Sensors

Ref :T. **Shimamoto, Seminar design (2013),** Tullis and Tullis, Experimetal deformation techniques (1986), Paterson and Wong Experimental rock déformation: the brittle field (2005), ...

Introduction

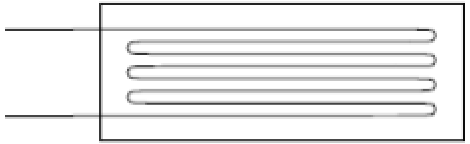
These are the sensors that convert the physical quantities essential to measurement objectives into electrical quantities that are easily measurable and recordable.

Common sensors:

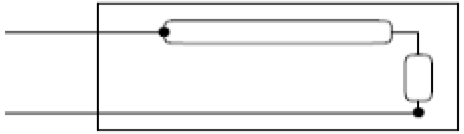
- Temperature sensors
- Strain gauge sensors
- Displacement sensors
- Piezoelectric sensors

Strain gages

- 2 types: train gauge sensor with metallic or semiconductor grid

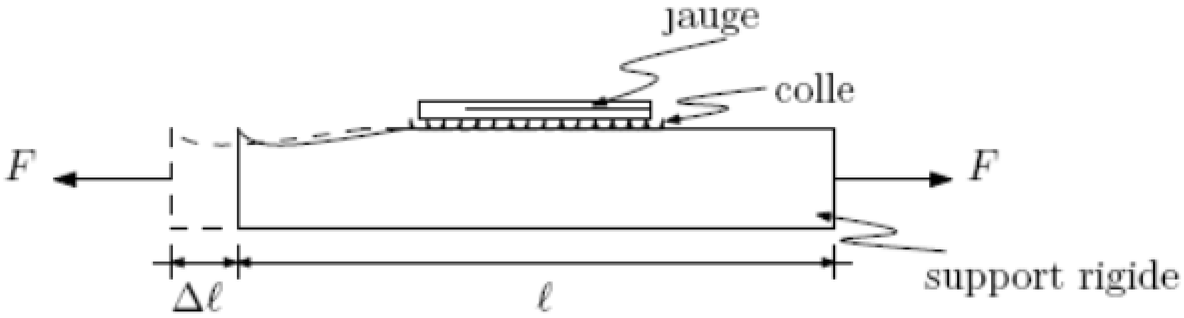


Jauge métallique

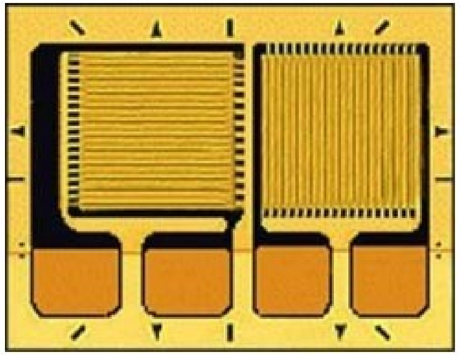


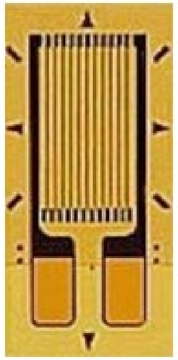
Jauge à semi conducteur

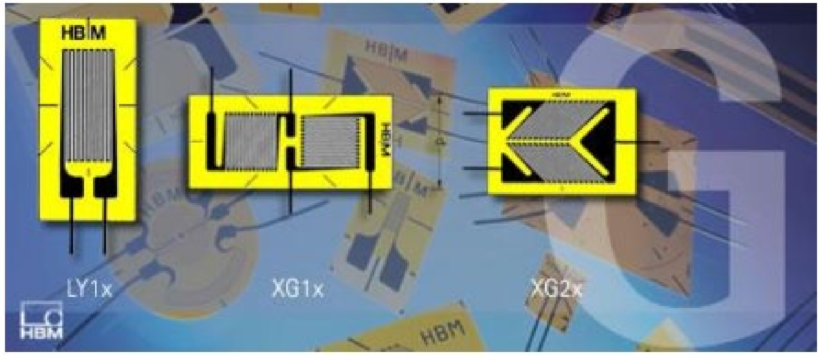
They are embedded in a flexible film that can be adhered to a rigid support.



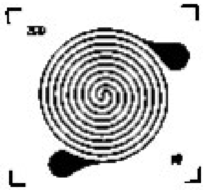
Strain gages

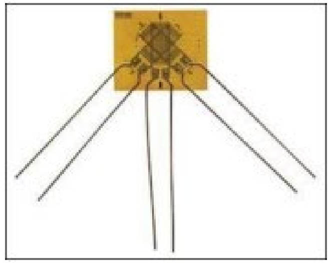

Jauges biaxiales Vishay

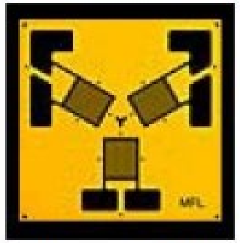

Jauges Vishay



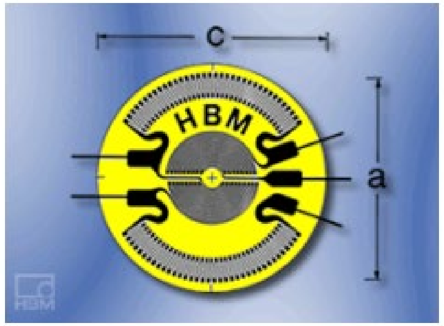
Diverses jauges de HBM


Rosette pour membrane


Rosette 45°

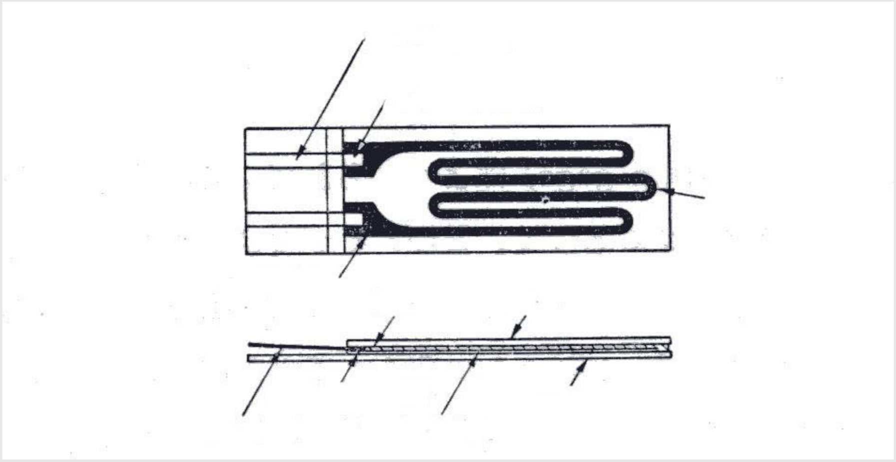


Rosette 120°

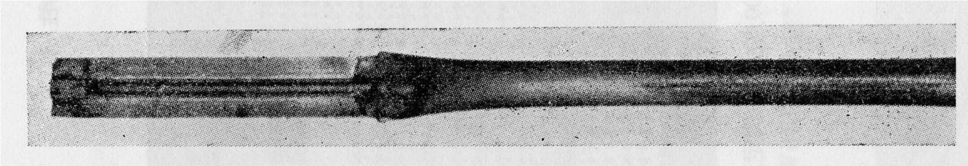


Rosette pour membrane

Metal-foil strain gauge

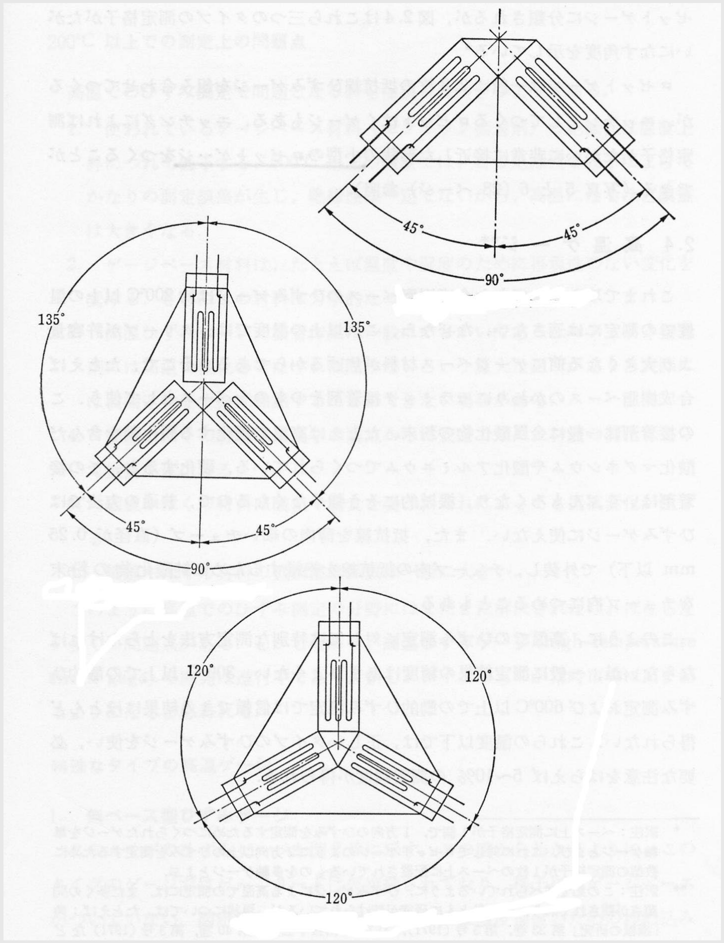


A semiconductor strain gauge



Very high sensitivity, but large Temp. dependence!

Rosette Gauges



Strain gages

• Strain gauges are used to measure deformations.
• Applying a stress σ (F/S) to a specimen while obeying Hooke's law (elastic domain 0.2%; deformation ~ stress).
• Creates a strain ε; $\varepsilon = \Delta l / l$.
• Young's modulus E links stress and strain when they are in the same direction: $\varepsilon = \sigma / E$.
• Poisson's ratio ν (~0.3) links the deformation in the direction of the principal stress to the perpendicular deformation: $\varepsilon_{\perp} = -\nu \cdot \varepsilon_{\parallel}$.

• Temperature sensitivity => temperature coefficient $\beta_{j/s} \approx 0.7 - 2.5 \times 10^{-5}/°C$.
Remedies: Self-compensated gauges $\beta_{j/s} \approx 1.5 \times 10^{-6}/°C$.
• Properties of the Wheatstone bridge.
• Bandwidth depends on size (100 kHz for a 1 mm² gauge).

Strain gages

Behavior Laws

Resistance variation due to: $R = \rho \cdot \frac{\ell}{S}$

The application of a force F on the metallic support results in a relative change in its length, inducing a relative change in the resistance of the strain gauge.

$$\frac{\Delta R}{R} = K \cdot \frac{\Delta \ell}{\ell}$$

With K: the gauge factor, ranging from 2 to 4 for metallic gauges and up to 150 for semiconductor gauges

Strain gages

- **Behavior Laws**
  The variation in resistance is due to changes in resistivity and geometric changes. $\frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} + \frac{\Delta l}{l} - \frac{2\Delta d}{d}$

- The piezoresistive effect $\frac{\Delta \rho}{\rho} = c\frac{\Delta V}{V}$, with **c** as the Bridgman constant, shows the link between the variation in metal resistivity and their volume change (change in structure, no much for metalic jauge)
- By considering longitudinal deformations $\boldsymbol{\varepsilon_l}$ and transverse deformations $\boldsymbol{\varepsilon_t}$, we obtain the expression $\frac{\Delta R}{R} = K \cdot \varepsilon_l$ with **K** as the gauge factor. $K = 1 + c + 2\nu(1 - c)$
- Metals used for metallic gauges have **c = 1** and **v = 0.3**, leading to **K ≈ 2** in most cases.

Evaluation of Gauge Factor

Using Poison's ratio μ,

$$-\mu\frac{dl}{l}=\frac{dD}{D}$$

the last equation in the last figure becomes,

$$\boxed{\frac{dR}{R}=\frac{d\rho}{\rho}+\frac{dl}{l}(1+2\mu)}$$

Intrinsic resistivity change is related to volume change:

$$\frac{d\rho}{\rho}=C\frac{dV}{V}$$

Volumetric strain is a sum of linear strains:

$$\frac{dV}{V}=2\frac{dD}{D}+\frac{dl}{l}$$

Then by using Poison ratio again,

$$\frac{d\rho}{\rho}=C(1-2\mu)\frac{dl}{l}$$

Substituting this into the second equation,

$$\frac{dR}{R}=C(1-2\mu)\frac{dl}{l}+(1+2\mu)\frac{dl}{l}$$

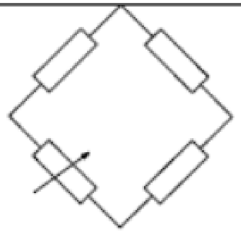
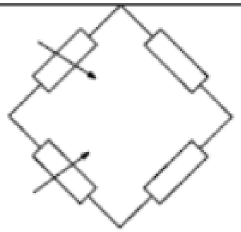
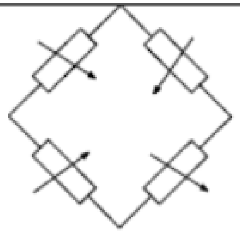
$$\frac{dR}{R}=\underline{(1+C+2\mu-2C\mu)}\frac{dl}{l}$$

Gauge factor

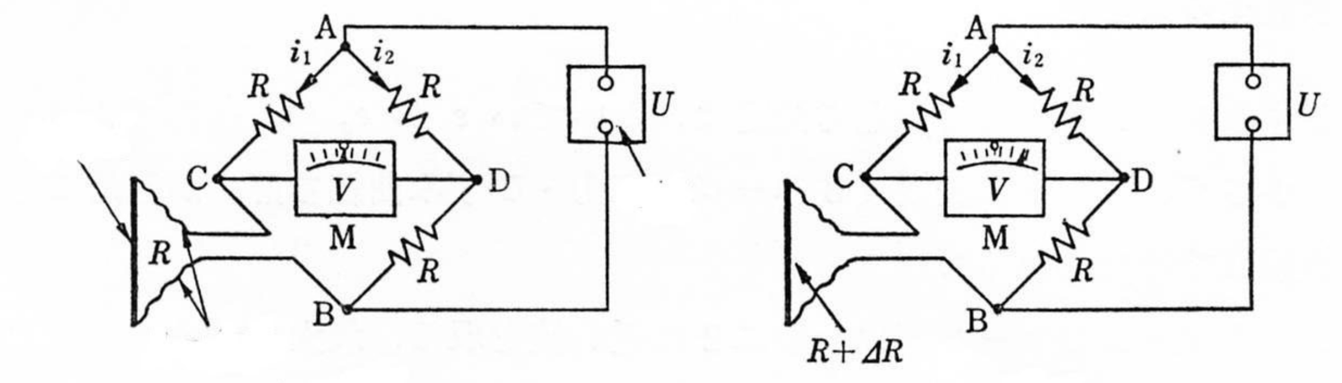
For a typical strain gauge material,
C = 1- 1.13, μ = 0.3, then the gauge factor is:

$$K=1+1.13+2\times0.3-2\times1.13\times0.3=2.05$$

bridges

		
Montage en 1/4 de pont - Une seule R varie - Montage non linéaire - Montage sensible à T	Montage en 1/2 de pont - $2R$ varient ; soit des adjacents, soit des opposés $\Rightarrow$ comportement dépend du choix. Mais généralement si 2 branches adjacents - Montage linéaire - Compensation de ΔT	Montage en pont complet - Les $4R$ varient selon les configurations de montage - Est linéaire, - A une meilleure sensibilité - Compense les efforts parasites (si on mesure de la flexion et qu'un effort parasite de traction apparaît, il est compensé)

Wheatstone Bridge



U = supply voltage, Vdc = output voltage"

Using Ohms's law,

$$i_2=\frac{U}{2R},\qquad V_{AD}=\frac{1}{2}U$$

$$V_{AC}=i_1R=\frac{U}{2R}\cdot R=\frac{1}{2}U$$

$$V_{DC}=V_{AD}-V_{AC}=\frac{1}{2}U-\frac{1}{2}U=0$$

For a bridge with an active gauge (right),

$$i_1=\frac{U}{R+(R+\Delta R)}\qquad V_{AC}=i_1R=U\cdot\frac{R}{2R+\Delta R}$$

$$i_2=\frac{U}{2R},\qquad V_{AD}=\frac{1}{2}U$$

$$V_{DC}=V_{AD}-V_{AC}$$

$$=U\cdot\frac{1}{2}-U\cdot\frac{R}{2R+\Delta R}$$

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

$$=U\left(\frac{2R+\Delta R-2R}{4R+2\Delta R}\right)=U\left(\frac{\Delta R}{4R+2\Delta R}\right)$$

割ってやると

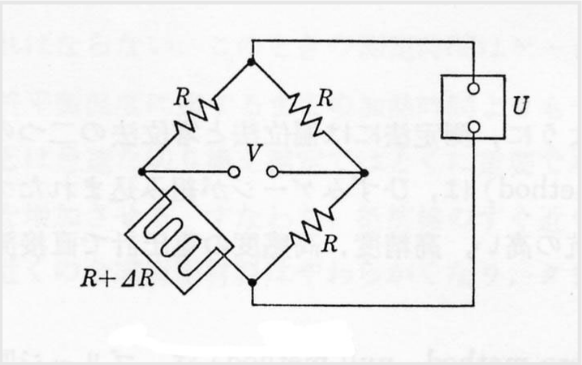
$$=\frac{\Delta R}{4R}-\frac{(\Delta R)^2}{8R}+\frac{(\Delta R)^3}{16R}+\cdots$$

$$\sim\frac{\Delta R}{4R}$$

$$V_{DC}=U\frac{\Delta R}{4R}=\frac{U}{4}\cdot\frac{\Delta R}{R}$$

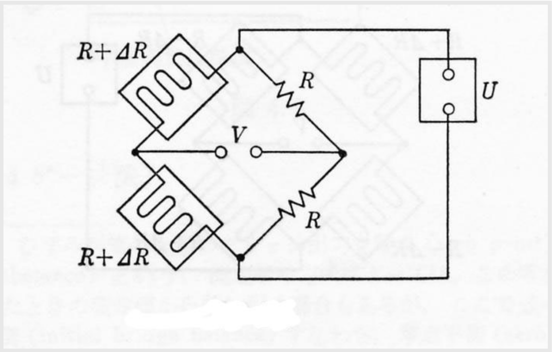
Quarter, Half & Full Bridges

Quarter bridge



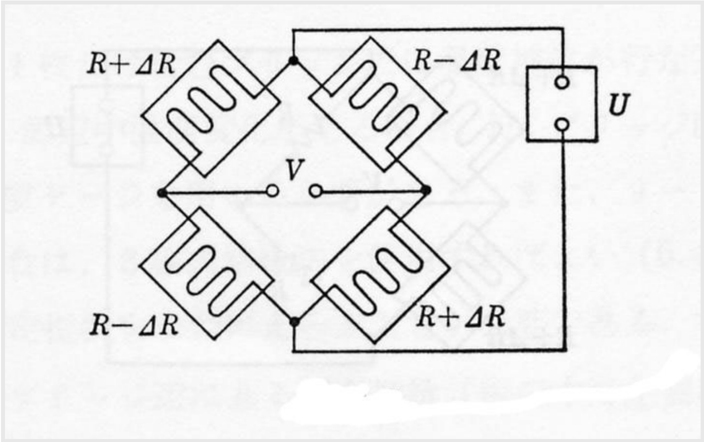
$$V = \frac{U}{4}\frac{\Delta R}{R}$$

Half bridge



$$V = \frac{U}{2R}(R+\Delta R) - \frac{U}{2} = \frac{U}{2}\frac{\Delta R}{R}$$

Full bridge

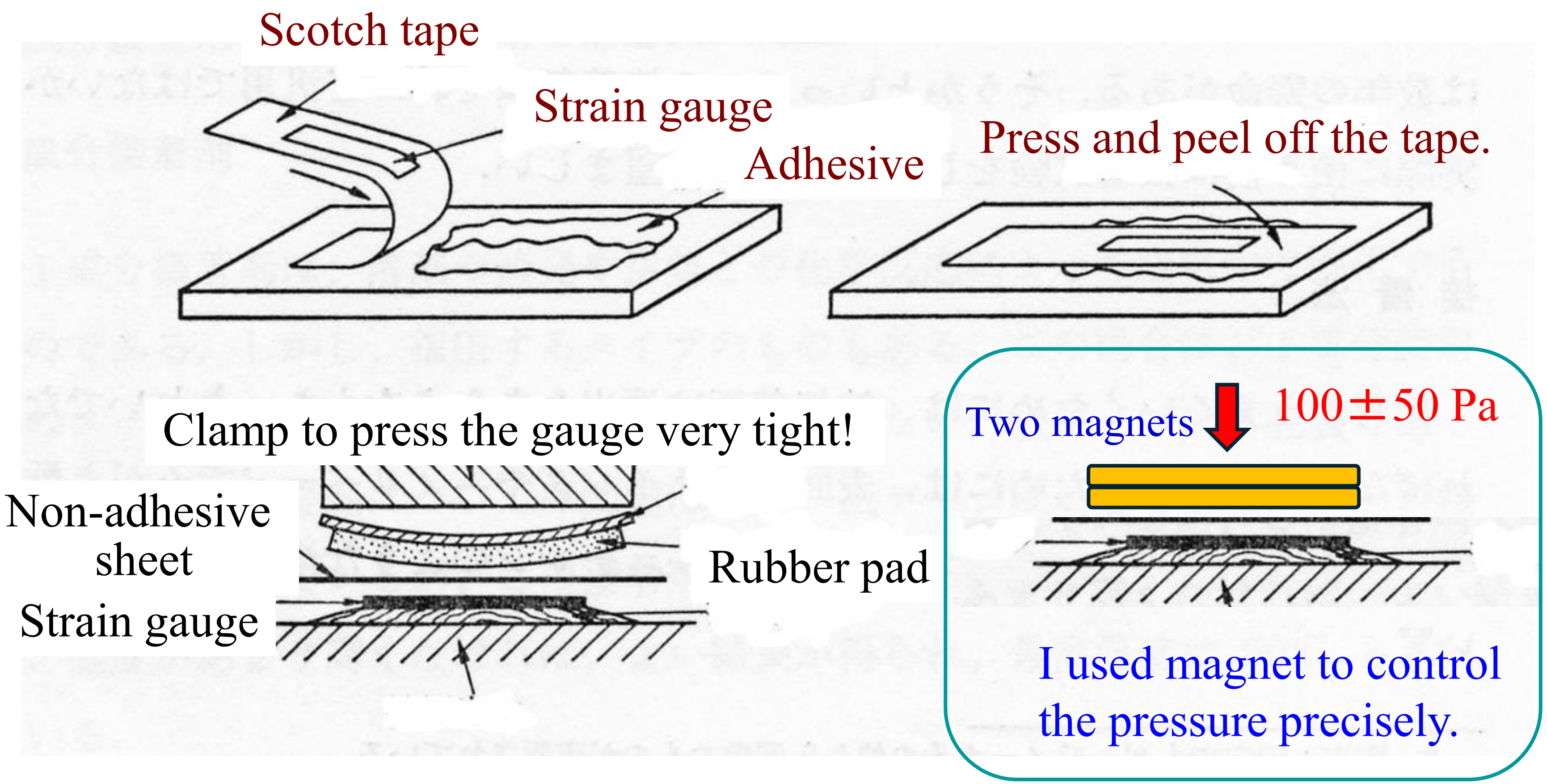


$$V = U \cdot \frac{\Delta R}{R}$$

(1) A quarter bridge is used for strain measurement.

(2) A full bridge is often used for transducers.

How to bond a strain gauge?

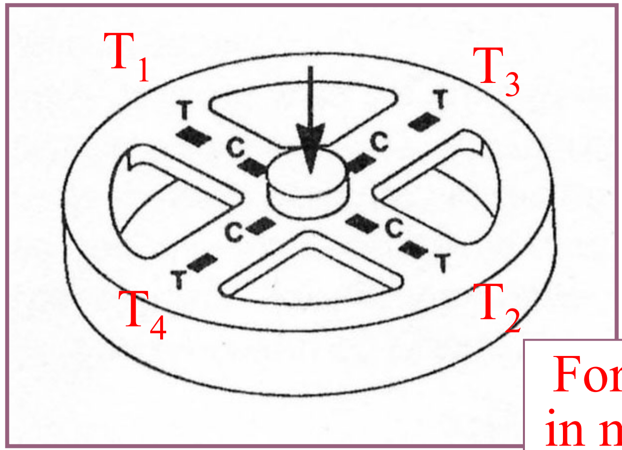


Good bonding: make adhesive as thin as possible!

It is safe to have gauges bonded by a manufacture for long-term use of force gauges.

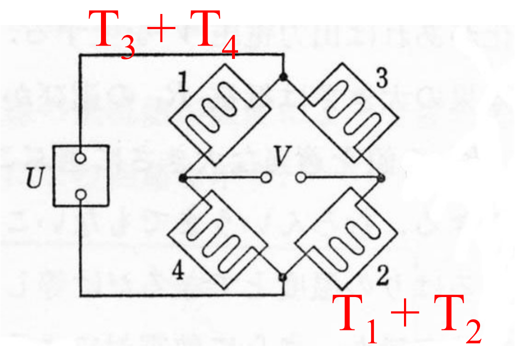
Wheel-Shaped Axial Force Gages

Stiff-connection with high sensitivity (bending)



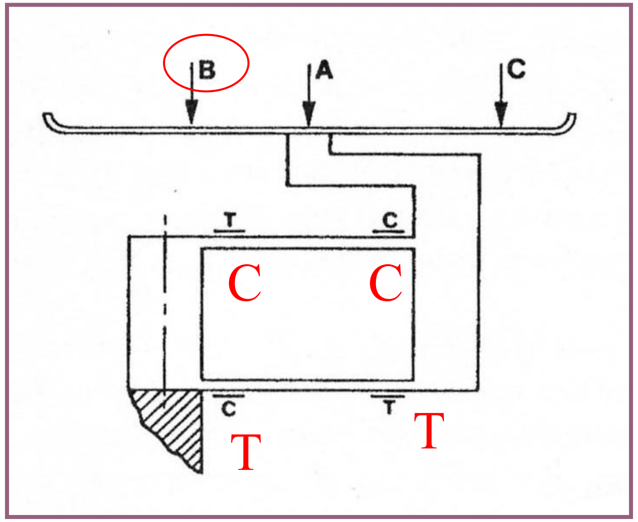
Force gauge in my gas rig

By using 8 gauges, bending effects can be averaged out!

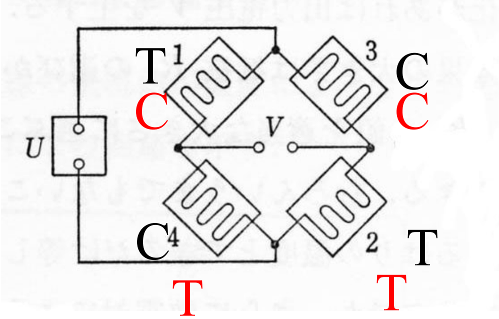


Art of a Balance

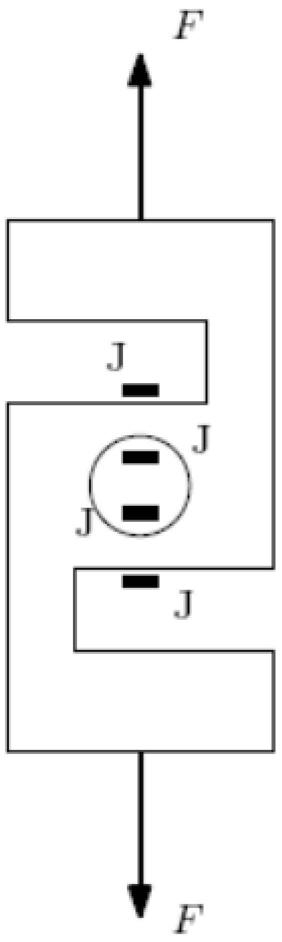
A balance has to be insensitive to bending due to off-centered loading.

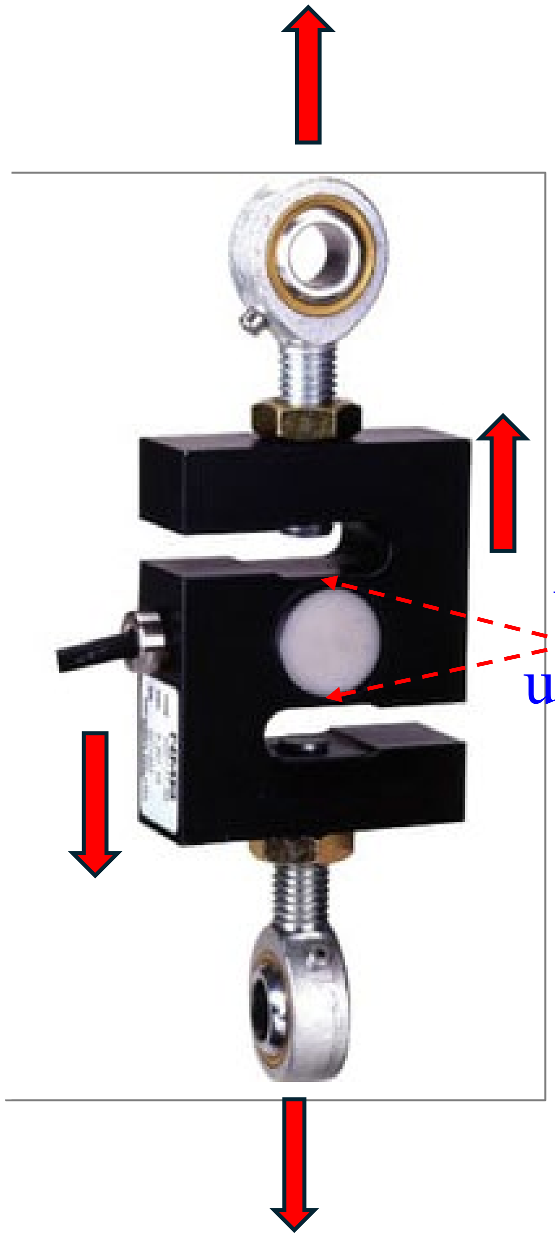


The bending does not break the bridge balance.



S-type Force Gauge for Compression and Tension





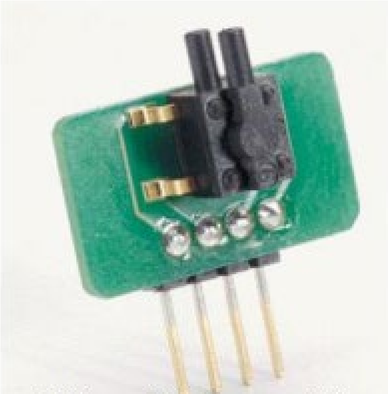
[1] Widely used and cheap force gauges.
[2] Usable for compression and tension.
But ways to fix the gauge are different.

Do you know how it works?

An apparatus in Hu san's lab uses this.

Capteurs de pression

•



différentiel"Honeywell"

PM Instrument

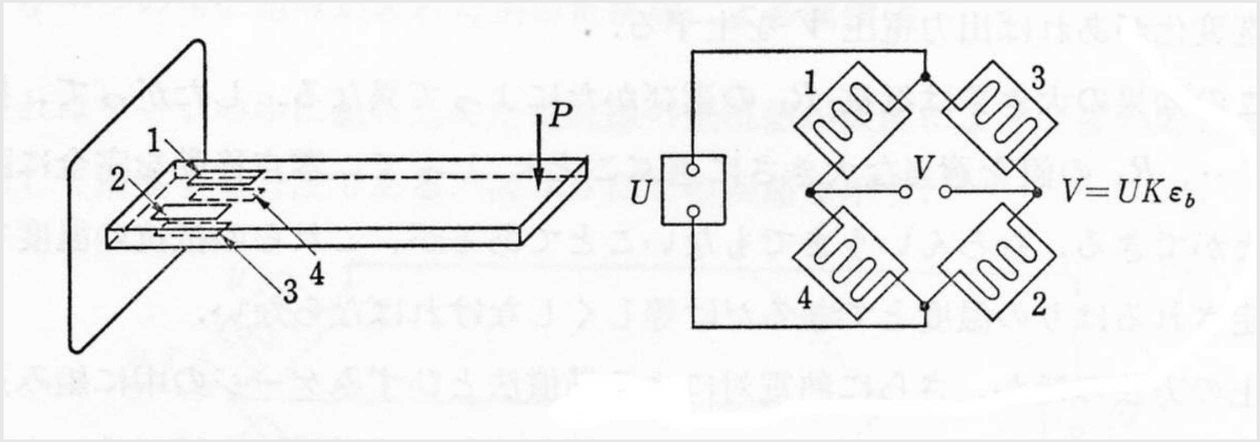
Pression diff. "FUJI"

Automobile

"ONERA"

Piezorésistif "Sensortechnics"

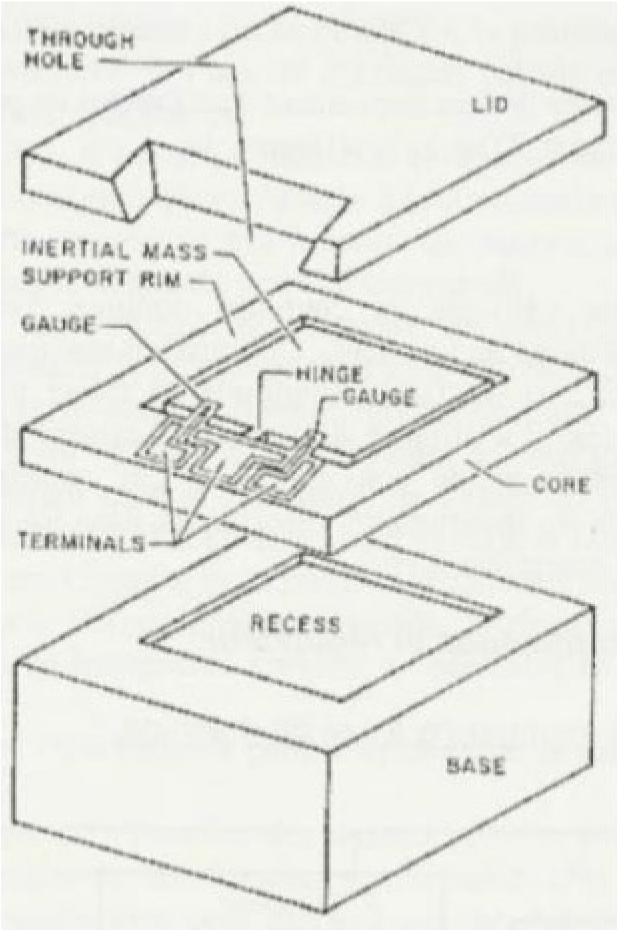
Displacement sensor WITH STRAIN GAGE



Simple, but sensitive!

If a plate is very thin, it can be used as a displacement transducer

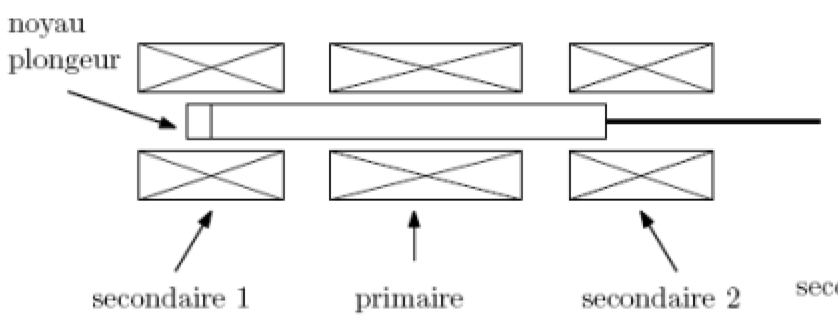
Accelaration sensor WITH STRAIN GAGE

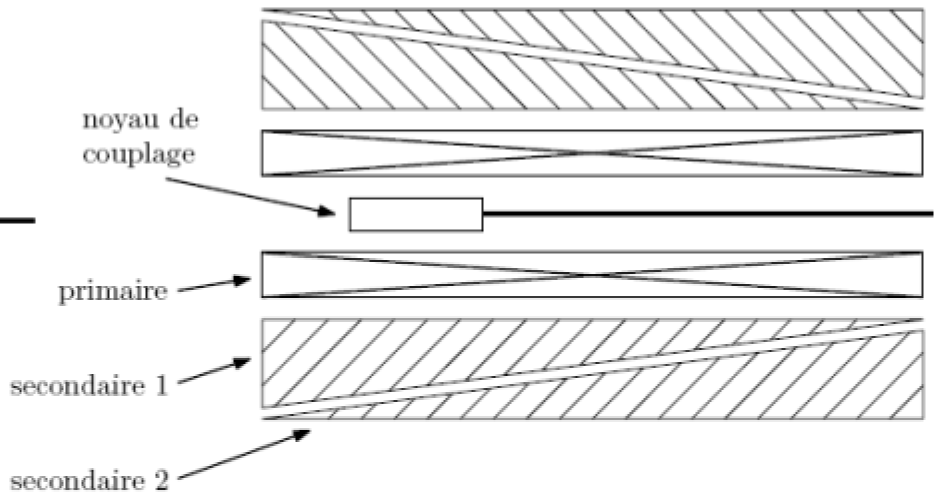


Displacement

LVDT: Linear Variable Différential Transformer

An LVDT (Linear Variable Differential Transformer) works by measuring linear displacement. It consists of a primary coil and two secondary coils arranged symmetrically. A ferromagnetic core moves along the axis of the coils. As the core shifts, the inductance of the secondary coils changes, producing a differential voltage. The voltage difference is proportional to the position of the core, allowing precise measurement of linear displacement.

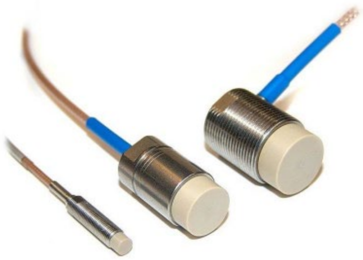


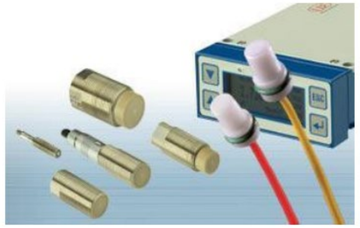


The LVDT is an absolute displacement sensor.
It is very robust.
Its resolution is submicronic.
The linearity is in the order of 0.1% of full scale.

Displacement

Eddy Current Displacement Sensor





Characteristics and Usage:

•Excellent resolution: 30 nm

•Used on a linear portion

•Detector versions also available

•Pay attention to the size of the target

•Consider the nature and structure of the target

How it works:

The sensor detects displacement by measuring changes in the electromagnetic field induced by an alternating current. The eddy currents created in the target affect the impedance of the sensor, which is then measured and correlated to displacement.

Displacement

Triangulation Displacement Sensors

Operating Principle: An incident light beam is focused on the target.

The reflected beam illuminates a specific spot on an optical sensor, such as a CCD (Charge Coupled Device) or PSD (Position Sensitive Device), depending on the distance.

Resolution can be low than 15 nm for 50um displacement
Resolution can be low than 5 microns for 75 mm displacement

Capteur à réflexion diffuse
"SUNX"

Capteur laser
"Keyence"

Displacement

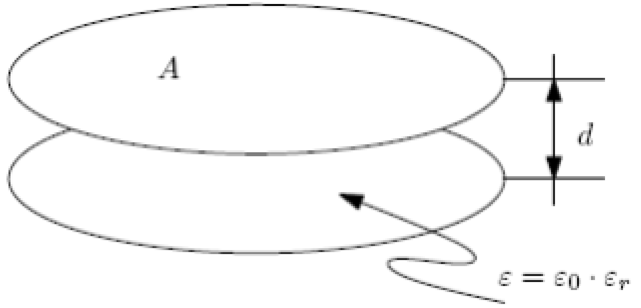
Capacitive Displacement Sensors

Operating Principle: These sensors are based on the variation in the capacitance of a parallel-plate capacitor as the distance between the plates changes.

Explanation: In a capacitive displacement sensor, the sensor consists of two conductive plates (electrodes) that form a capacitor. When the distance between the plates changes due to displacement, the capacitance (the ability to store charge) also changes. This variation is measured and correlated to the displacement. These sensors are sensitive to the proximity of objects, and the change in capacitance is used to detect even small displacements with high precision.

Pour cibles métalliques, et non métalliques
"Micro Epsilon"

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

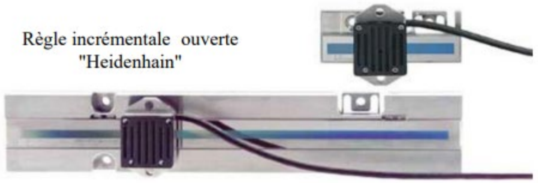


Displacement

Incremental Sensors

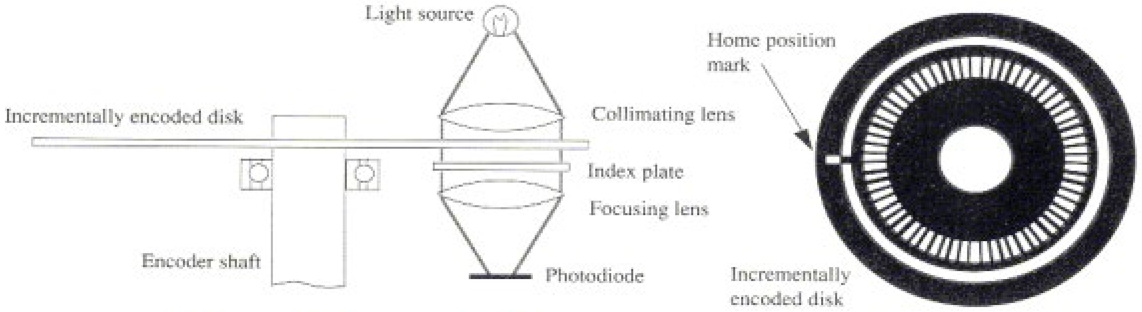
Explanation:
Incremental sensors, also known as incremental encoders, measure the change in position relative to a reference point. They provide information about the movement or displacement in discrete steps. When the sensor detects a change in position, it generates pulses, and the number of pulses corresponds to the amount of displacement. These sensors are commonly used in applications requiring precise position tracking, such as in motors or robotic systems. However, they do not provide an absolute position; instead, they track relative movement from an initial reference point.


Codeur incrémental "LTN"

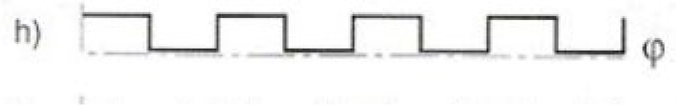

Règle incrémentale ouverte "Heidenhain"


Règle incrémentale fermée "Heidenhain"

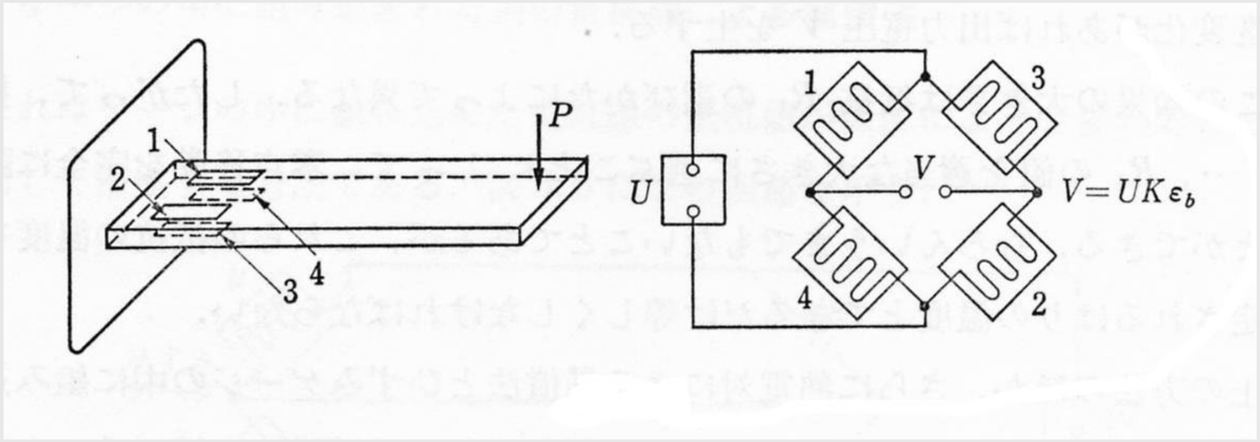
Palpeurs incrémentaux "Heidenhain"



Incrémental



Displacement sensor WITH STRAIN GAGE



Simple, but sensitive!

If a plate is very thin, it can be used as a displacement transducer

Piezoelectric Sensors

Operating Principle:
They are based on the variation of the polarization DD in a crystal lattice subjected to mechanical stress.

Explanation:
Piezoelectric sensors work by exploiting the piezoelectric effect, where certain materials generate an electrical charge when subjected to mechanical stress. When pressure or force is applied to the crystal lattice of the piezoelectric material, the internal charge distribution changes, resulting in an electrical voltage. This voltage is then measured and is proportional to the amount of stress or force applied. These sensors are commonly used for detecting vibrations, pressure changes, or accelerations due to their high sensitivity and fast response.

Accéléromètre piezoélectrique
Triaxial "Bruel&Kjaer"

Rondelle de charge
"Kistler"

Accelerometers:

•Excellent bandwidth, resonance frequency up to 150 kHz

Force Sensors:

•Higher stiffness and resonance frequency compared to strain gauge sensors

Pressure Sensors:

•Excellent temporal dynamics, wide pressure range

"Kistler"