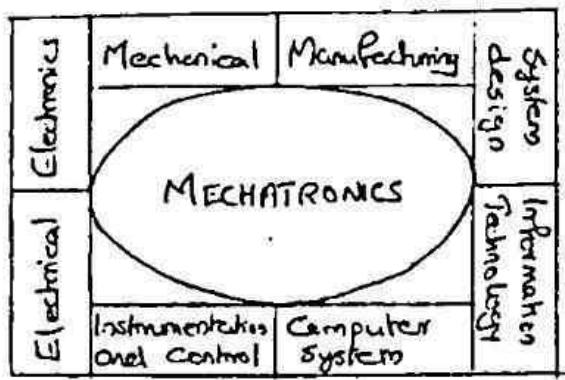


MODULE - 1

- Introduction to mechatronics: Structure of mechatronics system
- Sensors: Characteristics - Temperature, Flow, pressure Sensors
- Displacement, position and proximity sensing by magnetic, optical, ultrasonic, inductive, capacitive and eddy current methods.
- Encoders: Incremental and absolute, gray coded encoder
- Resolvers and synchros. Piezoelectric Sensors
- Acoustic emission Sensors
- Principle and types of Vibration Sensors.

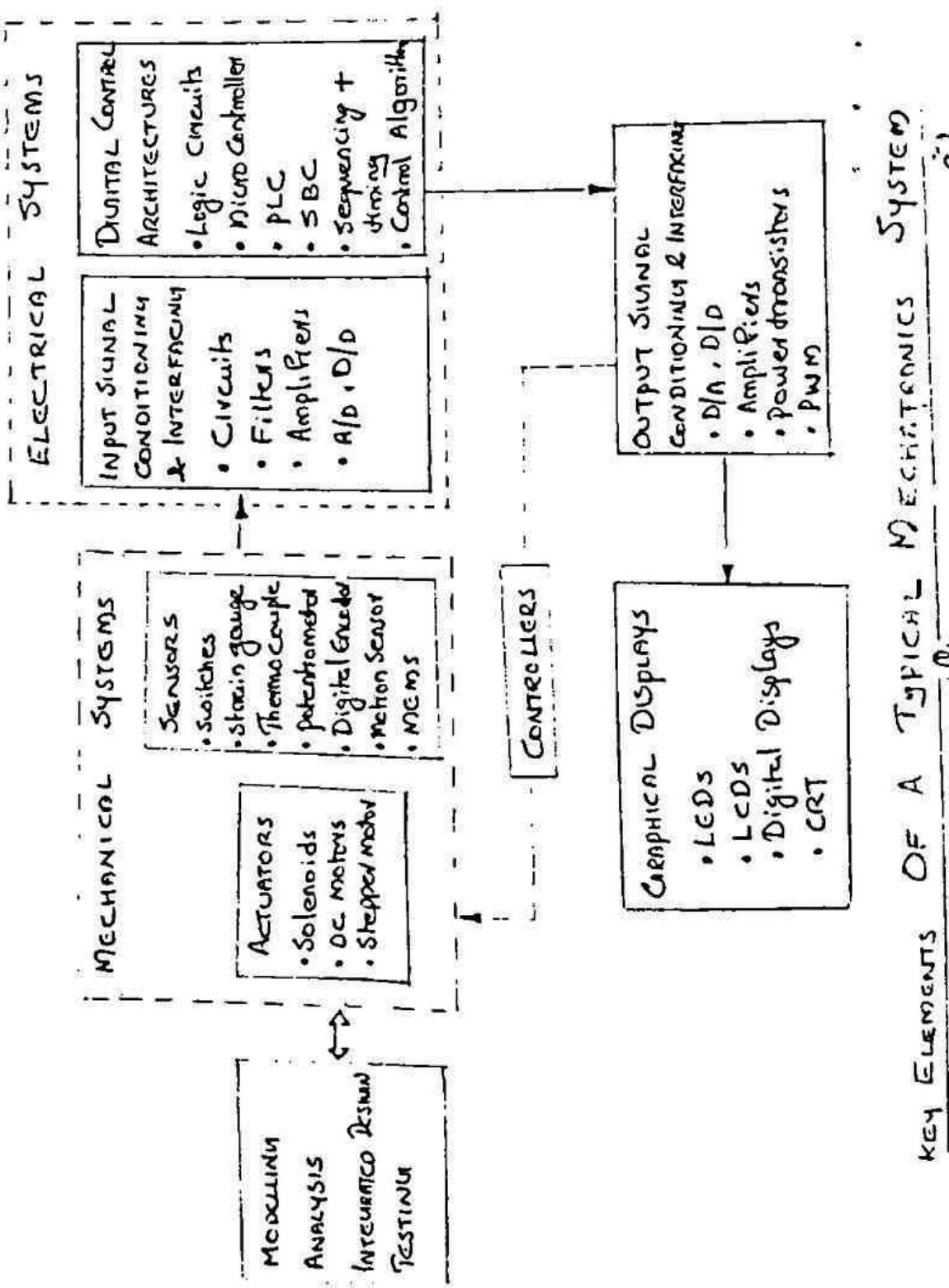
INTRODUCTION

- ⇒ The term mechatronics was invented by a Japanese engineer in 1969, as a combination of 'mecha' from mechanisms and 'tronics' from electronics.
- ⇒ Mechatronic products have many mechanical functions replaced with electronic ones resulting in a much greater flexibility, easy redesign and reprogramming, and the ability to carry out automated data collection and reporting.
- ⇒ Adopted in the design of cars, robots, machine tools, washing machines, cameras etc.
- ⇒ The word mechatronics describes a philosophy in which there is a co-ordinated and concurrently developed integration of mechanical engineering with electronics and intelligent computer control in the design and manufacture of products and processes.



CONSTITUENTS OF MECHATRONICS

ELEMENTS OF MECHATRONICS SYSTEM



- ⇒ A typical mechatronics system consists of mechanical systems, electrical systems and information technology.
- ⇒ The key elements of mechatronics systems can be classified under following categories.
 - ↳ Information Systems
 - ↳ Mechanical Systems
 - ↳ Electrical Systems
 - ↳ Computer Systems
 - ↳ Sensors and actuators
 - ↳ Real time interfacing.

- ⇒ The actuators and sensors form a mechanical system
- ⇒ The actuators produce motions or cause some action whereas the sensors detect the state of the system parameters, inputs and outputs.
- ⇒ The input signal conditioning and interfacing systems provide connections between the control circuits and input/output devices.
- ⇒ Overall control of the system is carried out by digital controls
- ⇒ The graphical display devices provide visual feedback to the user.

LEVELS OF MECHATRONICS SYSTEMS

- 2) Stand-alone systems
eg:- washing machine, auto focus camera
- 3) Systems with high level of distributed sensor - microcontroller - actuator relationships
eg:- Unmanned aircraft
- 2) A large factory system which links a number of major subsystems like machining centres, automated inspection stations
- 2) A system that incorporates artificial intelligence
eg:- Humanoid robot.

SENSORS

- ⇒ Sensor is an element which produces a signal relating to the quantity being measured.
- ⇒ The term transducer is often used in place of the term sensor. Transducers are defined as elements that when subjected to some physical change experience a related change. Thus, sensors are transducers.

PERFORMANCE TERMINOLOGY

RANGE : The limit between which the input can vary.

SPAN : Span is the maximum value of input minus the minimum value.

ERROR : Error is the difference between the measured value of the quantity and the true value.

ACCURACY : Accuracy is the extent to which the value indicated by a measuring system might be wrong.

SENSITIVITY : Sensitivity is the relationship indicating how much output is there per unit input ie; $\frac{\text{Output}}{\text{Input}}$.

STABILITY : The ability to give the same output when used to measure a constant input over a period of time.

DEAD BAND : It is the range of input values for which OR there is no output.

RESOLUTION : It is the smallest change in the input value that will produce an observable change in the output.

HYSTeresis : The effect of giving different outputs from the ERROR same value of quantity being measured according

to whether that value has been reached by a continuously increasing change or a continuously decreasing change

NON-LINEARITY: A linear relationship is assumed between the error input and output over the working range. The output vs Input plot is assumed to be a straight line. The error is defined as the maximum difference from the straight line.

REPEATABILITY: The ability to give the same output for repeated applications of the same input value.

$$\text{Repeatability} = \frac{\text{Max. - Min. values given}}{\text{Full range}} \times 100$$

STATIC AND DYNAMIC CHARACTERISTICS

RESPONSE TIME:

This is the time which elapses after a constant input, a step input, is applied to the transducer (sensor) up to the point at which the transducer (sensor) gives an output corresponding to some specified percentage of the value of the input

TIME CONSTANT:

Time Constant is a measure of the inertia of the sensor and so how fast it will react to changes in its input. The bigger the time constant, the slower the reaction to a changing input signal

RISE TIME:

This is the time taken for the output to rise to some specified percentage of steady-state output. Often the rise time refers to the time taken for the output to rise

from 10% of the steady-state value to 90 or 95% of the steady state value.

SETTLING TIME

This is the time taken for the output to settle to within some percentage (e.g.: 2%) of the steady-state value.

CLASSIFICATION OF SENSORS

I. Based on power requirement

(i) Passive Sensor :- Passive Sensors requires external power source. They work based on any one of the following principles : Resistance, Inductance and Capacitance
eg:- Strain gauge, Resistance thermometers etc.

(ii) Active Sensor :- The power required to produce the output is provided by the sensed physical phenomena itself. They are also called as 'self-generating transducers'
eg:- Thermocouple, thermometer etc.

II. Based on the type of output signal

(i) Analog Sensors :-

eg:- Potentiometers, LVDT

(ii) Digital Sensors :-

eg:- piezo electric transducers

(iii) Primary Sensors :- Primary Sensors produce the output which is the direct measure of the input phenomenon.

(iv) Secondary Sensors :- Secondary Sensors produce output which is not the direct representation of the physical phenomenon.

Active \rightarrow Primary Sensors

Passive \rightarrow Secondary Sensors

IV. Based on the parameters measured

(i) Displacement

(iv) Velocity

(vii) Level

(ii) Position

(v) Temperature

(viii) Flow

(iii) Pressure

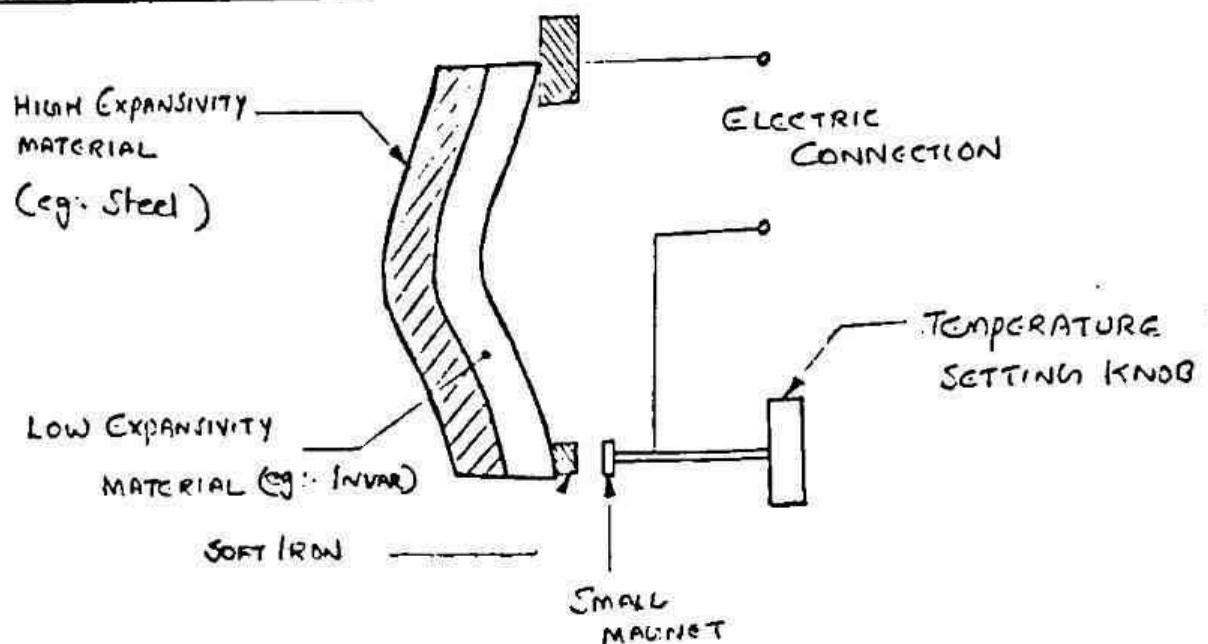
(vi) Light

(ix) Proximity

TEMPERATURE SENSORS

- ⇒ Bimetallic Strips
- ⇒ Resistance temperature detectors (RTDs)
- ⇒ Thermistors
- ⇒ Thermocouples

I BIMETALLIC STRIPS



BIMETALLIC STRIP

- ⇒ Bimetallic strips are used as thermal switch in controlling the temperature or heat in a manufacturing process or system.
- ⇒ It contains two different metal strips bonded together. The metals have different co-efficient of expansion.
- ⇒ On heating the strips bend into curved strips with the metal with higher co-efficient of expansion on the outside of the curve.
- ⇒ As the strips bend, the soft iron comes in closer proximity of the small magnet and further touches.
- ⇒ This completes the electric circuit and generate an alarm.
- ⇒ In this way the bimetallic strips help to protect the system from overheating above the pre-set value.

ADVANTAGES

- Power source not required
- Low cost
- Robust Construction
- Easy to use
- Can be used up to 500°C

DISADVANTAGES

- Less accurate
- Limited applications
- Not suitable for very low temperatures

II RESISTANCE TEMPERATURE DETECTORS (RTDs)

⇒ The resistance of a conductor changes with its temperature is changed. This property is used for measurement of temperature.

⇒ RTDs works on the principle that the electric resistance of a metal changes due to change in its temperature.

⇒ On heating up metals, their resistance increases and follows a linear relationship;

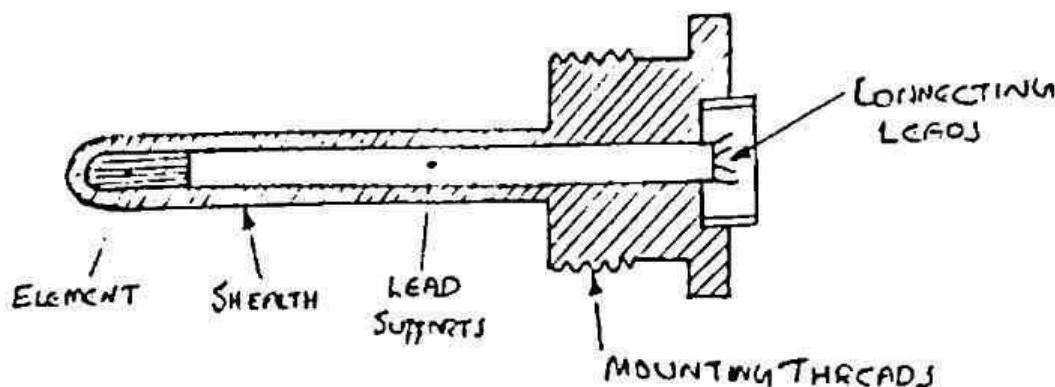
$$R_t = R_0(1 + \alpha T)$$

where;

R_t → Resistance at temperature $T^{\circ}\text{C}$

R_0 → Resistance at temperature 0°C

α → Temperature Co-efficient of resistance



Typical Resistance Temperature Detector

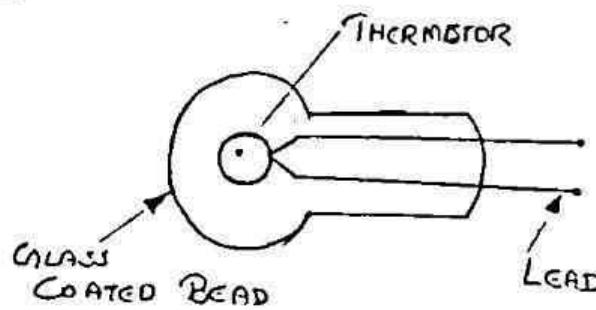
⇒ The sensor is usually made to have a resistance of 100Ω at 0°C

- ⇒ To measure the resistance across an RTD, apply a constant current, measure the resulting voltage and determine the RTD resistance.
- ⇒ RTDs are used as thin films, wire wound or coil
- ⇒ They are generally made of metals such as platinum, nickel or nickel-copper alloys
- ⇒ Platinum is especially suited for this purpose as it can withstand high temperatures while maintaining excellent stability
- ⇒ RTDs have higher accuracy and repeatability. They are slowly replacing thermocouples in industrial applications below 600°C

APPLICATIONS OF RTD:-

- ⇒ Air conditioning and refrigeration servicing
- ⇒ Food processing
- ⇒ Stoves and grills
- ⇒ Textile production
- ⇒ Plastic processing
- ⇒ Petrochemical processing

III THERMISTORS



- ⇒ Thermistors or thermal resistors are generally composed of semiconductor material such as Sintered metal oxide (mixtures of metal oxides, Chromium, Cobalt, Iron, manganese and nickel) or doped polycrystalline ceramic containing barium titanate (BaTiO_3) and other compounds.

⇒ Most thermistors have negative temperature coefficient of resistance i.e., resistance decreases with increase in temperature.

⇒ As the temperature of the semiconductor material increases the number of electrons able to move about increases which results in more current in the material and reduced resistance.

⇒ High sensitivity to temperature changes makes them extremely useful for precise temperature measurements in the range -60°C to 15°C .

⇒ Thermistors are rugged and small in dimensions.

⇒ They exhibit nonlinear resistance vs temperature characteristics.

⇒ They are available in the form of beads, rods and discs.

APPLICATIONS

⇒ To monitor the coolant temperature/oil temperature inside the engine.

⇒ To monitor the temperature of an incubator.

⇒ To monitor the temperature of hot ends of 3D printer.

⇒ To monitor the temperature of battery packs while charging.

⇒ Used in modern digital thermostats.

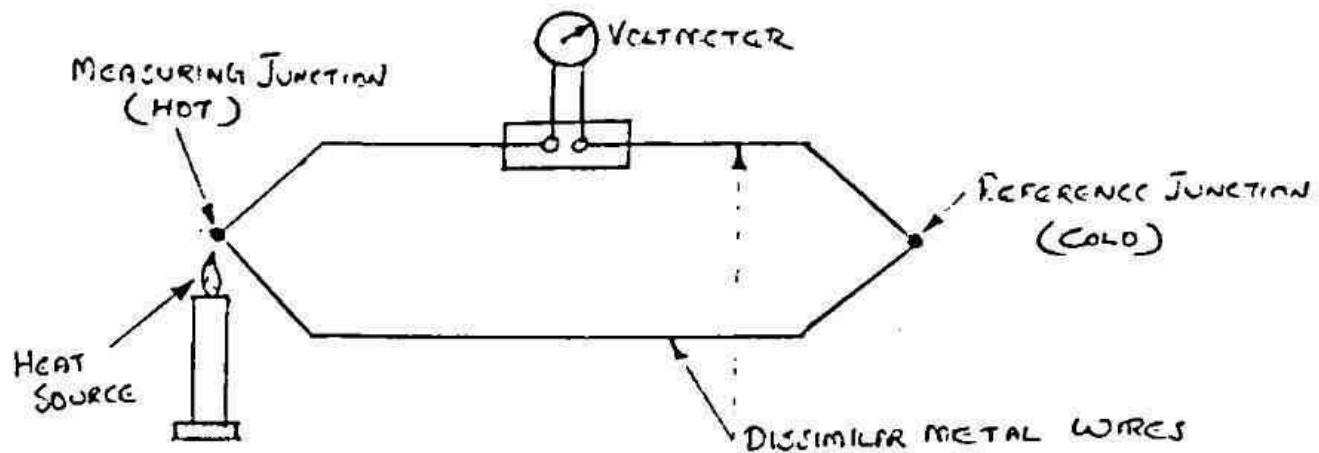
⇒ To control the operations of toasters, Coffeemakers, freezers, hair dryers etc.

Thermocouple

⇒ Thermocouple works on the fact that when a junction of dissimilar metals heated, it produces an electric potential related to the temperature (Seebeck effect).

⇒ As per Seebeck, When two wires composed of dissimilar metals are joined at both ends and one of the end

is heated, then there is a continuous current which flows in the thermo electric circuit.



MEASUREMENT OF TEMPERATURE WITH THERMOCOUPLE

⇒ The net open circuit voltage (Seebeck Voltage) is given by;

$$E = a \Delta \theta + b \Delta \theta^2$$

where;

$\Delta \theta \rightarrow$ Difference in temperature between hot junction and cold junction of thermocouple in $^{\circ}\text{C}$

a, b → Constants

⇒ Reference junction is usually kept at 0°C

⇒ Thermocouples are used for measurement of temperatures up to 1400°C

⇒ Common materials used are;

Chromel → 90% Nickel and 10% Chromium

Alumel → 95% Nickel, 2% Manganese, 2% Aluminium and 1% Silicon.

APPLICATIONS

⇒ To monitor temperatures throughout steel making process

⇒ Temperature profiling of ovens, furnaces etc

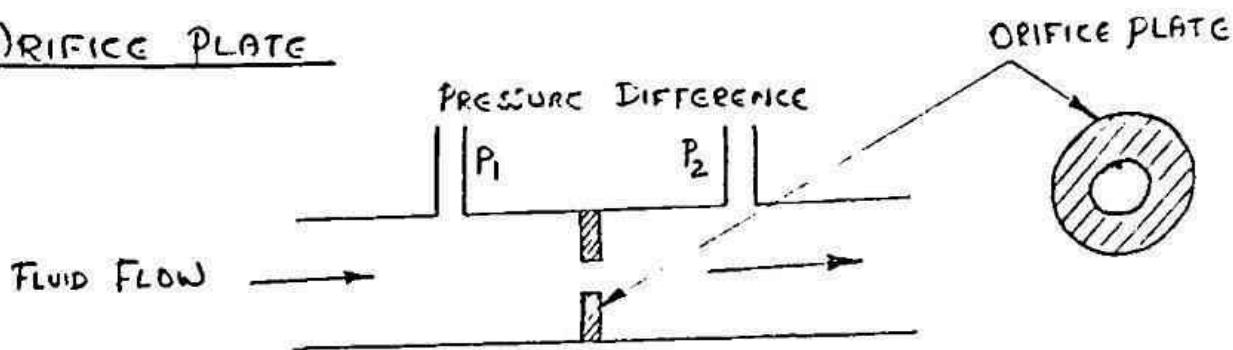
⇒ Temperature measurement of gas turbines and engine exhaust

⇒ Testing of heating appliance safety

FLUID FLOW SENSOR

- ⇒ Fluid flow is generally measured by applying the Bernoulli's principle of fluid flow through a constriction.
- ⇒ The fluid flow volume is proportional to square root of pressure difference at the two ends of the constriction.
- ⇒ Different types of devices are:
 - a) Orifice plate
 - b) Turbine meter

a) ORIFICE PLATE

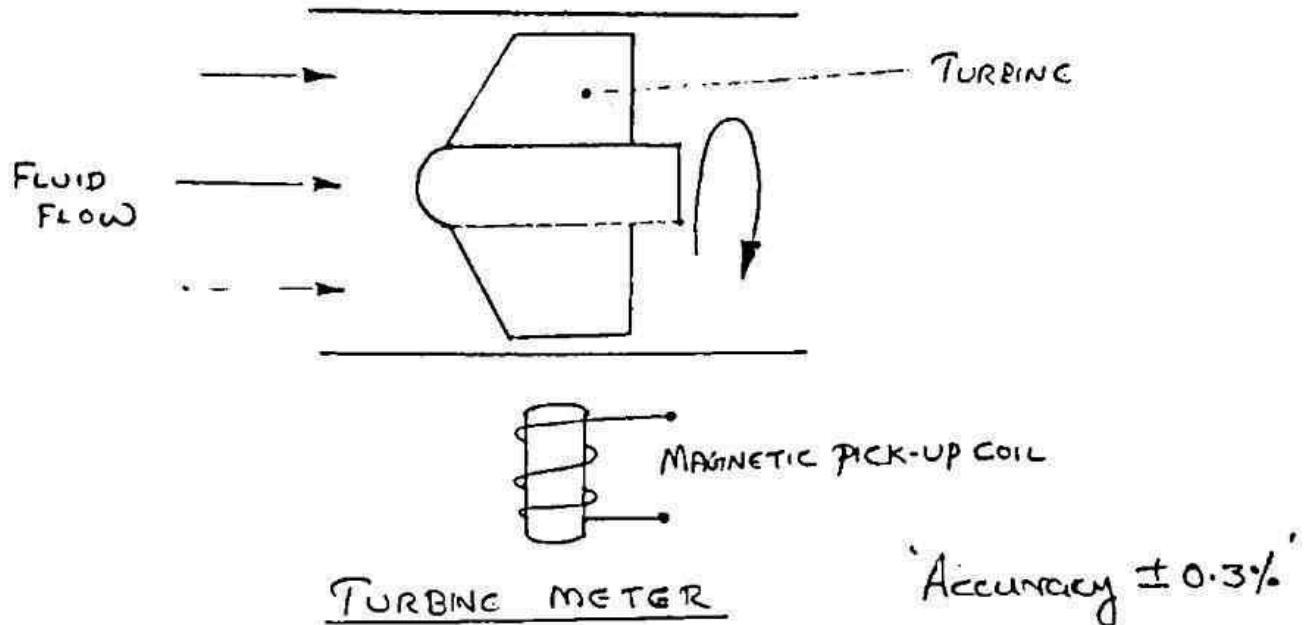


"Accuracy $\pm 1.5\%$. "

- ⇒ It has a disc with hole at its centre, through which the fluid flows.
- ⇒ The pressure difference is measured between a point equal to the diameter of the tube upstream and a point equal to half the diameter downstream.
- ⇒ It is inexpensive and simple in construction.
- ⇒ It exhibits non linear behaviour and does not work with slurries.
- ⇒ It finds application in medical, food & beverages, and chemical industries, waste water etc.

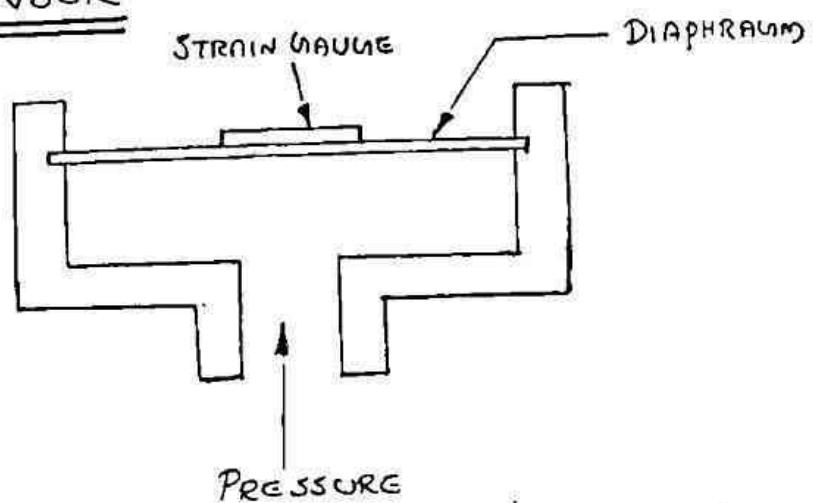
b) TURBINE METER

- ⇒ It has a multiblade rotor mounted centrally in the pipe along which the flow is to be measured.



- ⇒ The fluid flow rotates the rotor. Accordingly the magnetic pickup coil counts the number of magnetic pulses generating due to the distortion of magnetic field by the rotor blades
- ⇒ The angular velocity of the blade is proportional to the number of pulses and fluid flow is proportional to the angular velocity

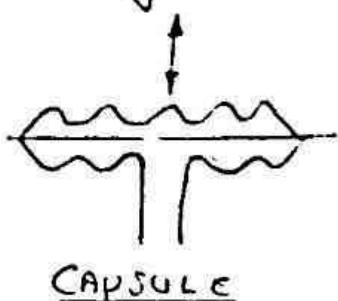
PRESSURE SENSOR



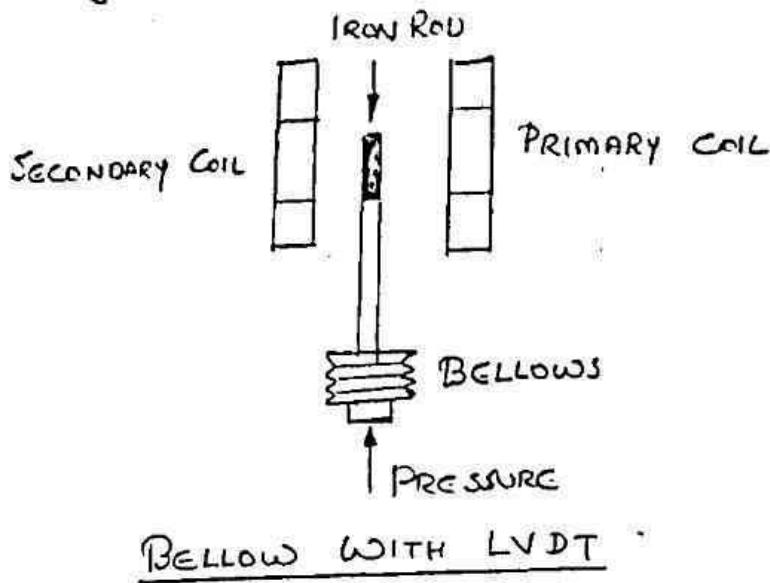
- ⇒ Various types of instruments such as diaphragm, capsule and bellows are used to monitor the fluid pressure
- ⇒ Pressurized fluid displaces the diaphragm, this causes radial / lateral strains. Strain gauges are

Connected to form arms of a Wheatstone's bridge.

⇒ A capsule is formed by combining two conjugated diaphragms.



⇒ A stack of capsules is called as 'Bellows'. Bellows, with a LVDT sensor measures the fluid pressure in terms of change in resultant voltage across the Secondary coils of LVDT.



DISPLACEMENT, POSITION & PROXIMITY SENSORS

⇒ Displacement sensors are concerned with the measurement of the amount by which some object has been moved.

⇒ Position sensors are concerned with the determination of position of some object in relation to some reference point.

⇒ Proximity sensors are a form of position sensor and are used to determine when an object has moved to

within some particular critical distance of the sensor. They are essentially devices which give on/off inputs.

⇒ Displacement & position sensors are grouped into two basic types

↳ Contact Sensors - the measured object comes in mechanical contact with the sensor

↳ Non Contact Sensors - there is no mechanical contact between the measured object and the sensor.

(ii) POTENTIOMETERS

⇒ A potentiometer consists of a resistance element with a sliding contact which can be moved over the length of the element. The sliding contact is called wiper.

⇒ Such elements can be used for linear or rotary displacements, the displacement being converted to potential difference.

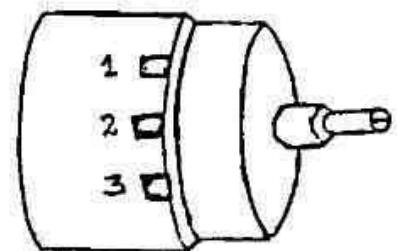
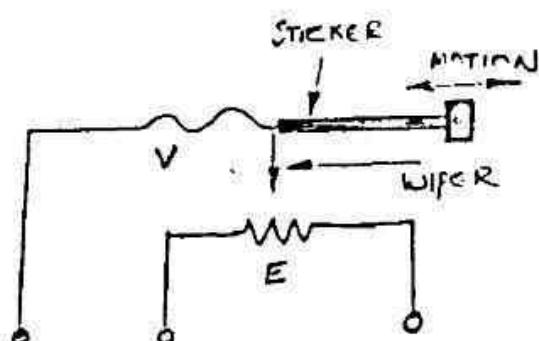
MATERIAL USED:-

↳ Constantan → 35% Cu + 45% Ni

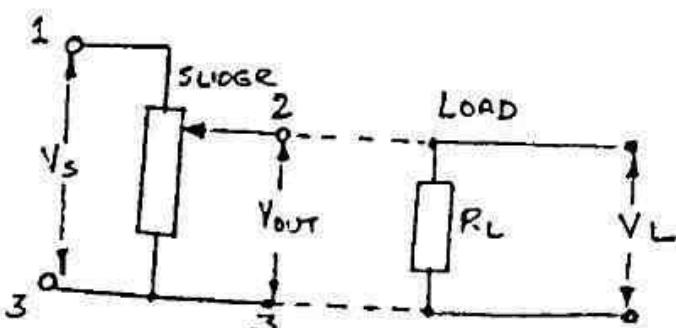
↳ Cermet → Ceramic/metal mixture

↳ Graphite → Inexpensive

↳ Manganin → 86% Cu + 12% Mn + 2% Ni



LINER POTENTIOMETER



ROTARY POTENTIOMETER

THE CIRCUIT WORKS CONNECTED TO A LOAD

⇒ The potentiometer consists of a circular wire wound track or a film of conductive plastic over which a rotatable sliding contact can be rotated.

⇒ The track may be a single turn or helical with a constant input voltage V_s , between terminals 1 & 3, the output voltage V_o between terminals 2 & 3 is a fraction of the input voltage

⇒ The fraction depending on the ratio of the resistance R_{23} with total resistance R_{13}

$$\text{ie;} \quad \frac{V_o}{V_s} = \frac{R_{23}}{R_{13}}$$

⇒ If the track has constant resistance / unit length, ie, per unit angle, then the output is proportional to the angle through which slider has rotated. Hence angular displacement can be converted into a potential difference.

⇒ The resistance element is a wire-wound track or conductive plastic. The track comprises of large number of closely packed turns of a resistive wire.

⇒ Conductive plastic is made up of plastic resin embedded with carbon powder.

⇒ Wire wound track has a resolution of the order of $\pm 0.01\%$ while the conductive plastic may have resolution of about $0.1/\text{deg}$.

APPLICATIONS:-

- ⇒ used in control systems with a feed back loop to ensure that the moving member or a component reaches its commanded position.
- ⇒ On machine tool controls, elevators, liquid-level control, automobile throttle controls.

- ⇒ In manufacturing - Control of injection molding machines, printing, spraying, robotics etc.
- ⇒ Computer controlled monitoring of sports equipment.

(ii) STRAIN GAUGES

- ⇒ Strain gauge is a device used to measure strain on an object, displacement, stress and force.
- ⇒ Strain in an element is the ratio of change in length in direction of applied load to the original length of the element
- ⇒ The strain changes the resistance R of the element

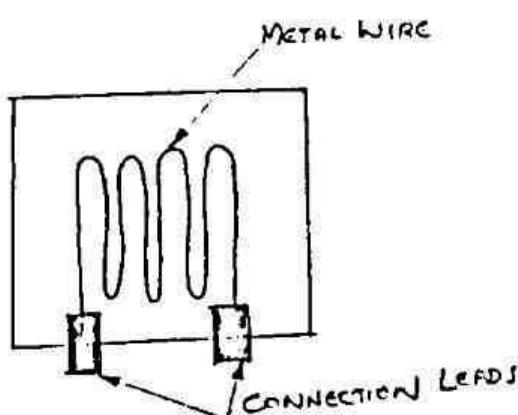
$$\frac{\Delta R}{R} \propto \epsilon \quad \Rightarrow \quad \frac{\Delta R}{R} = C_1 \cdot \epsilon$$

where;

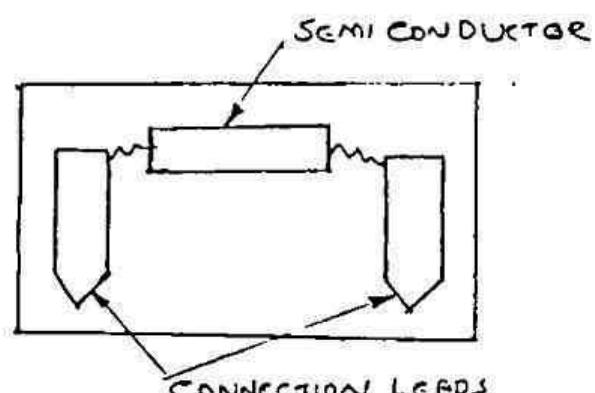
$\epsilon \rightarrow$ strain

$C_1 \rightarrow$ proportionality constant termed as gauge factor.

- ⇒ In general C_1 is in between 2 to 4 and resistances are taken of order of 100Ω .



METAL WIRE STRAIN GAUGE



SEMI CONDUCTOR STRAIN GAUGE

- ⇒ Strain gauge is a metal wire, metal foil strip or a strip of semiconductor material which can be stuck on to surfaces (workpiece). like postage stamp.
- ⇒ As the workpiece undergoes change in its shape

due to external loading, the resistance of the strain gauge changes. This change in resistance can be detected by using Wheatstone's resistance bridge.

⇒ A problem with all strain gauge is that their resistance not only changes with strain but also with temperature.

⇒ Semiconductor strain gauges have much greater sensitivity to temperature than metal wire strain gauges.

APPLICATIONS

⇒ Experimental stress analysis & diagnosis on machines & failure analysis, proof testing, residual stress & vibration measurement, torque measurement, compression & tension measurement.

⇒ As sensors for machine tools & safety in automobiles.

⇒ As impact sensors in aerospace vehicles.

vii) CAPACITANCE SENSORS

⇒ Capacitance sensor is a variable capacitor. It is used for measuring displacement, pressure etc.

⇒ It consists of two parallel metal plates separated by substance like air called dielectric. In a capacitance sensor the distance between the plate is a variable and hence there will be change in the capacitance which can be measured easily.

⇒ The capacitance of a parallel plate capacitor is;

$$C = \frac{\epsilon_0 \epsilon_r A}{d}$$

where;

ϵ_r → Relative permittivity of dielectric

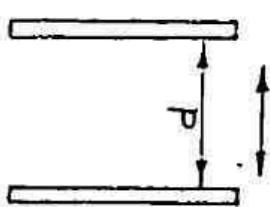
ϵ_0 → Absolute permittivity (Permittivity of free space)

A → Area of overlap between the two plates

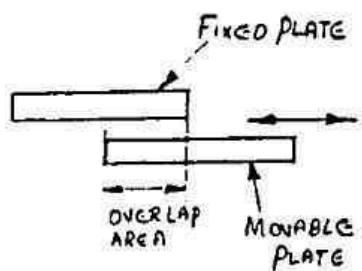
d → Distance between the plates

⇒ Depending upon the parameter which is used to change the capacitance, there are three types of capacitive sensors;

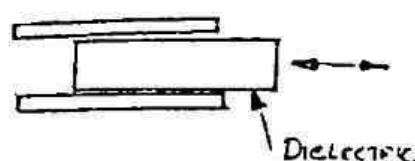
- ↳ Changing distance b/w plates type [Fig(a)]
- ↳ Changing area of the plate type [Fig(b)]
- ↳ Changing dielectric constant type [Fig(c)]



Fig(a)



Fig(b)



Fig(c)

TYPES OF CAPACITANCE SENSORS

⇒ In Fig(c), one of the plates is moved by the displacement so that the plate separation changes. In (b) the displacement causes the area of overlap to change. In (c) the displacement causes the dielectric between the plate to change.

⇒ Capacitive elements can be used as proximity sensor. The approach of object towards the sensor plates is used for induction of change in plate separation. This changes the capacitance which is used to detect the object.

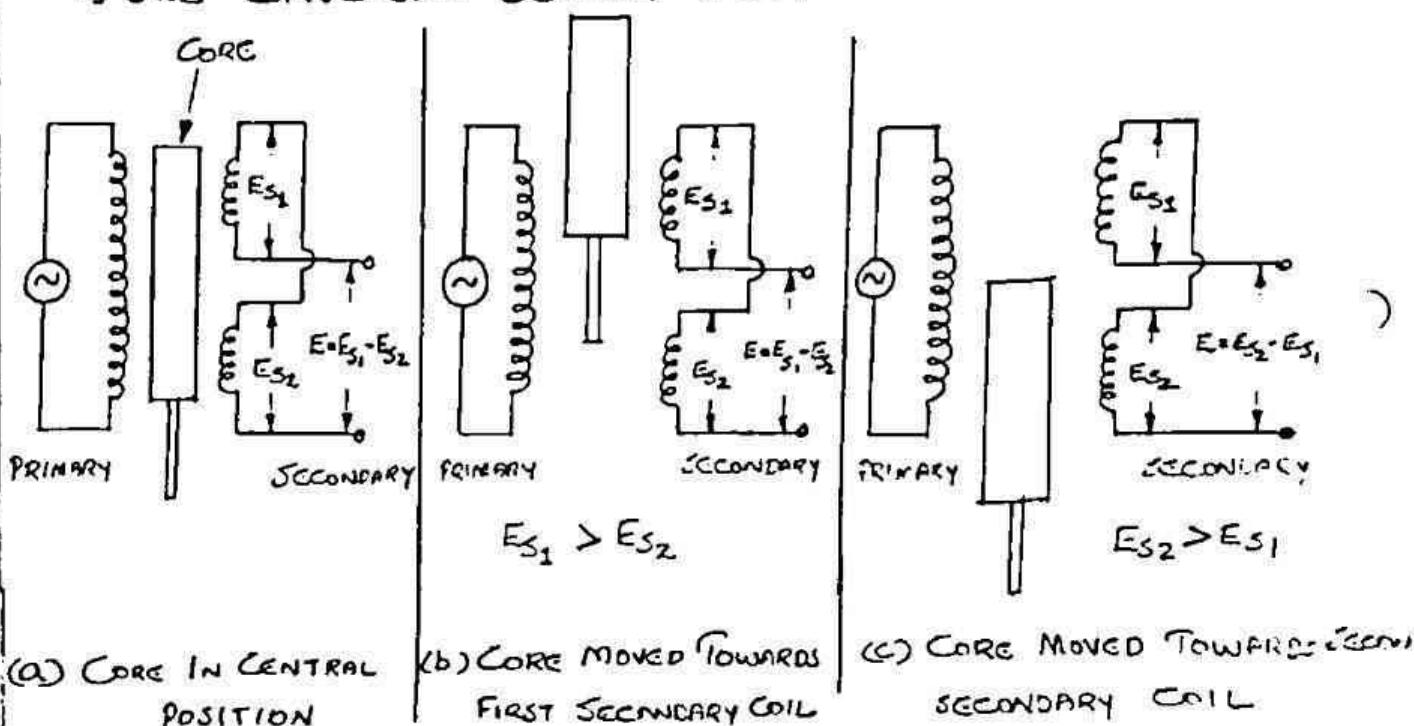
APPLICATIONS

- ⇒ Feed hopper level monitoring
- ⇒ Small vessel pump control
- ⇒ Grease level monitoring
- ⇒ Level Control of Liquids
- ⇒ Metrology applications

(iv) LINEAR VARIABLE DIFFERENTIAL TRANSFORMER (LVDT)

⇒ LVDT consists of a primary coil and two secondary coils and a core.

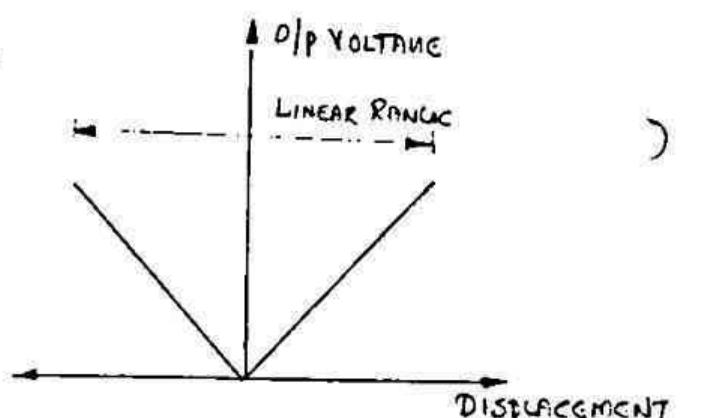
⇒ The two secondary coils are connected in phase opposition such that the resultant emf across them is the difference between their emfs.



⇒ When an alternating voltage is applied to primary coil, alternating emfs are induced in secondary coils.

⇒ With the core in central position, the amount of core in each of the secondaries is the same. So the resultant output voltage is zero.

⇒ When the core is moved from central position, there is a change in amount of core in the two secondaries, greater emf is induced in one coil than the other. There is a net output voltage from the coils. Hence displacement is being converted to voltage.



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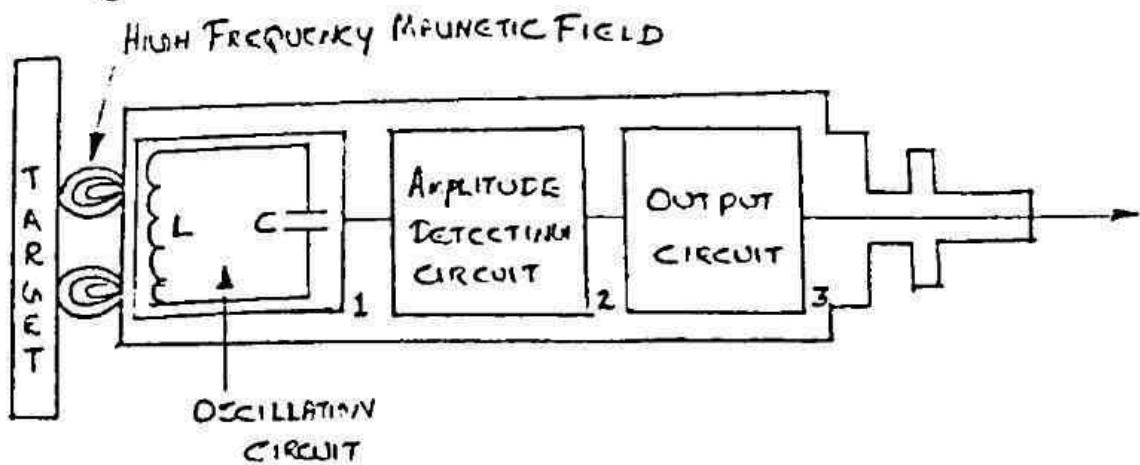
- ⇒ LVDT exhibits good repeatability and reproducibility
It's used as absolute position sensor
- ⇒ Since there is no contact or sliding between the constituent elements of sensor, it is highly reliable.
- ⇒ A rotary variable differential transformer (RVDT) can be used for measurement of rotation.

APPLICATIONS:-

- ⇒ To measure distance b/w approaching metals during friction welding process
- ⇒ To detect the number of currency bills dispensed by an ATM
- ⇒ To continuously monitor fluid level as part of leak detection system
- ⇒ To provide displacement feed back for hydraulic cylinders.

(v) EDDY CURRENT PROXIMITY SENSORS

- ⇒ Eddy current is the current induced by a conductor when it is kept in a changing magnetic field.
- ⇒ Eddy current sensors are used to detect the presence of non magnetic but conductive materials.



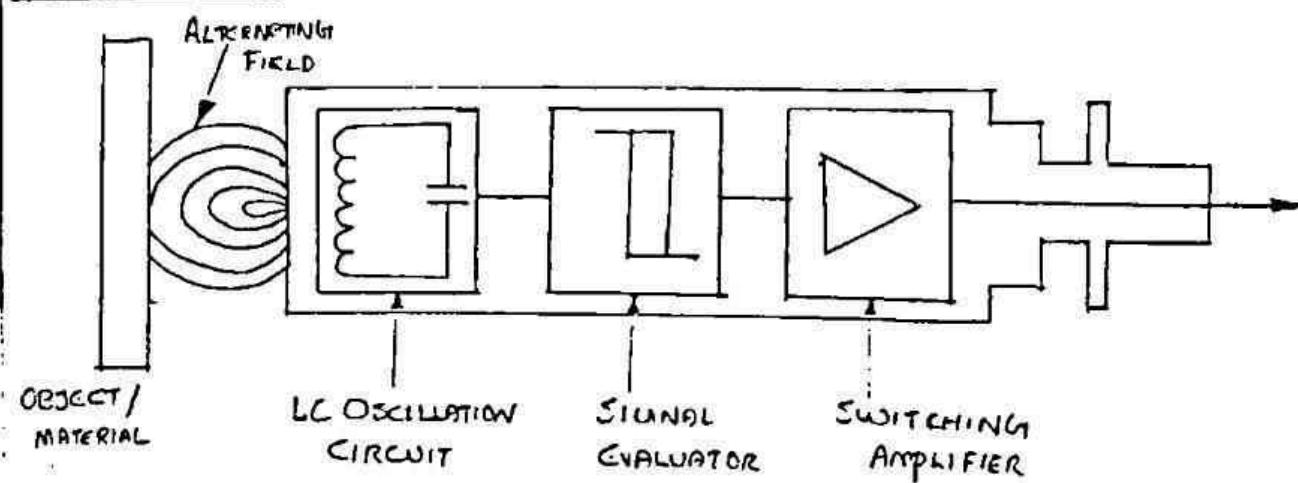
- ⇒ It comprises of a coil, an oscillator, a detector and a triggering unit.

- ⇒ If the coil is supplied with an alternating current an alternating magnetic field is produced. If a metal object comes in close proximity of the coil, then eddy currents are induced in it due to this magnetic field.
- ⇒ These eddy currents create their own magnetic field which distorts the magnetic field responsible for their generation.
- ⇒ As a result, impedance of the coil changes and so the amplitude of the alternating current. This can be used to trigger a switch at some predetermined level of change in current.
- ⇒ It is inexpensive, small in size, highly reliable and has high sensitivity to small displacements.

APPLICATIONS:-

- ⇒ Vibration measurement
- ⇒ Machine tool monitoring
- ⇒ Automation requiring precise location.

(iv) INDUCTIVE PROXIMITY SWITCH.

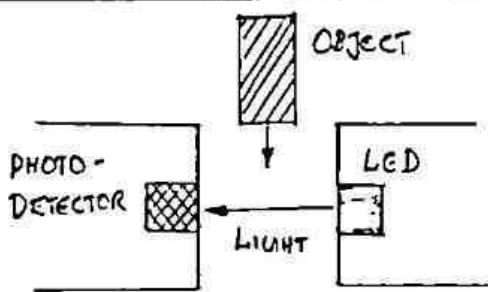


⇒ Inductive Proximity switches are basically used for detection of metallic objects.

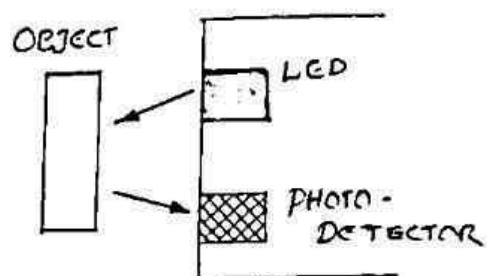
⇒ It has four components, the coil, oscillator, detection circuit and output circuit.

- ⇒ An alternating current is supplied to the coil which generates a magnetic field.
- ⇒ When a metal object comes closer to the end of the coil, inductance of the coil changes. This is continuously monitored by a circuit which triggers a switch when a preset value of inductance change is occurred.

(vii) PHOTOELECTRIC POSITION SENSORS



(a) OBJECT BREAKS THE BEAM



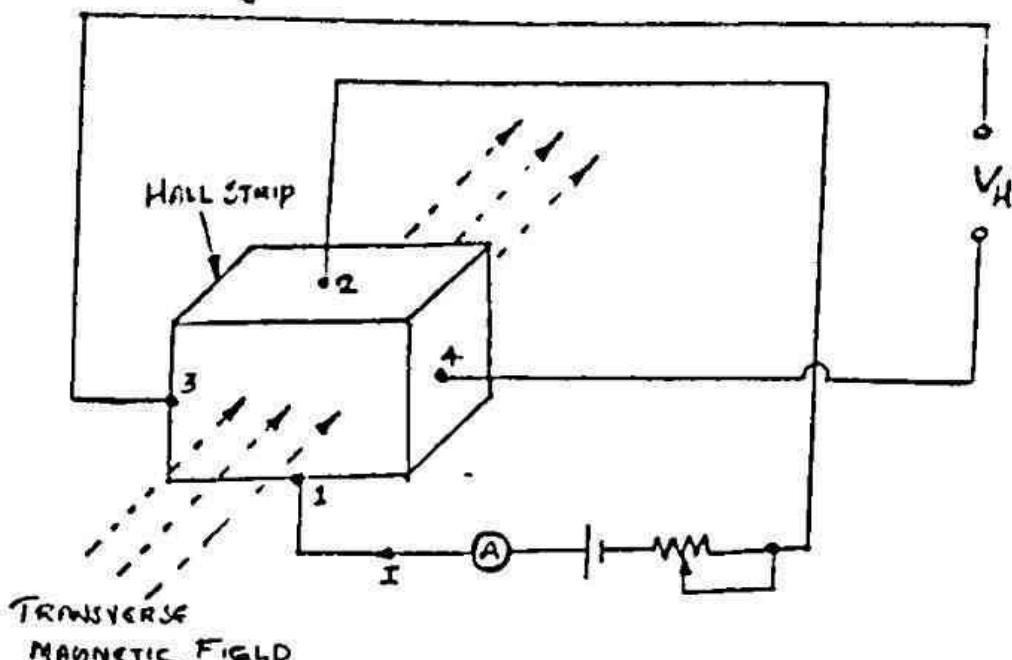
(b) OBJECT REFLECTING LIGHT

- ⇒ Photo electric sensors makes use of light emitted by an LED to sense the position of an object.
- ⇒ It is used to detect the object by breaking a beam of light or by detecting the light reflected back by the object.

(viii) HALL EFFECT SENSORS

- ⇒ A beam of charged particles passing through a magnetic field experience a force that deflects the beam from the straight line path. This is known as Hall effect.
- ⇒ If a strip of conducting material carries a current in the presence of a transverse magnetic field, a difference of potential is produced between the opposite edges of the conductor. The magnitude of the voltage depends upon the current and magnetic field.
- ⇒ In the figure, Current is passed through leads 1 and 2

if the strip and the output leads are connected to the chip
 \Rightarrow when a transverse magnetic field passes through the strip the voltage difference occurs in the output leads.



HALL EFFECT SENSOR

$$\text{Hall potential } V_H = H_c \frac{B \cdot I}{t}$$

where;

H_c \rightarrow Hall's Coefficient.

B \rightarrow Magnetic flux density

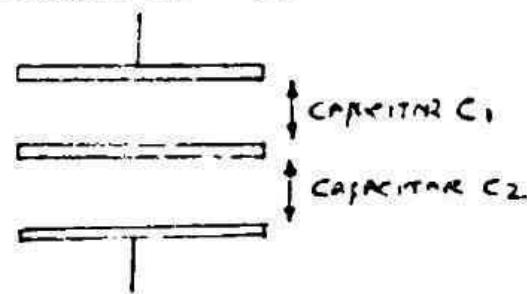
I \rightarrow current flowing through strip

t \rightarrow thickness of the strip.

ADVANTAGES:-

- 2 They can operate at high frequency
- 2 They cost less than electromechanical switches
- 2 They can be used as proximity, position and displacement sensors.
- 2 They can be used under severe environmental service conditions.

(ix) PUSH PULL Displacement Sensor



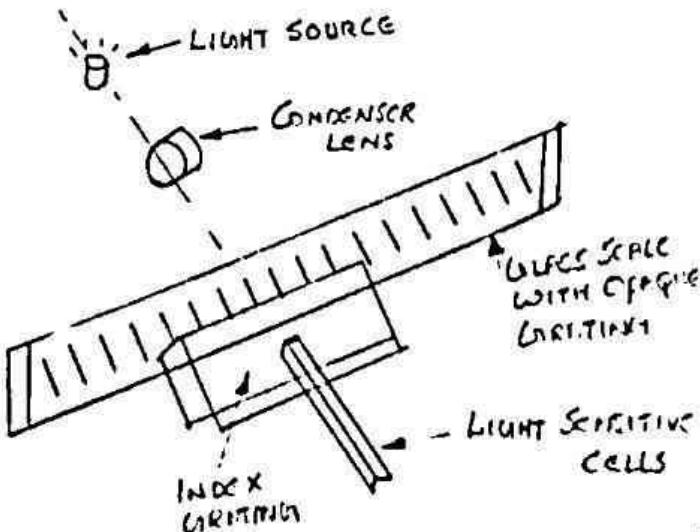
- ⇒ It has three plates with upper pair forming one capacitor and the lower pair forming another capacitor.
- ⇒ There is a non linear relationship between the change in capacitance, ΔC and displacement X .
- ⇒ The displacement moves the central plate between the two other plates, which will in turn cause a change in the capacitance of the two capacitors.

(x) OPTICAL ENCODERS

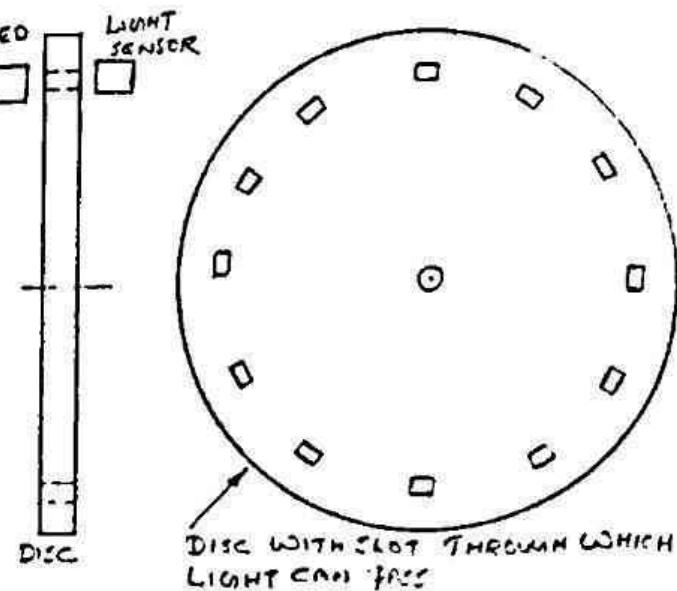
- ⇒ Encoder is a digital optical device that converts motion into a sequence of digital pulses.
- ⇒ By counting or decoding these bits, the pulses can be converted to relative or absolute position measurements.
- ⇒ Encoders are available in rotary and linear configurations.
- ⇒ Encoders are of two types;
 - ↳ Absolute encoder
 - ↳ Incremental encoder.

INCREMENTAL ENCODER

- ⇒ It comprises of a disc with three concentric tracks of equally spaced holes. Three light sensors are employed to detect the light passing through the holes.
- ⇒ These sensors produce electric pulses which give the angular displacement of the mechanical element.
e.g.: shaft on which optical encoder is mounted.
(Rotation of the shaft)

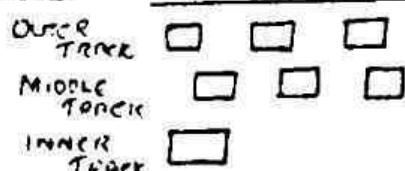


LINEAR ENCODER



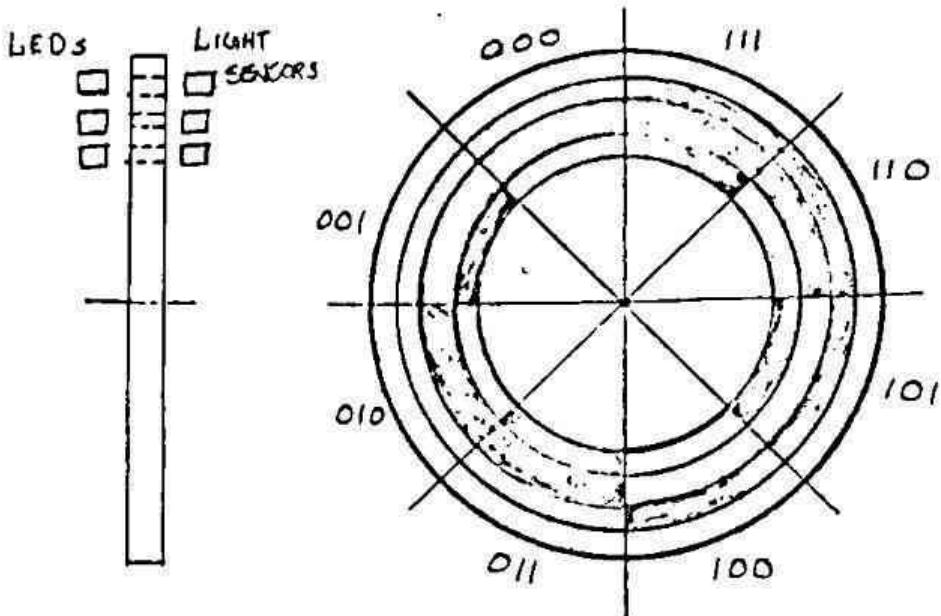
ROTARY ENCODER

- ⇒ The inner track has only one hole which is used to locate the 'home' position of the disc.
- ⇒ The holes on the middle track offsets from the holes of the outer track by one-half of width of the hole. This arrangement provides the direction of rotation to be determined.
- ⇒ When the disc rotates in clockwise direction, the pulses in the outer track lead those in the inner; in counterclock wise direction they lag behind.
- ⇒ The resolution can be determined by the number of holes on disc. With 60 holes in one revolution, the resolution is $360/60 = 6^\circ$.



ABSOLUTE ENCODER

- ⇒ This sensor gives as output in the form of binary number or several digits, each such number representing a particular angular position.
- ⇒ The rotating disc has three concentric circles of slots and three sensors to detect the light pulses. The slots are arranged in such a way that the sequential output from the sensors is a number in binary code.



3 tracks
 $\therefore 2^3 = 8$ positions
 $0 \rightarrow 7$

- ⇒ Typical encoders have 10 or 12 tracks. The number of bits in binary number will be equal to the number of tracks.
- ⇒ Thus with 10 tracks there will be 10 bits & so number of positions that can be detected is 2^{10} ie, 1024. In the resolution is $360/1024 = 0.35^\circ$.

GRAY CODED ENCODER

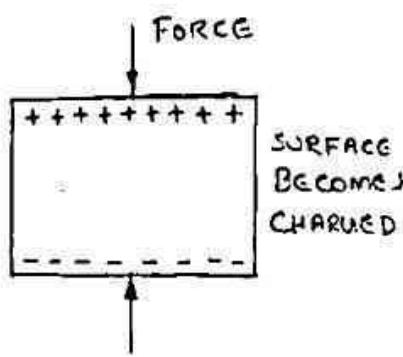
- ⇒ The normal form of binary code is generally not used because changing from one binary number to the next can result in more than one bit changing.
- ⇒ For example in changing from 001 to 110 we have two bits changing, and if, through some misalignment, one of the bits changes positionally before the others then an intermediate binary number is momentarily indicated and so can lead to Pulse Counting.
- ⇒ To overcome this Gray Code is generally used. It is such a code in which only one bit in the code group changes in going from one number to the next. It is widely used for devices such as absolute encoders.
- ⇒ Interface Integrated Circuits are available to decode the encoder and convert from ^{gray} binary code to give a binary output suitable for a microprocessor.

⇒ Figure show the track arrangement with normal binary code and gray code.

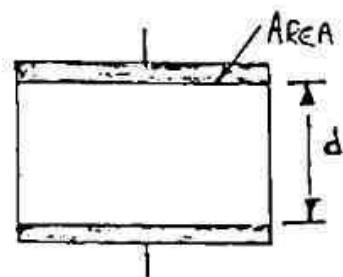
	NORMAL BINARY	GRAY CODE
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111

PIEZOELECTRIC SENSORS

- ⇒ Piezoelectric sensors are used for the measurement of pressure, force and acceleration.
- ⇒ Piezoelectric materials when stretched or compressed generates electric charges with one face of the material becoming positively charged and the opposite face negatively charged (fig(a)). As a result a voltage is produced.
- ⇒ Piezoelectric materials are ionic crystals which when stretched or compressed result in the charge distribution in the crystal changing so that there is a net displacement of charges with one face of the material becomes positively charged and the other face become negatively charged



(a) PIEZOELECTRICITY



(b) PIEZOELECTRIC CAPACITOR

$$\text{Net charge } q = kx = SF$$

Where;

x → the amount by which charges have been displaced.

S → Charge Sensitivity

k → is a constant

F → applied force.

⇒ In a piezoelectric capacitor (Fig (b)), metal electrodes are deposited on opposite faces of the piezoelectric crystal

$$\text{Capacitance } C = \frac{\epsilon_0 \epsilon_r A}{d}$$

where;

d → thickness of the crystal.

$$\text{charge } q = C \cdot V$$

where;

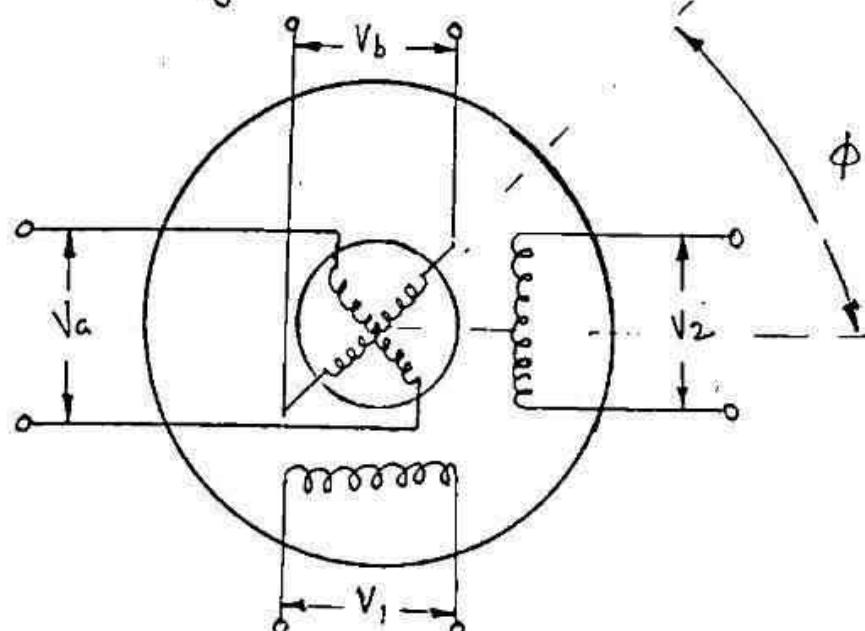
V → voltage produced across the capacitor.

⇒ The voltage produced is proportional to the pressure applied

⇒ Materials like quartz, barium titanate etc. can be used for piezoelectric sensors.

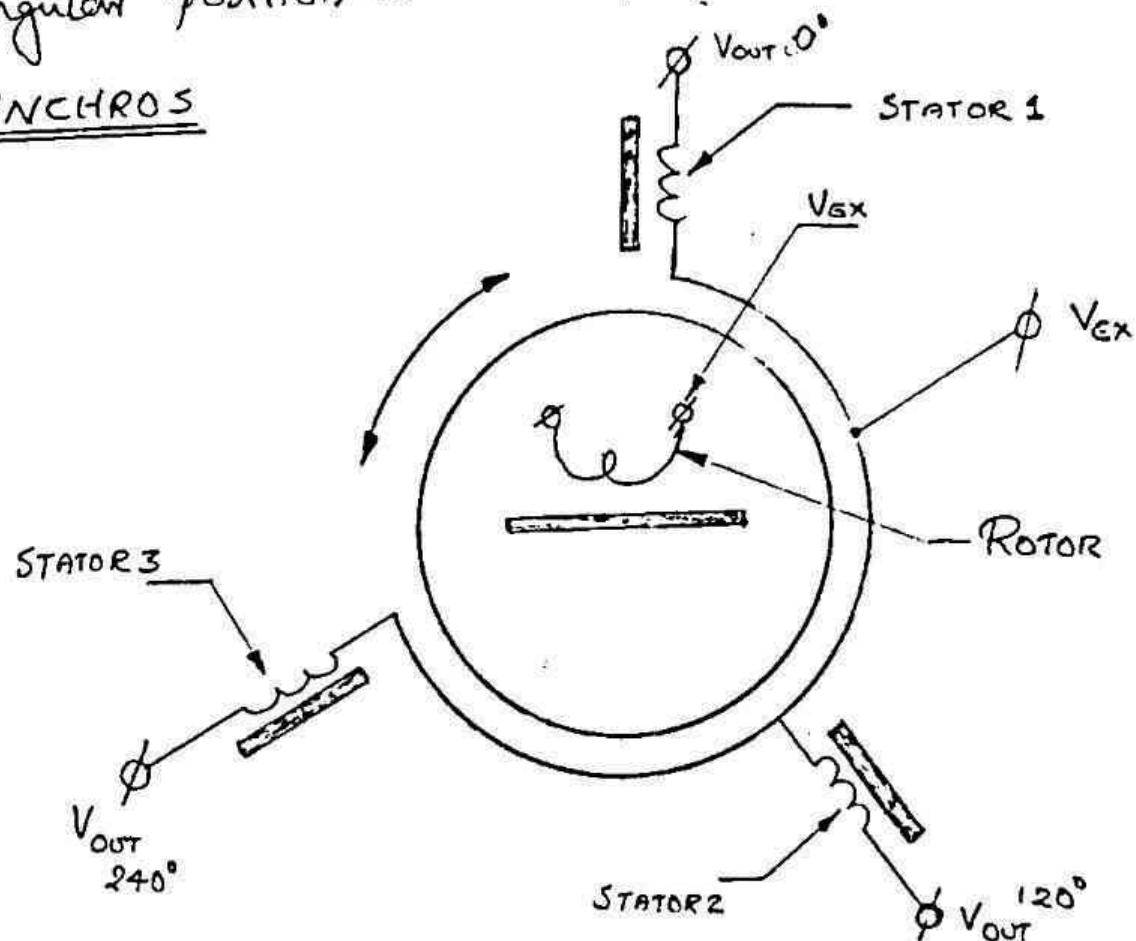
RESOLVERS

⇒ Resolver is used to measure the angular position of lead screw and thereby to measure the position of machine slide.



- => Resolvers have the same general construction features as a small ac motor. It consists of a rotor and a stator both having two windings at 90° to one another.
 => If an ac voltage is applied to one of the stator coils, a maximum voltage will appear on a rotor coil when those two coils are in line, and the voltage will be zero for a $\pm 90^\circ$ shift.
 => As the shaft is rotated, the voltage induced in one motor coil will follow a sine wave and voltage in other follows a cosine wave.
 => Similarly the ac voltage can be applied to one of the motor coils, resulting in a sine and cosine of the angular position of the rotor at the two stator winding outputs.
 => In NC applications only one of the rotor windings is used, and produces the feed back signal V_a . Phase which is contained in the feed back signal depends on the angular position of the rotor shaft.

SYNCHROS



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where;

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where;

d → thickness of the crystal.

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where;

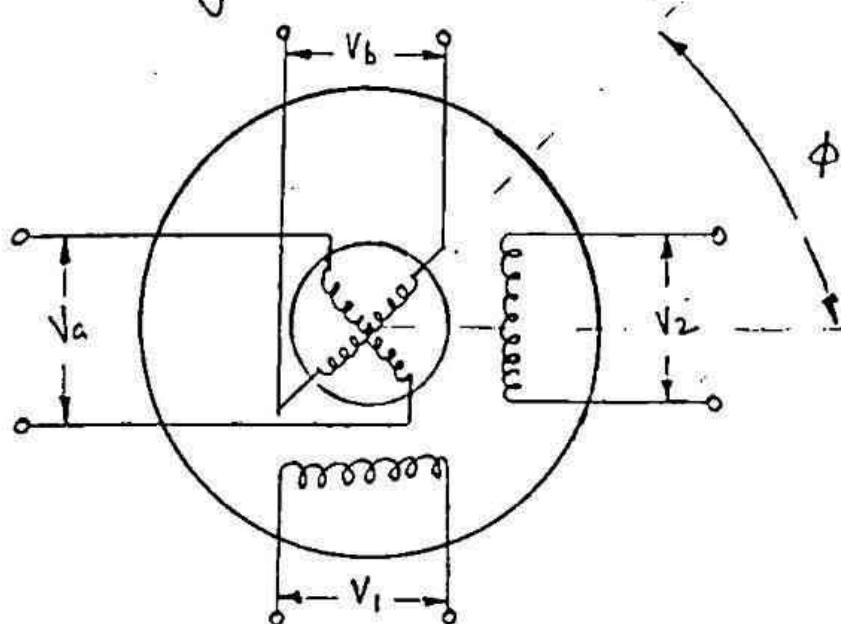
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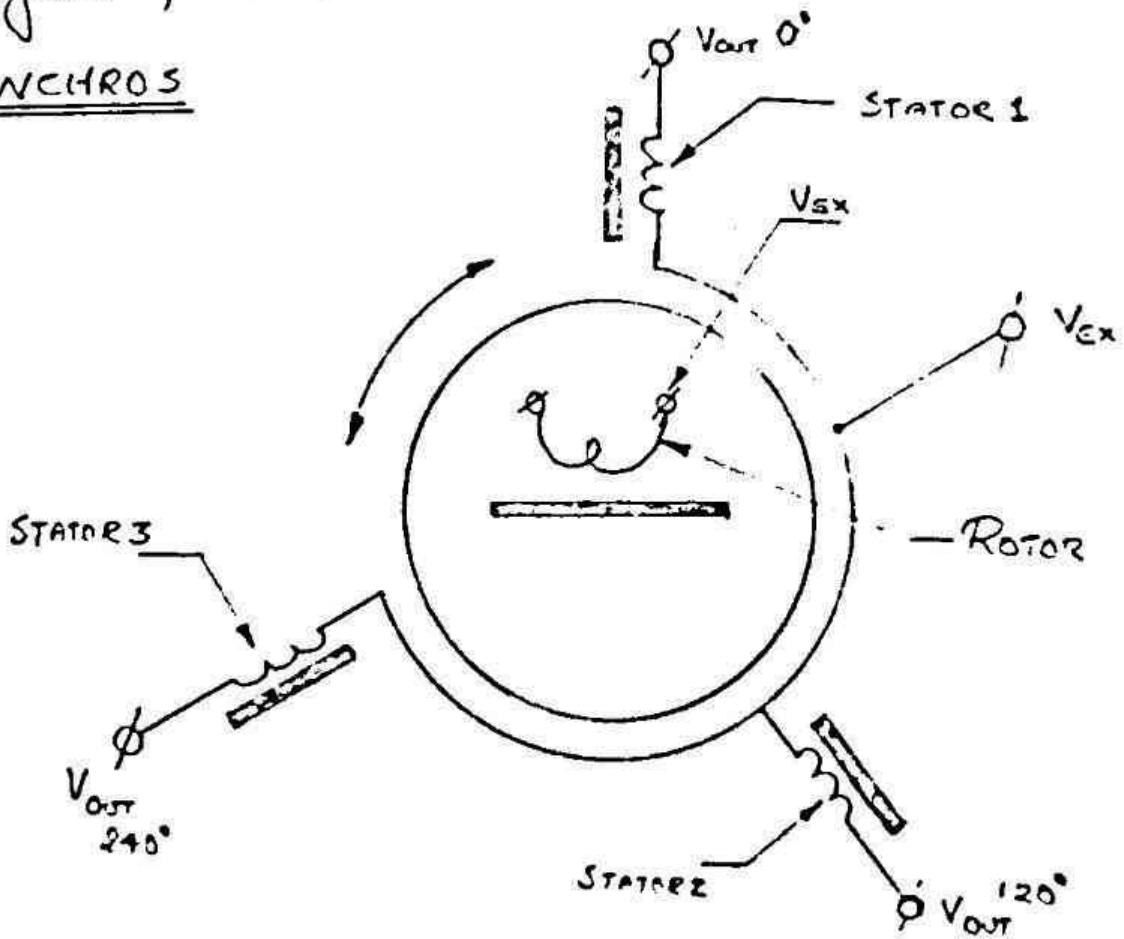
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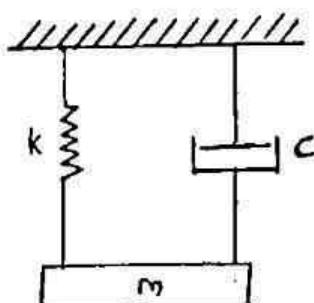
SYNCHROS



- ⇒ Synchro is a rotary transformer, whose primary & secondary coupling may be varied by physically changing the relative orientation of the two windings.
- ⇒ It is also known as Selsyn Synchro widely used for measuring the angle of a rotating machine.
- ⇒ The construction of a synchro is similar to an electric motor. The primary winding of the transformer, is fixed to the rotor which is excited by an alternating current.
- ⇒ This excited rotor AC current by electromagnetic induction, flows in three Y-connected secondary windings fixed at 120° to each other on the stator.

VIBRATION SENSORS

- ⇒ Vibrations are measured by measuring the displacement, velocity or acceleration of the vibrating body with the help of vibration measuring instruments.
- ⇒ The basic principle of operation is based on Newton's second law of motion and Hooke's law of elasticity.



- ⇒ According to Newton's second law if a mass 'm' is undergoing acceleration 'a', it will exert a force 'F_a' on the mass ; $F_a = ma$

- ⇒ This force is opposed by the restraining effect of the spring. Let k be the stiffness and dx be the displacement of the mass from original position. Then according to Hooke's law

$$F_s = k dx$$

\Rightarrow In a steady state;

$$F_a = F_s$$

$$Ma = kdx$$

$$a = \frac{kdx}{m}$$

\Rightarrow Without damping such systems undergo non-decaying sustained oscillations. Therefore it is necessary to provide a damper in the system.

$$\text{Damping force } F_d = Cv$$

$C \rightarrow$ damping Co-efficient

$v \rightarrow$ velocity of mass

\Rightarrow Now the modified equation is;

$$F_s + F_d = Fa$$

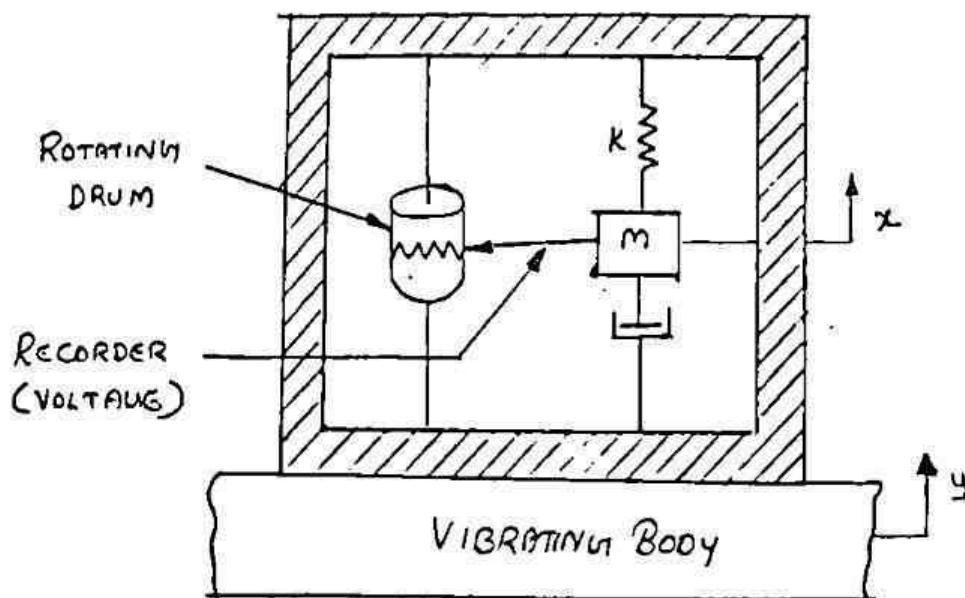
$$kdx + Cv = ma$$

\Rightarrow The mass which converts acceleration into the spring displacement is called the Seismic mass.

\Rightarrow There are three types of vibration sensors;

- ↳ Vibrometer or Seismometer
- ↳ Accelerometer
- ↳ Laser Doppler Vibrometer (LDV)

I. VIBROMETER (SEISMOMETER)

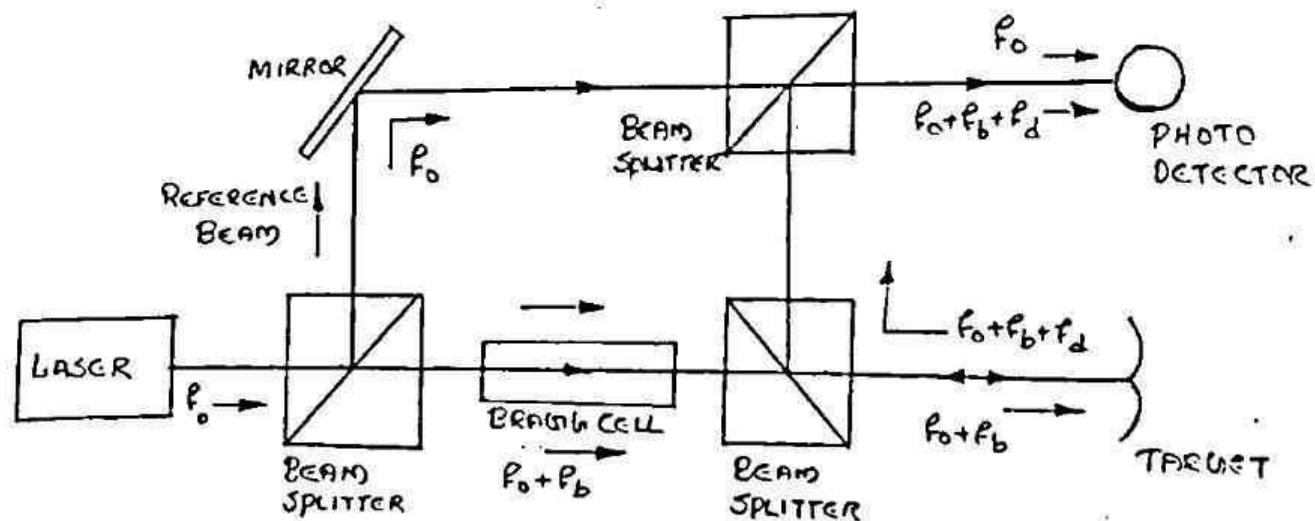


- ⇒ Vibrometer is designed with low natural frequency and hence it is known as low frequency transducer.
- ⇒ The relative motion between the mass and vibrating body is converted into proportional voltage and it can be recorded.

I. ACCELEROMETER

- ⇒ Used to measure the acceleration of a vibrating body.
- ⇒ Accelerometers are designed with high natural frequency and hence it is known as high frequency transducer.
- ⇒ The construction is similar to a Seismometer.
- ⇒ It is widely used because of its very small size and ability to measure displacement, velocity and acceleration simultaneously.

III. LASER DOPPLER VIBROMETER (LDV)



- ⇒ It is a non contact type vibration measuring instrument.
- ⇒ A laser beam is directed on the surface of interest, the vibration amplitude and frequency can be extracted from the doppler shift of the reflected laser beam frequency due to motion of the surface.
- ⇒ It is a two-beam laser interferometer, which measures the frequency difference between the reference beam and the test beam.
- ⇒ Helium-Neon laser is the most commonly used LDV.

⇒ The beam from the laser of frequency f_0 is divided into a reference beam and a test beam by a beam splitter while passing through the Bragg cell, a frequency shift Δf_b is added which is further directed to the detector.

⇒ Motion of the target adds a doppler shift to the beam which is given by;

$$\Delta f_d = 2 V(t) \cos(\alpha) / \lambda$$

Where;

$V(t)$ → Velocity of the target

α → Angle between the laser beam and velocity vector

λ → wavelength of the light

⇒ From the target, light scatters in all directions but only some portion of the light is collected by LDV and reflected by beam splitter to the photo detector. This scattered light is then combined with the interference beam at the photo detector.

ACOUSTIC EMISSION SENSORS

⇒ It is a type of sensor which converts the surface movement caused by an elastic wave into an electric signal, which can be processed by the measurement equipment.

⇒ The piezoelectric element of acoustic emission sensor should have high sensitivity and it should convert the surface movement efficiently to electric voltage.

⇒ Acoustic emission sensors are designed highly sensitive at a certain frequency or with broad frequency response.

⇒ It is very important to select an appropriate sensor for a specific AE application.

⇒ AE sensors are classified into two groups;

↳ Resonance model

↳ Wide band width model.

⇒ Resonance models are highly sensitive at a specific frequency and wide bandwidth models possess a constant sensitivity across a wide band of frequencies.

ADVANTAGES

- 2 It can observe progress of plastic deformation and microscopic collapse in real time.
- 2 It can diagnose facilities while they are in operation
- 2 It can locate flaws by using several AE sensors

APPLICATIONS

- ↳ Product testing
- ↳ Tool monitoring
- ↳ Safety monitoring in civil engineering projects
- ↳ Diagnosis of the integrity of large structures.

