INSTRUMENTATION
&
MEASUREMENTS

- For text books :

  pls. refer Syllabus

Suggested readings :

A course in Electronic and electrical measurements and Instrumentation by J.B. Gupta

A course in Electrical and electronic Measurements and Instrumentation by A.K. Sawhney

- Electronics: deals with motion of electrons

- <u>Measurement</u> :

man uses his imaginative skills

- to identify a physical phenomena
- Developed & utilized a means to understand this.

To measure = to determine the magnitude or extent or degree of the condition of system in terms of some standard.

All measuring systems- based on laws of nature.

Eg. Venturimeter- flow measurement – Bernoulli's theorem

- <u>Meter</u> : instrument used to indicate or record measured value
- <u>Measurand</u> : variable under measurement
- <u>Metrology</u> : science dealing with precise and accurate measurements

Instrument : tool or equipment for

- Sensing
- Detecting
- Measuring
- Recording
- Controlling
- Communicating

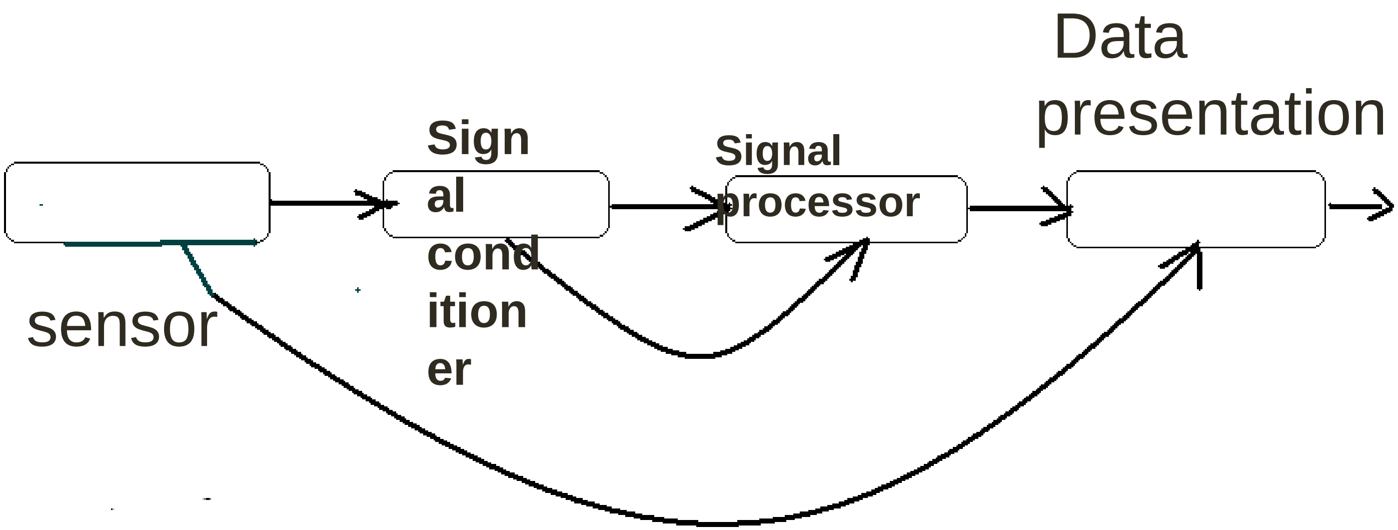
measurand

Can be manual or automatic

Instrumentation

- Deals with Science and technology of measurement of large no. of variables
- Uses principles in physics , chemistry & Appld. Science(Engg),Electrical. Electronics, Mech,computer, commn. etc.
  - I.e., parameters measured need to be txd, stored, may be processed (for control applns.)

General measurement systems



Sensor :

- detecting element
- Use to locate the presence of matter or energy

(energy in the form of heat, light,sound, electrical, pressure, velocity)

- Contacts with the process
- Sensitive to either light or temp. or impedance or capacitance etc.

Signal conditioner:

o/p of sensor is converted to required form by conditioner

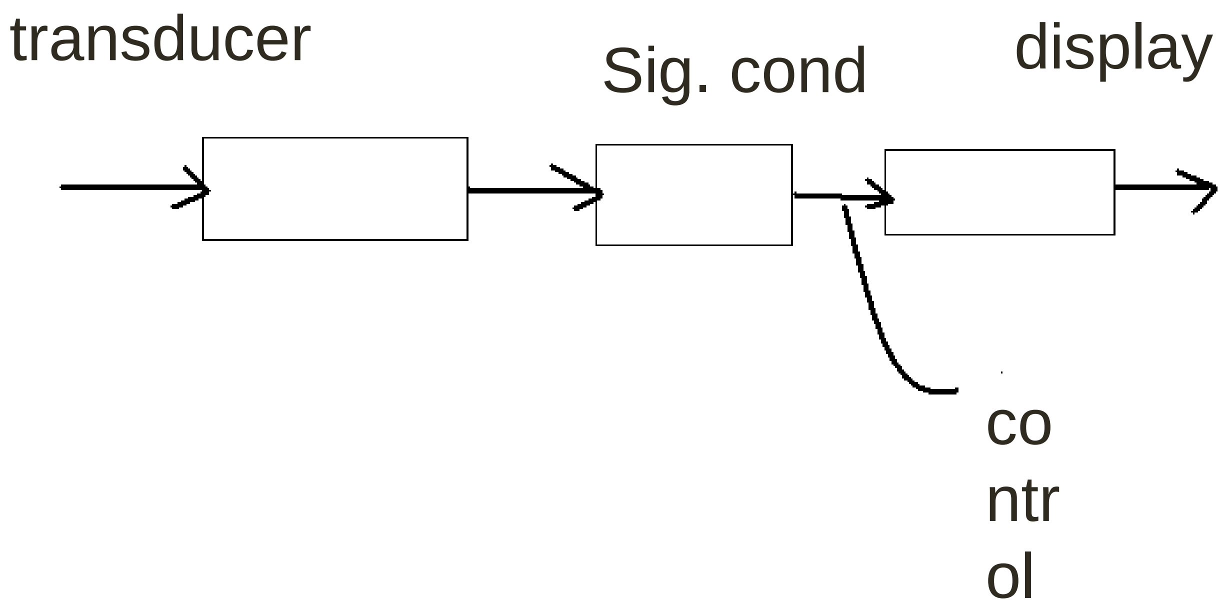
Signal processor :

filtering, shaping, adding, subtracting , multiplying, linearisation etc.

Data o/p :

display, recording etc.

Measuring system



Instrumentation Engg. Is

- Multi disciplinary branch of Engg.
- Deals with design , manufacture, & utilization of instruments

"

When you can measure , what you are speaking and express it in numbers, you know something about it "

Lord Kelvin

Units

_Standard measure of each kind of a Physical quantity

Two types:

a) Fundamental - LMT

b) Derived – area, volume etc

Without units , the number obtained by measuring has no physical meaning.

Systems of Units

- French system - Universal system of standard
- FPS – Foot Pound Second – The British
- CGS – Centimeter Gram Second-designed for practical engg.applications
- MTS-Meter Ton Second in France designed for engg purpose
- SI –Meter Kilogram Second Ampere

Standard Organizations to maintain International System of Units (SI)

1. International Bureau of Weights& Measures
2. General Conference on Weights&Measures
3. International Committee for Weight & Measures

European systems

Institute for Reference Materials & measurements- Geel,Belgium + 7 other

American systems

National Institute for stds.& tech +2 others

Standards

Physical representation of unit of measurement

Unit is realized by reference to a standard

Eg. 1.kg = mass of one cubic deci meter of as its temp of max density of 4c

Categories

1. International Standards
2. Primary standard
3. Secondary Standard
4. Working standards

International Standards

- defined by international agreement maintained at International Bureau of Weights and Measures (one organization for SI unit)
- Not available to ordinary uses

Primary or Basic Standards

Maintained by National standard labs of each country

India –National Physical Lab in New Delhi

Not available outside National Labs

Secondary standards

basic reference standards for industrial measurement labs

Maintained by particular industry

Checked locally

Occasionally sent to primary lab for calibration,then primary labs will give certificate

<u>Working standard</u>

Primary tool of measuring labs

General Instrumentation systems

Characteristics

Static

Dynamic

Static Characteristics

Features which does not vary or vary very slowly with respect to time.

Or they are features which considered when a system or instrument ,when a condition does not vary with time.

- Some are :***Accuracy, Sensitivity, Reproducibility,*** Drift, Static error, Dead zone etc.

True value :

ideal case (impossible to measure)

Measured by "*Examplar*" method (method agreed by experts as being sufficiently accurate).

Defined as average of infinite no. of measured values when the average deviation due to various factors tend to zero.

take it as best measured quality

- <u>Accuracy</u>

nearness to the true value

Or

closeness with which an instrument approaches the true value of quantity being measured

Accuracy is measured in terms of error.

Static error

defined as the difference b/w the measured value and true value of quantity.

i.e.,

$$\delta A = A_m - A_t$$

Where ,

δA = *error*

A_m = *measured value*

A_t = *true value*

δA – *static error of quantity A under measurement*

Quantity of measurement is provided by **relative static error**

Relative static error ε_r

$$\varepsilon_r = \delta A / A_t$$

$$= \varepsilon_o / A_t$$

$$\% \varepsilon_r = \varepsilon_r \times 100$$

$$A_t = A_m - \delta A$$

$$= A_m - \varepsilon_o$$

$$= A_m - \varepsilon_r \,.A_t$$

$$A_m = A_t / (1 + \varepsilon_r)$$

$$\text{So, } A_t = A_m / (1 - \varepsilon_r)$$

Static correction (δC)

$$\delta C = A_t - A_m$$

A_t = true value

A_m = measured value

Problems :

1. A meter reads 127.50 V and the true value of the voltage is 127.43 V . Determine the static error and static correction .

(Ans : error : 0.07, correction = -0.07)

2. A thermometer reads 95.45 C & static correction in correction curve is - 0.08 C. Find the true value

Ans : 95.37 C.

3. A voltage has a true value of 1.5 V on an analog indicating meter with a range 0 to 2.5 V shows a voltage of 1.46 V. Determine the value of absolute error and correction.Express the error as a fraction of true value & full scale defection

Ans : Abs. Error = -0.04, correction =0.04

relative error for true value =2.67%

relative error for full scale deflection = 1.6%

Recorders

Why?

- It is often necessary to have a permanent record on the state of a phenomenon being investigated.
- In many of the industrial and research processes it is necessary to monitor continuously the condition, state or value of the process variables such as flow, pressure, temperature, current, voltage etc.

What?

- A recorder thus records electrical and non-electrical quantities as a function of time.
- This record may be written or printed, and later on, can be examined and analyzed to obtain a better understanding and control of the process.

How?

- Currents and voltages can be recorded directly while the non-electrical quantities are recorded indirectly by first converting them to equivalent currents or voltages with the help of sensors or transducers.

Techniques

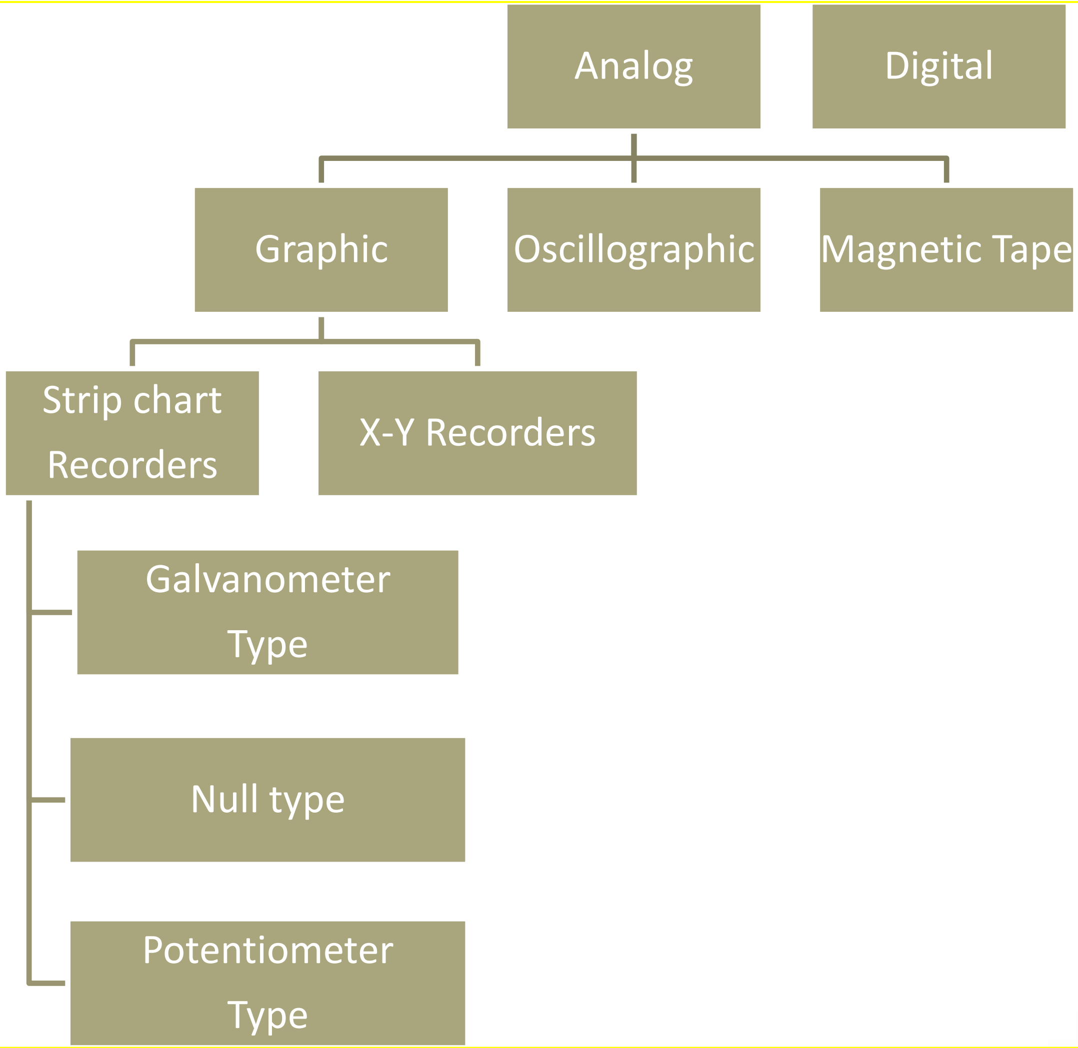
- Analog recording techniques:

  - Dealing with analog system.

- Digital recording techniques:

  - The system has digital output.

Types



Analog
Digital
Graphic
Oscillographic
Magnetic Tape
Strip chart Recorders
X-Y Recorders
Galvanometer Type
Null type
Potentiometer Type

Analog recorders

- Basic elements are,

  → Chart(for displaying and storing the recorded information)

  → Stylus(Moving in a proper relationship to the paper and suitable means of inter connection to couple the stylus to the source of information)

Strip chart Recorders

It consists of

- A long roll of graph paper moving vertically.
- A system for driving the paper at some selected speed.
- A stylus for marking marks on the moving graph paper. The stylus moves horizontally.
- A stylus driving system which moves the stylus in a nearly exact replica of the quantity being recorded.

Stress

In general, stress is expressed as

$$\sigma = \frac{F}{A}$$

σ is the average stress, also called **engineering** or **nominal stress**

F and is the force acting over the area A.

Strain

- The strain is defined as the fractional change in length

$$strain = \frac{\Delta l}{l}$$

- Strain is thus a unitless quantity
- Relation between stress and strain is

strain=stress/young's modulus of elasticity

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Strain Gauges

- Senses strain produced by the force on the wires and converts that into change in resistance.
- If a metal conductor is stretched or compressed, its resistance changes on account of the fact that both the length and diameter of the conductor changes.
- Also, there is a change in the resistivity value of the conductor, when subjected to strain, a property called piezo resistive effect.
- Strain gauge is also called as piezo resistive gauges.

- When a gauge is subjected to a positive stress, its length increases while its area of cross-section decreases.
- Since the resistance of a conductor is directly proportional to its length and inversely proportional to its area of cross section, the resistance of the gauge increases with positive strain.
- The change in resistance value of a conductor under strain is more than for an increase in resistance due to its dimensional changes. This property is called piezo-resistive effect.

Strain gauge

From the equation of resistance,

$$R = \frac{\rho L}{A}$$

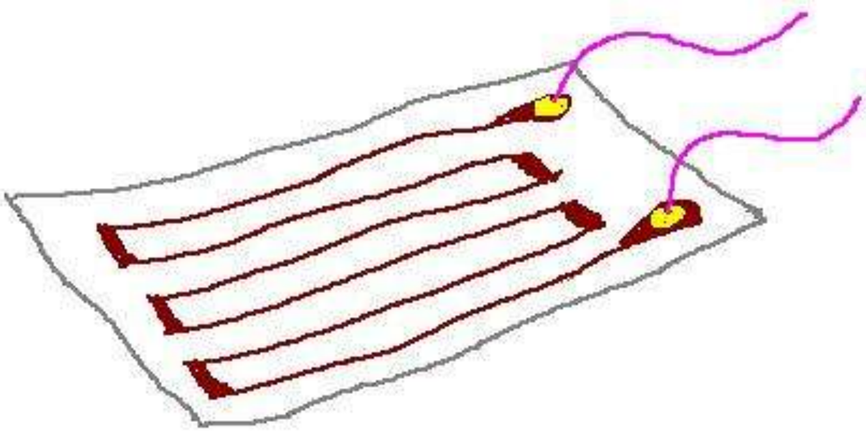
R = resistance

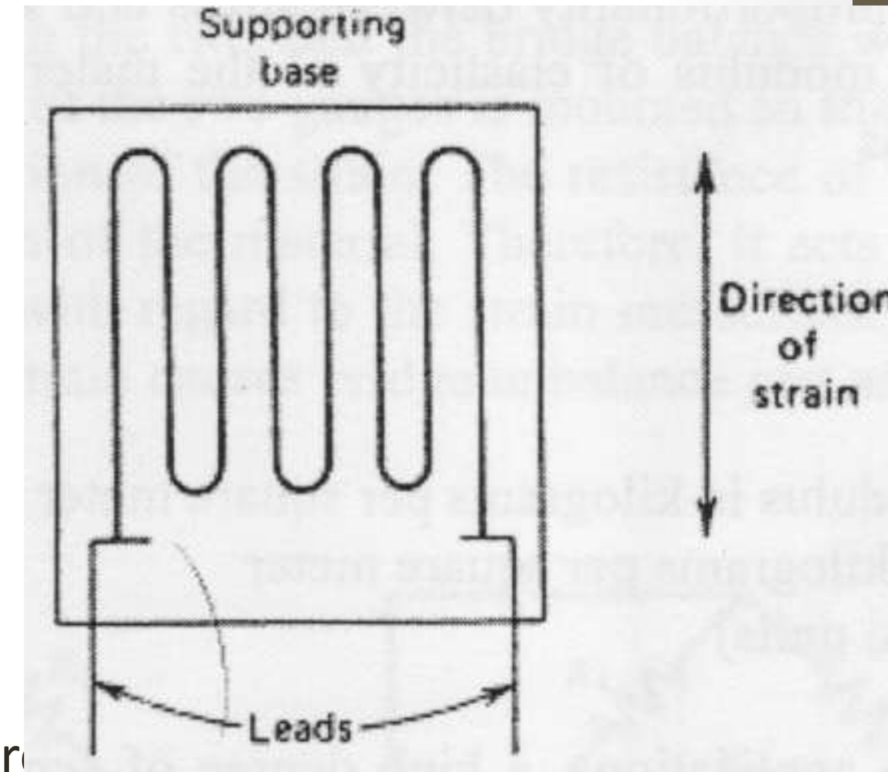
ρ = specific resistance of the conductor material

L = the length of the conductor in meters

A = the area of the conductor in square meters

Strain gauge





When a strain produced by a for

increase and *A* decrease.

Strain gauge

L – increase

A – decrease

From the equation of resistance,

R – increase

$$R = \frac{\rho L}{A}$$

Strain gauge – the gauge factor

$$K = \frac{\Delta R / R}{\Delta L / L}$$

K = the gauge factor

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

Strain gauge – the gauge factor

$$K = \frac{\Delta R / R}{\Delta L / L}$$

strain

K = the gauge factor

R = the initial resistance in ohms (without strain)

ΔR = the change of initial resistance in ohms

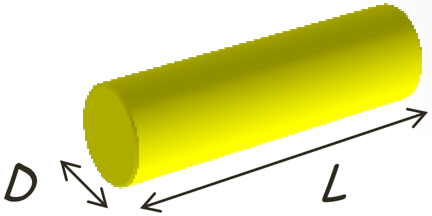
L = the initial length in meters (without strain)

ΔL = the change of initial length in meters

Strain gauge – the gauge factor

$$K = \frac{\Delta R / R}{G}$$

Strain Gauge: Gauge Factor



- Remember: for a strained thin wire
  - $\Delta R/R = \Delta L/L - \Delta A/A + \Delta\rho/\rho$
    - $A = \pi (D/2)^2$, for circular wire
- Poisson's ratio, μ: relates change in diameter D to change in length L
  - $\Delta D/D = -\mu\, \Delta L/L$
- Thus
  - $\Delta R/R = (1+2\mu)\, \Delta L/L + \Delta\rho/\rho$

    dimensional effect piezoresistive effect
- Gauge Factor, K, used to compare strain-gate materials
  - $K = \dfrac{\Delta R/R}{\Delta L/L} = (1+2\mu) + \dfrac{\Delta\rho/\rho}{\Delta L/L}$

$K = (1+2\mu)$ (Neglecting Piezo-resistive effect)

Types of strain gauge

- Wire strain gauges
  - i) Resistance wire
    1. Bonded wire
    2. Unbonded wire
  - ii)Rossette type
  - iii)Torque type
  - iv)Helical type
- Foil strain gauges
- Semiconductor strain gauges

Example 6.9:

A resistance strain gauge with a gauge factor of 2 is fastened to a steel member, which is subjected to a strain of 1×10^{-6}. If the original resistance value of the gauge is 130Ω, calculate the change in resistance.

Solution:

$$K = \frac{\Delta R / R}{\Delta L / L} = \frac{\Delta R / R}{G}$$

$$\Delta R = KGR = (2)(1 \times 10^{-6})(130\ \Omega) = 260\ \mu\Omega$$

Problem-5

- A resistance wire strain gauge uses a soft iron wire of small dia. The gauge factor is +4.2. Neglecting the piezo-resistive effects, calculate the poisson's ratio.

Problem-6

- A strain gauge with gauge factor of 2 is fastened a metallic member subjected to a stress of 1000 Kg/cm^2. The modulus of elasticity of the metal is $2 \times 10^6 Kg/cm^2$. Calculate the percentage change in resistance of the strain gauge. What is the value of poisson’s ratio.

Problem-7

- Two electrical strain gauges each of resistance 150Ω are mounted on a cantilever as shown in fig. and connected in the bridge ckt.(Half Bridge ckt).The supply to bridge is 6 volt and K=2. The applied stress is 300 Mn/m^2 and young's modulus of elasticity of cantilever material is 60gN/m^2 . Determine

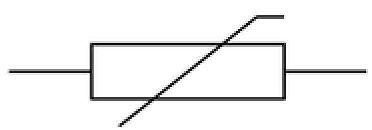
- Strain
- Change in Resistance
- The output voltage.

Thermistor

- THERMally sensitive resISTOR are Semiconductor resistance sensors.
- It is made by mixtures of mettallic oxides such as manganese, nickel, cobalt, copper and uranium.
- Unlike metals, thermistors has Negative Temperature Coefficient. i.e.

Temperature ↑ semiconductor resistance ↓

- Symbol



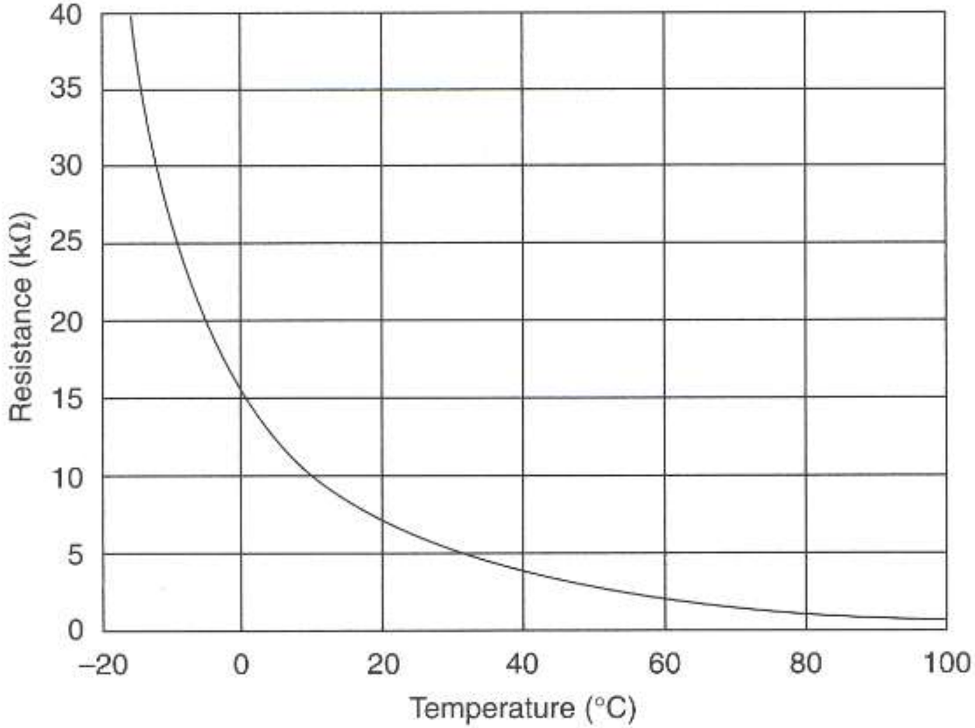
- Thermistors has very non-linear Resistance-Temperature relation.

$$R=\alpha e^{\beta/T}$$

α= Temperature coefficient
β= Thermistor constant

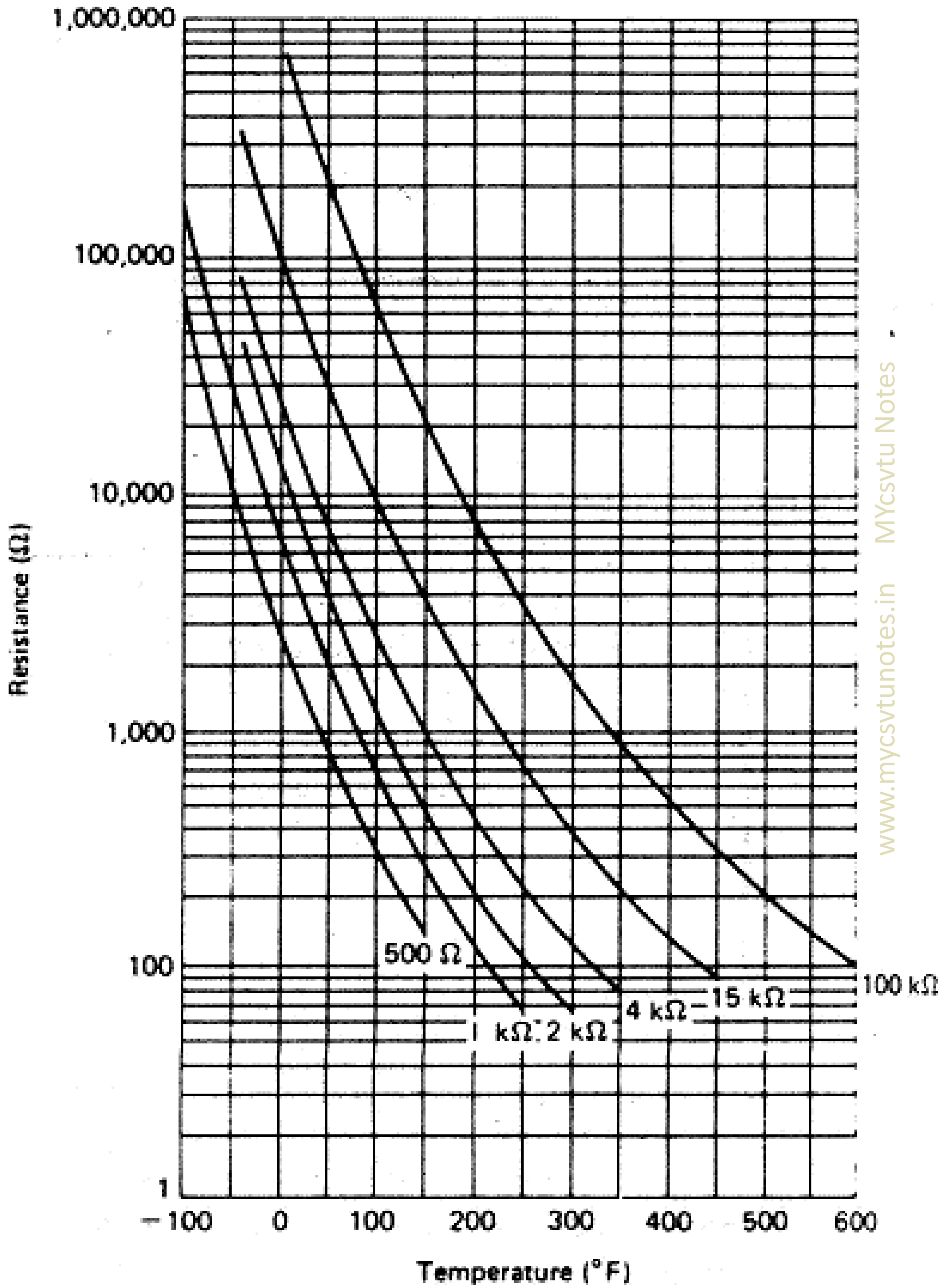
- Both the constants will be defined by manufacturer.

Thermistor: resistance vs temperature



Thermistor resistance versus temperature is highly nonlinear and usually has a negative slope.

Thermistor



1,000,000
100,000
10,000
1,000
100
1
Resistance (Ω)
−100
0
100
200
300
400
500
600
Temperature (°F)
500 Ω
1 kΩ
2 kΩ
4 kΩ
15 kΩ
100 kΩ

Example 6.3:

Circuit in Figure 6.7 is used for temperature measurement. The thermistor is a 4kΩ type identified in Figure 6.6(a). The meter is a 50mA ammeter with a resistance of 3Ω, R_c is set to 17Ω, and the supply voltage V_T=15V. What will the meter readings at 77°F and at 150°F be?

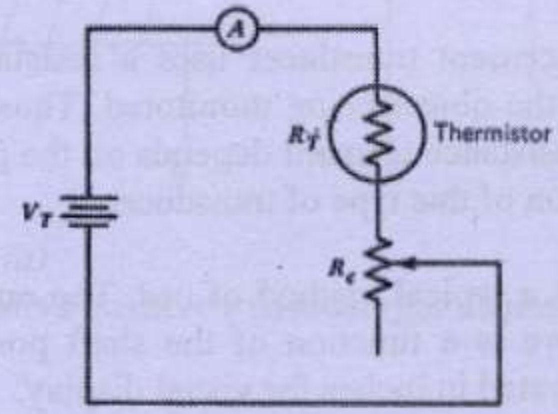


Figure 6.7: Basic thermistor circuit for measuring

Solution:

The graph for 4kΩ thermistor in Figure 6.6(a) shows that its resistance at 77°F is 4kΩ. Therefore the current at 77°F is,

$$I = \frac{V_T}{R_T} = \frac{15V}{4000\Omega + 17\Omega + 3\Omega} = 3.73mA$$

At 150°F, the graph shows the thermistor resistance to be 950Ω. The meter reading at this temperature, therefore, should be,

$$I' = \frac{V_T}{R'_T} = \frac{15V}{950\Omega + 17\Omega + 3\Omega} = 15.5mA$$

Problem-9

- A thermistor has a temperature coefficient of resistance of -0.05 over a temperature range of 25 degree celsius to 50 degree celsius . Determine the resistance of thermistor at 40 degree celsius, if the resistance of the thermistor at 25 degree celsius is 120 Ω.

Inductive transducer

Inductive Transducer

- An Inductive transducer is a device that converts physical motion (position change) into a change in inductance.
- Inductive transducers works on any one of the following principles.
    - Variation of self inductance.
    - Variation of mutual inductance.
    - Production of eddy currents.

Self inductance- variation

- The self inductance of a coil is given by

$$L = \frac{N^2}{l/\mu A} = \frac{N^2 \mu A}{l} = N^2 \mu G$$

N= Number of turns

l = Mean length of the magnetic path.

A = Area of the x-section of the magnetic path.

μ = Permeability of the magnetic materials.

A/l is Geometric form factor G

- Self inductance changes, if any one of the following changes
    - Number of turns.
    - Geometric configuration.
    - Permeability of the magnetic material or magnetic circuits.

Eddy

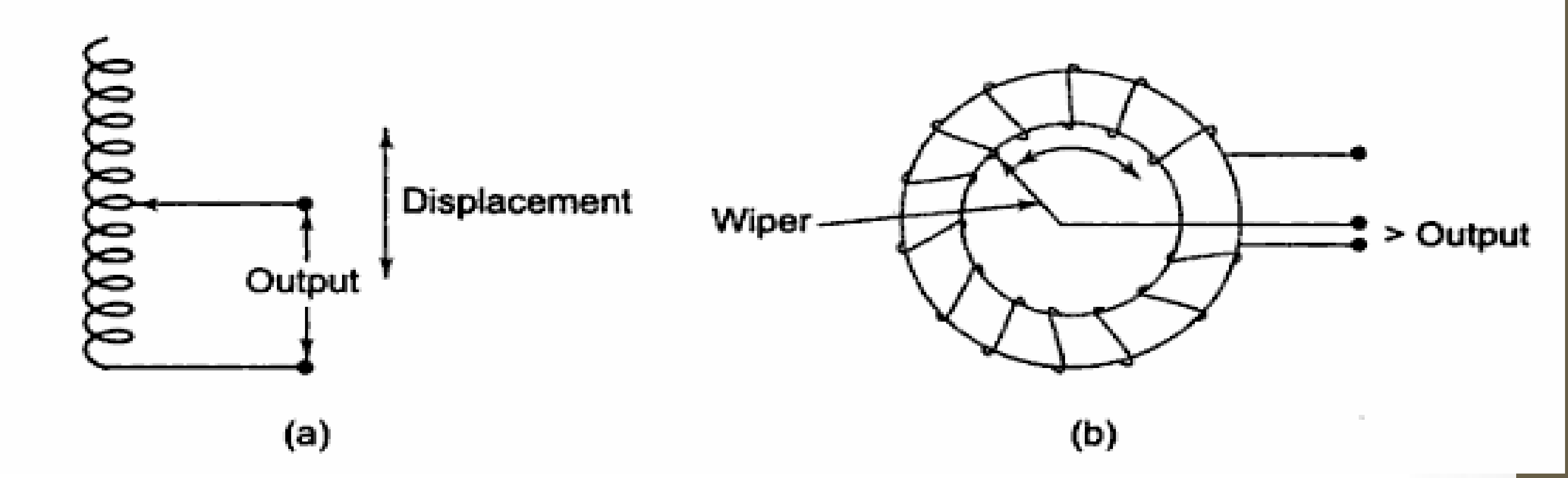
- **Eddy currents** are currents induced in conductors to oppose the change in flux that generated them. It is caused when a conductor is exposed to a changing magnetic field due to relative motion of the field source and conductor; or due to variations of the field with time. This can cause a circulating flow of electrons, or a current, within the body of the conductor
- The energy wasted by eddy currents creating heat in the core, as this does not aid in the induction process is eddy current loss.

Inductive Displacement Transducer (Change in N)

- It converts displacement into change in inductance.
- Its operation is based on change in no. of turns which leads to change in self inductance.
- It can be of air-cored or iron-cored.
- Air-cored coils can be operated at high frequencies, because of absence of eddy current losses in the air cores.
- But change in inductance of air-cored coils will be small because of low permeability of air.

- Iron cored coils produce larger inductance variations.

- L v



Permeability

- In electromagnetism, **permeability** is the measure of the ability of a material to support the formation of a magnetic field within itself.
- Ferrite (nickel zinc--→ $2.0\times10^{-5} - 8.0\times10^{-4}$
- Ferrite (manganese zinc) --→ $>8.0\times10^{-4}$
- Vacuum -----→ 0

Change in μ

- It has a coil wounded on a former (non-conductive tube) and an iron core, to which movable element is attached.

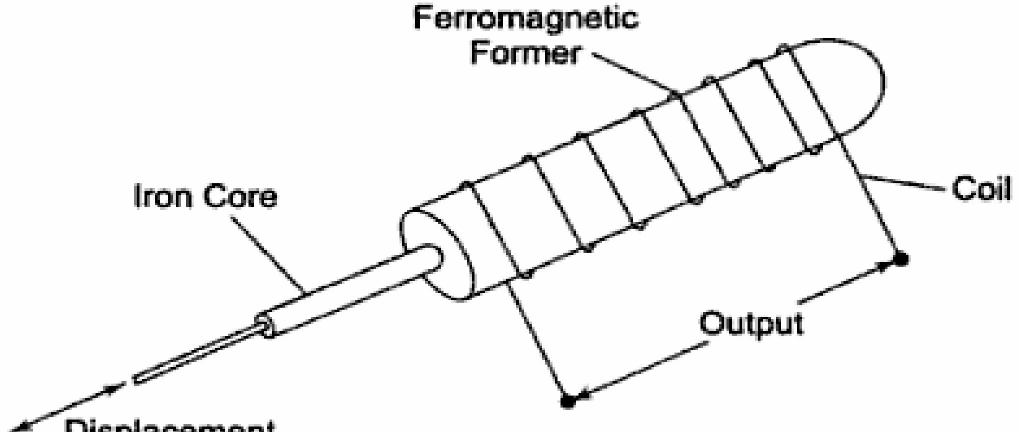


Fig. 13.15 Inductive Transducer Working on the Principle of Variation of Permeability

- When iron core is completely inside the coil, self inductance of the coil is maximum, because permeability is increased.

- When the iron core is moved out of the winding the permeability decreases, So self inductance is reduces.

Pressure inductive transducer

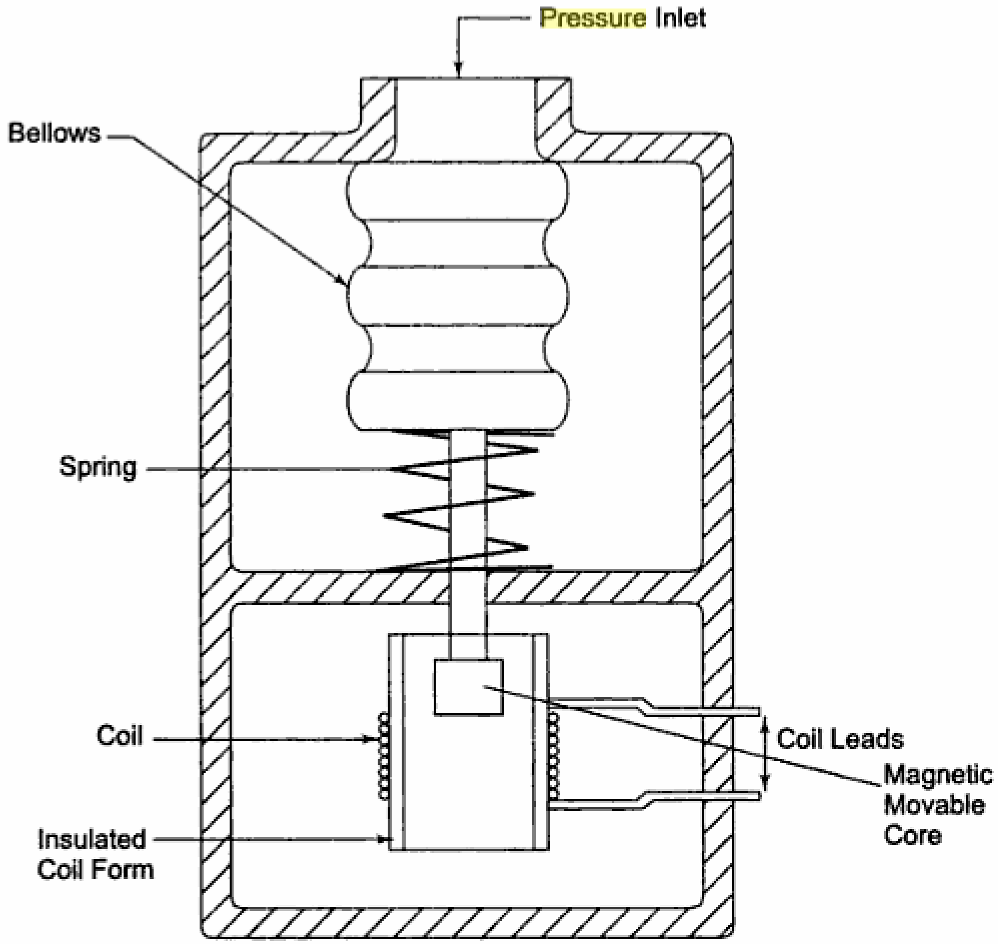


Fig. 13.22 Pressure Inductive Transducer

- Pressure acting on a magnetic core causes an increase in coil inductance corresponding to the acting pressure.
- The change in inductance can again be made on the basis of an electrical signal, using an ac bridge.
- Advantage→ No Moving contact.

What is reluctance?

- A material's resistance to becoming magnetized.
- **Magnetic reluctance**, or **magnetic resistance**, is a concept used in the analysis of magnetic circuits. It is analogous to resistance in an electrical circuit, but rather than dissipating magnetic energy it stores magnetic energy.
- In likeness to the way an electric field causes an electric current to follow the path of least resistance, a magnetic field causes magnetic flux to follow the path of least magnetic reluctance.

Inductive transducer

What is reluctance?

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- The self inductance of the coil is given by,

$$L = \frac{N^2}{R_i + R_g}$$

- N = Number of turns
- R_i = Reluctance of iron parts
- R_g = Reluctance of air gap

- $R_i << R_g$ so , $L= N^2/R_g$

Reluctance of air gap is given by $R_g = l_g/(\mu_0 \times A_g)$

l_g =length of the air gap

A_g = area of the flux path through air

μ_0 = permebility

so,

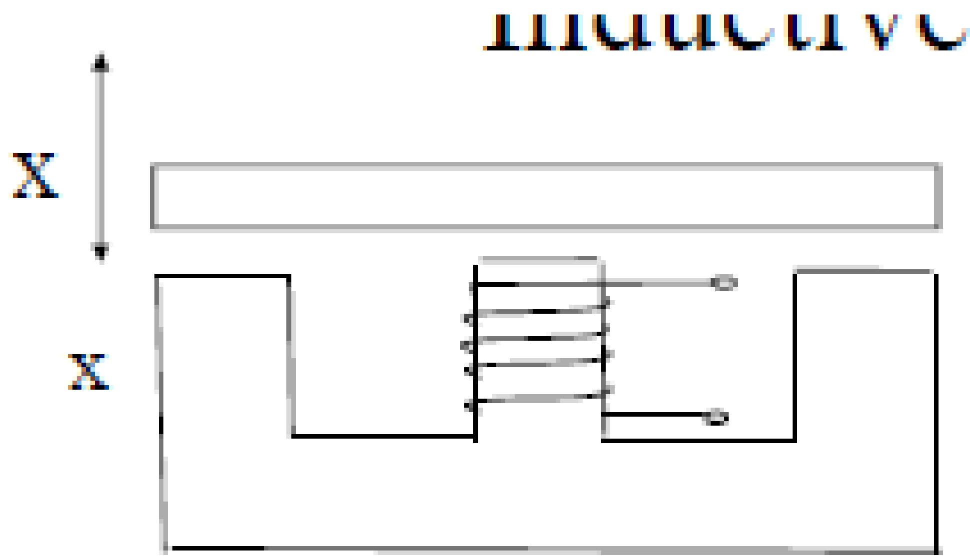
$R_g \propto l_g$ (μ_0 , A_g are constants)

- Whenever target is near the core , the length l_g is small and therefore L is large and viceversa.

$$L \propto 1/l_g \propto \text{Displacement}$$

Variable Reluctance Type Transducer

- It consist of a coil wound on a ferromagnetic core.



- The displacement which is to be measured is applied to a ferromagnetic target.
- The target does not have any physical contact with the core on which it is mounted.
- The reluctance of the magnetic path is determined by the size of the the air gap.

Variable Reluctance Bridge

- It consist of a transformer , E core and an iron bar is pivoted on the centre leg.

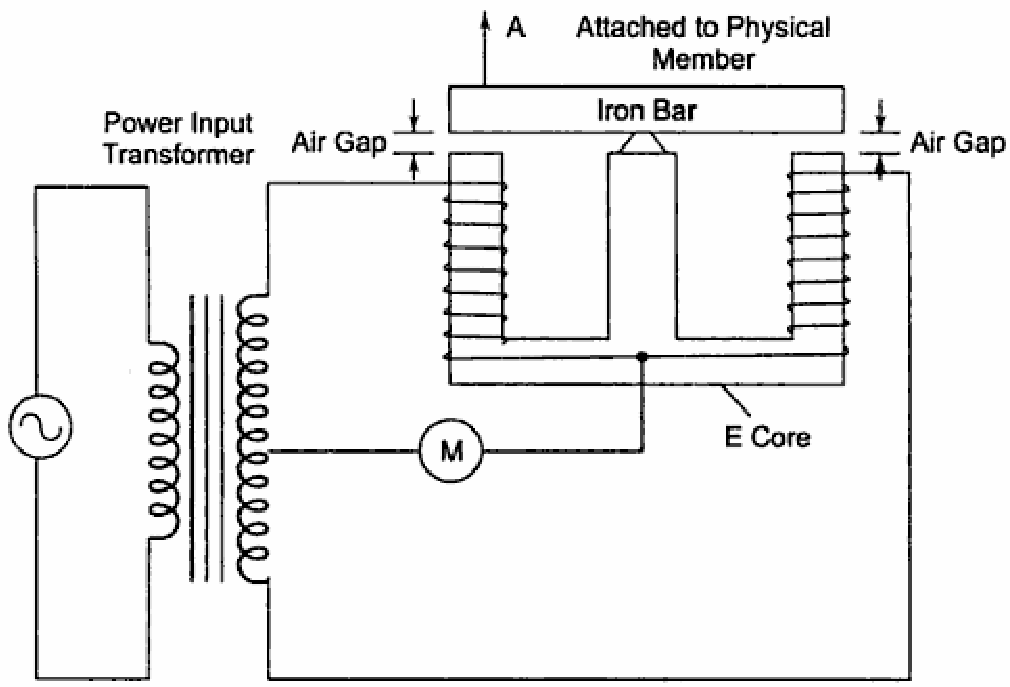


Fig. 13.16(b) Variable Reluctance Bridge Circuit

- The moving member is attached to one enf of the iron bar and causes the bar to wobble back and forth.($l_g$varies).
- Bridge balanced only when inductance of two coils are equal.
- Iron bar at point A moves→ The bridge un balanced→ Amount of L α Displacement

Synchro

- It is angular position transducer.
- Synchro is a group of inductive devices which can be connected in various ways to form shaft angle measurement.
- It is otherwise called as selsyn.
- It may be viewed as a variable coupling transformer.
- It consist of stator and rotor.
- Stator has a 3-phase winding with the windings of the 3-phase displaced by 120^0 .

- Primary winding is a single phase winding wound on a rotor made of laminations.
- It works on the basis of transformer action.
- When an ac excitation voltage is applied, to the rotor, the resultant current produces a magnetic field and by transformer action induces a voltage in stator coils.

Differential output transducer--Need

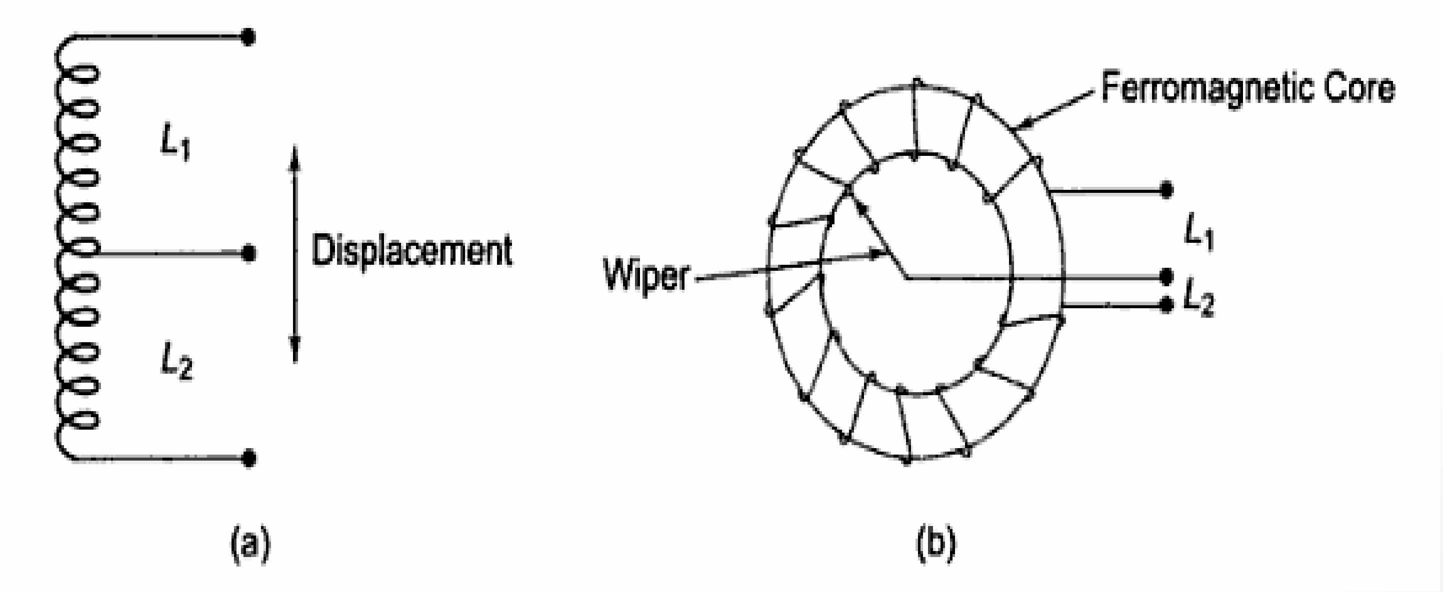
- If instruments are cascaded as stages,
  - In ordinary "'L' change" transducers, every stage will respond only for L+ΔL or M+ ΔM.
  - If the instruments is responding to ΔL or ΔM, rather than L+ΔL or M+ ΔM, then

Differential output transducer--Need

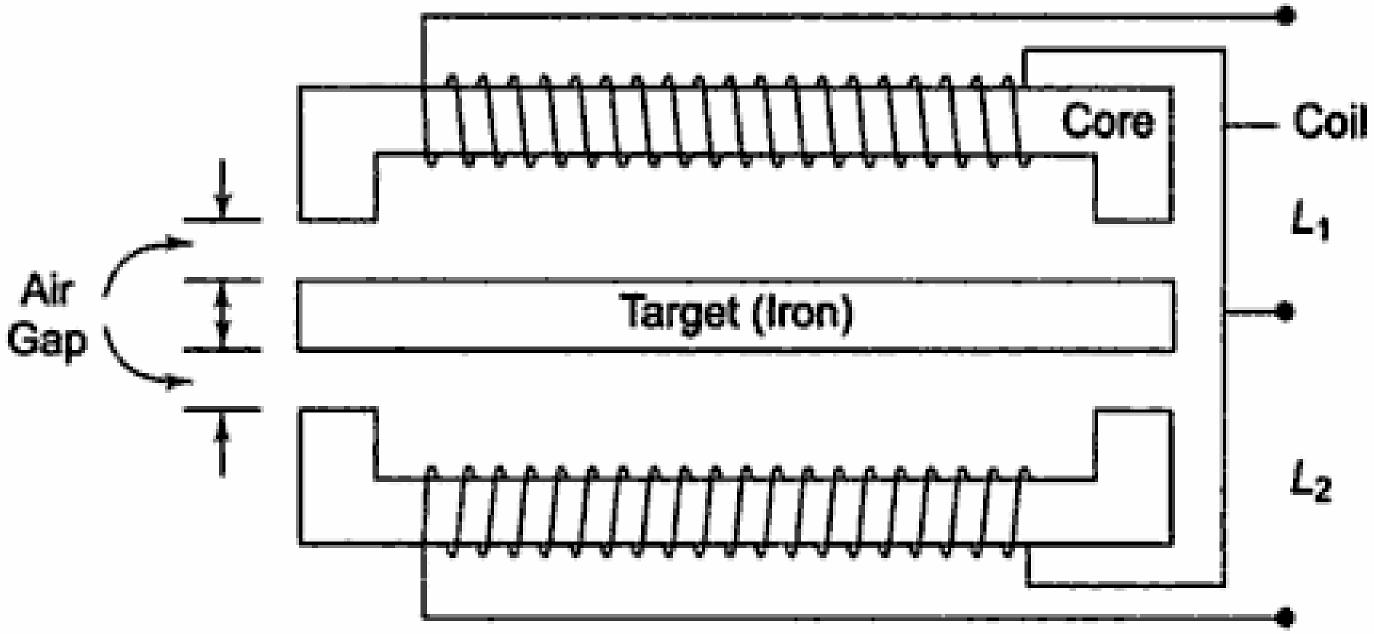
- If instruments are cascaded as stages,
  - In ordinary "'L' change" transducers, every stage will respond only for L+ΔL or M+ ΔM.
  - If the instruments is responding to ΔL or ΔM, rather than L+ΔL or M+ ΔM, then sensitivity and accuracy will be higher.

Differential output transducer

- The succeeding stages of the instrumentation, system measure the difference between two outputs. This is known as differential output.

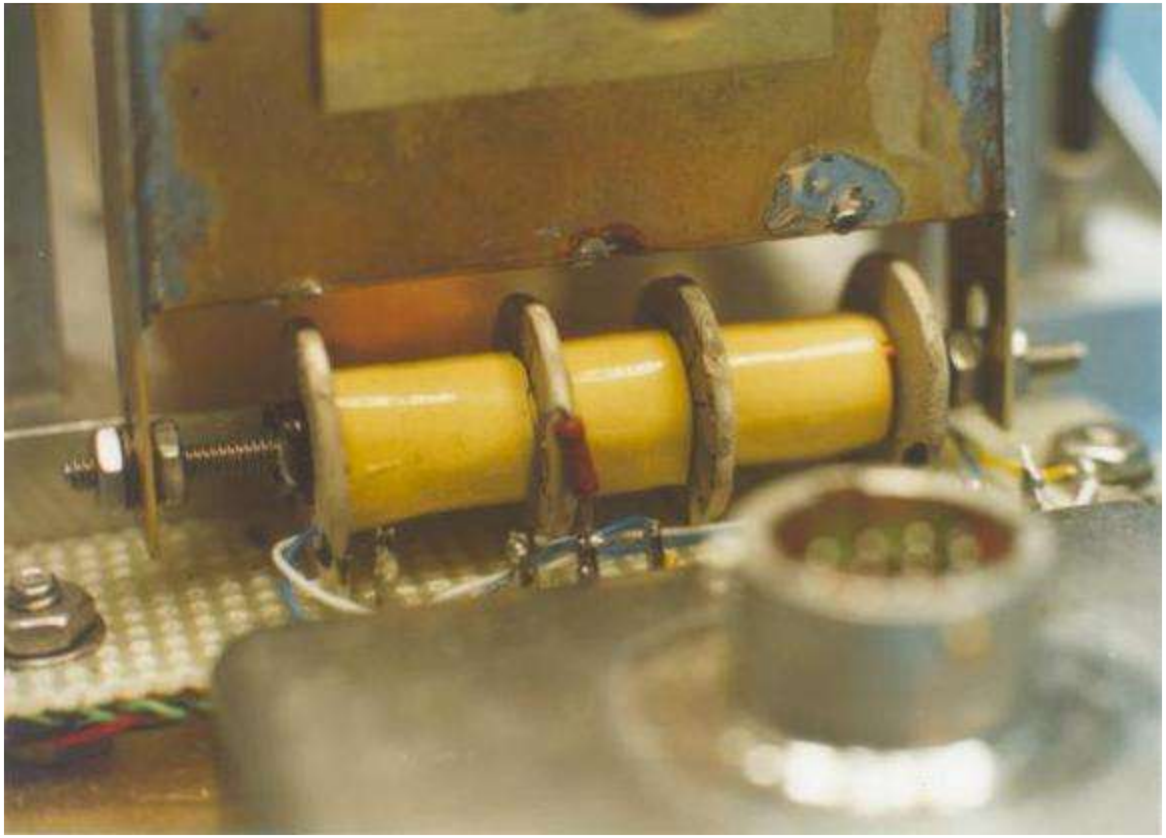


- It consist of a coil which is divided into two parts.
- One part increases from L to L+ΔL , while that of the other part decreases from L to L-ΔL .
- The change is measured as difference of the two.
- Resulting in an output of 2ΔL instead of ΔL . Thus sensitivity increases even for a one winding is used.


Core
Coil
L_1
Air Gap
Target (Iron)
L_2

Linear Variable Differential Transformer

Linear Variable Differential Transformer Displacement Transducer



LVDT used to measure very small displacements in a seismometer that measures movements in the earth's crust due to earthquakes. It consists of a middle primary coil and two outer secondary coil. The magnetic core moves freely without touching bobbins, and at the null (zero) position, it extends halfway into each secondary coil.

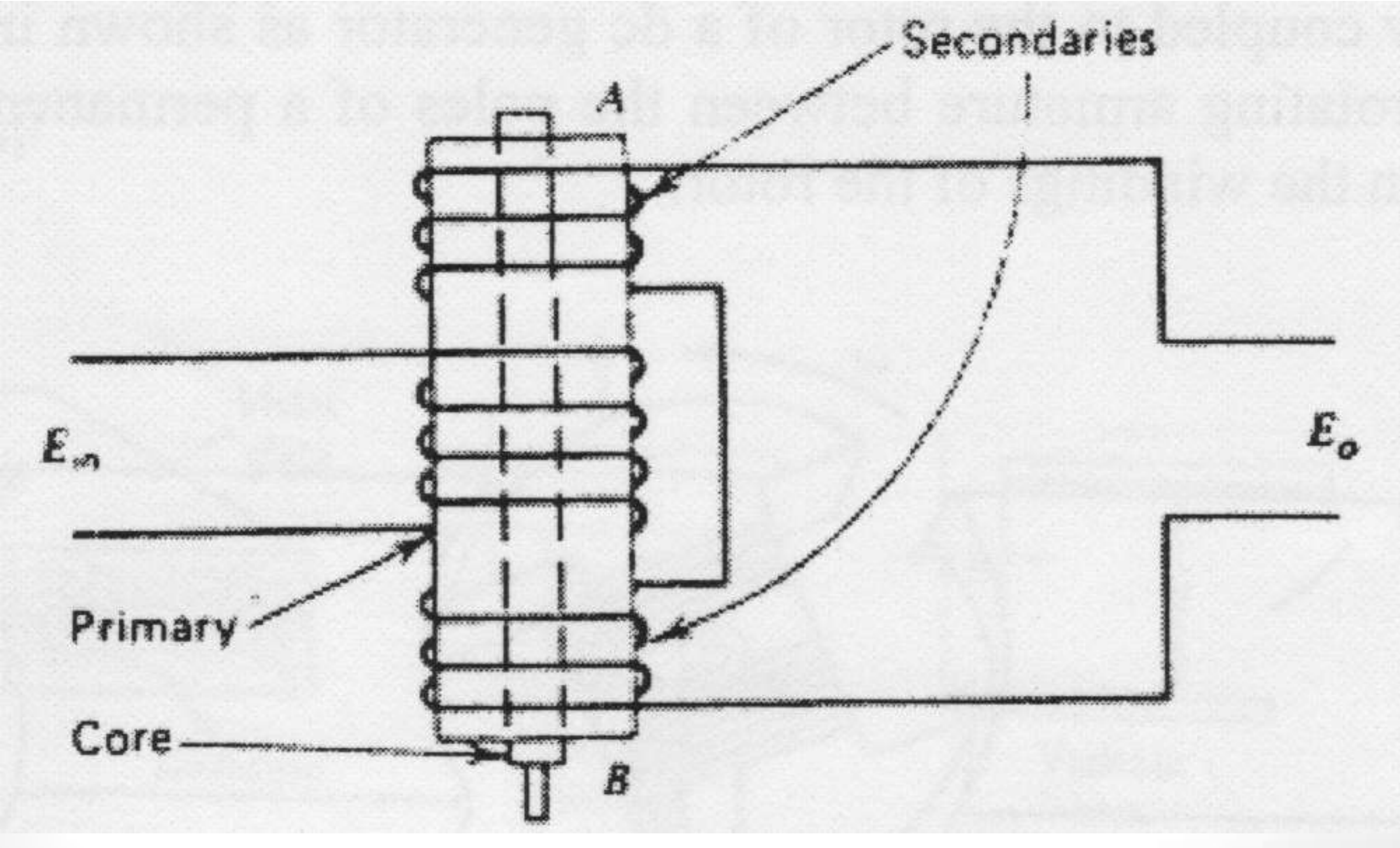
LVDT

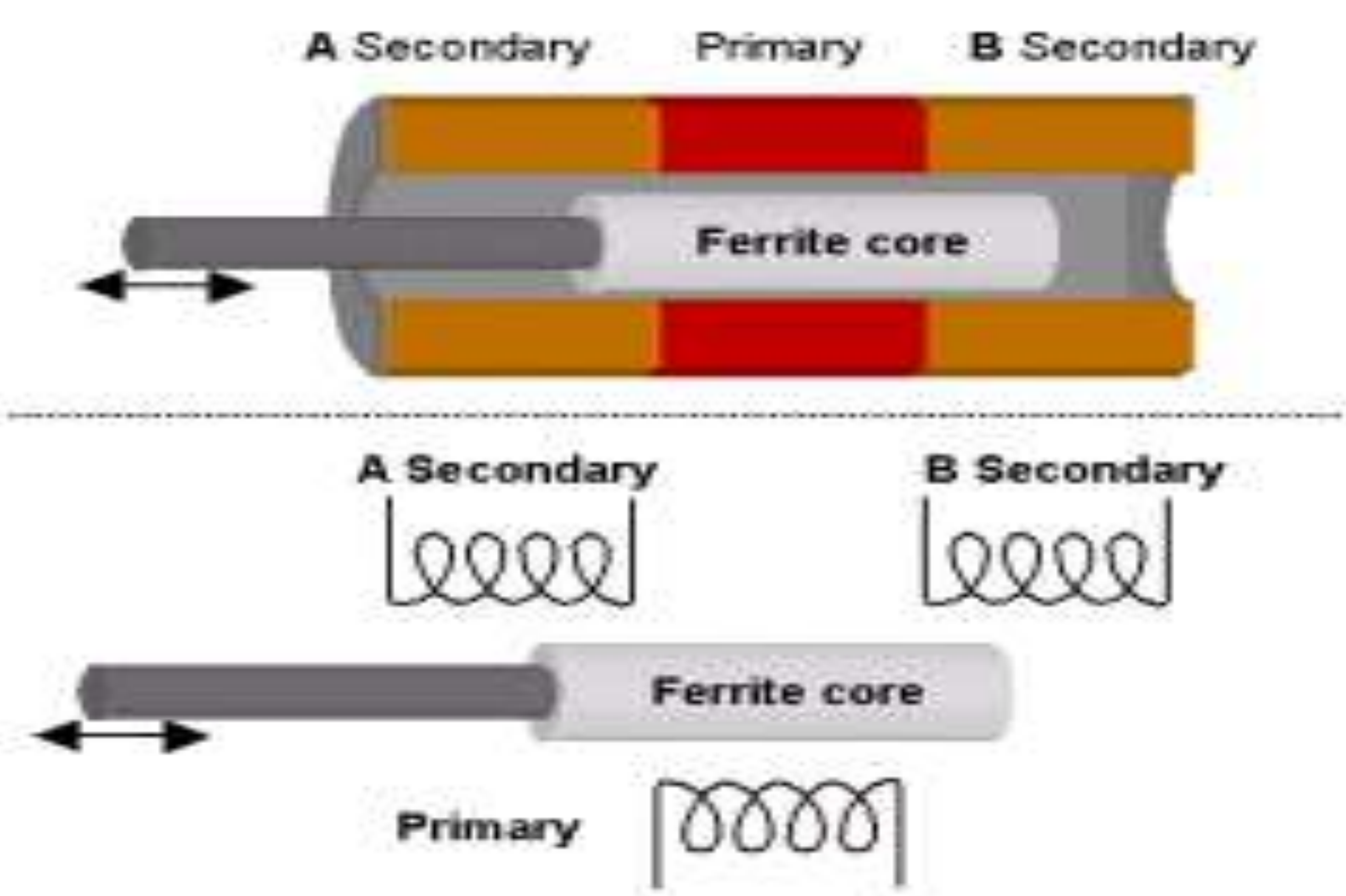
- It is a variable output inductive transducer.
- It is used to measure the displacement.
- Principle: modulation of the excitation signal.

LVDT

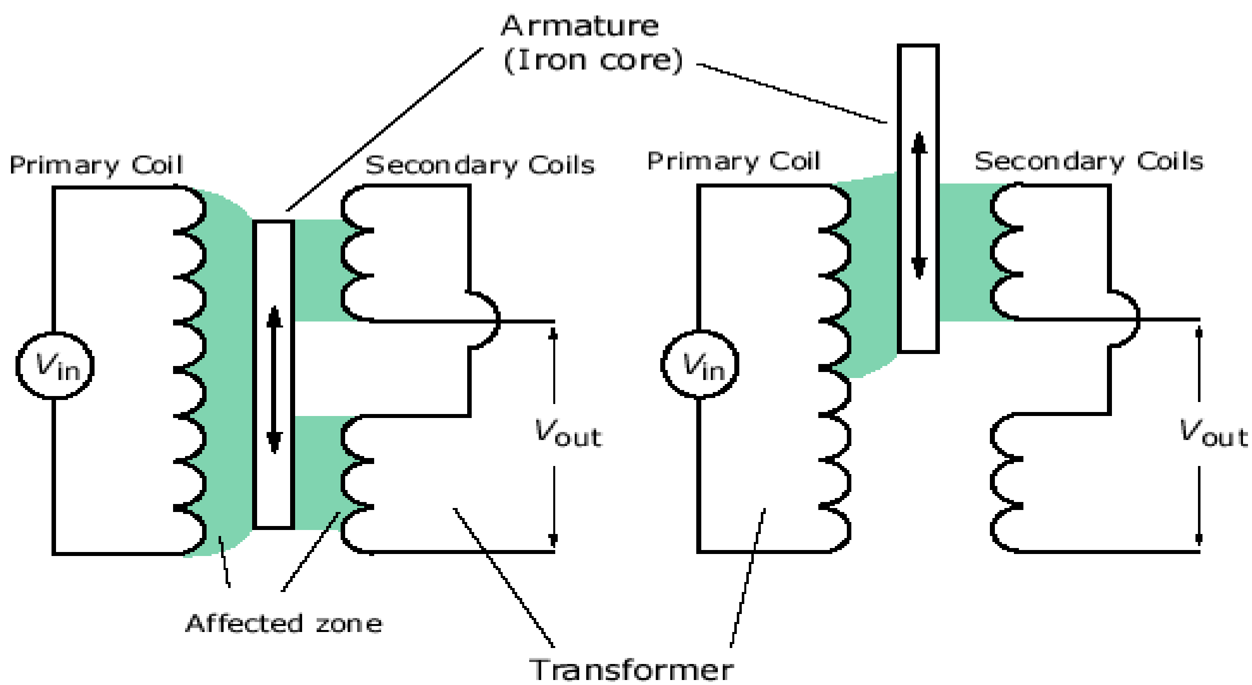
- Consist of a primary winding and two secondary windings, wound over a hollow tube and positioned so that the primary is between two secondary.
- An movable iron core slides within the hollow tube or former.
- IF THE CORE IS ATTACHED TO A MOVING OBJECT, THE LVDT OUTPUT VOLTAGE CAN BE A MEASURE OF THE POSITION OF THE OBJECT.

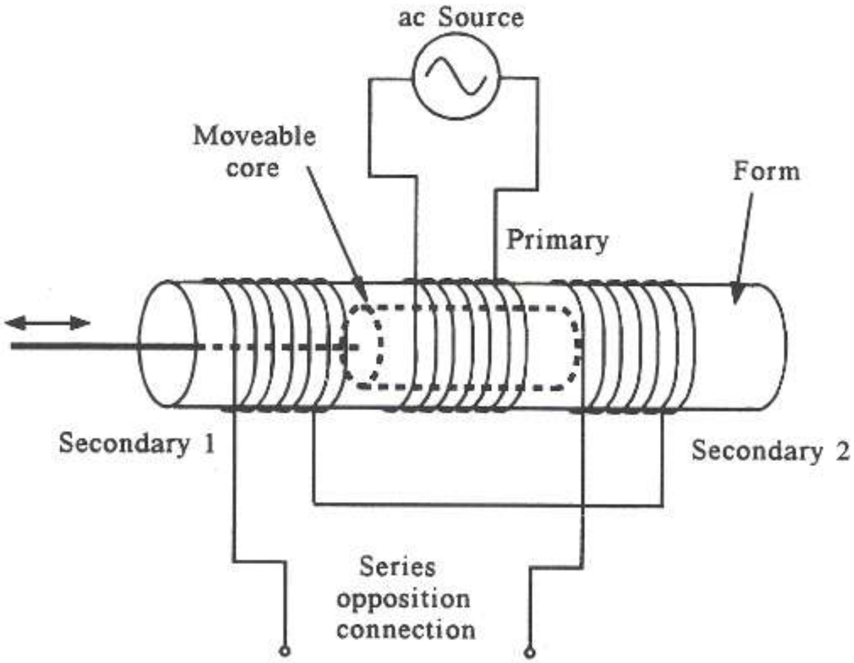
LVDT - construction




A Secondary
Primary
B Secondary
Ferrite core
A Secondary
B Secondary
Ferrite core
Primary

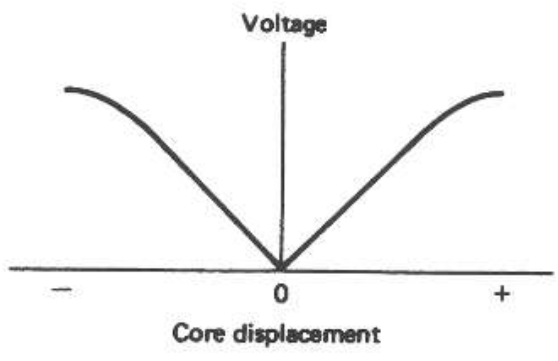
- When the core is in the center, the voltage induced in the two secondaries is equal.
- When the core is moved in one direction from the center, the voltage induced in one winding is increased and that in the others is decreased.
- Movement in the opposite direction reverse the effect.

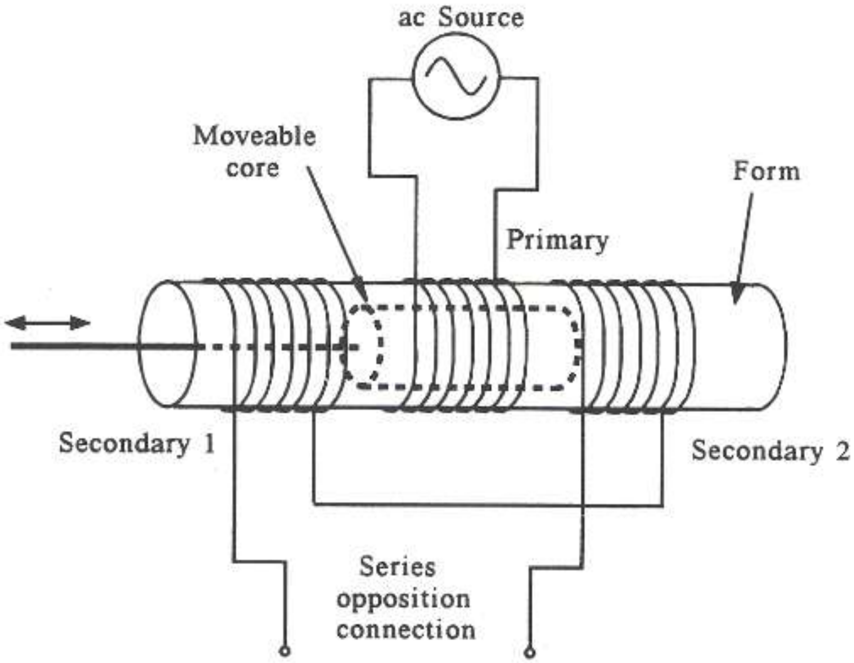

Armature
(Iron core)
Primary Coil
Secondary Coils
V_{in}
V_{out}
Primary Coil
Secondary Coils
V_{in}
V_{out}
Affected zone
Transformer



The LVDT has a movable core with the three coils as shown.

The LVDT secondary voltage amplitude for a series-opposition connection varies linearly with displacement.





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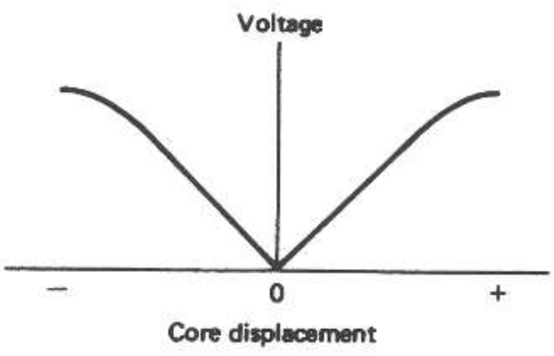
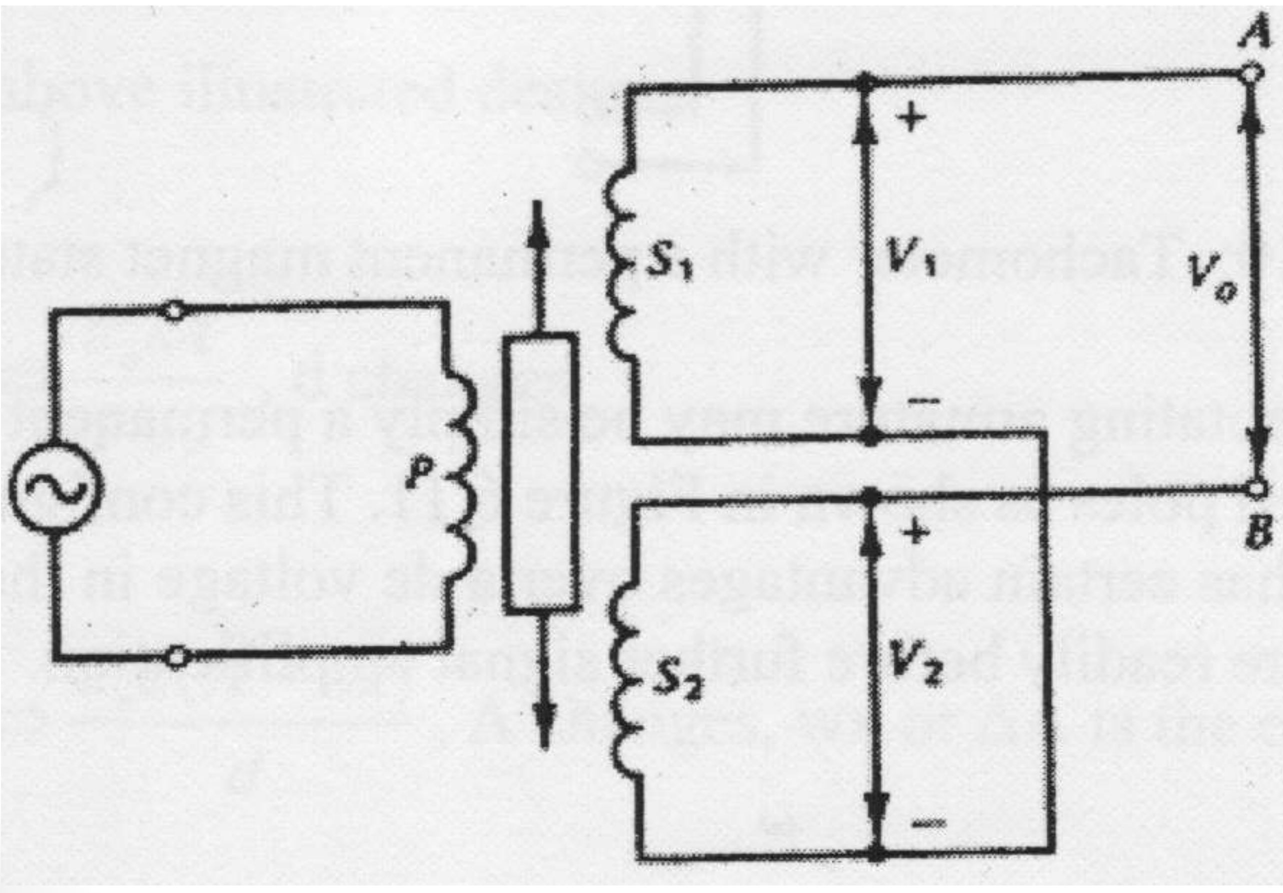
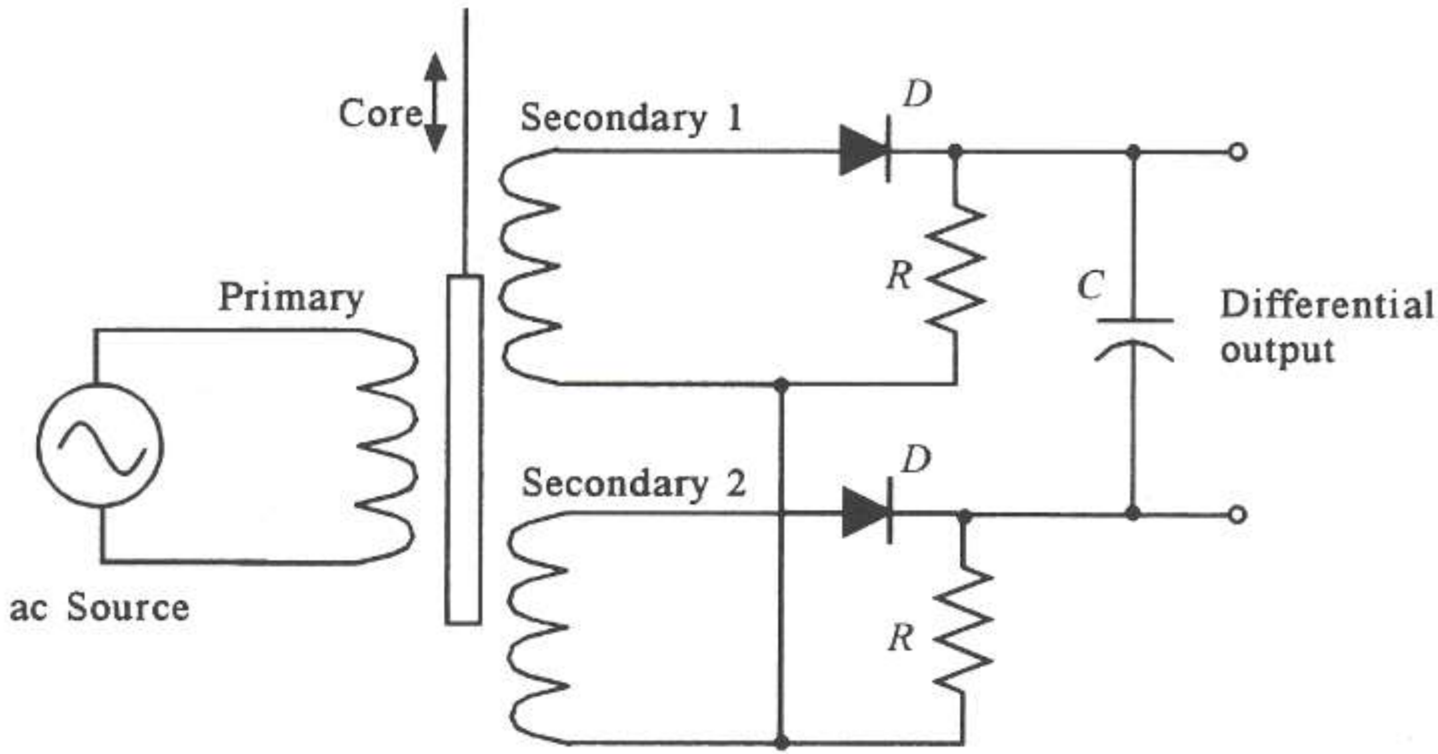


LVDT – schematic diagram





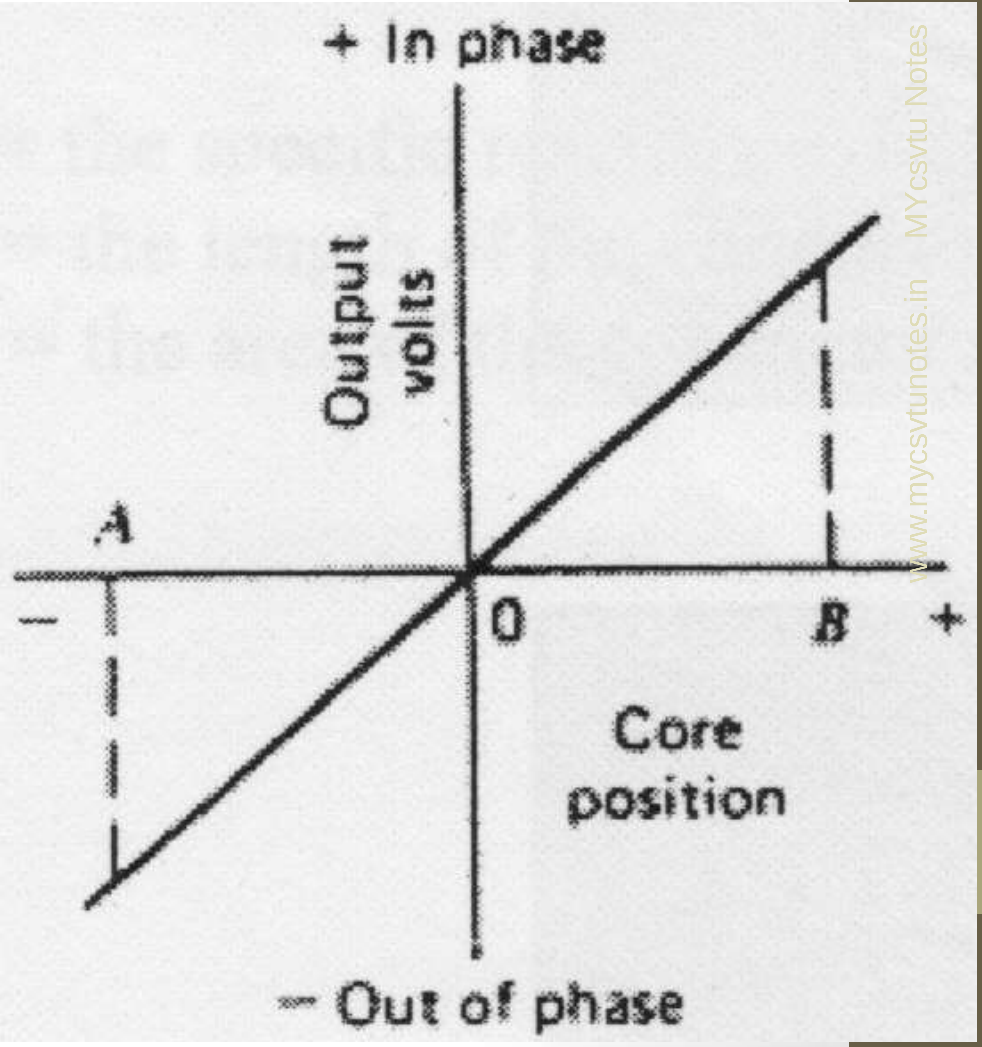
This simple circuit produces a bipolar dc voltage that varies with core displacement.

LVDT – operation

Core at the center

$V_1 = V_2$

$Vo = 0$



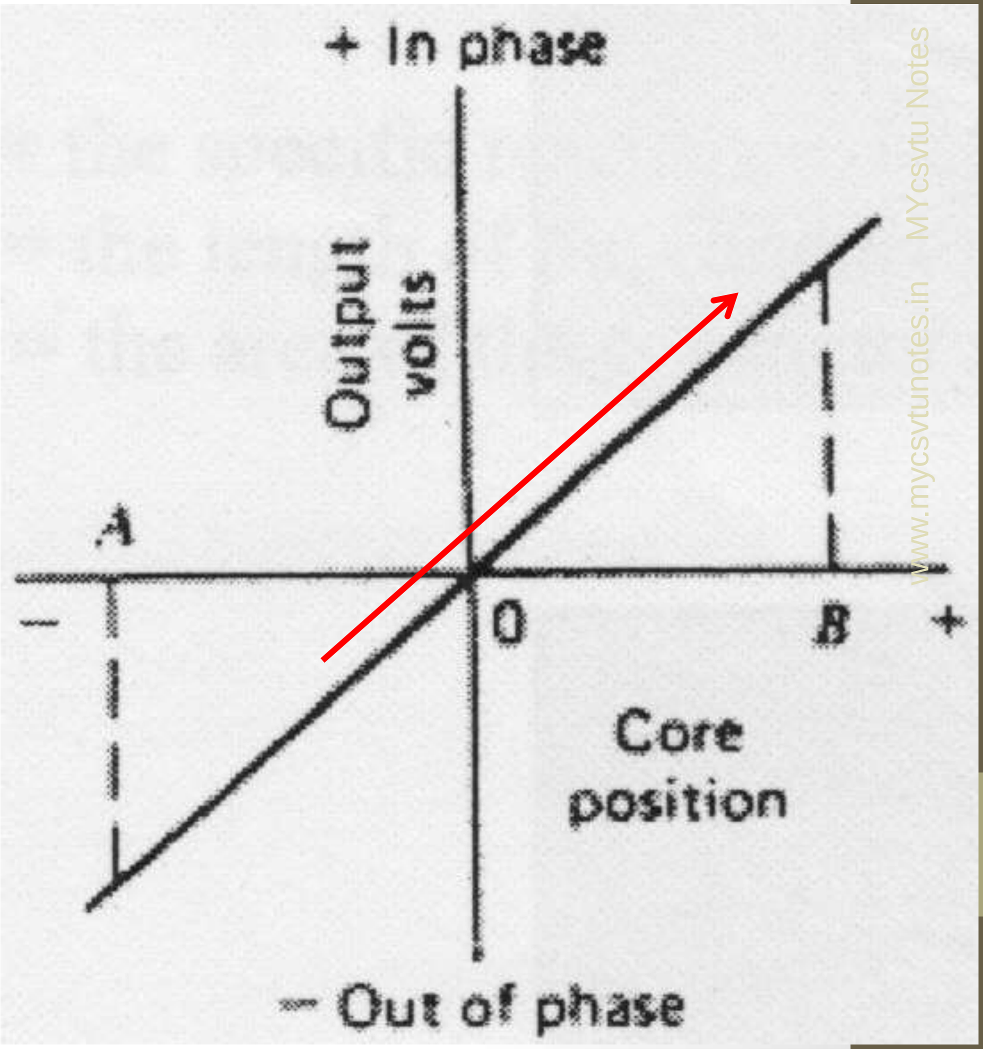
LVDT – operation

Core moves towards S_1

$V_1 > V_2$

Vo increase(in-phase

with V_1).



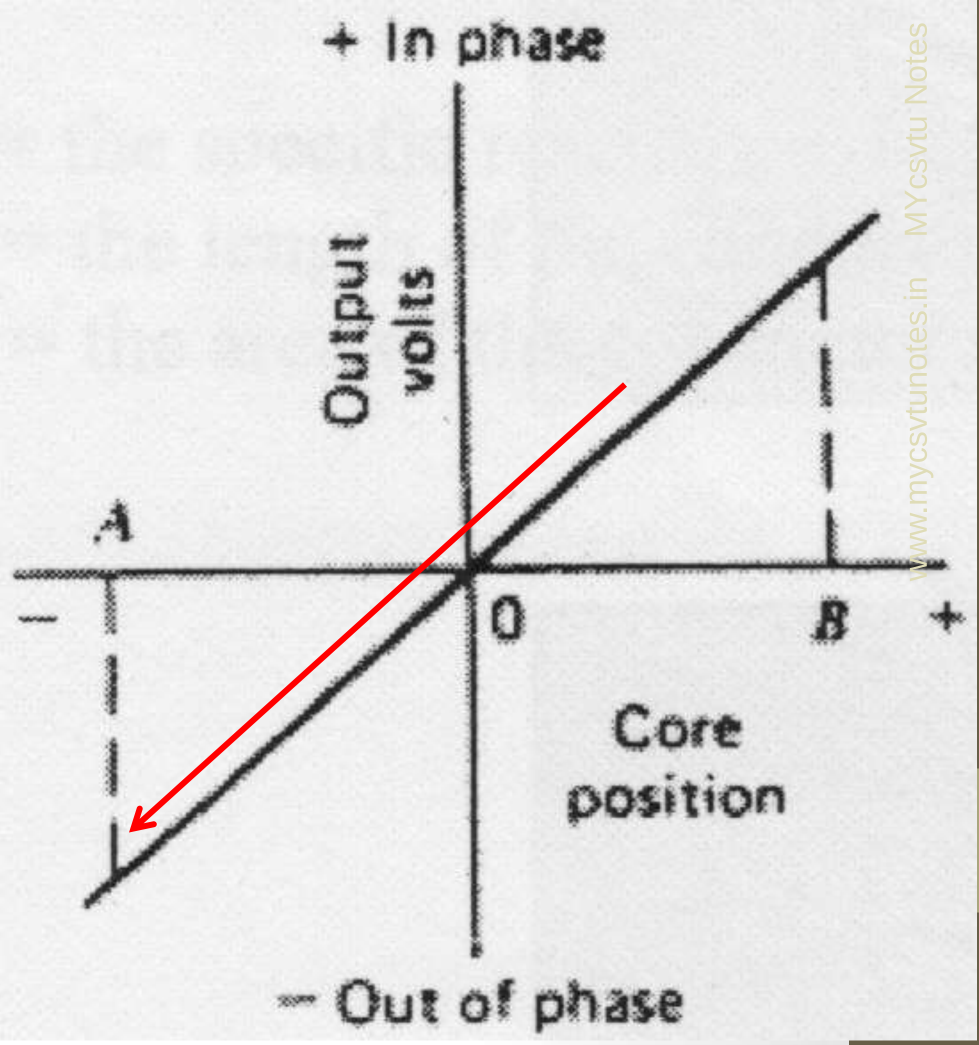
LVDT – operation

Core moves towards S_2

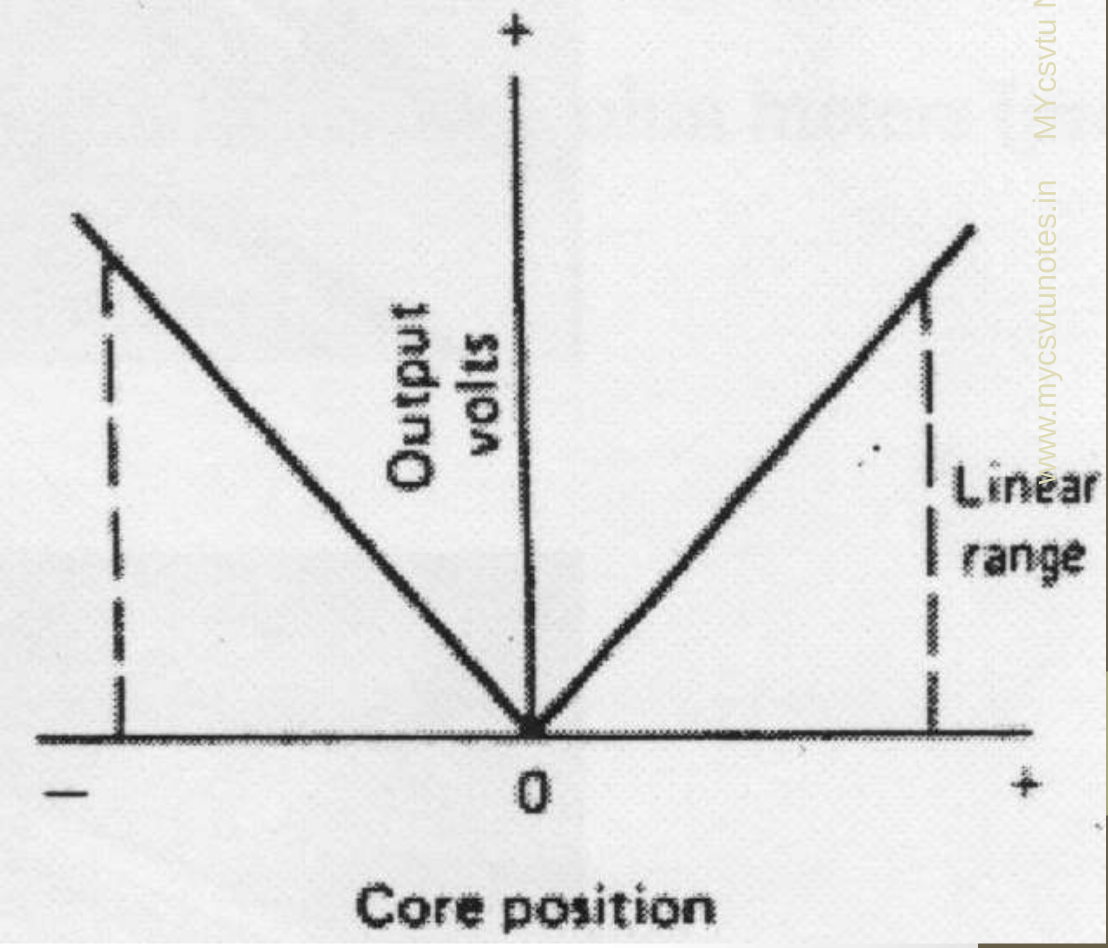
$V_2 > V_1$

Vo decrease(in-phase

with V_2)



LVDT – with absolute magnitude



O/P voltage

- V0 α Movement of core α Displacement

- Amplitude → Motion
- Polarity or phase→ Direction of motion.

EXAMPLE An LVDT has a maximum core motion of ±1.5 cm with a linearity of ±0.3% over that range. The transfer function is 23.8 mV/mm. If used to track work-piece motion from −1.2 to +1.4 cm, what is the expected output voltage? What is the uncertainty in position determination due to nonlinearity?

EXAMPLE An LVDT has a maximum core motion of ±1.5 cm with a linearity of ±0.3% over that range. The transfer function is 23.8 mV/mm. If used to track work-piece motion from −1.2 to +1.4 cm, what is the expected output voltage? What is the uncertainty in position determination due to nonlinearity?

Solution

Using the known transfer function, the output voltages can easily be found,

$$V(-1.2\,\text{cm}) = (23.8\,\text{mV/mm})(-12\,\text{mm}) = -285.6\,\text{mV}$$

and

$$V(1.4\,\text{cm}) = (23.8\,\text{mV/mm})(14\,\text{mm}) = 333\,\text{mV}$$

The linearity deviation shows up in deviations of the transfer function. Thus, the transfer function has an uncertainty of

$$(\pm 0.003)(23.8\,\text{mV/mm}) = \pm 0.0714\,\text{mV/mm}$$

This means that a measured voltage, V_m (in mV), could be interpreted as a displacement that ranges from $V_m/23.73$ to $V_m/23.87$ mm, which is approximately ±0.3%, as expected. Thus, if the sensor output was 333 mV, which is nominally 1.4 cm, the actual core position could range from 1.40329 to 1.39506 cm.

- An LVDT has the following data.

I/P =6.3 V, O/P= 5.2 V, range+ or – 0.5 inches. Determine

i) Calculate the o/p voltage v_s core position for a core movement from + 0.45 in. to -30 in.

ii) The o/p voltage when the core is -0.25 in. from the centre.

- An LVDT has the following data.

I/P =12 V, O/P= 10.4 V, range+ or – 1 cm. Determine

i) Calculate the o/p voltage v_s core position for a core movement from + 0.9 cm to -0.6 cm

Capacitive transducers

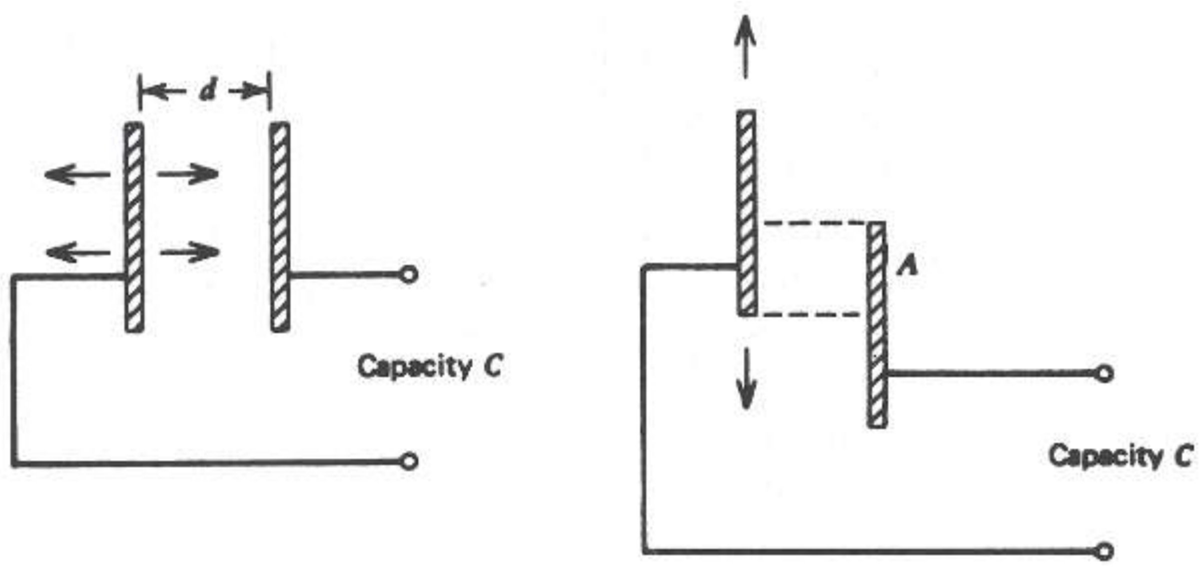
- The capacitance of a parallel-plate capacitor is given by

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

ε = dielectric constant
ε_o = 8.854 x 10^{-12}, in farad per meter
A = the area of the plate, in square meter
d = the plate spacing in meters

- Capacitance of the capacitive transducer can be varied by,
  - Varying effective area of the plates
  - Varying distance between the plates
  - Varying permitivity of the dielectric material between the plates.

Capacitive transducers –Varying area



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

$$c = \frac{\varepsilon_0 \varepsilon_r b l}{d} \ farads$$

Angular displacement

$$c = \frac{\varepsilon_0 \varepsilon_r r2}{2d}\theta$$

$$s = \frac{\partial c}{\partial \theta} = \frac{\varepsilon 0 \varepsilon r r2}{2d}$$

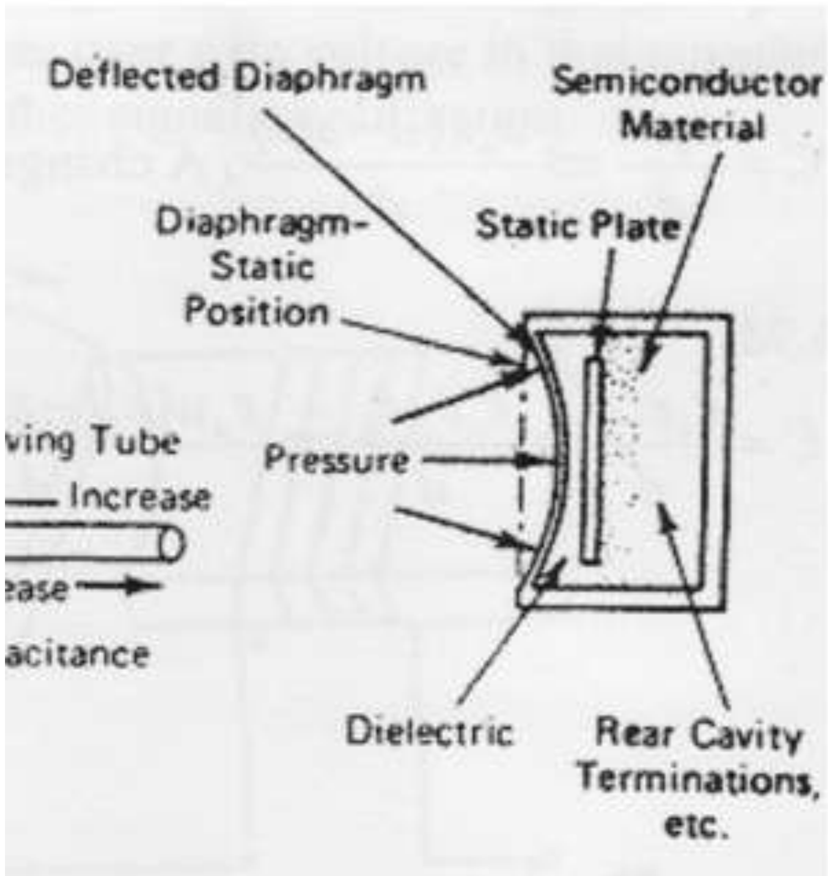
r = radius of the movable plate
d = distance between two plates
Θ = angular displacement

$$s = \frac{\partial c}{\partial \theta} = \frac{\varepsilon 0 \varepsilon r r2}{2d}$$

s = Sensitivity

By varying distance

- It consist of one fixed plate and one movable plate.
- As the moving plate moves away from or towards the fixed plate as per displacement under measurement, the capacitance decreases or increases.


Deflected Diaphragm
Semiconductor Material
Diaphragm-Static Position
Static Plate
Pressure
Increase
Dielectric
Rear Cavity Terminations, etc.

Rotational displacement

- As rotor rotates in anti clockwise direction, C increases.
- Torque can also be measured.

By varying Dielectric

- In this arrangement, a dielectric material of relative permittivity, ϵ_r moves between the two fixed parallel plates, according to displacement.

Problem

- A capacitance transducer uses two quartz diaphragms of area $600mm^2$ separated by a distance of 2.5 mm. A pressure of 8×10^5 N/m^2, when applied to the top diaphragm, causes a deflection of 0.5mm. The capacitance is 400×10^{-12} F when no pressure is applied to the diaphragms. Determine the value of capacitance after the applications of a pressure of 8×10^5 N/m^2

Frequency generating Transducer

- It measure physical variable in terms of a pulse repetition rate. Since frequency is a anolog quantity these can be treated as either anolog or digital devices.

Piezo electrical transducers

Piezo electric effect

- A symmetrical crystalline materials such as quartz, rochelle salt and barrium titanate produce an emf, when they are placed under stress. This is called piezo electric effect and such materials are piezo electric materials.
- Piezo electric effect is possible only in crystals having assymmetrical charge distribution.

Piezo electrical transducers

- When a pressure is applied on the crystal, lattice deformation occurs only due to relative displacement of +ve and –ve charges within the lattice.
- This displacement of the internal charges produces equal external charges of opposite polarity on the opposite sides of the crystal and the external charges can be measured by potential difference between electrodes fitted.

- When a pressure is removed, it returns to its original shape and losses its electric charge.
- The output voltage is affected by temperature of the crystal also.
- Charge coupling coefficient,

$$K = \frac{\text{Mechanical energy converted into electrical energy}}{\text{Applied Mechanical energy}}$$

Hall effect Transducer

Hall effect

- When a conductor is kept perpendicular to the magnetic field and a direct current is passed through it, results in an electric field perpendicular to the direction of both magnetic field and current.

- The generated electric field's magnitude is proportional to the magnetic field strength and current. This is called Hall effect.

- The voltage generated is very small to detect in other materials. But some semiconductors like germanium, this voltage is enough for measurement.

$$V_H = \frac{K_H I B}{t} volts$$

- I-> current through the slab in amperes.
- B-> Flux density of the magnetic field in wb/m^2
- t->Thickness of slab in metre.
- K_H ->Hall effect coefficient inversely proportional to current density in the solid.

Hall effect Transducer

- Hall effect element is located in the gap, adjacent to permanent magnet.
- Field strength produced in the gap, due to permanent magnet is changed by changing position of the ferromagnetic plate.

- VH α Field strength of gap α Ferromagnetic plate position α Displacement

Photo Electric Transducer

Types

- Photo emissive

  radiation falling on a cathode causes electrons to be emitted from the cathode surface.
- Photo conductive

  the resistance of a material is changed when it is illuminated.
- Photo Voltaic

  generate an output voltage proportional to the radiation intensity.

- **Photovoltaic**
  - light falling on a *pn*-junction can be used to generate electricity from light energy
    (as in a solar cell)
  - small devices used as sensors are called **photodiodes**
  - fast acting, but the voltage produced is *not* linearly relatec light intensity

- **Photoconductive**
  - such devices do not produce electricity, but simply change their resistance
  - photodiode can be used in this way to produce a linear device
  - phototransistors act like photodiodes but with greater sensitivity
  - light-dependent resistors (LDRs) are slow, but respond like the human eye

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Photo diode

- A reverse biased semi-conductor diode passes only a small leakage current.
- If the diode junction is exposed to the light , the current rises almost in direct proportion to the light intensity.
- Reverse bias→ photo conductive
- Forward bias→ photo voltaic

Photo transistor

- Photo transistor can be constructed by adding a junction on photo diode.
- Some photo transistors can respond to both incident light and base current.
- It is not as linear as ordinary junction transistor.
- It is much more sensitive(50 to 100 times) than photo diodes.

Frequency generating Transducer

- It measure physical variable in terms of a pulse repetition rate. Since frequency is a analog quantity these can be treated as either analog or digital devices.
- It produce a series of voltage or current pulses or cycles in proportion to the change in the physical parameter being measured.
- E.g. Variable reluctance pulse pick-up,

  photo-tubes

Reluctance pulse pick-ups

Principle: If the field of any magnet is varied momentarily by the motion of an external magnetic body near it, a voltage pulse is generated at the coil of the magnet(reluctance change)

- A voltage pulse is produced every time a tooth enters or leaves the area of the pick-up coil.

- Frequency of pulse α Speed of the gear

VELOCITY MEASUREMENTS

- Velocity = Distance /Time

- If the distance travelled is small, linear velocity measurement can be made by direct method.

- If the distance travelled is large, linear velocity measurement can be made by converting linear motion into an angular motion for long distance.

Linear velocity- Moving coil Pickup

- When the flux linking in the coil changes, an emf is induced .
- The magnitude of the induced emf is proportional to the component of the velocity in a direction perpendicular to the direction of magnetic field.

$$e = Blv \sin\theta$$

- B→ Magnetic flux density
- l→ Length of the coil
- θ→ angle coil movement with the direction of the magnetic field.

Measurement of angular velocity

- There are many methods to measure angular velocity, few are listed below;

- Eddy current Tachometer
- DC Generator Tachometer
- AC Generator Tachometer
- Drag cup rotor AC generator Tachometer
- Toothed Rotor or variable reluctance Tachometer
- Photo-electric pickup Tachometer

DC Generator Tachometer

- It is ordinary mini DC generator consists of a small armature rotating in a constant magnetic field.
- Magnetic field is created by a PM mounted on a stator or by separately excited EM on the stator.
- Armature is coupled with the device whose speed is to be measured.
- Emf generated α Speed of rotation
- Polarity of emf = Direction of rotation

AC Tachogenerator

- Magnetic field is produced by PM or EM mounted on the rotor.
- Rotor is coupled mechanically to the shaft of the test machine.
- The coil is wounded on the stator.
- The rotation of a magnet induces an AC voltage in the coil.
- Amplitude & Frequency of the AC voltage

  α rotational speed