Theory and Practice of strain gages

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Related Sections in the Textbook

E. O. Doebelin, Measurement Systems:- Application and design, 5th ed., McGraw Hill, 2003

- ✓ Sec.4.3 pp. 228-253
- ✓ Chap.5 pp. 432-480
- ✓ Sec.10.1 pp.837-843

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Introduction to resistance strain gage

- Equipment for strain measurement.
- Basic theory of resistance strain gage
- Fundamental structure of strain gages
- How to Install a strain gage
- The Wheatstone bridge
- Factors that affect the accuracy of strain gages
- How to select a suitable strain gage

The Wheatstone bridge

- The Wheatstone bridge
- Interrogation of the Wheatstone bridge
- Balancing the bridge
- Calibration of the bridge
- Temperature compensation techniques
- Strain gage layout for different applications

General sensor characteristics

- Sensors:
  Convert a Signal or Stimulus (Representing a Physical Property) into an Electrical Output
- Transducers:
  Convert One Type of Energy into Another
- The Terms are often Interchanged
- *Active* Sensors Require an External Source of Excitation:
  RTDs, Strain-Gages
- *Passive* (Self-Generating) Sensors do not:
  Thermocouples, Photodiodes

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Typical sensors and their output formats

PROPERTY	SENSOR	ACTIVE/ PASSIVE	OUTPUT
Temperature	Thermocouple	Passive	Voltage
	Silicon	Active	Voltage/Current
	RTD	Active	Resistance
	Thermistor	Active	Resistance
Force / Pressure	Strain Gage	Active	Resistance
	Piezoelectric	Passive	Voltage
Acceleration	Accelerometer	Active	Capacitance
Position	LVDT	Active	AC Voltage
Light Intensity	Photodiode	Passive	Current

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Gages for measuring strain

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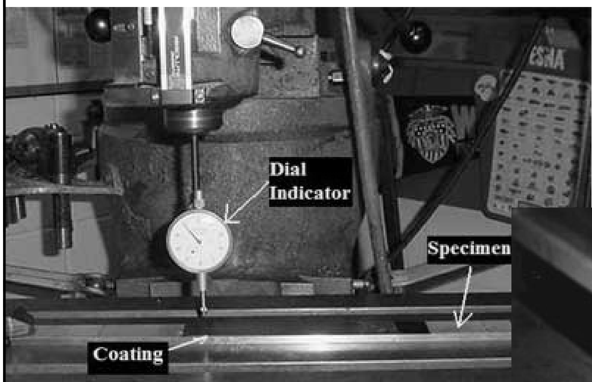
Mechanical strain gage

➢ A mechanical dial gage.



http://measure.feld.cvut.cz/groups/edu/e38sz/Lectures/04-mechanical_strain.pdf

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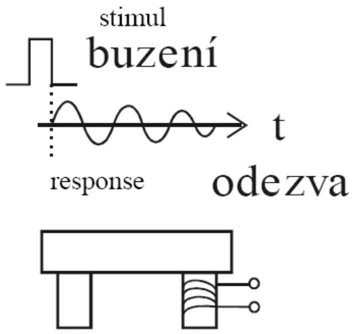
Acoustical strain gage

- resonant frequency f_o of string with length l and mass m depends on stretching force F

$$f_o = \frac{1}{2}\sqrt{\frac{F}{ml}}$$



$$\rho = \frac{m}{V} = \frac{m}{lS}$$

$\frac{\Delta l}{l} = \varepsilon$ ... relative deformation

$$\sigma = \frac{F}{S} = \varepsilon E$$

E ... Young module of elasticity

σ ... mechanical stress

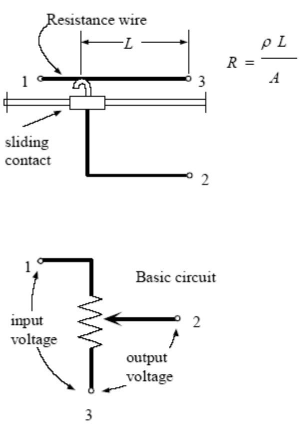
$$\Downarrow$$

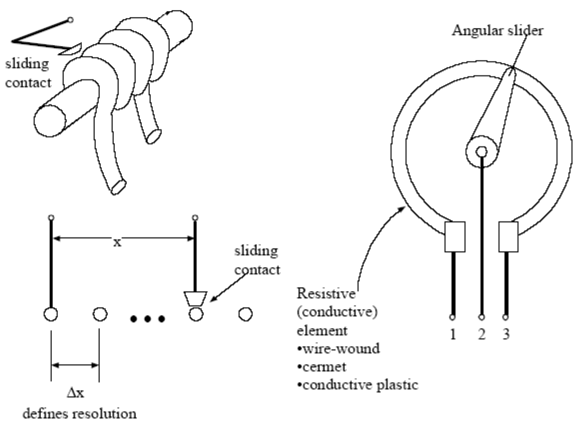
$$f_o = \frac{1}{2l}\sqrt{\frac{\sigma}{\rho}} = \frac{1}{2l}\sqrt{\frac{\varepsilon E}{\rho}}$$

http://measure.feld.cvut.cz/groups/edu/e38sz/Lectures/04-mechanical_strain.pdf 單秋成

Some resistance displacement/strain sensors

Potentiometric Sensors





http://www.me.utexas.edu/~lotario/me244L/leks/sensors/rsensors.pdf 單秋成

Resistance Strain gage

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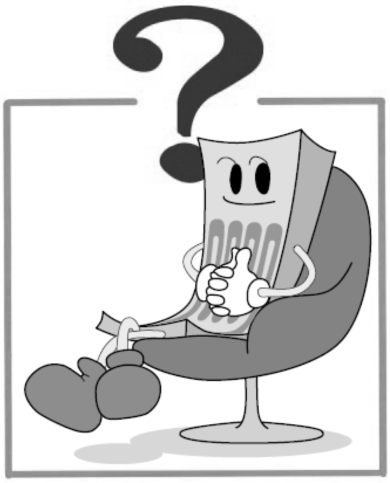
What is a resistance strain gage?



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Pizeoresistive effect

- Lord Kelvin showed in 1856 that the resistance of copper and iron wires changed when they are subjected to mechanical strain.
- The change in resistance is very small and cannot accurately be measured by an digital ohmmeter on a DVM.
- In the absence of any electronic amplifier, Lord Kelvin used a null detection method to measure the resistance changes.

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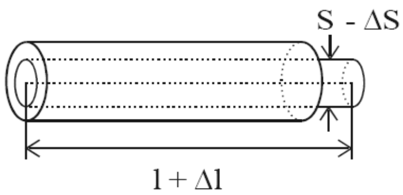
Principle of Piezoresistive effect

- basic relation: $R = \frac{l}{S}\rho$



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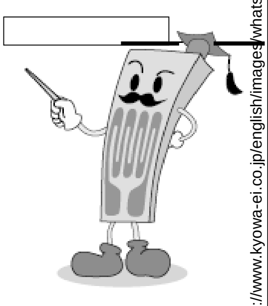
Sensitivity of a strain gage

Gage factor (GF)



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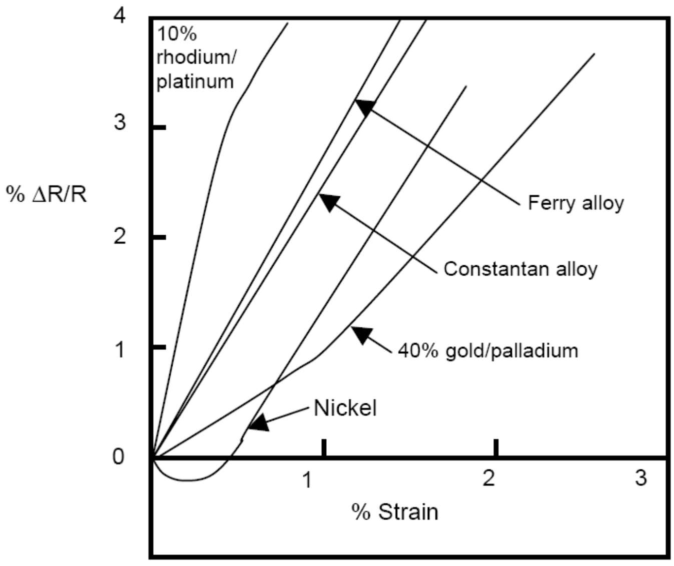
Gage factors of some metals



http://www.ae.gatech.edu/people/jcraig/ae3145/Lab2/strain-gages.pdf

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Gage factors of some metals

Table 1. Gage Factors for Various Grid Materials

Material	Gage Factor (GF)		Ultimate Elongation (%)
	Low Strain	High Strain	
Copper	2.6	2.2	0.5
Constantan*	2.1	1.9	1.0
Nickel	-12	2.7	--
Platinum	6.1	2.4	0.4
Silver	2.9	2.4	0.8
40% gold/palladium	0.9	1.9	0.8
Semiconductor**	~100	~600	--

* similar to “Ferry” and “Advance” and “Copel” alloys.

** semiconductor gage factors depend highly on the level and kind of doping used.

http://www.ae.gatech.edu/people/jcraig/ae3145/Lab2/strain-gages.pdf 單秋成

Gage factors of some metals

Example 1

Assume a gage with GF = 2.0 and resistance 120 Ohms. It is subjected to a strain of 5 microstrain (equivalent to about 50 psi in aluminum). Then

Example 2

Now assume the same gage is subjected to 5000 microstrain or about 50,000 psi in aluminum:

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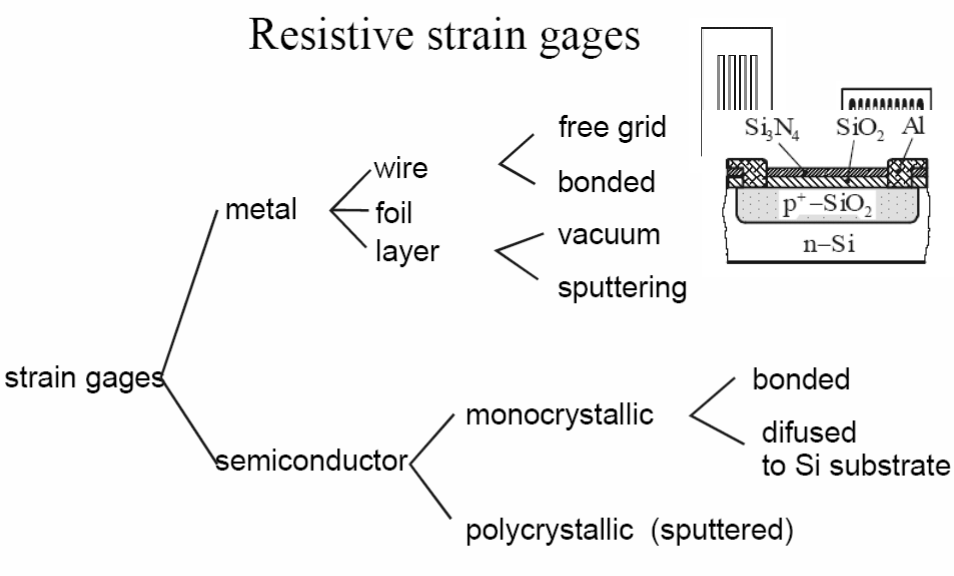
Different types of piezoresistive strain gage



http://measure.feld.cvut.cz/groups/edu/e38sz/Lectures/04-mechanical_strain.pdf

PARAMETER	METAL STRAIN GAGE	SEMICONDUCTOR STRAIN GAGE
Measurement Range	0.1 to 40,000 με	0.001 to 3000 με
Gage Factor	2.0 to 4.5	50 to 200
Resistance, Ω	120, 350, 600, …, 5000	1000 to 5000
Resistance Tolerance	0.1% to 0.2%	1% to 2%
Size, mm	0.4 to 150 Standard: 3 to 6	1 to 5

Figure 4-26: *A comparison of metal and semiconductor type strain gages*

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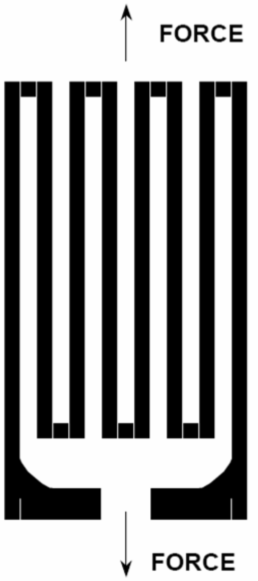
Transverse sensitivity

A single section of wire along a small gage length is not sensitive enough. Must has a number of section looped together.

Transverse strain affects the resistance of the strain gage:

- ✓ through poisson ratio effect, on the axial portion of the gage.
- ✓ On the transverse portion of the gage.

The metal foil strain gage



- PHOTO ETCHING TECHNIQUE
- LARGE AREA
- STABLE OVER TEMPERATURE
- THIN CROSS SECTION
- GOOD HEAT DISSIPATION

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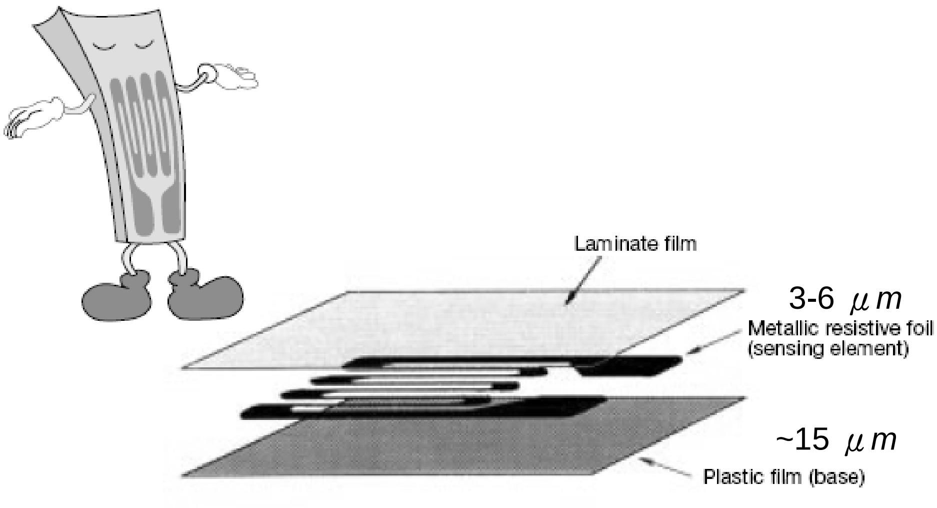
Structure of a foil strain gage



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Introduction to resistance strain gage

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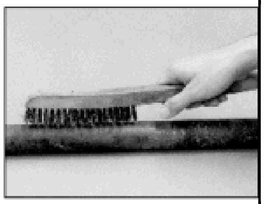
How to install a gage

Surface preparation

- Brushing off loose particles
- Remove paint, rust and plating
- degreasing
- Abrading for optimum bonding



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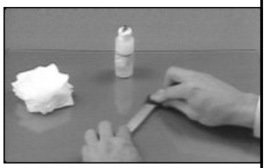


Class of installation	Surface Finish, rms microinch	Surface Finish, rms micrometer
General stress analysis	63 - 125	1.6 - 3.2
High elongation	>250*	>6.4*
Transducers	16 - 63	0.4 - 1.6
Ceramic cement	>250	>6.4

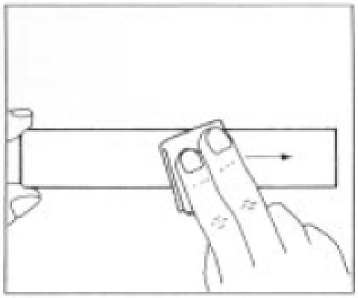
http://www.vishay.com/brands/measurements_group/guide/ib/b129/129c1.htm

Surface preparation

- For transducer application where good and long lived bonding is needed, etching with dilute acid may be applied followed by neutralizing with an alkali.
- Mark off the layout lines for the strain gage position using light scribing or burnishing with a 4H drafting pencil .

Surface preparation

- Re-clean the gage position thoroughly with degreaser (move in one direction with force) , neutralize if necessary.



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Handling of the strain gages

- Never touch strain gages by hand
- Handled only with rounded tweezers, or vacuum pen.
- Hold strain gage at the backing support, not at sensor grid.
- Strain gages do not require cleaning before bonding unless they have been accidentally contaminated by the user.
- Should strain gages have been touched by hand, clean it immediately with IPA and cotton tipped applicators, (do not use cotton applicators with plastic grip).

http://www.blh.de/application/appl145b.htm

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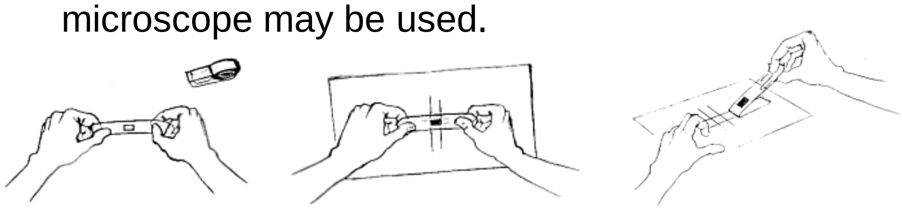
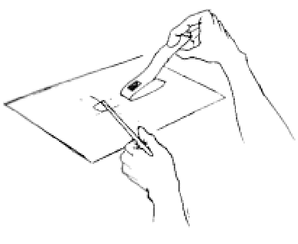
Gage bonding

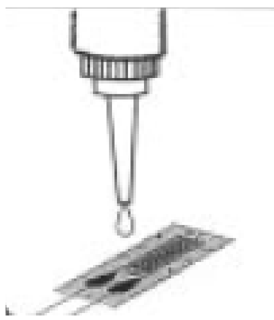
- Wash hand thoroughly with soap and water. Clean the working desk area and all related tools with solvent or degreasing agent.
- Use tweezer to take out the strain gage from package and fix it with low tack adhesive tape .
- Position the gage against the layout lines. For very accurate work, a low magnification microscope may be used.



http://www.efunda.com/designstandards/sensors/strain_gages/strain_gage_install_bond.cfm 單秋成

- Apply adhesive according to manufacturer's recommendation. Do not spread the adhesive throughout the surface yet as this accelerates curing.





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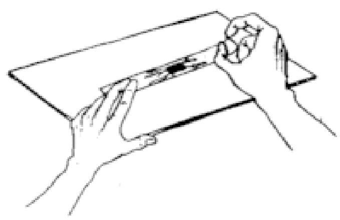

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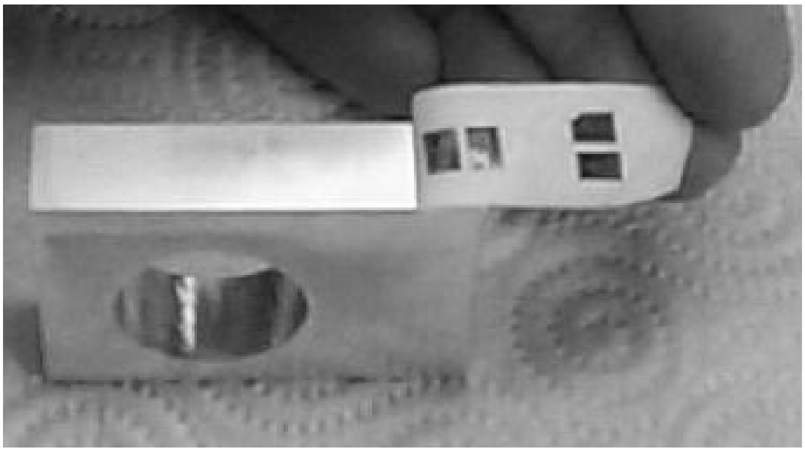
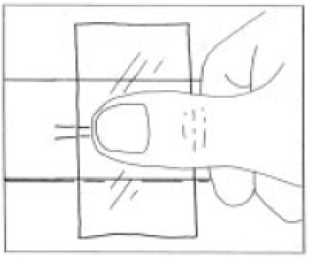


http://www.nakka-rocketry.net/articles/Gages.PDF 單秋成

- Press with finger using considerable pressure for duration specified by the manufacturer.(pressure and temperature from the finger aid curing)
- Special clamping tool and oven curing may be needed for transducer grade operation.



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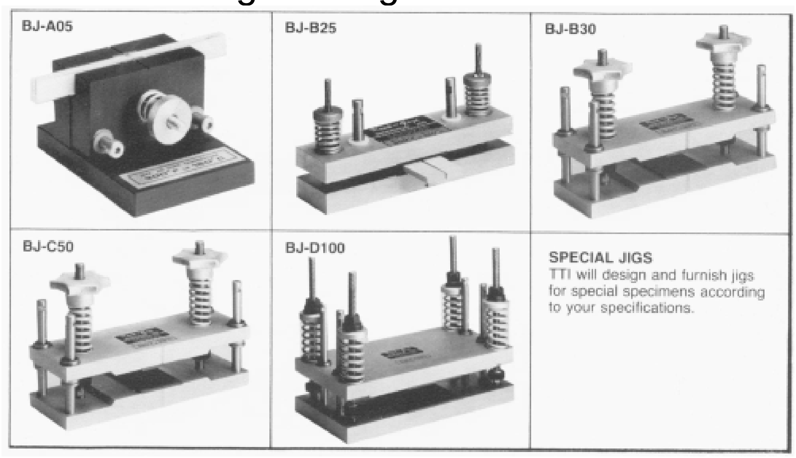
Transducer grade preparation often involves clamping with special tool and baking in the oven to ensure thorough curing.



From krak gage catalogue

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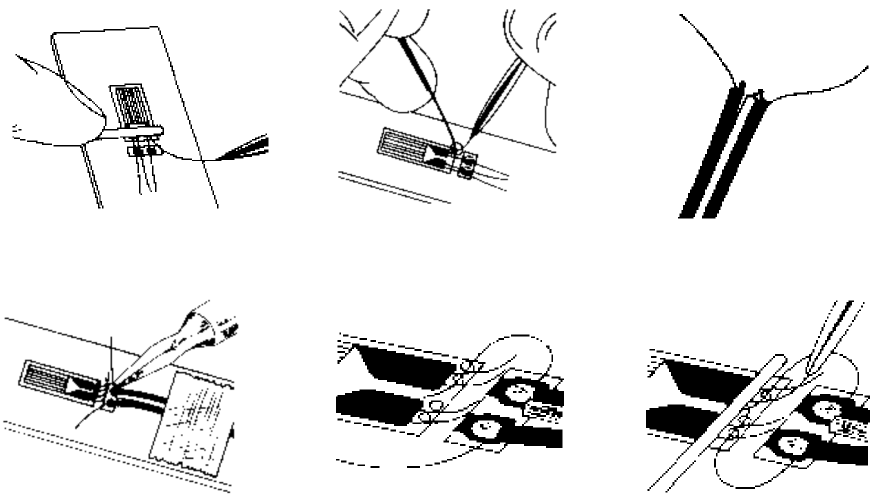
Soldering of lead wire



http://www.vishay.com/brands/measurements_group/guide/tt/tt604/604index.htm

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Cleaning, checking and protection

- Clean the solder flux from the joints.
- Inspect the gage bonding and solder joints.
- Check gage resistance and insulation.
- Anchor the lead wires and connecting wires.
- Apply appropriate protective coating.
- Check bridge wiring and resistance.

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Examples of Bad installation

- Misaligned gage
- Unbonded backing
- Insufficient curing
- Bumps and wrinkles in the grid
- Trapped gas bubbles
- Uneven adhesive layer
- Bad lead wire soldering
- Insufficient insulation or protection

http://www.vishay.com/brands/measurements_group/guide/ta/iv/iv.htm

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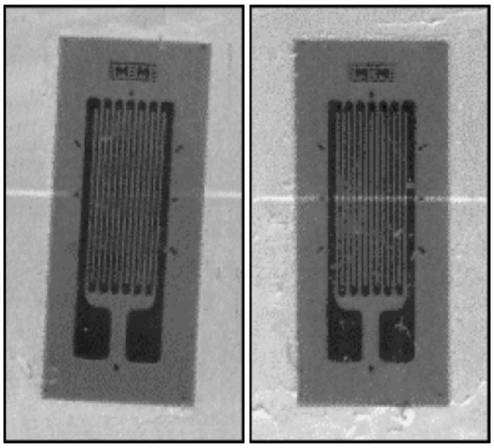
Examples of Bad installation

➢ Gage Misalignment



Misaligned Aligned

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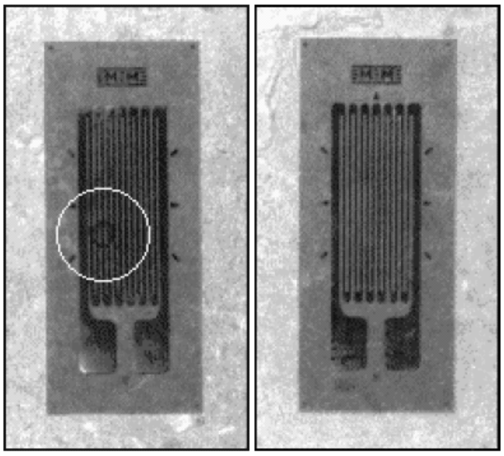
Examples of Bad installation

➢ Trapped gas bubble



Unacceptable Bubble-free

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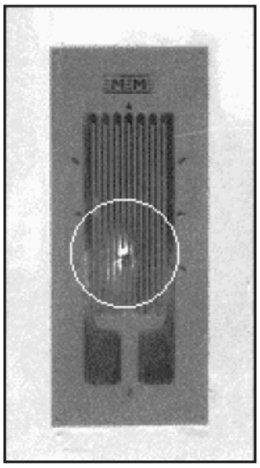
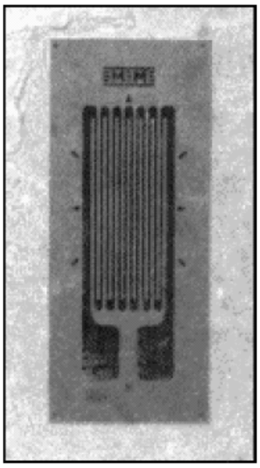
Examples of Bad installation

- Trapped foreign matter



Unacceptable



Bump-free

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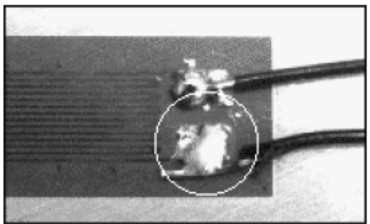
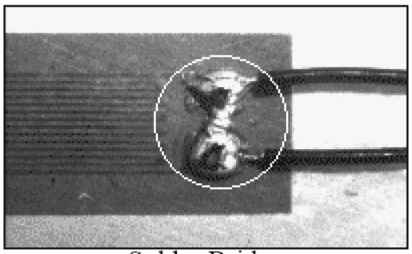
Examples of Bad installation

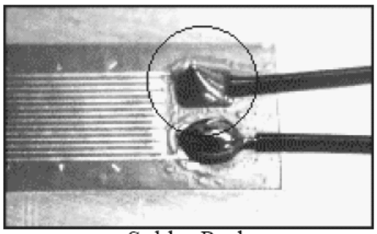
Bad solder joint



Cold Solder Joint

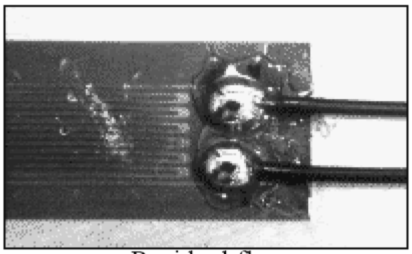


Solder Bridge



Solder Peak

Interfere with flux removal and environmental protection



Residual flux

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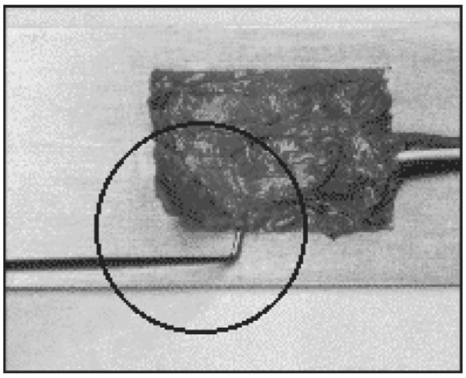
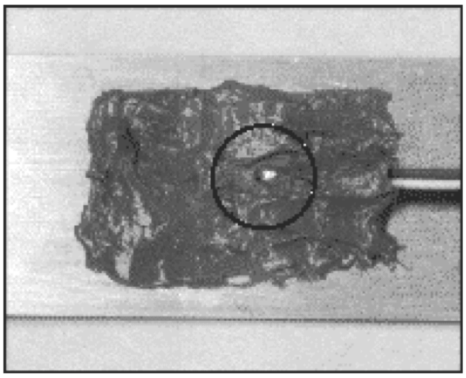
Examples of Bad installation

➢ Defective protective coating



Unbonded Coating



Coating Void

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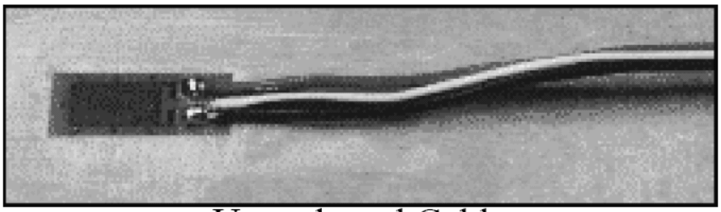
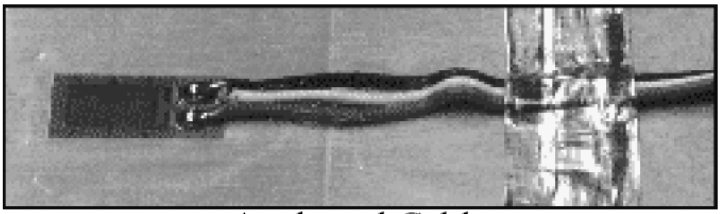
Examples of Bad installation



Unanchored Cable



Anchored Cable

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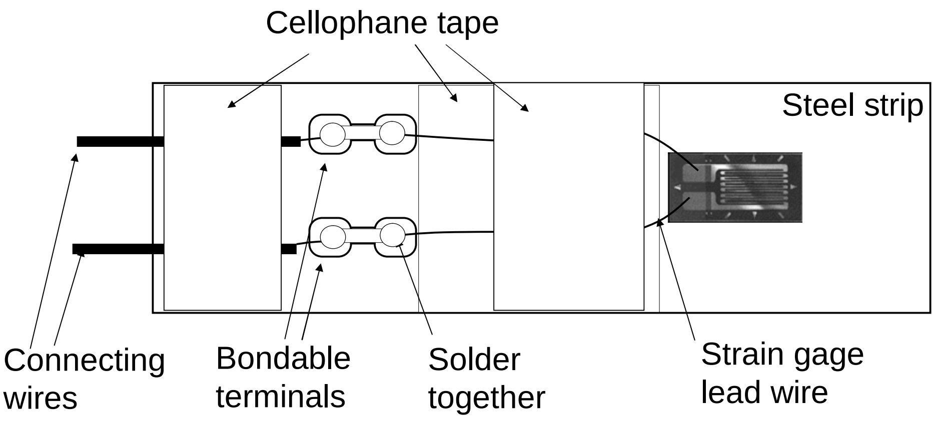
Examples of Bad installation

- Good lead wire anchoring practice
  (with bondable terminals)



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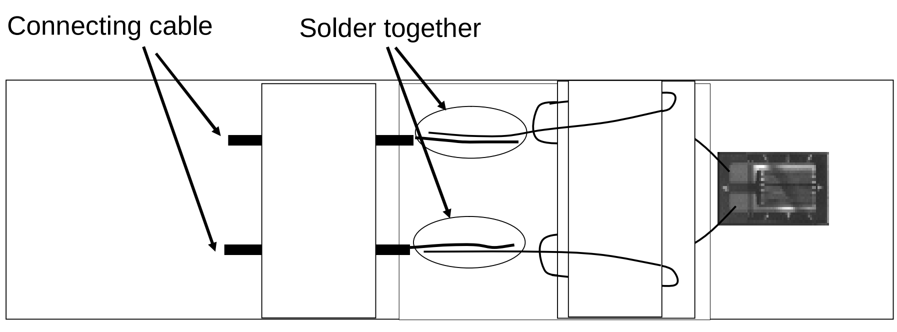
Examples of Bad installation

- Good lead wire anchoring practice
  (without bondable terminals)



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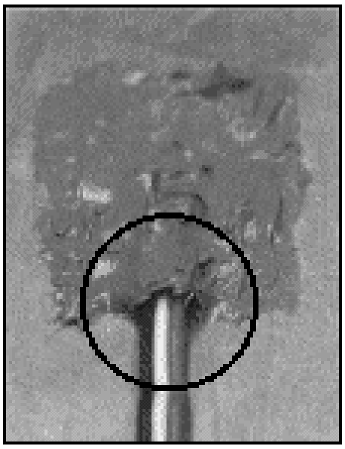
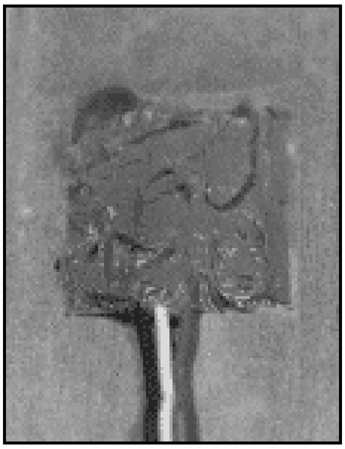
Examples of Bad installation

- Lead wire motion leading to tunnel in coating



Tunnel



No Tunnel

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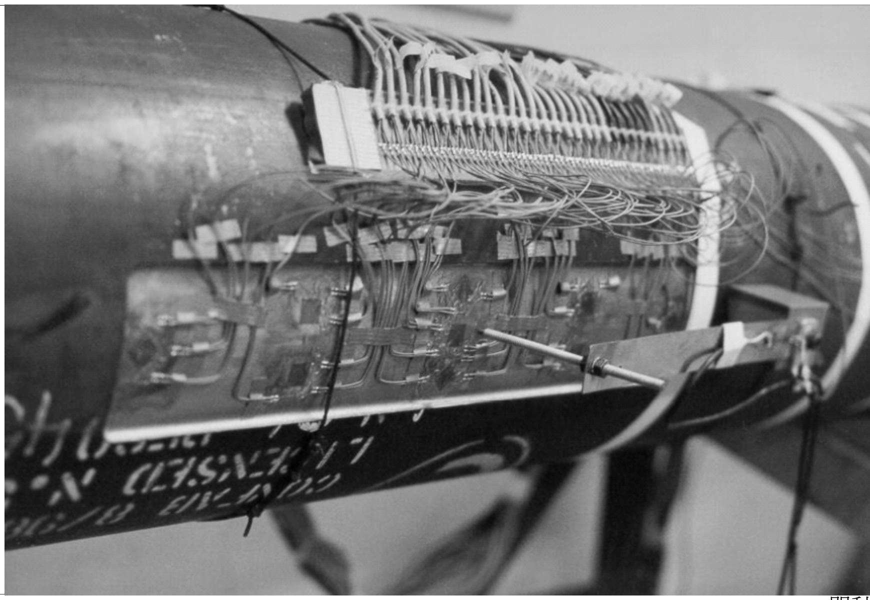

http://www.eng.ucalgary.ca/PEC/2004/2_PUC_Presentation.PDF 單秋成

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The Wheatstone Bridge

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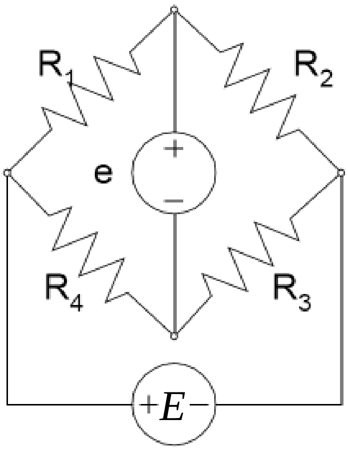
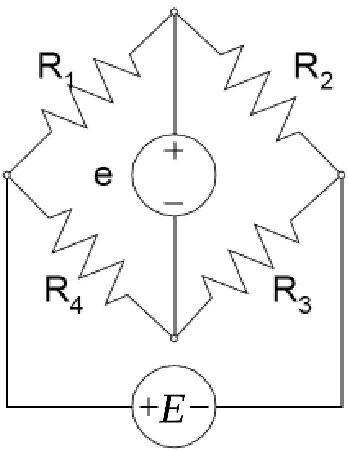
The Wheatstone bridge



$$e = \left[\frac{R_2}{R_1 + R_2} - \frac{R_3}{R_3 + R_4}\right]E$$

http://www.ae.gatech.edu/people/jcraig/ae3145/Lab2/strain-gages.pdf 單秋成

The Wheatstone bridge



$$e = \left[\frac{R_2}{R_1 + R_2} - \frac{R_3}{R_3 + R_4}\right]E$$

$$= \frac{R_2R_4 - R_1R_3}{(R_1 + R_2)(R_3 + R_4)}E$$

Bridge balanced if:

$$R_2\, R_4 = R_1\, R_3$$

Suppose $R_1 = R_4$, $R_2 = R_3$

$$de = \frac{\partial e}{\partial R_1}dR_1 + \frac{\partial e}{\partial R_2}dR_2 + \frac{\partial e}{\partial R_3}dR_3 + \frac{\partial e}{\partial R_4}dR_4$$

http://www.ae.gatech.edu/people/jcraig/ae3145/Lab2/strain-gages.pdf 單秋成

The Wheatstone bridge

$$de = \frac{\partial e}{\partial R_1} dR_1 + \frac{\partial e}{\partial R_2} dR_2 + \frac{\partial e}{\partial R_3} dR_3 + \frac{\partial e}{\partial R_4} dR_4$$

or

$$de = \left[\frac{R_1 R_2}{(R_1 + R_2)^2} \left(\frac{dR_1}{R_1} - \frac{dR_2}{R_2} \right) + \frac{R_3 R_4}{(R_3 + R_4)^2} \left(\frac{dR_3}{R_3} - \frac{dR_4}{R_4} \right) \right] E$$

Ignoring second order terms: Non-linearity may occur!!

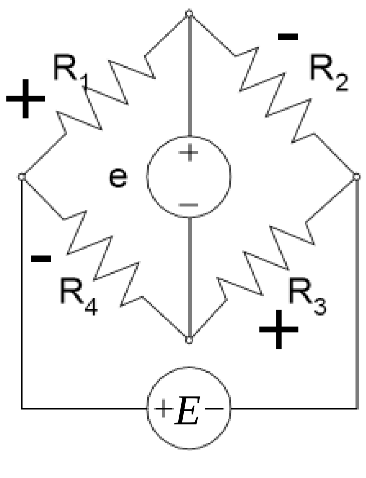
$$de = \tfrac{1}{4} \left[\frac{dR_1}{R_1} - \frac{dR_2}{R_2} + \frac{dR_3}{R_3} - \frac{dR_4}{R_4} \right] E$$

Note the signs!

$$de = \frac{GF}{4} [\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4] E$$

http://www.ae.gatech.edu/people/jcraig/ae3145/Lab2/strain-gages.pdf 單秋成

The Wheatstone bridge



$$de = \tfrac{1}{4} \left[\frac{dR_1}{R_1} - \frac{dR_2}{R_2} + \frac{dR_3}{R_3} - \frac{dR_4}{R_4} \right] E$$

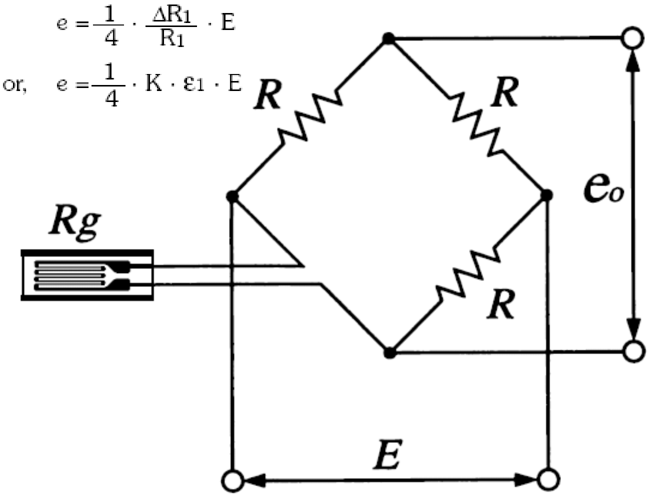
$$de = \frac{GF}{4} [\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4] E$$

http://www.ae.gatech.edu/people/jcraig/ae3145/Lab2/strain-gages.pdf 單秋成

How to form a bridge

$$e = \frac{1}{4} \cdot \frac{\Delta R_1}{R_1} \cdot E$$

or, $$e = \frac{1}{4} \cdot K \cdot \varepsilon_1 \cdot E$$



Quarter bridge.

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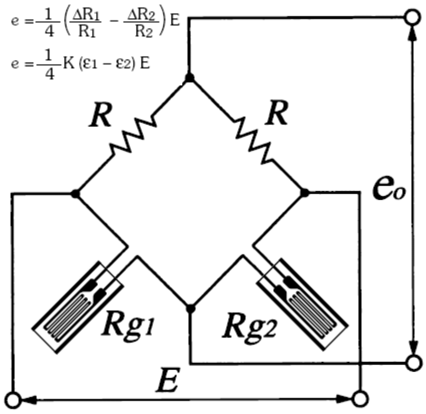
How to form a bridge

$$e = \frac{1}{4}\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2}\right) E$$

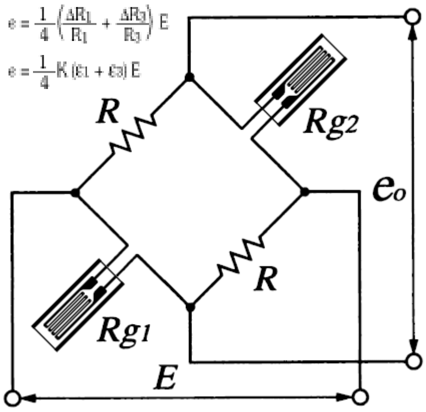
or, $$e = \frac{1}{4} K (\varepsilon_1 - \varepsilon_2) E$$



For strains of different signs.

$$e = \frac{1}{4}\left(\frac{\Delta R_1}{R_1} + \frac{\Delta R_3}{R_3}\right) E$$

or, $$e = \frac{1}{4} K (\varepsilon_1 + \varepsilon_3) E$$



For strains of the same signs.

Half bridge.

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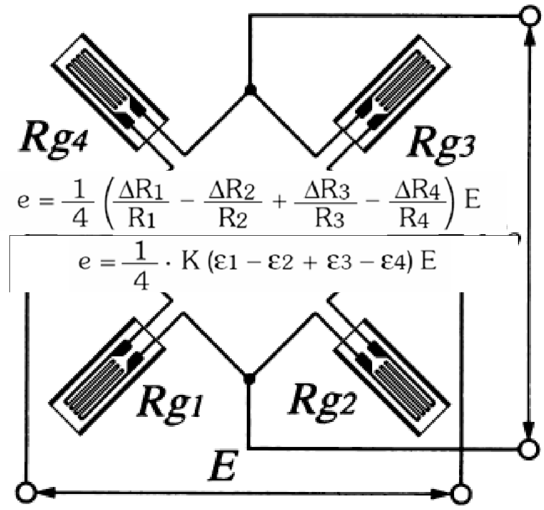
How to form a bridge



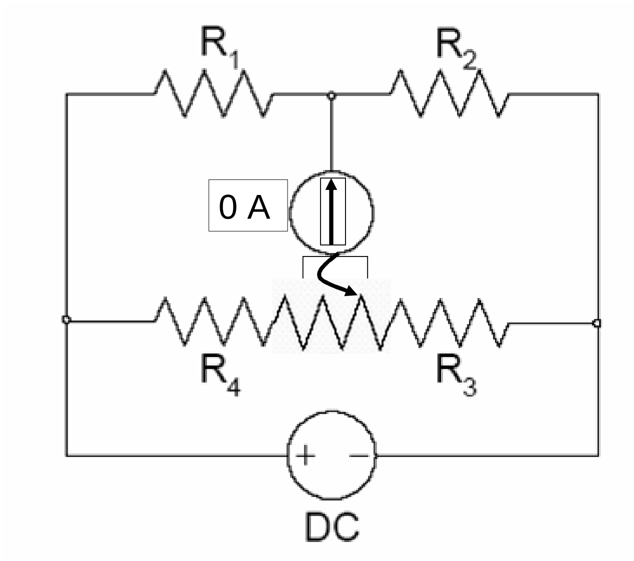
$$e = \frac{1}{4}\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right) E$$

$$e = \frac{1}{4} \cdot K\,(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4)\,E$$

Full bridge.

Interrogating the Wheatstone Bridge

The null indication method



Slow and inefficient!

Not easily automated!

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Basic Op-Amp circuits

Differential Amplifier

Rule II : $(V_1 - V_-)/R_1 = I_1 = (V_- - V_{out})/R_f$

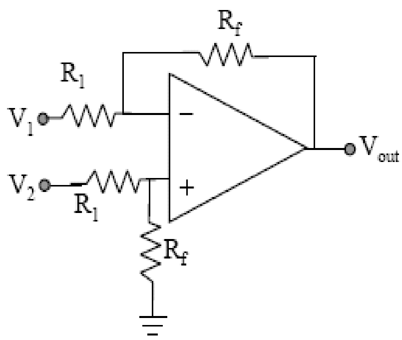
so: $V_- = (V_1R_f + V_{out}R_1)/(R_1 + R_f)$

Rule II : $(V_2 - V_+)/R_1 = I_2 = V_+/R_f$

so: $V_+ = V_2R_f/(R_1 + R_f)$

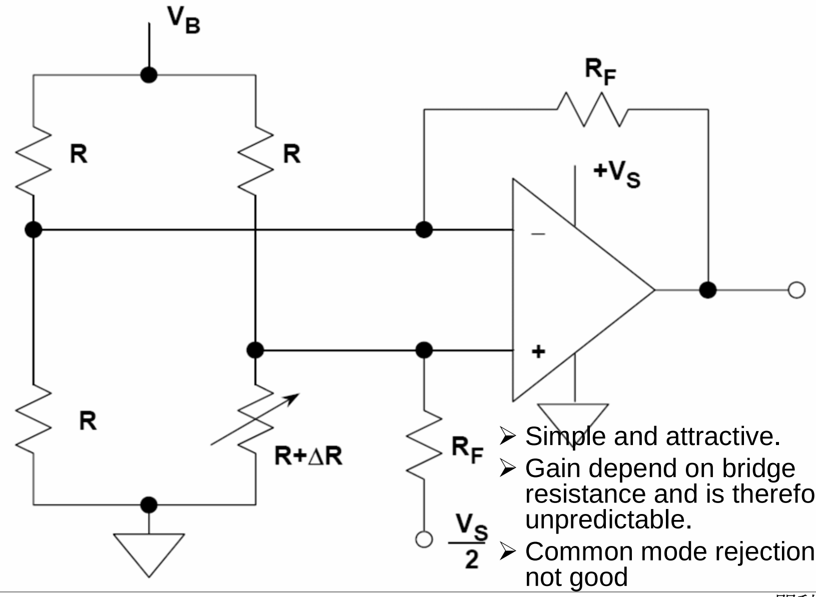
Since $V_+ = V_-$, can write as

$$V_{out} = (V_2 - V_1)R_f/R_1$$



- Another option for carrying out subtraction.
- Good common mode rejection.

http://www.ee.unb.ca/Courses/EE3121/AdditionalMaterial/OpAmpsIntro.pdf 單秋成



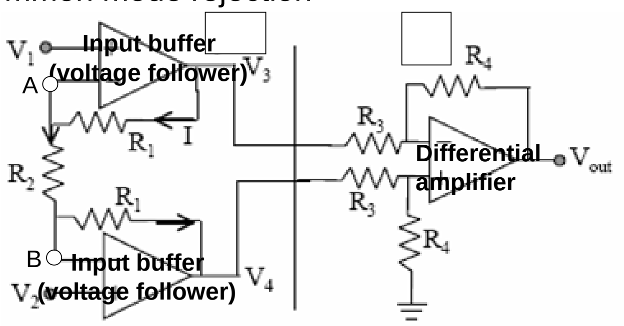
- Simple and attractive.
- Gain depend on bridge resistance and is therefore unpredictable.
- Common mode rejection not good

www. analog.com\library\analogDialogue\archives\39-05\Web_Ch4_final.pdf 單秋成

Basic Op-Amp circuits

Instrumentation Amplifier

Main aim is to improve the input impedance while maintaining a good common mode rejection



Rule II: no input I, ∴same I flows thru R_1-R_2-R_1

Rule I: $V_A=V_1$, $V_B=V_2$,∴ $(V_1-V_2)=IR_2$

Also $(V_3-V_1)=IR_1$, $(V_2-V_4)=IR_1$, ∴ $V_4 - V_3=(V_2-V_1) -2(V_1-V_2) R_1/R_2$

$V_{out} =R_4/R_3(V_4 - V_3)=$ $\boxed{(V_2-V_1) (1+ 2R_1/R_2) R_4/R_3}$

http://www.ee.unb.ca/Courses/EE3121/AdditionalMaterial/OpAmpsIntro.pdf 單秋成

3 Op-amp in-amp single chip

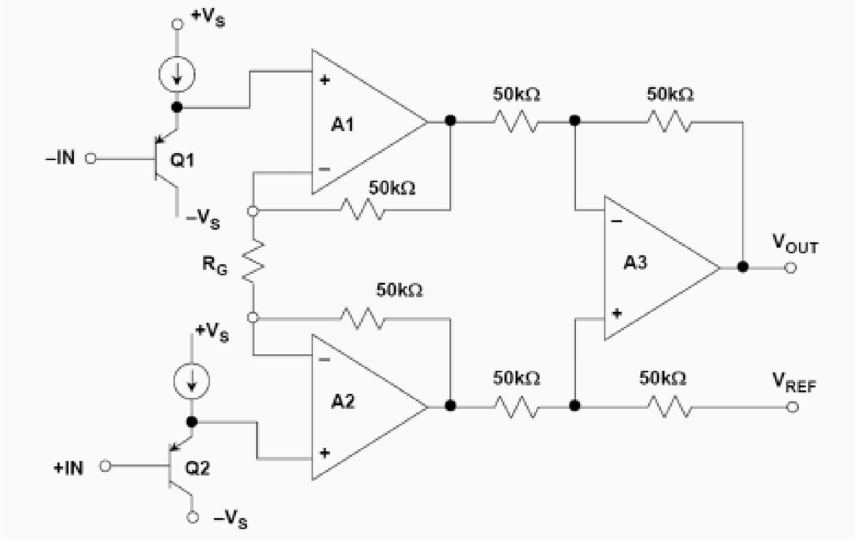
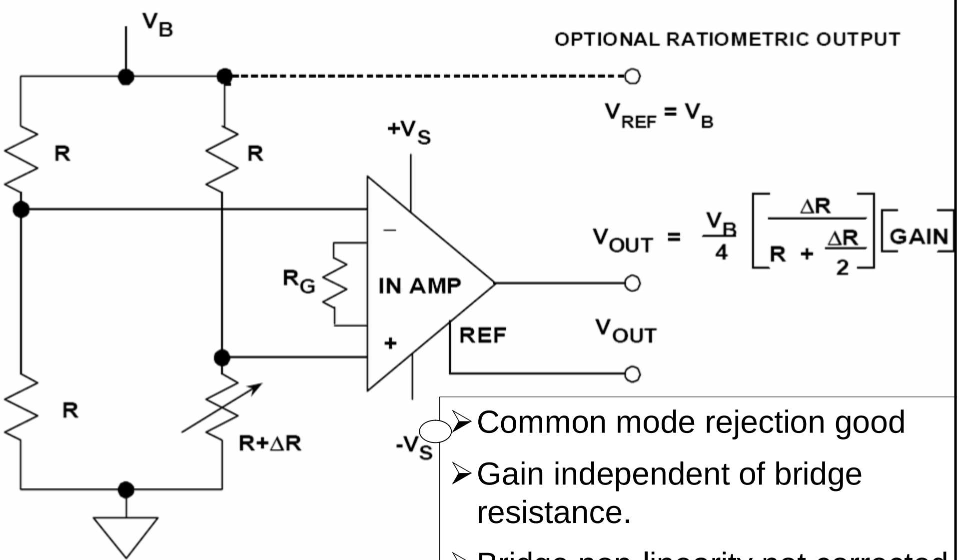


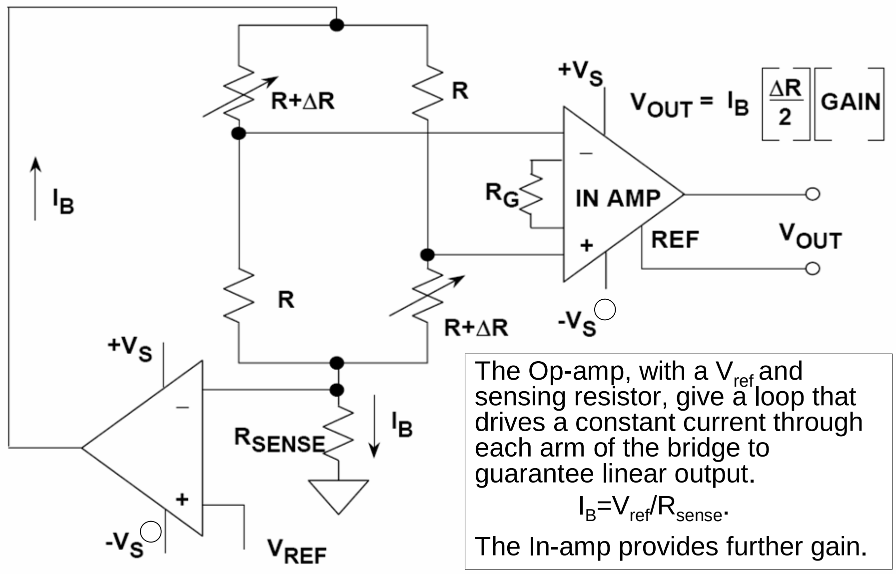
Figure 2-17: *AD623 single-supply in-amp architecture*

http://www.analog.com/library/analogDialogue/archives/39-05/op_amp_applications_handbook.html 單秋成



- Common mode rejection good
- Gain independent of bridge resistance.
- Bridge non-linearity not corrected

www. analog.com\library\analogDialogue\archives\39-05\Web_Ch4_final.pdf 單秋成



The Op-amp, with a V_{ref} and sensing resistor, give a loop that drives a constant current through each arm of the bridge to guarantee linear output.

$I_B = V_{ref}/R_{sense}$.

The In-amp provides further gain.

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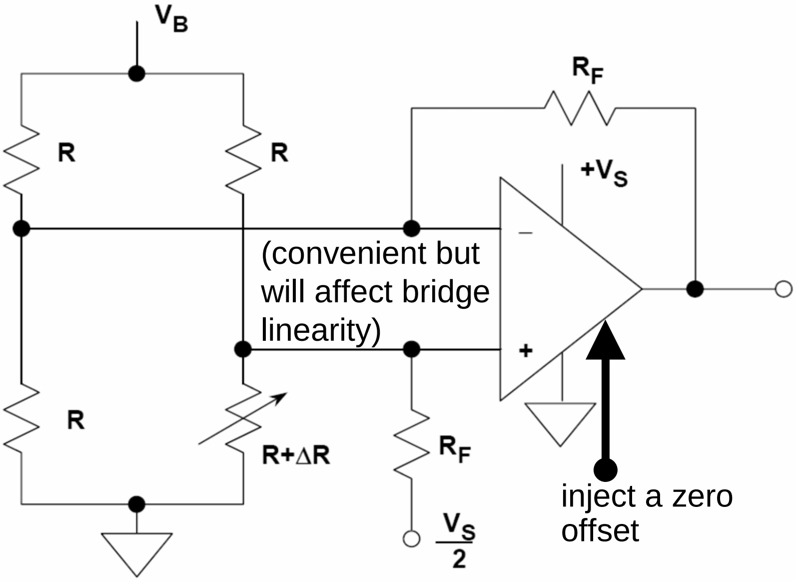
Bridge balancing



http://www.ae.gatech.edu/people/jcraig/ae3145/Lab2/strain-gages.pdf

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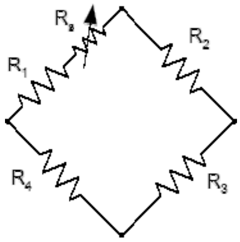
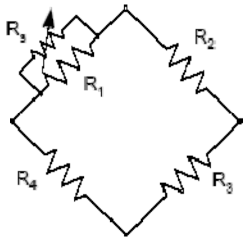
Bridge balancing

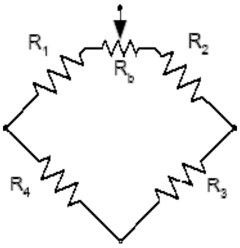


(a) Series

Series R:
Must be very small.
Difficult to apply!

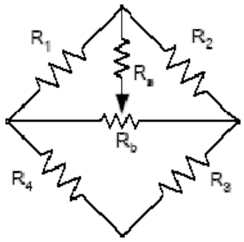


(b) Shunt



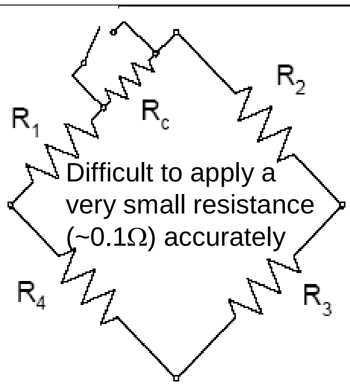
(c) Potentiometric

Shunt R:
Usually large.
Easier to apply!



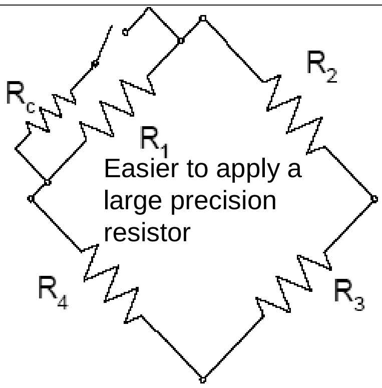
(d) General

Bridge Calibration



Difficult to apply a very small resistance (~0.1Ω) accurately

(a) Series



Easier to apply a large precision resistor

(b) Shunt

$$v = A\frac{GF}{4}[\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4]E$$

Introduction to resistance strain gage

- Equipment for strain measurement.
- Basic theory of resistance strain gage
- Fundamental structure of strain gages
- How to Install a strain gage
- The Wheatstone bridge
- Factors that affect the accuracy of strain gages
- How to select a suitable strain gage

Temperature induced apparent strain

Temperature induced apparent strain

Temperature affects:

- Resistivity of a material.
- Thermal expansion of the
  - ✓ gage material
  - ✓ structure to be measured.

Note that the temp. effects vary with temperature

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Temperature effect

Table 2. Properties of Various Strain Gage Grid Materials

Material	Composition	Use	GF	Resistivity (Ohm/mil-ft)	Temp. Coef. of Resistance (ppm/F)	Temp. Coef. of Expansion (ppm/F)	Max Operating Temp. (F)
Constantan	45% NI, 55% Cu	Strain Gage	2.0	290	6	8	900
Isoelastic	36% Ni, 8% Cr, 0.5% Mo, 55.5% Fe	Strain gage (dynamic)	3.5	680	260		800
Manganin	84% Cu, 12% Mn, 4% Ni	Strain gage (shock)	0.5	260	6		
Nichrome	80% Ni, 20% Cu	Ther-mometer	2.0	640	220	5	2000
Iridium-Platinum	95% Pt, 5% Ir	Ther-mometer	5.1	135	700	5	2000
Monel	67% Ni, 33% Cu		1.9	240	1100		
Nickel			-12	45	2400	8	
Karma	74% Ni, 20% Cr, 3% Al, 3% Fe	Strain Gage (hi temp)	2.4	800	10		1500

http://www.ae.gatech.edu/people/jcraig/ae3145/Lab2/strain-gages.pdf

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Temperature effect

Table 2. Properties of Various Strain Gage Grid Materials

Material	Composition	Use	GF	Resistivity (Ohm/mil-ft)	Temp. Coef. of Resistance (ppm/F)	Temp. Coef. of Expansion (ppm/F)	Max Operating Temp. (F)
Constantan	45% NI, 55% Cu	Strain Gage	2.0	290	6	8	900

For a "constantan" gage on an aluminum substrate with a thermal expansion coefficient of 13 ppm/ ^oF, the differential thermal expansion strain is:

$$\varepsilon = 13 - 8 = 5 \ \textit{microstrain} / {}^oF$$

Thus the net apparent strain due to resistive as well as expansion effects would be roughly:

$$\varepsilon = 3 + 5 = 8 \ \textit{microstrain} / {}^oF$$

Note: GF=2.0

$$GF = \frac{dR/R}{\varepsilon}$$

http://www.ae.gatech.edu/people/jcraig/ae3145/Lab2/strain-gages.pdf 單秋成

Self Temperature compensated gages

(STC gages)

The temperature coefficients of the grid materials depend on:

- ✓ Alloying contents.
- ✓ Degree of cold working/heat treatment.

Hence there is a batch to batch difference in temperature coefficient even for the same alloy.

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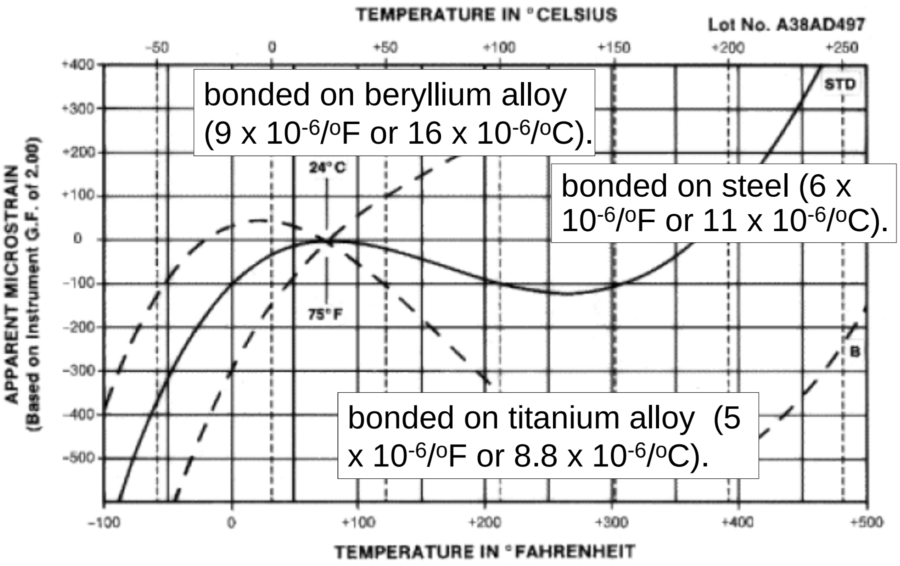
Self Temperature compensated gages



http://www.vishay.com/brands/measurements_group/guide/tn/tn513/513b.htm

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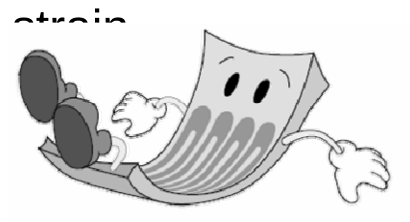
Temperature compensation

➢ Temperature effect on strain measurement



✓ Temperature coefficient of the grid.

✓ Thermal expansion mismatch between the gage material and the substrate structure.

✓ Lead wire resistance changes.

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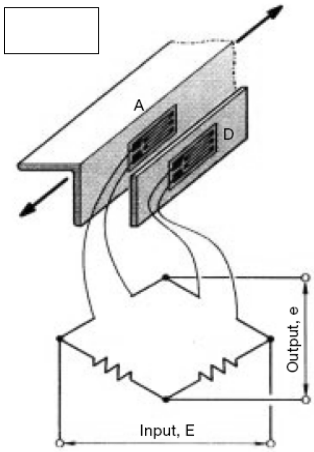
Temperature compensation

➢ Active-dummy method



http://www.kyowa-ei.co.jp/english/images/whats.pdf

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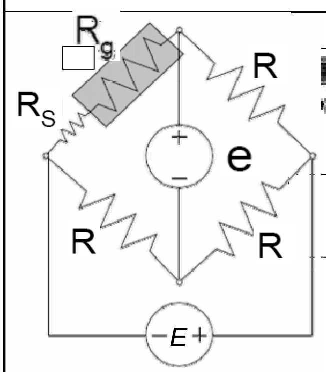
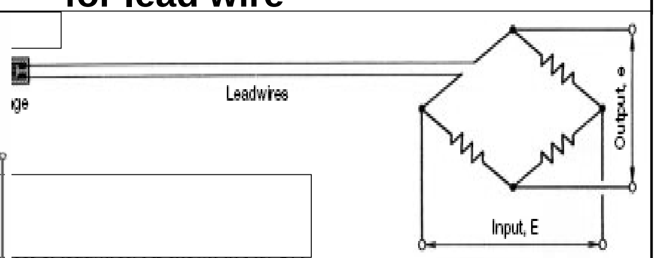
Temperature compensation
for lead wire





For remote measurement, the lead wire resistance is considerable and will:

- ➢ subject to temperature effects.
- ➢ Cause desensitization of signals.

http://www.ae.gatech.edu/people/jcraig/ae3145/Lab2/strain-gages.pdf http://www.kyowa-ei.co.jp/english/images/whats.pdf

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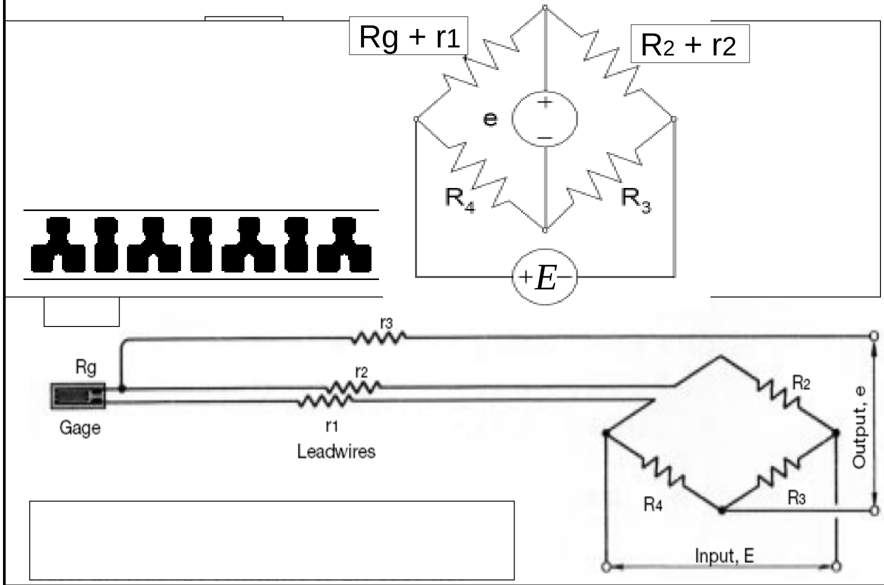
Temperature compensation

for lead wire (3 lead wire technique)



http://www.kyowa-ei.co.jp/english/images/whats.pdf

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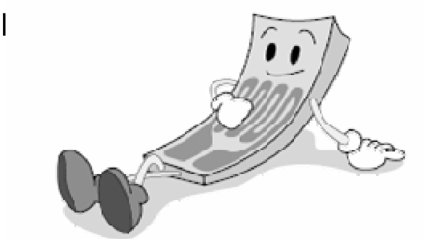
Other factors that will affect a strain gage

- Large plastic strain
- Corrosive environment
- Cyclic fatigue
- Magnetic field



http://www.kyowa-ei.co.jp/english/images/whats.pdf

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Selecting a gage

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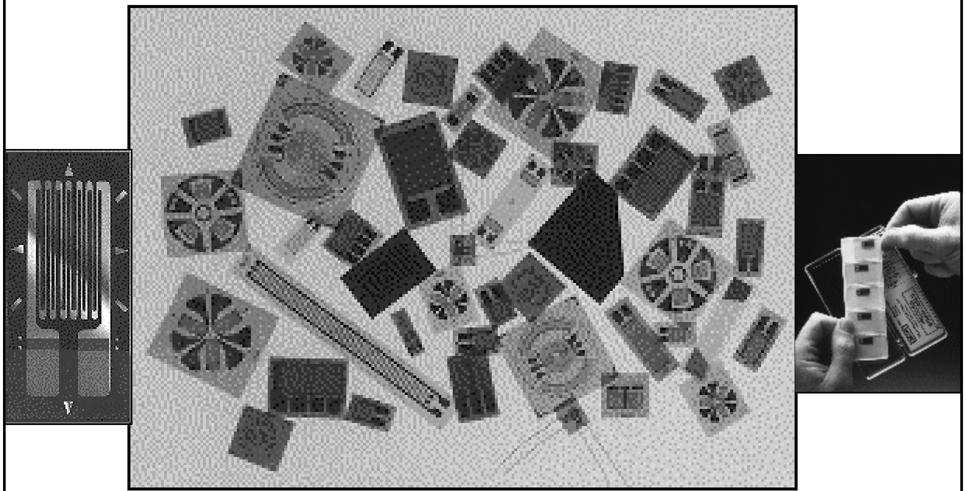
Different types of strain gages



http://www.vishay.com/brands/measurements_group/strain_gages/mm.htm

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Different types of strain gages

- Difference in make-up
  - ✓ Backing sheets
  - ✓ Metal foil
  - ✓ cement
- Difference in sizes
- Difference in shapes

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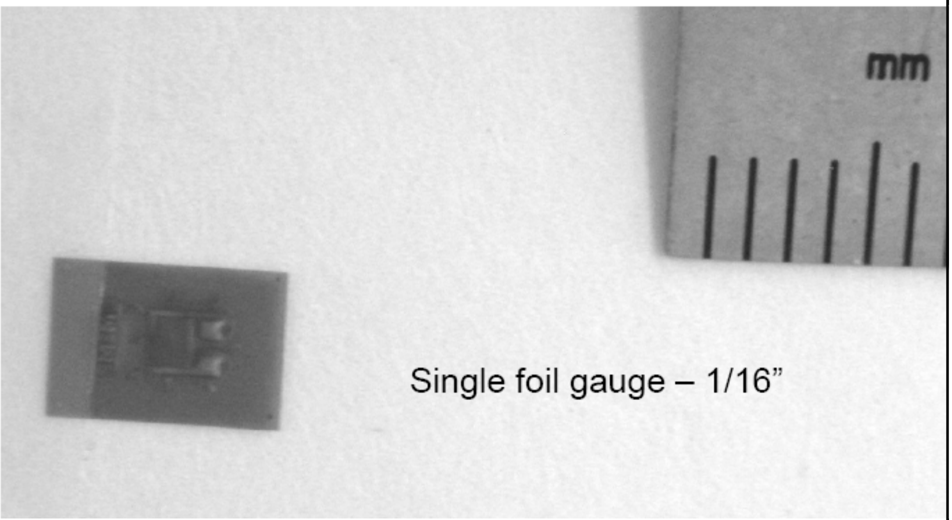
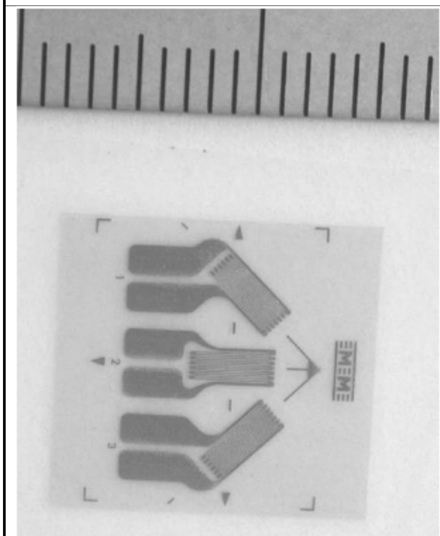
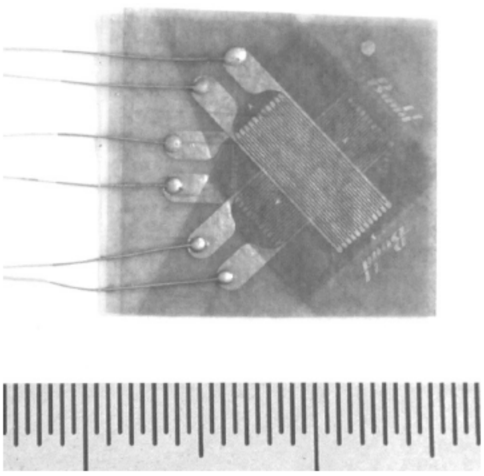


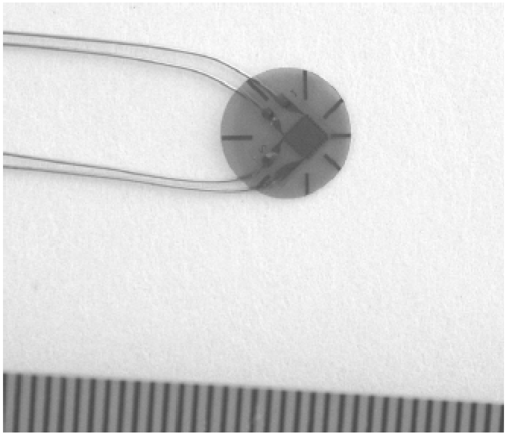
http://courses.washington.edu/mengr556/Examples%20of%20strain%20gauges.pdf 單秋成





Rectangular rosettes – 3 gauges at 45 degrees

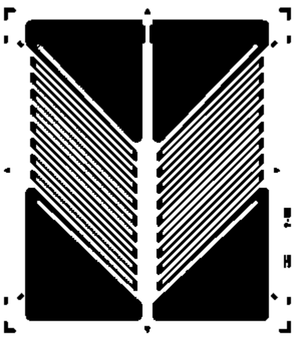
http://courses.washington.edu/mengr556/Examples%20of%20strain%20gauges.pdf 單秋成

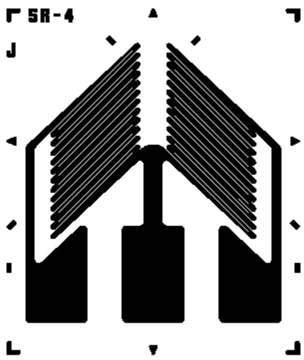


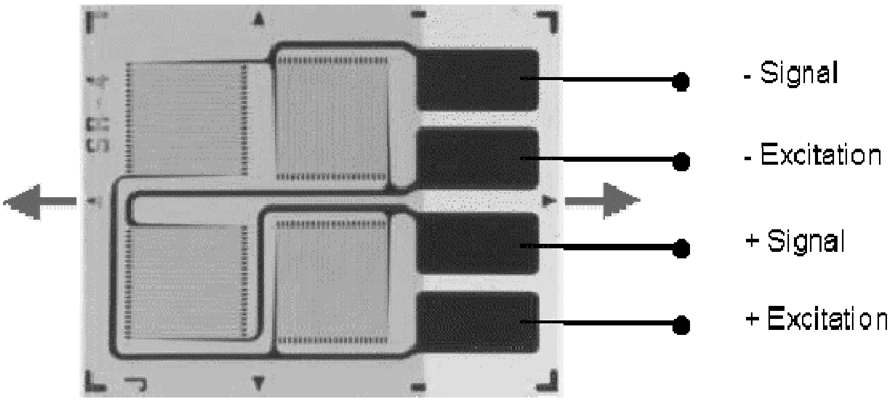
2 gauge 90 degree rosette

http://courses.washington.edu/mengr556/Examples%20of%20strain%20gauges.pdf

- For shear and torque measurement



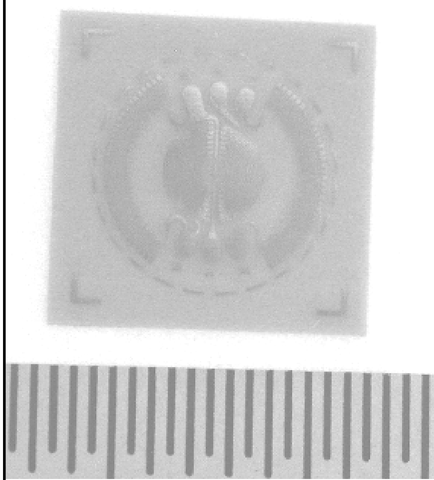


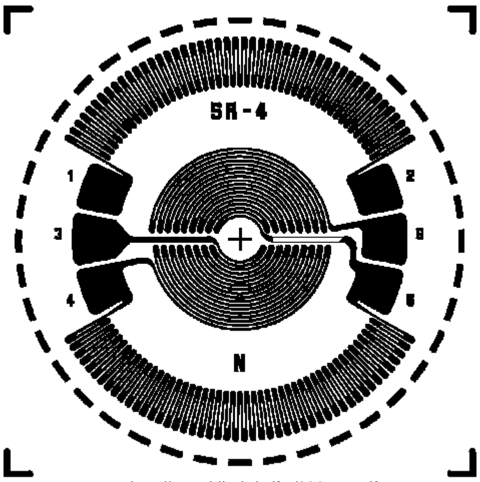


Full bridge gages for bending beam.

http://www.blh.de/wiring.htm 單秋成

Circular diaphragm gage for pressure transducers

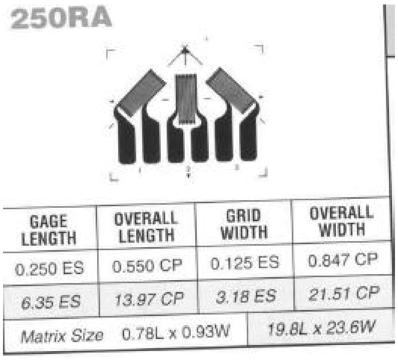




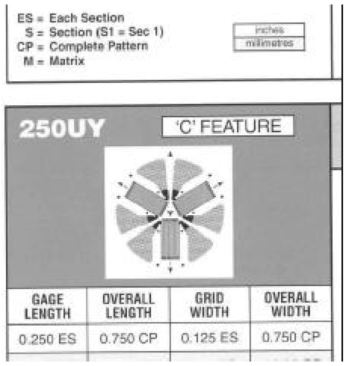
http://www.blh.de/pdftg/306p14.pdf

http://courses.washington.edu/mengr556/Examples%20of%20strain%20gauges.pdf 單秋成

Examples of special gauge layouts:



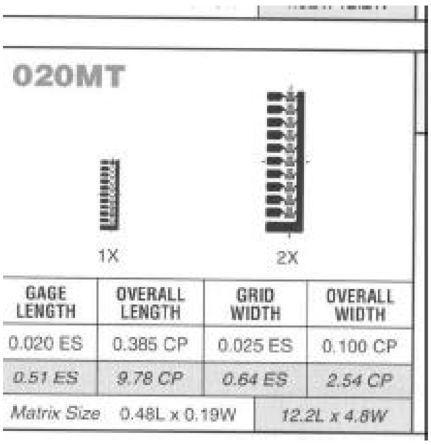
GAGE LENGTH	OVERALL LENGTH	GRID WIDTH	OVERALL WIDTH
0.250 ES	0.550 CP	0.125 ES	0.847 CP
6.35 ES	*13.97 CP*	*3.18 ES*	*21.51 CP*
Matrix Size	0.78L x 0.93W	*19.8L x 23.6W*	



GAGE LENGTH	OVERALL LENGTH	GRID WIDTH	OVERALL WIDTH
0.250 ES	0.750 CP	0.125 ES	0.750 CP

45 rectangular rosette

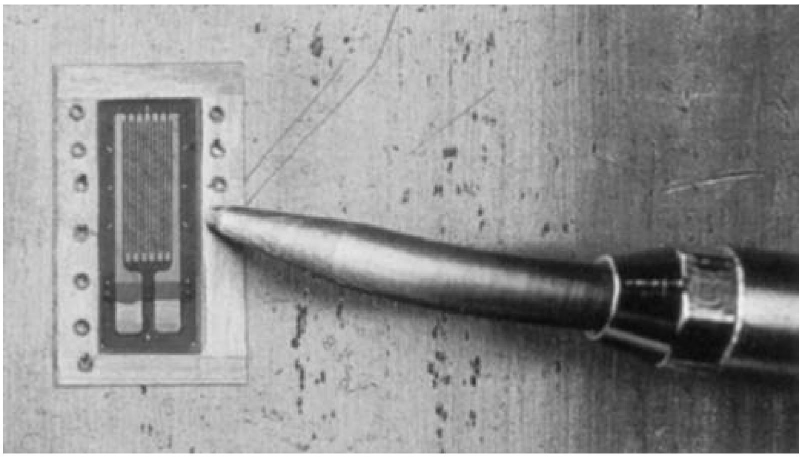
60 delta rosette



GAGE LENGTH	OVERALL LENGTH	GRID WIDTH	OVERALL WIDTH
0.020 ES	0.385 CP	0.025 ES	0.100 CP
0.51 ES	*9.78 CP*	*0.64 ES*	*2.54 CP*
Matrix Size	0.48L x 0.19W	*12.2L x 4.8W*	

Strain gradient gauge

- Weldable strain gage



Measurement Group strain gage catalogue

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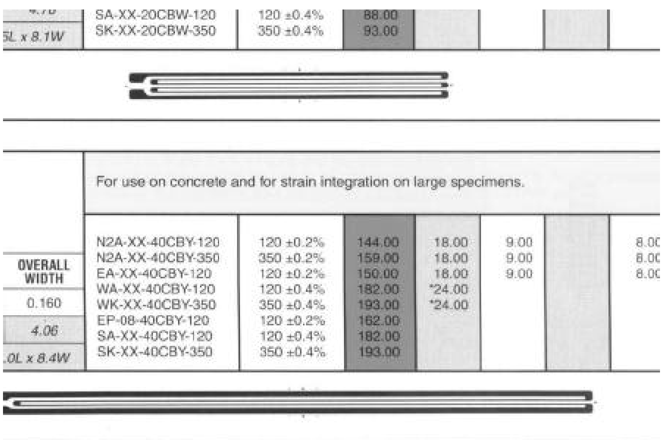

5L x 8.1W	SA-XX-20CBW-120 SK-XX-20CBW-350	120 ±0.4% 350 ±0.4%	88.00 93.00				

	For use on concrete and for strain integration on large specimens.						
OVERALL WIDTH 0.160 4.06 .0L x 8.4W	N2A-XX-40CBY-120 N2A-XX-40CBY-350 EA-XX-40CBY-120 WA-XX-40CBY-120 WK-XX-40CBY-350 EP-08-40CBY-120 SA-XX-40CBY-120 SK-XX-40CBY-350	120 ±0.2% 350 ±0.2% 120 ±0.2% 120 ±0.4% 350 ±0.4% 120 ±0.2% 120 ±0.4% 350 ±0.4%	144.00 159.00 150.00 182.00 193.00 162.00 182.00 193.00	18.00 18.00 18.00 *24.00 *24.00	9.00 9.00 9.00		8.0 8.0 8.0

Examples of gauges used for work on concrete. Note the very long gauges used to measure over a representative sample of aggregate and cement.

http://courses.washington.edu/mengr556/Strain_basics.pdf

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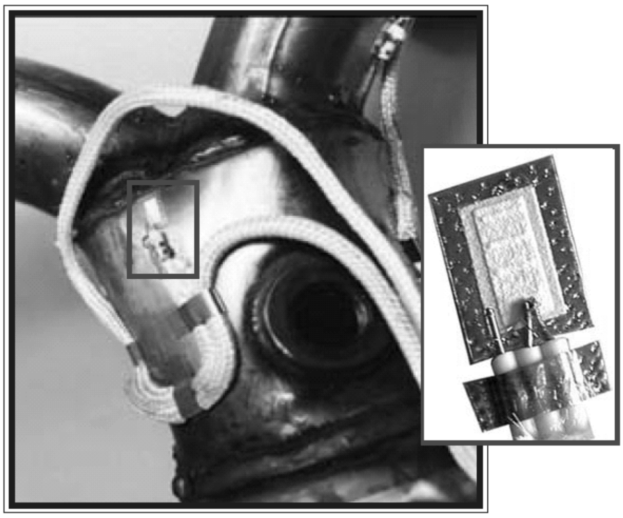
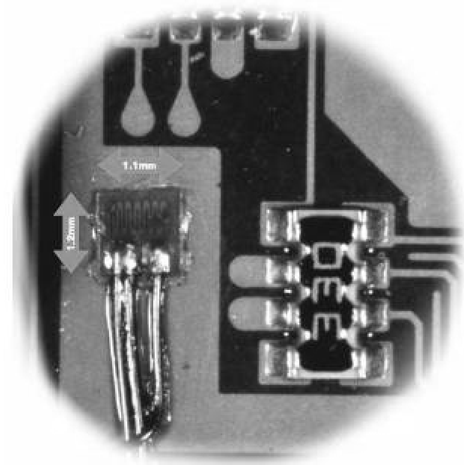


The complex strain measuring system used for jet engine blade vibrations is now available pre-installed on an easily spot weldable shim for test measurements to 1000°C.

HBWANV-12-250-X-2CB

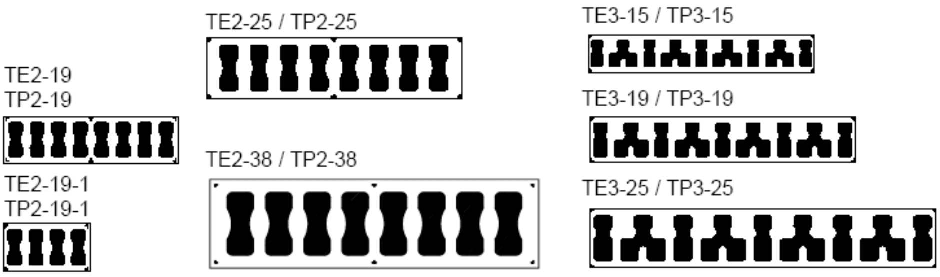
http://www.hitecprod.com/Pdf%20files/70_HtempweldSC.pdf 單秋成



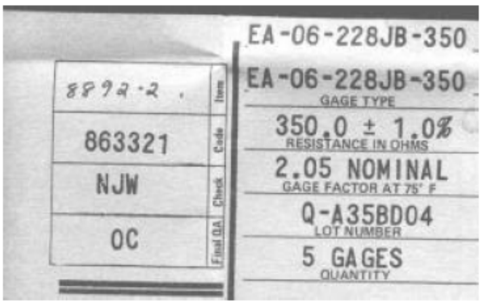
Miniature gage used in printed circuit board

http://www.kyowa-ei.co.jp/english/kfrs/top.htm 單秋成

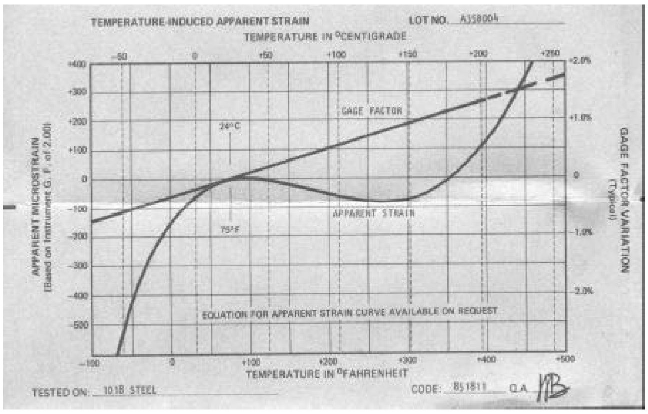
Terminals



Foil gauges are, by the nature of the fabrication process, made in large batches. The characteristics of all gauges in a batch are very consistent. A few gauges in each batch are tested and calibrated and the test values are provided for all gauges in a batch.



Data on the temperature dependence of the characteristics of the gauge are also provided. Note that both the resistance and gauge factor vary with temperature.



http://courses.washington.edu/mengr556/Strain_basics.pdf

How to choose a gage

How to choose a gage

The answer to this question requires the user to define more specifically his application. Namely,

- ✓ What is to be measured?
- ✓ Is this a stress analysis or a transducer application?
- ✓ What are the Ambient Conditions?
- ✓ What is the operating Temperature Range?
- ✓ Is the Magnitude of Strain known?
- ✓ Is the Principal Axis Known?
- ✓ Are there Strain Gradients?
- ✓ What is the duration of the Measurement?
- ✓ Number of cycles
- ✓ Accuracy Requirements

http://www.blh.de/faq.htm

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General selecting procedures

- ➢ Determine the gage alloy and backing material.
- ➢ Self temperature compensation.
- ➢ Gage length and size
- ➢ Gage pattern
- ➢ Other special requirement (fatigue life, maximum strain, maximum service temperature)

TN-505

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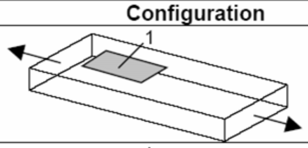
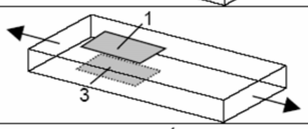
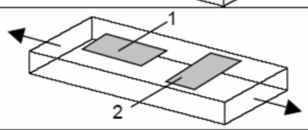
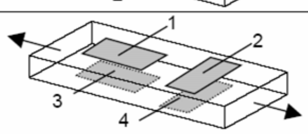
Strain gage layout for different applications

Table 5. Bridge Configurations for Uniaxial Members

K	Configuration	Notes
1		Must use dummy gage in an adjacent arm (2 or 4) to achieve temperature compensation
2		Rejects bending strain but not temperature compensated; must add dummy gages in arms 2 & 4 to compensate for temperature.
$(1+\nu)$		Temperature compensated but sensitive to bending strains
$2(1+\nu)$		**Best**: compensates for temperature and rejects bending strain.

http://www.ae.gatech.edu/people/jcraig/ae3145/Lab2/strain-gages.pdf

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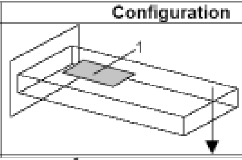
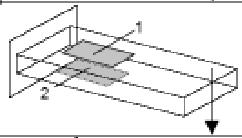
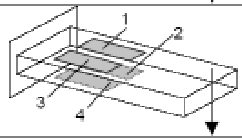
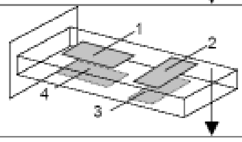
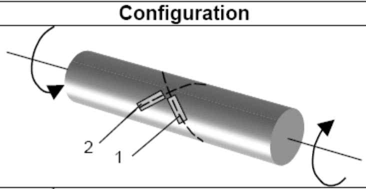
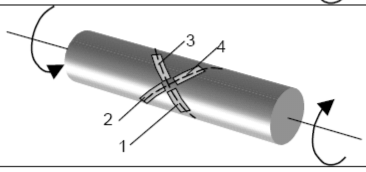
Table 6. Bridge Configurations for Flexural Members

K	Configuration	Notes
1		Also responds equally to axial strains; must use dummy gage in an adjacent arm (2 or 4) to achieve temperature compensation
2		Half-bridge; rejects axial strain and is temperature compensated; dummy resistors in arms 3 & 4 can be in strain indicator.
4		**Best**: Max sensitivity to bending; rejects axial strains; temperature compensated.
2(1+v)		Adequate, but not as good as F-3; compensates for temperature and rejects axial strain.

http://www.ae.gatech.edu/people/jcraig/ae3145/Lab2/strain-gages.pdf 單秋成

Table 7. Bridge Configuration for Torsion Members

No.	K	Configuration	Notes
T-1	2		Half Bridge: Gages at ±45° to centerline sense principal strains which are equal & opposite for pure torsion; bending or axial force induces equal strains and is rejected; arms are temperature compensated.
T-2	4		**Best**: full-bridge version of T-1; rejects axial and bending strain and is temperature compensated.

http://www.ae.gatech.edu/people/jcraig/ae3145/Lab2/strain-gages.pdf 單秋成

END

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Strain gage calibration Lab

準備事項：

（1）帶游標卡尺;

（2）**Review instrumentation amplifier;**

（3）複習黏貼應變計方法與注意事項;

（4）研習**Wheatstone bridge** 相關原理，並嘗試回答預習報告中的相關問題；

（5）複習梁之彎曲理論，請預先計算一厚度為 t mm, 曲率半徑為 R mm之梁，其表面應變為若干。

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Strain gage calibration Lab

1. Sticking of strain gage.
2. Soldering of lead wire.
3. Bridge completion.
4. Bridge balancing.
5. Direct calibration:- Strip bending.
6. Indirect calibration:- Shunt calibration.
7. Strain gage amplifier characteristics

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Strain gage calibration Lab

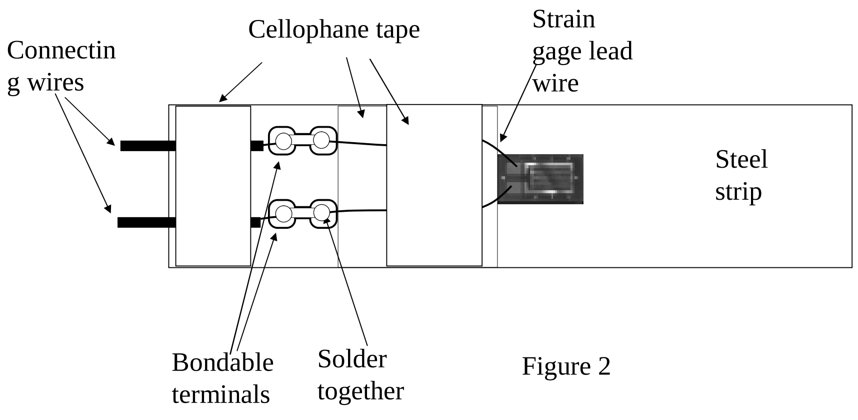

Figure 2

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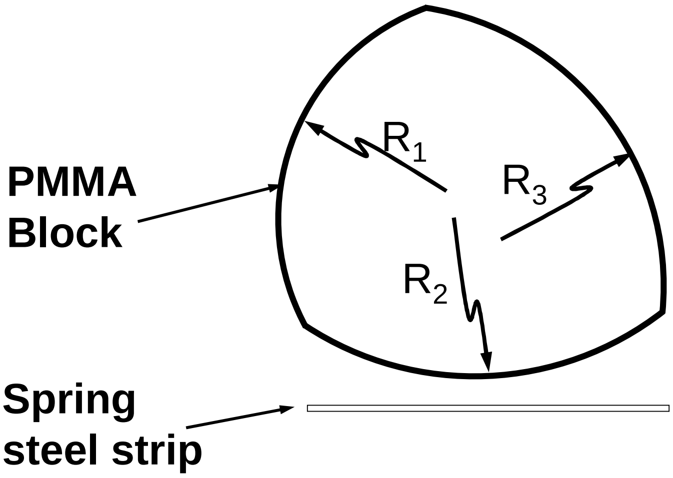
Generating a chosen curvature



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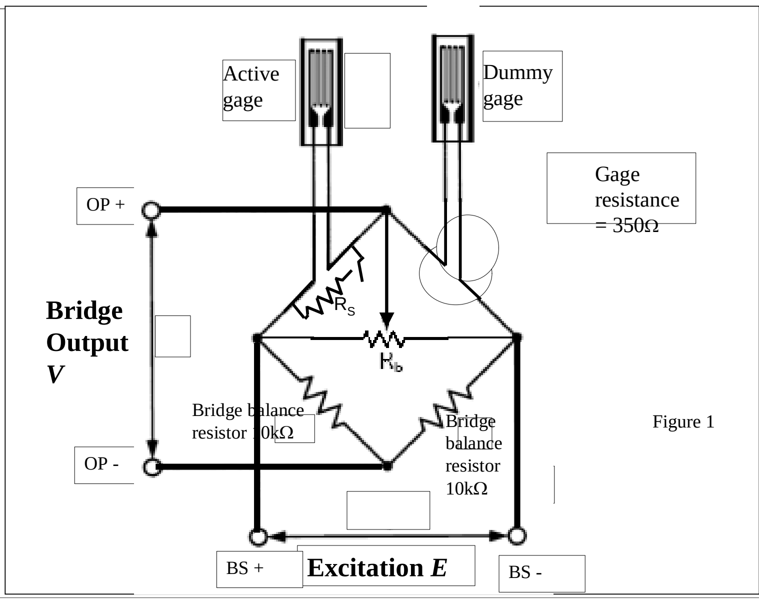
Strain gage calibration Lab



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Strain gage calibration Lab

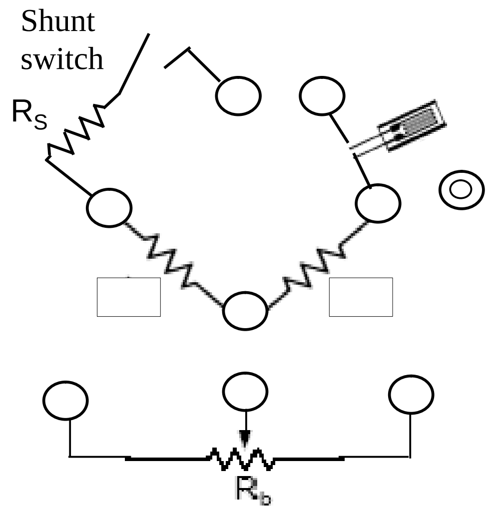

Figure 3: Bridge completion box layout.

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預習報告

- Suppose R_b and R_s are non-existent, what is the relationship between the Bridge output voltage *V*, Excitation *E* and the change in resistance ΔR_g in the active gage.
- What is the gage factor? In the absence of R_b and R_s, what is the relationship between the Bridge output voltage *V*, Excitation *E* and the strain ε sensed by the active gage?
- The bridge balance resistors provided are 10 kΩ, *Can they have different values?*

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預習報告

- What is the use of R_b in the bridge circuit in Figure 1? Please briefly explain the underlying principle.
- What is the use of R_s in the bridge circuit in Figure 1? Please briefly explain the underlying principle.
- Suppose R_s =100kΩ and the bridge is initially balanced. What will the bridge output voltage become if R_s is shunted across the active gage.

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預習報告

- What happen if +ve and –ve bridge excitation voltage are interchanged?
- What happen if the bridge output and bridge excitations are interchanged (ie. OP+ is interchanged with BS+ and OP- is interchanged with BS-)?
- What is the relation between the surface strain, radius of curvature, Young's modulus and the thickness of a beam under bending?

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Strain gage amplifier characteristics

- What happen if you interchange the BS+ and BS-?
- What happen if you interchange the OP+ and OP-?
- What happen if you have not zero the bridge before measurement?