UNIT 1: MECHATRONICS, SENSORS AND TRANSDUCERS

MECHATRONICS:

The term mechatronics is used for the integration of microprocessor control systems, electrical systems and mechanical systems. A mechatronic system is a marriage between electronic control systems and mechanical engineering.

Eg., Automatic camera, The truck suspension, The automatic production line etc.,

IMPORTANCE OF MECHATRONICS:

A mechatronic system is more than a control system. It is an integrated and interdisciplinary approach to engineering design. The integration of mechanical, electrical, electronics and control engineering has to occur at the earliest stages of the design process. This results in cheaper, more reliable, more flexible systems. Mechatronics has to involve a concurrent approach to these disciplines rather than a sequential approach of developing.

Mechatronics brings together areas of technology involving sensors, measurement systems, drive and actuation systems, analysis of the behaviour of systems, control systems and microprocessor systems.

SYSTEMS:

A system can be thought of as a box which has an input and an output where we are concerned with only the relationship between the output and the input. Thus, a motor is a system which has as its input electric power and as output the rotation of a shaft.

A measurement system can be thought of as a box which is used for making measurements. It has as its input the quantity being measured and its output the value of that quantity.

Eg., A temperature measurement system i.e., a thermometer has an input of temperature and an output of a number on a scale.

A control system can be thought of as a box which is used to control its output to some particular value or sequence of values.

Eg., A domestic central heating control system has as its input, the temperature required in the house and as its output, the house at that temperature on the thermostat or controller and the heating furnace adjusts itself to pump water through radiators and produce the required temperature in the house.

1.2 Systems

Fig. 1.1 An example of a system

Fig. 1.2 An example of a measurement system

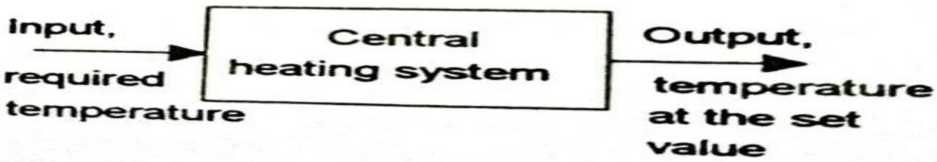
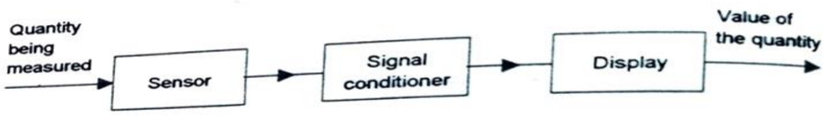


Fig. 1.3 An example of a control system

Measurement systems:

Measurement systems can be considered to be made up of three elements as illustrated in fig.

Fig. 1.4 A measurement system and its constituent elements



1. A Sensor responds to the quantity being measured by giving as its output a signal which is related to the quantity.

Eg., A thermocouple is a temperature sensor. The input to the sensor is a temperature and the output is an e.m.f. which is related to the temperature value.

2. A Signal Conditioner takes the signal from the sensor and manipulates it into a condition which is suitable for either display or to exercise control in a control system.

Eg., The output from a thermocouple is a small e.m.f. and fed through an amplifier to obtain a bigger signal. The amplifier is the signal conditioner

3. A Display system where the output from the signal conditioner is displayed.

Eg., This might be a pointer moving across a scale or a digital readout.

Example: Consider a digital thermometer. This has an input of temperature to a sensor (semi-conductor diode). The potential difference across the sensor at constant current is a measure of the temperature. This potential difference is then amplified by an operational amplifier to give a voltage which can directly drive a display. The sensor and operational amplifier may be incorporated on the same silicon chip.

Control Systems:

1.4 Control systems

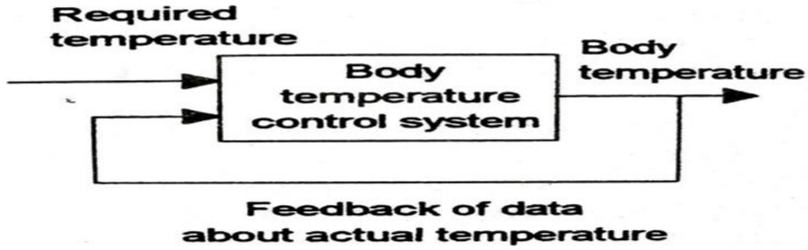


Fig. 1.5 Feedback control for human body temperature

Fig. illustrates the feedback control. Signals are fed back from the output, comparing the output of the system with what is required and adjusting its output accordingly. Our body has a temperature control system. If body temperature begins to increase above the normal, we sweat, if it decreases we shiver. Both these mechanisms are used to restore the body temperature back to its normal value.

20 Mechatronics

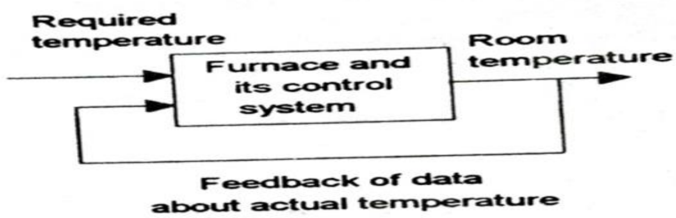


Fig. 1.6 Feedback control for room temperature

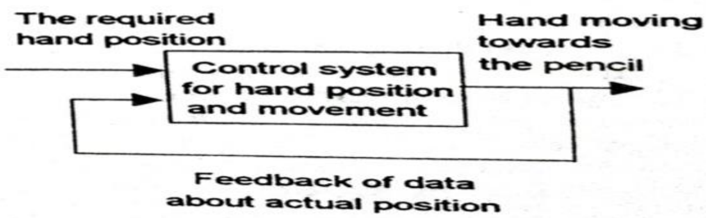


Fig. 1.7 Feedback control for picking up a pencil

Feedback control systems are widely used in Industry.

Eg., Process control where temperature, liquid level, fluid flow, pressure etc., are maintained constant.

Open and Closed loop Systems:

The two basic forms of control systems are open loop and closed loop.

Open loop systems have the advantage of being relatively simple, low cost with good reliability. However, they are inaccurate since there is no correction for error.

Closed loop systems have the advantage of being relatively accurate in matching the actual to the required values. They are more complex, more costly with greater chance of breakdown because of greater number of components

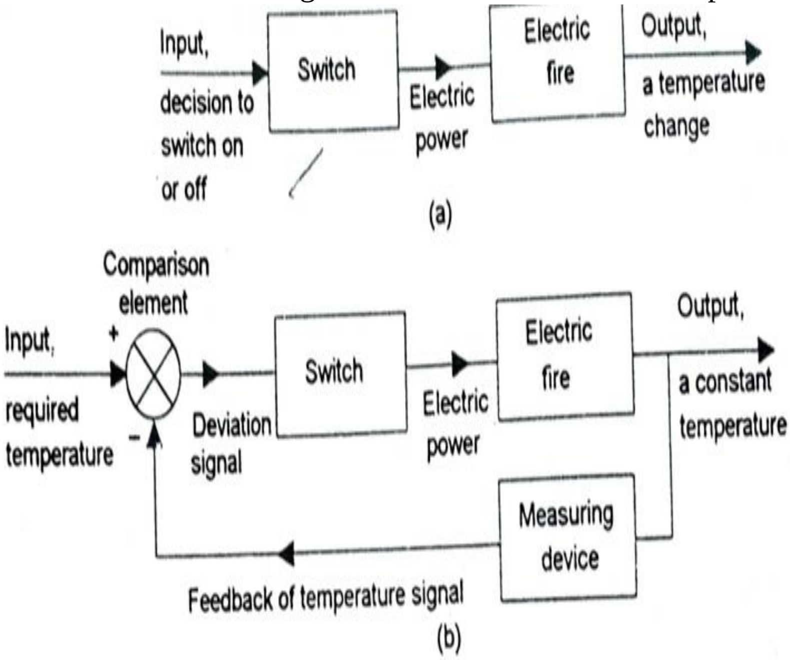


Fig. 1.8 Heating a room:
(a) an open-loop system,
(b) a closed-loop system

Applications of Mechatronics:

There are many applications of mechatronics in the mass produced products used in the home. Microprocessor-based controllers are used in domestic washing machines, dish washers, microwave ovens, cameras, cam-corders, watches, hi-fi & video recorder systems, central heating controls, sewing machines etc. They are found in cars in the active suspension, anti-skid brakes, engine control, speedometer display, transmission etc.

A larger scale application of mechatronics is a FMS involving computer controlled machines, robots, automatic material conveying and overall supervisory control.

Sensors and Transducers:

The sensor is an element which produces a signal relating to the quantity being measured. In case of an electrical resistance temperature element, the quantity being measured is temperature and the sensor transforms an input of temperature into a change in resistance.

The transducer is often used in place of sensor. Transducers are defined as elements that when subject to some physical change experience a related change. Thus sensors are transducers. However, a measurement system may use transducers, in addition to the sensor, in other parts of the system to convert signals in form to another form.

Performance terminology:

The following terms are used to define the performance of transducers and often measurement systems as a whole.

1. Range and Span:
   The range of a transducer defines the limits between which the input can vary. The span is the maximum value of the input minus the minimum value.
   Eg., a load cell for the measurement of forces may have a range of 0 to 50KN and a span of 50KN.
2. Error:
   Error is the difference between the result of the measurement and the true value of the quantity being measured.
   Error = Measured value – True value
   Eg., If a measurement system gives a temperature reading of 25 degree C when the actual temperature is 24 degree C, then the error is +1 degree C. If the actual temperature is 26 degree C, then the error is -1 degree C. A sensor might give a resistance change of 10.2 ohm when the true change is 10.5 ohm. The error is -0.3 ohm.
3. Accuracy:
   Accuracy is the extent to which the value indicated by a measurement system might be wrong. It is the summation of all the possible errors that are likely to occur, as well as the accuracy to which the transducer has been calibrated. A temperature measuring instrument may be specified as having an accuracy of + or - 2 degree C. This means that, the reading lie within + or -2 degree C of the true value. Accuracy is often expressed as a percentage of full scale deflection for circular and linear scale measuring systems. A sensor be specified as having an accuracy of + or – 5% of full range output. Thus if the range of the sensor is 0 to 200 degree C, then the reading given can be expected to be within + of – 10 degree C of the true reading.

4. Sensitivity:

The sensitivity is the relationship indicating how much output we get per unit input. i.e., output/input. Eg., a resistance thermometer may have a sensitivity of 0.5 ohm/^{0}C. This term is also used to indicate the sensitivity to inputs other than that being measured i.e., environmental changes. Thus, there can be the sensitivity of the transducer to temperature changes in environment or fluctuations in the mains voltage supply. A transducer for the measurement of pressure might be quoted as having a temperature sensitivity of + or – 0.1% of the reading per ^{0}C change in temperature.

5. Hysterisis error:

   Transducers can give different outputs from the same value of quantity being measured according to whether that value has been reached by a continuously increasing change or a continuously decreasing change. This effect is called hysteresis. Fig. shows such an output with the hysterisis error as the maximum difference in output for increasing and decreasing values.

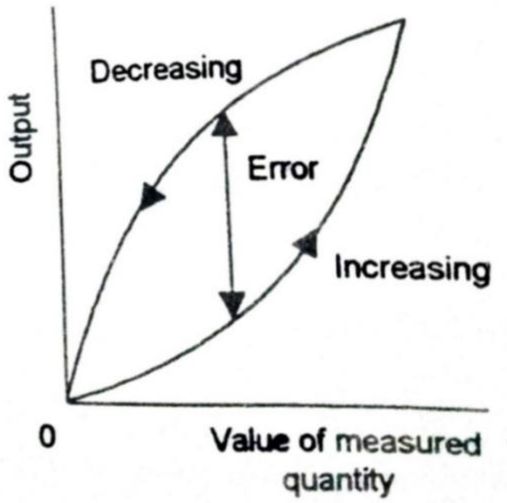


Fig. 2.1 Hysteresis

6. Non-linearity error:

   For many transducers a linear relationship between the input and output is assumed over the working range. i.e., a graph of output plotted against input is assumed to give a straight line. Few transducers have a truly linear relationship and errors occur as a result of the assumption of linearity. The error is defined as the maximum difference from the straight line. Various methods are used for the numerical expression of the non-linearity error. The differences occur in determining the straight line relationship against which the error is specified.

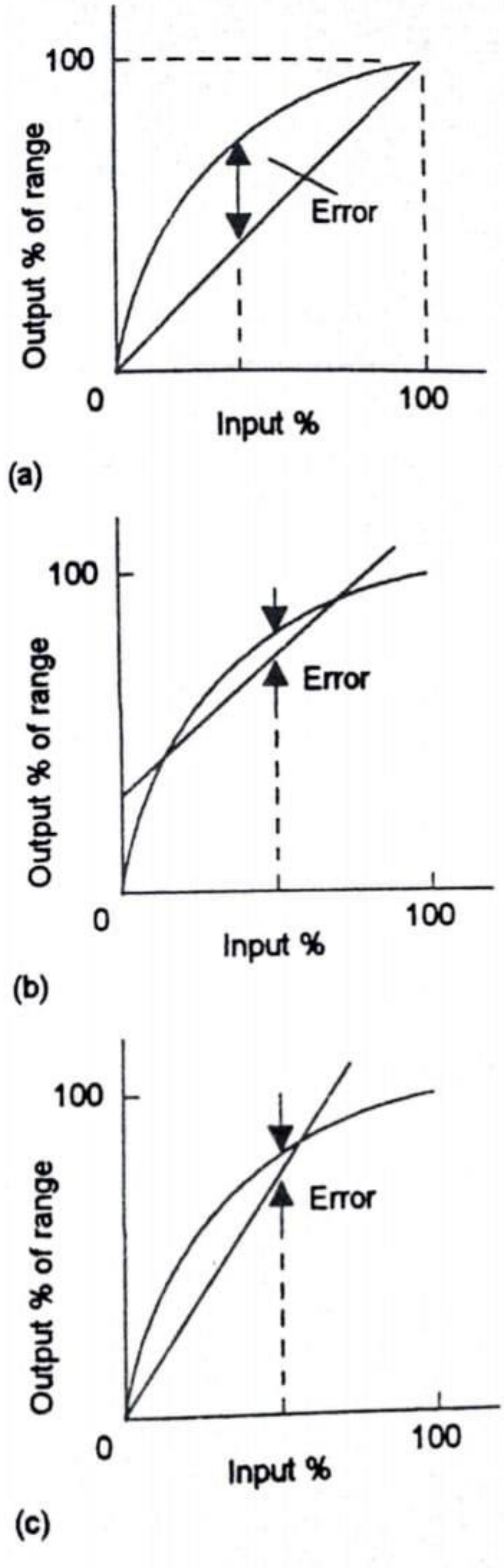


Fig. 2.2 Non-linearity error using:
(a) end-range values,
(b) best straight line for all values,
(c) best straight line through zero point

One method is to draw the straight line joining the output values at the end points of the range.

Another method is to find the straight line by using the method of least squares to determine the best fit line when all data values are considered equally in error.

Another is to find the straight line by using the method of least squares to determine the best fit line which passes through the zero point.

Fig. illustrates these three methods and how they can affect the non-linearity error. The error is generally quoted as a percentage of the full range output.

Eg., A transducer for the measurement of pressure might be quoted as having a non-linearity error of + or – 0.5% of the full range.

7. Repeatability/reproducibility:

The terms repeatability and reproducibility of a transducer are used to describe its ability to give the same output for repeated applications of the same input value. The error resulting from the same output not being given with repeated applications is expressed as a percentage of the full range output.

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

Eg., A transducer for the measurement of angular velocity typically might be quoted as having a repeatability of + or – 0.01% of the full range at a particular angular velocity.

8. Stability:

The stability of a transducer is its ability to give the same output when used to measure a constant input over a period of time. The term drift is used to describe the change in output that occurs over a time. The drift may be expressed as a percentage of the full range output. The term zero drift is used for the changes that occur in output when there is zero input.

9. Dead band/time:

The dead band or dead space of a transducer is the range of input values for which there is no output.

Eg., bearing friction in a flowmeter using a rotor means that, there is no output until the input has reached a particular velocity threshold.

The dead time is the length of time from the application of an input until the output begins to respond and change.

10. Resolution:

When the input varies continuously over the range, the output signals for some sensors may change in small steps.

Eg., A wire-wound potentiometer is such a sensor, the output going up in steps as the slider moves from one wire turn to the next.

The resolution is the smallest change in the input value that will produce an observable change in the output. For a wire-wound potentiometer, the resolution might be specified as 0.5^0 or a percentage of full scale deflection. For a sensor giving a digital output the smallest change in input signal is 1 bit. Thus for a sensor giving a data word of N bits i.e., a total of 2^N, the resolution is generally expressed as $1/2^N$.

11. Output Impedance:

When a sensor giving an electrical output if interfaced with an electronic circuit, it is necessary to know the output impedance since this impedance is being connected in either series or parallel with that circuit. The inclusion of the sensor can significantly modify the behaviour of the system to which it is connected.
Eg., Consider the significance of the terms in the following specification of a strain gauge pressure transducer.
Ranges: 70 to 1000 KPa, 2000 to 70,000 KPa
Supply voltage: 10V d.c. or a.c. r.m.s.
Full range output: 40 mV
Non-linearity and hysterisis : + or – 0.5% of full range output
Temperature range: - 54^0 C to + 120^0 C when operating
Thermal zero shift : 0.030% full range output / ^{0}C.

Displacement, Position and 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 the position of some object with reference 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 devices which give on-off outputs.

In selecting a displacement, position or proximity sensor, consideration has to be given to

1. The size of displacement (fractions of mm, mm or m). For a proximity sensor, how close should the object before it is detected?
2. Whether the displacement is linear or angular.
   Linear displacement sensors might be used to monitor the thickness or other dimensions of sheet materials, position or presence of a part, the size of a part while angular displacement methods might be used to monitor the angular displacement of shafts.
3. The resolution required.
4. The accuracy required.
5. What material the measured object is made of. Some sensors will only work with ferromagnetic materials, some only with metals & some with only insulators.
6. The cost.

Displacement and position sensors may be of contact type or non-contact type in which the measured object comes in mechanical contact with the sensor and there is no physical contact between the measured object and the sensor respectively.

In linear displacement methods involving contact, there is usually a sensing shaft which is in direct contact with the object. The displacement of this shaft is then monitored by a sensor. The movement of the shaft may be used to cause changes in electrical voltage, resistance, capacitance or mutual inductance.

For angular displacement methods involving mechanical connection, the rotation of a shaft might directly drive, through gears, the rotation of the transducer element. Non-contacting sensors might involve the presence in the vicinity of the measured object causing a change in the air pressure in the sensor or a change in inductance or capacitance.

Eg., Potentiometer sensor (linear or rotary displacements)
Strain gauged element, capacitive sensors, capacitive proximity sensor,
LVDT, Pneumatic proximity sensors, proximity switches, Hall effect sensors etc.

VELOCITY AND MOTION:

Sensors can be used to monitor linear and angular velocities and detect motion. The application of motion detectors includes security systems used to detect intruders, interactive toys and appliances.

Eg., The cash machine screen becomes active when we get near to it.

INCREMENTAL ENCODER (OPTICAL ENCODER):

It can be used for measurement of angular velocity by counting the number of pulses produced per second.

An encoder is a device that provides a digital output as a result of a linear or angular displacement. Position encoders can be grouped into (1) Optical encoders and (2) Absolute encoders.

Incremental encoders detects changes in rotation from some datum position and absolute encoders give the actual angular position.

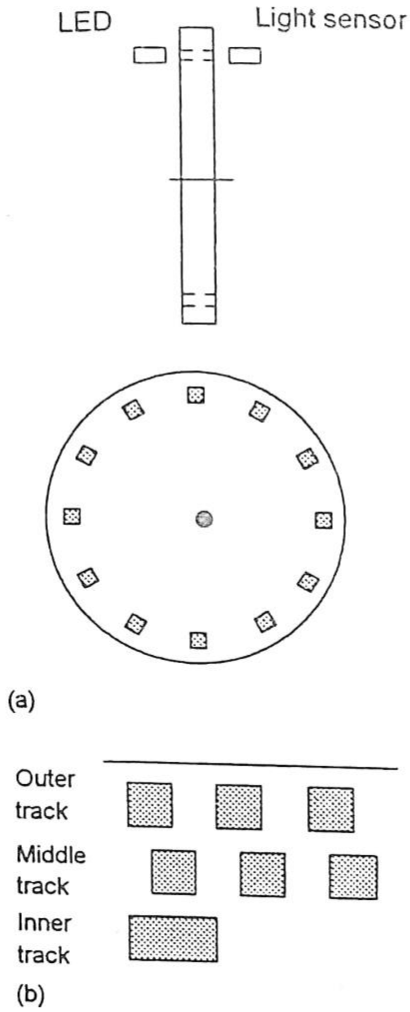


Fig. 2.16 Incremental encoder: (a) the basic principle, (b) concentric tracks

Fig. shows the basic form of an incremental encoder. A beam of light passes through slots in a disc and is detected by a suitable light sensor. When the disc is rotated, a pulsed output is produced by the sensor with the number of pulses being proportional to the angle through which the disc rotates. Thus, the angular position of the disc and hence the shaft rotating it can be determined by the number of pulses produced from datum position.

TACHO-GENERATOR:

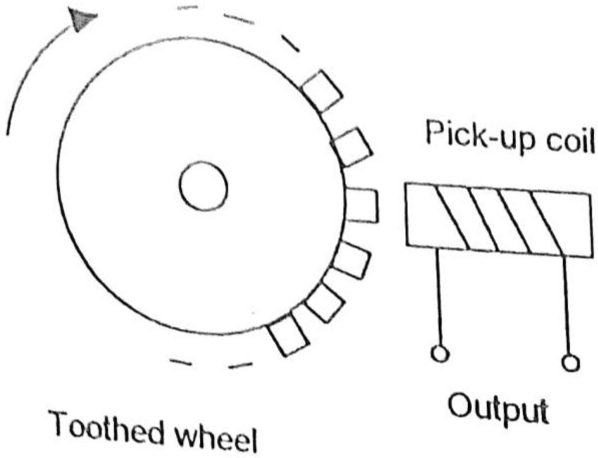


Fig. 2.26 Variable reluctance tachogenerator

The tacho generator is used to measure angular velocity. One form, the variable reluctance tacho generator consists of a toothed wheel of ferro magnetic material which is attached to the rotating shaft. A pick-up coil is wound on a permanent magnet. As the wheel rotates, so the teeth move past the coil and the air gap between the coil and the ferro magnetic material changes. Thus the flux linked by a pick-up coil changes. The resulting cyclic change in the flux linked produces an alternating e.m.f. in the coil.

If the wheel contains ‘n’ teeth and rotates with an angular velocity ‘w’, then the flux change with time can be of the form

$\Phi = \Phi 0 + \Phi a \text{ Cos } nwt$

Where $\Phi 0$ = Mean value of the flux

Φa = amplitude of the flux variation

The induced emf ‘e’ in the N turns of the pick-up coil is

$$e = -N\frac{d\emptyset}{dt} = -N\frac{d}{dt}(\Phi 0 + \Phi a \text{ Cos } nwt) = N\,\Phi a\, nw \text{ Sin } wt$$

so, we can write

$e = E_{max}$ Sin wt where $E_{max} = N\,\Phi a\, nw$

Maximum value of the induced emf E_{max} is a measure of the angular velocity.

Instead of using maximum emf as a measure of the angular velocity, a pulse shaping signal conditioner can be used to transform the output into a sequence of pulses which can be counted by a counter, the number counted in a particular time interval is a measure of angular velocity.

AC GENERATOR FORM OF TACHO GENERATOR:

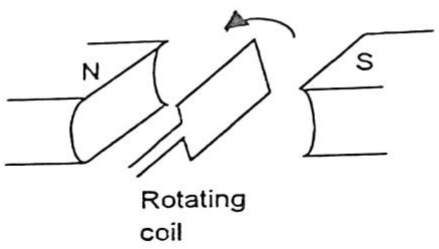


Fig. 2.27 A.C. generator form of tachogenerator

Another form is a.c. form of tacho generator. It consists of a coil (rotor) which rotates with the rotating shaft. This coil rotates in the magnetic field produced by a stationary permanent magnet or electro magnet and so an alternating emf is induced in it. The amplitude or frequency of this alternating emf can be used as a measure of the angular velocity of the rotor. The output may be rectified to d.c. voltage proportional to the angular velocity. Non-linearity error for such sensors is of the order of ± 0.15% of the full range & theses sensors are used for rotations upto about 10,000 rpm.

PNEUMATIC SENSORS:

Pneumatic sensors involve the use of compressed air, displacement or the proximity of an object being transformed into a change in air pressure.

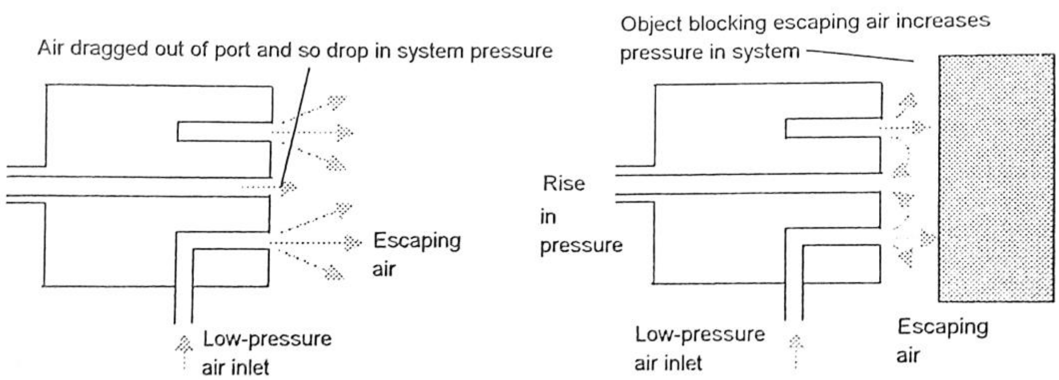


Fig. 2.19 Pneumatic proximity sensor

Fig. shows the basic form of a pneumatic sensor. Low pressure air is allowed to escape through a port in the front of the sensor. The escaping air, in the absence of any closeby object, escapes and hence reduces the pressure at the output port. However, if there is a close-by object, the air cannot so readily escape and the result is, pressure increases in the sensor output port. The output pressure from the sensor thus depends on the proximity of objects.

Such sensors are used for the measurements of fractions of mm in ranges which typically are about 3 to 12 mm.

PROXIMITY SWITCHES:

There are various forms of switch which can be activated by the presence of an object in order to give a proximity sensor with an output which is either on or off.

The micro switch is a small electrical switch which requires physical contact and a small operating force to close the contacts.

Eg., In case of determining the presence of an item on a conveyor belt, this might be actuated by the weight of the item on the belt depressing the belt and hence a spring loaded platform under it, with the movement of this platform then closing the switch. Fig. shows lever operated, roller-operated and cam-operated switches.

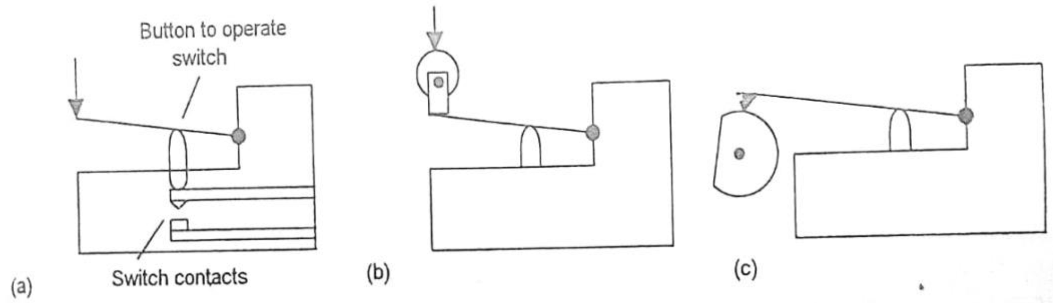


Fig. 2.20 (a) Lever-operated, (b) roller-operated, (c) cam-operated switches

Force:

A spring balance is an example of a force sensor in which a force, a weight is applied to the scale pan and causes a displacement i.e., the spring stretches. The displacement is a measure of force. Forces are commonly measured by the measurement of displacements.

STRAIN GAUGE LOAD CELL:

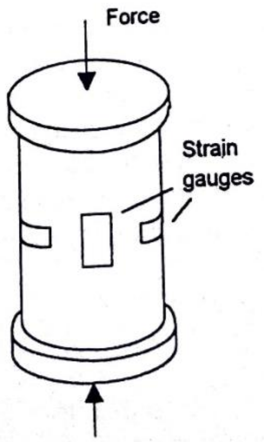


Fig. 2.33 Strain gauge load cell

A very commonly used form of force measuring transducer is based on the use of electrical resistance strain gauges to monitor the strain produced in some member when stretched, compressed or bent by the application of the force. The arrangement is generally referred as a load cell. Fig. shows such a load cell. This is a cylindrical tube to which strain gauges have been attached. When forces are applied to the cylinder to compress it, then the strain gauges give a resistance change which is a measure of the strain and hence the applied forces. Since temperature also produces a resistance change, the signal conditioning circuit used has to be able to eliminate the effects due to temperature. Typically, such load cells are used for forces upto about 10MN, the non-linearity error about ± 0.03% of full range, hysteresis error ± 0.02% of full range and repeatability error ± 0.02% of full range. Strain gauge load cells based on the bending of a strain-gauged metal element are used for smaller forces with ranges varying from 0 to 5N upto 0 to 50KN.

FLUID PRESSURE:

Many of the devices used to monitor fluid pressure in industrial processes involve the monitoring of the elastic deformation of diaphragms, capsules, bellows and tubes. The types of pressure measurements required are: absolute pressure where the pressure is measured relative to zero pressure i.e., vacuum, differential pressure where a pressure difference is measured and gauge pressure where the pressure is measured relative to barometric pressure (atmospheric pressure).

2.6 Fluid pressure

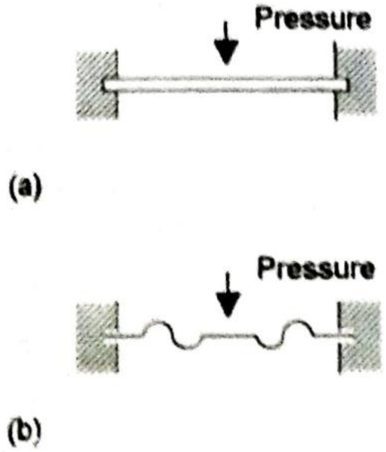


Fig. 2.34 Diaphragms: **(a)** flat, **(b)** corrugated

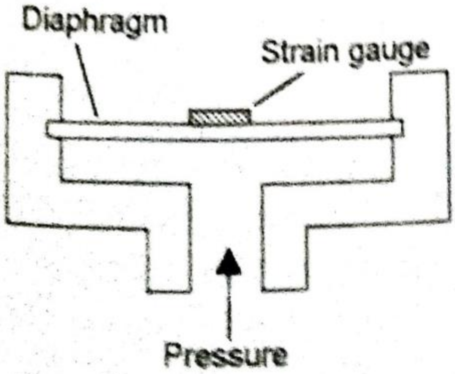


Fig. 2.35 Diaphragm pressure gauge

For a diaphragm (fig.a & b), when there is a difference in pressure between the two sides, then the centre of the diaphragm becomes displaced. Corrugations in diaphragm result in a greater sensitivity. This movement can be monitored by some form of displacement sensor, a strain gauge as illustrated in fig.2.34

A specially designed strain gauge is often used, consisting of four strain gauges with two measuring the strain in a circumferencial direction while two measure strain in a radial direction. The four strain gauges are then connected to form the arms of a wheatstone bridge. Strain gauges can be stuck on a diaphragm, an alternate is to create a silicon diaphragm with the strain gauges as specially doped areas of diaphragm.

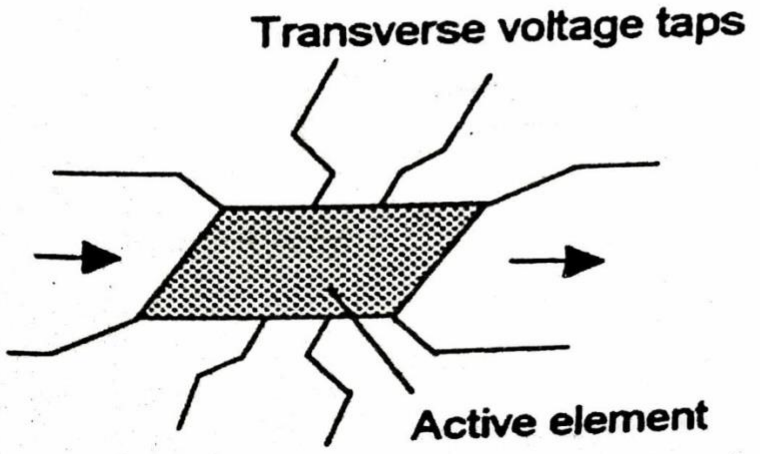


Fig. 2.36 Pressure sensor element

Another from of silicon diaphragm pressure sensor is used for the Motorola MPx pressure sensors. The strain gauge element integrated, together with a resistive network, in a single diaphragm chip. When a current is passed through the strain gauge element and pressure applied at right angles to it, a voltage is produced in a transverse direction. This together with signal conditioning circuitry, is packaged as the MPx sensor. The output voltage is directly proportional to the pressure. These sensors are available for measurement of absolute pressure (Mx numbering system ends with A, AP, AS or ASX), differential pressure (Mx numbering system ends with D or DP) and gauge pressure (Mx numbering system ends with GP, GVP, GS, GVS, GSV or GVSX)

Eg., MPx 2100 series has a pressure range of 100 kpa & with a supply voltage of 16V d.c. gives absolute pressure and differential pressure forms a voltage output over the full range of 40mV. The response time, 10 to 90% for a step change from 0 to 100 kpa is about 1.0 ms & output impedance is of the order of 1.4 to 3.0 kΩ.

The absolute pressure sensors are used for applications such as altimeters and barometers. The differential pressure sensors for air flow measurements and the gauge pressure sensors for engine pressure and tyre pressure.

Other examples of fluid pressure sensors are capsule, bellows, tube pressure sensors, piezo-electric sensors, tactile sensors.

LIQUID FLOW:

The method of measuring the flow rate of liquids involves devices based on the measurement of the pressure drop when the fluid flows through a constriction. For a horizontal tube,

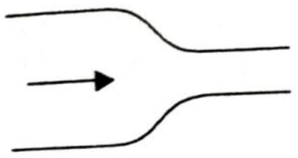


Fig. 2.44 Fluid flow through a constriction

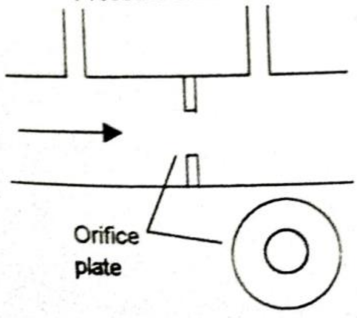


Fig. 2.45 Crifice plate

Let V1 = fluid velocity, P1 = the pressure A1 = cross-sectional area of the tube prior to constriction.

V2= fluid velocity, P2 = the pressure A2 = cross-sectional area at the constriction.

ρ = the fluid density.

Bernoulli’s equation states that fluid flowing in a tube of varying cross-section, the mass flow rate if the same every where in the tube.

Bernoulli’s equation gives

$$\frac{V_1^2}{2g}+\frac{P1}{\rho g}=\frac{V_2^2}{2g}+\frac{P2}{\rho g}$$

Since the mass of liquid passing per second prior and at the constriction must be equal.

We have A1V1 ρ = A2V2 ρ

But the quantity Discharge Q of liquid passing through the tube per second is ,

Q = A1V1 = A2V2. Hence

$$Q = (A2/\sqrt{1 - (A2/A1)^2}\ ) \times \sqrt{2 \times (p1 - p2)/\rho}$$

Thus, the quantity of fluid Q flowing through the pipe per second is proportional to √ (pressure difference). Measurements of pressure difference can be used to give a measure of the rate of flow. There are many devices based on this principle.

Eg., Orifice plate is most common.

TURBINE METER:

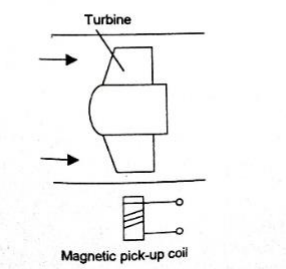


Fig. 2.46 Turbine flowmeter

The turbine flowmeter consists of a multi-bladed rotor that is centrally supported in the pipe along which the flow occurs. The fluid flow results in the rotation of the rotor, the angular velocity is proportional to the flow rate. The rate of revolution of the rotor can be determined by using a magnetic pick-up. The pulses are counted and so the number of revolutions of the rotor can be determined. The meter is expensive with an accuracy of about ± 0.3%.

LIQUID LEVEL:

The level of a liquid in a vessel can be measured directly by monitoring the position of the liquid surface or indirectly by measuring some variable related to the height. Direct methods can involve floats and indirect methods include the monitoring of the weight of the vessel by load cells. The weight of the liquid is Ah ρg where

A = cross-sectional area of the vessel.

h = height of liquid

ρ = density

g = acceleration due to gravity.

Thus changes in the height gives weight changes.

Indirect method involve the measurement of pressure at some point in the liquid, the pressure due to a column of liquid of height ‘h’ being h ρg where ρ is the liquid density.

FLOATS:

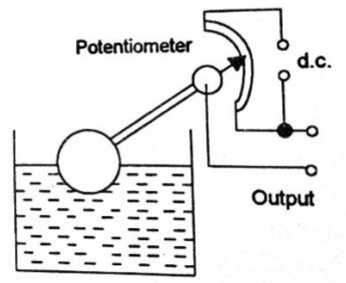


Fig. 2.47 Float system

A direct method of monitoring the level of liquid in a vessel is by monitoring the movement of a float. Fig. illustrates a simple float system. The displacement of the float causes a lever arm to rotate and so move a slider across a potentiometer. The result is an output of a voltage related to the height of liquid. Other forms involve the lever causing the core in a LVDT to become displaced or stretch or compress a strain-gauged element.

TEMPERATURE: Changes that are commonly used to monitor temperature are the expansion or contraction of solids, liquids or gases, the change in electrical resistance of conductors, semi-conductors and thermoelectric e.m.f's.

BI-METALLIC STRIPS:

2.9 Temperature

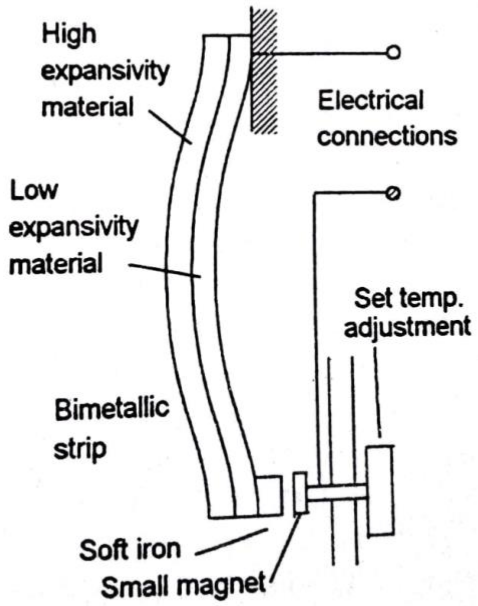


Fig. 2.49 Bimetallic thermostat

It is used in temperature control system. This device consists of two different metal strips bonded together. The metals have different co-efficients of expansion and when the temperature changes, the composite strip bends into a curved strip, with the higher co-efficient metal on the outside of the curve. This deformation may be used as temperature controlled switch as in the simple thermostat used with domestic heating systems. The small magnet enables the sensor to exhibit hysteresis, means that the switch contacts close at a different temperature from that at which they open.

HALL EFFECT SENSORS:

When a beam of charged particles passes through a magnetic field, forces act on the particles and the beam is deflected from its straight line path. A current flowing in a conductor is like a beam of moving charges and thus can be deflected by a magnetic field. This effect was discovered by E.R.Hall in 1879 and is called the Hall effect.

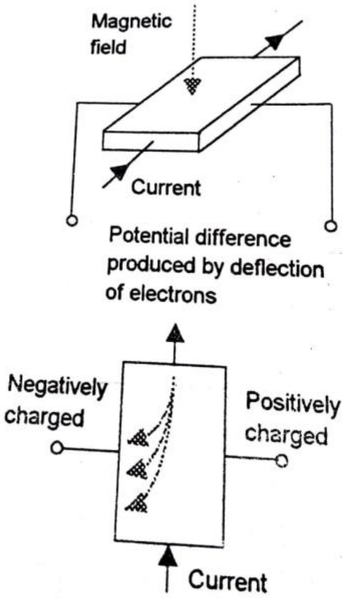


Fig. 2.23 Hall effect

Consider electrons moving in a conductive plate with a magnetic field applied at right angles to the plane of the plate (fig.) As a consequence of the magnetic field, the moving electrons are deflected to one side of the plate and that side becomes negatively charged while the opposite side becomes positively charged since the electrons are directed away from it. This charge separation produces an electric field in the material. The charge separation continues until the forces from the electric field just balance the forces produced by the magnetic field. The result is a transverse p.d. V given by

$$V = K_H BI/t$$

Where B is the magnetic flux density at right angles to the plate

I, the current through it

t, the plate thickness

K_H , a constant called Hall co-efficient

Thus, if a constant current source is used with a particular sensor, the Hall Voltage is a measure of the magnetic flux density.

Hall effect sensors can be used to determine the level of fuel in an automobile fuel tank.

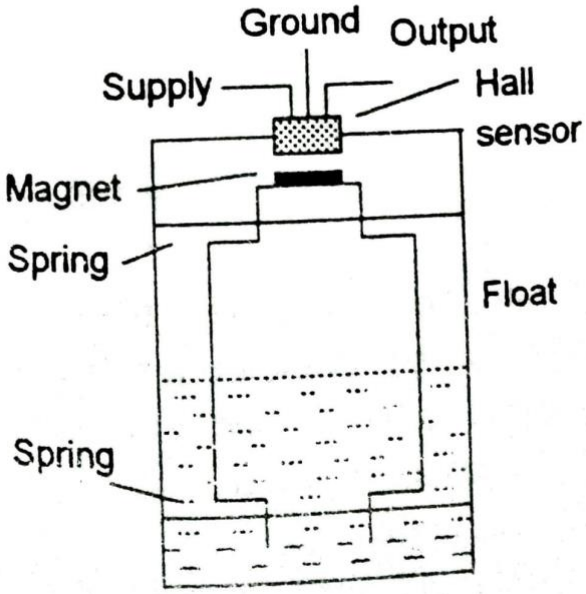


Fig. 2.25 Fluid level detector

PIEZOELECTRIC SENSORS:

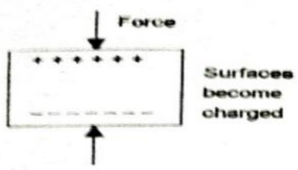


Fig. 2.40 Piezoelectricity

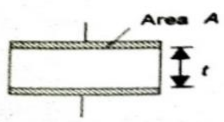


Fig. 2.41 Piezoelectric capacitor

Piezoelectric materials are ionic crystals, when stretched or compressed generate electric charges with one face of the material becoming positively charged and the opposite face negatively charged. As a result a voltage is produced. The net charge q on a surface is proportional to the amount 'x' by which the charges have been displaced and since the displacement is proportional to the applied force, F

$Q = kx = SF$

Where k is a constant and S, a constant termed the Charge Sensitivity.

Metal electrodes are deposited on opposite faces of the piezoelectric crystal (fig.). The capacitance C of the piezoelectric material between the plates is

$$C = \epsilon_0 \epsilon_\tau A/t$$

Where ϵ_τ is the relative permittivity of the material

A is area and t its thickness.

Since the charge q = CV where V is the p.d. produced across a capacitor.

Therefore V = q/C

Then, $V = \frac{S\,t}{\epsilon_0 \epsilon_\tau A} F$

The force F is applied over an area A and so the applied pressure P is F/A and $S = \frac{S}{\epsilon_0 \epsilon_\tau}$ this being termed the Voltage Sensitivity factor

$V = S_v\, t\, p$

The voltage is proportional to the applied pressure. The voltage sensitivity for quartz is about 0,055 V/mPa. For barium titanate,it is about 0.011 V/mPa.

Piezo electric sensors are used for the measurement of Pressure, Force and Acceleration.

LVDT (Linear Variable Differential Transformer):

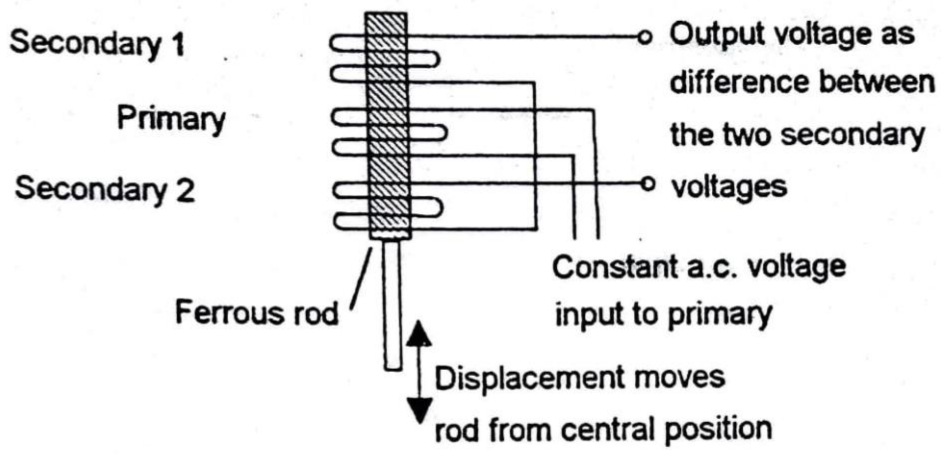


Fig. LVDT

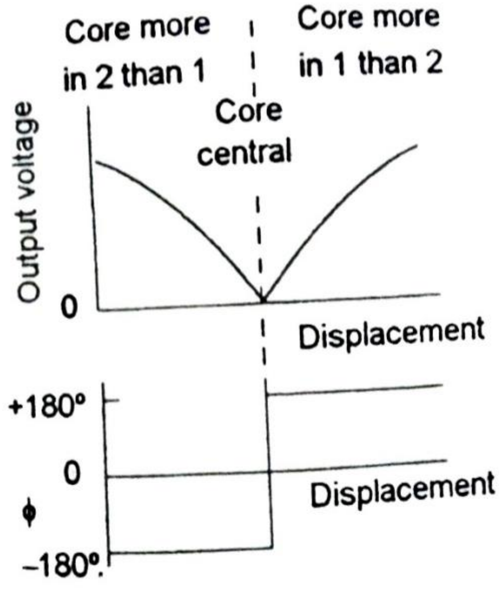


Fig. 2.12 LVDT output

The LVDT consists of three coils symmetrically spaced along an insulated tube (fig.). The central coil is the primary coil and the other two are identical secondary coils which are connected in series in such a way that their outputs oppose each other. A magnetic core is moved through the central tube as a result of the displacement being monitored.

When there is an alternating voltage input to the primary coil, alternating emf's are induced in the secondary coils. With the magnetic core central , the amount of magnetic material in each of the secondary coils is the same. Thus, the emf's induced in each coil are the same. They are so connected that their outputs oppose each other, the net result is zero output.

When the core is displaced from the central position, there is a greater amount of magnetic core in one coil than the other eg., more in secondary coil 2 than coil 1. The result is that a greater emf is induced in one coil than the other, then, there is a net output from the two coils. Since a greater displacement means, the output, the difference between the two emf's increases, the greater the displacement being monitored (fig.2).

Fig.2.12 shows how the size and phase of the output change with the displacement of the core.

With this form of output, the same amplitude output voltage is produced for two different displacements. To give an output voltage which is unique to each value of displacement we need to distinguish a phase difference of 180^0. A phase sensitive demodulator, with a low-pass filter, is used to convert the output into a d.c. voltage which gives a unique value for each displacement (fig.2.13). Such circuits are available as integrated circuits.

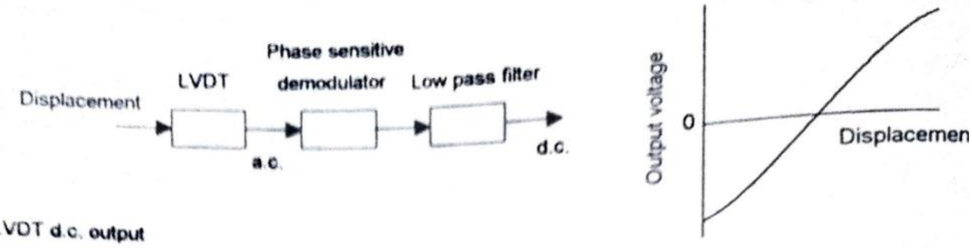


Fig. 2.13 LVDT d.c. output

Typically LVDTs have operating ranges from ± 2 to ± 400 mm with non-linearity errors of about ± 0.25%. LVDTs are widely used as primary transducers for monitoring displacements. They are also used as secondary transducers in the measurement of force, weight and pressure; these variables are transformed into displacements which can then be monitored by LVDTs.

LIGHT SENSORS:

Photo diodes are semi-conductor junction diodes which are connected in to a circuit in reverse bias, so giving a very high resistance and when the light falls on the junction, the diode resistance drops & the current in the circuit rises appreciably.

Eg., the current in the absence of light with a reverse bias of 3V might be 25μA and when illuminated by 25,000 lumens/m^2, the current rises to 375 μA. The resistance of the device with no light is $3/(25 \times 10^{-6}) = 120k\Omega$ and with light is $3/(375 \times 10^{-6}) = 8k\Omega$. A photo diode thus can be used as a variable resistance device controlled by the light incident on it. Photo diodes have a very fast response to light.

The photo transistor have a light sensitive collector base P n junction. When there is no light incident, there is a very small collector-to-emitter current. When the light is incident, a base current is produced that is directly proportional to the light intensity. This produces a collector current, which is a measure of the light intensity. Photo transistors are available as integrated packages with the photo transistor connected in a Darlington arrangement with the conventional transistor (fig.). This arrangement gives higher collector current for a given light intensity.

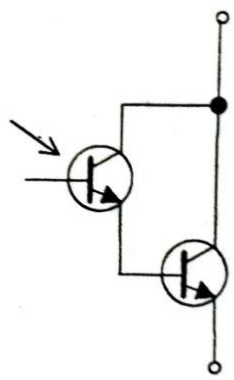


Fig. 2.58 Photo Darlington

A photo resistor has a resistance which depends on the intensity of the light falling on it, decreasing linearly as the intensity increases. The cadmium sulphide photo resistor is most responsive to light having wavelengths less than 515nm and cadmium selenide s

An array of light sensors is required in a small space to determine the variations of light intensity across that space.
Eg., In an automatic camera to determine the exposure that will be most appropriate to take account of the varying light intensities across the image. Array devices are available with large number of photo diodes in an array.

SELECTION OF SENSORS:

In selecting a sensor for a particular application, the following factors are to be considered.

1. The nature of measurement required i.e., variable to be measured, its nominal value, range of values, the accuracy required, the required speed of measurement, the reliability required, the environmental conditions under which the measurement is to be made.
2. The nature of the output required from the sensor, this determining the signal conditioning requirements to give suitable output signals from the measurement.
3. Then possible errors can be identified, taking into account factors such as their range, accuracy, linearity, speed of response, reliability, maintainability, life, power supply requirements, ruggedness, availability and cost.

The selection of sensors cannot be isolated from the consideration of the form of output required from the system after signal conditioning. Thus, there has to be a suitable marriage between sensor and signal conditioner.