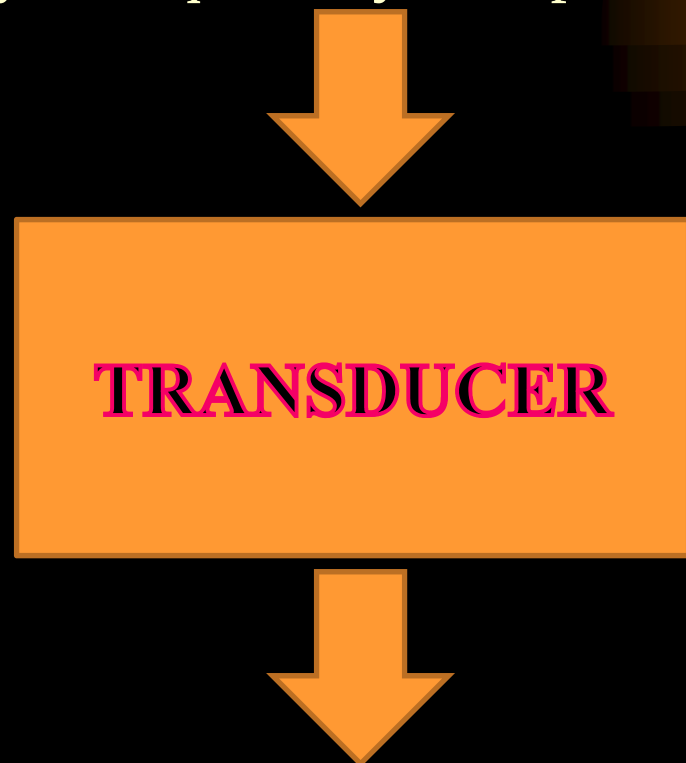
SECTION-D

TRANSDUCERS & SIGNAL CONDITIONING

What is transducer?

Non-electrical physical quantity: temperature, sound or light



Electrical signal

Introduction

- A transducer is an electronic device that converts energy from one form to another for various purposes like measurement or Information transfer eg.,Pressure sensors.
- Common examples include microphones, loudspeakers, thermometers, position and pressure sensors, and antenna.

Transducer efficiency

- Efficiency is an important consideration in any transducer. Transducer efficiency is defined as the ratio of the power output in the desired form to the total power input. Mathematically, if P represents the total power input and Q represents the power output in the desired form, then the efficiency E is given by:
- $E = Q/P$

Contd..

- No transducer is 100-percent efficient; some power is always lost in the conversion process. Usually this loss is manifested in the form of heat. Some antennas approach 100-percent efficiency.
- The worst transducers, in terms of efficiency, are incandescent lamps. A 100-watt bulb radiates only a few watts in the form of visible light. Most of the power is dissipated as heat

Significance of transducer in measurement & instrumentation system contd….

- **First stage(sensing device)**:-If the quantity under measurement i.e. the non-electrical quantity should be into electrical signal by the device transducer

Note: Here it is imp. to discuss the term **sensor.** The sensor is a part of transducer which senses or responds to a physical quantity or measurand.The response of sensor is converted to electrical signals by the transduction stage.

Significance of transducer in measurement & instrumentation system contd…..

- **<u>Second stage(Signal conditioning)</u>**:-

Function of this stage is amplification,filteration ,conversion etc of the o/p of transducer so that it can be compatible with the o/p device or stage.

- **<u>Third stage(output)</u>:-** The o/p of Signal conditioning stage is displayed or monitored on display devices,recorders.These devices are CRO,magnetic tape,printer,computer etc.

Classification of Transducers

On the basis of method used for Transduction:

- Active and Passive
- Analog and digital transducer
- Transducer and inverse transducer
- Primary and secondary transducer

Classification of transducer

- Active or Self generating type – do not require an external power, and produce an analog voltage or current when stimulated by some physical form of energy
  - Thermocouple
  - Photovoltaic cell
  - Tachogenerators
  - Piezoelectric crystals

Classification of transducer

- Passive transducers – require an external power, and the output is a measure of some variation (resistance or capacitance)
  - Slide-wire resistor
  - Resistance strain gauge
  - Differential transformer

Classification of transducer

- Analog Transducers-These transducers convert the input quantity into an analog output which is a continuous function of time.
  - Strain Gauge
  - LVDT
  - Thermocouple
  - Thermistor

Classification of transducer

- Digital Transducers-These transducers convert the input quantity into an electrical output which is in the form of pulses.
  - Glass Scale can be read optically by means of a light source,an optical system and photocells.

Classification of transducer

- Transducers and Inverse Transducers-

-A Transducer can be broadly defined as a device which converts a non-electrical quantity into an electrical quantity.

Ex:-Resistive,inductive and capacitive transducers

-An inverse transducer is defined as a device which converts an electrical quantity into a non-electrical quantity.

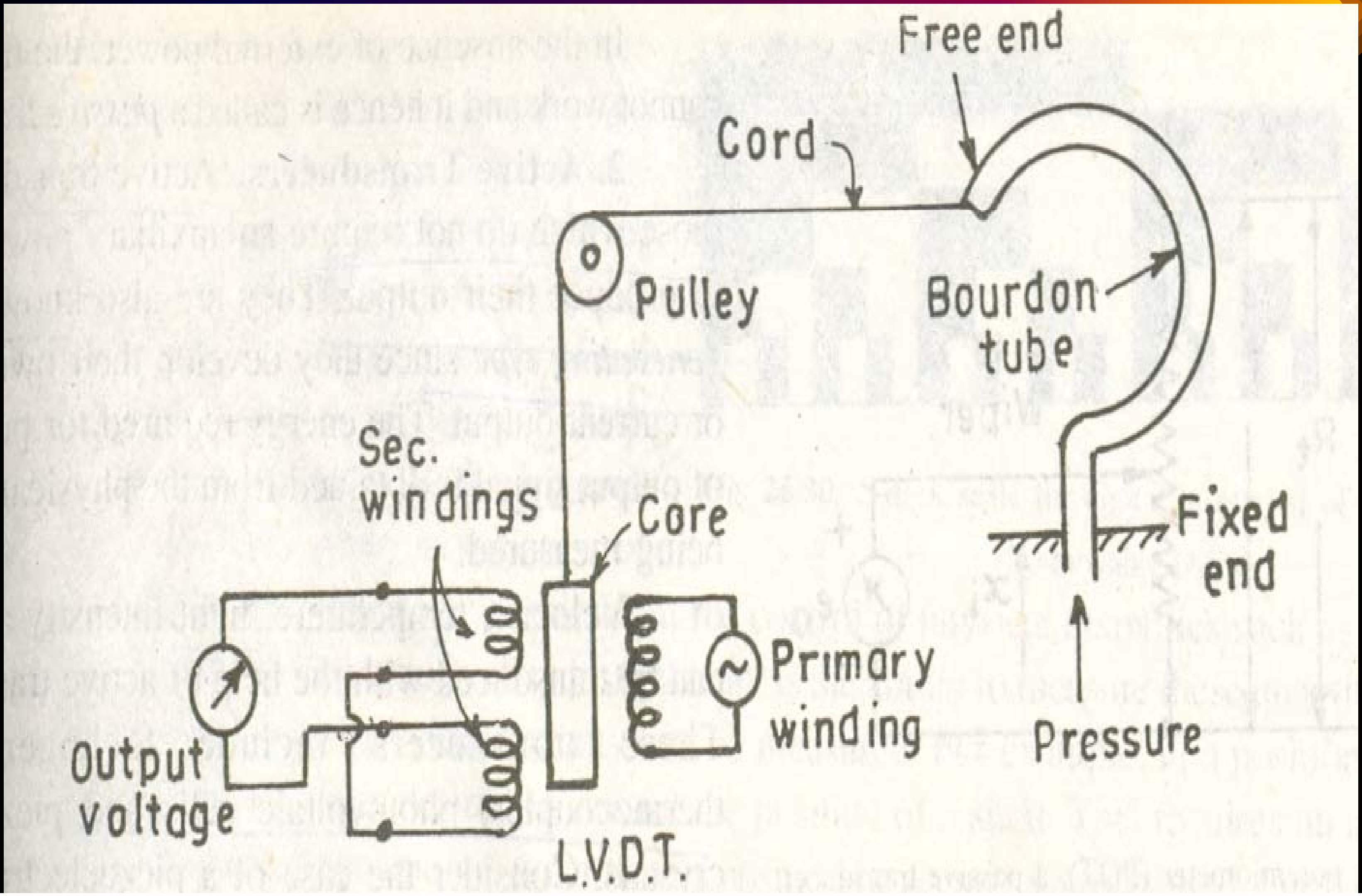
Ex:-Piezoelectric crystals

Classification of transducer

- Primary Transducers and Secondary Transducers-

Bourden tube acting as a primary detecter senses the pressure and converts the pressure into a displacement of its free end.The displacement of the free end moves the core of a linear variable differential transformer(LVDT) which produces an output voltage.

Classification of transducer



Characteristics of Transducers

- Input characteristics

-Type of input and operating range

-Loading effects

- Transfer characteristics

-Transfer function

-Error

-Response of transducer to environmental influences

- Output characteristics
- Environmental response

Factors affecting choice of transducer

- Operating Principle
- Sensitivity
- Operating Range
- Accuracy
- Cross sensitivity
- Errors
- Trasient and Frequency response

Factors affecting choice of transducer

- Loading Effects
- Environmental Compatibility
- Insensitivity to Unwanted Signals
- Usage and Ruggedness
- Electrical Aspects
- Stability and Reliability
- Static Characteristics

Resistive Transducers

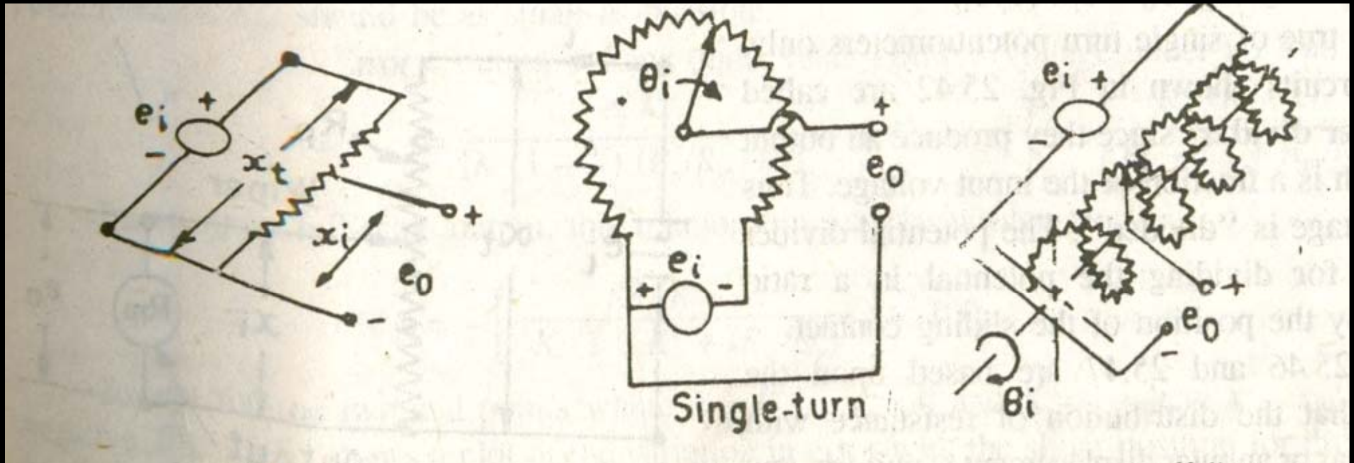
- It is used for ac as well as dc current and voltages measurements.
- $R = \rho L/A$

1)Potentiometers

•POT is a *PASSIVE TRANSDUCER.*

•The ***translation and rotational potentiometers*** which work on the basis of change in the value of resistance with change in the length of the conductor can be used for measurement of translational or rotary displacements.

•Some POTS use the combination of the 2 motions,i.e.translational as well as rotational. These POTS have their resistive element in the form of a helix and therefore they are called ***helipots***



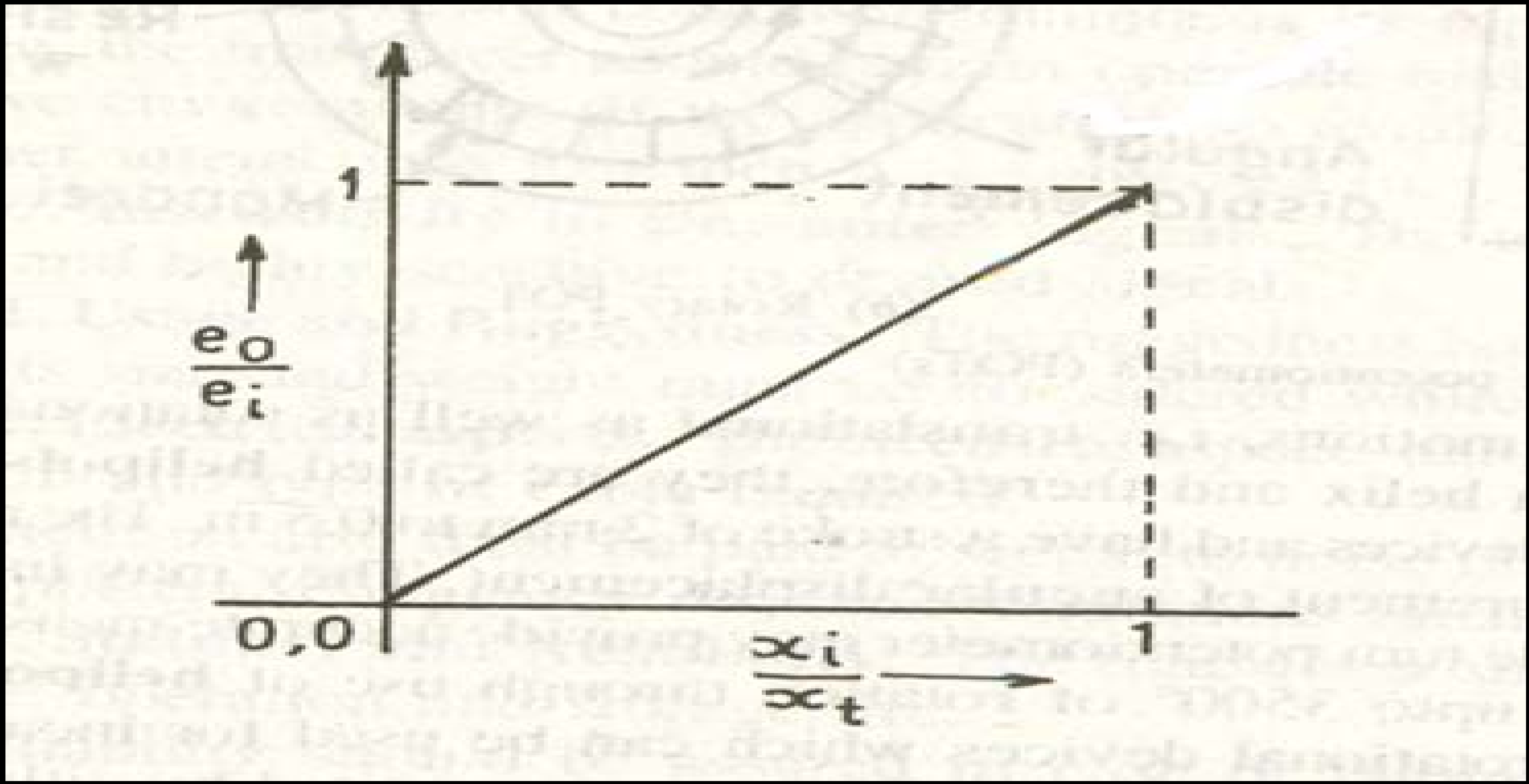
(a) Translational (b) Rotional (c) Helipot

1)Potentiometers Contd……

- ***The Translation elements*** are straight devices & have a stroke of 2mm to 0.5m.
- ***The rotational elements*** are circular in shape and are used for measurement of angular displacement small as 10º(full scale angular displacement)
- ***The Helipots*** may ***measure upto 3500º of rotation.***

Resistive Transducers

- Characteristics of potentiometer-



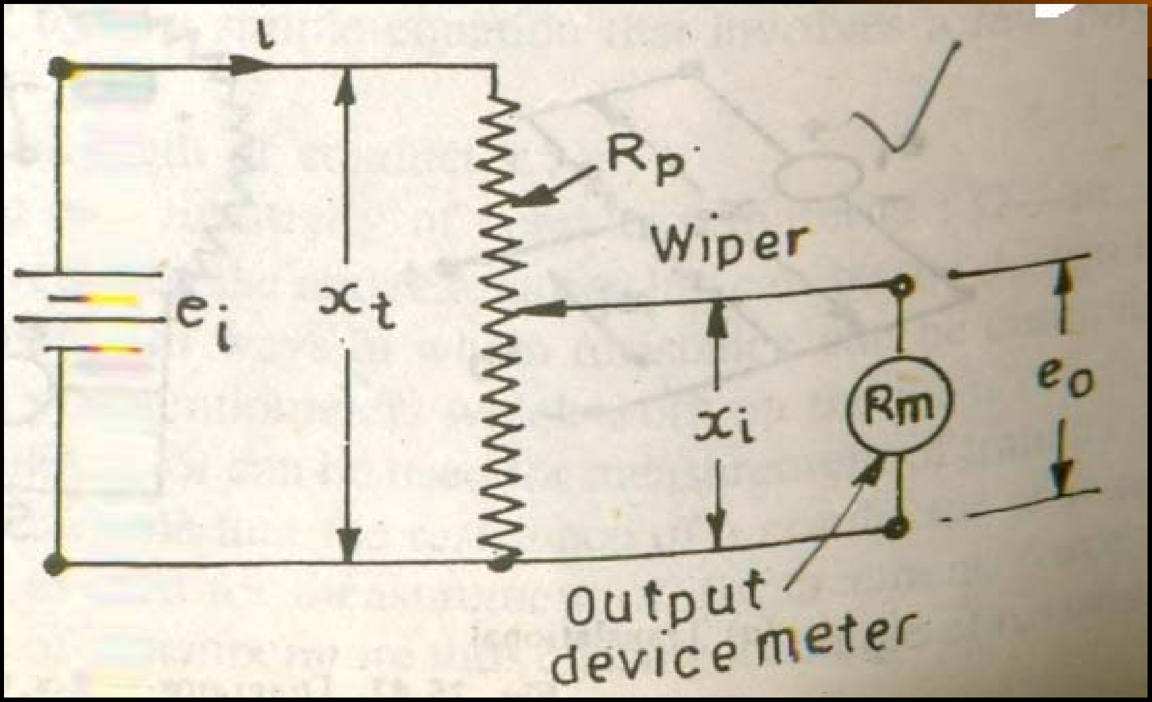
Resistive Transducers

- e_0= (resistance at the output terminals)*input voltage

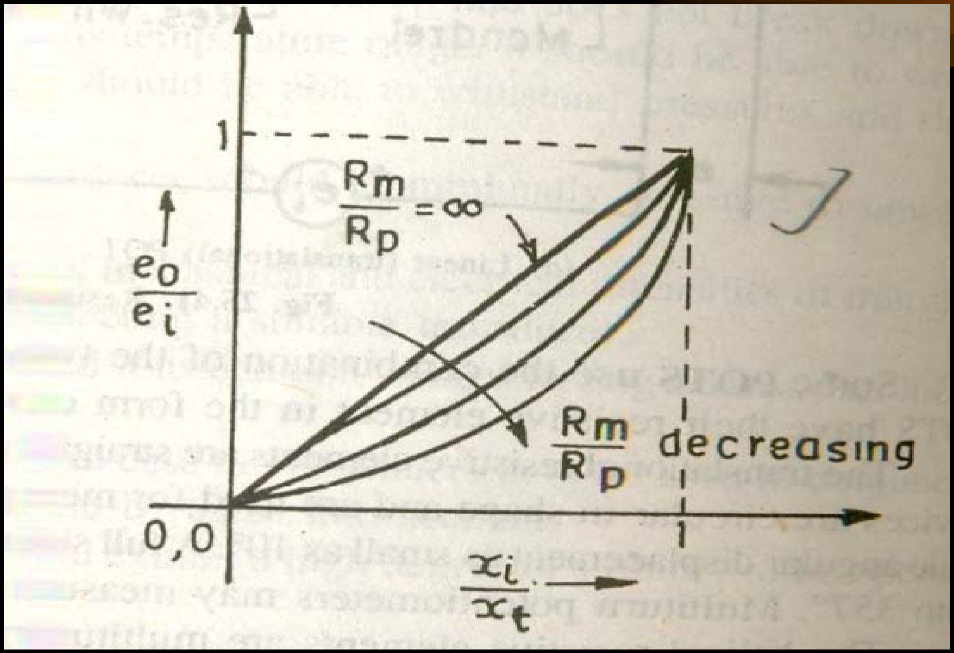
  resistance at the input terminals
- $e_0 = [R_p(x_i/x_t)/R_p]*e_i = (x_i/x_t)\ e_i$
- Sensitivity S=output/input= $e_0/x_i = e_i/x_t$

Under ideal conditions the sensitivity is constant & the o/p is faithfully reproduced & has a linear relationship with i/p.

Loaded potentiometer



Characteristics of potentiometer



Power rating of potentiometer

- The potentiometer are designed with a definite power rating which is directly related to heat dissipating capacity.
- A single turn potentiometer with diameter of 50mm with a wide range of ohmic values ranging from 100 Ω to 10kΩ.
- They have same heat transfer capabilities.
- Their rating is 5W at an ambient temp.of 21ºC.
- Since power $P = e_i^2/R_p$,the max.i/p excitation voltage that can be used is

$$(e_i)max = \sqrt{PR_p}, \text{ volt}$$

Linearity and senstivity

- In order to achieve good linearity, the resistance of potentiometer $R_{p,}$ should be as low as possible when using a meter for reading the o/p voltage which has a fixed value of i/p resistance $R_{m.}$ The R_p cannot be made low because if we do so the power dissipation goes up with the result we have to make the i/p voltage small to keep the power dissipation to acceptable level.this results in lower sensitivity.
- In order to achieve high **sensitivity the o/p voltage** $\mathbf{e_o}$ should be high which ion turn requires a high i/p voltage $\mathbf{e_{i.}}$
- **The Linearity and senstivity are therefore two conflicting requirements.**

Materials used for potentiometer

1.Wire Wound Potentiometer:

- These are platinum ,nickel chromium,nickel copper,or some other precious resistance elements.
- It carry relatively large currents at high temperatures.
- Their resistance temperature coefficient is usually small is of the order of $20*10^{-6}/^{o}C$ or less.
- Resolution is 0.025 – 0.05 & is limited by the number of turns that can be accommodated on the card.
- The interwinding capacitance b/w turns & b/w windings & shaft, housing etc. limits the use of wire wound potentiometer to low frequencies to about 5Hz.
- Max speed is about 300rpm.

Materials used for potentiometer

2. Non Wire Potentiometer or Continuous Potentiometer:-

- It has improved resolution & life.
- Max speed is 2000rpm.
- They are more sensitive to temperature changes, have a higher wiper contact resistance, which is variable & can carry moderate currents.

Materials used for Non Wire Potentiometer are :-

1. Cermet:-It uses precious metal particles fused into ceramic base & these fused particles acts as a resistance elements.

Advatages :

1.Large power ratings at high temperatures.

2. Low cost.

3. Moderate temperature co-efficients of the order of $100*10^{-6}/^{o}C$

Applications:-

Used for a.c. applications.

Materials used for potentiometer

2. Hot Moulded Carbon:-The resistance element is fabricated by moulding together a mixture of carbon & a thermosetting plastic binder

Applications:-

Used for a.c. applications.

3. Carbon Film:- A very thin film of carbon deposited on a non-conductive base forms the resistance element.

Advatages :

Low Cost.

Temperature Co-efficient are upto $100*10^{-6}/^{o}C$

4. Thin Metal Film:-A very thin,vapour deposited layer of metal on glass or ceramic is used as resistance element.

Advatages :

1.Its excellent resistance to changes in environments

2.Used for a.c. applications

3.Cost is also moderate

Advatages and Disadvantages of resistance potentiometer

Advatages:-

- They are inexpensive.
- They are simple to operate.
- They are very useful for measurement of large amplitudes of displacement.
- Their electrical efficiency is very high & they provide sufficient o/p to permit control operations without further amplification.
- It should be understood that while the frequency response of wire wound potentiometers is limited.
- In wire wound potentiometers the resolution is limited while in cermet & metal film the resolution is infinite.

Disadvantages:-

- Linear potentiometer requires a large force to move their sliding contacts.
- The other problem with sliding contacts are that they can be contaminated ,can wear out,become misaligned & generate noise. so life is limited.

Strain

Strain is the geometrical expression of deformation caused by the action of **stress** on a physical body. Strain is calculated by first assuming a change between two body states: the beginning state and the final state. Then the difference in placement of two points in this body in those two states expresses the numerical value of strain. Strain therefore expresses itself as a change in size and/or shape.

Strain Gauges

- If a metal conductor is stretched or compressed ,its resistance changes on account of the fact that both length and diameter of conductor change.also there is a change in the value of resistivity of the conductor when it is strained and this property is called piezoresistive effect.
- Resistance strain gauges are also called piezoresistive gauges.

Strain gauges contd….

- To find how R depends upon the material physical quantities,the expression for R is differentiated w.r.t to stress.Thus we get:

$$\frac{dR}{ds} = \frac{\rho}{A}\frac{\delta L}{\delta s} - \frac{\rho L}{A^2}\frac{\delta A}{\delta s} + \frac{L}{A}\frac{\delta \rho}{\delta s}$$ …………..(1)

Dividing eq.1 by resistance we have

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\delta L}{\delta s} - \frac{1}{A}\frac{\delta A}{\delta s} + \frac{1}{\rho}\frac{\delta \rho}{\delta s}$$ …………..(2)

- It is evident from eqn.(2) that per unit change in resistance is due to:
- (i) per unit change in length = $\Delta L / L$ (ii) per unit change in Area = $\Delta A / A$
- (iii) per unit change in resistivity = $\Delta \rho / \rho$

Area

$$A = \frac{\pi}{4} D^2 \qquad \frac{\delta A}{\delta s} = 2\,\frac{\pi}{4}\,D\,\frac{\delta D}{\delta s}$$ …………..(3)

Strain gauges contd….

$$\frac{1}{A}\frac{\delta A}{\delta s} = (2\pi/4)D/(\pi/4)D^2\frac{\delta D}{\delta s} = \frac{2}{D}\frac{\delta D}{\delta s} \quad \ldots\ldots\ldots.(4)$$

Therefore eqn(2) can be written as:

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\delta L}{\delta s} - \frac{2}{D}\frac{\delta D}{\delta s} + \frac{1}{\rho}\frac{\delta \rho}{\delta s} \quad \ldots\ldots\ldots\ldots(5)$$

$$\nu = \frac{\text{lateral strain}}{\text{longitudinal strain}} = -\frac{\delta D/D}{\delta L/L}$$

$$\text{or} \quad \frac{\delta D}{D} = -\nu\,\delta L/L$$

Therefore

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\delta L}{\delta s} - \nu\frac{2}{L}\frac{\delta L}{\delta s} + \frac{1}{\rho}\frac{\delta \rho}{\delta s} \quad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Strain gauges contd….

- For small variations the above relation can be written as:

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} + 2v\frac{\Delta L}{L} + \frac{\Delta \rho}{\rho}$$ ……….(7)

- The gauge factor is defined as the ratio of per unit change in resistance to change in per unit length.
- gauge factor

$$G_f = \frac{\Delta R / R}{\Delta L / L}$$ ………(8)

$$\frac{\Delta R}{R} = G_f\frac{\Delta L}{L} = G_f \in$$ ……..(9)

Strain gauges contd….

$$\in = strain = \frac{\Delta L}{L}$$

The gauge factor can be given as

$$G_f = 1 + 2\nu + \frac{\Delta\rho/\rho}{\in} \quad \ldots\ldots\ldots..(10)$$

$$G_f = \frac{\Delta R/R}{\Delta L/L} = 1 + 2\nu + \frac{\Delta\rho/\rho}{\in}$$

The gauge factor is usually expressed in microstrain.

Strain gauge – the gauge factor

- $G_f = \Delta R / R / \Delta L / L$

R = the initial resistance in ohms (without strain)
ΔR = the change of initial resistance in ohms
L = the initial length in meters (without strain)
ΔL = the change of initial length in meters

- The poisson's ratio for all metals is between 0 and 0.5.This gives a gauge factor of approximately ,2.

Strain gauge – contd…………….

- A resistance wire strain gauge uses a soft iron wire of small diameter.The gauge factor is +4.2.Neglecting the piezoresistive effects,calculate the poisson's ratio.
- Ans:1.6

Types of strain gauges

- Unbonded metal strain gauges
- Bonded metal wire strain gauges.
- Bonded metal foil strain gauges.
- Vacuum deposited thin metal film strain gauges.
- Sputter deposited thin metal strain gauges.
- Bonded semiconductor strain gauges.
- Diffused metal strain gauges.

Semiconductor Strain Gauges

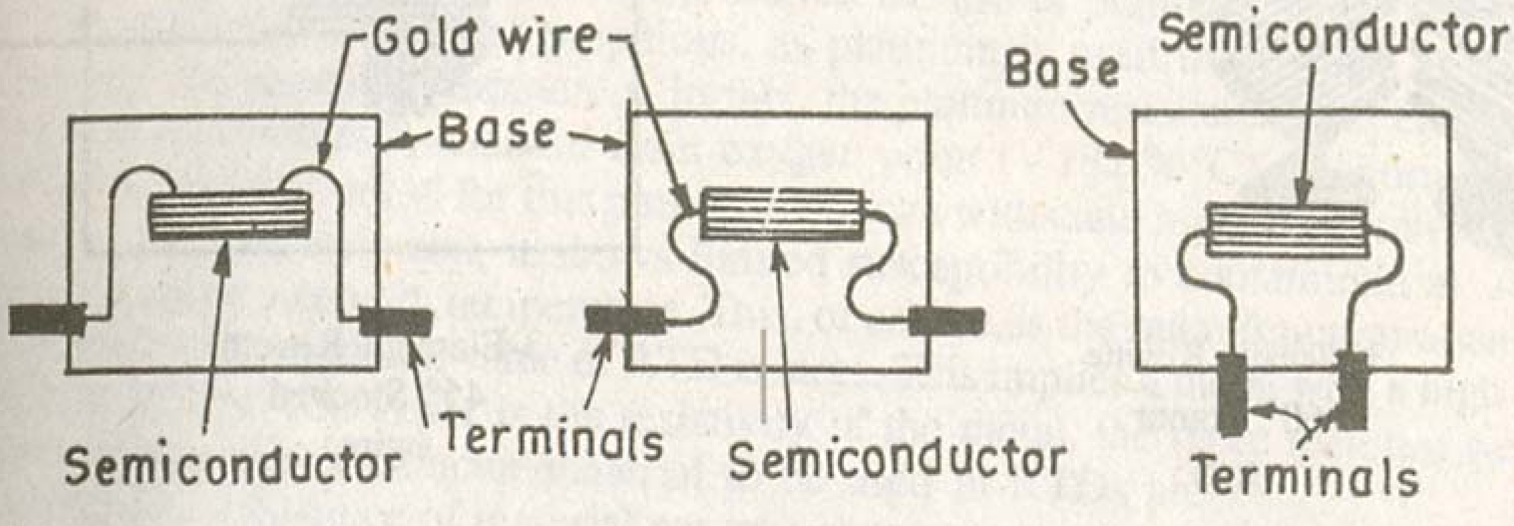


Fig. Semi-conductor strain gauge.

Semiconductor Strain Gauges

- These gauges are used where a very high gauge factor is required.
- The resistance of the semiconductors changes with change in applied strain.
- The semiconductor strain gauge depend for their action upon piezo-resistive effect,i.e the change in the value of the resistance due to change in resistivity.

Semiconductor Strain Gauges

- Si and Ge are used as resistive materials for semiconductor strain gauges.
- A typical strain gauge consists of a strain sensitive crystal material and leads that are sandwiched in a protective matrix.
- The production of these gauges employs conventional semiconductor technology.

Semiconductor Strain Gauges

- Gold leads are generally employed for making the contacts.
- These gauges can be fabricated along with IC operational amplifiers which can act as pressure sensitive transducers.

Semiconductor Strain Gauges

- Advantages :-

- They have high gauge factor of about $\pm$ 130.
- This allows measurement of very small strains of order of .01 microstrain.
- Hystersis characteristics of these gauges are excellent.
- Fatigue life is in excess and frequency response is upto 10^{12} Hz.

Semiconductor Strain Gauges

- They are very small ranging in length from .7 to 7 mm.

- Disadvantages :-

- They are very sensitive to changes in temperature.
- Linearity of the semiconductor strain gauge is poor.
- More expensive and difficult to attach to the object under study.

Rosettes

- In addition to single element strain gauges, a combination of strain gauges called "rosettes" are available in many combinations for specific stress analysis or transducer applications.

Resistance Temperature Detectors

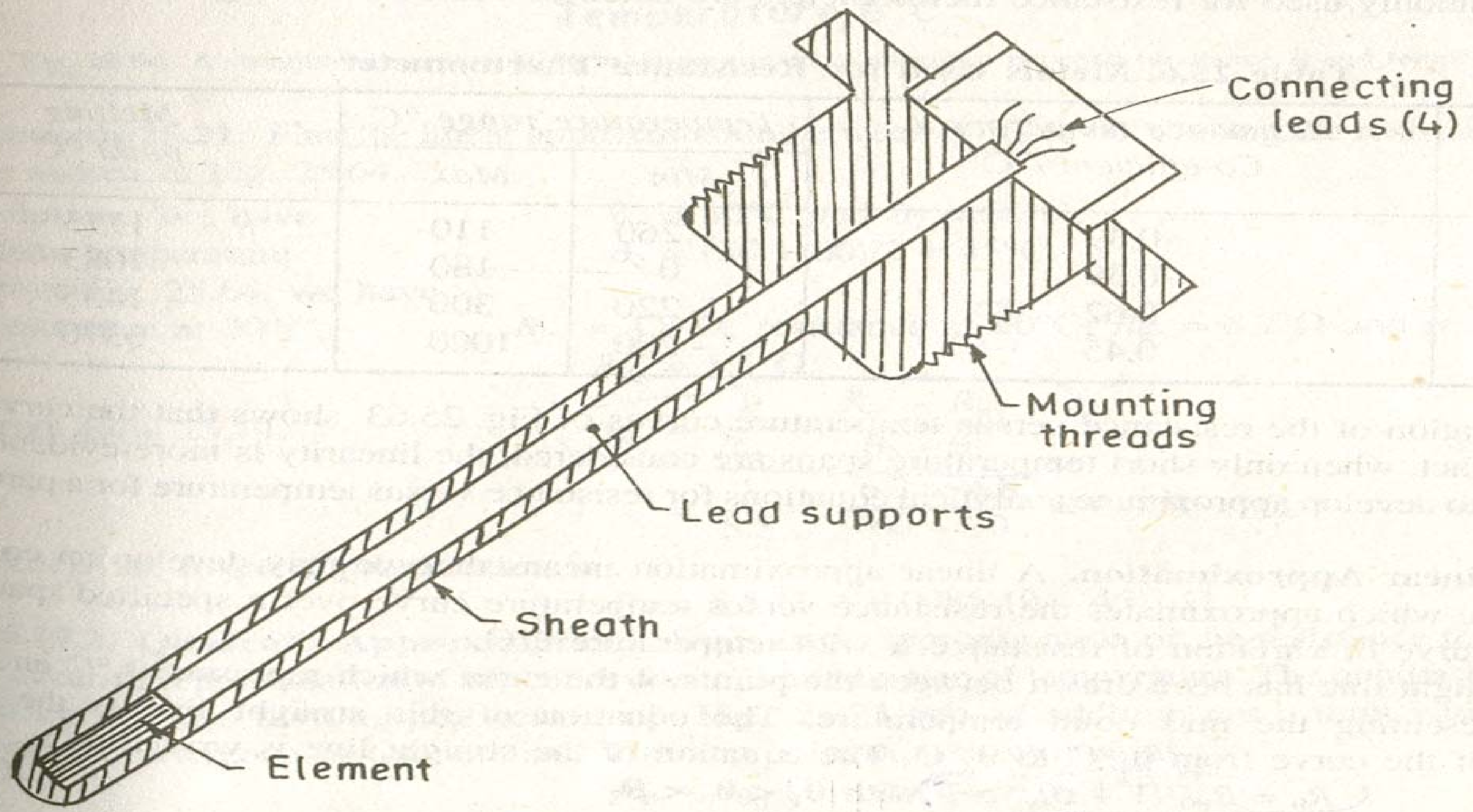


Fig. Industrial platinum resistance thermometer.

Resistance Temperature Detectors

- In RTD,the resistance of a conductor changes when its temperature is changed.
- $R=R_0(1+\alpha_1 T+ \alpha_2 T^2+\ldots\ldots\ldots\ldots\ldots\ldots \alpha_n T^n+\ldots.)$

Where R_0=resistance at temperature T=0 and $\alpha_1,\alpha_2,\ldots\ldots\ldots\ldots\ldots\ldots A_n$ are constants.

- Platinum is especially suited for this purpose,it can withstand high temperatures while maintaining excellent stability.

Resistance Temperature Detectors

- All metals produce a positive change in resistance with temperature.
- The requirements of a conductor material to be used in RTDs are:-

➢ The change in resistance of material per unit change in temperature should be as large as possible.

➢ The material should have a high value of resistivity so that minimum volume of material is used for the construction of RTD.

Resistance Temperature Detectors

- The resistance of materials should have a continuous and stable relationship with temperature.

Characteristics of Resistance Thermometers

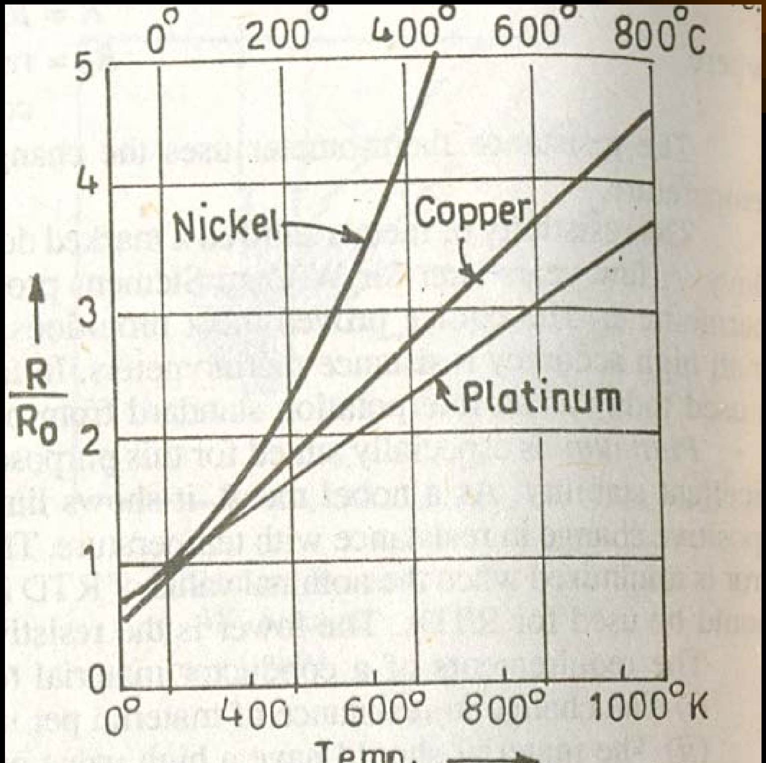


Fig. . Characteristics of materials used for resistance thermometers.

Metals used for RTDs

Table Metals Used for Resistance Thermometers

Metal	*Resistance temperature Co-efficient /°C*	*Temperature range °C*		*Melting point °C*
		Min	*Max*	
Platinum	0.39	– 260	110	1773
Copper	0.39	0	180	1083
Nickel	0.62	– 220	300	1435
Tungsten	0.45	– 200	1000	3370

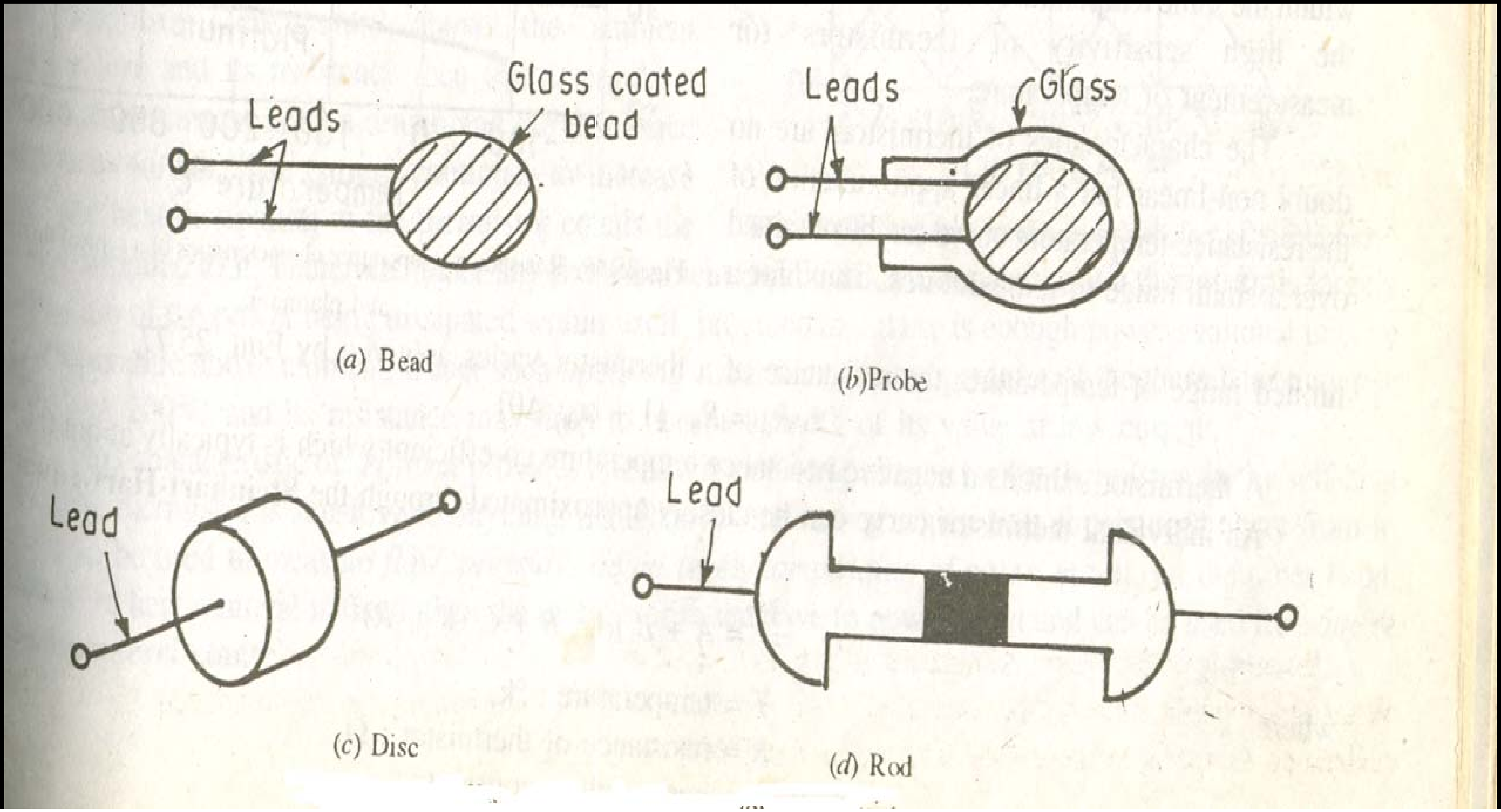
Thermistors

- These are composed of semiconducting materials.
- Because of negative temperature coefficients of thermistors,they can detect very small change in temperature which could not be possible with RTDs or thermocouples.
- High sensitivity to temperature,it will be useful for precision temperature measurements control and compensation.

Thermistors

- It can measure temperature from -60^{0}C to 15^{0}C.
- Resistance of thermistor range from 0.5 ohm to 0.75 ohm.
- Thermistor exhibits a highly nonlinear characteristics of resistance versus temperature.

Thermistors



Thermistors

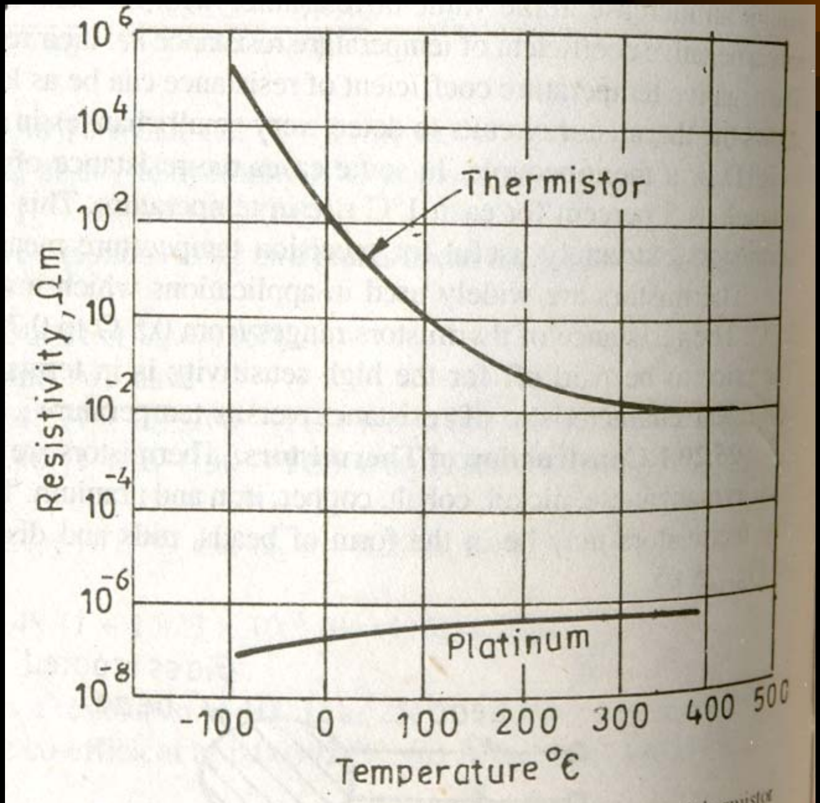


Fig. . Resistance-temperature characteristics of a typical thermistor and platinum

Resistance temperature characteristics of Thermistors

- $R_{T1}=R_{T2}\exp[\beta\{(1/T_1)-(1/T_2)\}]$

- Where R_{T1}=reistance of the thermistor at absolute temperature T_1;^{0}K
- R_{T2}=reistance of the thermistor at absolute temperature T_2;^{0}K
- β =a constant depending upon the material of thermistor,typically 3500 to 4500 ^{0}K.

Thermistors

- An individual thermistor curve can be closely approximated through the Steinhart-Hart equation:
- $1/T = A + B \log_e R + C(\log_e R)^3$

Where T=temperature :^{0}K,

R=resistance of thermistor;Ω

A,B,C=curve fitting constants.

T=(B/logeR-A)- C

Applications of Thermistors

- Measurement of temperature.
- Control of temperature.
- Temperature compensation.
- Measurement of power at high frequencies.
- Measurement of thermal conductivity.
- Measurement of level,flow and pressure of liquids.
- Measurement of composition of gases.
- Vacuum measurements and
- Providing time delays.

Thermocouples

- What Is A Thermocouple Sensor??
- Basic Working Principle
- Practical Thermocouple Construction
- Thermocouple Materials
- Standard Thermocouple Types
- Thermocouple Color Codes
- Characteristics
- Major Specifications
- Capabilities and Limitations
- Selecting A Temperature Sensor
- Comparisons

What Is A Thermocouple Sensor??

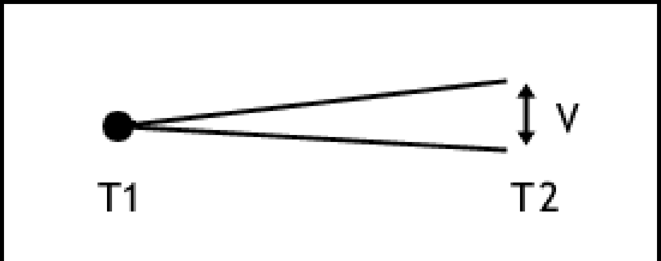
Thermocouples are among the easiest temperature sensors to use and obtain and are widely used in science and industry.

Thermocouples are the most common temperature sensing device. They can be made in very tough designs, they are very simple in operation and measure temperature at a point. Over different types they cover from -250C to +2500C.

Accurate temperature measurements can be made with thermocouples sensors at low cost with shop-built probes and ordinary low-level voltmeters.

Basic Working Principle

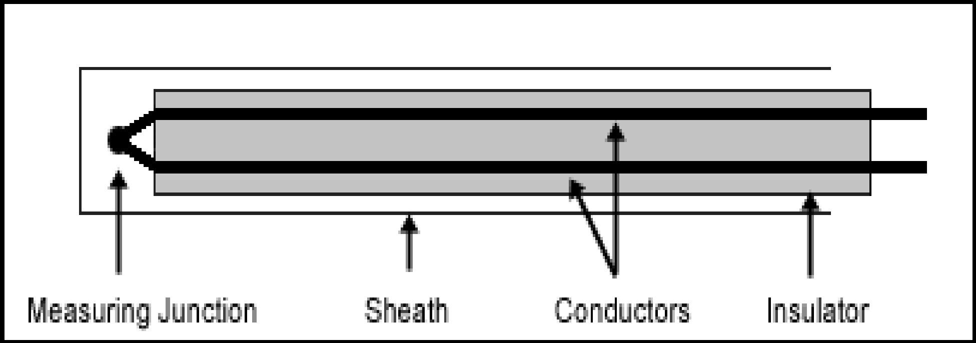
The principle of operation is on the Seebeck effect. A temperature gradient along a conductor creates an EMF. If two conductors of different materials are joined at one point, an EMF is created between the open ends which is dependent upon the temperature of the junction. As T1 increases, so does V. The EMF also depends on the temperature of the open ends T2.



The junction is placed in the process, the other end is in iced water at 0C. This is called the reference junction.

Practical Thermocouple Construction

A thermocouple construction consist of two conductors, welded together at the measuring point and insulated from each other long the length. It will usually have an outer protection sheath.



Thermocouple Materials

The three most common thermocouple materials for moderate temperatures are Iron-Constantan (Type J), Copper-Constantan (Type T), and Chromel-Alumel (Type K).

1-) The first named element of the pair is the positive element.

2-) The negative wire is color coded red.

All three types (J, K, and T) are available as insulated duplexed pairs from 0.001-inch diameter on up. For accuracy, and minimum system disturbance, the smaller the wire the better, but wire smaller than 0.003-inch diameter is very fragile.

Standard Thermocouple Types

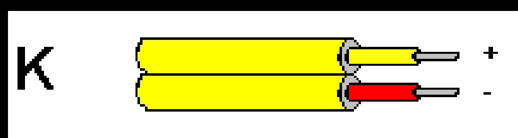
Iron-Constantan: Iron-Constantan (Type J, color coded white and red) generates about 50 μV/°C (28 μV/°F). The Iron wire is magnetic. Junctions can be made by welding or soldering, using commonly available solders and fluxes.Iron-Constantan thermocouples can generate a galvanic EMF between the two wires and should not be used in applications where they might get wet.

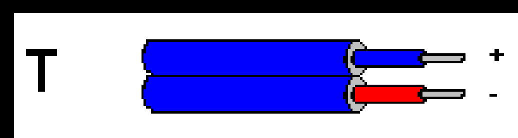
Chromel Alumel: Chromel-Alumel (Type K, color coded yellow and red) generates about 40 μV/°C (22 μV/°F). The Alumel wire is magnetic. Junctions can be made by welding or soldering, but high temperature silver-solders and special fluxes must be used.Chromel-Alumel thermocouples generate electrical signals, while the wires are being bent, and should not be used on vibrating systems, unless strain relief loops can be provided.

Copper-Constantan: Copper-Constantan (Type T, color coded blue and red) generates about 40 μV/°C (22 μV/°F). Neither wire is magnetic. Junctions can be made by welding or soldering with commonly available solders and fluxes.Copper-Constantan thermocouples are very susceptible to conduction error, due to the high thermal conductivity of the copper, and should not be used unless long runs of wire (100 to 200 wire diameters) can be laid along an isotherm.

Thermocouple Color Codes

Thermocouple wiring is color coded by thermocouple types. Different countries utilize different color coding. Jacket coloring is sometimes a colored stripe instead of a solid color as shown.





Characteristics

Thermocouples have non-linear characteristics given by an approximating polynomial.

For example for type J (range 1, -210 to 760°C) the characteristic is given by

$$V = c_0 + c_1 T + c_2 T^2 + c_2 T^2 + c_3 T^3 + c_4 T^4 + c_5 T^5 + c_6 T^6 + c_7 T^7$$

where V is in and T in °C

The output signal from a thermocouple is up to 50mV.

Major Specifications

- Type J: Iron / Constantan:Useful range of temperature is -300F to 1200F. Maximum temperature 1600F. Possible problems: Oxidizes rapidly due to the iron wire. The use of the stainless steelmetal sheathed MgO style of construction has overcome some of this problem and is much preferred over the beaded bare wire style of thermocouple.
- Type K: Chromel / Alumel Useful range of temperature is -300F to 1800F. Maximum temperature 2300F.
- Type E: Chromel / ConstantanUseful range of temperature is -300F to 1800F. Maximum temperature 1000F.
- Type T: Copper / ConstantanUseful range of temperature is -300F to 700F. Maximum temperature 700F.

Major Specifications……

Type R and S: Platinum / Platinum-Rhodium Useful range of temperature is 40F to 3000F. Maximum temperature 2300F.Both the R and S thermocouples are used for very high temperatures. These couples are relatively expensive compared to other thermocouples since they are made of platinum.These thermocouples must not touch the sheath if a metal sheath is used for construction. Normally a ceramic protective tube and ceramic beads are used for construction for both high temperature reasons and to prevent contamination of the noble metal.

Capabilities and Limitations

Capabilities:

- Wide Range
- Fast Response
- Passive
- Inexpensive

Limitations:

- CJC
- Non-Linear

Selecting A Temperature Sensor

Choosing a temperature sensor can often be very straightforward, sometimes tricky, but always worth doing well. That's because these sensors, especially in science and engineering uses, can spell the difference between repeatable results and nonsense numbers. The name of the game in measurement is to measure with an amount of inaccuracy or uncertainty that is acceptable. So, the first thing you need to know is how well you need to know the value of the temperature numbers you expect to get. A simple series of questions, when answered, will usually get you started.

cont….

Selecting A Temperature Sensor

The three things that we need to keep in mind when selecting temperature sensor:

1-) What is the desired temperature range, the tolerable limit to the error in measurement and the conditions under which the measurement is to be performed?

2-) Is it possible to touch the object and if so would the sensor or the temperature of the object be likely to be seriously affected by the contact?
If the answer is yes, then a non-contact temperature sensor is needed.
If no, then the answer probably lies with one of the other sensor types.

3-) If a contact sensor appears satisfactory, then questions revolve more around temperature measuring range, satisfying the conditions of use and meeting the acceptable error allowance.

Comparisons

PEAK SENSORS LTD temperature measurement & control	Thermocouple	Resistance Thermometer (RTD)	Thermistor	Infrared
Stability (Drift)	Reasonable for limited lifetime	Good	Good	Good
Repeatability	Reasonable	Good	Good	Good
Hysteresis	Excellent	Good	Good	Good
Vibration	Very Resistant	Less Resistant	Good	Tolerant
Measurement Area	Single Point	Whole RT Element	bead (Small)	Varies
Diameter	Small Sizes (to 0.25mm)	Larger (3.0mm min)	Small (0.5mm min)	Varies
Linearity	Not Linear	Reasonably Linear	Not Linear	Reasonably Linear
Reference Junction	Required	Not Required	Not Required	Not Required
Lead Wire Resistance	No Problem	Must be Considered	No Problem	Not Required
Contact Required	Yes	Yes	Yes	No
Response	Fast	Slower	Medium	Fast

Displacement transducers

- Capacitive transducer
- Inductive transducer
- Variable inductance transducer

Capacitive transducers

- The capacitance of a parallel-plate capacitor is given by

$$C = \frac{\varepsilon \varepsilon_o A}{d}$$

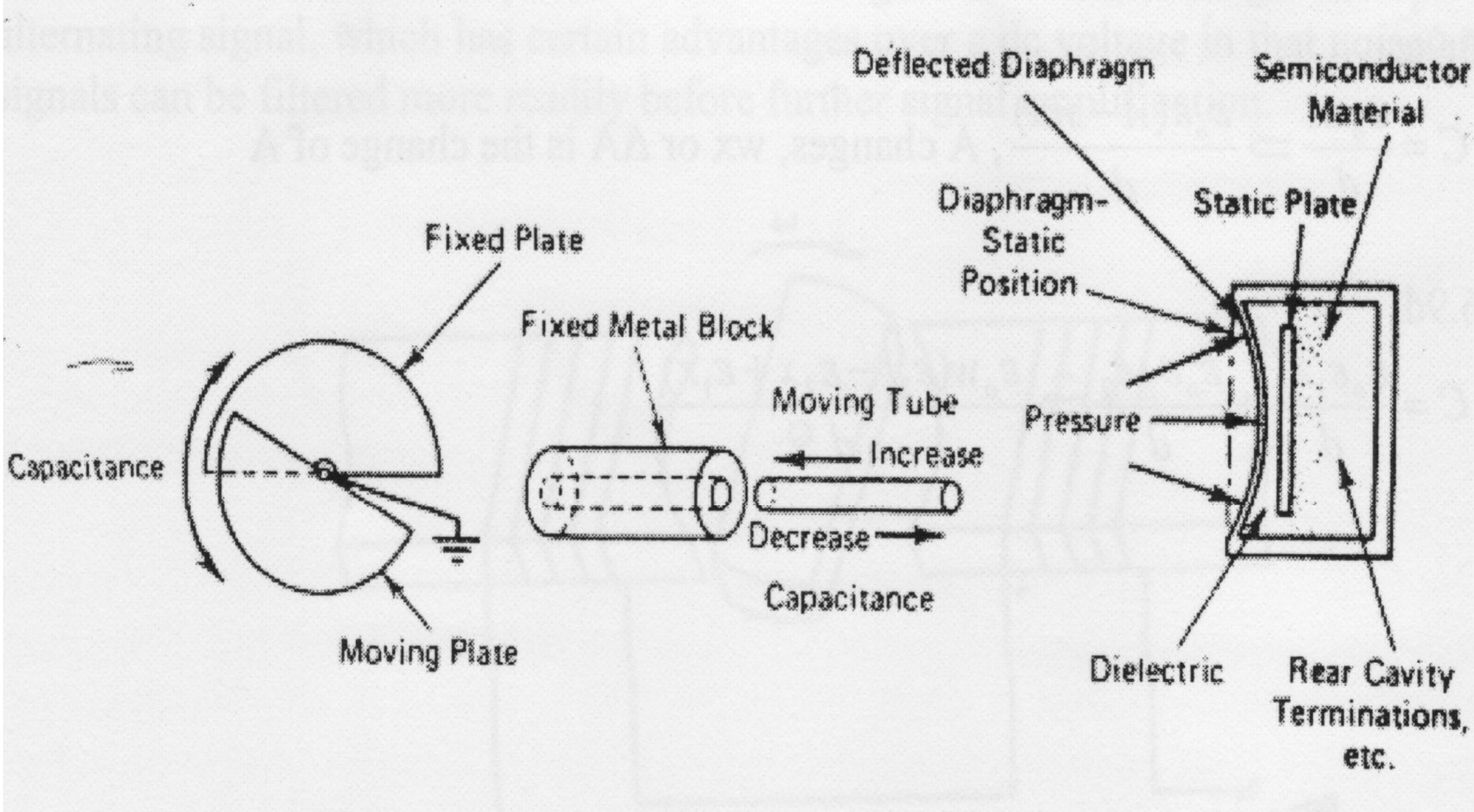
ε = dielectric constant

$\varepsilon_o = 8.854 \times 10^{-12}$, in farad per meter

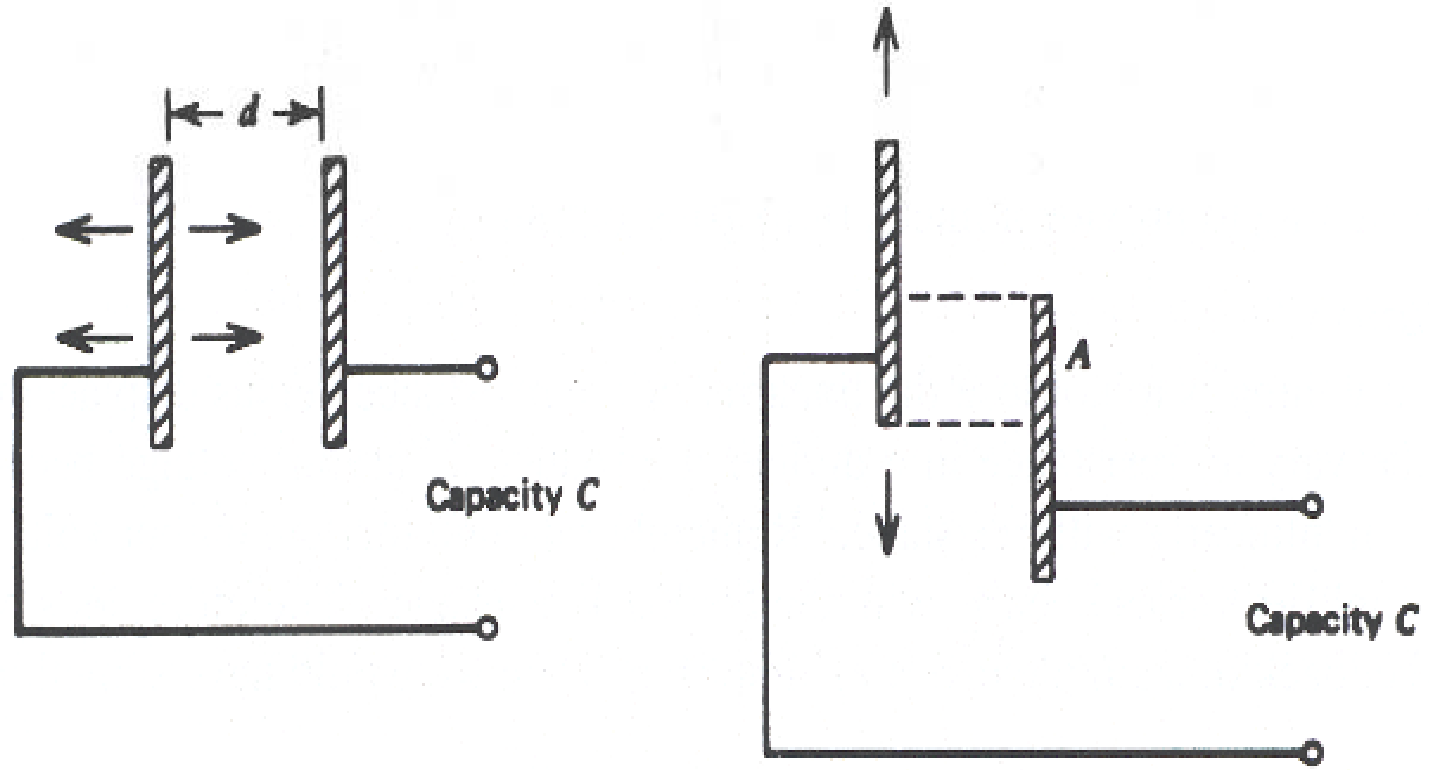
A = the area of the plate, in square meter

d = the plate spacing in meters

Capacitive transducers – physical design



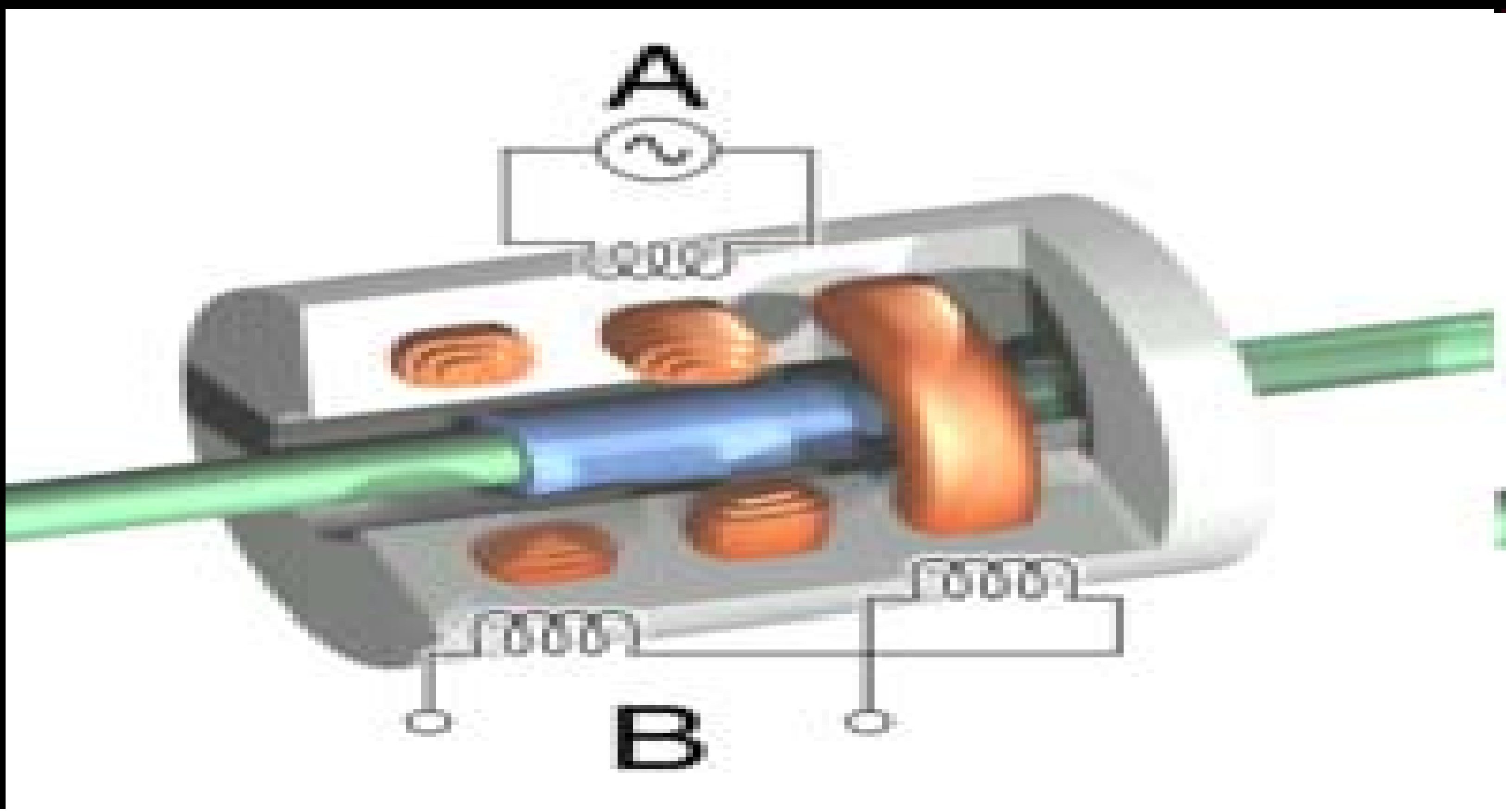
Capacitive transducers



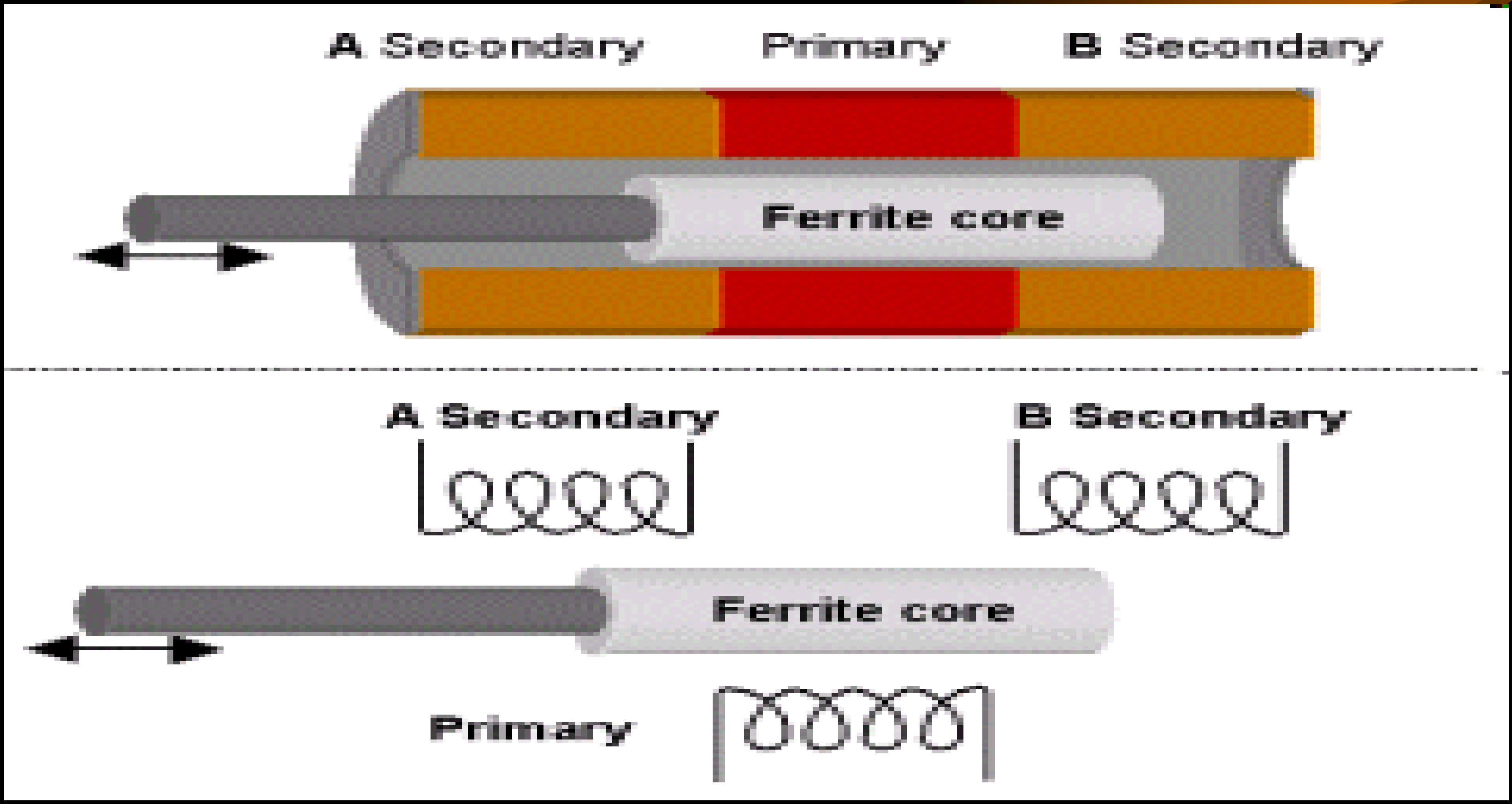
Capacity varies with the distance between the plates and the common area. Both effects are used in sensors.

LVDT(Linear Variable Differential Transformer)

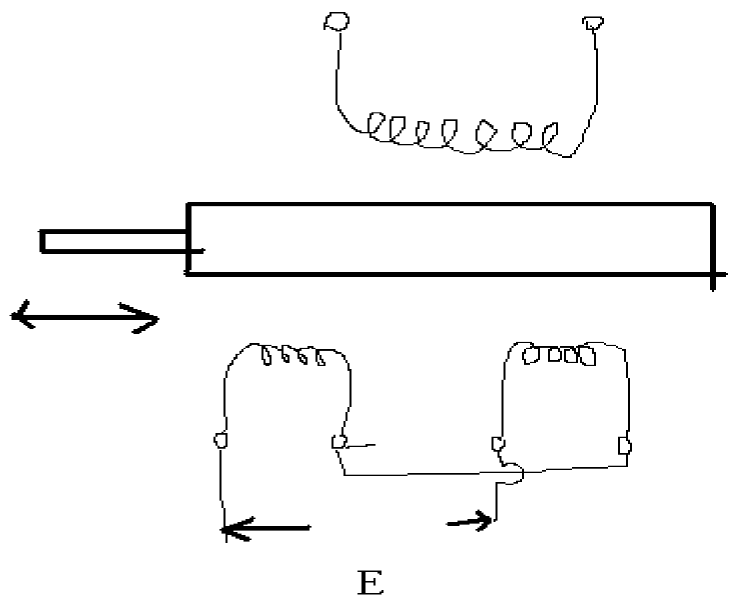
Construction



LVDT Working



LVDT Working



Linear Variable Differential Transducer (LVDT)

- The most widely used inductive transducer to translate the linear motion into electrical signals is the Linear variable differential transducer(LVDT).
- The assembly is placed in stainless steel housing & the end lids provide electrostatic & electromagnetic shielding.
- The frequency of a.c.applied to primary winding is b/w 50Hz to 20KHz.
- The o/p voltage of secondary, S_1 is E_{S1} and that of secondary, S_2 is E_{S2} .
- In order to convert the o/p from S_1 and S_2 into a single voltage signal, the two secondaries S_1 and S_2 are connected in series. Thus the o/p voltage of the transducer is the difference of two voltages .

Differential o/p voltage ,

$$E_o = E_{S1} - E_{S2}$$

When the core is at its normal position the flux linking with both the secondary windings is given as:

$$E_{S1} = E_{S2}$$

Linear Variable Differential Transducer(LVDT) contd…….

- Now if the core is moved to the Left of the Null position the magnitude of the o/p voltage is given by:

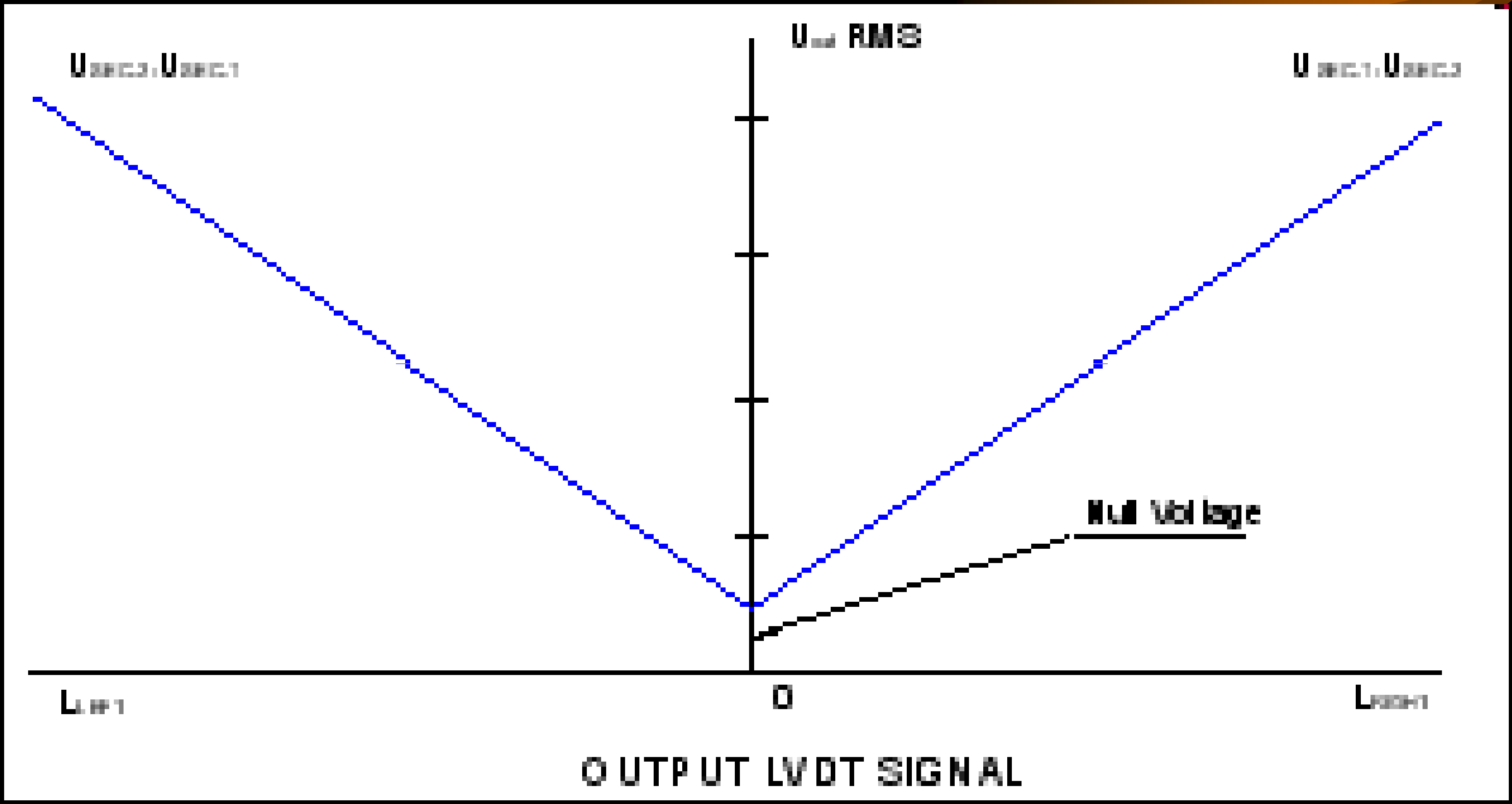
$$E_o = E_{S1} - E_{S2}$$

- Now if the core is moved to the Right of the Null position the magnitude of the o/p voltage is given by:

$$E_o = E_{S2} - E_{S1}$$

& it is 180º out of phase & negative with the primary voltage.

Displacement Vs O/p V



Characteristics of LVDT Contd……..

- The o/p voltage of an L.V.D.T is a linear function of core displacement within a limited range of motion, say 5mm from the null position.
- Beyond this range of displacement ,the curve starts to deviate from a straight line.
- Ideally the o/p voltage at the null position should be equal to zero.However,in actual practice their exists a small voltage at the null position.

Reasons of residual voltage:-

- This may be on account of I/P supply voltage and also due to harmonics produced in the o/p voltage on account of use iron core.
- An incomplete magnetic or electrical unbalance or both which result in a finite O/P voltage at the null position .This finite residual voltage is generally less than 1% of the max.o/p voltage in the linear range
- Other causes of residual voltage is stray magnetic fields and temperature effects.

Advantages of LVDT

1.***High Range:***

- For measurement of displacement ranging from 1.25 mm to 250 mm.
- .025 % of linearity.

2.***Friction and Electrical Isolation:***

- There is no physical contact b/w the movable core & coil structure which means that the L.V.D.T is a frictionless device
- The absence of friction b/w coil & core of an L.V.D.T means that there is no wear out. This gives an L.V.D.T essentially infinite mechanical life.
- The infinite mechanical life is also important for high reliability mechanisms and systems.
- System found applications in space vehicles, aircrafts, missiles & critical industrial equipment.
- The frictionless operation combined with induction principle can respond to even minute motion of the core & produce an output.

Advantages of LVDT

3.High input & high sensitivity:

- The L.VD.T gives a high o/p and many times there is no need for amplification
- The transducer has high sensitivity which is typically about 40v/mm.

4.Ruggedness:

- These transducer can usually tolerate high degree of shock and vibrations especially when the core is spring loaded without any adverse effects.
- They are simple in construction and by virtue of their being small and light in weight, they are easy to align and maintain.

5.Low Hysteresis:L.V.D.T show a low hence hysteresis & repeatability is excellent under all conditions.

6.Low Power Consumption: Most of L.V.D.T consume which is less than 1W.

Disadvantages of LVDT

1. Relatively large displacements are required for appreciable differential o/p.
2. They are sensitive to stray magnetic fields but shielding is possible. This is done by providing magnetic shields with longitudinal slots.
3. Many times ,the transducer performance is affected by vibrations
4. Temp.affects the performance of the transducer.

Photoelectric Transducers

- Photo emissive cells or phototubes
- Photoconductive cells
- Photovoltaic cells
- Photojunctions