Lesson 9

Thermomechanical Measurements for Energy Systems (MENR)

Measurements for Mechanical Systems and Production (MMER)

A.Y. 2015-16

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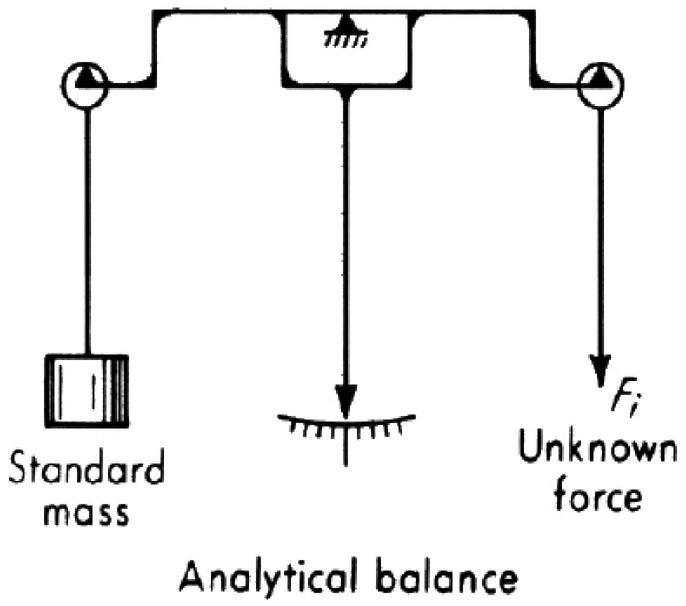
Force and mass measurements

There are many physical quantities in mechaniches that are measured through the ***force*** : *pressure*, mechanical *strain*, *acceleration*, mechanical *torque*, mechanical *power*, …

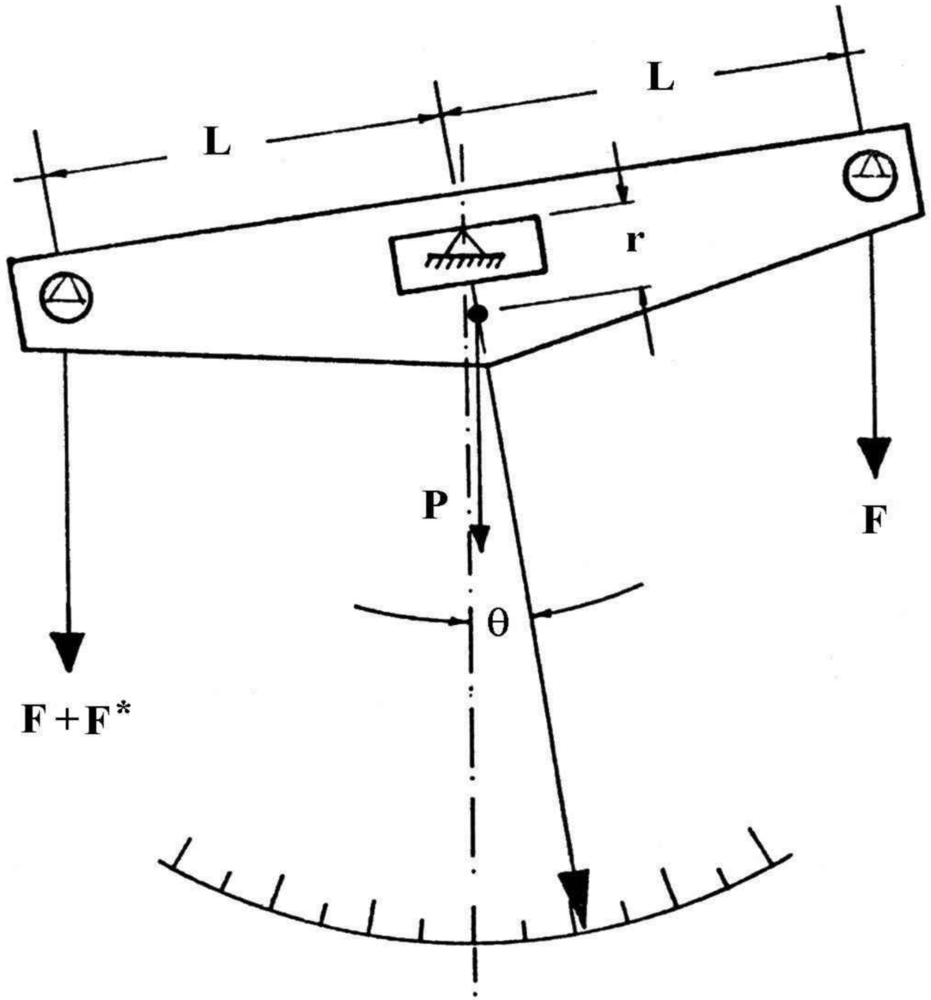
The measurement of the ***mass*** of an object, in practical situations, is intimately related to the measurement of a force : the weight !

$$F_p = m \cdot g \qquad \rightarrow \qquad 1kg_m \cdot 9.81 m/s^2 = 1kg_f$$



Zero metod (or instrument)

Analytical balance



The balance of momentum around the fulcrum of the balance gives the equations:

$$(F+F^*)\cdot L\cos\theta = F\cdot L\cos\theta + P\cdot r sen\theta$$

$$F+F^* = F + P\frac{r\cdot sen\theta}{L\cdot\cos\theta}$$

$$F^* = \frac{P\cdot r}{L}tg\theta$$

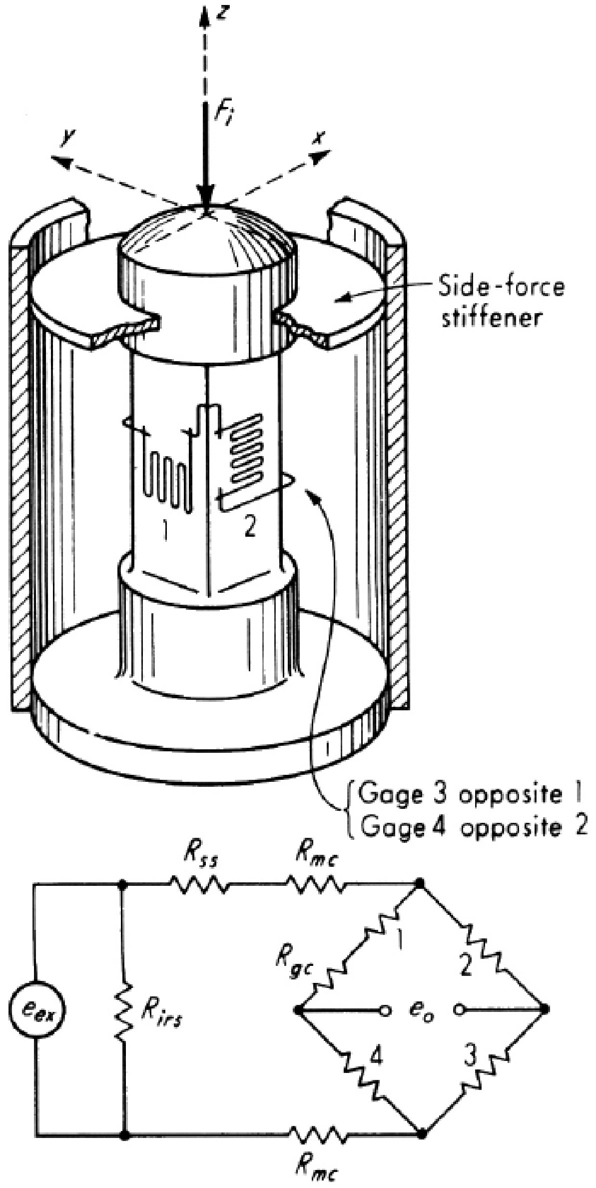
The *graduation curve* is not linear but, for small rotations ϑ, we can confound the angle with its tangent :

$$tg\theta \cong \theta \qquad \theta \cong \frac{L}{P\cdot r}\times F$$

The *sensitivity* is : $$S = \frac{\Delta\theta}{\Delta F} \cong \frac{L}{P\cdot r}$$

When forces are directed in "any direction" different from the direction of *gravity*, they must be measured by other instruments: the ***dynamometers,*** which are almost all based on the measurement of the strain caused by the force (the *measurand*) on an *elastic element* inside !

Load cells:



Basic law of elasticity : $F = k \cdot x$

For a cylindrical elastic element which is axially loaded we can write : $k = \frac{AE}{l}$

l is the length of the element
A is the transversal section
E is the Young's modulus of the material

The *graduation curve* is linear : $x = \frac{l}{AE} \cdot F$

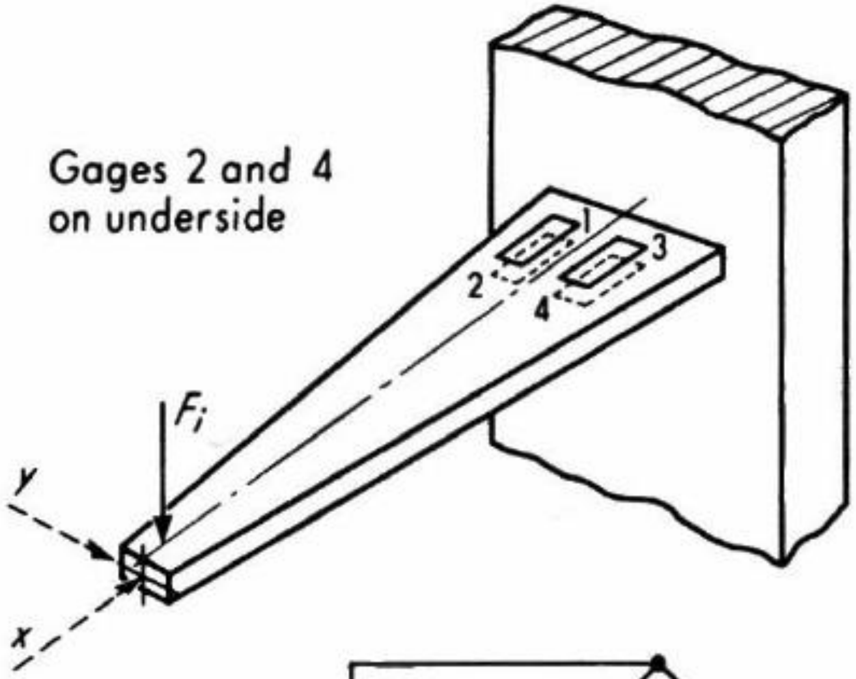
The *sensitivity* is constant : $S = \frac{\Delta x}{\Delta F} = \frac{l}{AE}$

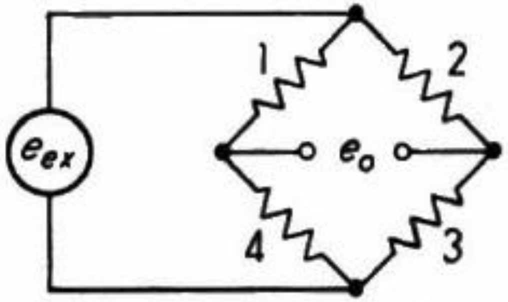
Bending load cells:

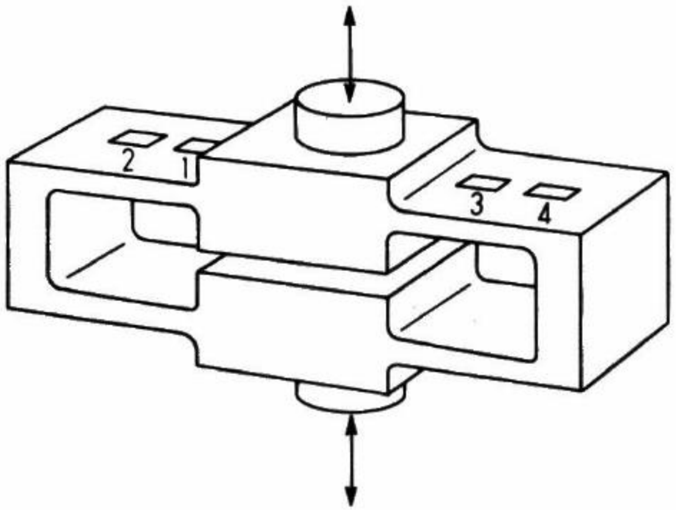
When you have small forces to measure and you need more sensitivity, the bending elastic element is preferred. The basic law of elasticity $F = k \cdot x$ is still valid.

But $k = \dfrac{3EI}{l^3}$

l is the *length* of the bending element
I is the *moment of inertia* of the bending element section
E is the Young's modulus



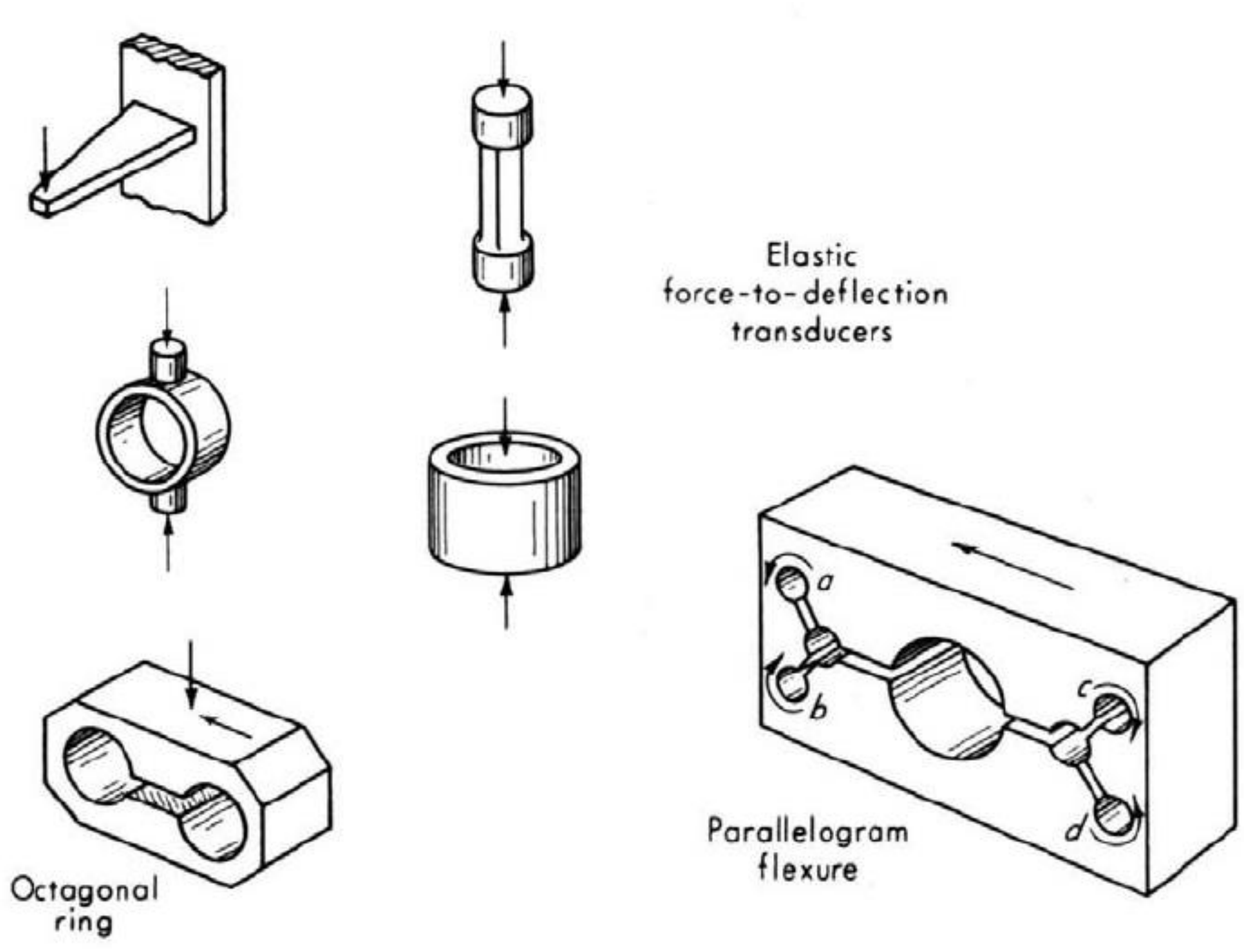


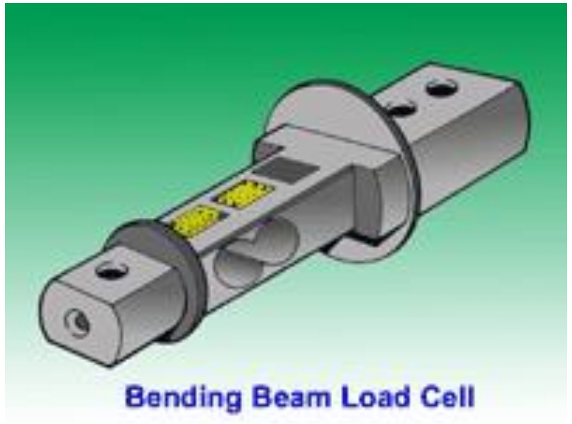


Graduation curve: $x = \dfrac{l^3}{3EI} \cdot F$

Sensitivity: $S = \dfrac{\Delta x}{\Delta F} = \dfrac{l^3}{3EI}$

Examples of bending load cells:

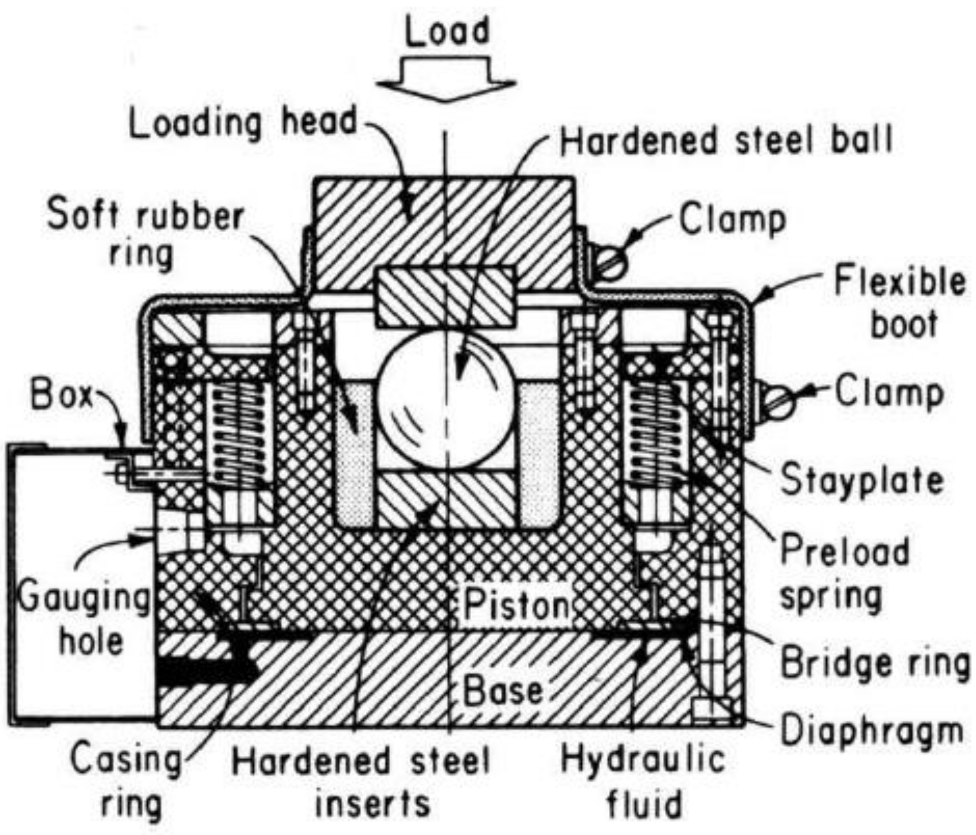




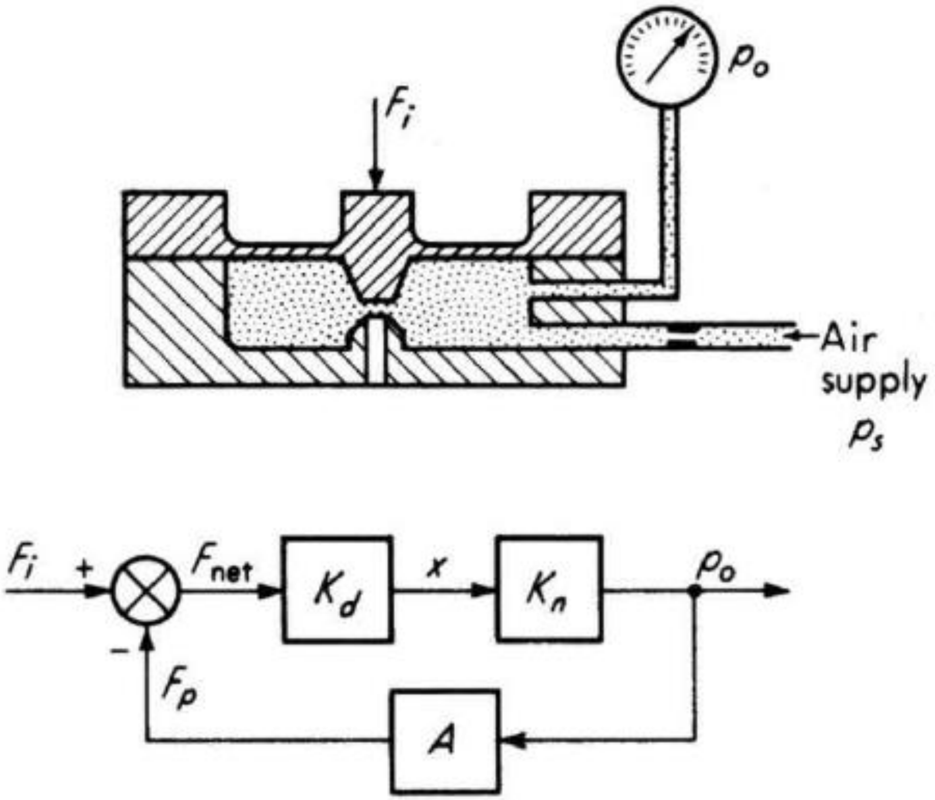
hydraulic or pneumatic load cells: are employed to measure very big forces. The measurement is done "indirectly" passing through the *pressure measurement of a particular fluid* (generally oil)

$F = P \cdot A$

the area "*A*" of the surface which *compresses the fluid* is a design parameter of the instrument
The force *F* can then *be calculated immediately* from the pressure measurement !



Hydraulic load cell



Pneumatic load cell

Measurement of PRESSURE : *it is also an indirect measurement…*

$$p = \frac{F_\perp}{S}$$

There are many measurement units for **pressure** :

- pascal (Pa): in the International System = 1 newton over squared meter (1 N/m^2) or $kg \cdot m^{-1} \cdot s^{-2}$
- Baria: in the old CGS System (dina/cm^2)
- Bar: (10^5 Pa = 1 daN/cm^2) submultiples of the **bar** are also widespread, in particular the millibar is used much in meteorology and the microbar in acustics
- torr: the pressure exerted by a mercury column high 1 mm (133,3 Pa)
- mm H_2O: the pressure exerted by a water column high 1 mm (9,81 Pa)
- atmosphere (atm): about equal to the pressure exerted by the atmosphere at sea level (101325 Pa = 760 mmHg = 760 torr)
- Force kilogram (kg_f): over cm^2 or over m^2
- Tecnical atmosphere (symbol: at or ata): equal to 1 kg_f/cm^2 (10.000mmH_2O), little bit smaller than the physical atmosphere (0,96784 atm). Also known as **ata**, when understood as absolute pressure, and **ate**, when thought as relative pressure.

PRESSURE measurement is often realized directly from the physical definition:
Measurement of the “force F” exerted by a fluid on a “surface A”

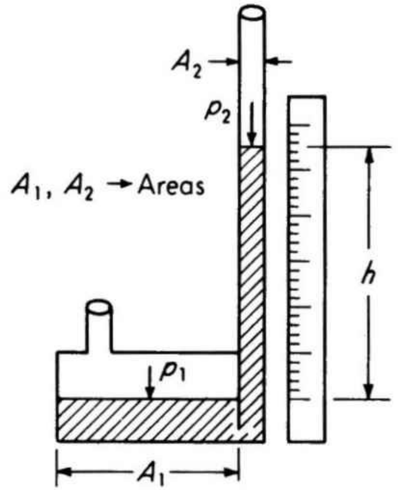
- **Absolute pressure** or real pressure (ata, absolute atm): is the pressure measured assuming the vacuum as reference pressure
- **Relative pressure** (ate, relative atm): is the pressure measured assuming another pressure as reference pressure (typically the atmospheric pressure)

Pressure P is technically measured by 3 different manometer types:

- Liquid manometers
- Metallic manometers
- Electric manometers

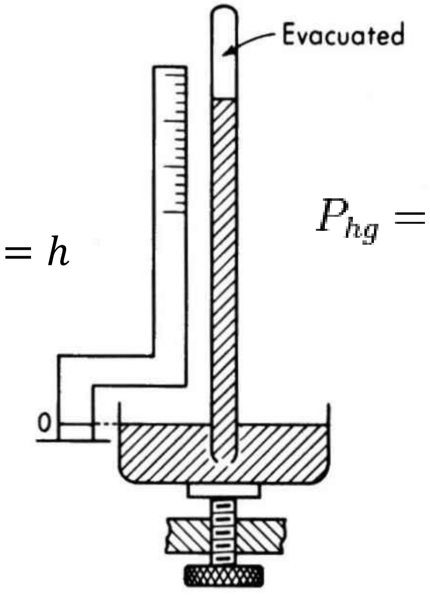
Liquid manometers:

Based on a fluid which rises inside a tube due to the pressure:



Well-type (single-leg) manometer

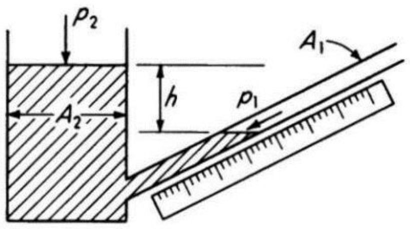
$$\frac{P_1 - P_2}{\rho_m g} = h$$



Barometer

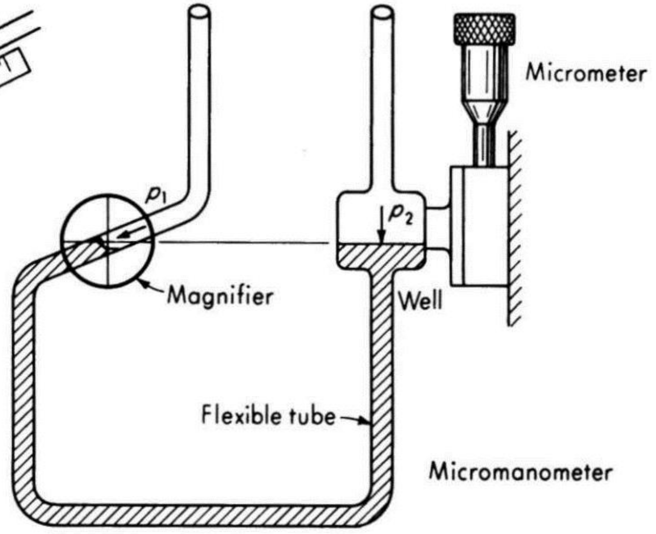
$$P_{hg} = \delta \cdot g \cdot h_{hg} = 13579\frac{kg}{m^3} \cdot 9,8\frac{m}{s^2} \cdot 0,76m = 1,013 \cdot 10^5 Pa$$

$$\frac{P_1 - P_2}{\rho_m g} = h = l \cdot sen\vartheta$$



Inclined manometer

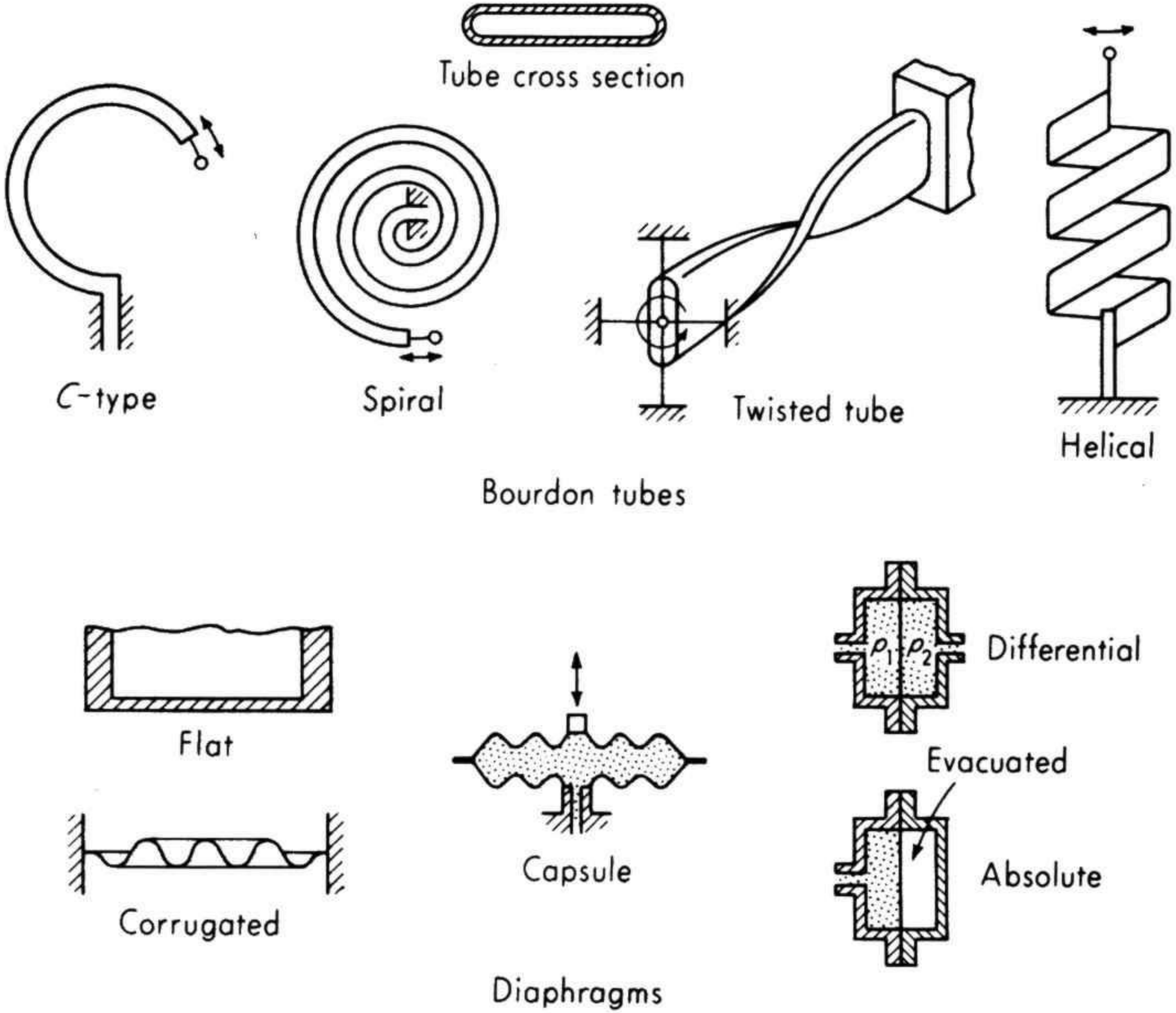
Differential (Prandtl) manometer or *null-out manometer*:



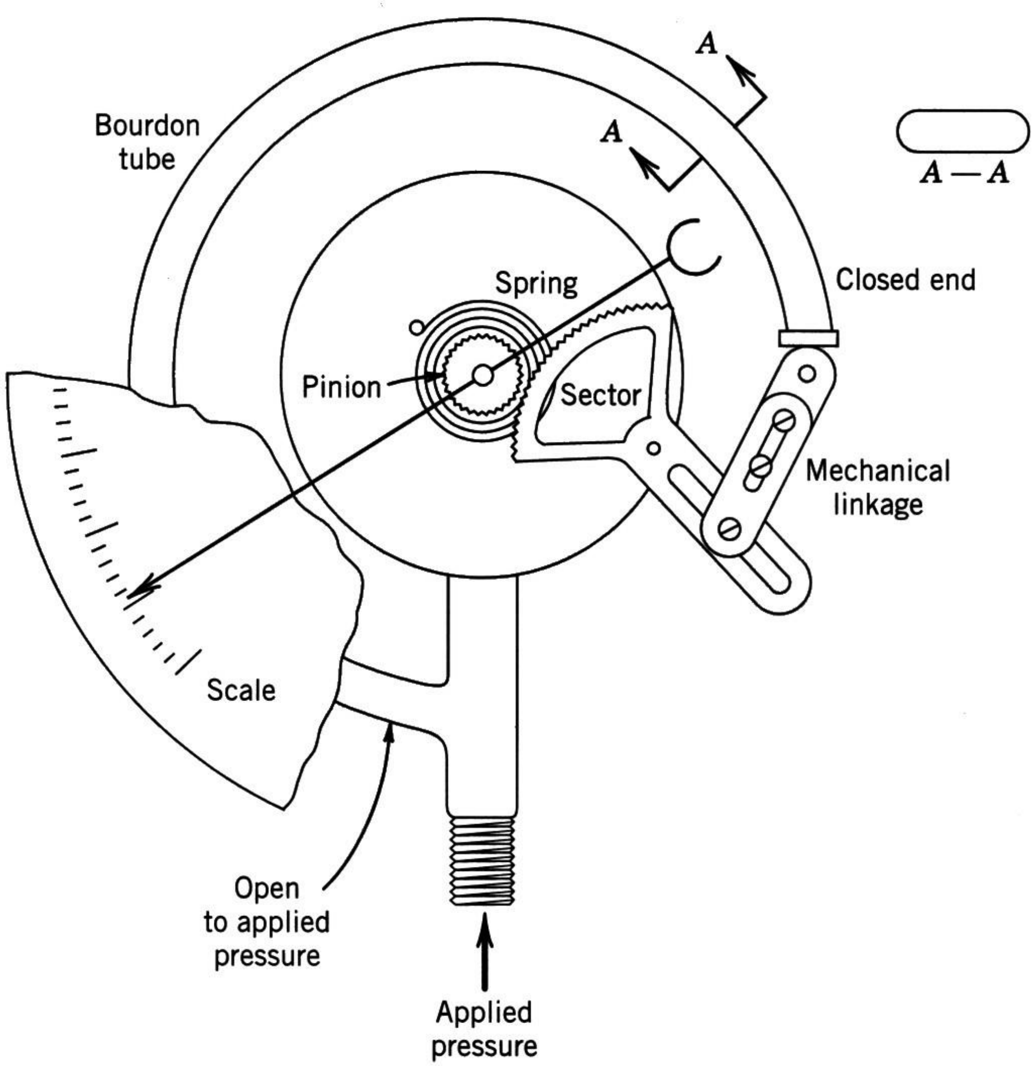
Micromanometer

Metallic manometers:

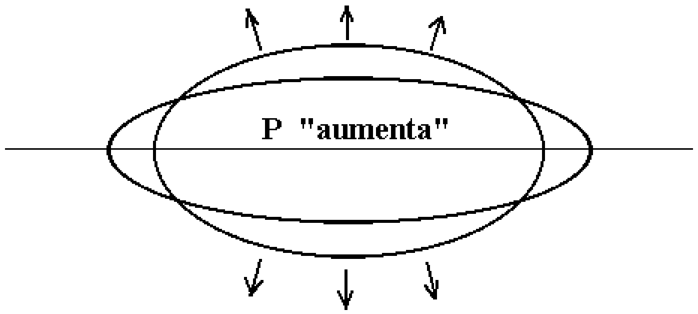
They are all based on the deformation of an elastic element caused by the pressure forces :

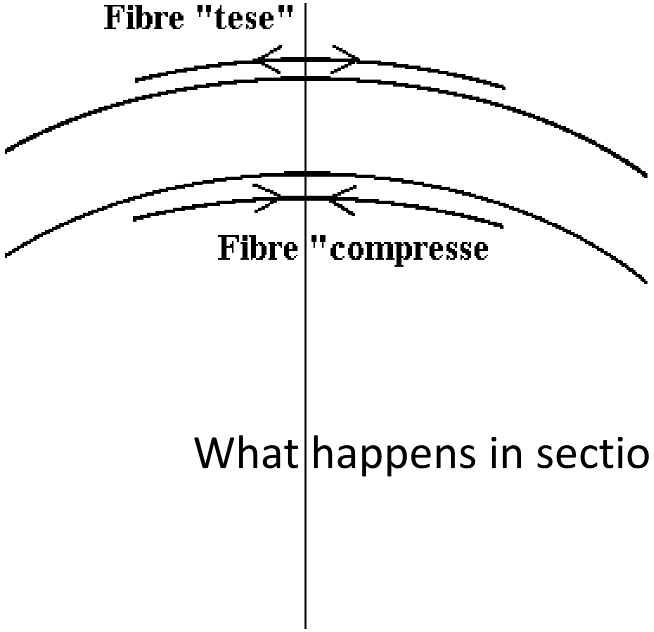


Bourdon manometer …

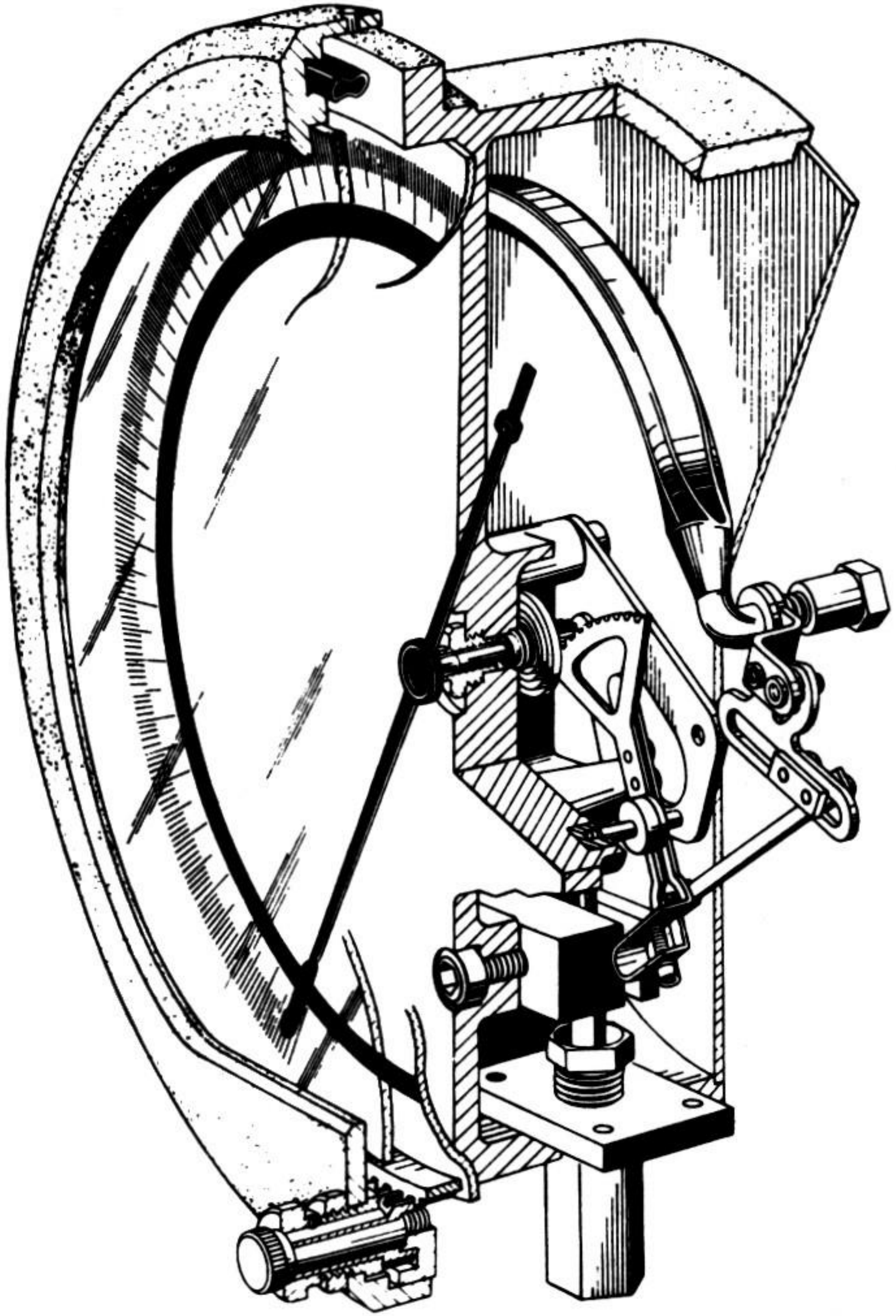


Bourdon tube pressure gauge.



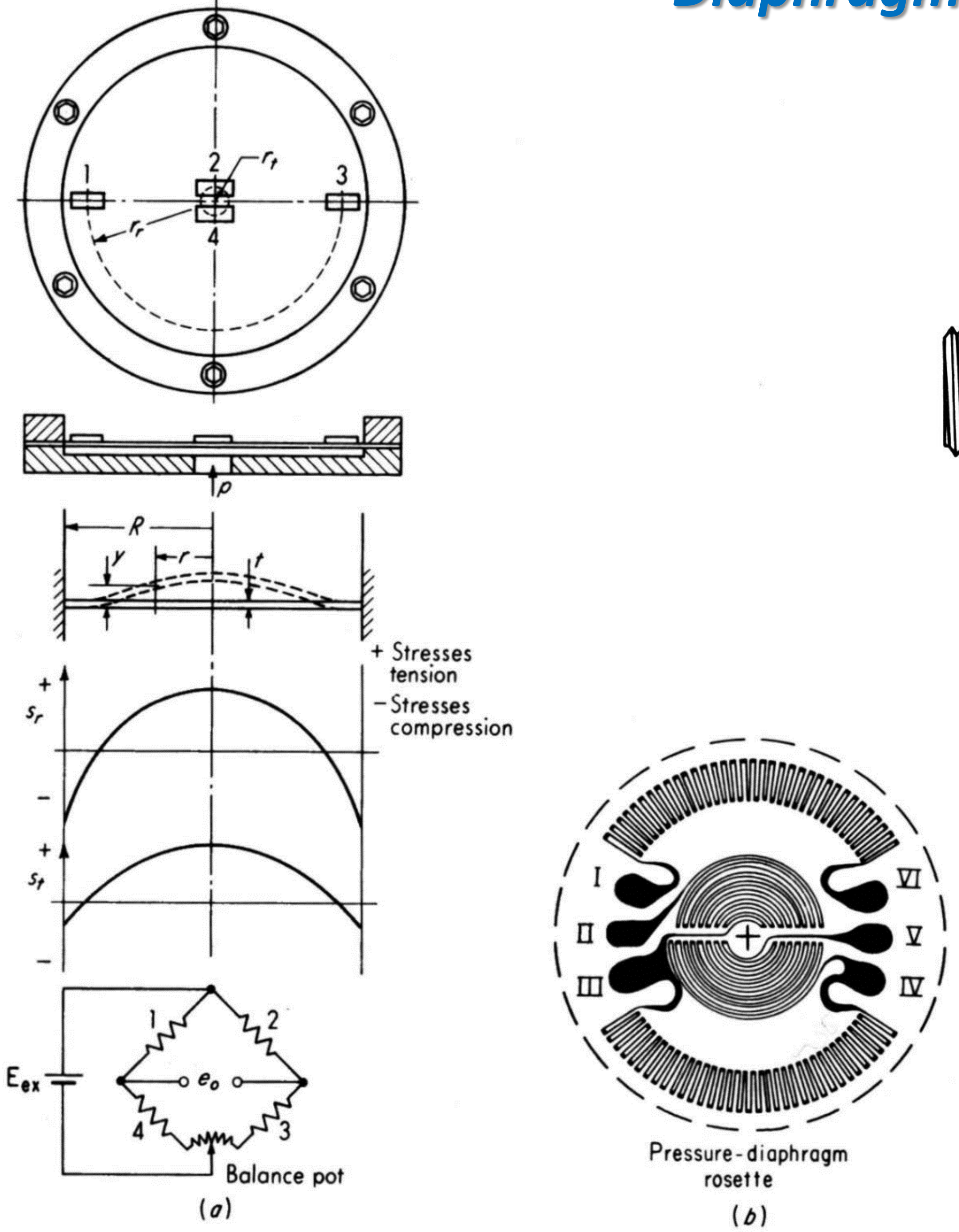


What happens in section AA ?

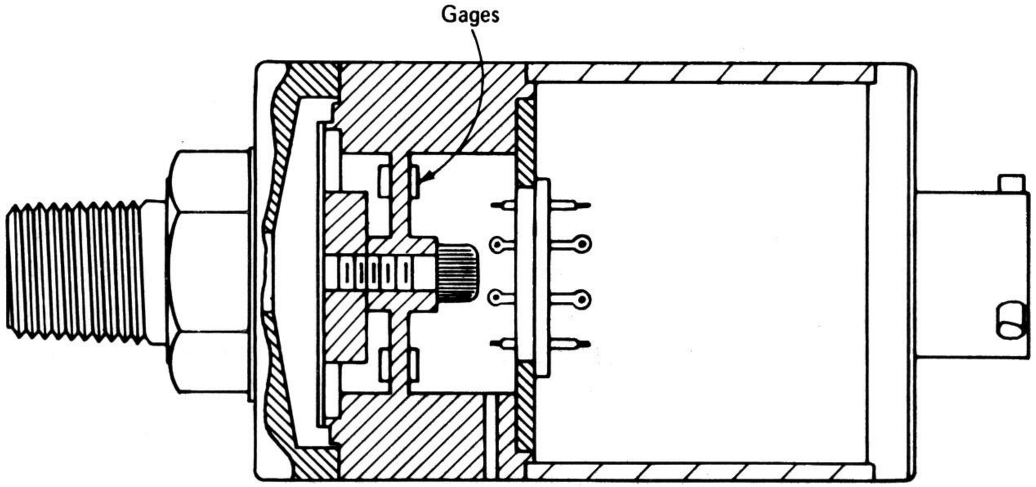



EN 837-1
bar
0
5
10
15
20
25
cl. 1,6

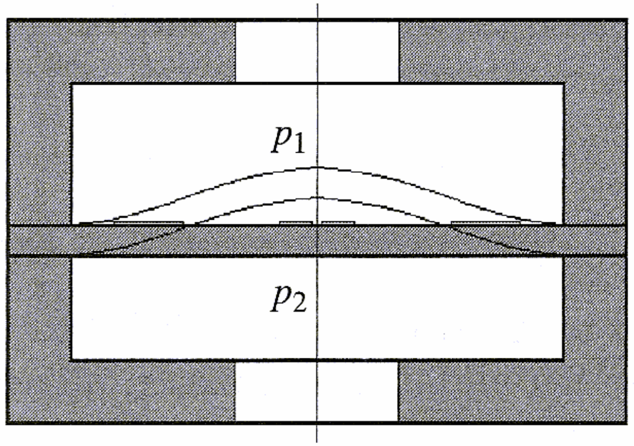
Diaphragm membrane manometer:



Diaphragm-type strain-gage pressure pickup.

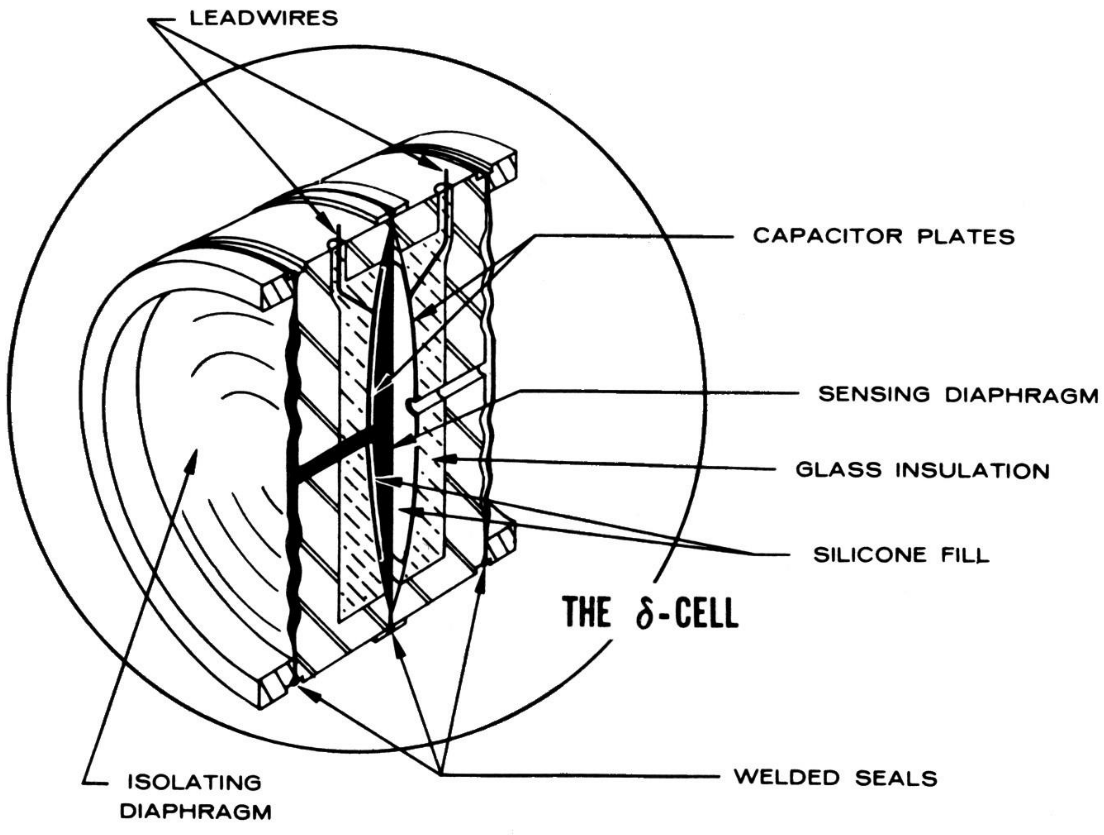


Bonded foil strain-gage pressure transducer. (*Courtesy Sensotec Inc., Columbus, Ohio.*)

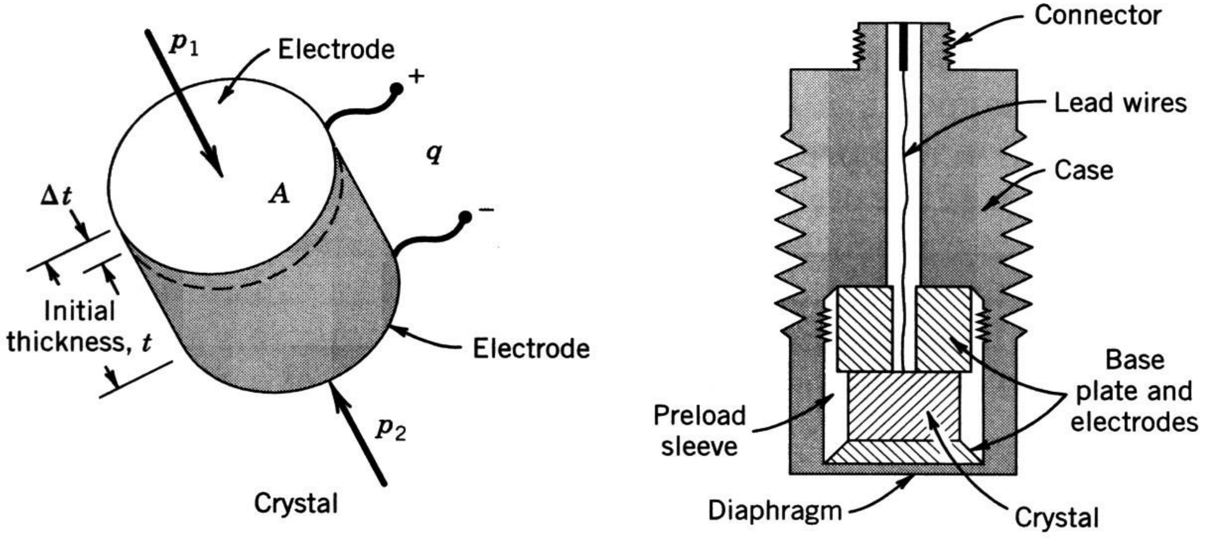


Electric manometers:

Capacitive transducers must be supplied with *alternating current* …

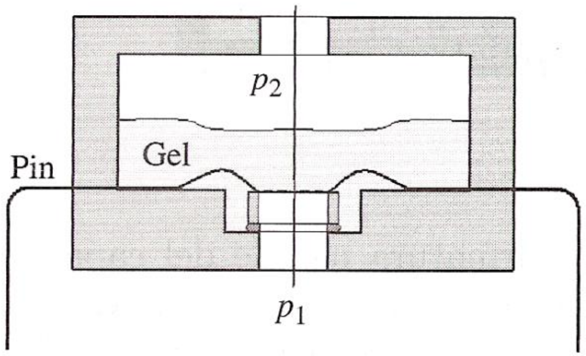


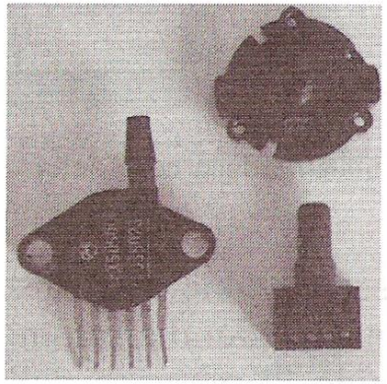
Capacitive differential-pressure transmitter. (*Courtesy Rosemount Inc., Minne*



Piezoelectric pressure transducer.

Semiconductor silicon chip pressure transducer:



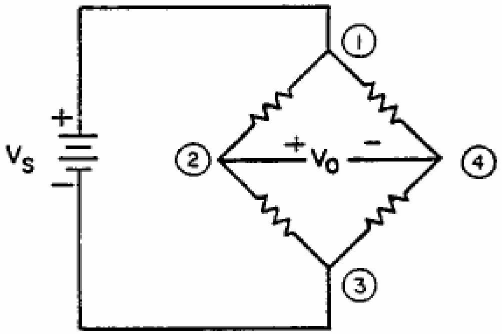


Trasduttore di pressione su chip di silicio.

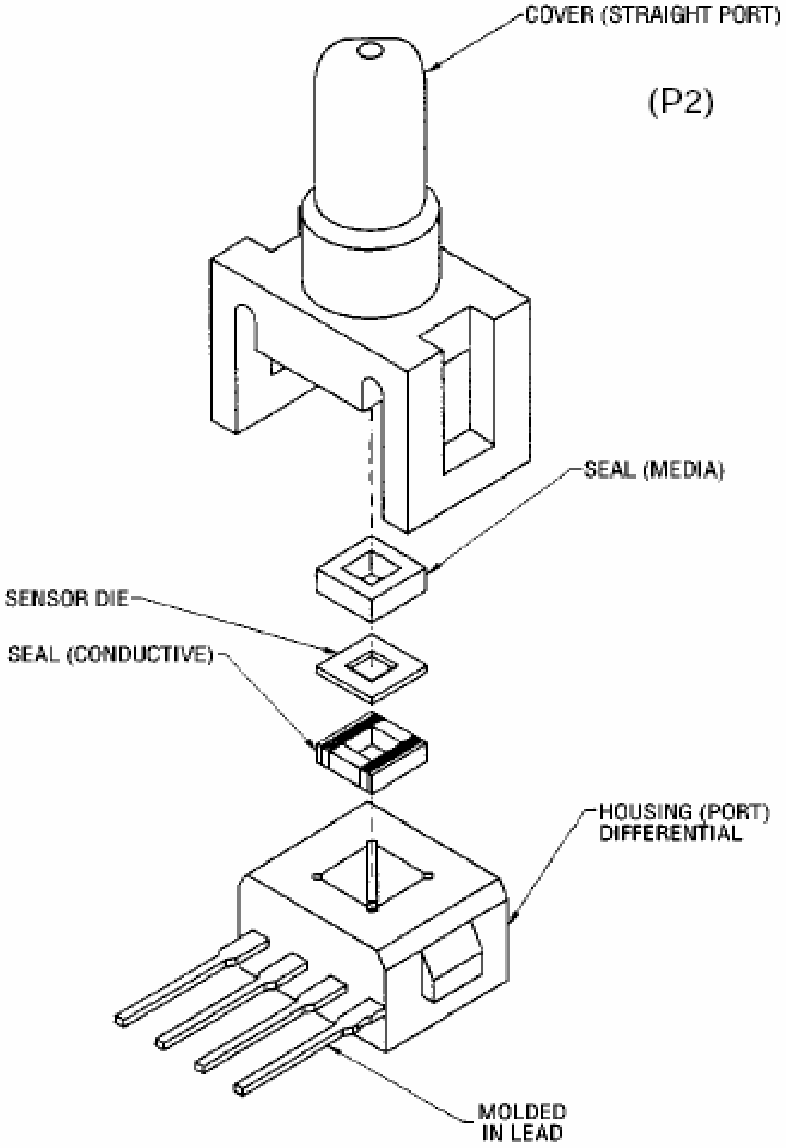
Pin Designation

Pin 1	V_S (+)
Pin 2	Output (+)
Pin 3	Ground (–)
Pin 4	Output (–)

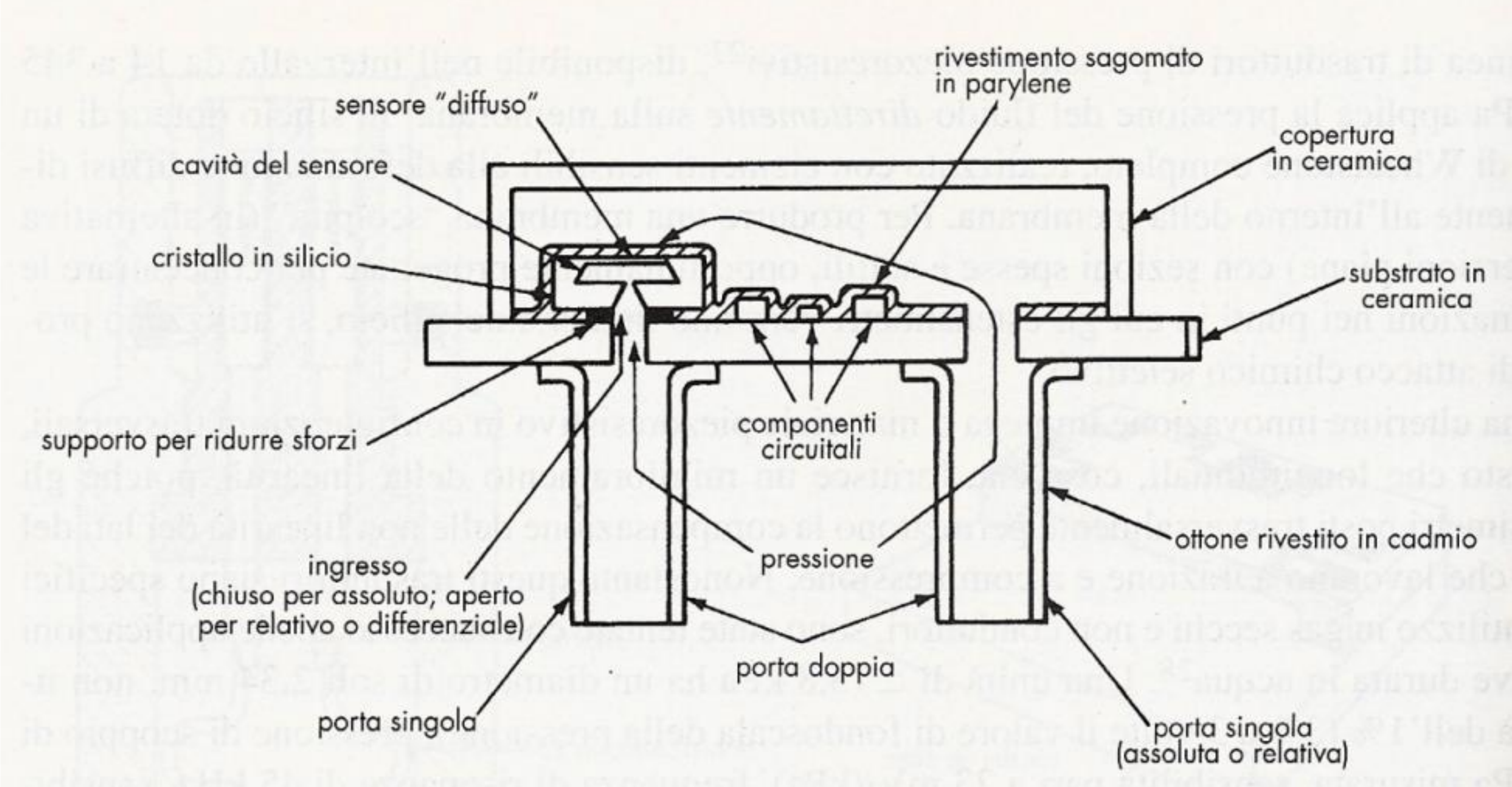
EXCITATION

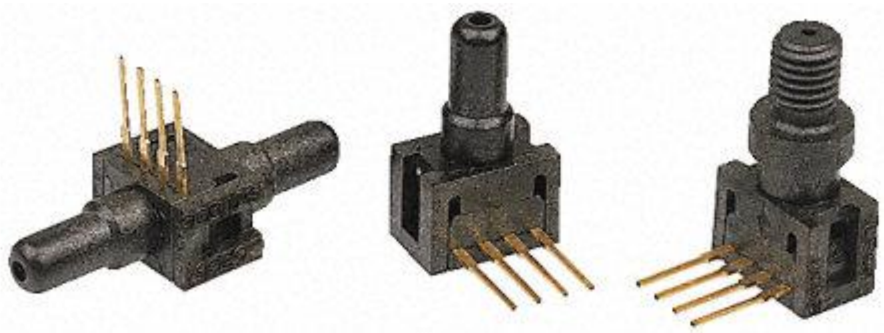


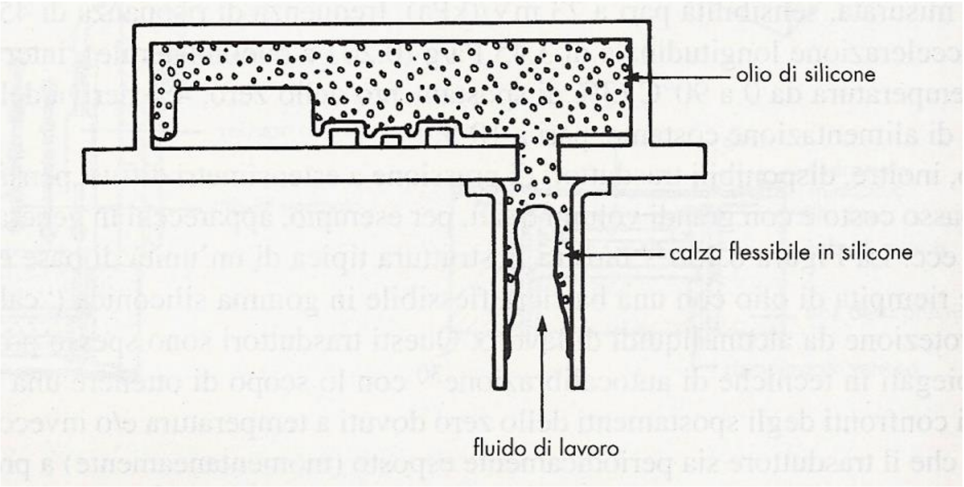
20PC Construction



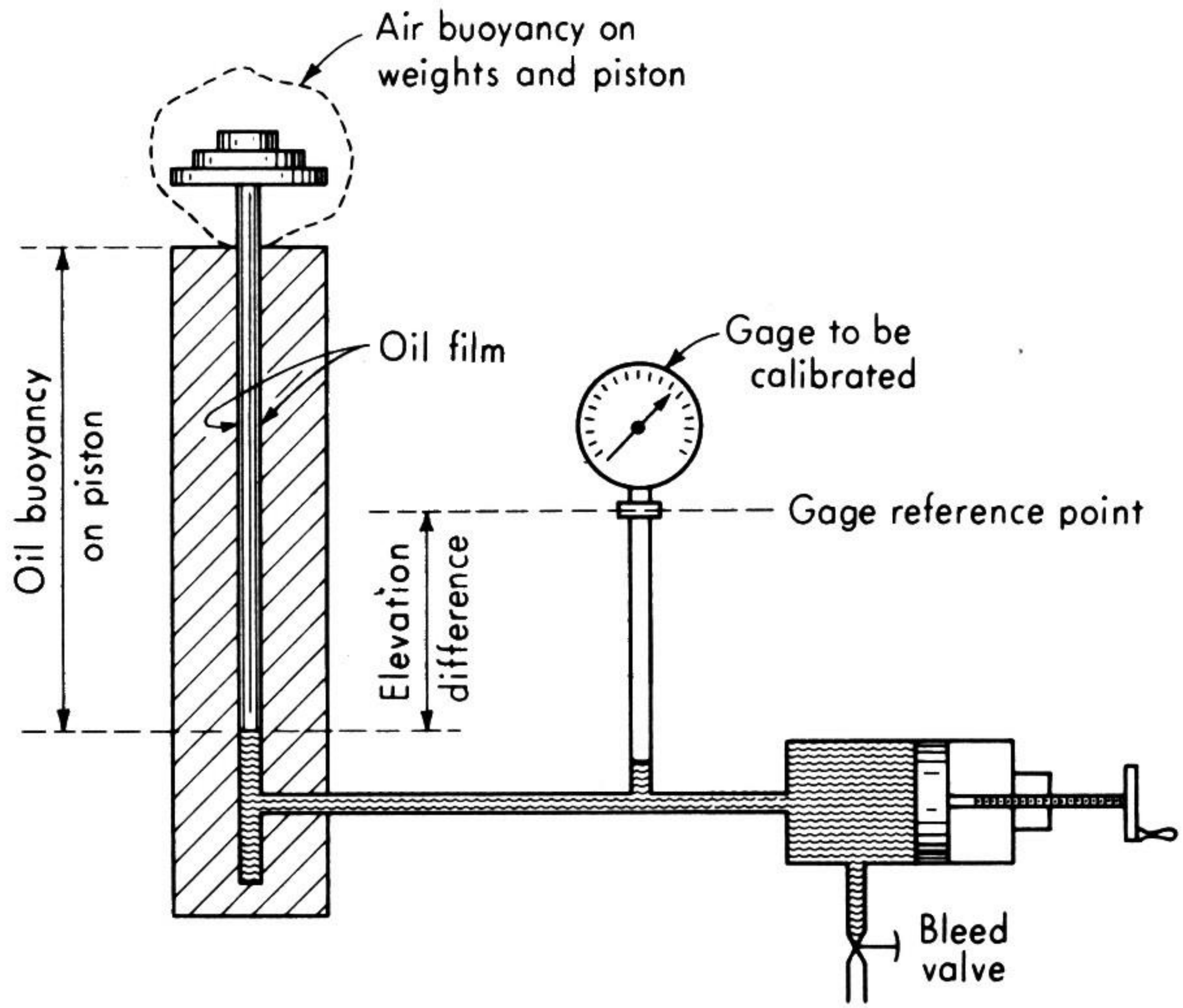

SMC PRESSURE
-94.0
OUT
SET
SMC PRESSURE
20.6
OUT
SET


rivestimento sagomato in parylene
sensore "diffuso"
copertura in ceramica
cavità del sensore
cristallo in silicio
substrato in ceramica
supporto per ridurre sforzi
componenti circuitali
ottone rivestito in cadmio
pressione
ingresso (chiuso per assoluto; aperto per relativo o differenziale)
porta doppia
porta singola
porta singola (assoluta o relativa)



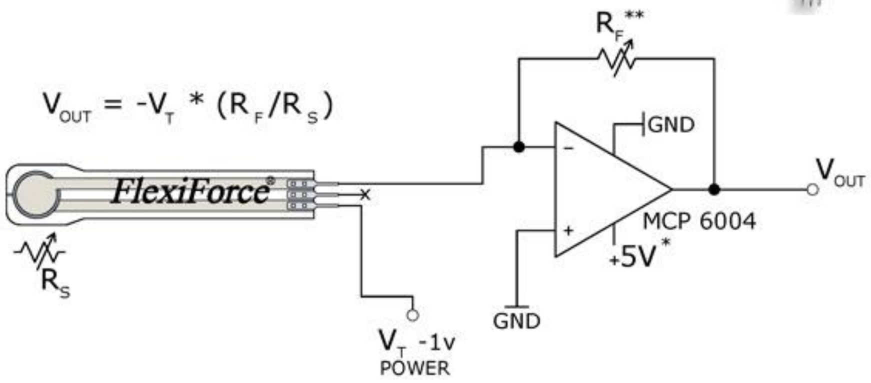

olio di silicone
calza flessibile in silicone
fluido di lavoro

Pressure gauge calibration bench:

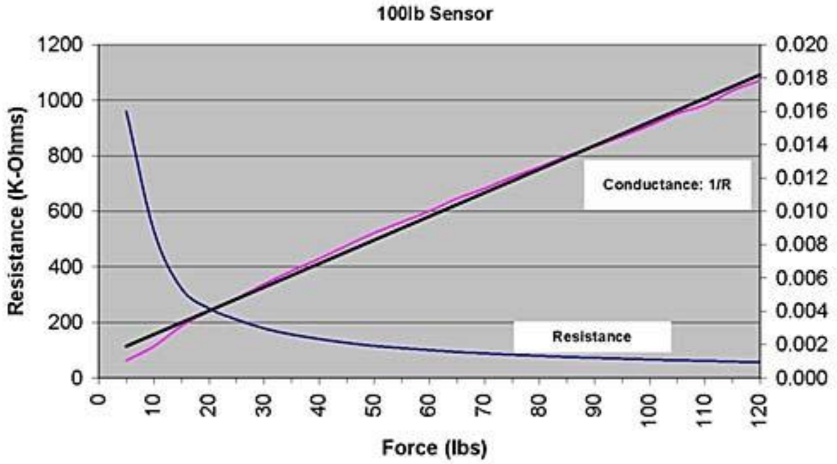


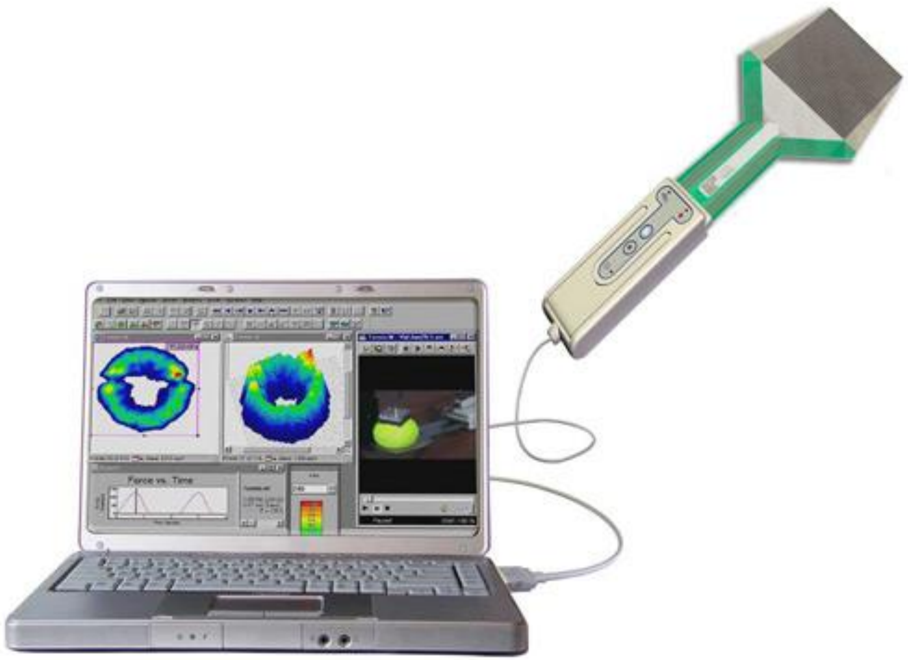
Deadweight gage calibrator.

Piezo-resistive film pressure transducers :

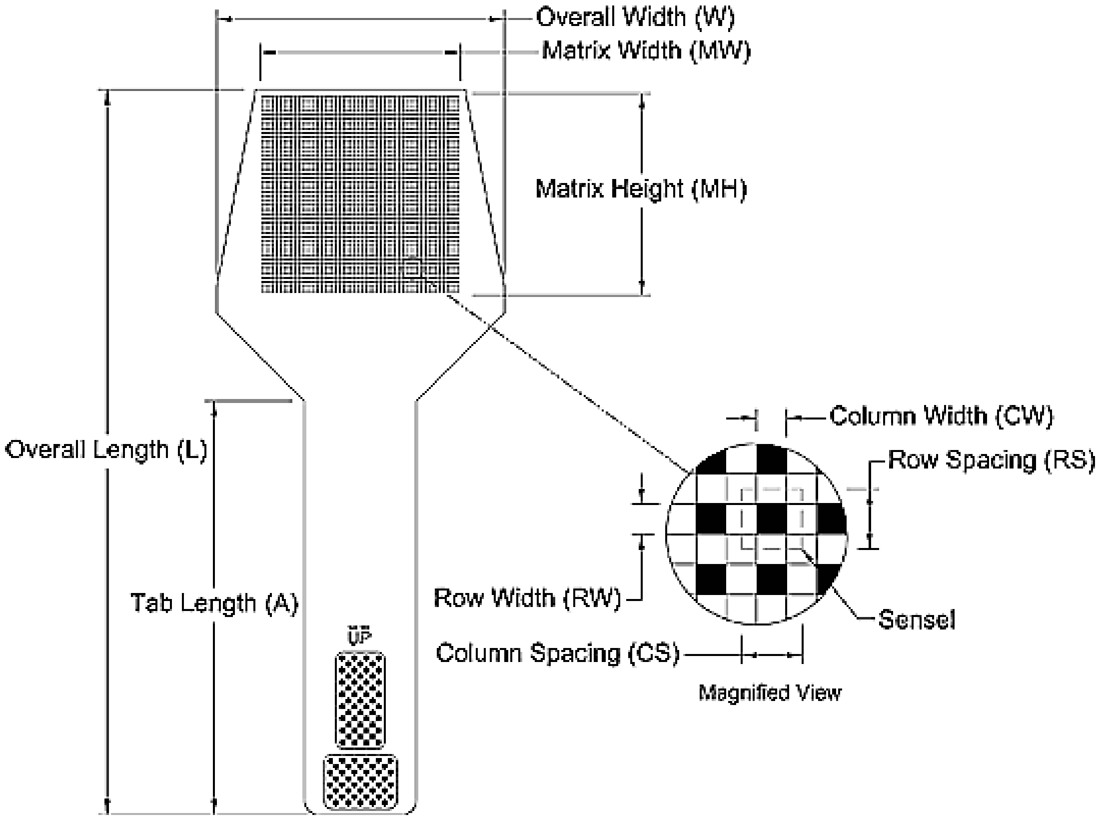


- * Supply Voltages should be constant
- ** Reference Resistance R_F is 1kΩ to 100kΩ
- Sensor Resistance R_S at no load is >5MΩ
- Max recommended current is 2.5mA

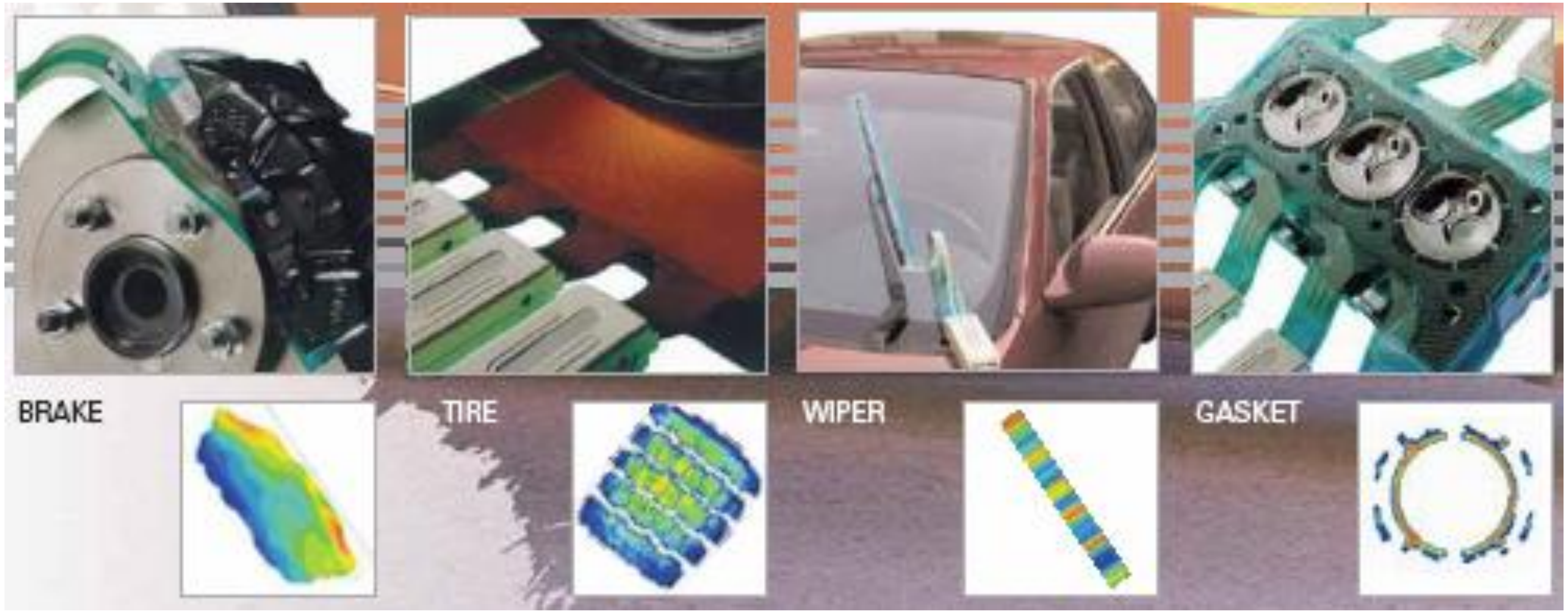




Thickness --> 0,2 mm

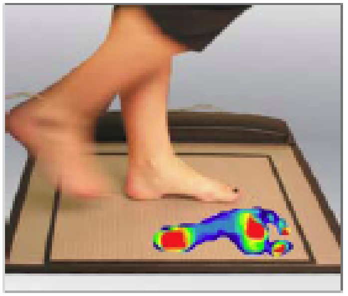


Sensing Area				Total		
Width		Height		Sensels	Sensel Density	
4.40	in.	4.40	in.	1,936	100.0	$in.^2$
111.8	mm	111.8	mm	1,936	15.5	cm^2


BRAKE
TIRE
WIPER
GASKET


DOOR SEAL
IMPACT
SEATING
FUEL CELL

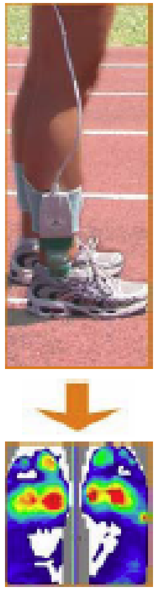
Pressure Mapping for Patient Care, Medical Research, and Animal Studies



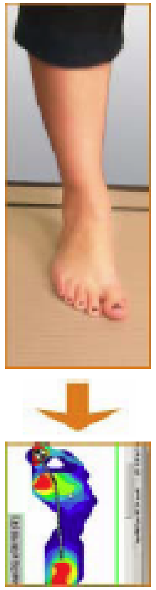
The search for cost-effective tools in the prevention and management of pressure-related problems for at risk patients has been a constant source of frustration for clinicians and hospital administrators. Tekscan's pressure measurement devices provide accurate, reliable data that is outcome focused and provides important insights into the formation of pressure-related sores. This information is an important quantitative adjunct to other qualitative assessment tools, assisting the clinician in providing results-oriented, cost-effective assessments and preventative care.

See All Medical Pressure Mapping Products

In-Shoe Pressure Analysis

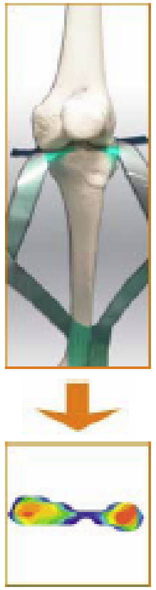


Barefoot Pressure Analysis

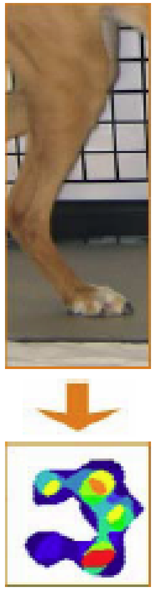


Seating & Positioning Pressure Analysis

Joint Pressure Analysis



Animal Gait Pressure Analysis



Our medical pressure sensors and systems help in the management of:

- diabetic foot
- orthotic assessment
- optimization of the seating and positioning of the neurologically compromised
- animal gait
- burn garment assessment
- prosthesis and brace fitting
- design and development of pressure-reducing support surfaces
- orthopedic joint research