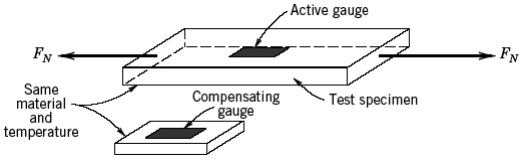
$\delta E_0/E_i = GF/4*\varepsilon$

Temperature Compensation of Strain Gauge

Temperature sensitivity of strain gauge:

- Change in resistivity due to temperature change
- Thermal strain: strain experienced by the gauge due to differential thermal expansion between the gauge and the specimen materials





Active gauge: resistance change due to strain and temperature, $\delta R/R = GF(\varepsilon_a+\varepsilon_T)$ ➔ $\varepsilon = \varepsilon_a+\varepsilon_T$
Compensating gauge: resistance change due to temperature only, $\delta R/R = GF*\varepsilon_T$ ➔ $\varepsilon = \varepsilon_T$

Resistance Temperature Detector (RTD)

RTD: a metal wire that exhibits an increase in electrical resistance with temperature:

- $R=R_0[1+\alpha(T-T_0)+\beta(T-T_0)2+...]$
  - R_0: reference resistance measured at T_0
  - α, β: material constants
- Linear over small temperature range:
  - $R=R_0[1+\alpha(T-T_0)]$
  - α: temperature coefficients of resistivity
- Resistance measurement: Wheatstone bridge