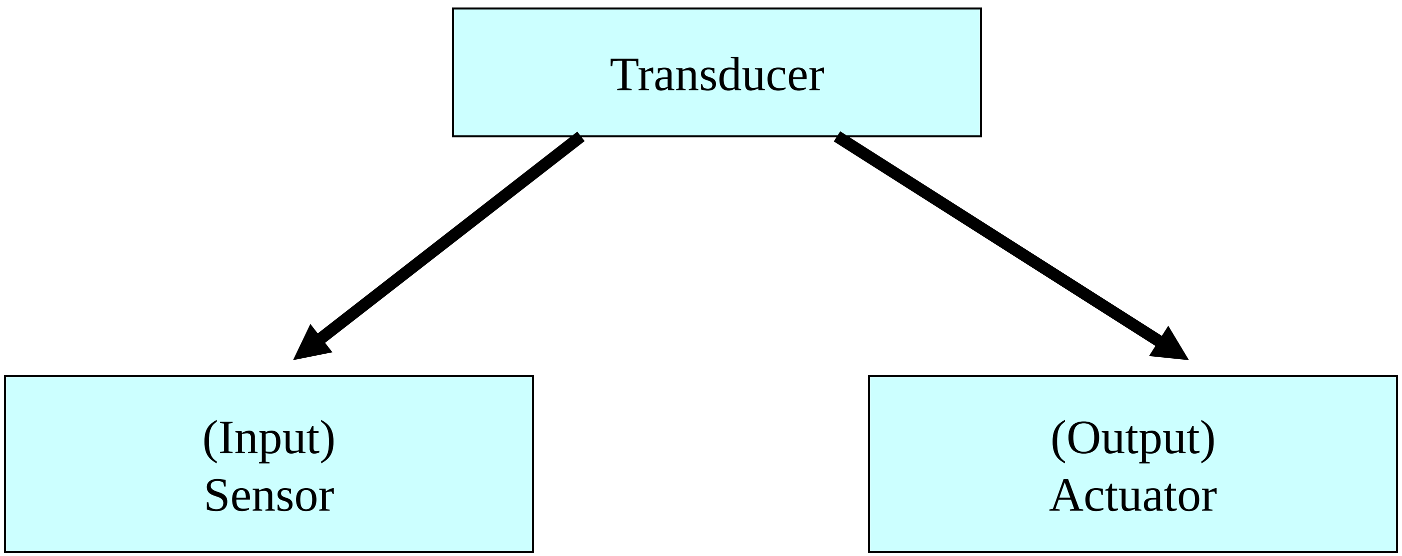
Transducer

A device to which change or converts physical quantity to a more easily measurable quantity

Transducer Basic Requirements:
- Ruggedness
- Linearity
- Repeatability
- High Signal to Noise Ratio
- High stability and reliability



Sensor

A device which senses and detects the physical quantity of measurand and converts to electrical form.

Example of sensors:

Mechanical : Bourdon tube pressure meter.

Electrical : Potentiometer

Optical : Photon counter

Chemical : Thermocouples

*All sensors are transducers but not all transducers are sensors

Actuator

A device that senses and detects the electrical quantity and converts to physical form.

Example of actuator:

- Valve in heat exchanger system
- Motor speed control where the motor is driving the conveyor belt
- Magnetic relays that turn on/off of the fans
- Compressor in a control air conditioning

Transducers

- Transducer - is a device which converts the quantity being measured into an optical, mechanical or electrical signal.

- The energy conversion process is referred to as transduction.

- Transducers are of fundamental important for any application that is not purely electronic in nature (i.e. EVERY application) must rely on a transducer at some point.

- Transducer elements – most transducers consist of a sensing element and a conversion or control element .

- The relationship between the measurand and transducer output signal is usually obtained by calibration test

Transducer

- There are two further distinctions that can be made with regards to transducers:

-Passive Transducers operate without the need for an external power source (that is: additionally to the power being converted.)

-Active transducers must draw power from an external power source in order to work.

Variable Conversion Element

A device that converts analogue signals to digital form or vice versa.

Example of converters:

ADC -- Analogue to digital converter

DAC -- Digital to analogue converter

Transducer

- Resistance transducers
- Resistance strain gauge
- Resistance temperature transducer
- Photo-emisive cell
- Capacitive transducer
- Inductive transducer
- Linear variable differential transformer
- Piezos-electric transducer
- Electromagnetic transducers
- thermoelectric transducer
- Photoelectric cell

a) Electrical transducers

- Exhibit many of the ideal characteristics
- High sensitivity and useful for remote sensing.
- Can be classified into:

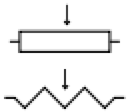
-Variable- control – parameter types, which relies on an external excitation voltage e.g resistance, capacitance .

-Self generating types, which produces an output voltage in response to the measurand input and their effects are reversible e.g electromagnetic , thermoelectric ,piezoelectric.

Resistance transducers

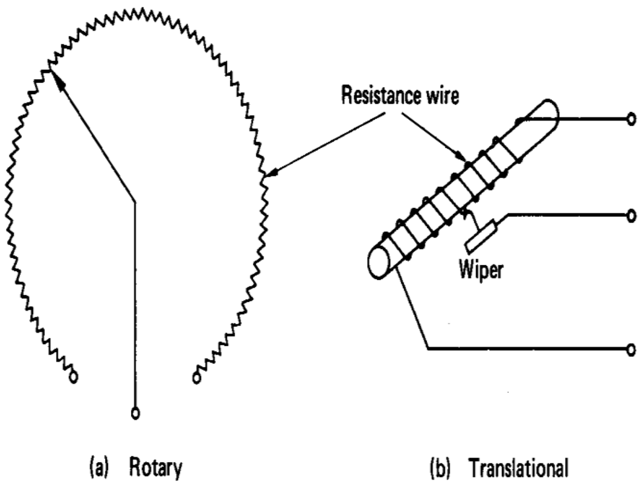
Potentiometers – the excitation voltage maybe AC or DC and output voltage is proportional to the input motion.

- The wiper displacement can be rotary, translational or both. Electrical device which has a user-adjustable resistance.
- Usually, this is a three-terminal resistor with a sliding contact in the center (the wiper) - If all three terminals are used, it can act as a variable voltage divider.
- If only two terminals are used (one side and the wiper), it acts as a variable resistor - Such potentiometers suffer from the linked problems of resolution and electrical noise



Schematic symbol for a potentiometer. The arrow represents the moving terminal, called the *wiper*.

Potentiometer



Construction principles of resistance potentiometers

•Construction of a wire-wound circular potentiometer.
-The resistive element (1) which is trapezoidal, giving a non-linear relationship between resistance and turn angle.
 -The wiper (3) rotates with the axis (4), providing the changeable resistance between the wiper contact (6) and the fixed contacts (5) and (9).
-The vertical position of the axis is fixed in the body (2) with the ring (7) (below) and the bolt (8) (above).

Potentiometer

The output voltage v_0 of the unloaded potentiometer circuit shown is determined as follows .

Let

$$R_1 = \frac{x_i}{x_T} R_T$$

Where: x_i = input displacement

x_T= maximum possible displacement

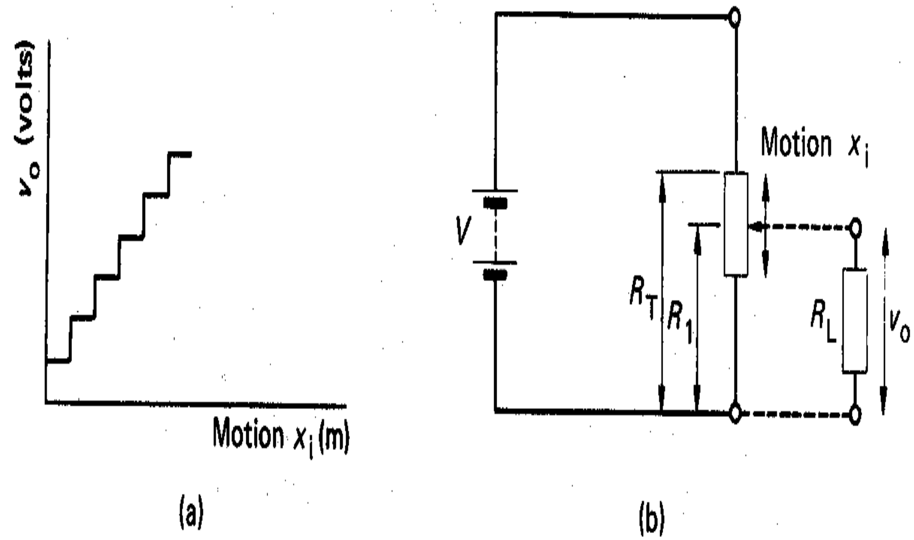
R_T= total resistance of the potentiometer

Then output voltage

$$v_o = V \times \frac{R_1}{R_1 + (R_T - R_1)} = V \frac{R_1}{R_T} = V \frac{x_i}{x_T} x \frac{R_T}{R_T} = V \frac{x_i}{x_T}$$

Maximum value of V = $\sqrt{P R_T}$

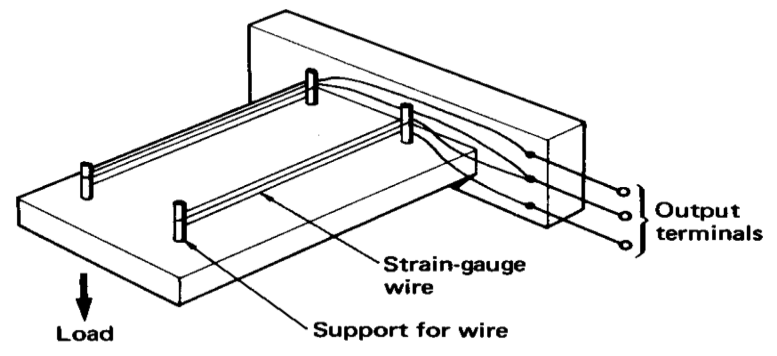
where P = maximum power dissipation



Resolution effects and circuit diagram of resistance potentiometer

b) Resistance strain gauges tranducer

- Resistance strain gauges are transducers which exhibit a change in electrical resistance in response to mechanical strain.

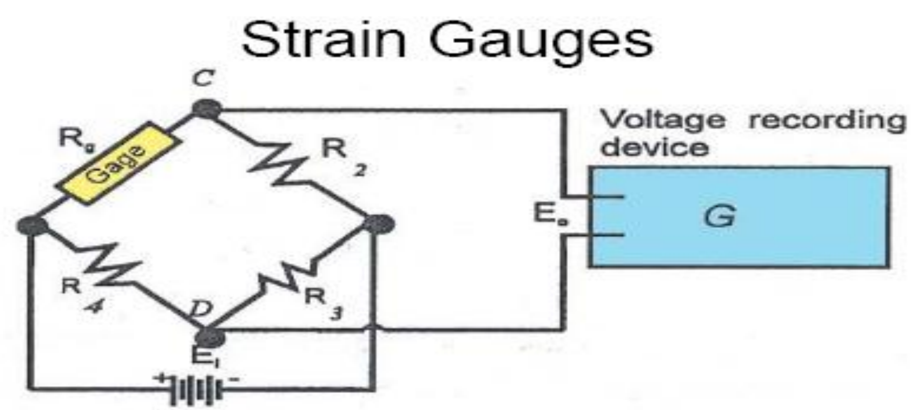


Unbonded strain gauge

Classified into

- i) Bonded
- ii) Unbonded

Strain rosettes are used to measure strain at different direction simultaneously



- The Wheatstone bridge

c) Resistance Temperature Transducers (RTD)

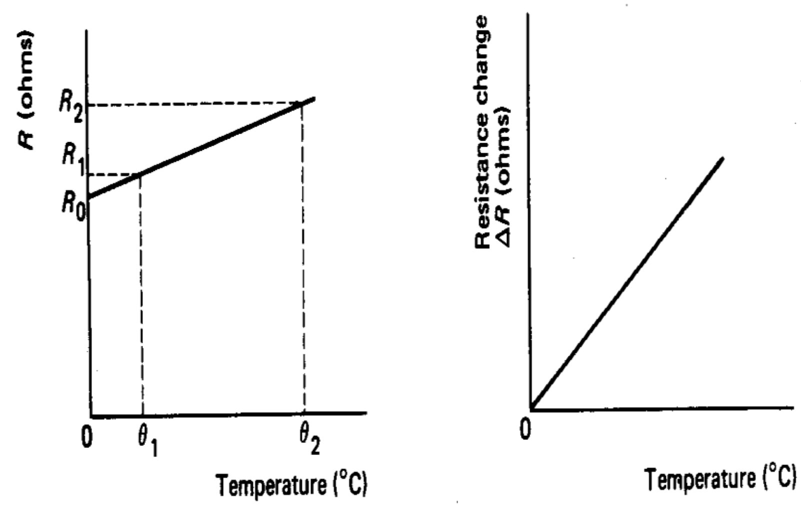
- Metals such as platinum copper ,tungsten exhibits small increase in resistance as the temperature rise.
- Positive temperature coefficient of Resistance depend upon the relationship:

$R1=Ro[1+ \alpha (\theta 1 - \theta o)]$

where

α = temperature coefficient of resistance in °C -1

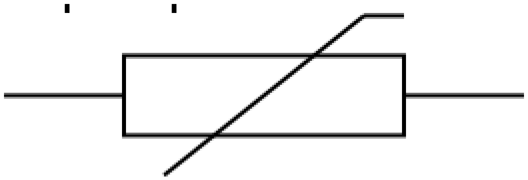
Ro= resistance in ohms at the reference temperature θo = 0 °C

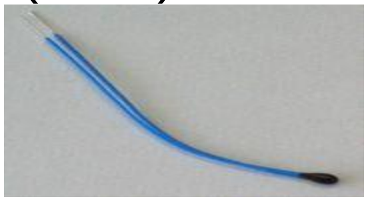


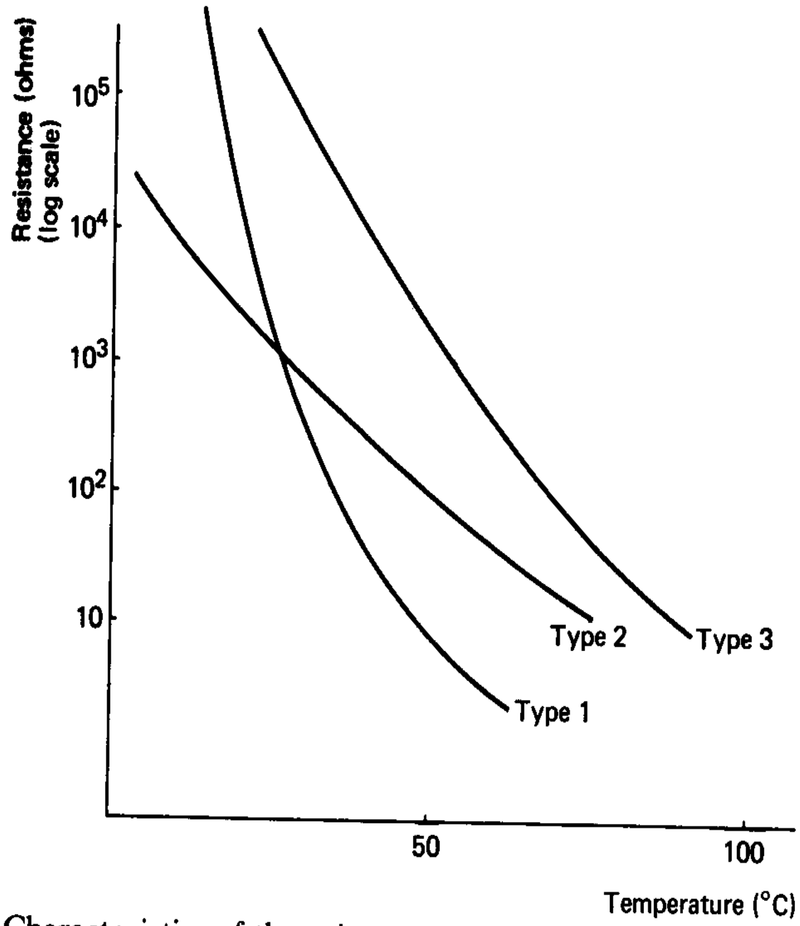
Characteristics of a platinum resistance thermometer

Semiconductors - thermistors

- A **thermistor** is a type of resistor used to measure temperature changes, relying on the change in its resistance with changing temperature
- Semicondictor such as thermistors which use oxides of manganese, chromium, nickel exhibits large non linear resistance changes with temperature variations.
- Negative temperature coefficient of resistance. Normally made in the form of discs or small (1mm)



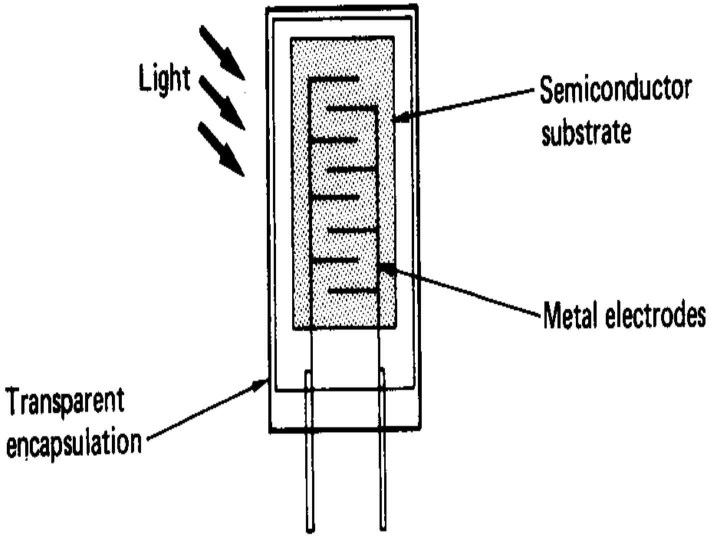




Characteristics of thermistors

d) Photoconductive cells

- Uses light sensitive semiconductors material e .g. cadmium sulphide, lead sulphide , copper doped germanium.
- When these semiconductor materials are exposed to light, their electrical conductivity is increased.
- The resistance between the metal electrodes decreases as the intensity of the light increases



Photoconductive cell

Photoemisive cells

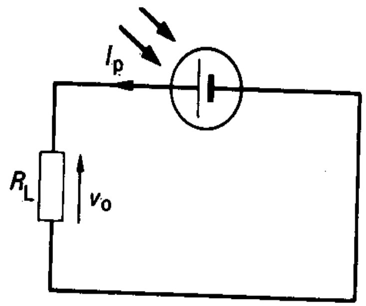
- When light strikes the cathode of the photo emissive cell

- Electrons are given sufficient energ to leave the cathode. The positive anode attract these electrons, producir current Ip through a resistance RL an producing output voltage ,

vo = IpRL .

Also Ip=Kt φ ,

Kt=sensitivity (A/lm) , φ = illumination input (lumen)



Photoemissive cell

f) Capacitive transducers

- The capacitance of a parallel plate capacitor is given by

$$C = \varepsilon_o \varepsilon_r \frac{A}{d} \text{ farads}$$

where $C = \varepsilon_o \varepsilon_r \frac{A}{d}$ farads

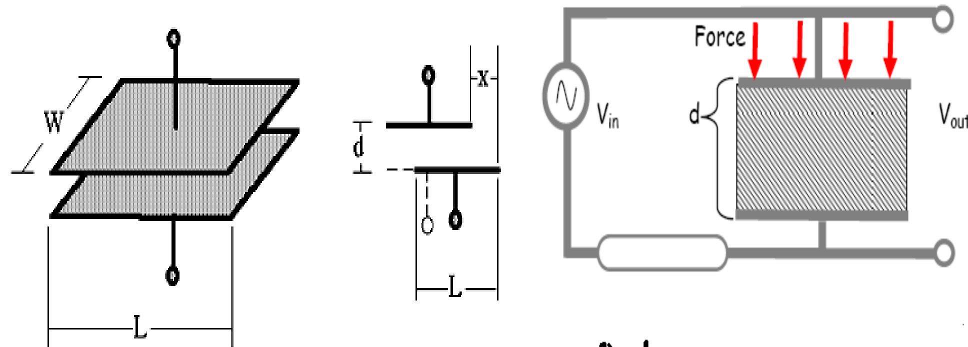
ε_0 = permittivity of free space = 8.854×10^{-12} F/m

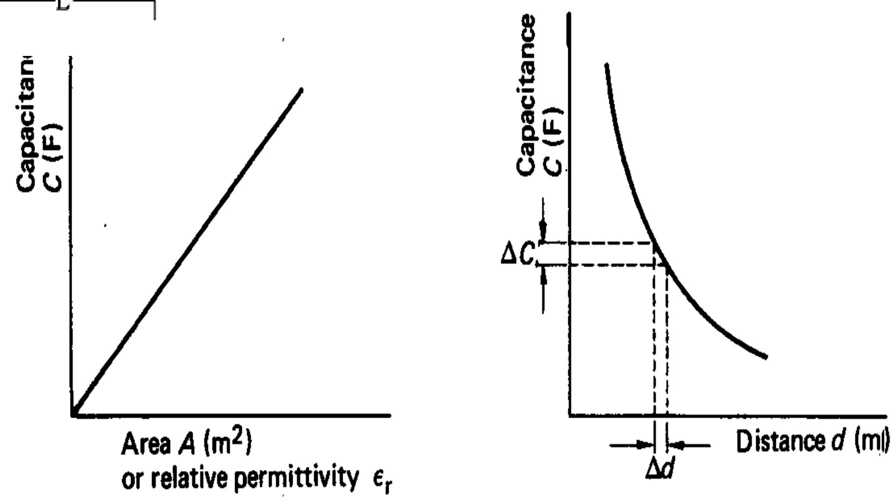
ε_r = relative permittivity of the material between the plates

A = overlapping or effective area between plates (m^2)

d = distance between plates (m)

- The capacitance can thus be varied by changing either ε_r, A or d.

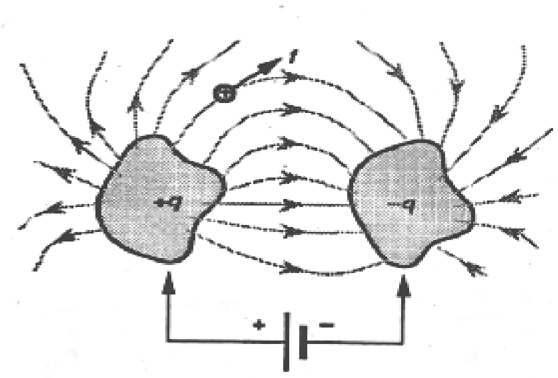


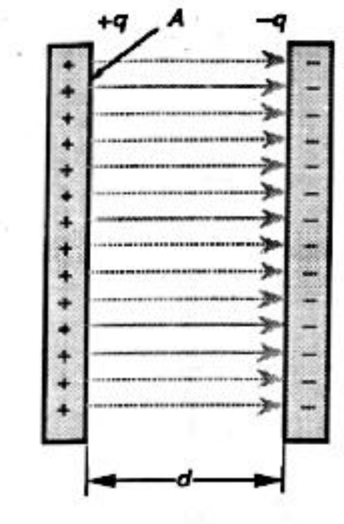


Characteristics of capacitive transducers

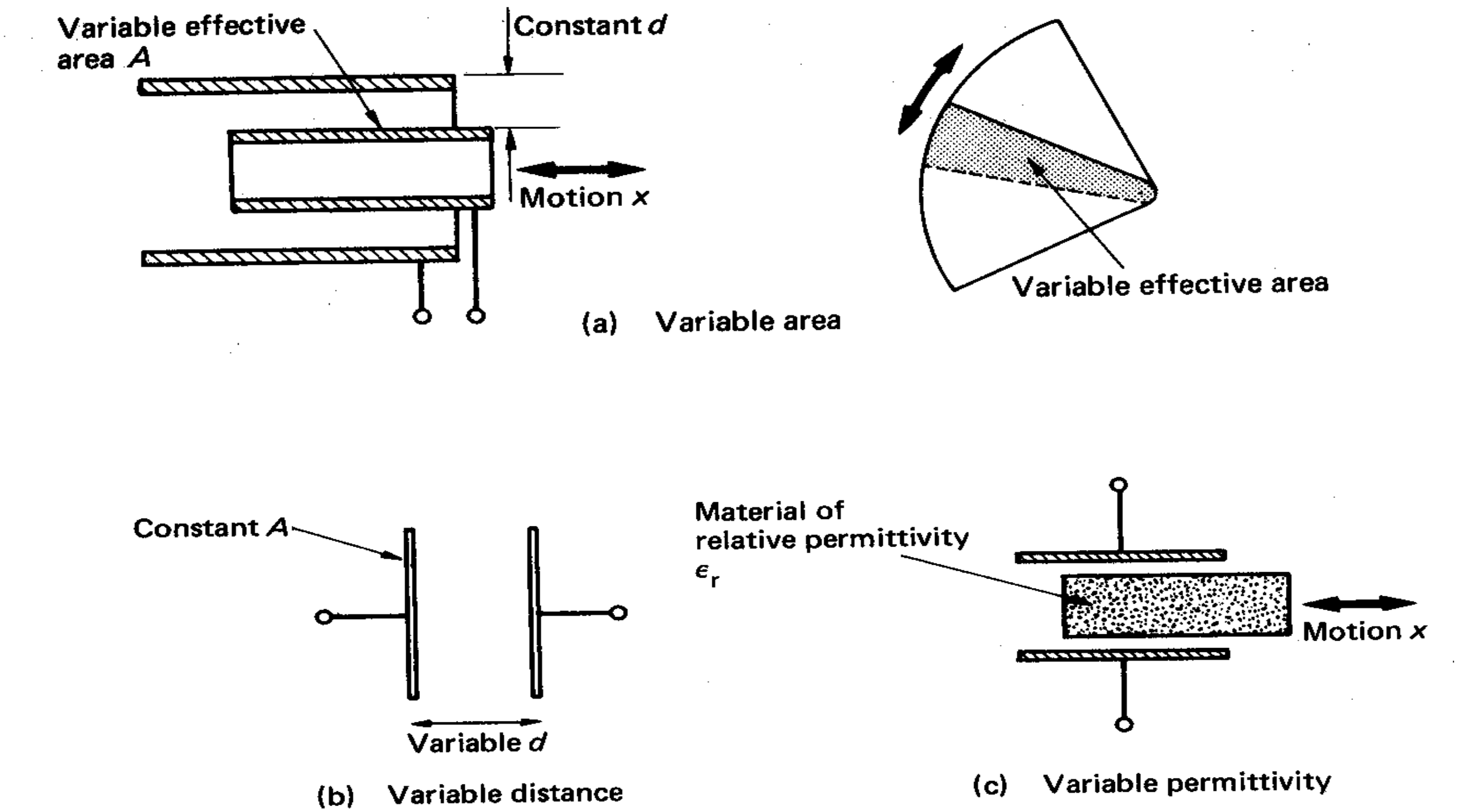
Capacitive transducers

- First, what is capacitance? Any two metallic objects, positioned in space, can have voltage applied between them .
- Depending on their separation and orientation, the amount of charge that must be applied to the two elements to establish a certain voltage level varies.
- The capacitance is defined as the ratio of the charge to the voltage for a given physical situation. If the capacitance is large, more charge is needed to establish a given voltage difference.





Example of capacitive transducer



Example of capacitive transducer

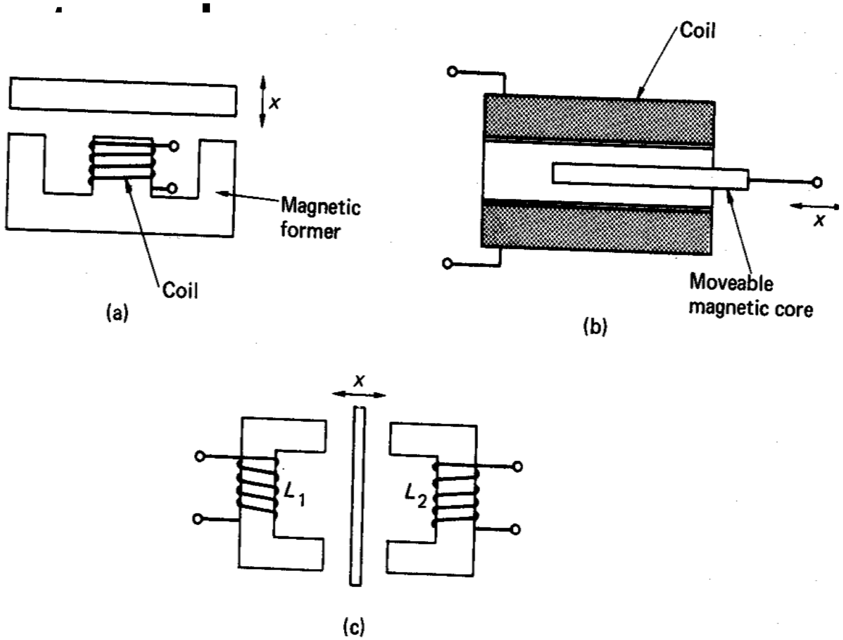
- Variable distance capacitive transducers has an infinite resolution, making it most suitable for measuring small increments of displacement.

Important features of capacitive transducers

- Resolution infinite
- Accuracy $\pm$ 0.1 % of full scale
- Displacement ranges 25 x10-6 m to 10 x10-3 m
- Rise time less than 50 μs

g) Inductive transducers

- **Characteristics of inductive**



Inductive transducers – The inductance of a coil wound a magnetic circuit is given by

$$L = \frac{\mu_o \mu_r N^2 A}{l}$$

where

μo = permeability of free space =4 x 10-7 H/m

μr = relative permeability

N = number of turns of coil l = length of magnetic circuit (m)

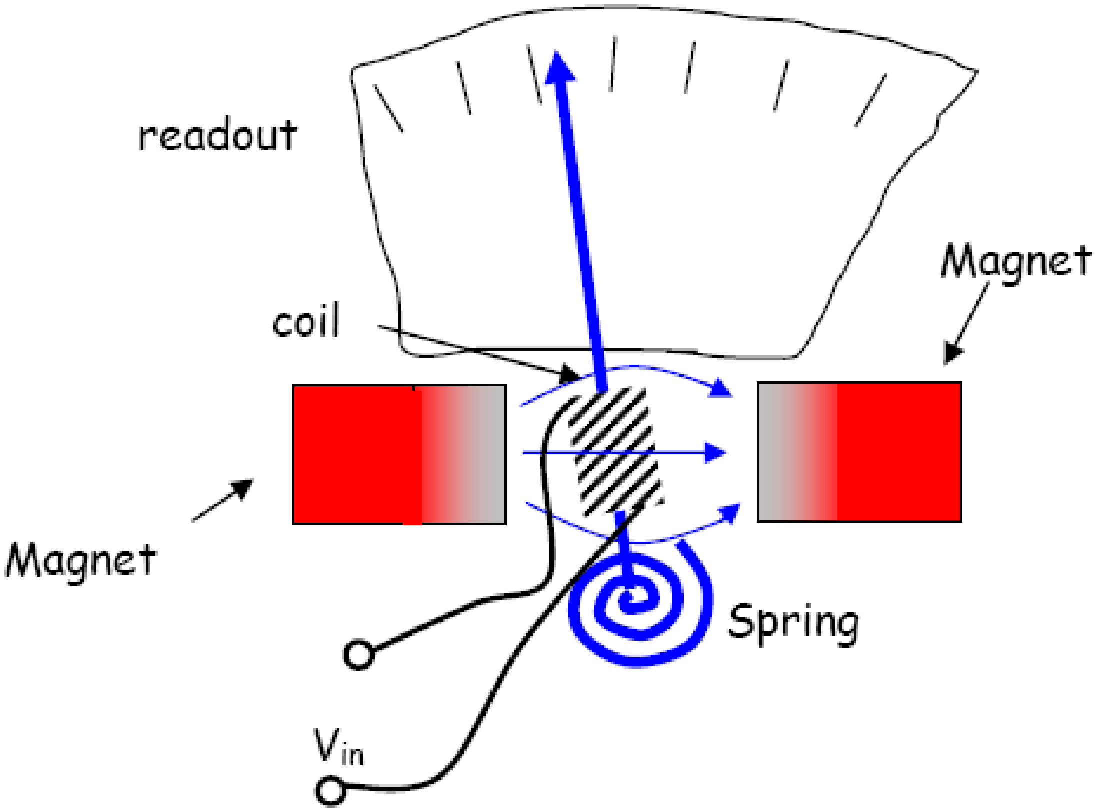
A = cross sectional area of magnetic circuit (m2)

This can be written as

$$L = \frac{N^2}{S}$$

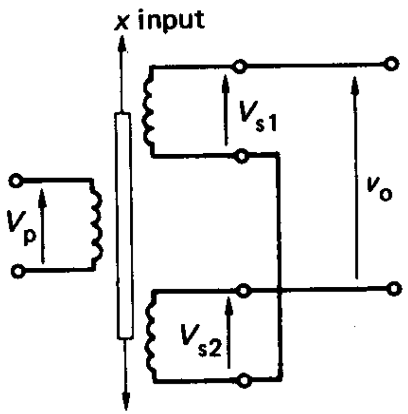
Where S = l /($\mu_o \mu_r$A) = magnetic reluctance of the inductive circuit

Inductive transducers

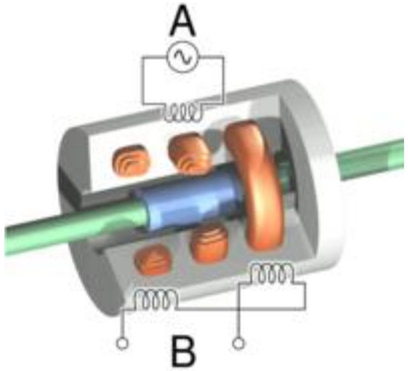


h) Linear Variable-Differential Transformer – LVDT

- Consist of a primary coil , two secondary coil and a movable magnetic core.
- When excitation voltage Vp is applied to the primary winding, due to transformer action
- voltages Vs1 and Vs2 are induced in the primary coils.



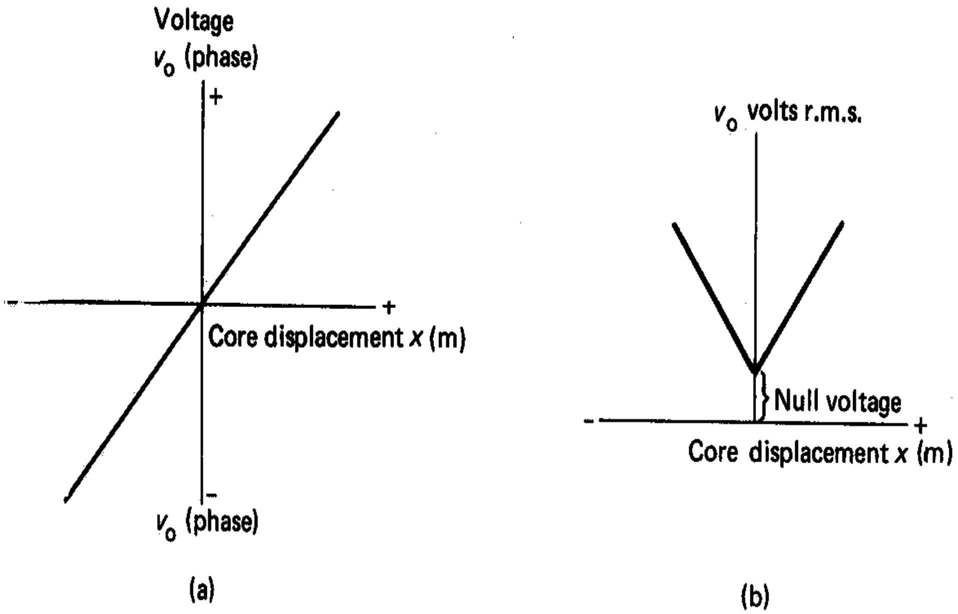
Details of an l.v.d.t.



Cutaway view of an LVDT. Current is driven through the primary coil at *A*, causing an induction current to be generated through the secondary coils at *B*.

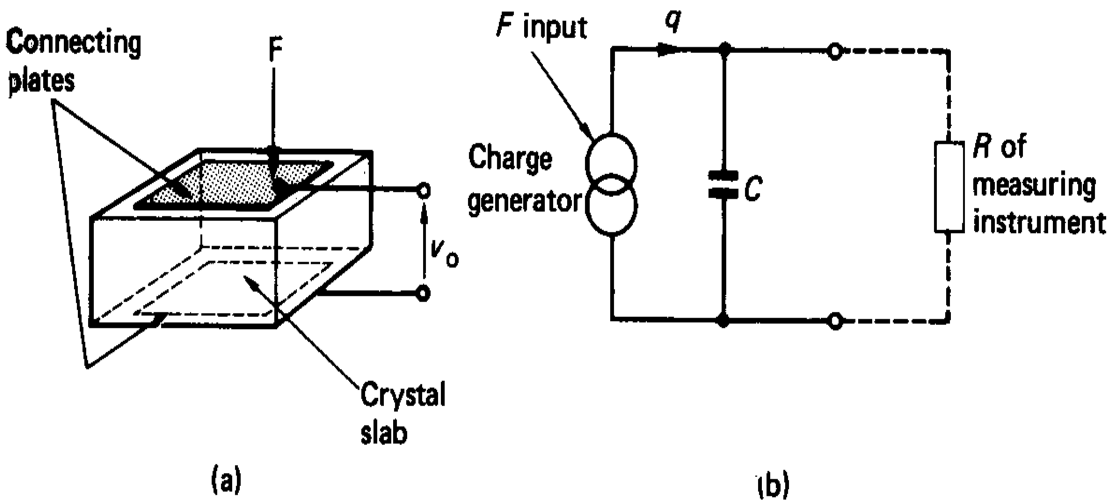
LVDT

- The amplitudes of these secondary voltages are dependent on the core displacement x



i) Piezo-electric transducers

- **Piezoelectricity** is the ability of crystals and certain ceramic materials to generate a voltage in response to applied mechanical stress.

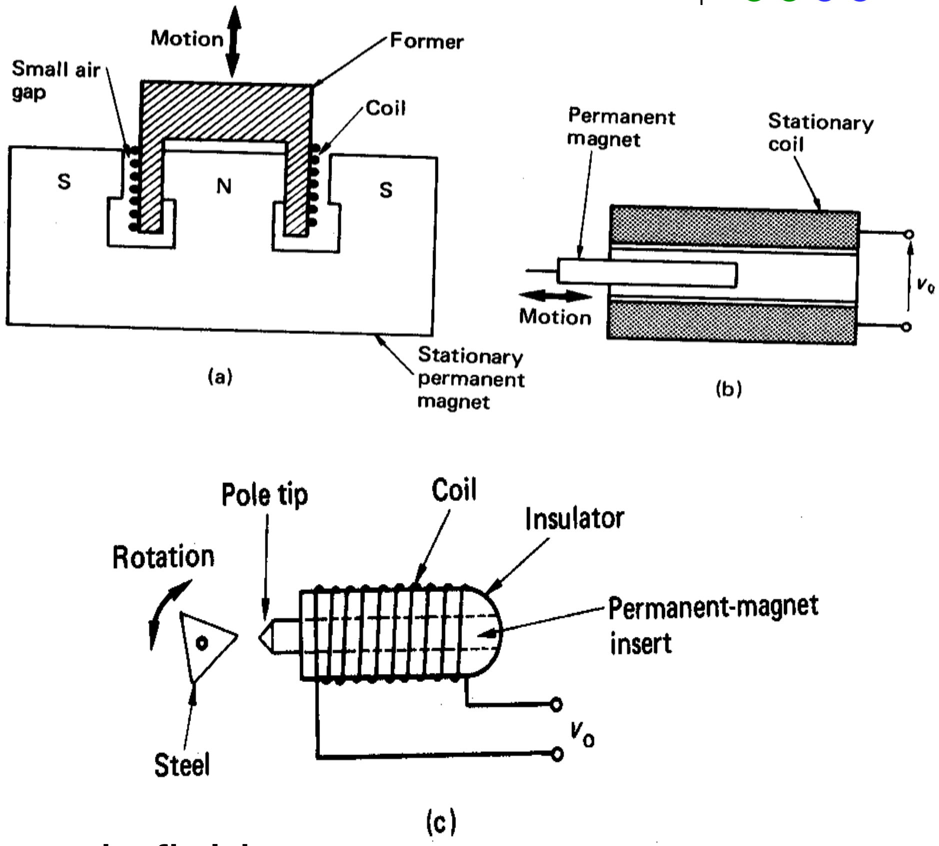


Piezo-electric transducer

- When a force is applied across the faces of certain crystal materials- electrical charges (proportional to the applied force) of opposite polarity appear on the faces .
- These transducers are made from natural crystals such as quartz ,Rochelle salt, Lithium sulphate or barium titanate.
- To enhance the response of the transducer charge amplifier is normally used.

J) Electromagnetic transducers

- Employs the generator principle of a coil moving in a magnetic field. The output voltage of the transducer is given
- as follows . Widely used as velocity transducers.



Output voltage $v_o = -N\frac{d\varphi}{dt}$

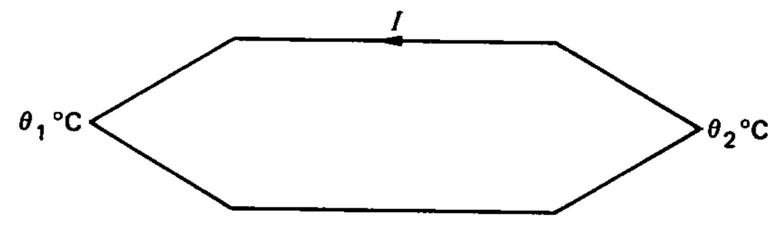
N = number of turns on coil

$\frac{d\varphi}{dt}$ = rate of flux changes (Wb/s)

For the single conductor moving in a magnetic field,
Output voltage v0 = Blv
B = flux density (T), l =   length of conductor (m), v =   velocity of conductor perpendicular to flux direction (m/s)

k) Thermoelectric transducers(thermocouple)

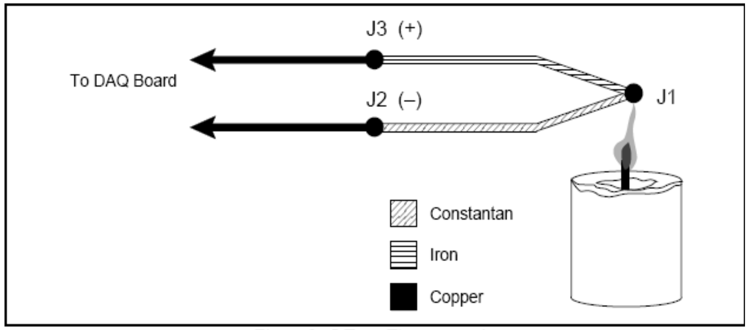
- When two dissimilar metals or alloys are joined together at each end to form a thermocouple and the ends are at different temperatures, an emf will be developed causing a current to flow around the circuit



Thermocouple circuit

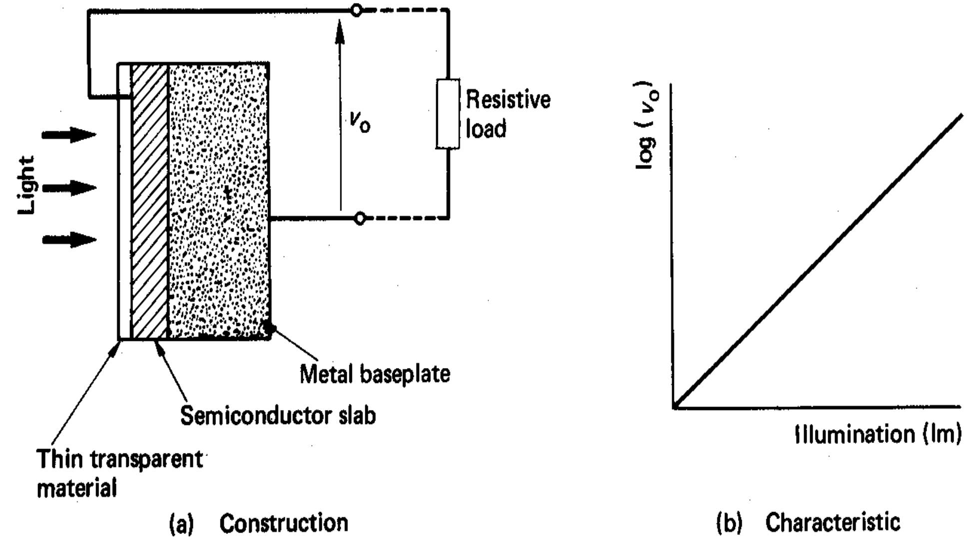
- The emf is proportional to the temperature gradien

- This is called Seebeck effect This transducers has operating range from –250 °C- 2600 °C .



I) Photoelectric cells

- Make use of the voltaic effect ,which is the production of the emf by light energy ,incident on the junction of two dissimilar materials.
- The transducer is highly sensitive ,good frequency response and can be used for wide range of light intensities.

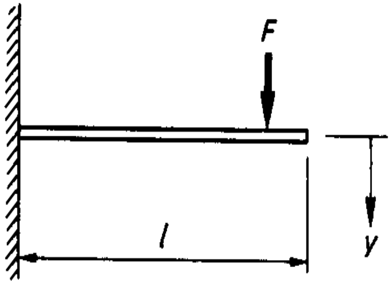


Photoelectric cell

Mechanical transducers

- **Mechanical transducers –** convert measurand into mechanical parameters eg displacement, pressure or force. Often used in cascade with electrical transducers.

a) Force- to- displacement transducers



Cantilever

Spring – is the simplest form of mechanical transducer

F = λ x

λ = spring siffness (N/m) and sensitivity = i.e the stiffer the spring the smaller the sensitivity .

- Cantilever – the deflection, y caused by force F, is **y = k F**

k = a constant depending on the material and dimensions of the cantilever .

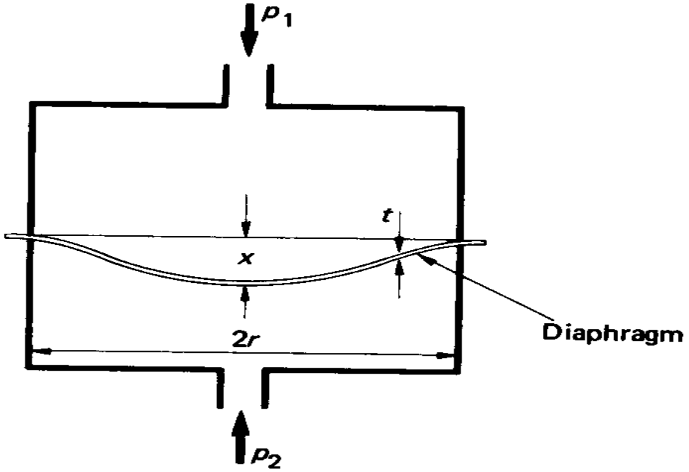
Mechanical transducers

b) Pressure- to- displacement transducers

i) Diaphragms-displacement, x is proportional to the pressure difference.

$$x = k\,(p1 - p2) \quad ;$$

k depend on material and dimensions.

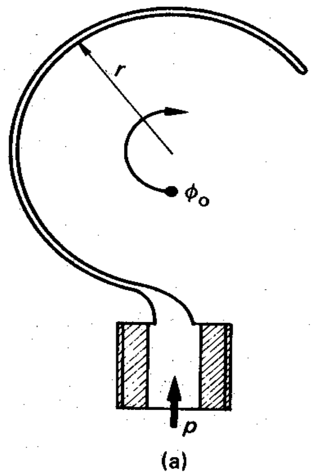


Diaphragm

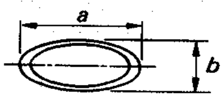
Mechanical transducers

ii) Bourdon tubes – widely used in pressure gauges. The relationship between pressure, p and deflection ϕ is ;

- $\phi = k\,p$



Bourdon tube

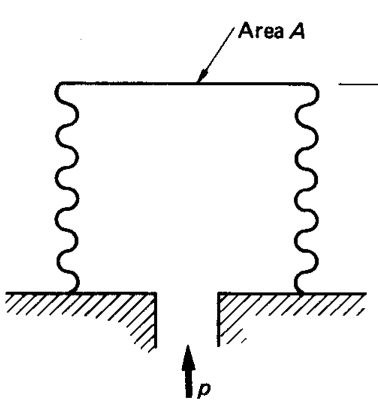


(b) Tube cross-section

Mechanical transducers

iii) Bellows – also known as pneumatic spring .

The relationship between defection, x, Area A and stiffness λ can be composed.

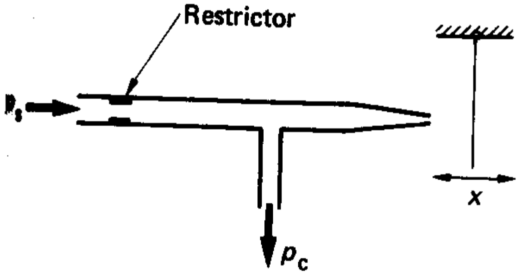


Bellows

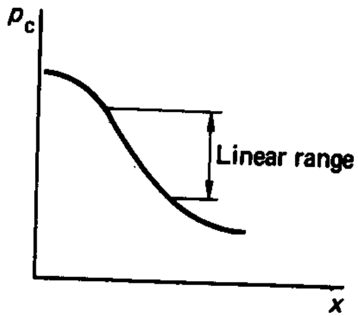
Mechanical transducers

c) Displacement –to –pressure transducers
– Fapper –Nozzle

Control pressure pc varies with flapper movement, x if supply pressure p is constant



(a) Construction



(b) Characteristic with constant supply pressure p_s

Summary

- Types of transistors, and characteristics of transistor has been described.