Lecture 7 – INSTRUMENTATION (1)

Outline
:

- Sensors
  - Straingage based
  - Electro and electromagnetic
  - Piezoelectric
  - Fiber-opticcs
  - Cameras
- Conditioners
  - Strain
  - Image
  - Clocks
  - Synchronization
- Amplifiers
  - Mechanical
  - Electronic
- Monitoring and Data collection
  - Real time (oscilloscope, analysers)
  - A/D – D/A
  - Digital
  - Video
  - Streaming
- Repository
  - Local
  - Central
  - Grid

Measurements shall be made of all response parameters that significantly affect test article behavior and shall be used to evaluate and quantify:

- important dynamic characteristics (stiffness, strength, deformability)
- important dynamic characteristics (frequencies, damping, shapes)
- non-linear response (yielding stresses and strains)
- failure modes.

Measurement of

- accelerations,
- velocities,
- absolute and/or relative displacements,
- strains and
- forces

Additional observations:

- visual
- video recorders (as sensors)
- still pictures

Instrumentation planning:

- model configuration,
- type,
- location and
- orientation
- reference system

The minimum recommended instrumentation:

(a) <u>Accelerometers to measure applied acceleration levels in two principal horizontal and vertical axes of the shake table</u>
(b) <u>Accelerometers to measure absolute acceleration response of test article.</u>
(c) <u>Displacement (position) transducers to measure absolute and/or relative deformation response of test article.</u>
(d) <u>Load cells (..washers) to measure anchor forces.</u>

Sensor ranges
Sensors shall have a minimum operational frequency depending on the largest frequency searched or range of 0.5 to 100 Hz.
Load cell washers shall have a minimum capacity of three times weight of the test article.

Additional instrumentation shall be required wherever there is a concern regarding a condition that may affect the test article response.

Instrument calibrations
- shall conform to **NIST traceable** primary standards.
- shall be recalibrated once every year and
- shall be verified before each test

Monitoring
- sensors
- connectors
- conditioners
- amplifiers
- data acquisition
- repository

Sensors: ***Stress, Force, and Acceleration Devices***

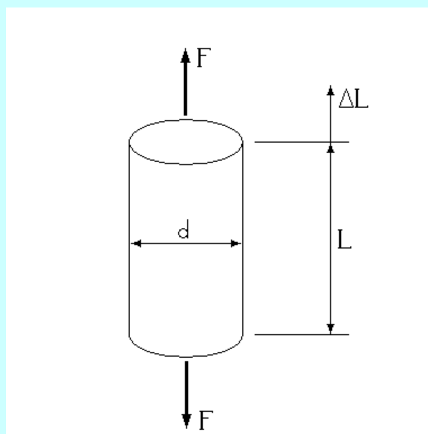
1. Strain Measurements and
2. Basic Electrical Circuits
3. Principal Stresses
4. Force Measuring Devices

Strain Measurements:

Purpose:

- Determine stress distributions in elastic materials.
- Determine deformed shapes of any material.

Direct Stress Measurements:



Axial Effects:

$$\varepsilon_{axial} = \frac{\sigma_{axial}}{E} = \frac{F/A}{E}$$

$$\varepsilon_{axial} = \frac{\Delta L}{L} \quad \text{(average)}$$

Note that this is for elastic behavior only!

Knowing E, L, and $A = \frac{\pi d^2}{4}$, ΔL is measured and so F can be found.

Transverse Effects:

$$\varepsilon_t = -\nu\varepsilon_{axial}$$

$$\varepsilon_t = \frac{dD}{D}$$

$$\varepsilon_{axial} = \frac{\Delta L}{L}$$

$$\Rightarrow \frac{dD}{D} = -\nu\frac{\Delta L}{L}$$

For plastic material, the volume remains constant, at V=AL

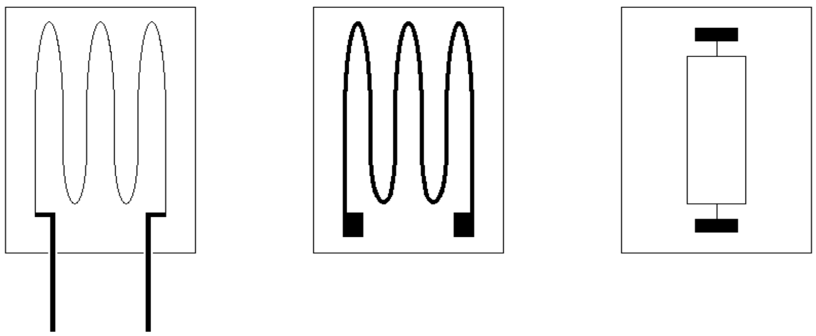
$$\therefore dV = 0 = LdA + AdL$$

or $$\frac{dA}{A} = -\frac{dL}{L}$$

$$\Rightarrow \frac{2\pi D dD}{\pi D^2} = \frac{2dD}{D} = -\frac{dL}{L}$$

$\therefore \nu$=0.5 (plastic materials)

Electrical Resistance Strain Gauges



wire gauge foil gauge semiconductor gauge

Basic Behavior of Resistive Gauges

$$R = \rho \frac{L}{A}$$

where:

R=resistance (Ω)

ρ=resistivity of gauge material (including temperature effects)

A=cross-sectional area of gauge

L=length of gauge

$$\therefore \frac{dR}{R} = \frac{d\rho}{\rho} + \frac{dL}{L} - \frac{dA}{A}$$

$$\frac{dA}{A} = 2\frac{dD}{D} = -2v\frac{dL}{L}$$

$$\Rightarrow \frac{dR}{R} = \varepsilon_a(1+2v) + \frac{d\rho}{\rho}$$

We define:

$$\text{Gauge Factor} = \frac{dR/R}{\varepsilon_a}$$

$$= (1+2v) + \frac{\partial\rho}{\rho\varepsilon_a}$$

Gauge Factor (GF) is usually specified by the manufacturer and is established such that $\frac{d\rho}{\rho\varepsilon_a}$ is zero over a wide range of strains.

$$\boxed{\therefore \varepsilon_a = \frac{1}{GF} \cdot \frac{dR}{R}}$$

Characteristics of Gauge Material

Material	GF	R	remarks
Cu-Ni	2	~100 Ω	low temperatures <500°F (260°C)
platinum alloys	4	~50 Ω	high temperatures >1000°F (540°C)
silicon semiconductors	100-150	~200 Ω	low strains (extremely brittle)

Manufacturers:

Micro Measurements Inc.
Texas Measurements Inc.
Baldwin-Lima-Hamilton Inc.

TML Strain Gauges

Characteristics of Strain Gauges

- Bonded Wire Gauges (12-25 μm diameter)
- Foil Gauges (1 μm diameter)
- Semiconductors (0.25 mm thickness)

Performance Characteristics

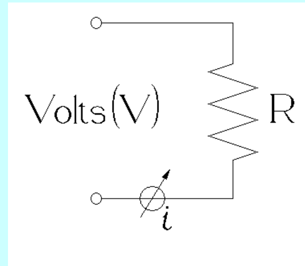
- Adhesives → epoxy- cements (surface conditioning)
- Temperature effects → $\left(\partial\rho / \rho\right)$ circuit connections
- Moisture effects → isolation of gauges
- Wires → soldering

Measurements

1. Direct Resistance (ohms)

$$R_0 = \frac{V}{i_0}$$

$$\Delta R + R_0 = \frac{V}{i_0 + \Delta i}$$



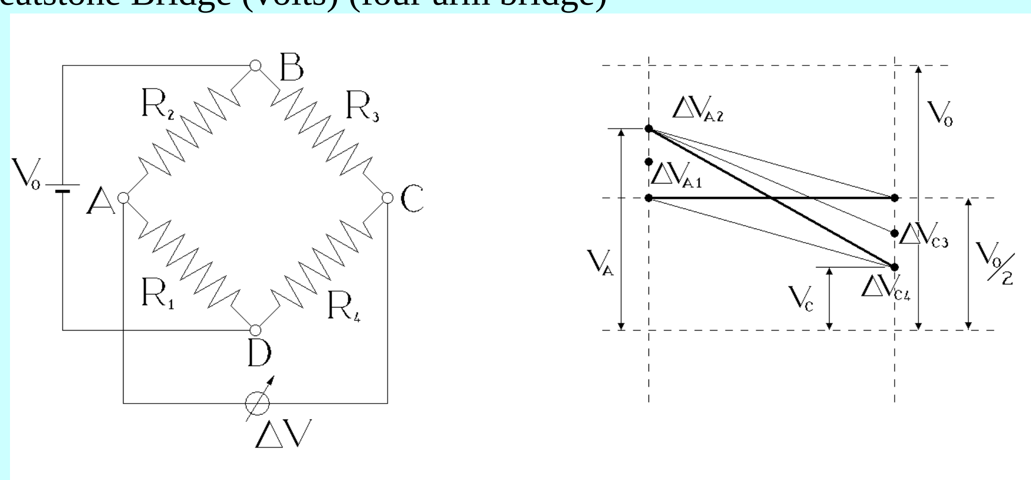
Divide by R_0 (or V/i_0)

$$\frac{\Delta R}{R_0} + 1 = \frac{1}{\frac{\Delta i}{i_0} + 1}$$

$$\Rightarrow \frac{\Delta R}{R_0} = -\frac{\Delta i}{i_0} \cdot \frac{1}{1 + \frac{\Delta i}{i_0}}$$

This is extremely inaccurate since $\Delta R/R_0$ is very small!

2. Wheatstone Bridge (volts) (four arm bridge)



V_0 = External supply voltage (usually 10 volts)

ΔV (from voltmeter) = Change in voltage across bridge

$$\Rightarrow \Delta V = V_A - V_C$$

$$V_A = V_0 \cdot \frac{R_1}{R_1 + R_2} \quad \text{and} \quad V_C = V_0 \cdot \frac{R_4}{R_3 + R_4}$$

For $R_1 = R_2 = R_3 = R4$

$$V_A = \frac{1}{2} V_0 \qquad V_C = \frac{1}{2} V_0 \qquad \Rightarrow \Delta V = 0$$

When $\Delta V = 0 \equiv$ Balanced Circuit

When $\Delta V \neq 0$, the circuit can be balanced by adding a small resistor in parallel to one resistor.

Now, $$V_A = V_0 \cdot \frac{R_1}{R_1 + R_2}$$

$$\frac{dV_A}{dR_1} = V_0 \cdot \left[\frac{(R_1 + R_2) - R_1}{(R_1 + R_2)^2} \right] = V_0 \cdot \frac{R_2}{(R_1 + R_2)^2}$$

or $$dV_A = V_0 \cdot \left(\frac{dR_1}{R_1} \right) \cdot \frac{\frac{R_2}{R_1}}{\left[1 + \left(\frac{R_2}{R_1} \right) \right]^2}$$

For a balanced circuit: $\Delta V=0$ since $R_1 = R_2 = R_3 = R_4$ and there is no change in dR_1 (or $dR_1=0$)

For a change in resistance, i.e. $\Delta R_1 \neq 0$

$$\Delta V = (V_A + dV_A) - V_C = dV_A =\sim \frac{dR_1}{R_1}$$

For a change in resistor R_2 $(\Delta R_2 \neq 0)$

$$\frac{dV_A}{V_0} = \frac{-dR_2}{R_2}\left\{\frac{R_1/R_2}{\left(1+R_1/R_2\right)^2}\right\}$$

or $$\Delta V = (V_A + dV_A) - V_C = dV_A = -\frac{dR_2}{R_2}$$

The same applies for resistors 3 & 4

Therefore

$$\frac{\Delta V}{V_0} = \left(\frac{dR_1}{R_1} - \frac{dR_2}{R_2} + \frac{dR_3}{R_3} - \frac{dR_4}{R_4}\right)\cdot\frac{1}{(1+\alpha)^2}$$

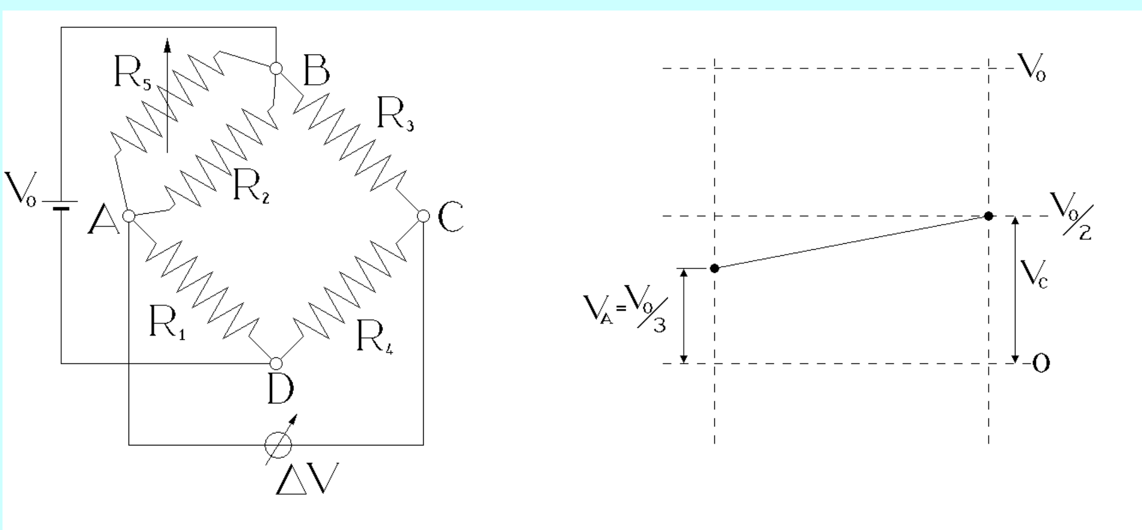
where $\alpha = R_1/R_2$ or $\alpha = R_3/R_4$

or $$\boxed{\frac{\Delta V}{V_0} = \frac{GF}{(1+\alpha)^2}(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4)}$$

Recall $\frac{dR_1}{R_1} = GF\cdot\varepsilon_1$

- This is for a full bridge circuit!!!
- Half bridge circuits ($\varepsilon_1 = \varepsilon_2 = 0$, or any other two)
- Quarter bridge circuits ($\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = 0$, or any other three)

See ‘two and three wire circuits’



$$R_1 = R_3 = R_4 = {R_2}/{2},\ R_5 = 0$$ initially

$$\therefore V_A = V_0 \cdot \frac{R_2/2}{R_2/2 + R_2} = \frac{1}{3} V_0$$

$$V_C = \frac{1}{2} V_0 \qquad \Delta V = -\frac{1}{6} V_0$$

To balance the bridge, a resistor is added in parallel to one arm: This means…..

$$\frac{1}{R_{BA}} = \frac{1}{R_2} + \frac{1}{R_5}$$

$$R_{BA} = \frac{R_2 R_5}{R_2 + R_5}$$

Now find R_5 such that $\Delta V=0$

$$V_A = \frac{R_2/2 * V_0}{R_2/2 + \frac{R_2 R_5}{R_2 + R_5}} = \frac{1}{2} V_0$$

$$\Rightarrow \frac{R_2/2}{R_2/2 + \frac{R_2 R_5}{R_2 + R_5}} = \frac{1}{2}$$

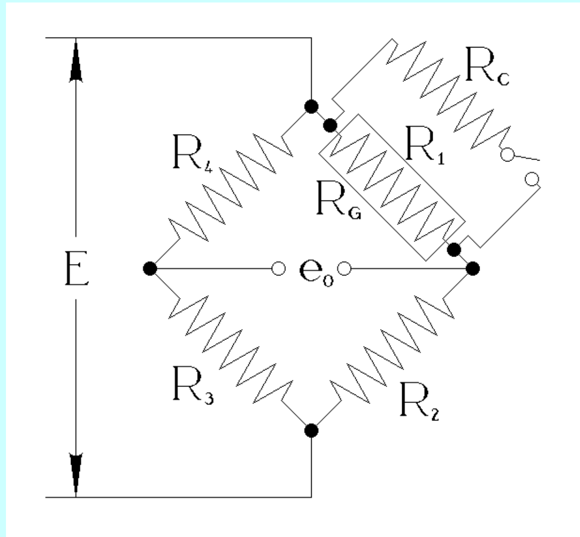
*when $R_2=1$

$$\frac{1R_5}{1 + R_5} = \frac{1}{2} \Rightarrow R_5 = 1$$

$$\therefore R_5 = R_2$$

Shunt Calibration

When the shunt calibration register is shunted across R1, the resistance of the bridge arm becomes $\frac{R_1 R_C}{(R_1 + R_C)}$, and the change in arm resistance is:



$$\Delta R = \frac{R_1 R_C}{R_1 + R_C} - R_1$$

Or,

$$\frac{\Delta R}{R_1} = \frac{-R_1}{R_1 + R_c}$$

Re-expressing the unit resistance change in terms of strain yields a relationship between the simulated strain and the shunt resistance required to produce it. The result is usually written here in the form $R_C = f(\varepsilon_S)$, but the simulated strain for a particular shunt resistance can always be calculated by inverting the relationship.

The unit resistance change in the gauge is related to strain through the definition of the gauge factor, GF.

$$\frac{\Delta R}{R_G} = GF\varepsilon$$

where: R_G = the *nominal* resistance of the strain gauge (e.g., 120 ohms, 350 ohms etc.).

Combining the two previous equations, and replacing R_1 by R_G, since there is no other resistance in the bridge arm,

$$GF\varepsilon_s = \frac{-R_G}{R_G + R_C}$$

Or,

$$\varepsilon_S = \frac{-R_G}{GF(R_G + R_C)}$$

where: ε_S = strain (compressive) simulated by shunting R_G with R_C.
Solving for R_C,

$$\mathbf{R_C = -\frac{R_G}{GF\varepsilon_S} - R_G}$$

Since the simulated strain in this mode of shunt calibration is always negative, it is common practice in the strain gauge field to omit the minus sign in front of the first term in the above equation, and write it as:

$$\mathbf{R_C = -\frac{R_G}{GF\varepsilon_S} - R_G = -\frac{R_G \ x\ 10^6}{GF\varepsilon_{S(\mu)}} - R_G}$$

where: $\varepsilon_{S(\mu)}$ = simulated strain, in microstrain units.

When substituting into this equation, the user must always remember to substitute the numerical value of the compressive strain, without the sign.

Shunt Calibration Resistors

GAUGE CIRCUIT	RESISTANCE IN OHMS	EQUIVALENT MICROSTRAIN
120-OHM	599,880	100
	119,880	500
	59,880	1,000
	29,880	2,000
	19,880	3,000
	14,880	4,000
	11,880	5,000
	5,880	10,000
350-OHM	349,650	500
	174,650	1,000
	87,150	2,000
	57,983	3,000
	43,400	4,000
	34,650	5,000
	17,150	10,000
1000-OHM	999,000	500
	499,000	1,000
	249,000	2,000
	165,666	3,000
	124,000	4,000
	99,000	5,000
	49,000	10,000

Note that in the above table the ‘Equivalent Microstrain’ column gives the true compressive strain in a quarter bridge circuit, simulated by shunting each calibration resistor across an active strain gauge arm of the exact indicated resistance. These values are based on a circuit gauge factor setting of 2.000.

See: Shunt Calibration of Strain Gauge Instrumentation

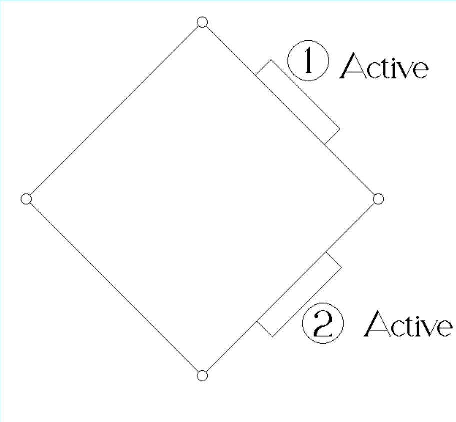
Temperature Compensation

$$\Delta R^{T^\circ} = \alpha_T \Delta T^\circ R \rightarrow \text{change in resistance}$$

This produces a strain reading

$$\varepsilon^{T^\circ} = \frac{\Delta R^{T^\circ}/R}{GF}$$

Apply circuit compensation (half and/or full bridge)



$$\varepsilon_1 = \varepsilon_1 + \varepsilon^{T^\circ}$$

$$\varepsilon_2 = \varepsilon_2 + \varepsilon^{T^\circ}$$

$$\Rightarrow \frac{\Delta V}{V} = \frac{GF}{(1+\alpha)^2}\left[\left(\varepsilon_1 + \varepsilon^{T^\circ}\right) - \left(\varepsilon_2 + \varepsilon^{T^\circ}\right)\right]$$

$$\frac{\Delta V}{V} = \frac{GF}{(1+\alpha)^2}\left[\varepsilon_1 + \varepsilon_2\right]$$

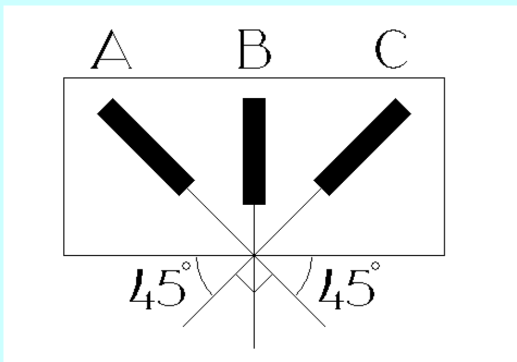
Note: Temperature effects cancel!!

Recommendations:

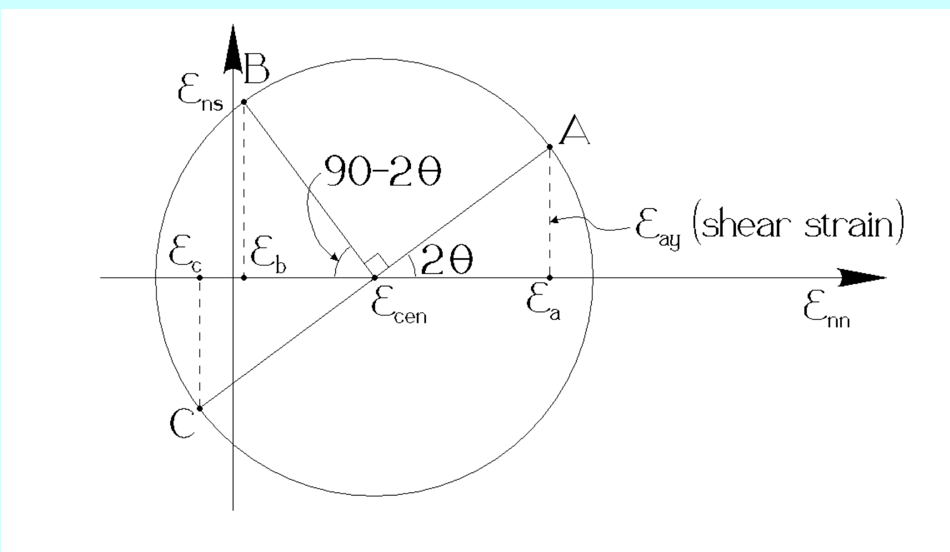
- Use compensated circuits for instruments.
- Use non-compensated circuits for quick measurements of strains. Requires calibration before each test.

Strain Rosettes – Principal Stresses

45° Rosette



- ε_A, ε_B, ε_C are known
- Use Mohr's Circle:



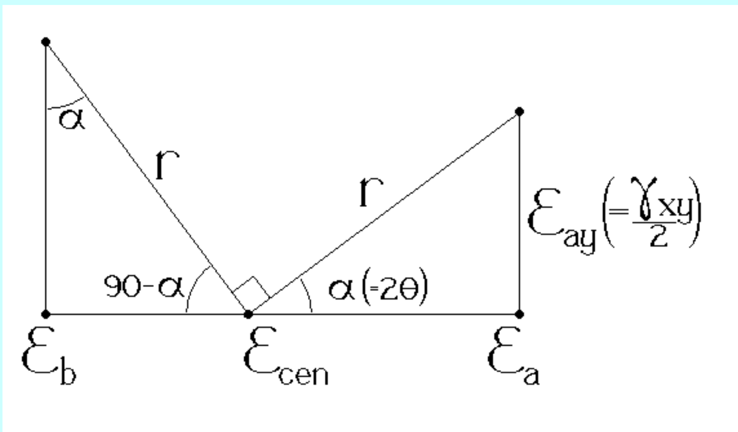
$$\varepsilon_{ay} = \varepsilon_{cen} - \varepsilon_{\mathbf{B}}$$

$$= \frac{\varepsilon_A + \varepsilon_C}{2} - \varepsilon_B$$

(Where ε_B is zero since there is no normal strain.)

$$\varepsilon_{cen} = \frac{\varepsilon_A + \varepsilon_C}{2}$$

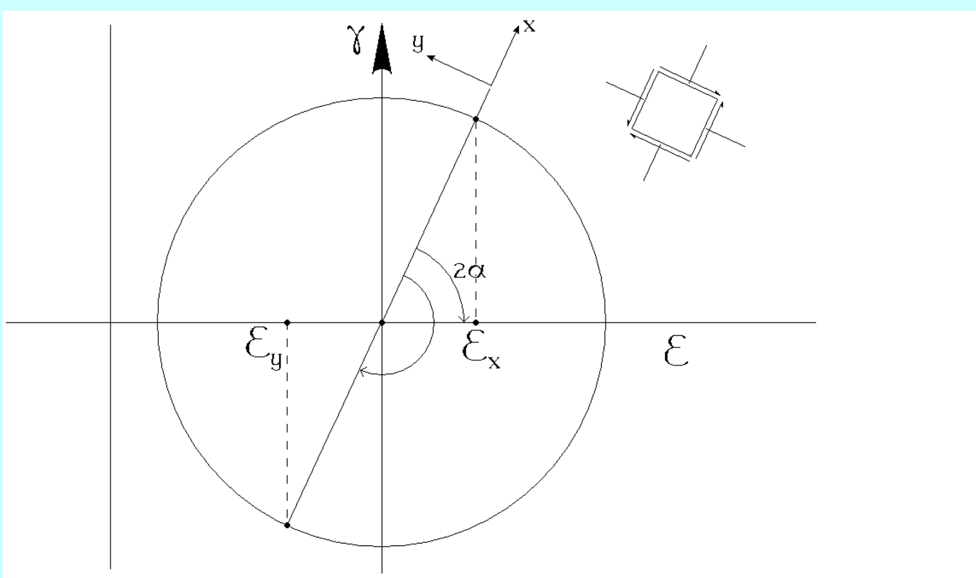
So, from geometry:



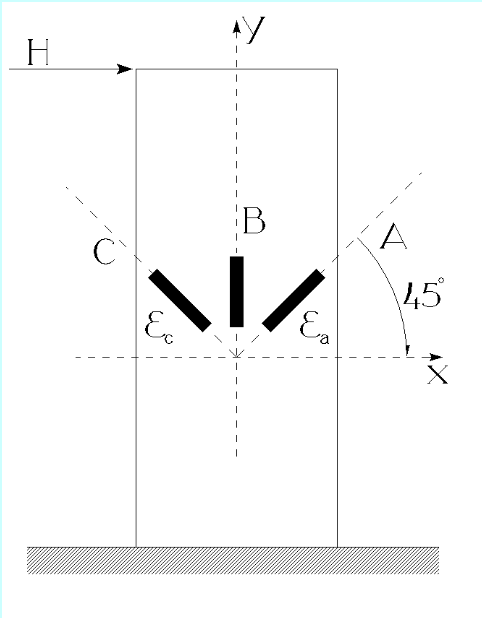
$$\sin\alpha = \frac{\varepsilon_{ay}}{r}$$

$$\sin\alpha = \frac{\varepsilon_{cen} - \varepsilon_B}{r}$$

$$\Rightarrow \varepsilon_{ay} = \varepsilon_{cen} - \varepsilon_B$$



Problem: Determine the arrangement of a rosette to measure shear stress at a point

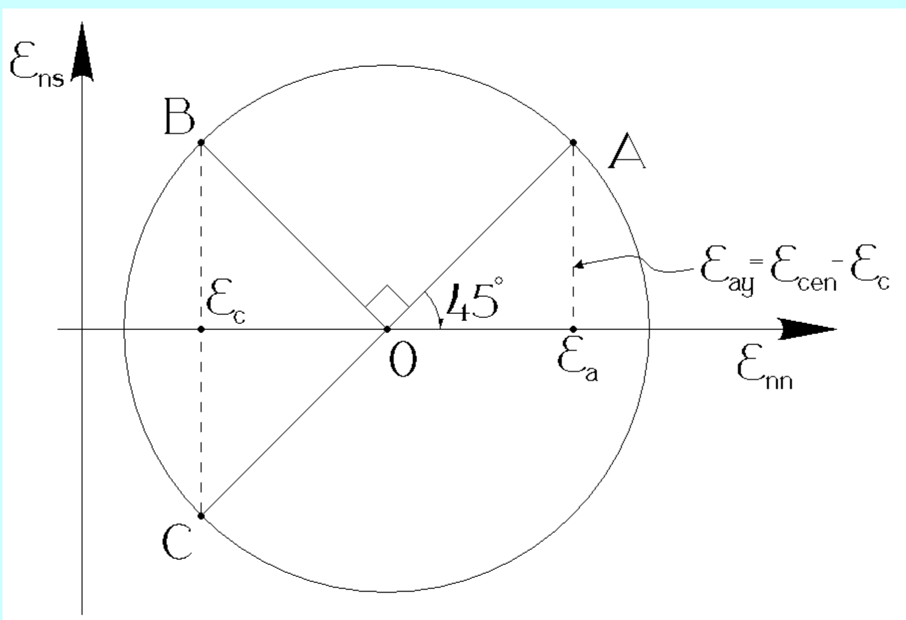


$$\sigma_x = 0$$

$$\sigma_y = 0$$

$$\tau_{xy} = H/A_x$$

where A_x = corresponding shear area

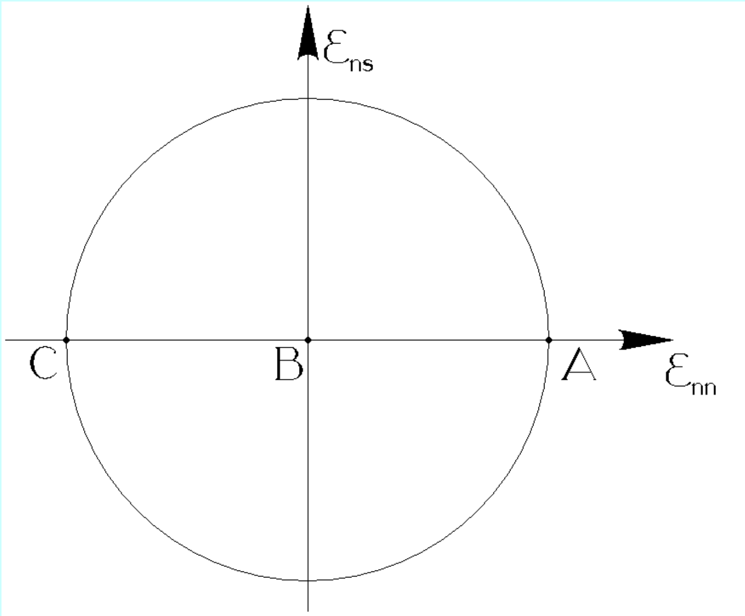


$$= \frac{\varepsilon_A + \varepsilon_C}{2} - \varepsilon_C$$

$$= \frac{\varepsilon_A - \varepsilon_C}{2}$$

Note that this is independent of the magnitude of ε_B, since $\varepsilon_B = \varepsilon_C$;
So it is sufficient to use two gauges to determine ε_{xy}!!

For pure shear behaviour,



$\varepsilon_B = 0,$

$\varepsilon_A = 0,$

$\Rightarrow \varepsilon_{xy} = \varepsilon_A = \varepsilon_C$

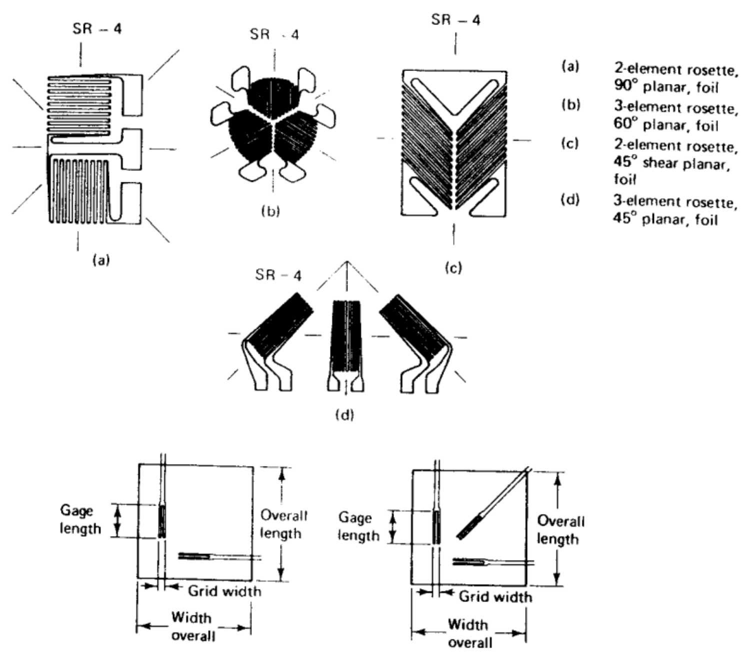


Figure 7.14 Various types of rosettes. (a) Two-element rosette, 90° planar, foil. (b) Three-element rosette, 60° planar, foil. (c) Two-element rosette, 45° shear planar, foil. (d) Three-element rosette, 45° planar, foil.

Principal Strains

$$\varepsilon_{max,min} = \frac{\varepsilon_A + \varepsilon_C}{2} \pm \sqrt{\frac{(\varepsilon_A - \varepsilon_B)^2 + (\varepsilon_B - \varepsilon_C)^2}{2}}$$

$$\text{radius} = \sqrt{(\varepsilon_A - \varepsilon_{cen})^2 + (\varepsilon_{cen} - \varepsilon_B)^2}$$

$$= \sqrt{\left(\varepsilon_A - \frac{\varepsilon_A + \varepsilon_C}{2}\right)^2 + \left(\frac{\varepsilon_A + \varepsilon_C}{2} - \varepsilon_B\right)^2}$$

$$= \sqrt{\left(\frac{\varepsilon_A}{2} - \frac{\varepsilon_C}{2}\right)^2 + \left(\frac{\varepsilon_A}{2} + \frac{\varepsilon_C}{2} - \varepsilon_B\right)^2}$$

$$= \left(\frac{\varepsilon_A^2}{4} - \frac{2\varepsilon_A\varepsilon_C}{4} + \frac{\varepsilon_C^2}{4} + \frac{\varepsilon_A^2}{4} + \frac{\varepsilon_A\varepsilon_C}{4} - \frac{\varepsilon_A\varepsilon_B}{2} + \frac{\varepsilon_C^2}{4} + \frac{\varepsilon_C\varepsilon_A}{4} - \frac{\varepsilon_C\varepsilon_B}{2} + \varepsilon_B^2 - \frac{\varepsilon_B\varepsilon_A}{2} - \frac{\varepsilon_B\varepsilon_C}{2}\right)^{\frac{1}{2}}$$

$$= \left(\frac{2\varepsilon_A^2}{4} + \frac{2\varepsilon_C^2}{4} + \varepsilon_B^2 - \varepsilon_B\varepsilon_A - \varepsilon_C\varepsilon_B\right)^{\frac{1}{2}}$$

$$= \left[\frac{1}{2}(\varepsilon_A^2 + \varepsilon_C^2) + \varepsilon_B^2 - \varepsilon_B\varepsilon_A - \varepsilon_C\varepsilon_B\right]^{\frac{1}{2}}$$

$$= \left[\frac{(\varepsilon_A - \varepsilon_B)^2 + (\varepsilon_B - \varepsilon_C)^2}{2}\right]^{\frac{1}{2}}$$

checks!

Principal Direction (Axes)

$$\tan 2\theta = \frac{\varepsilon_{Ay}}{\varepsilon_A - \varepsilon_{cen}} = \frac{\frac{\varepsilon_A + \varepsilon_C}{2} - \varepsilon_B}{\varepsilon_A - \frac{\varepsilon_A + \varepsilon_C}{2}} = \frac{\varepsilon_A + \varepsilon_C - 2\varepsilon_B}{\varepsilon_A - \varepsilon_C}$$

Principal Stresses

Hooke's Law (General Case $\varepsilon_2 = 0$)

$$\sigma_1 = \frac{E}{1 - v^2}\left(E_1 + vE_3\right)$$

$$\sigma_3 = \frac{E}{1 - v^2}\left(E_3 + vE_1\right)$$

$$\sigma_{cen} = \frac{\sigma_A + \sigma_C}{2} = \frac{1}{2}\frac{E}{1 - v^2}(1 - v)(\varepsilon_A + \varepsilon_C)$$

$$= \frac{E(\varepsilon_A + \varepsilon_C)}{2(1 - v)}$$

$$\sigma_{radius} = \frac{\sigma_1 - \sigma_3}{2} = \frac{1}{2}\frac{E}{1 - v^2}(1 - v)(\varepsilon_1 - \varepsilon_3)$$

$$= \frac{E(\varepsilon_1 + \varepsilon_3)}{2(1 - v)} = \frac{E(\varepsilon_r)}{1 + v}$$

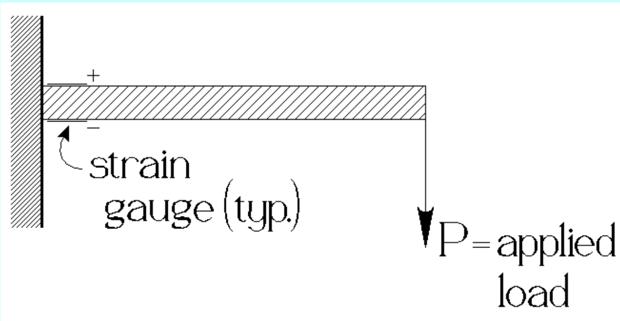
where ε_r = radius normal strain

$$\therefore \sigma_{\max,\min} = \frac{E(\varepsilon_A + \varepsilon_C)}{2(1 - v)} \pm \frac{E}{1 + v}\sqrt{\frac{(\varepsilon_A - \varepsilon_B)^2 + (\varepsilon_B - \varepsilon_C)^2}{2}}$$

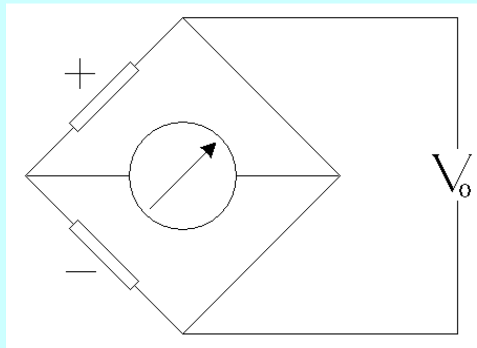
Force Measuring Devices

Moment

i.e.



+ means positive volt reading
- means negative volt reading



Recall:

$$\frac{\Delta V}{V} = \frac{GF}{(1+\alpha)^2}(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4)$$

since $R_1 = R_2$ (assumed), and $\alpha = 1$ (so $(1 + \alpha)^2 = 4$)

$$\therefore \frac{\Delta V}{V_0} = \frac{GF}{4}(\varepsilon^+ - \varepsilon^-)$$

Now, $$\varepsilon^+ = \frac{\sigma}{E} = \frac{M}{ES} = \frac{PL}{ES} = -\varepsilon^-$$

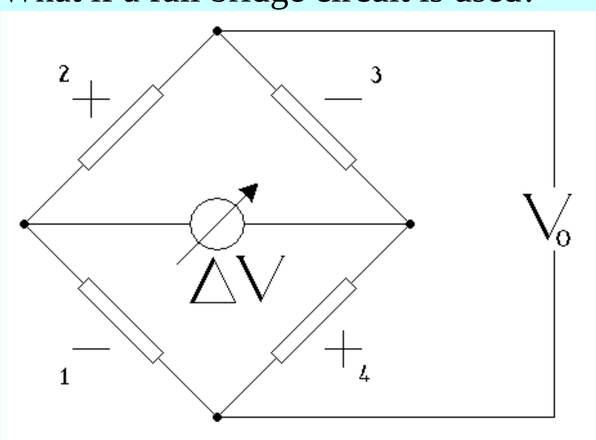
Note: S = Section Modulus = I/Y

$$\therefore \frac{\Delta V}{V_0} = \frac{GF}{4} \cdot 2 \cdot \frac{PL}{ES}$$

or $$\Delta V = \frac{GF \cdot L \cdot V_0}{2E \cdot S} \cdot P = K_0 \cdot P$$

where K_0 = Calibration Factor (Volt/Force)

What if a full bridge circuit is used?



$$\frac{\Delta V}{V} = \frac{GF}{4}\left(\varepsilon^{+} - \varepsilon^{-} + \varepsilon^{+} - \varepsilon^{-}\right)$$

$$= \frac{GF}{4} \cdot 4 \cdot \frac{PL}{E \cdot S} = \frac{GF \cdot L}{E \cdot S} \cdot P$$

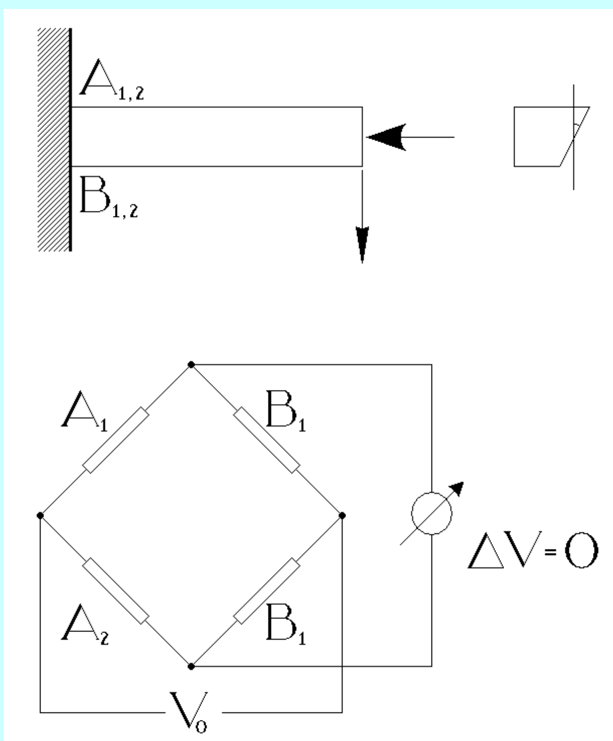
$$\Rightarrow K_0 = \frac{GF \cdot L}{E \cdot S}$$

Note that the calibration factor is doubled (it is twice as sensitive).

What about temperature compensation?

$\varepsilon_T^+ = \varepsilon_T^-$ So the net effect in $\dfrac{\Delta V}{V}$ cancels!!

By using half bridges and full bridges, temperature compensation is automatic.

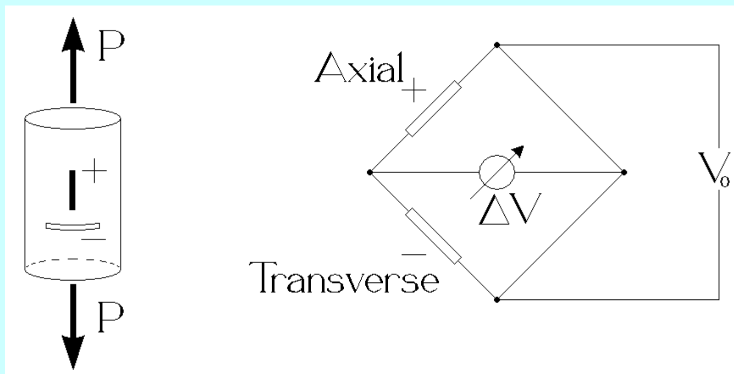


Axial Load Measurement

Using one gauge for axial strain measurements;

- Problem of no temperature compensation
- Probably OK for quick measurements

Use a ‘dummy’ gauge to measure transverse strains.



$$\frac{\Delta V}{V}=\frac{GF}{4}\cdot(\varepsilon_{axial}-\varepsilon_{transverse})$$

$$\varepsilon_{axial}=\varepsilon^{+}=\frac{\sigma}{E}=\frac{P}{AE}$$

$$\varepsilon_{transverse}=-v\varepsilon^{+}=\frac{-vP}{AE}$$

$$\therefore\frac{\Delta V}{V}=\frac{GF}{4}\cdot\left(\frac{P}{AE}+\frac{vP}{AE}\right)$$

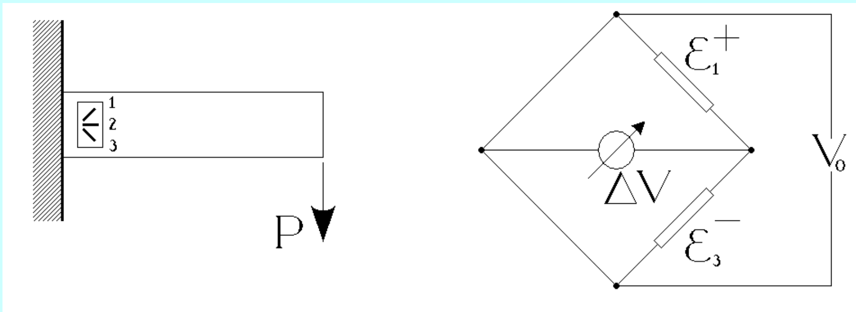
$$\frac{\Delta V}{V}=\frac{GF(1+v)}{4\ AE}\cdot P$$

$$K_0=\frac{GF\cdot(1+v)}{4\cdot AE}$$

Note that the transverse gauge created more sensitivity (1+v). Use four gauges (a full bridge) for double sensitivity.

Shear Measurements

Use a rosette with the gauges at 90° apart (1 & 3 in the diagram below).



$$\frac{\Delta V}{V} = \frac{GF}{4}\left(\varepsilon_1 - \varepsilon_3\right)$$

$$\varepsilon_1 = \frac{P}{A_x E}$$

$$\varepsilon_3 = -\varepsilon_1$$

Note that for double sensitivity, a full bridge may be used. Shear strains may not be uniform throughout a solid cross section. For this reason, thin wall circular tubes are recommended for accurate shear measurements.

Static Calibration

- Known load applied
- Repeatable values of output
- Errors should be small
- Calibration should be periodically checked
- Environmental conditions should be constant

Procedure for linear (elastic) measuring systems

- Zero output gauge verification
- Sensitivity verification
- Linear and hysteresis verification
- Repeatability verification

Axial Circuit Calibration:

$$\frac{\Delta V}{V_0} = \frac{GF(1+v)}{4AE} \cdot P = K_o \cdot P$$

K_o is the calibration constant of the cell without conditioning

$$\therefore K_o = \frac{\Delta V / V}{P} \qquad \left(\text{units} = \frac{\text{Volts}}{\text{Force}} \right)$$

$$\Delta V_{max} = \frac{GF(1+v)}{4AE} \cdot V_o \cdot P_{max} = K \cdot P_{max}$$

Apply amplifier gain. When amplified, we would want output ΔV_{max} to be 10 volts when the maximum load is applied

$$\therefore \text{Gain} = \frac{10}{\Delta V_{max}} \cdot 1000 \qquad \text{with } \Delta V \text{ in mV}$$

$$10V = \text{Gain } \frac{GF(1+v)}{4AE} \cdot V_o \cdot P_{max} = \text{Gain } V_o \ K \cdot P_{max}$$

$$10V / P_{max} = K \ V_o \ \text{Gain}$$

Size of Voltage Output (ΔV)

Strain Output is usually smaller than 2000μSt.

$$\varepsilon_y = \frac{\sigma_y}{E} \cong 2060\mu St \qquad \text{(for steel)}$$

Gauge Factor (GF) for most gauges is typically about 2.0

$$\therefore \frac{\Delta V}{V_0} = \frac{2.0}{4}(2000) = 1000\mu St = 1\times10^3$$

or

$$\Delta V_{max} \cong 10^{-3}\times V_0$$

For an excitation voltage of V_0=10V

$$\Delta V_{max} = 10^{-2} V = 10mV$$

This is extremely small and therefore requires amplification (or gain)!!

Amplification is applied by special conditioners

i.e.

National Instruments SCXI-: 4 Channel Isolation Amplifier
with Excitation Adjustable Gains from 1 to 2000
MicroMeasurements –Vishay - 2100 0r 2300

Example of load cell design:

Program for design:

Example circuits

Calibration:A See below

Calibration B