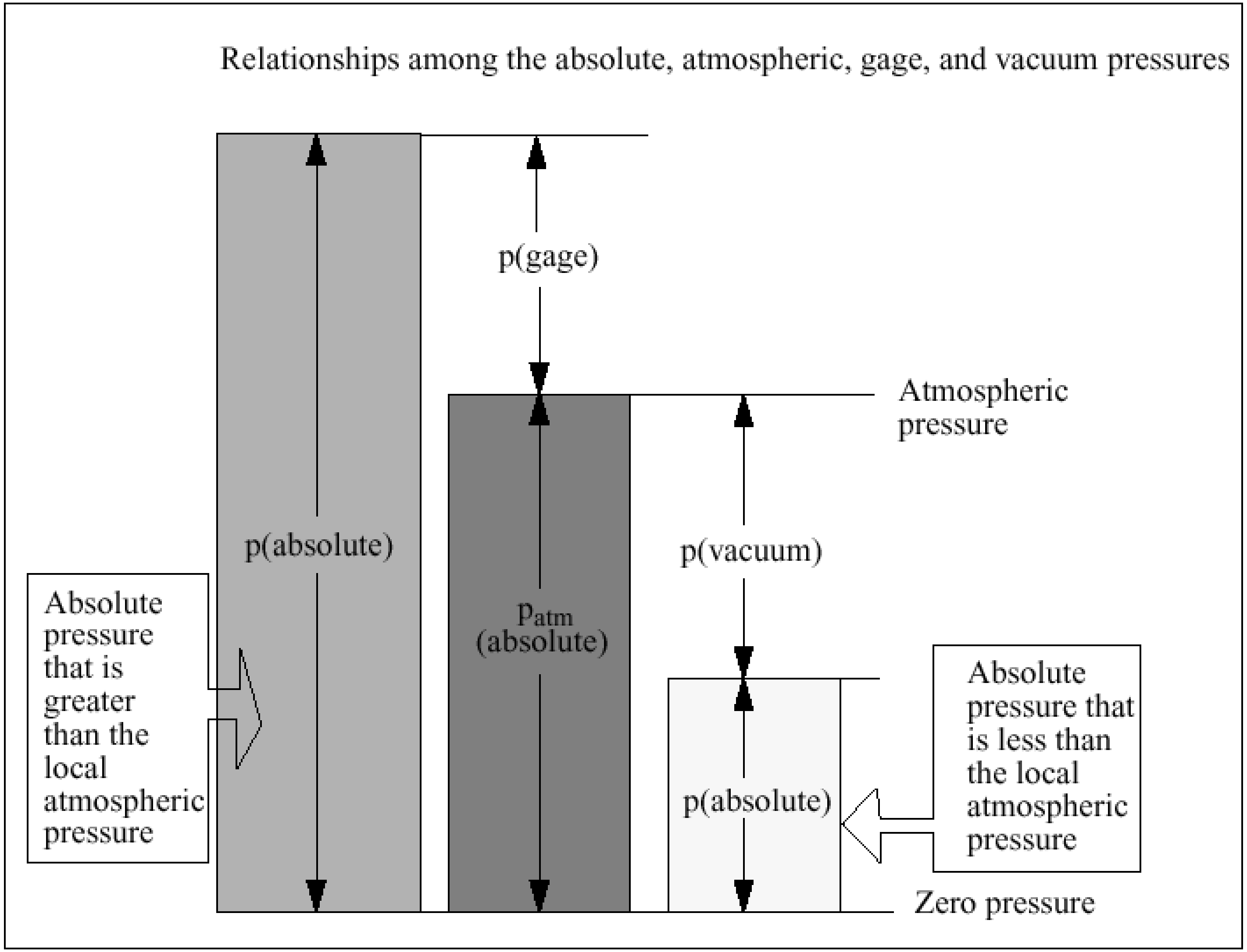
Measurable pressures

- Absolute pressure
- Gage pressure
- Differential pressure
- Atmospheric/barometric pressure

- Static pressure
- Total Pressure



Relationships among the absolute, atmospheric, gage, and vacuum pressures
p(gage)
Atmospheric pressure
p(absolute)
p(vacuum)
p_{atm} (absolute)
Absolute pressure that is greater than the local atmospheric pressure
Absolute pressure that is less than the local atmospheric pressure
p(absolute)
Zero pressure

Pressure Measurement

- Mechanical Pressure Measurement
  - Manometer
  - Mechanical deflection

$$P = \lim_{A \to continuum} \frac{F_{normal}}{A}$$

- Pressure Sensitive Paint
  - Measures the oxygen concentration in a polymer paint layer

$$p \sim p_{O_2} \sim c[0_2]$$

Static pressure	Oxygen Partial pressure	Henry's Constant x oxygen concentration

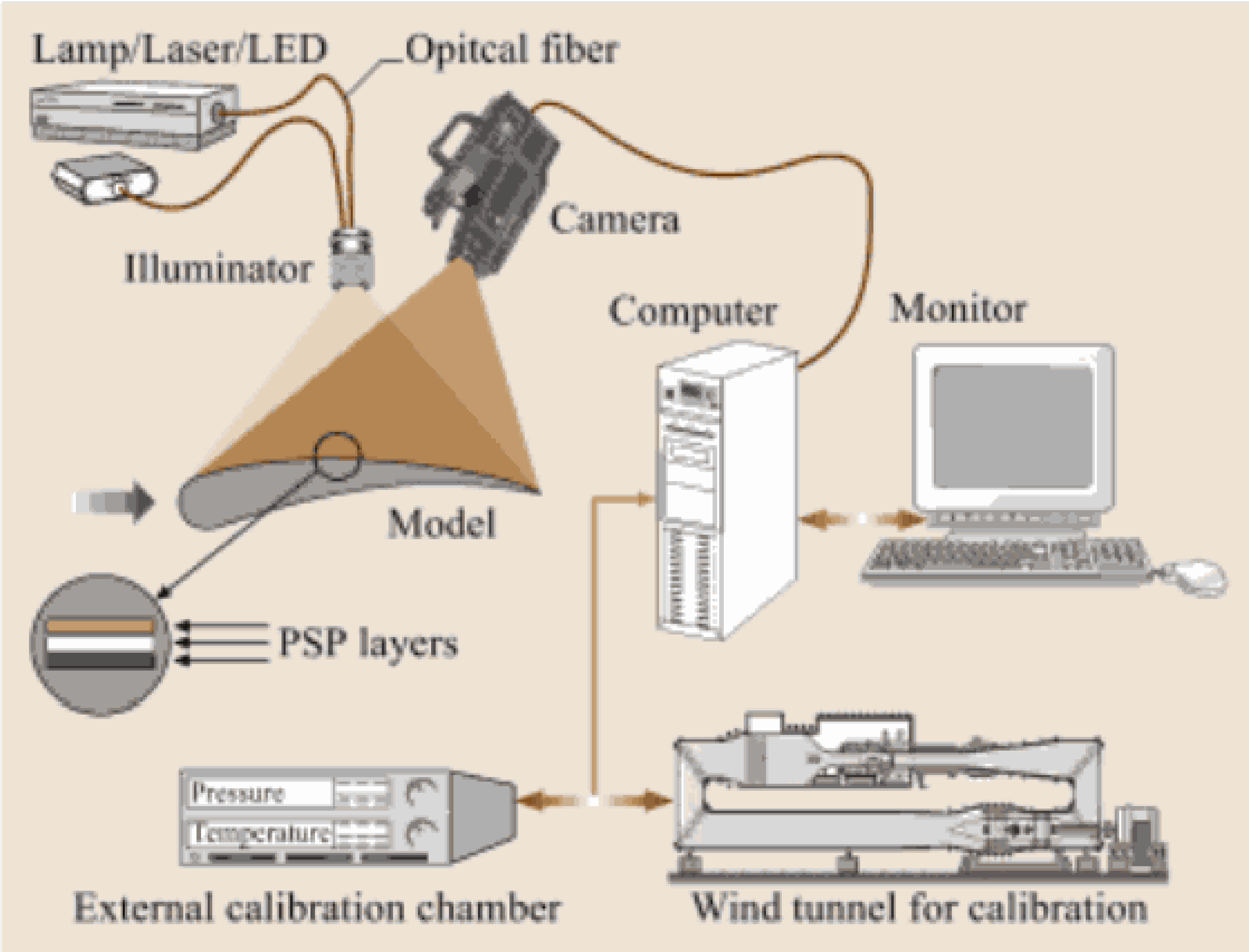


Fig. 4.10 Schematic of pressure-sensitive paint measurement system

The method is based on the phenomenon of deactivation of photoexcieted molecules of organic luminosphores by oxygen molecules (quenching).

The ability of oxygen to quench the luminescence of organic luminophores was discovered by H. Kautsky and H. Hirsch in 1935.

Certain materials are luminous when excited by the correct light wavelength.

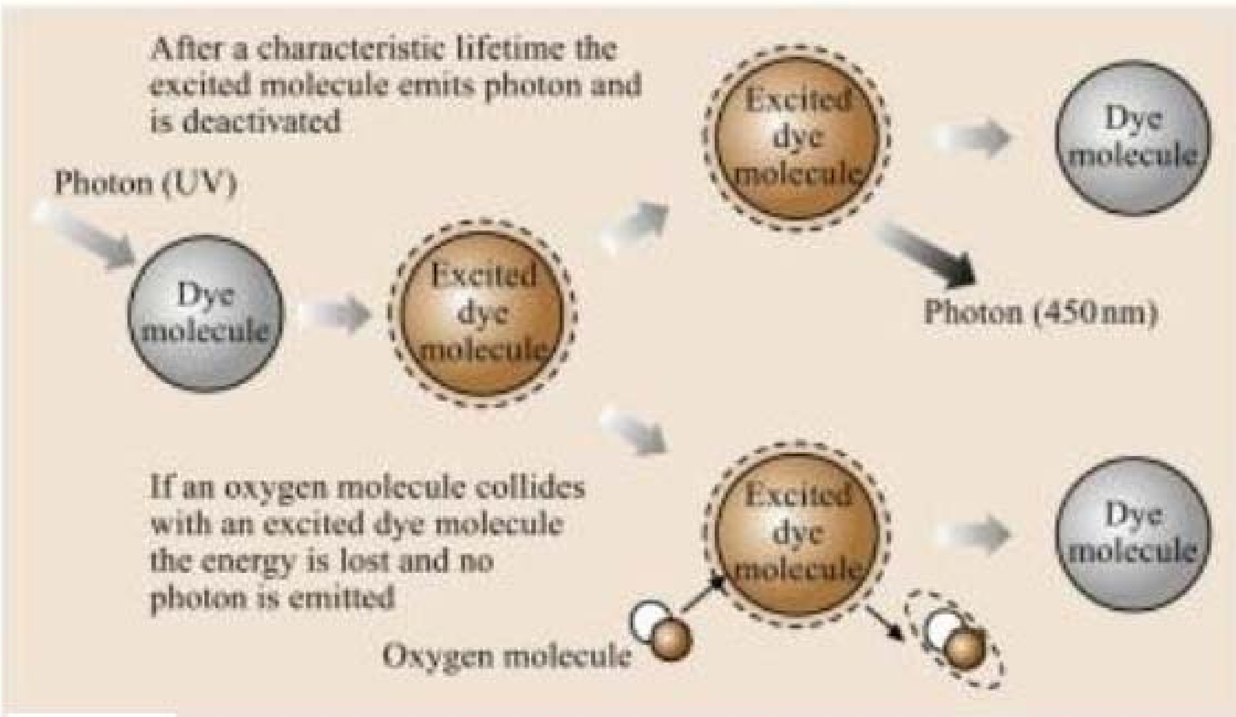
This luminescence can be quenched by the addition of another material.

The luminescence is dependent on air pressure.

A pressure sensitive paint consists of a **dye** held **in an oxygen permeable binder**. The dye absorbs light, and the energy is used to shift an electron from one part of the molecule to another.

The former part of the molecule gains a positive charge with a negative charge on the latter and these are stabilized and held apart.

For pyrene based paints, the excitation wavelength is in the ultraviolet (UV, λ=340nm) and the emission wavelength is in the blue (λ =450nm)



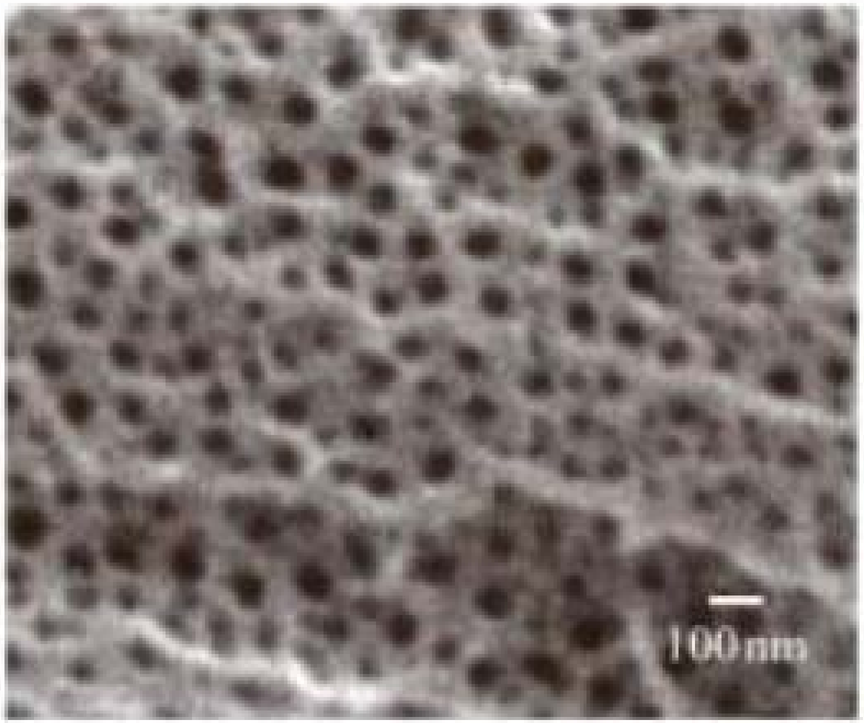
Schematic of oxygen quenching

Table Historical review of paint development

Luminophore	Binder	Mechanical properties	Year
Trypaflavin	Silicagel	Powder	1964
Pyrene, coronene, p-terphenyl	Mineral oil, apiezon, decaline, glycerol, silicagel, alumina, molecular sieves	Viscous liquid, powder	1971
Anthracene	solution	Liquid	1974
Platinum group metal complexes; porphyrin and phthalocyanine complexes of VO^{+-}, Cu^{++}, Zn^{++}, Pt^{++}, Pd^{--}; dimeric Rh, Pt, Ir complexes.	Plexiglas, polystyrene, polycarbonate, resins, polyvinylchloride, latex, teflon, polypropylene, polyvinylidene, fluoride, silicon rubbers	Films	1986
$[Ru(Ph_2phen)_3](ClO_4)_2$	GE RTV SILASTIC 118	Film	1986
PtOEP, PdOEP	Polysterene	Film	1995
$[Ru(Ph_2phen)_3](ClO_4)_2$	Polystyrene	Film	1995
$Ru(bipy)_3^{++}$	Zeolite+silicone	Paint, film	1995
$[Ru(Ph_2phen)_3](ClO_4)_2$ $Ru(bipy)_3^{++}$	Silicagel+silicone	Paint, film	1995

- These rubbers contain powerful adhesives that bind to many substances (so that they are easily binded to the aerodynamic model)
- They are highly permeable to oxygen.
- Distribution of oxygen in the paint layer is detected.

Binder example:



Surface of modified aluminum (anodised aluminum)

Fig. 4.12 PSP paint spraying in the covered test section itself

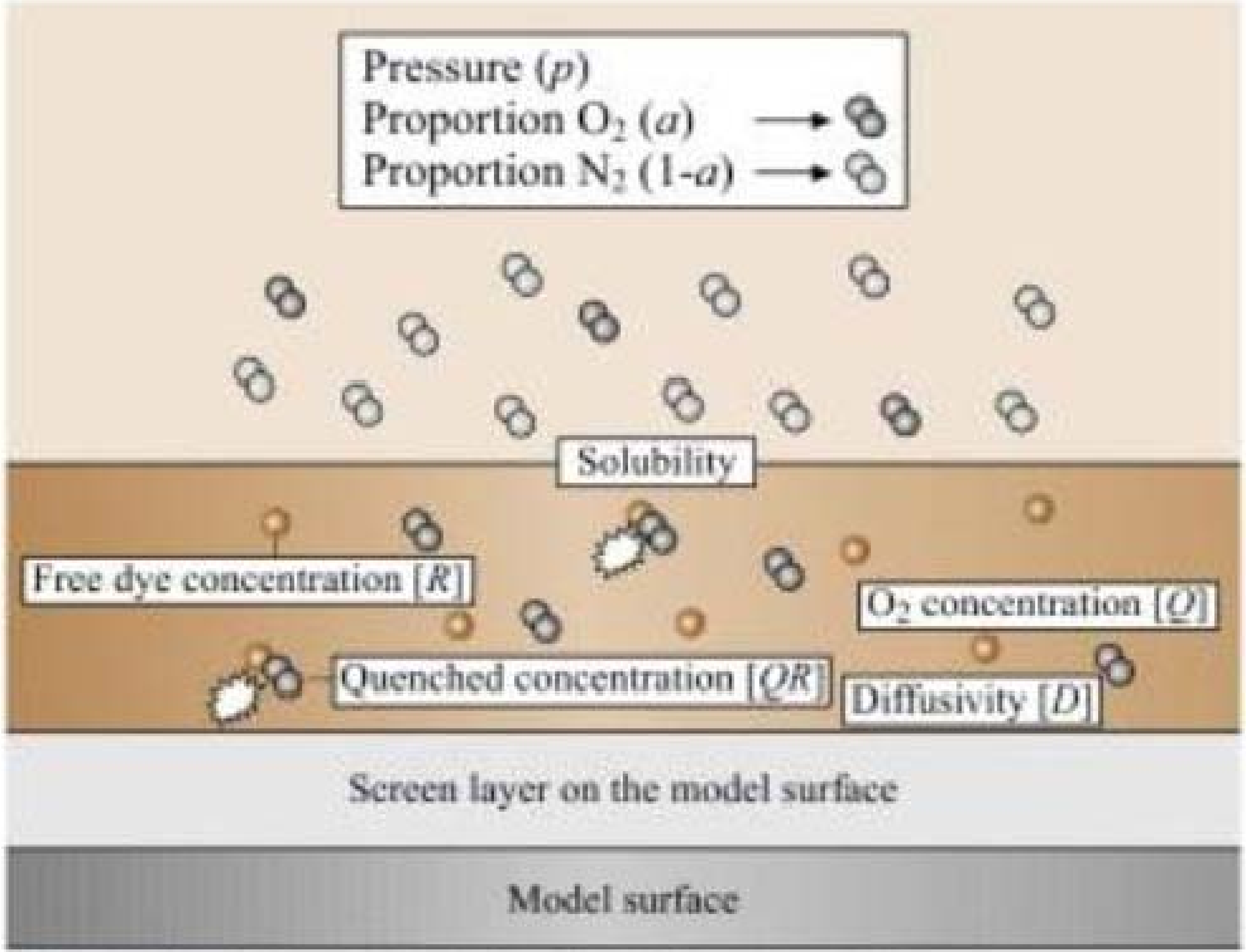


Fig. 4.17 Schematic of paint photochemistry

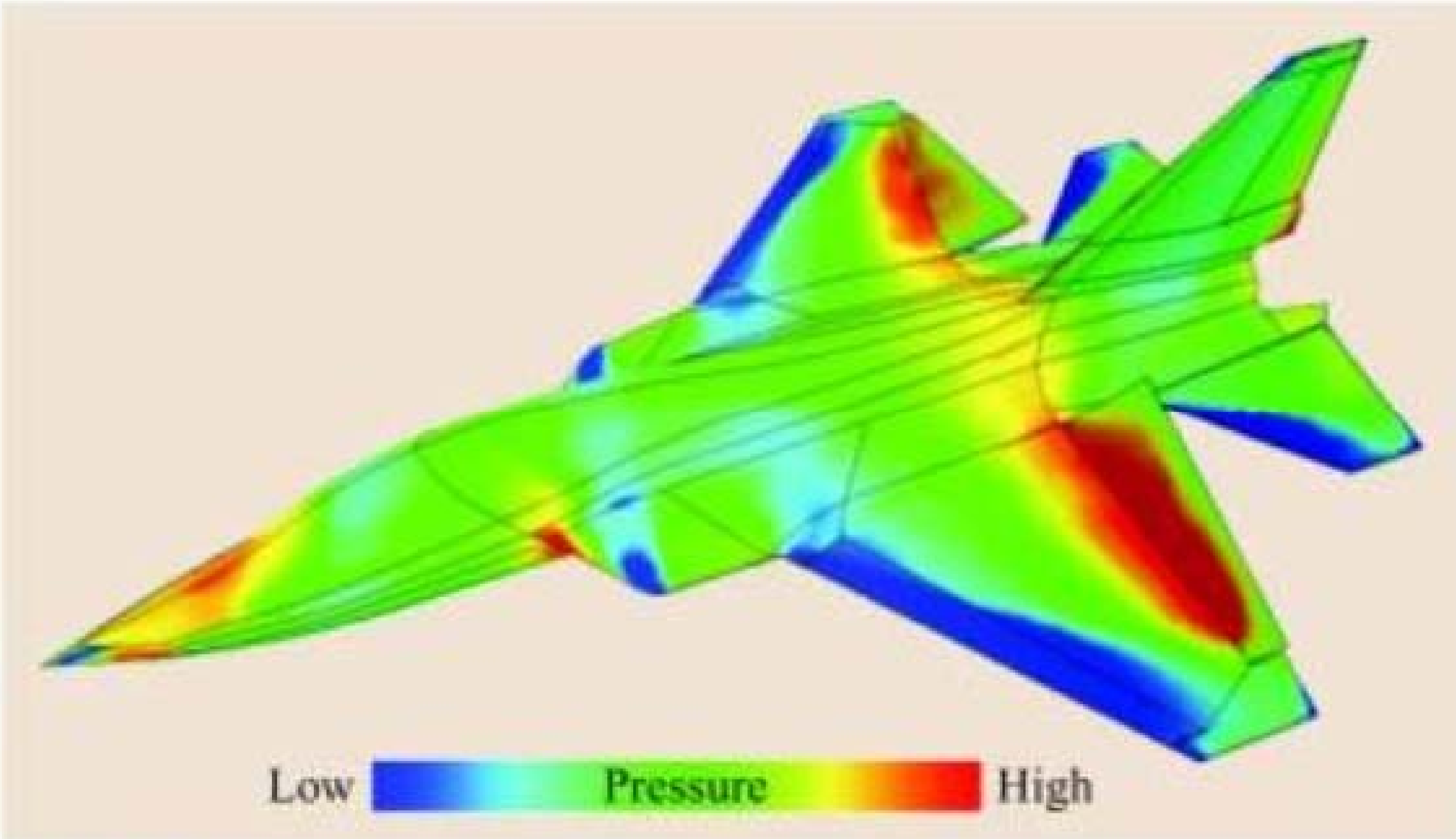
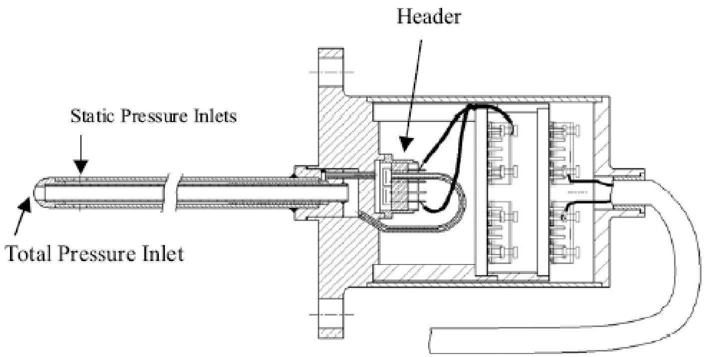


Fig. 4.26 Completely PSP-coated model with absolute pressure distribution to calculate loads

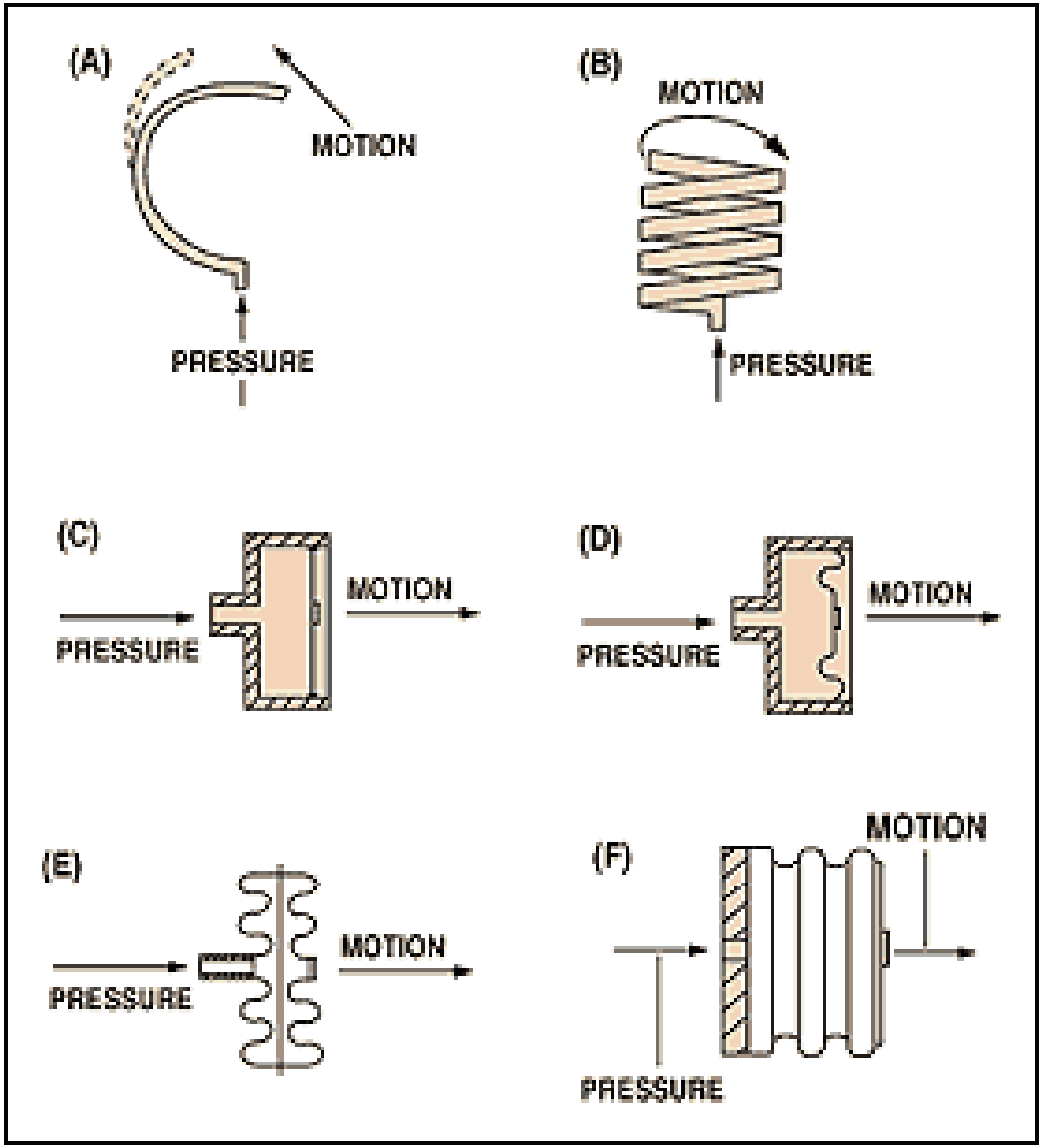
Oxygen concentation is detected by CCD cameras

Pressure Transducers



Pitot-static transducer

Pressure sensing elements



The basic pressure sensing elements can be configured as:

(A) a C-shaped Bourdon tube
(B) a helical Bourdon tube
(C) flat diaphragm
(D) a convoluted diaphragm
(E) a capsule
(F) a set of bellows

A pressure transducer might combine the sensor element with a mechanical-to-electrical or mechanical-to-pneumatic converter and a power supply.

Pressure sensing elements

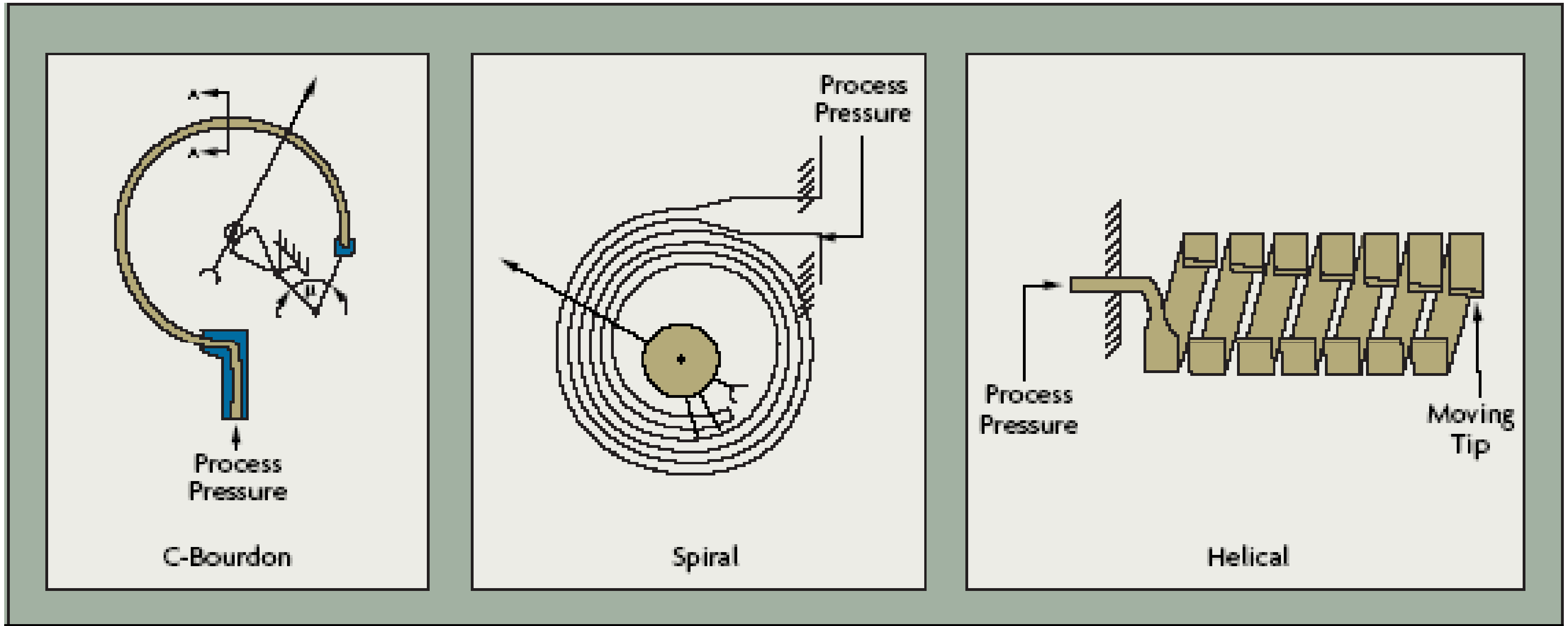


Figure 3-1: Bourdon Tube Designs

Classification of electrical pressure transducers

There are basically two general types of electrical transducers:

- **<u>1. Active devices:</u>** the physical effect to be identified produces an electrical quantity, e.g. a voltage.

Typical examples are piezo-electric transducers, thermocouples, etc.

Their sensitivity is expressed as the ratio of the change of electrical output to the change of physical input.

$S = \Delta V / \Delta p$

Their typical overall accuracy is of the order of 1%.

Classification of electrical pressure transducers

2. Passive devices:

-Cannot do anything by themselves. There has to be an external power source (voltage) so that the device can be activated.

-an electrical circuit element (R,L,C) is modified by the physical effect

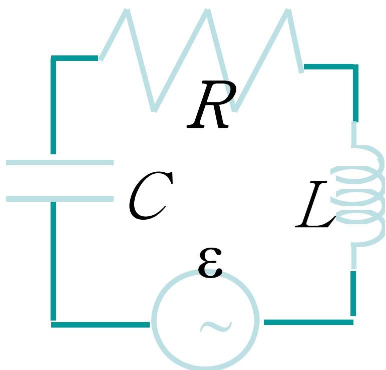
(input pressure or voltage).

-The sensitivity of passive transducers is expressed as the ratio of the relative impedance variation ΔZ/Z to the change of physical input.

S= (ΔZ/Z) / Δp

Typical examples are resistive, inductive and capacitive transducers.

Their typical overall accuracy is also of the order 1%.



$$V_R = RI \qquad V_L = L\frac{dI}{dt} \qquad V_C = \frac{1}{C}\int I \, dt$$

Classification of electrical pressure transducers

Electrical transducers can also be classified according to their modulation mode.

-**continuous mode (DC):** the analog output is a DC signal; proportional to the input signal.

-**amplitude modulation (AM):** the output signal is an AC signal; its amplitude is a function of the measured quantity whereas its frequency is constant.

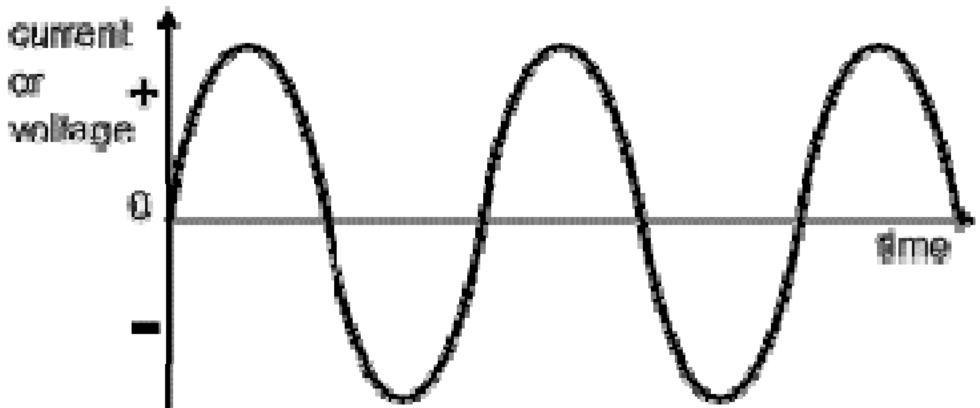
-**frequency modulation (FM):** the output signal is an AC signal; its frequency is a function of the measured quantity whereas its amplitude is constant.

❑ Alternating current (AC current)

Alternating Current (AC) flows one way, then the other way, continually reversing direction.

An AC voltage is continually changing between positive (+) and negative (-).

The rate of changing direction is called the **frequency** of the AC and it is measured in **hertz (Hz)** which is the number of forwards-backwards **cycles per second**.

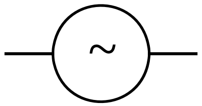


AC from a power supply(**sine wave**)

An AC supply is suitable for powering some devices such as lamps and heaters but almost all electronic circuits require a steady DC supply

❑ Alternating current (AC current)

• Current which varies sinusoidally in time is called alternating current (AC) as opposed to direct current (DC).

The symbol  is used to denote an AC source. In general a source means either a source of alternating current or voltage.

$$\upsilon = V\cos\omega t \text{ for alternating voltage, V = voltage amplitude}$$

$$i = I\cos\omega t \text{ for alternating current, I = current amplitude}$$

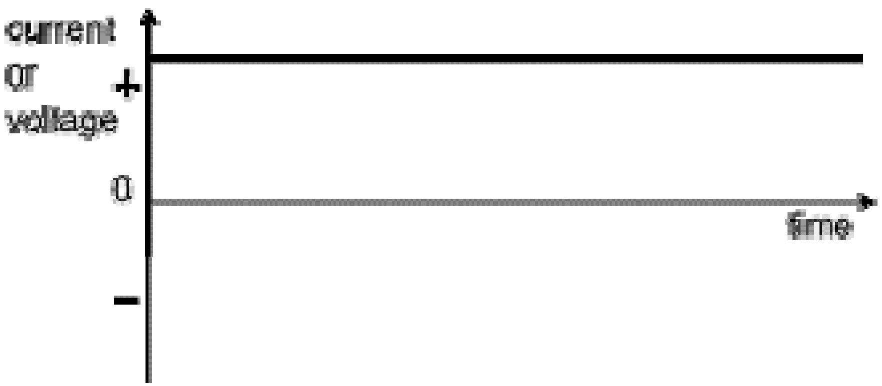
• In the U.S. and Canada, commercial electric-power distribution system uses a frequency of f = 60 Hz, corresponding to ω = 377 rad/s. In much of the rest of the world uses f = 50 Hz. In Japan, however, the country is divided in two regions with f = 50 Hz and 60 Hz.

❑ Direct Current (DC current)

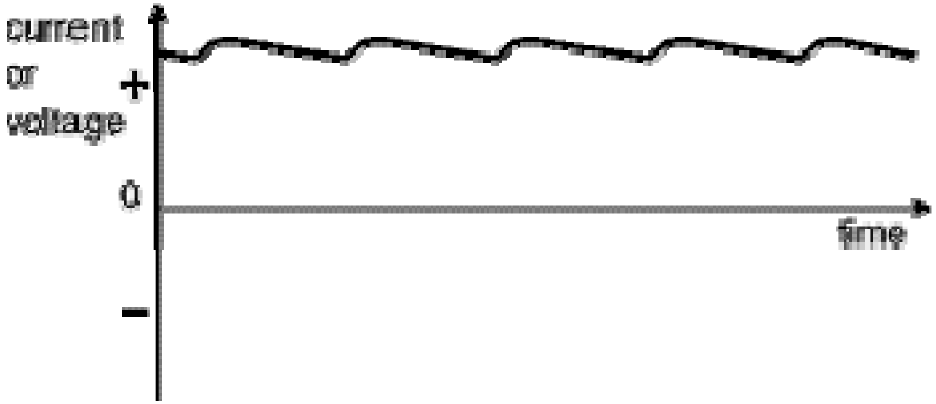
A DC voltage is always positive (or always negative), but it may increase and decrease.

Electronic circuits normally require a **steady DC** supply which is constant at one value or a **smooth DC** supply which has a small variation called **ripple**.

Cells, batteries and regulated power supplies provide **steady DC** which is ideal for electronic circuits.



Steady DC (from a battery or regulated power supply, this is ideal for electronic circuits)



Smooth DC (from a smoothed power supply, this is suitable for some electronics)

Different Types of Pressure Transducers

Pressure is a force acting on a surface. It is usually measured as a force per unit area.

Pressure transducers can also be classified according to the type of pressure measured.

-**<u>the gage pressure transducer:</u>** it measures pressure referenced to local atmospheric pressure and is vented to atmosphere. When its pressure port is exposed to atmosphere, the transducer indicates a zero output.

-**<u>the absolute pressure transducer:</u>** it measures pressure referenced to an internal chamber sealed at 0 Pascal. When its pressure port is exposed to the atmosphere, the transducer indicates local atmospheric pressure.

-**<u>the differential pressure transducer:</u>** it measures the difference between two pressures applied to its pressure ports.

-**<u>the sealed pressure transducer:</u>** it measures pressure referenced to an internal chamber, sealed at a given pressure

Different Types of Pressure Transducers

As many other instruments, the transducer is affected by its environment. The accuracy of its output strongly depends upon a correct calibration as well as upon the conditions in which it is used.

In general, great care must be taken with respect to:

- the transducer operating temperature
- its reference pressure
- electrical and magnetic fields eventually present
- mechanical vibrations

A correct selection of the transducer to be used in a particular application requires a correct knowledge of

- its pressure sensitivity,
- its range,
- its frequency response or resonant frequency
- its sensitivity to acceleration, etc…

Variable capacitance transducers

The capacitance is given by the equation:

$$C = \frac{KS(N-1)}{d}$$

C: capacitance
K: dielectric constant of the material between the plates
S: Area of one side of one plate
N: Number of plates
d: distance between two adjacent plates

A capacitance transducer operates on the principle that the physical property to be sensed changes one of the variables in the above equation (usually the distance d) which then changes the capacitance C.

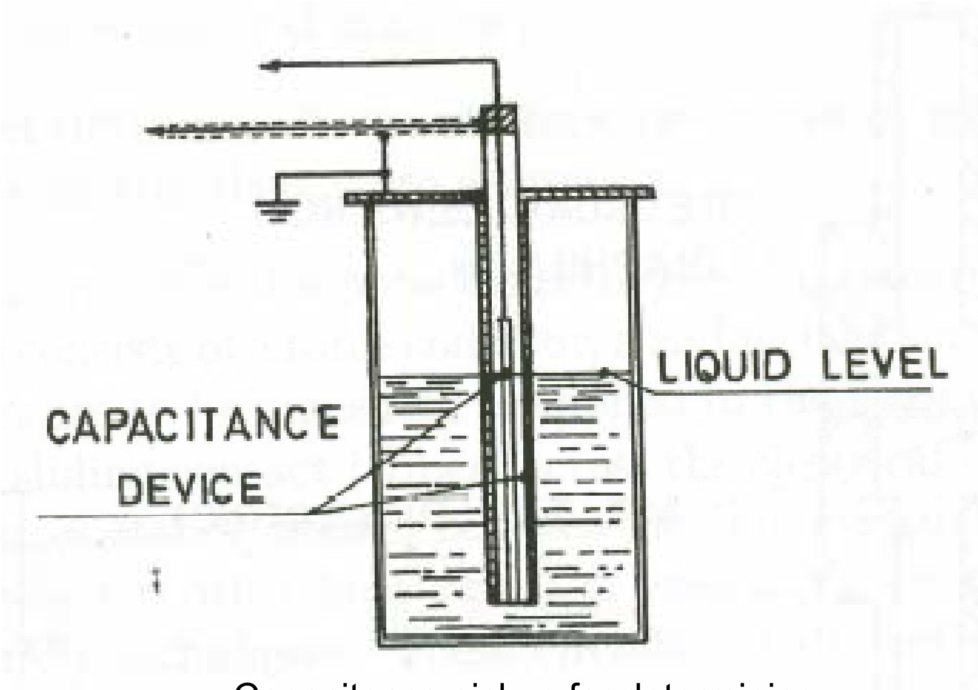
If the distance d is modified, such transducer is in fact a displacement transducer, but it is also used to measure force, pressure and acceleration.

Variable capacitance transducers

Example:

This capacitance transducer is used to determine the level of liquid hydrogen.

The capacitance between the central rod and the surrounding tube varies with the changing dielectric constant K, varying because of the changing liquid level.



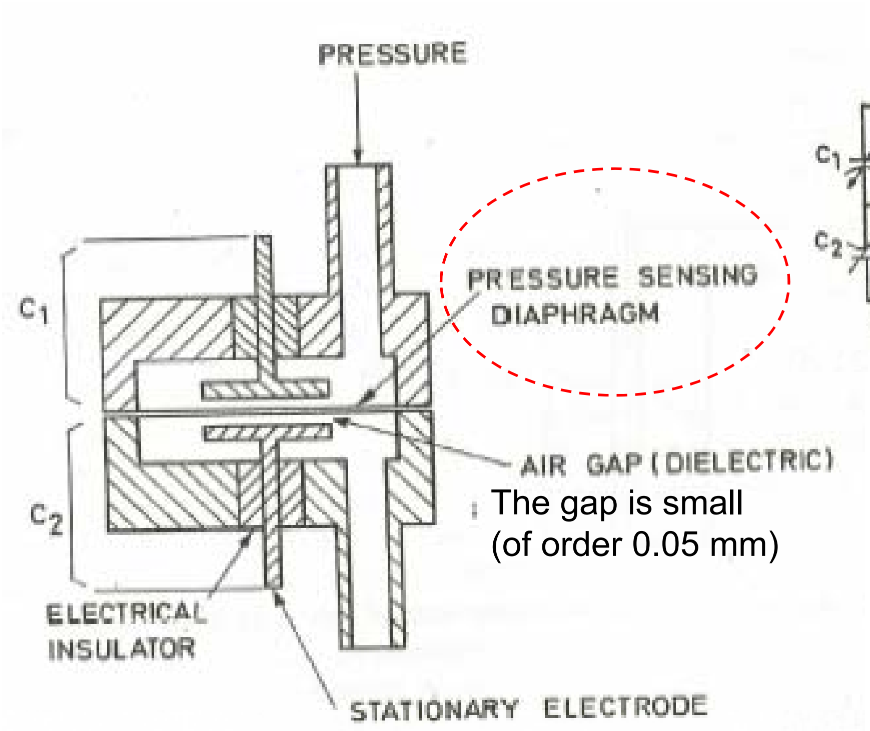
Capacitance pickup for determining level of liquid hydrogen

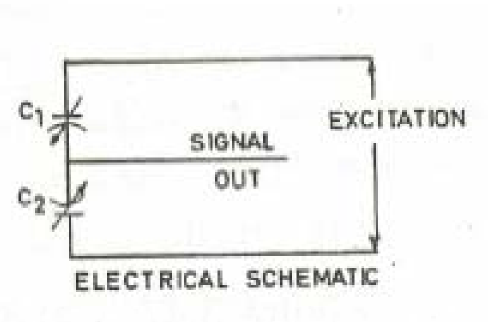
$$C = \frac{KS(N-1)}{d}$$

C: capacitance
K: dielectric constant
S: Area of one side of one plate
N: Number of plates
d: distance between two adjacent plates

Variable capacitance transducers

A classical type of capacitive transducer for pressure measurements:





Variable Capacitance
Pressure Transducer

A diaphragm is suspended between two parallel metallic plates in order to form two capacitances C1 and C2.

The capacitance will change their value according to the diaphragm deflection due to a pressure difference between its two sides.

This type of transducers is mostly used to measure small changes of a fairly low static pressure.

Capacitance Pressure Transducer

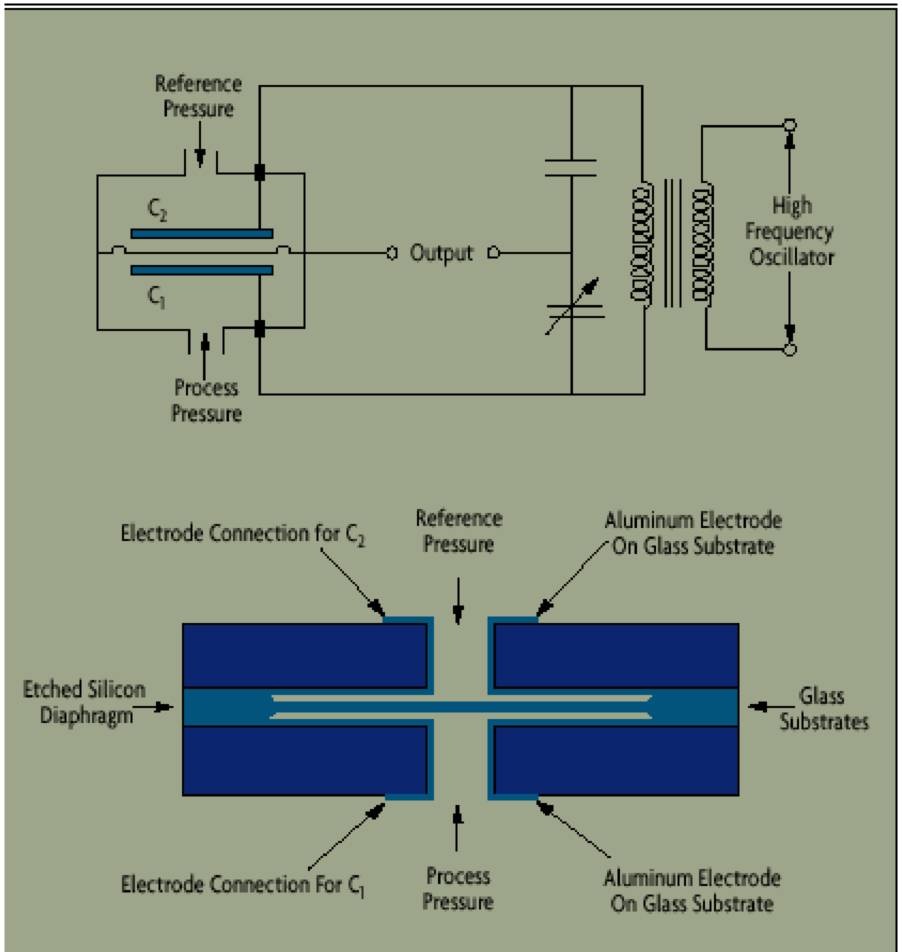
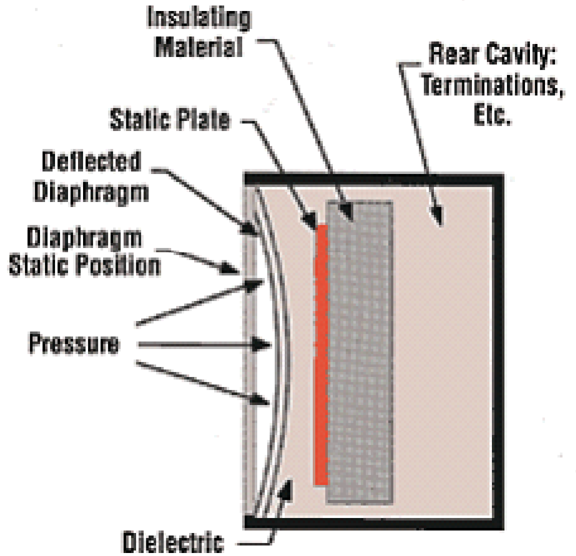


Figure 3-5: Capacitance-Based Pressure Cell



Variable resistance transducers

The resistance of a conductor is given by:

$$R = \rho \frac{l}{S}$$

R: resistance
ρ: thermal resistivity of the resistance material
l : length of the conductors
S: cross sectional area of the conductors

A resistive transducer operates on the principle that the physical property to be sensed changes one of the variables in the above equation.

The simplest of these devices is the ordinary switch.

Another type is a sliding contact resistive transducer: it converts a mechanical displacement into an electrical output, either voltage or current. This is accomplished by changing the length of the conductor.

Variable resistance transducers

There are basically two types of variable resistance pressure measurements:

- -Transducers which detect large resistance changes usually operate in <u>potentiometer circuits</u>.

- -Transducers which detect small resistance changes are used in <u>bridge circuits</u> (strain gage transducers are a classical example)

Variable resistance transducers

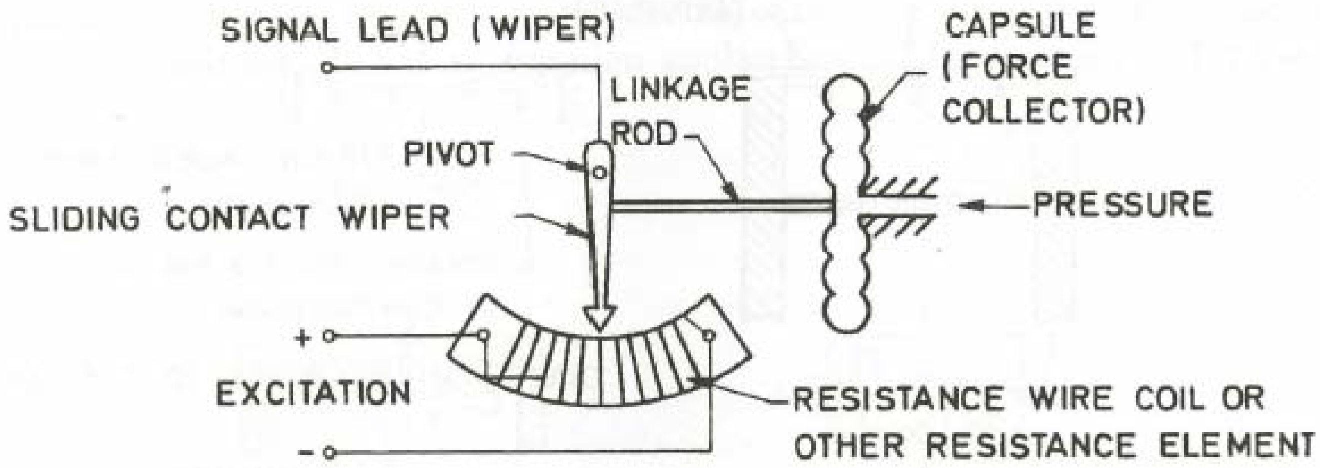
Potentiometric pressure transducer:

The basic operating principle of a potentiometer circuit pressure transducer is shown in Figure.

This device consists of a capsule, a sliding contact wiper and the resistance wire winding.

•The pressure to be measured is applied to the capsule which, through a linkage rod, moves a sliding contact (wiper) across the electrical resistance wire windings.

•The movement of the wiper arm across the potentiometer converts the mechanically detected sensor deflection into a resistance measurement



Potentiometric pressure transducer schematic

Variable resistance transducers

Strain gage transducer:

A strain gage transducer transforms a deformation (or a micro-displacement) into a resistance variation.

By using 2 or 3 gages, the components of the local deformation can be obtained.

Several types of strain gage pressure transducers are:

1. Gaged diaphragm pressure transducers
2. Cantilever type transducers
3. Embedded strain gage transducers
4. Unbounded strain gage transducers

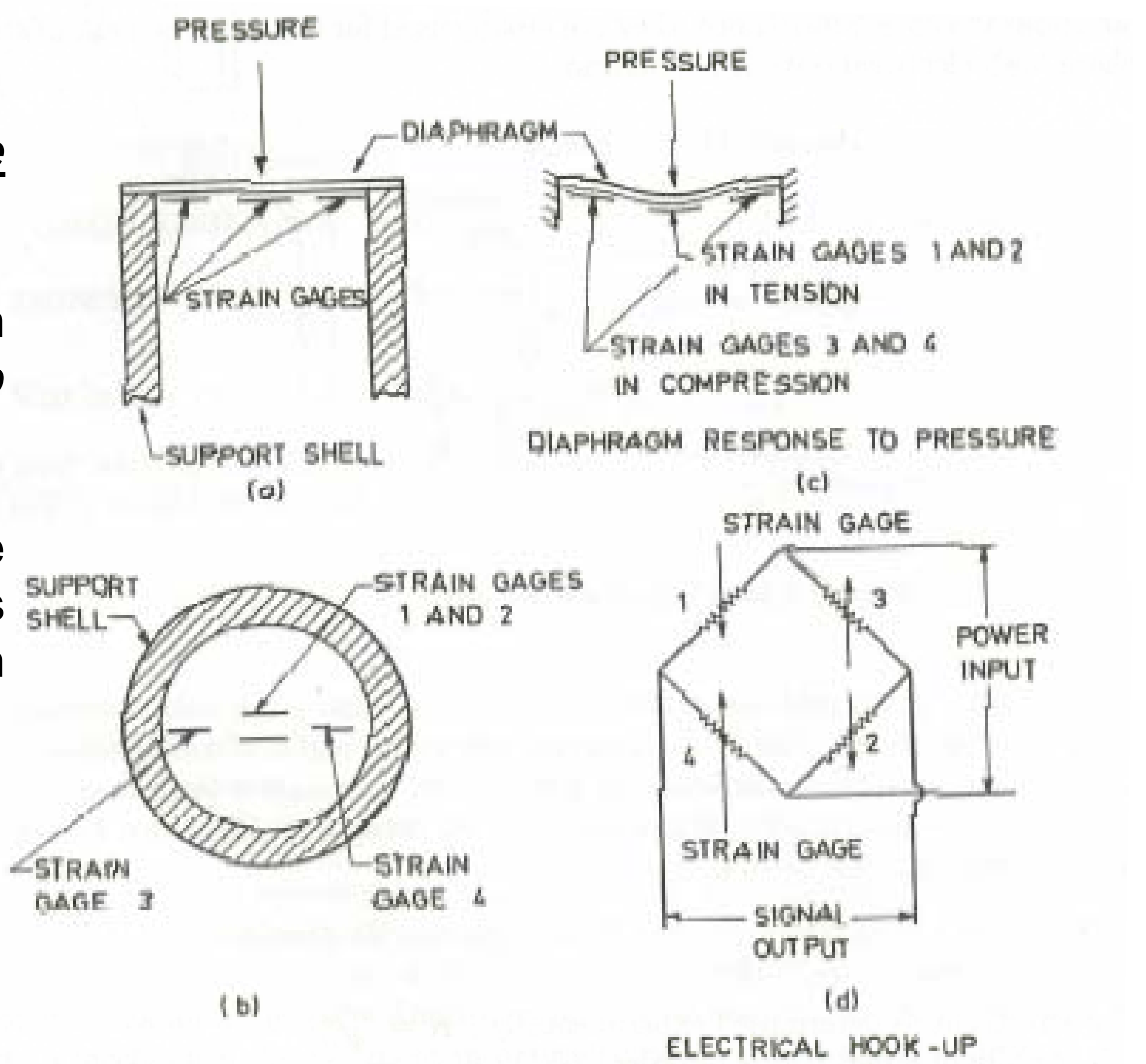
Variable resistance transducers

<u>*Strain gage transducer:*</u>

<u>1. Gaged diaphragm pressure transducers:</u>

They contain a diaphragm with *strain gages bounded directly to the surface*.

When pressure is applied to the surface, the diaphragm deflects and the resistance of the strain gages change.



Variable resistance transducers

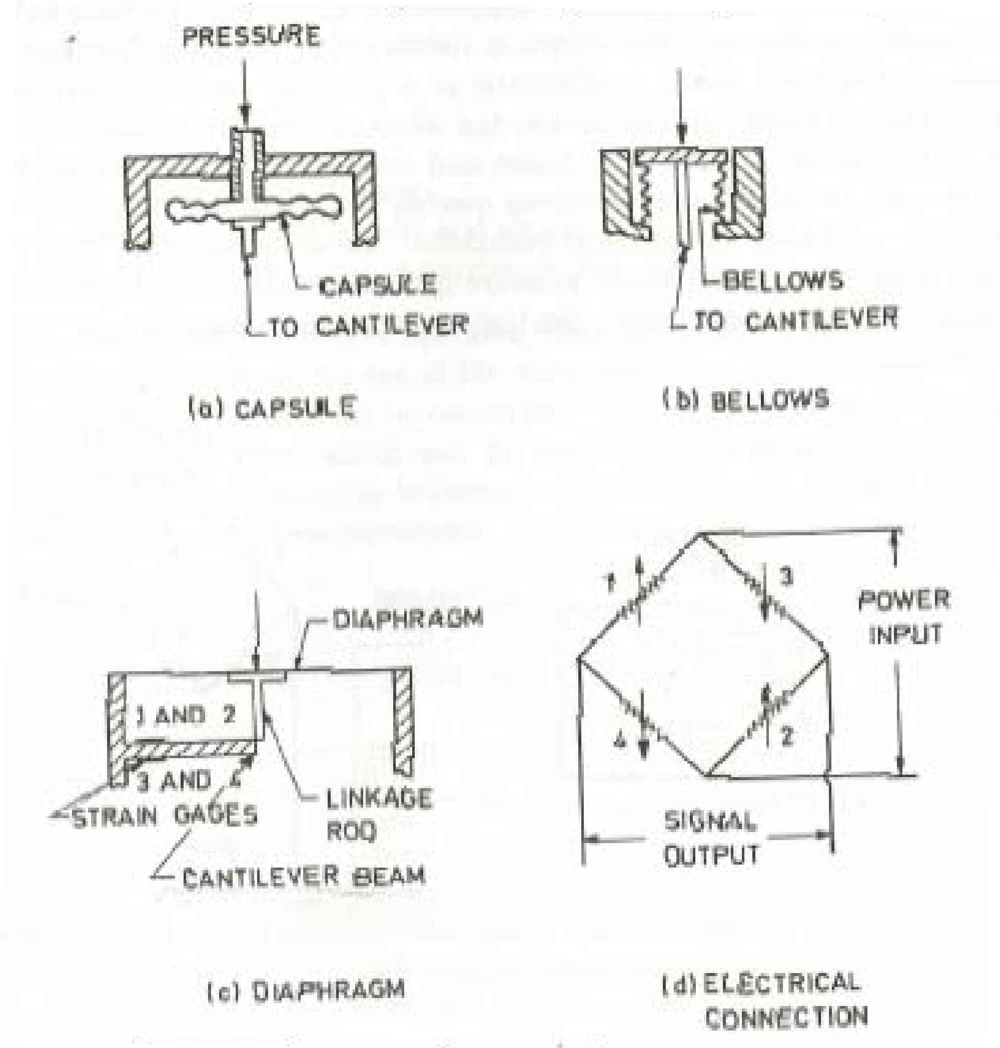
<u>*Strain gage transducer:*</u>

<u>2. Cantilever type transducers:</u>

These transducers consist of a pressure velocity element connected through a linkage rod to some type of *cantilever instrumented with strain gages*.

The most frequently used types of pressure collecting elements are diaphragms, capsules and bellows.

The most common application of these devices is for low pressure measurements.



Bounded strain gage cantilever type transducers

Variable resistance transducers

Strain gage transducer:

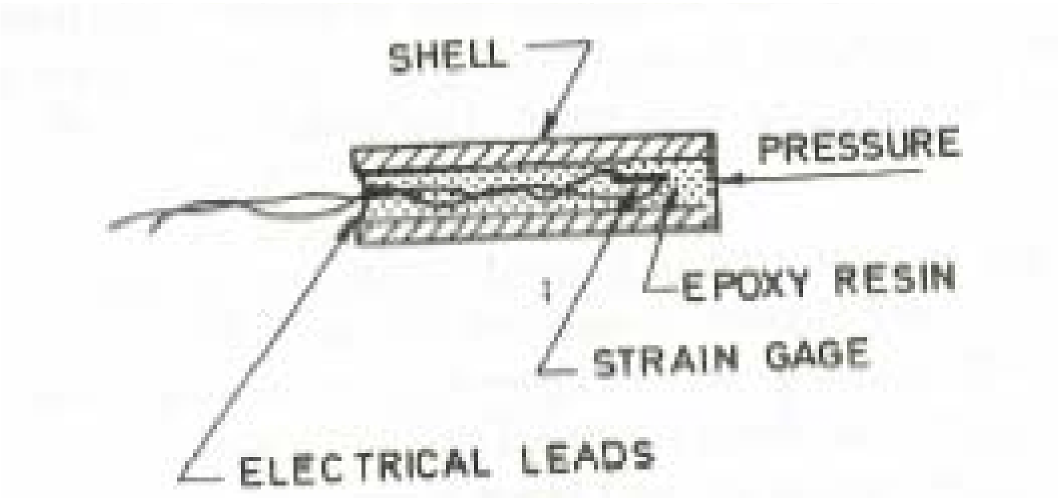
3. Embedded strain gage transducers:

Generally, the embedding material is an epoxy resin which transmits the strain when a uniaxial pressure is applied.

The strain gage then provides a proportional resistance change.

Generally embedded strain gage transducers are very small.

They are useful for high pressure environments where a fast time response is required.



Embedded strain gage transducers

Variable resistance transducers

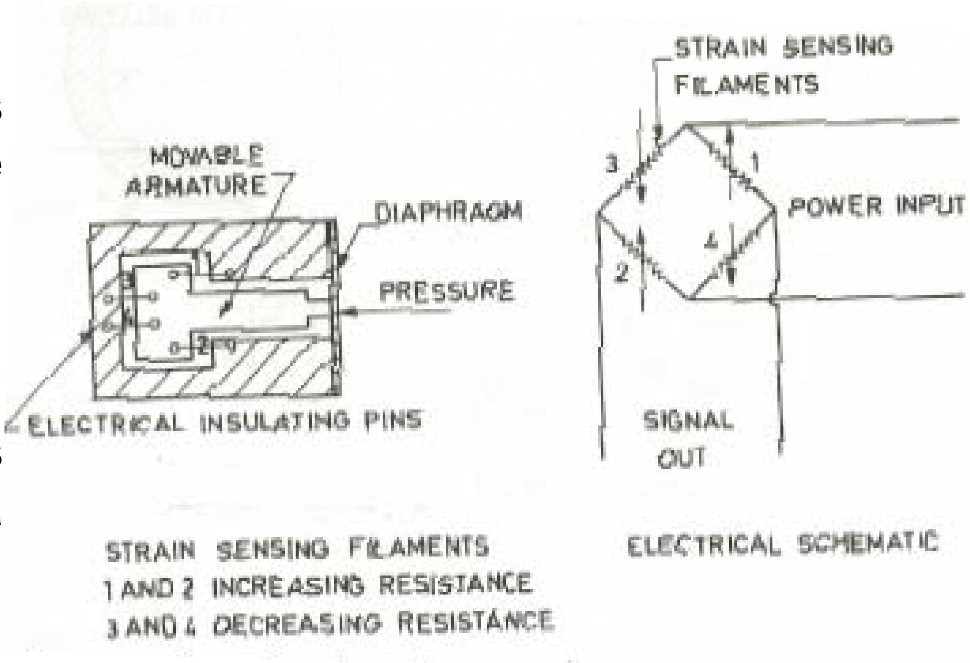
Strain gage transducer:

4. Unbounded strain gage pressure transducers:

They operate on the same principle as bounded strain gage transducers: the electrical resistance of a .wire varies with strain changes.

In the device, the wires are strung on electrical insulating pins, one of which is on a fixed frame and one of which is on a movable armature.

Under pressure, the diaphragm elongates moving the armature, then causing the strain gages to produce a change in electrical resistance.



Unbounded strain gage transducers

Variable inductance transducers

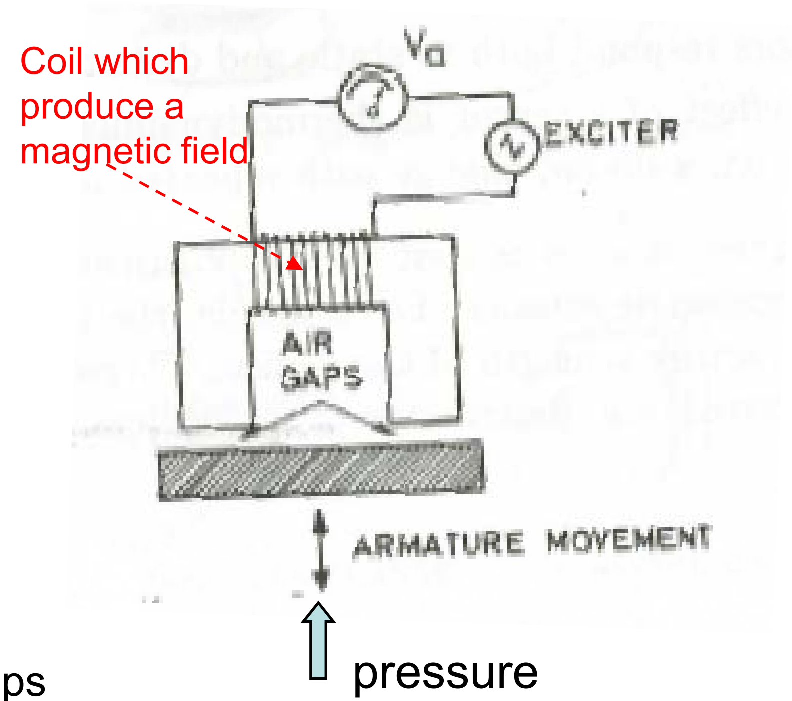
Inductive transducers operate on the principle that the voltage drop across a coil which produces a magnetic field is proportional to the rate of change of current with respect to time.

$$V_a = -L\frac{dI}{dt}$$

V_a : applied voltage
I : current
t : time
L : inductance

$$L = \frac{N^2}{\frac{l_i}{\mu S_i} + \frac{l_a}{S_a}}$$

N: number of windings in the coil
l_i,l_a: length of iron circuit and air gaps
S_i,S_a: cross sectional area of iron circuit and air gaps
μ : permeability of magnetic material



A simple self-inductance arrangement wherein a change in the air gap changes the output.

Piezoelectric transducers

The piezoelectric effect is the ability of a material to generate an electrical potential when subjected to a mechanical strain.

This is the ability of a material to change dimensions when subject to a voltage.

Some materials which exhibit these characteristics are:
Quartz, Rochelle salt, ammonium dihydrogen phosphate and even ordinary sugar.

One problem with these devices is that very sophisticated technology is required for the manufacture of piezoelectric sensors.

Piezoelectric Pressure Transducer

Only for Unsteady Measurements

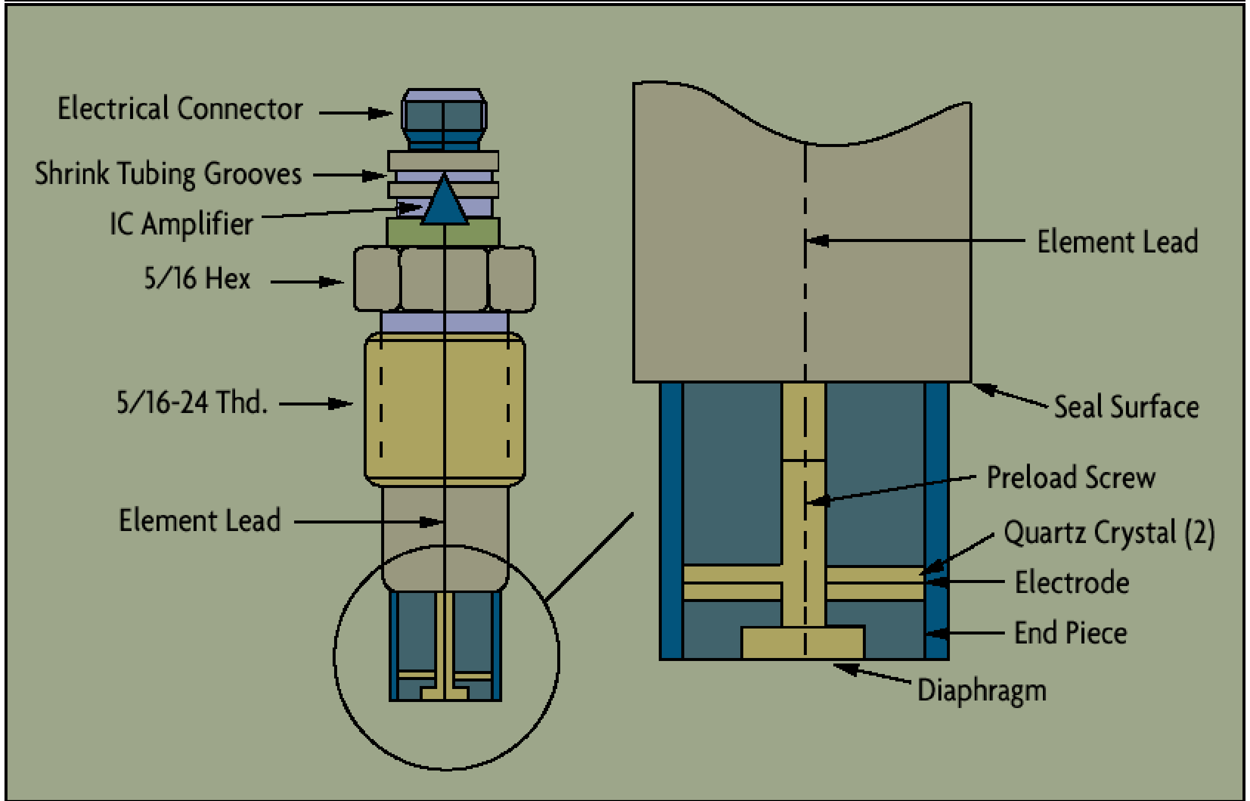
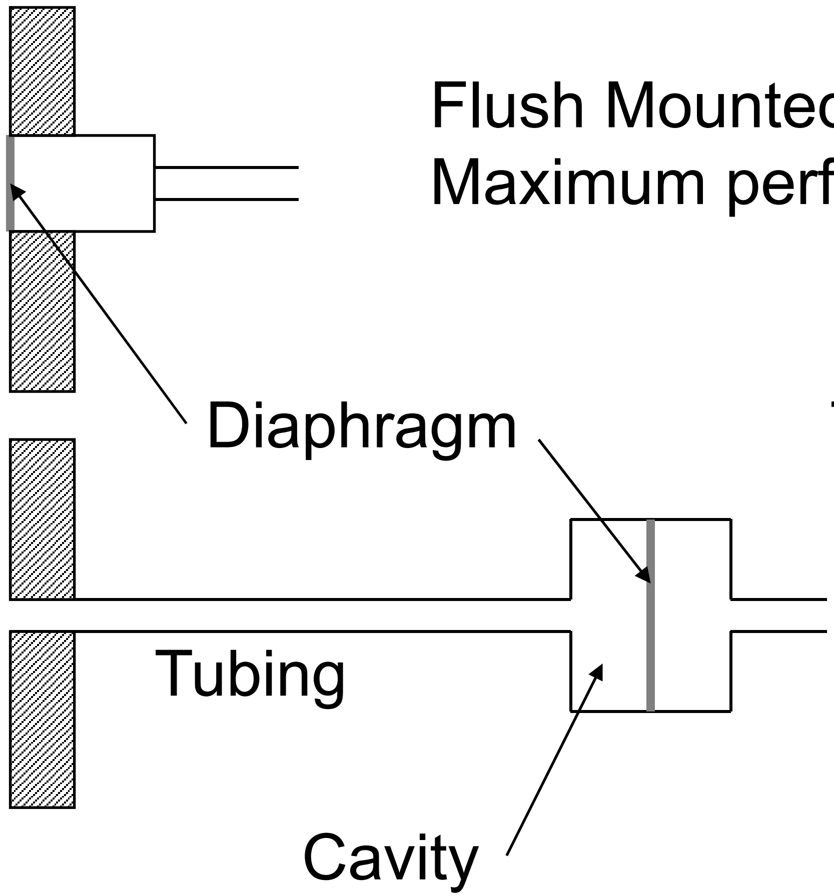


Figure 3-8: Typical Piezoelectric Pressure Sensor

Kulite Transducer
Used in shock tube

Pressure System Response Time



Flush Mounted Transducer
Maximum performance

Time response depends on
- Volume Change
- Friction in Tube
- Acceleration of fluid and diaphragm
- Compressibility of fluid