9.1 INTRODUCTION

The data acquisition is nothing but collecting the data (or) information. The data acquisition systems are used to measure and record the signals. Basically, these can be obtained in two ways i.e.,

(1) Signals originating from direct measurement of electrical quantities, these may include DC voltages, AC voltages , frequency (or) resistance and are typically found in such areas as electronic component testing, environmental studies and quality analysis work.

(2) Signals originating from transducers such as strain gauges and thermocouples etc.

9.2 DATA ACQUISITION SYSTEM

(1) Data Acquisition System (DAS) plays a significant role in industrial plants. The function of DAS is to collect input information (or data) in digital form efficiently, accurately simultaneously to process, store and display the data.

(2) A data acquisition system must meet the following objectives,

(i) The necessary data should be acquired by DAS at proper timing and with appropriate speed.

(ii) The data acquired should be used efficiently in order to control the plant properly.

(iii) The data collected must be processed and stored in order to have a record for diagnosis of the plant operation at any time.

(iv) DAS should be able to determine the performance of each of its unit using online real-time data.

(v) The operation of whole plant must be monitored by DAS to maintain online best and safe operations.

(vi) DAS should posses the flexibility of being expanded for future requirements.

(vii) It should be able to identify the problems that encounter in the plant and provide effective human communication system.

(3) Data acquisition systems find applications in many industrial and scientific areas such as,

(i) Aerospace.

(ii) Telemetry.

(iii) Biomedical fields.

9.2.1 Block Diagram of a General DAS

The block diagram of a general Data Acquisition System (DAS) is shown in Fig. 9.2.1.

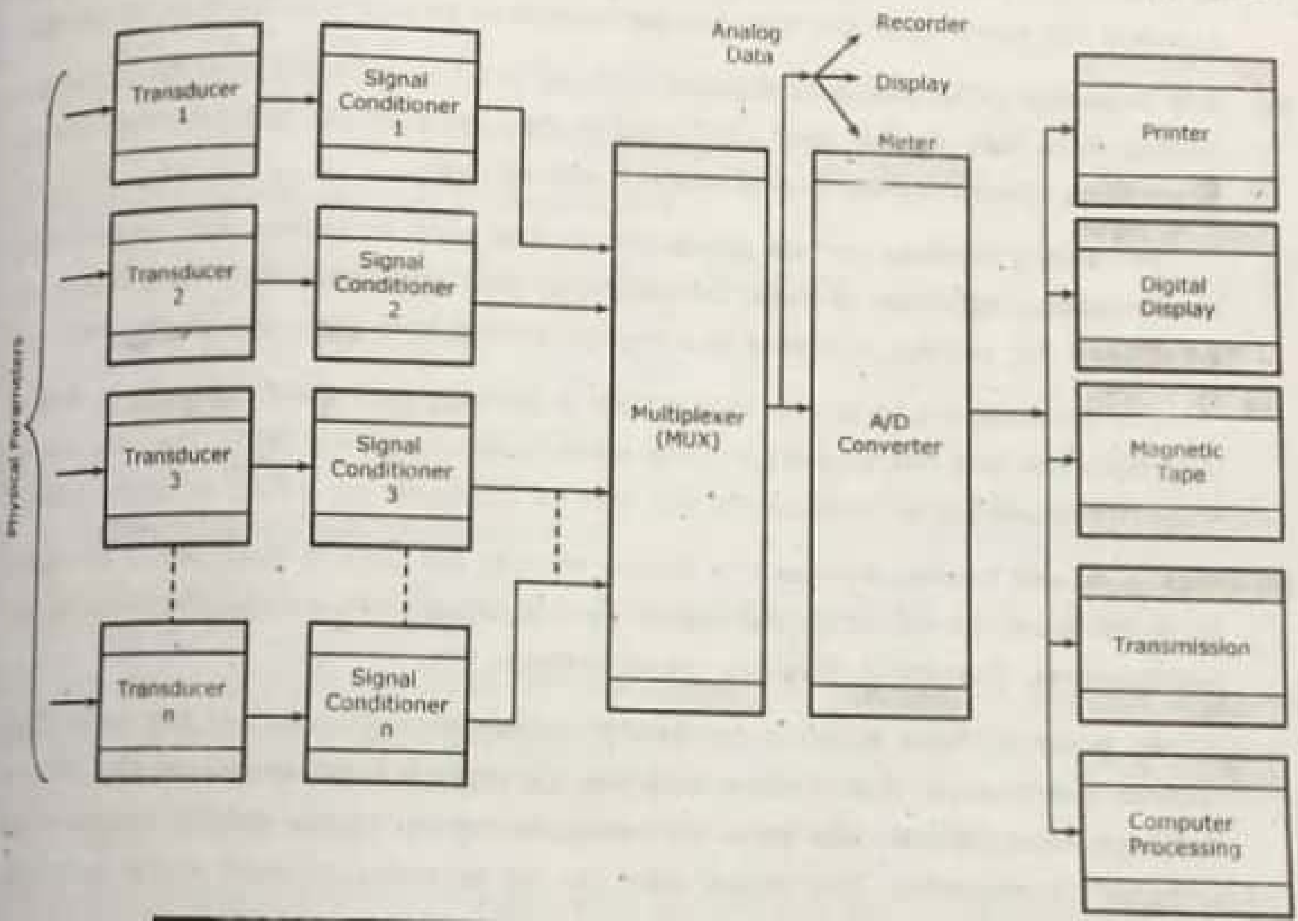


Fig. 9.2.1 Block Diagram of a Typical Data Acquisition System

The components of data acquisition system are explained below,

(1) **Transducer/Sensor :** It is the input stage of any data acquisition system. Physical quantities, which are to be measured or controlled, are applied to transducers. The function of the transducers is to convert the physical quantities into electrical signals acceptable by the DAS.

(2) **Signal Conditioner :** Usually the output signals of the transducer will be of very low level (weak) which cannot be used for further processing. In order to make the signals strong enough to drive the other elements the signal conditioners such as amplifiers, modifiers, filters etc., are used.

In short, the function of signal conditioners is to modify or improve the output of transducers for recording or displaying and storing purposes.

(3) **Multiplexer :** The function of the multiplexer is to accept multiple analog inputs and provide a single output sequentially according to the requirements. It is also called as scanner. In instrumentation systems, multiplexer circuit is used when distance between the transmitter and the receiver is large or several inputs are to be handled.

(4) **A/D Converter :** The analog-to-digital (A/D) converter is generally used to convert the analog data into digital form. The digital data is used for the purpose of easy processing, transmission, digital display and storage.

Processing involves various operations on data such as comparison, mathematical manipulations, collection of data, conversion of data into useful form such that it can be utilized for various purposes like for the control operation and display etc.

The transmission of data in digital form is possible over short distances as well as long distances and has advantages over transmission in analog form. The data can be stored permanently or temporarily and can be displayed on a CRT or digital panel.

(5) **Recorders and Display Devices :** In display devices the data is displayed in a suitable form in order to monitor the input signals. Examples of display devices are oscilloscopes, numerical displays, panel meters, etc.

In order to have either a temporary or permanent record of the usual data, recorders are used. The analog data can be recorded either graphically or on a magnetic tape Optical recorders, ultraviolet recorders, styles-and-ink recorders are some of its examples. The digital data can be recorded through digital recorders.

9.3 STUDY OF TRANSDUCERS

An electronic instrumentation system consists of a number of components which are used to perform both measurement and record the result. In general, instrumentation system consists of three major components, i.e., an input device, a signal conditioning device (or) processing device and an output device. The input device receives non-electrical signal under measurement and transfer to pure electrical signal to the signal conditioning device. In this, the signal is amplified, filtered (or) modified the signal which format (or) type, the output device is acceptable. Magnetic tape recorders, indicating meters, oscilloscope and digital computers are used as output devices.

The input quantity for most of the instrumentation systems is non-electrical. Hence, a device is required to convert the non-electrical quantity into electrical signal inorder to use the electrical methods and techniques for measurement, manipulation or control. Such a device is called as a "transducer".

"A transducer is a device which converts non-electrical form of energy into the electrical form of energy". It is a measuring device which measures and converts the non-electrical variable into electrical variable. The non-electrical form of energy can be mechanical, chemical, optical (radiant) or thermal.

Many other physical parameters such as heat, light intensity, humidity etc., may also be converted into electrical energy by means of a transducer.

9.3.1 Classification of Transducers

Transducers are categorized as following four types,

(1) Classification on the basis of transduction principle.

(2) Active and Passive Transducers.

(3) Analog and Digital Transducers.

(4) Primary and secondary Transducers.

9.3.1.1 Classification Based on Transduction Principle Used

The transducers can be classified according to the transduction principle used, that is how the measurand (input quantity) is being converted into electrical quantity like capacitance, resistance and inductance. Accordingly these are named as capacitive transducer, resistance transducer and inductance transducers respectively.

(1) **Resistance Transducers :** In resistance transducers, the measurand (input physical quantity) is converted into a change in resistance. The principle of operation of resistance transducers is based upon the familiar equation for resistance of conductor (wire) given by,

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

Where,

R = Resistance (ohm).

ρ = Resistivity of conductor (Ω-m).

l = Length of conductor (m).

A = Cross-sectional area of the conductor (m^2).

Resistive transducer works on the principle of change in the value of resistance with change in parameters ρ, l or A caused by any physical quantity.

Few types of resistance transducers with their operating principles and their applications are listed in Table 9.3.1,

Table 9.3.1 Resistance Transducers

Types of Transducers	Principle of Operation	Typical Applications
Potentiometer	Position of the slide contact is varied by an external force causing change in resistance.	Pressure, displacement.
Resistance pyrometer (thermometer)	Resistance of pure metal wire varies with temperature.	Temperature radiant head.
Resistance strain guage	Resistance of a wire changes when elongated or compressed by externally applied stress.	Stress, strain.
Photoconductive cell	Resistance of the cell varies with incident light.	Photosensitive relay.

(2) Capacitance Transducer : The principle of operation of capacitive transducers is based on the familiar equation for capacitance of a parallel plate capacitor,

$$C = \frac{A \epsilon}{d}$$

Where,

C = Capacitance.

A = Overlapping area of plates (m^2).

ϵ = Dielectric constant.

d = Distance between plates.

Capacitive transducers operates on principle "Change in the value of capacitance with change in A, ϵ or d caused by any physical quantity".

Table 9.3.2 lists the various types of capacitance transducers with their operating principles.

Table 9.3.2 Capacitance Transducers

Types of Transducers	Principle of Operation	Typical Applications
Variable capacitance pressure guage	Variation in capacitance is produced by variation of the distance between plates by an externally applied force.	Displacement, pressure.
Capacitor microphone	Sound pressure varies the capacitance between a fixed plate and movable diaphragm.	Speech, music, noise.
Dielectric guage	Changes in dielectric varies the capacitance.	Thickness, liquid level.

(3) **Inductance Transducer :** Inductance transducers are based on principle that "change in the magnetic characteristic of an electrical circuit in response to a measurand." Inductance transducers are categorized as two types,

(i) **Self Generating Type :** In this type voltage is generated because of the relative motion between a conductor and a magnetic field. These may be further classified as follows,

- Electromagnetic type.
- Electrodynamic type.
- Eddy current type.

(ii) **Passive Type :** In this type the motion of an object results in changes in the inductance of the coils of the transducer. These may be further classified as follows,

- Variable reluctance.
- Mutual inductance.
- Differential transfer type.

Table 9.3.3 lists the various types of inductance transducers with their operating principles,

Table 9.3.3 Inductance Transducers

Types of Transducers	Principle of Operation	Typical Applications
Magnetic circuit Transducer	Self or mutual inductance of a.c. excited coil is varied by changes in the magnetic circuit.	Displacement.
Reluctance pick up	Reluctance of the magnetic circuit is varied.	Displacement, vibration and position.
Differential transformer	The differential voltage of two secondary windings of a transformer is varied by varying the position of the magnetic core by an externally applied force.	Displacement and position.

9.3.1.2 Active and Passive Transducers

(1) Active Transducers : The transducer which does not require any external excitation to provide their output are referred as active transducers. Since, these transducers do not use any auxiliary source and generate their own current or voltage output, these are also known as 'self generating type transducers'.

Table 9.3.4 lists the various types of active transducers with their operating principles,

Table 9.3.4 Active Transducers

Types of Transducers	Principle of Operation	Typical Applications
Thermocouple	An e.m.f. is generated across the junction of two dissimilar metals.	Temperature, heat flow and radiation.
Moving coil generator	Motion of a coil in a magnetic field generates a voltage.	Velocity, vibration.
Piezo electric pick up	When an external force is applied across certain crystalline materials, such as quartz, an e.m.f. is generated.	Sound, vibration, acceleration and pressure changes.
Photo voltaic cell	An e.m.f is generated in a semiconductor junction device when radiant energy stimulates the cell.	Lighmeter, solar cell.

(2) **Passive Transducers :** The transducers which require an external excitation to provide their output are referred as passive transducers. Since, these transducers use power from an auxiliary source, these can also be called as 'externally powered transducers'.

Examples : Resistance thermometers and thermistors, potentiometric devices, differential transformer, photoemission cell etc.

9.3.1.3 Analog and Digital Transducers

(1) **Analog Transducers :** These transducers convert the input physical phenomenon into an analog output which is a continuous function of time.

Examples : Strain gauge, a thermocouple, a thermistor or an LVDT (linear voltage differential transformer).

(2) **Digital Transducers :** These transducers convert the input physical phenomenon into an electrical output which may be in form of pulse.

Example : Turbine meter used in flow measurements.

9.3.1.4 Primary and Secondary Transducers

(1) **Primary Transducer :** The transducer which converts the measurement of one physical variable into another variables (like displacement, strain etc.) and whose output forms the input of another transducer is called as primary transducer.

Examples : Bourdon tube, strain gauge.

(2) **Secondary Transducer :** The transducer which converts the output of first transducer into some electrical output is called secondary transducer.

Example : LVDT (Linear Variable Differential Transformer).

9.3.2 Factors for Selection of a Transducer

Selecting a transducer plays an important role because the transducer is the input element which converts one form of physical quantity to a proportional electrical quantity. Hence appropriate selection of transducer results in having accurate results. Some of the factors to be considered while selecting a transducer are,

(1) **Operating Principle :** Basically the transducers are selected based on their operating principle. Examples of operating principles used by the transducers are resistive, capacitive, piezoelectric, inductive, optoelectronic principle etc.

(2) **Operating Range :** The transducer should be able to function within the specified range with good resolution. Every transducer should be provided with some rating so that it will perform its function within that range without any breakdown.

(3) **Sensitivity :** The transducer must give a sufficient output signal per unit of measured input in order to yield meaningful data.

(4) **Accuracy :** The transducer should be such that, it does not require frequent calibration and has a small value of repeatability, so that high degree of accuracy is assured.

(5) **Linearity :** The input-output characteristics of the transducer should be linear. The transducers are designed with linear output/measured relationship as this tends to facilitate data reduction.

(6) **Dynamic Response :** In case of input varying with time, the transducer should be able to respond to the changes in the input as quickly as possible.

(7) **Ruggedness :** The ruggedness both of mechanical and electrical intensities of transducer versus its size and weight must be considered, while selecting a transducer.

(8) **Cross Sensitivity :** This factor, is considered when measuring mechanical quantities. Here, the actual quantity to be measured is in one plane and the transducer is subjected to variations in another plane. As the sensitivity to variations of the measured quantity in a plane perpendicular to the required plane has been such as to give completely erroneous results when the transducer has been used in practice, so more than one promising transducer design had to be abandoned.

(9) **Errors :** Errors inherent in the transducer itself should be small enough in order to yield meaningful data.

(10) **Loading Effects :** The transducer should have a high input impedance and a low output impedance in order to avoid the loading effects.

(11) **Insensitivity to Unwanted Signals :** The transducer must be highly sensitive to desired signals and minimal sensitive to unwanted signals.

(12) **Electrical Parameters :** The electrical parameters like type and length of cable required, signal to noise frequency response limitations should also be considered.

(13) **Static Characteristics :** The selected transducer should have low hysteresis, high linearity and high resolution.

(14) **Stability and Reliability :** The transducer should have high degree of stability during its function and also storage life. It should also have a high degree of reliability.

(15) **Environmental Compatibility :** When the transducer operates under conditions which are different from room conditions, errors should not appear at the output of transducer. In addition to this external forces should not affect the performance of the transducer. Hence a transducer should be operative under its temperature range, should be able to work in corrosive environments, should be able to withstand pressures and shocks and other interactions to which it is subjected to.

9.3 Linear Variable Differential Transformer (LVDT)

LVDT is a most simple and popular type of displacement transducer (i.e., converts applied displacement into its proportional electrical output) operates on the principle "change in inductance in accordance with the displacement". This is achieved either by varying the mutual inductance between the two coils (linear variable differential transformer) or by varying self inductance (variable reluctance sensor).

9.3.1 Construction and Working Operation of LVDT

CONSTRUCTION OF LVDT

The basic construction of a LVDT is shown in Fig. 9.3.1,

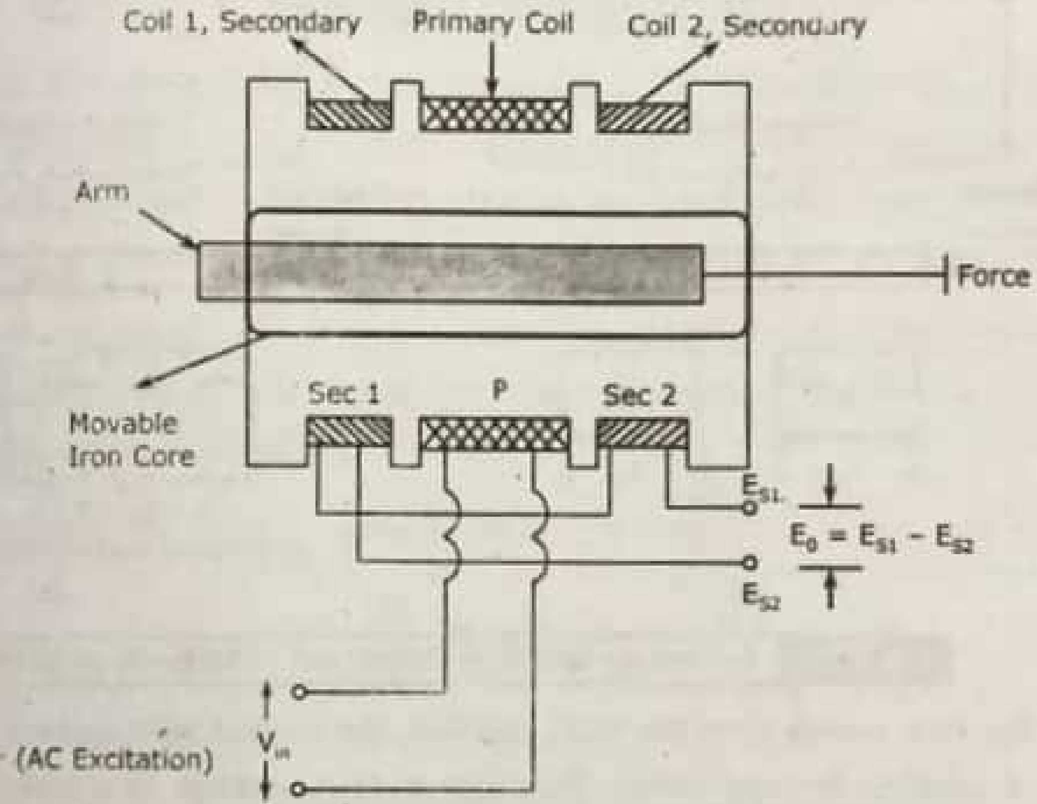


Fig. 9.3.1 Basic Construction of LVDT

LVDT consist of a single primary winding P and two secondary windings S1 and S2 wound on a hollow cylindrical former. The secondary coil having an equal number of turns are connected in series opposition so that the e.m.f.s induced in the coils oppose each other. The primary winding is connected to an a.c. excitation whose frequency may range from 50 Hz to 20 kHZ. A movable soft iron core slides inside the hollow former.

The position of the movable core determines the flux linkage between the a.c. excited primary winding and each of the two secondary windings. The core made up of nickel iron alloy is slotted longitudinally to reduce eddy current losses. The displacement to be measured is applied to an arm attached to the core.

OPERATION OF LVDT

As the primary winding is excited by sinusoidal voltage, an alternating magnetic field gets induced. This magnetic field induces alternating voltages in two secondary windings. The induced voltage depends on the position of magnetic core with respect to the NULL condition. The NULL position is the position, at which the output voltage E_o is zero. The two secondary coils S_1 and S_2 are connected in series opposite mode as shown in Fig. 9.3.2(a) and (b). Let the voltage induced at the secondary coil S_1 is E_{S1} and that at S_2 is E_{S2}. E_{out} is the output voltage.

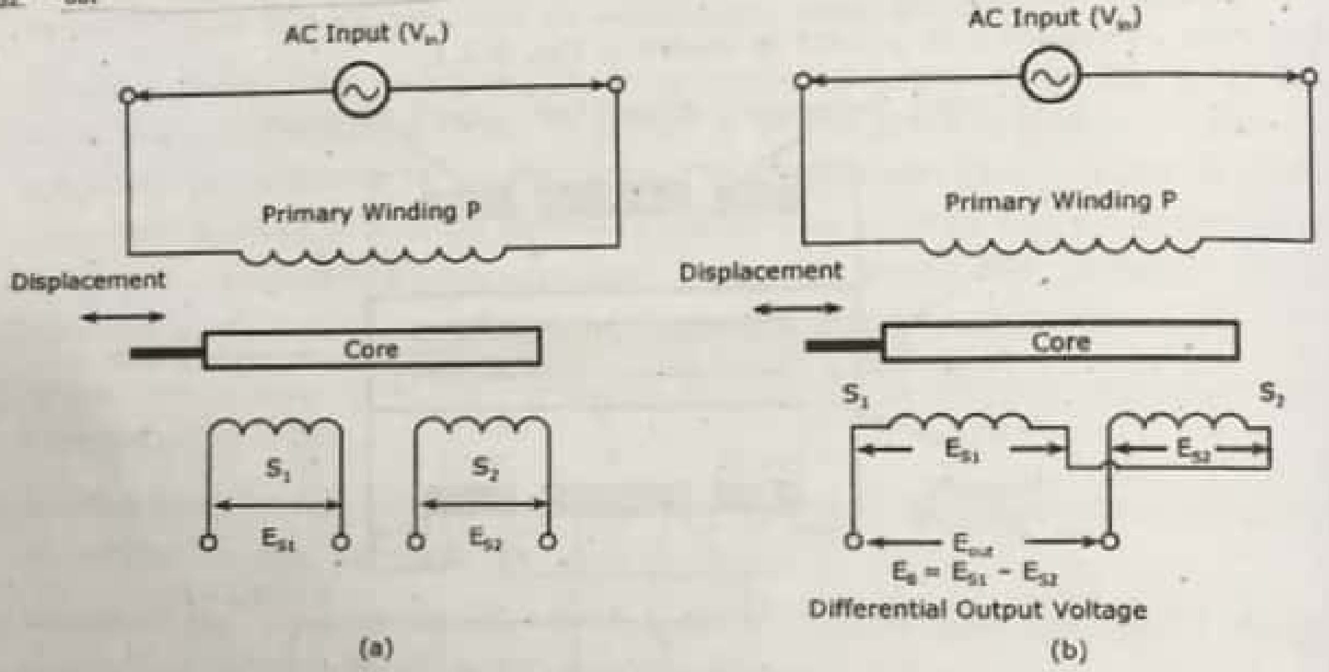


Fig. 9.3.2 Secondary Windings Connected in Series in an LVDT

When the core moves from the NULL position, the mutual inductance is more for one winding and smaller for the other. Thus the output voltage is a linear function of displacement (position) of the core with respect to the NULL position. The operation of an LVDT is divided into three modes which are discussed below,

(1) Mode 0 : When the core is at the NULL position, the emfs induced in the secondary windings are equal. Therefore, the output voltage E_o is 0, i.e., $E_{S1} = E_{S2}$, as shown in Fig. 9.3.3(a).

(2) Mode 1 : When the core is moved to the right side with respect to the NULL position, more flux gets linked with the right side secondary coil S_2 than left sided secondary coil S_1. Therefore, the output voltage, $E_o = E_{S2} - E_{S1}$, i.e., the voltage across the coil S_2 is more than that across the coil S_1 as shown in Fig. 9.3.3(b).

(3) **Mode 3 :** When the core is moved to the left side with respect to the NULL position, more flux gets linked in the secondary coil S_1. Therefore, the output voltage $E_0 = E_{S1} - E_{S2}$, i.e., the voltage across the coil S_1 is more than that across the coil S_2 as shown in Fig. 9.3.3(c).

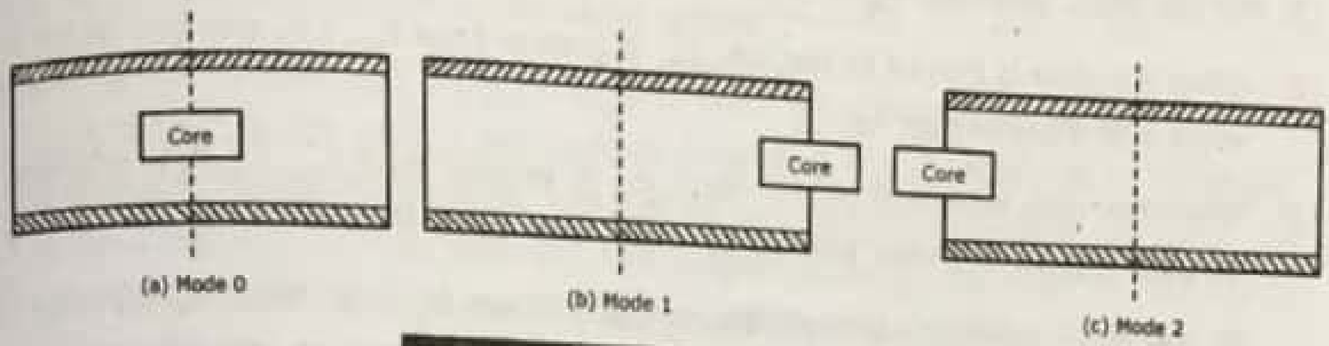


Fig. 9.3.3 Operation of an LVDT

The above discussion indicates that the output, i.e., the differential voltage, is out of phase by 180⁰ when the core passes through NULL position. The output voltage E_0 across the secondary winding is proportional to the linear displacement applied to the movable core. The output voltage may be applied to recorder or controller for analysis.

The displacement can be measured by comparing the amplitude and phase of differential output voltage with the amplitude and phase of the excitation or source voltage and direction of movement.

Fig. 9.3.4 shows the transfer characteristics between output voltage and displacement of LVDT.

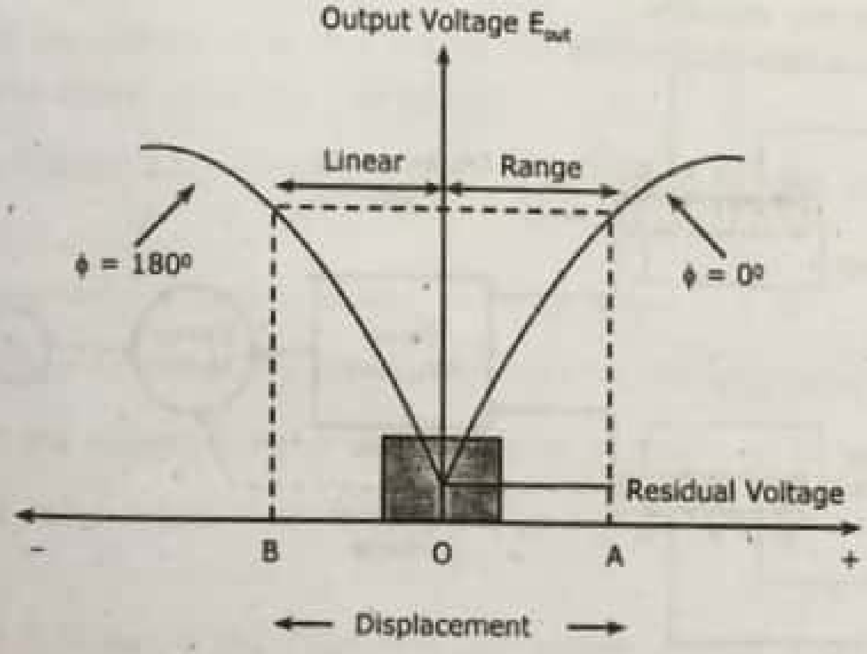


Fig. 9.3.4 Output Voltage Versus Displacement Characteristics

It indicates that the output voltage E_o is linear with the displacement of the core, but there is a phase shift of 180^0 when the core moves through the NULL position. This characteristic is linear between OA and OB, becomes non linear outside this portion.

(1) At the NULL position, $E_{S1} = E_{S2}$. So $E_o = 0$ (position O).

(2) When the core is moved to the left, E_{S1} is greater than E_{S2}, i.e., positive. So the phase angle ϕ is 0^0 (Position A).

(3) When the core is moved to the right, E_{S2} is greater than E_{S1}. So E_o is negative. The output voltage is phase shifted by 180^0, $\phi = 180^0$ (Position B).

At the NULL position, though the output voltage $E_o = 0$, there is a small voltage because of residual voltage. This residual voltage occurs due to the following reasons,

(1) Stray electric and magnetic field between the windings.

(2) Harmonics present in the excitation voltage E_{in}.

(3) Temperature effects.

(4) Improper isolation between the windings.

The problem of residual voltage can be minimized by using low pass filter, proper grounding circuits, shunt capacitive and resistive circuits, isolation techniques and so forth.

9.3.3.2 Displacement Measurement Using LVDT

The operation of LVDT can be explained with the help of a closed loop servo system. Fig. 9.3.5 depicts the scenario,

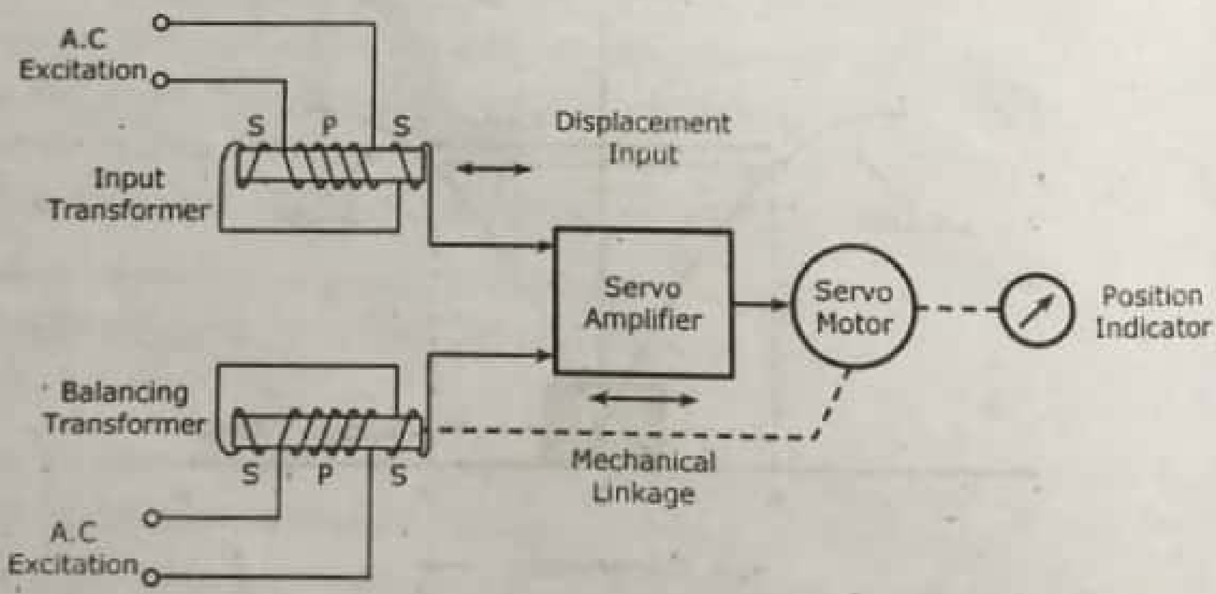


Fig. 9.3.5 Displacement Measurement using LVDT

Scanned by CamScanner

There are two transformers, input transformer and balancing transformer. These two are connected in series opposition. The sum of these two voltages are fed to a servo motor by servo amplifier. The servo motor is a two-phase motor.

When the two transformers are at reference positions, the sum of the voltages is zero and no voltage is supplied to the servo motor.

When the core of the input transformer is moved away from the reference position, voltage is produced at the output and is then amplified and rotates the servo motor. The shaft of the motor is mechanically coupled to the balancing transformer. Since the output of balancing transformer opposes the output of input transformer, the motor continues to rotate until the outputs of two transformers are equal.

The indication on the motor shaft is calibrated to read the displacement of balancing transformer, indirectly, the displacement of input transformer.

9.1.3 Advantages/Characteristics of LVDT

The characteristics which make the LVDT the most popular transducer are as follows,

(1) It is an electrical transformer containing a separable non-contacting type of core.

(2) **Linearity :** LVDT has good linearity i.e., it produces linear output voltages for the applied input. Generally, it can be used to measure displacements of about 1.25 mm to 250 mm. However, it permits the measurement range down to 0.003 mm with 0.25% full scale linearity. A commercial LVDT provides a linearity of 0.05%.

(3) **Sensitivity :** An LVDT has high sensitivity of about 40 V/mm.

(4) **Resolution :** It has infinite resolution. Mostly the effective resolution depends on the test equipment rather than the transducer.

(5) **Output :** It produces high output. Therefore, it doesn't require any amplification devices.

(6) **Power Consumption :** It consumes less power of about < 1 W.

(7) **Hysteresis :** It exhibits low hysteresis. Therefore, it has very good repeatability.

(8) **Sizes :** LVDTs are designed within the ranges of $\pm$ 0.05 - $\pm$ 25 inches.

(9) The operating temperature range of LVDT is as high as $\pm$ 600° C and as low as − 265° C.

(10) **Ruggedness :** It is simple and rugged in construction. Hence, it can withstand high degree of shocks and vibrations.

9.3.3.4 Demerits of LVDT

Following are the demerits of LVDT,

(1) It is sensitive to stray magnetic fields.

(2) The performance of LVDT is affected by variations in temperature.

(3) It has limited dynamic response.

(4) To provide high differential output, it requires large displacements.

(5) It provides A.C output. Therefore, it requires a demodulator circuit if the receiving device operates only on D.C.

9.3.3.5 Applications of LVDT

Some of the principle applications of LVDT are as follows,

(1) LVDT is used to measure linear displacements ranging from a fraction of mm to cm.

(2) It can be used for measurement of force and vibrations.

(3) LVDT can be used to measure weight and pressure exerted by liquid in a tank.

(4) It can be used to measure and control thickness of a metal steel being rolled.

(5) It can be used to measure tension in a cord.

9.3.4 Strain Gauge

Strain gauge is a passive transducer which operates on the principle of piezo resistive effect. *"When a metal wire (or conducting wire) is stretched or compressed, its length and diameter changes due to which the resistance of the wire changes"*. Hence strain gauges are also called as Piezo resistive gauges.

In general, a strain gauge is used to measure the strain (by measuring the change in resistance when strained) and its associated stress. (force per unit area). The strain gauges are also used as secondary transducers, in many other detectors and transducers i.e., the load cells, diaphragm type pressure gauges, temperature sensors, accelerators and flow meters.

9.3.4.1 Gauge Factor

DEFINITION

The sensitivity of a strain gauge is described in terms of a characteristic called gauge factor, G_f. The gauge factor of a strain gauge is defined as "the ratio is per unit change in resistance to per unit change in length",

$$G_f = \frac{\Delta R/R}{\Delta L/L} \quad \text{... (9.3.1)}$$

Where,

G_f = Gauge factor.

R = Nominal gauge resistance/actual resistance.

ΔR = Change in gauge resistance.

L = Actual length or length in unstressed condition.

ΔL = Change in specimen length.

Since the change in length to the actual length i.e., $\Delta L/L$ is defined as strain, σ, thus gauge factor given by Eq. (9.3.1) can be rewritten as,

$$G_f = \frac{\Delta R / R}{\sigma} \quad \text{... (9.3.2)}$$

DERIVATION OF EXPRESSION FOR GAUGE FACTOR

The resistance, of the wire (conductor) when it is unstrained, is given by,

$$R = \frac{\rho L}{A} = \frac{\rho L}{KD^2} \quad \text{... (9.3.3)}$$

Where,

ρ = Resistivity of the material of wire (of strain gauge)

L = Length of the wire.

A = Cross sectional area of the wire.

K, D = A constant and diameter of the wire respectively.

When the wire is subjected to a stress, its length (longitudinal strain) increases and diameter (lateral strain) decreases. As a result there is an increase in resistance. The change in resistance, dR is obtained by differentiating Eq. (9.3.3),

$$dR = \frac{KD^2(\rho.dL + L.d\rho) - \rho L(2KD.dD)}{(KD^2)^2}$$

$$= \frac{1}{KD^2}\left[(\rho\,.dL + L\,.\,d\rho) - 2\rho L\,.\,\frac{dD}{D}\right]$$

$$\Rightarrow \frac{dR}{R} = \frac{\frac{1}{KD^2}\left[(\rho\,.dL + L\,.\,d\rho) - 2\rho L\,.\,\frac{dD}{D}\right]}{\frac{\rho L}{KD^2}}$$

$$\Rightarrow \frac{dR}{R} = \frac{dL}{L} + \frac{d\rho}{\rho} - 2\frac{dD}{D} \quad \text{... (9.3.4)}$$

Poisson's ratio is defined as the ratio of lateral strain to longitudinal strain.

$$\gamma = \frac{-\text{Lateral strain}}{\text{Longitudinal strain}} = \frac{-dD/D}{dL/L}$$

$$\Rightarrow \qquad \frac{dD}{D} = \gamma \frac{dL}{L} \qquad \dots (9.3.5)$$

Substituting the Eq. (9.3.5) in Eq. (9.3.4), we get,

$$\frac{dR}{R} = \frac{d\rho}{\rho} + \frac{dL}{L} + 2\gamma\frac{dL}{L}$$

$$= \frac{d\rho}{\rho} + \frac{dL}{L}(1 + 2\gamma)$$

Dividing the above equation by $\frac{dL}{L}$, we get,

$$\frac{dR/R}{dL/L} = \frac{d\rho/\rho}{dL/L} + 1 + 2\gamma$$

For small changes, we have,

$$\frac{\Delta R/R}{\Delta L/L} = \frac{d\rho/\rho}{dL/L} + 1 + 2\gamma$$

The term $\frac{\Delta R/R}{\Delta L/L}$ is called gauge factor (G_f) of the strain gauges. Therefore,

$$\therefore \qquad \boxed{G_f = 1 + 2\gamma + \left[\frac{\Delta\rho/\rho}{\Delta L/L}\right]} \qquad \dots (9.3.6)$$

Eq. (9.3.6) gives an expression for gauge factor of the strain gauge. In Eq. (9.3.6), the term $\frac{\Delta\rho/\rho}{\Delta L/L}$ represents piezo resistive effect. (*i.e.,* change in resistivity due to strain) When piezo resistive effect is ***neglected,*** the gauge factor can be rewritten as,

$$\boxed{G_f = 1 + 2\gamma} \qquad \dots (9.3.7)$$

Eq. (9.3.4) is valid only when ***piezo resistive effect*** is ***almost negligible.*** The Poisson's ratio of all metals lies between 0 and 0.5. This gives gauge factor as 2 approximately. In case of wire wound strain gauges, where the common value for Poisson's ratio is 0.3, the value of G_f amounts to 1.6.

EXAMPLE PROBLEM 1

A resistance strain gauge with a gauge factor 2.04 is fastened to subjected to a strain of 1×10^{-6}. If the original resistance of the gauge is the change in resistance.

SOLUTION

Given Data : Strain, $\sigma = 1 \times 10^{-6}$

Gauge factor, $(G_f) = 2.04$

Original resistance of gauge, $(R) = 120\ \Omega$.

Therefore change in resistance,

$$\Delta R = G_f\, \sigma R$$

$$= 2.04 \times 1 \times 10^{-6} \times 120 = 0.2448\ m\Omega$$

$$\therefore \quad \Delta R = 0.2448 \times 10^{-3}\ \Omega$$

9.3.4.2 Types of Strain Gauges

Following are the few types of strain gauges which are explained below,

9.3.4.2.1 Wire Wound Strain Gauge

Wire wound strain gauges are made from thin resistance wire. These are generally small in size, have minimal leakage and can be used at high temperatures. The wire wound strain gauges are divided into two types. They are explained below,

(1) **Bonded Wire Strain Gauges :** The usual form of strain gauges used for the measurement of strains is the bonded type. In bonded type, the strain gauge (made up of thin resistance wire of 25μm or less in diameter) is directly passed on the resin base or thin paper sheet which is usually cemented to the device undergoing stress as shown in Fig. 9.3.6,

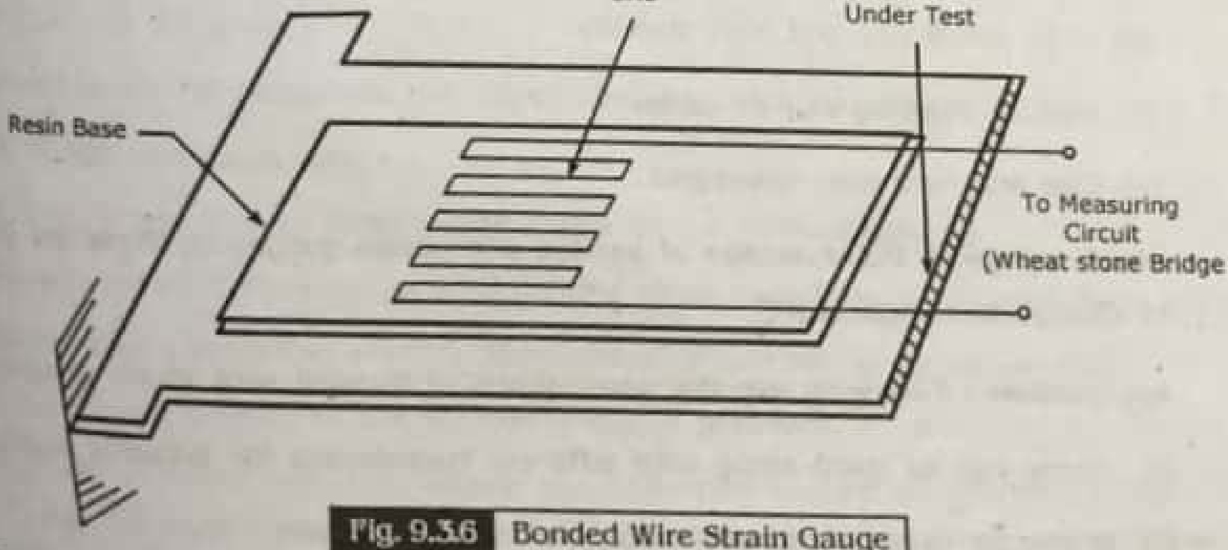


Fig. 9.3.6 Bonded Wire Strain Gauge

When a force or pressure is applied to the device, the physical dimensions will change. Since, a metal foil strain gauge is pasted on its surface, the dimensions of metal foil strain gauge changes which causes it to change its resistance. The measure of change in resistance will become the measure of applied pressure or force.

This change in resistance can be measured by connecting to the measuring circuit (to one of the 4 arms of balanced Wheatstone bridge). This connection makes the bridge to become unbalance and some output voltage will be generated which gives the value of resistance. This measured resistance gives the applied force.

The difficulty faced in using a bonded strain guage is to fix the guage to the object. The adhesive material used for this purpose must have the following properties,

(i) It must hold the guage firmly to the structure.

(ii) It must have sufficient elasticity to go under strain without loosing its adhesive property.

(iii) It should offer resistance to environmental conditions such as temperature and humidity.

Advantages : Following are the advantages of bonded wire strain guages,

(i) Accuracy is more.

(ii) These can be available in different shapes.

(iii) High sensitivity and high stability.

(iv) Perfect bonding can be done.

(v) Can measure high pressures.

Disadvantages : Disadvantage of bonded wire strain guages is, these are sensitive to change in temperature.

Applications : Following are the applications of bonded wire strain guages,

(i) These can be used along with different transducers for different applications.

(ii) It can be used in the applications of stress analysis.

(2) Unbounded Strain Gauges : An unbonded strain gauge consists of a resistance wire stretched between two frames, one being movable and other fixed one as shown in Fig. 9.3.7.

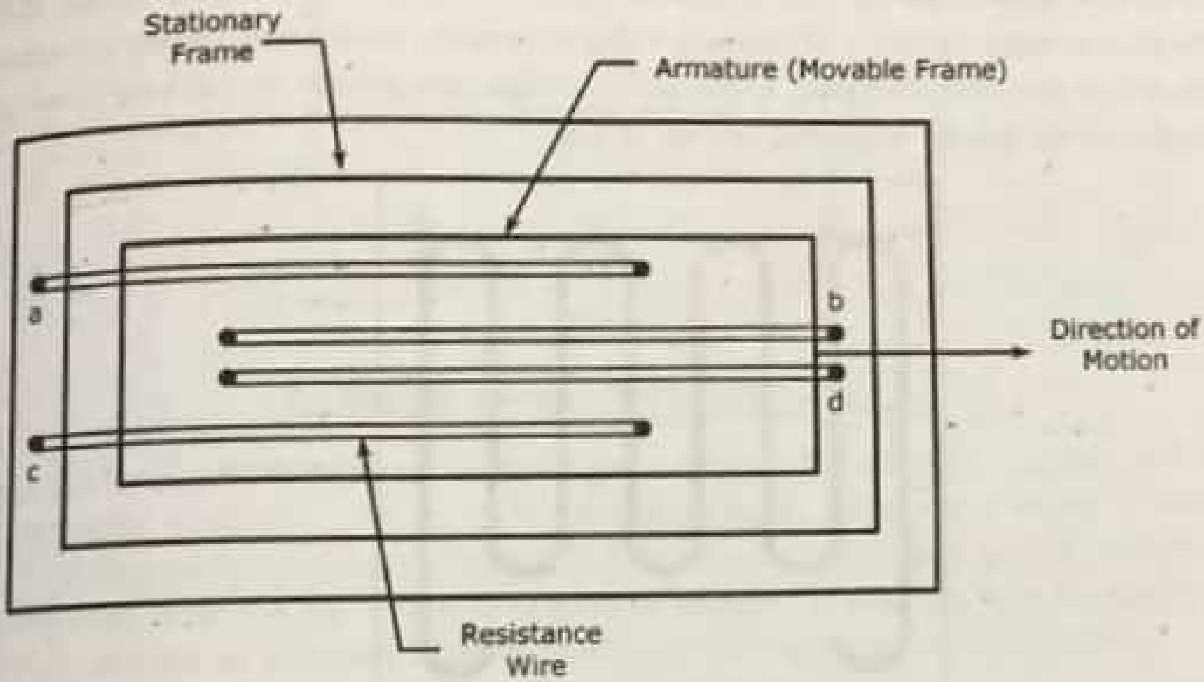


Fig. 9.3.7 Principle of Construction of Unbonded Strain Guage

When a force is applied to the right hand side, then the tension in wires a and c increases and reduces the tension in wires b and d. A force applied to the left side does just the reverse. These changes in tensions of wires causes the change in the resistance of wires, the four resistance wires are generally connected in four arms of a Wheatstone bridge. With no external load applied (with only preload present), the bridge is balanced. Variation in the resistance of wires leads to unbalanced condition of the bridge and giving an output voltage e_0 in proportion to the motion.

The motions directly measurable by this type of gauge are very small, of the order of 0.04 mm full scale.

Advantages : Following are the advantages of unbonded strain guages,

(i) It has greater accuracy.

(ii) This gauge can be used in the range of ± 0.15% strain.

Disadvantages : Disadvantage of unbonded strain guages is, it requires more space.

Applications : Following are the applications of unbonded strain guages,

(i) It can be applied in the measurement of pressure, acceleration and force.

(ii) Used in those systems, where gauge can be placed at different places and requires measurement of pressures or stress frequently or more number of times.

9.3.4.2.2 Foil Strain Gauge

Foil strain gauges looks like a wire gauge except it uses a thin sheets of metal foil to sense the applied strain. The materials used for its construction are nickel, nichrome, platinum, isoelastic (nickel + chromium + molybdenum), constantan (nickel + copper). The gauge factor and characteristics of foil strain gauges are similar to the wire strain gauges. Foil type strain gauge is shown in Fig. 9.3.8,

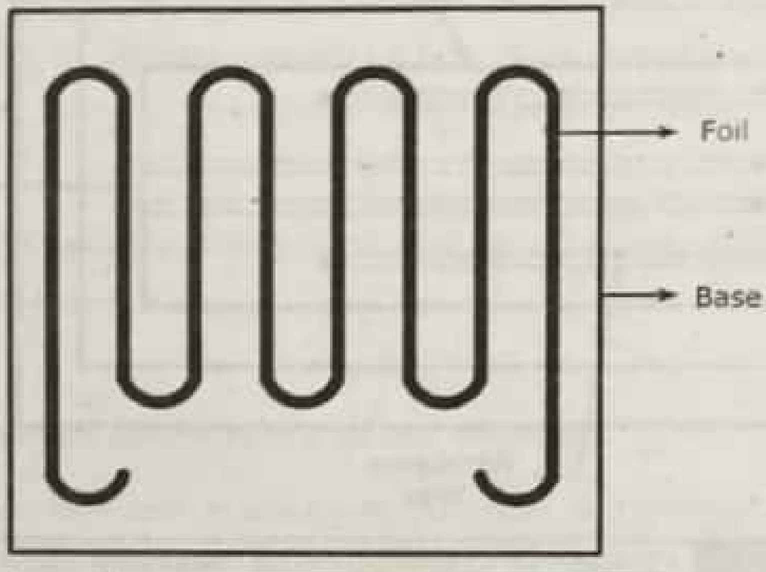


Fig. 9.3.8 Foil Type Strain Gauge

The metal foil gauges can be easily etched on a flexible insulating carrier film. In the construction of etched foil strain gauge first a layer of strain sensitive material is bonded to a thin sheet of bakelite or paper. The part of metal which is to be used as wire element is covered with some masking material and then to this unit an etching solution is applied. Therefore, the unmasked part of the metal will be removed thereby leaving the required grid structure. By this method of construction, the etched foil strain gauges are made in thinner sizes.

9.3.4.2.3 Semiconductor Strain Gauges

(1) When a high value of gauge factor is required, a semiconductor strain gauge is preferred. The gauge factor (G_f) of a semiconductor strain gauge is 50 times that of the resistance (wire) strain gauge.

(2) A typical semiconductor strain gauge is formed by the semiconductor technology i.e., the semiconducting wafers or filaments of length varying from 2 mm to 10 mm and thickness of 0.05 mm are bonded on suitable insulating substrates (for example teflon). The gold leads are usually employed for making electrical contacts. The electrodes are formed by vapour deposition. The assembly is placed in a protective box as shown in the Fig. 9.3.9.

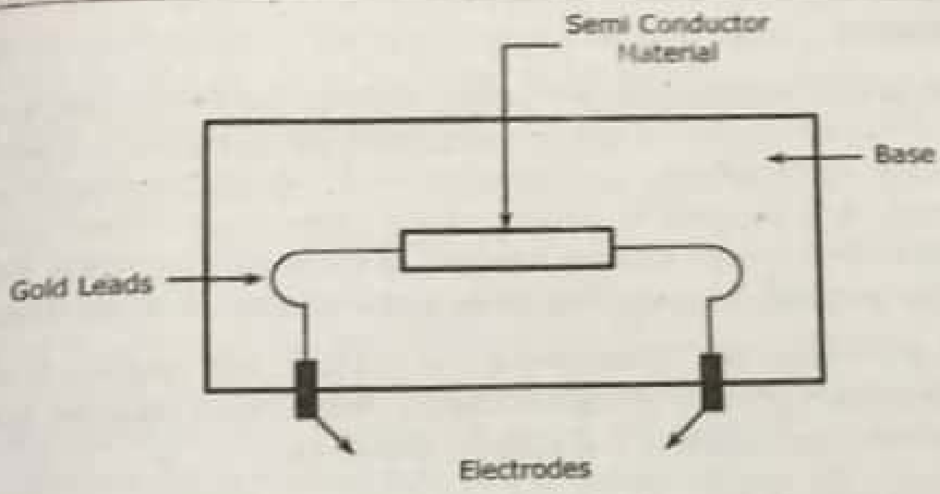


Fig. 9.39 Semiconductor Strain Gauge

(3) The strain sensitive elements used by the semiconductor strain gauge are the semiconductor materials such as silicon and germanium. When the strain is applied to the semiconductor element a significant change in resistance occurs, which can be measured with the help of a Wheatstone bridge. The strain can be measured with high degree of accuracy due to relatively high change in resistance.

(4) A temperature compensated semiconductor strain gauge can be used to measure small strains of the order of 10^{-6} i.e., micro strain. This type of gauge will have a gauge factor of 130 ± 10% for a semiconductor material of dimension 1 x 0.5 x 0.005 inch having the resistance of 350 Ω.

Advantages of Semiconductor Strain Gauge : Following are the advantages of semiconductor strain guage,

(1) The gauge factor of semiconductor strain gauge is very high.

(2) They are useful in measurement of very small strains of the order of 0.01 micro strain due to their high gauge factor.

(3) Semiconductor strain gauge exhibits very low hysteresis (more elastic).

(4) The semiconductor strain gauge has much higher output, but it is as stable as a metallic strain gauge.

(5) It posses a high frequency response of 10^{12} Hz.

(6) It has a large fatigue life i.e., 10×10^{6} operations can be performed.

(7) They can be manufactured in very small sizes, their lengths ranging from 0.7 to 7.0 mm.

Disadvantages : Following are the disadvantages of semiconductor strain guage,

(1) Its linearity is poor and it is more expensive.

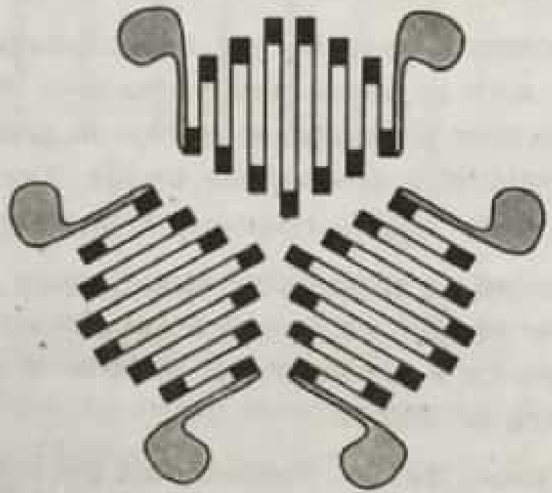
(2) Very sensitive to temperature.

9.3.4.3 Rosettes

Many transducer applications and stress analysis techniques use a combination of strain gauge. This combination of two or more strain gauge elements is known as rosette. With conventional strain gauges, it is not possible to indicate the direction of the applied stress. Therefore, it is required to develop strain gauge measurement system which can determine strain and stress without knowing the direction of stress and strain. This problem can be avoided by employing three strain gauges as a unit known as rosette.

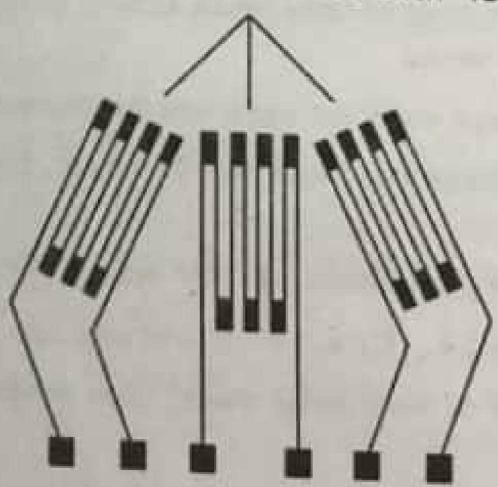
Rosettes are often used to determine the direction and magnitude of the principle strains resulting from complex structural loading. Mostly used Rosettes have 45° or 60° angular displacements between the sensing elements.

Fig. 9.3.10(a) shows the basic structure of a three element rosette using 60° planer foil.



(a) 3 Element Rosette, 60° Planar (Foil Type)

Fig. 9.3.10(b) shows a three element rosette with 45° planar foil.



(b) 3 Element Rosette, 45° Planar (Foil Type)

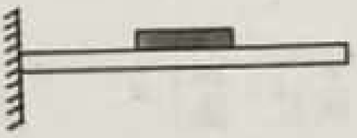
Fig. 9.3.10 Rosette Configurations

The 60^0 rosette is used when the direction of principal strain is unknown. On the other hand 45^0 rosette is used when the direction of the principal strains are known and it provides greater angular resolution.

9.3.4.4 Strain Measurement

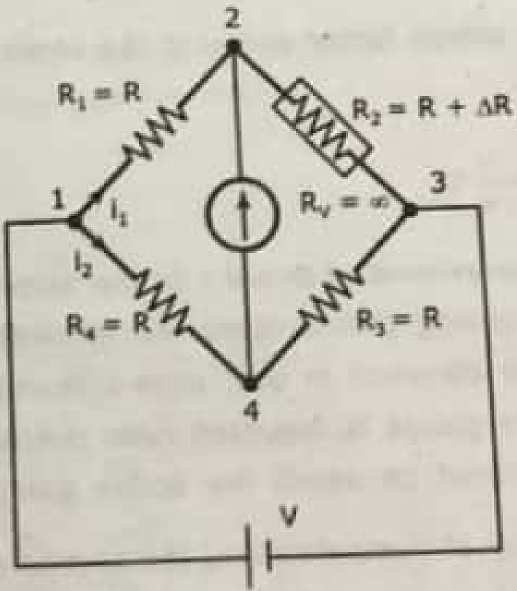
Strain gauges discussed in Section 9.3.4.2 are used for the measurement of strain and stress. If a conductor is stretched or compressed, the resistance of the conductor changes because of dimensional changes of length and cross sectional area. The change is resistance, is usually of the order of 0.2% hence extremely sensitive and sophisticated instrumentation is needed for measurement. Generally, Wheatstone stone bridge circuits which are more sensitive to very small changes in resistance are employed for strain measurement. It consists of four arms, in which one arm consists of the strain gauge while the other three arms have standard resistances of nearly equal resistance as that of the gauge resistance under unstrained condition.

(1) **First Method of Measurement of Strain :** A single strain gauge bonded on a cantilever beam is shown in Fig. 9.3.11(a).



(a)

The gauge is under tension and hence its resistance increases. The strained resistances of the gauge are measured with a Wheatstone bridge as shown in Fig. 9.3.11(b).



(b)

Fig. 9.3.11 Measurement of Strain

In the bridge R_2 is the strain gauge, while others are fixed resistances. The bridge is balanced when strain in the cantilever beam is zero.

The output of the bridge V_0, the voltage across terminals 2 and 4,

$$V_0 = i_2 R - i_1 R$$

The current in arm–1,

$$i_1 = \frac{V}{2R + \Delta R} = \frac{V}{2R}\left(1 + \frac{\Delta R}{2R}\right)^{-1}$$

Using $(1 + X)^{-1} = 1 - X + X^2 - X^3 + ...$ Neglecting higher order terms, since $\Delta R/2R << 1$, we obtain,

$$i_1 = \frac{V}{2R}\left(1 - \frac{\Delta R}{2R}\right) \qquad \text{(approximately)}$$

and the current in arm-4,

$$i_2 = \frac{V}{2R}$$

Hence,
$$V_0 = \frac{V}{2R} . R - \frac{V}{2R}\left(1 - \frac{\Delta R}{2R}\right) . R$$

$$= \frac{V}{4} . \frac{\Delta R}{R}$$

$$= \frac{V}{4} G_f . \sigma$$

Where, G_f is the gauge factor and σ is the strain. Therefore, the sensitivity of the system,

$$S = \frac{V_0}{\sigma} = \frac{V}{4} G_f \qquad ... (9.3.8)$$

(2) **Second Method of Measurement of Strain :** In the above method of measuring strain, the variation of surrounding temperature will influence the result. One method of compensation, which is common in use, uses a dummy gauge in the third arm of the bridge. The dummy gauge is mounted near the active gauge on an unstrained specimen of same material on which the active gauge is mounted.

In an alternative way of compensation, the second gauge (in arm 3) is also made active, but it is mounted on the opposite side of the beam. So, the strain developed in the second gauge is of opposite sign as it is under compression. The bridge arrangement is shown in Fig. 9.3.12,

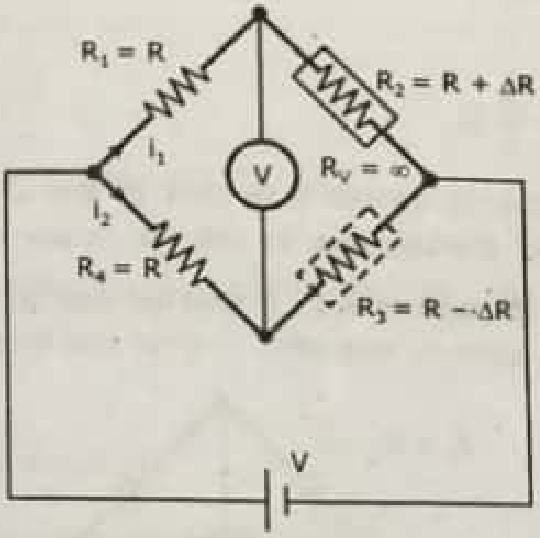


Fig. 9.3.12 Four Strain Gauge Method of Measuring Strain

The output of the bridge,

$$V_0 = i_2 R - i_1 R$$

The current in arm –1,

$$i_1 = \frac{V}{2R + \Delta R + \Delta R_t}$$

$$= \frac{V}{2R}\left(1 + \frac{\Delta R + \Delta R_t}{2R}\right)^{-1}$$

$$= \frac{V}{2R}\left(1 - \frac{\Delta R}{2R} - \frac{\Delta R_t}{2R}\right)$$

Where, ΔR and ΔR_t are the change in resistance of the gauge due to strain and surrounding temperature changes respectively.

The current in arm –4,

$$i_2 = \frac{V}{2R - \Delta R + \Delta R_t}$$

$$= \frac{V}{2R}\left(1 - \frac{\Delta R - \Delta R_t}{2R}\right)^{-1}$$

$$= \frac{V}{2R}\left(1 + \frac{\Delta R}{2R} - \frac{\Delta R_t}{2R}\right)$$

$$V_0 = \frac{V}{2R}\left(1 + \frac{\Delta R}{2R} - \frac{\Delta R_t}{2R}\right) . R - \frac{V}{2R}\left(1 - \frac{\Delta R}{2R} - \frac{\Delta R_t}{2R}\right) . R$$

$$= \frac{V}{2}\frac{\Delta R}{R} = \frac{V}{2} . G_f \sigma$$

Hence, sensitivity,

$$S = \frac{V_0}{\sigma} = \frac{V}{2} G_f \quad \cdots (9.3.9)$$

The sensitivity, thus, is double than that of the bridge in Fig. 9.3.11(b). Also, it compensates for the change due to change in surrounding temperature.

(3) **Third Method of Strain Measurement :** If another pair of strain gauges are connected in the remaining arms (arm–1 and arm – 4) of the bridge as shown in Fig. 9.3.13.

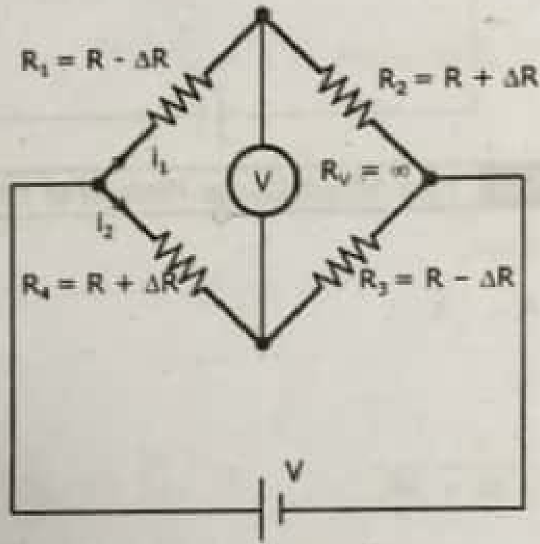


Fig. 9.3.13 Two Strain Gauge Method of Measuring Strain

The sensitivity will be four times than that in Eq. (9.3.8). The output is given by,

$$V_0 = i_2 (R + \Delta R) - i_1 (R - \Delta R)$$

The current in arm - 1

$$i_1 = \frac{V}{R - \Delta R + R + \Delta R} = \frac{V}{2R}$$

and that in arm -4,

$$i_2 = \frac{V}{R + \Delta R + R - \Delta R} = \frac{V}{2R}$$

$$V_0 = \frac{V}{2R}(R + \Delta R) - \frac{V}{2R}(R - \Delta R)$$

$$\Rightarrow \quad V_0 = \frac{V}{2R} \cdot R\left(1 + \frac{\Delta R}{R}\right) - \frac{V}{2R} \cdot R\left(1 - \frac{\Delta R}{R}\right)$$

$$\therefore \quad V_0 = V \cdot \left(\frac{\Delta R}{R}\right) = VG_f\sigma$$

The sensitivity, therefore, is

$$S = \frac{V_0}{\sigma} = VG, \quad \text{... (9.3.10)}$$

which is four times than that in Eq. (9.3.10).

Measurement of Stress : For measurement of stresses the strains caused by them are measured and the stresses can be calculated from the relation.

$$f = Y\sigma$$

Where,

f = Stress

Y = Young's modulus for the material

σ = Strain developed.

Thus, as Y is a known constant for a material the stress can be calculated.

9.3.5 Transducers for Temperature Measurement

(1) Now a days temperature measurement is most significant in various processes, plants and industries, because there are various changes in the physical or chemical state of most substances (materials) when they are cooled or heated.

(2) The term *"temperature is defined as the degree of hotness or coldness of a substance or a medium measured on a definite scale"*. It may also be defined as a thermal state of a body which distinguishes a hot body from a cold body.

(3) Thermometers are the instruments used for the measurement of ordinary temperatures, whereas pyrometers are used for the measurement of high temperature.

(4) The temperature measuring instruments can be broadly categorized as two types,

(i) **Electrical Methods :** When a temperature of body is changed, the electrical methods of temperature measurement devices uses the following effects to measure temperature.

- Change in resistance of material.

  Example : Resistance wire thermometers and semiconductor thermometers.

- Change in the intensity of total radiation emitted.

  Example : Pyrometers.

- Generation of emf at the junction of two dissimilar materials.

  Example : Thermocouples.

(ii) **Non Electrical Methods :** These methods use the following effects to measure temperature when a body is heated or cooled.

- Change in volume of a liquid.

  Example : Liquid in glass thermometers.

- Change in pressure of a gas.

  Example : Gas filled thermometers.

(5) Electrical methods of temperature measurement are used in practice due to the following reasons,

(i) They furnish signal that is easily detected, amplified or used for control purposes.

(ii) They are usually quite accurate when properly calibrated and compensated.

9.3.5.1 Resistance Wire Thermometers

9.3.5.1.1 Operating Principle

Resistance wire thermometers operates on the principle, *"resistance of wire (or conductor) changes in direct proportion with change in temperature"*. Since wires usually made up of metals like platinum, copper and nickel which have positive temperature coefficient of resistance, thus resistance of wire increases as temperature increases and vice versa

Resistance wire thermometers are also called resistance temperature Detector (RTD).

In case of variation of resistance R(R = $\frac{\rho L}{A}$, where R is the resistivity, L length and A is the cross sectional area of the electrical conductor) with temperature for most of the metals, the following quadratic relationship gives good accuracy,

$$\boxed{R = R_0(1 + \alpha t + \beta t^2)} \quad \text{... (9.3.11)}$$

Where,

R_0 = Resistance at temperature 0°C

α, β = Constants.

For a narrow range, the following relationship may be used with sufficiently good accuracy.

$$R = R_0 (1 + \alpha t) \quad \text{... (9.3.12)}$$

Where,

α = Resistance temperature coefficient (/°C).

Factors for Selection of Sensing Elements in RTDs

The metal to be used for fabricating sensing elements in RTDs should satisfy the following properties,

(1) High temperature coefficient of resistance in order to produce a RTD with good sensitivity.

(2) Good repeatability, that is, to provide consistent results in adverse situations.

(3) High sensitivity.

(4) Linearity of resistance.

(5) Ability to withstand corrosion, friction, and oxidation etc.

Construction of Resistance Wire Thermometers

The construction details of resistance wire thermometers is shown in Fig. 9.3.14,

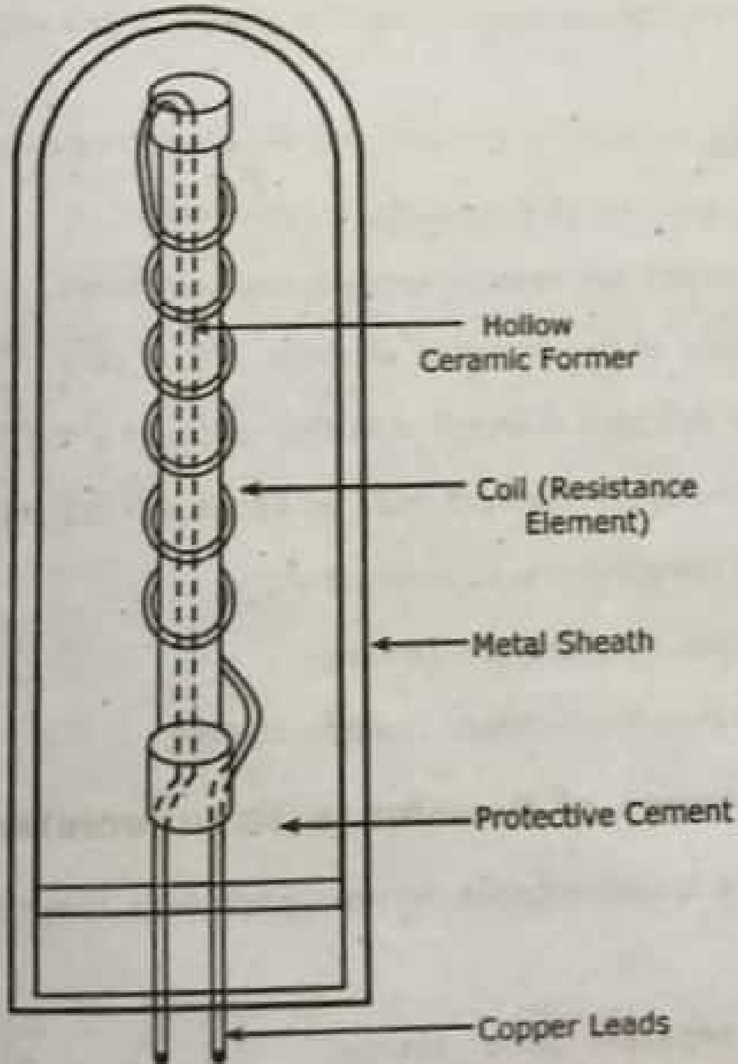


Fig. 9.3.14 Platinum Resistance Thermometer

It consists of,

(1) A resistance wire (platinum) in spiral shape enclosed inside a protective sheath to protect the wire from corrosion, mechanical damages and so on.

(2) Electrical leads are taken out of the thermometer for measurement of the changes in the resistance to determine the value of temperature.

The change in resistance of this device is precisely determined by a "Wheatstone bridge" or ohmmeter. Otherwise a separate circuit can be used to calibrate the value of resistance in terms of voltage or current.

RTDs are generally of the probe type for immersion in the medium whose temperature is to be measured. RTDs are useful for measurements in the range of $-200^{0}C$ to $650^{0}C$.

9.3.5.1.4 Advantages of Resistance Wire Thermometers

Following are the advantages of resistance wire thermometers,

(1) The RTDs are most accurate of all the temperature transducers ($0.001^{0}C$ accuracy).

(2) More than one resistance element can be joined to the same indicating/recording instrument.

(3) The temperature resistance element can be easily installed and replaced.

(4) Convenient for even small temperature differences.

(5) They are best suited for remote sensing and indication.

(6) The response time of the resistive element is 2 - 10 s.

(7) The error of the resistive element is in the range of ± 0.25% of the scale reading.

(8) The size of the resistive element may be about 6 - 12 mm in diameter.

(9) No necessity of temperature compensation.

(10) Extremely accurate temperature sensing.

(11) Performance stability over longer periods of time.

9.3.5.1.5 Disadvantages of Resistance Thermometers

Following are the disadvantages of resistance wire thermometers,

(1) High cost.

(2) Requirement of separate power source.

(3) Heat loss (I^2Rt), theorem emf.

9.3.5.2 Thermocouples

Thermocouples are widely used in industrial applications for temperature measurement. Thermocouple is an active transducer because there is no need for voltage source and transducer bridge circultary.

9.3.5.2.1 Operating Principle (Seebeck Effect)

A thermocouple works on the following principle,

"When two dissimilar metals A and B are welded or joined together to form a closed circuit and the junctions (J_1 and J_2) are kept at two different temperatures (T_1 and T_2), then an emf is generated resulting flow of current in the circuit or loop."

Fig. 9.3.15 shows operating principle of thermocouples,

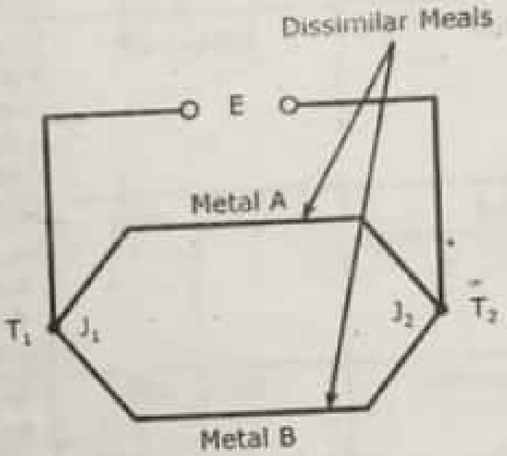


Fig. 9.3.15 Operating Principle of Thermocouples

The generated emf (E) is proportional to the difference of the temperatures T_1 and T_2 the materials used for the thermocouple. This phenomenon is called seebeck effect. Thus the amount of emf generated is a function of temperature at hot and cold junctions.

One of the two junctions in the loop is reference or cold junction which is generally kept at 0°C and the other is the measuring or hot junction at which the temperature is to be measured. The emf developed in a circuit assuming $T_1 > T_2$ may be approximately written as,

$$E = a(T_1 - T_2) + b(t_1 - T_2)^2$$

Let us define $\Delta\theta$ as the difference of temperatures of hot and cold junctions in °C $= T_1 - T_2$. Therefore,

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

Where a and b are constants whose values depends upon the materials used. Usually a is very large as compared with b and therefore emf of thermocouple is $E = a(\Delta\theta)$ or $\theta = E/a$

9.3.5.2.2 Thermocouple Materials and Construction

THERMOCOUPLE MATERIALS

Thermocouples may be made of base metals or Rare metals. Important thermocouple pairs and the maximum temperatures upto which they can be used are given in Table 9.3.5. Thermocouples are also given type numbers which are also shown in this table,

Table 9.3.5 Rare and Base Metal Couples

	Type	Thermocouple Pair	Temperature Range	Characteristics
Base Metal Couples	T	Copper Constantan	- 250 to + 400	Resists oxidising and reducing atmospheres up to 350^0 C. Requires protection from acid fumes.
	J	Iron Constantan	- 200 to + 850	Low Cost Corrodes in the presence of moisture oxygen, and sulphurbearing gases. Suitable for reducing atmospheres
	K	Chromel Alumel	- 200 to + 1100	Resistant to oxidising but not to reducing atmosphere Susceptible to attack by carbon Bearing gases sulphur, and cyanide fumes.
Rare Metal Couples	E	Chromel Constantan	- 200 to + 850	Suitable for oxidising but not for reducing atmoshperes, carbon bearing gases and Cyanide fumes. High emf.
	K	Platinum Platinum	0 to + 1400	Low emf. Good resistance to oxidising atmospheres, poor with reducing atmospheres, Calibration is affected by metallic vapours and contact with metallic oxides.
	K	Rhodium Iridium	0 to + 2100	Similar to platinum rhodium platinum

The choice of thermocouple material listed in Table. 9.3.5 depends on the factors such as,

(1) Good linear Response.

(2) High sensitivity.

(3) Must be physically strong to withstand high temperatures.

(4) Resistance to atmospheric conditions.

(5) Temperature range to be measured.

CONSTRUCTION DETAILS OF THERMOCOUPLE

Fig. 9.3.16 depicts the construction of a typical industrial thermocouple,

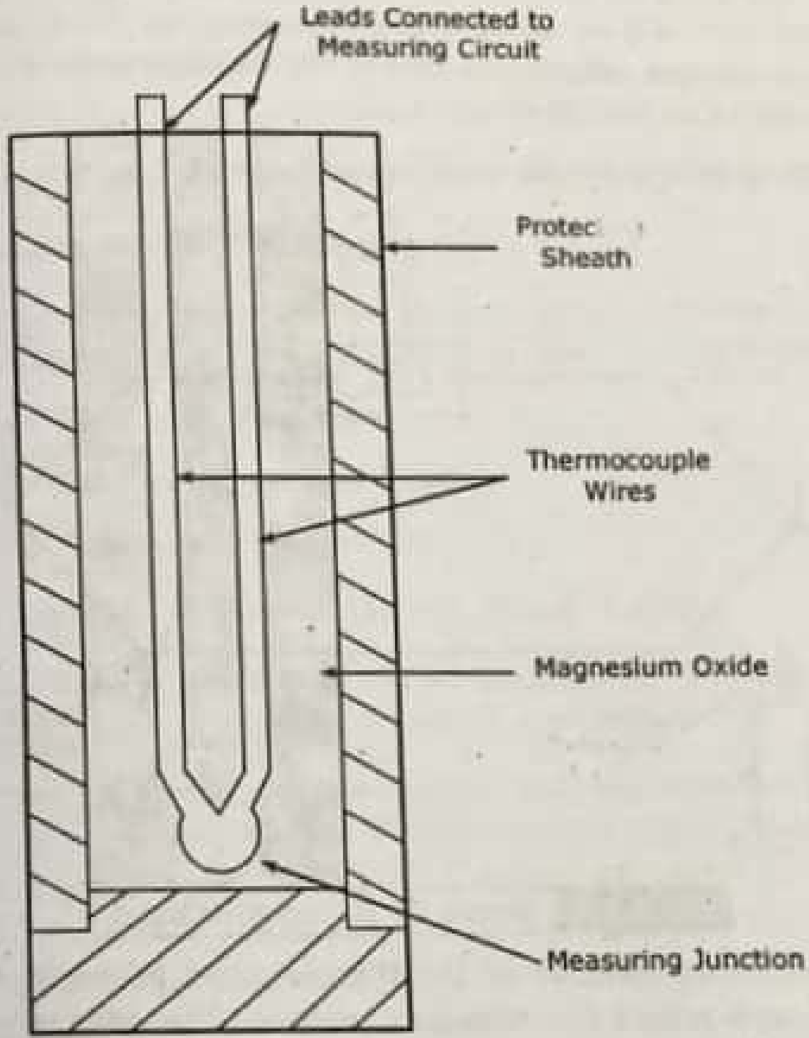


Fig. 9.3.16 Construction of Typical Thermocouple

Here the thermocouple is fitted inside a protective sheath made of suitable materials. Nickel, stainless steel and ceramic are common sheath material. The use of sheaths makes the thermocouples robust but suffers from slow response with time constants of 1 min. Magnesium oxide or Alumina are the common insulating materials that surrounds the thermocouple wires to prevent vibration that damage the fine wires and to enhance the heat transfer between the measuring junction and the medium supporting the thermocouple. The measuring junction is normally formed at the bottom of the thermocouple housing. This type of thermocouples are called sheathed thermocouples.

In protected environments like laboratory, plain wire type thermocouples with sheaths are used. The advantages of such type of thermocouples are high speed of response and low cost.

9.3.5.2.3 Thermocouple Operation

Using a heat source, it will cause an electric current to flow in the attached circuit when one of the junctions of thermocouple is subjected to change in temperature. The amount of current that will be produced is dependent on the temperature difference between the measuring and reference junction, the characteristics of the two metals used and the characteristics of the attached circuit.

Fig. 9.3.17 illustrates a simple thermocouple circuit,

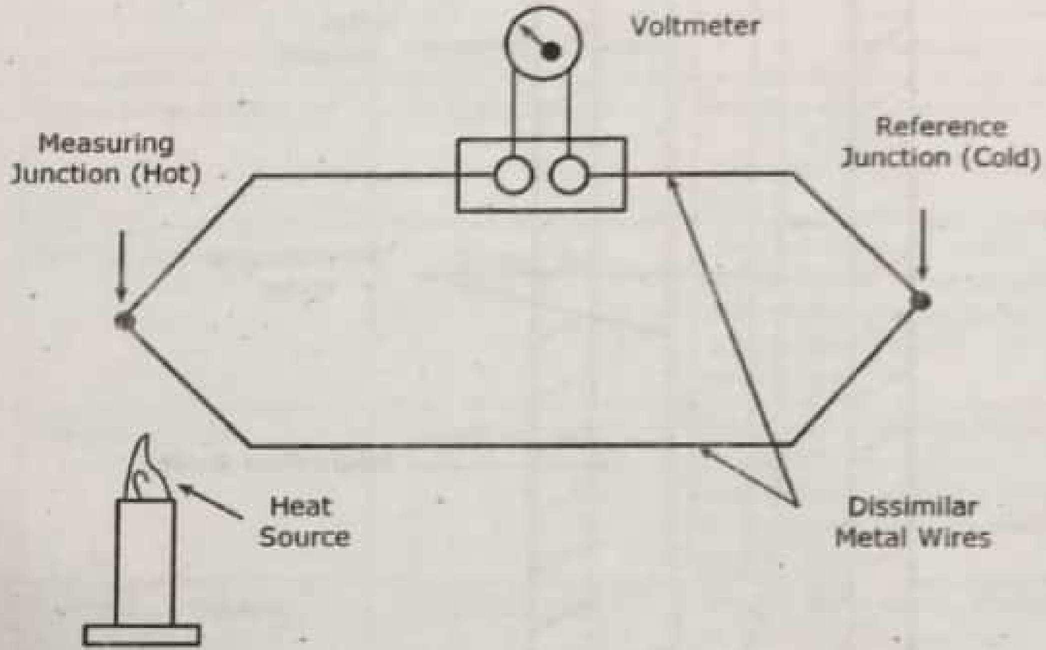


Fig. 9.3.17 Simple Thermocouple Circuit

Heating the measuring junction of the thermocouple produces a voltage which is greater than the voltage across the reference junction. The difference between the two voltages is proportional to the difference in temperature and can be measured on the voltmeter (in millivolts). For ease of operator use, some voltmeters are set up to read out directly in temperature through use of electronic circuitary.

9.3.5.2.4 Advantages of Thermocouple

Following are the advantages of thermocouple,

(1) Construction is mechanically strong and rigid.

(2) It is suitable for reading (measurement) of rapidly varying temperatures.

(3) Low cost.

(4) There is no need of bridge circuit.

(5) Installation and calibration is easy.

(6) It is suitable for temperature range of -270 to 2800°C.

9.3.5.5 Disadvantages of Thermocouple

Following are the disadvantages of thermocouple,

(1) It requires a protective wall or sheath.

(2) Thermocouple needs compensating arrangement.

(3) Amplifier circuit is necessary to increase the output voltage level.

(4) For long distance temperature measurement, compensating wires are necessary.

9.3.6 Transducers for Measurement of Force

Any cause that produces, stops or changes the motion of a body or tends to produce these effects is defined as force. The various types used for measurement of force are,

(1) Measurement of force using loadcells.

(2) Measurement of force using proving rings.

(3) Measurement of force using piezoelectric.

9.3.6.1 Measurement of Force Using Load Cells

Load cells are elastic devices that can be used for measurement of force through indirect methods i.e., through use of secondary transducers.

Load cells utilize an elastic member as the primary transducer and strain gauges as secondary transducer. When the combination of the strain gauge elastic member is used for weighing, it is called as "load cell". The load cell which uses a cantilever beam (elastic member) as primary transducer and strain gauge as secondary transducer is shown in Fig. 9.3.18 and 9.3.19,

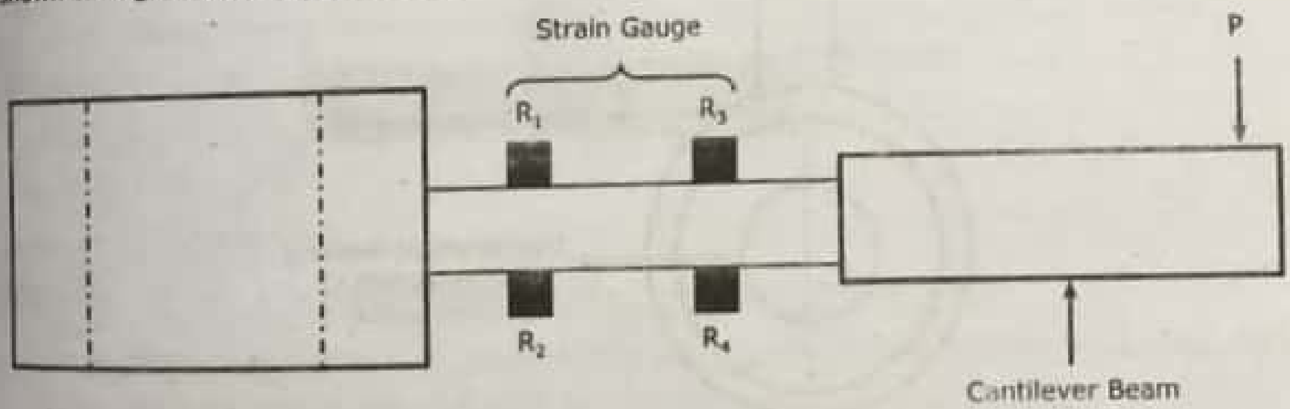


Fig. 9.3.18 Cantilever, R_1, R_2, R_3, R_4 (Strain Gauges Load Cell)

In Fig. 9.3.18, R_1, R_2, R_3 and R_4 are the strain gauges. The strain experienced by the strain gauges R_2 and R_4 is opposite in nature of strain that is experienced by strain gauges R_1 and R_3. The arrangement of these strain gauges in the arms of a Wheatstone bridge is shown in Fig. 9.3.19,

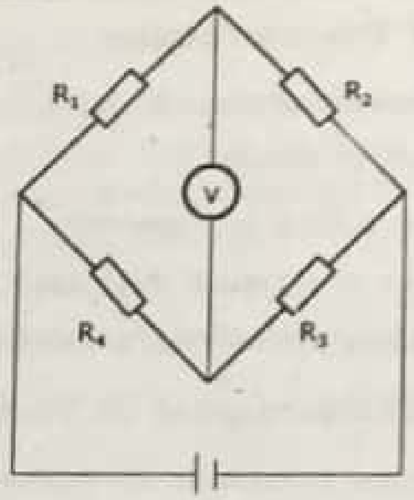


Fig. 9.3.19 Arrangement of Gauges in Wheatstone Bridge

In Fig. 9.3.19, when force is applied to cantilever beam it will bend, with this the resistance of the gauges will be changed. Since these are connected to the arms of Wheatstone bridge, the bridge becomes unbalanced and produces some output which gives the value of applied input.

9.3.6.2 Force Measured Using LVDT (or) Proving Ring

A proving ring consists of a high grade steel ring with two loading bosses attached at the ends of one of its diameters with a displacement sensing device situated at the center of the ring as shown in the Fig. 9.3.20,

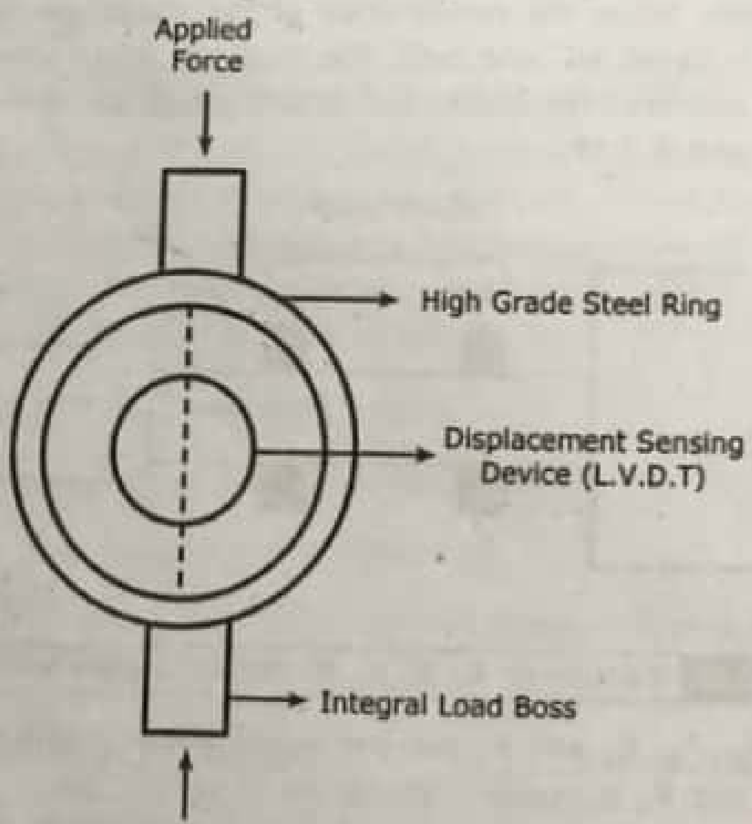


Fig. 9.3.20 Force Transducer Proving Ring

When the force is applied on the load boss, the ring tends to distort and this distortion is directly proportional to the applied force. This distortion is measured by a displacement sensing device. For low accuracy the distortion is measured by dial gauge or micrometer, where as for high accuracy applications, L.V.D.T. is used as displacement sensor. This displacement measurement is a measure of force applied.

The proving rings may be used for both tensile and compression force measurements. The range of proving ring is 2 kN to 2000 kN with accuracy of 0.2 to 0.5 percent. Proving rings are high precision devices which are extensively used for materials testing machines.

9.3.6.3 Measurement of Force Using Piezo Electric Transducer

Piezoelectric transducer works on the principle of piezoelectric effect. It is capable of measuring compressive forces from new KN to about 1 MN with accuracy from 0.5 - 1.5%.

The construction of a basic piezoelectric transducer is shown in Fig. 9.3.21,

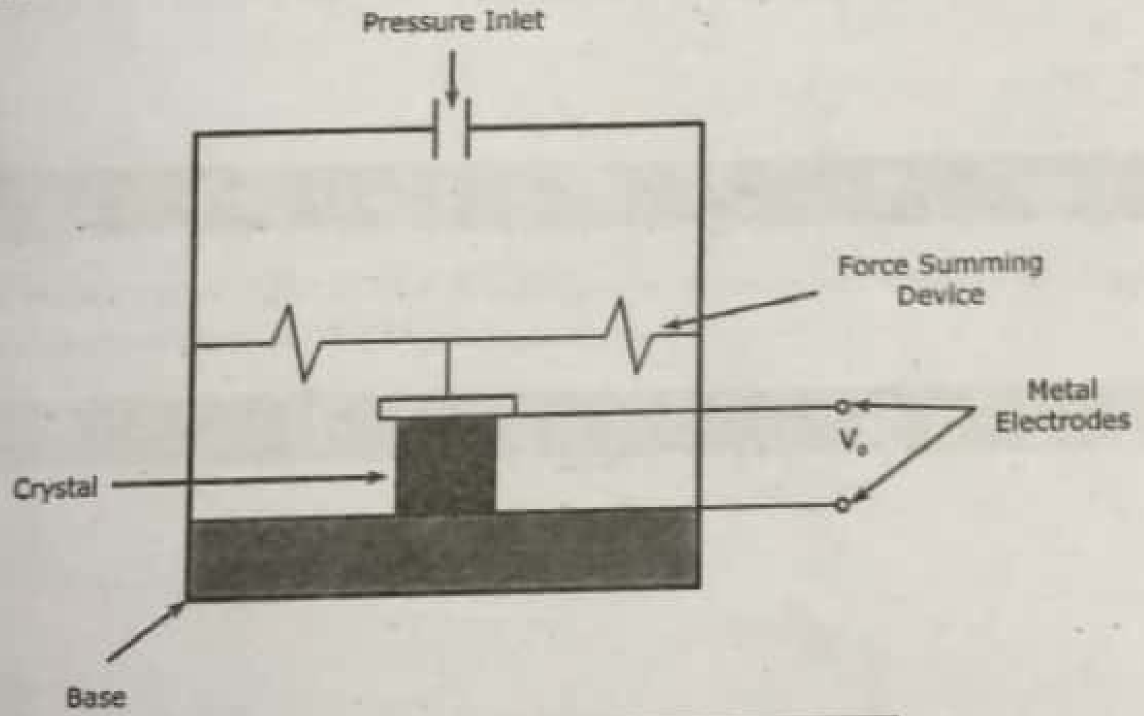


Fig. 9.3.21 Force Transducer Proving Ring

A piezoelectric crystal is placed between a solid face and force summing member. Force summing device are mechanical elements used to convert the applied force into a displacement, metal electrodes placed onto the faces of crystal are taken out to measure output V_o. An externally applied force entering pressure inlet generates an emf, V_o across the metal electrodes proportional to the magnitude of pressure given by,

$$V_o = \frac{gtF}{A} = gtp$$

Where,

g = Voltage sensitivity (V_m/N).

F = Force (Newtons).

A = Area of the crystal (m^2)

P = Pressure (=F/A) in N/m^2

t = Thickness of the crystal.

10.1 PHOTO DIODE

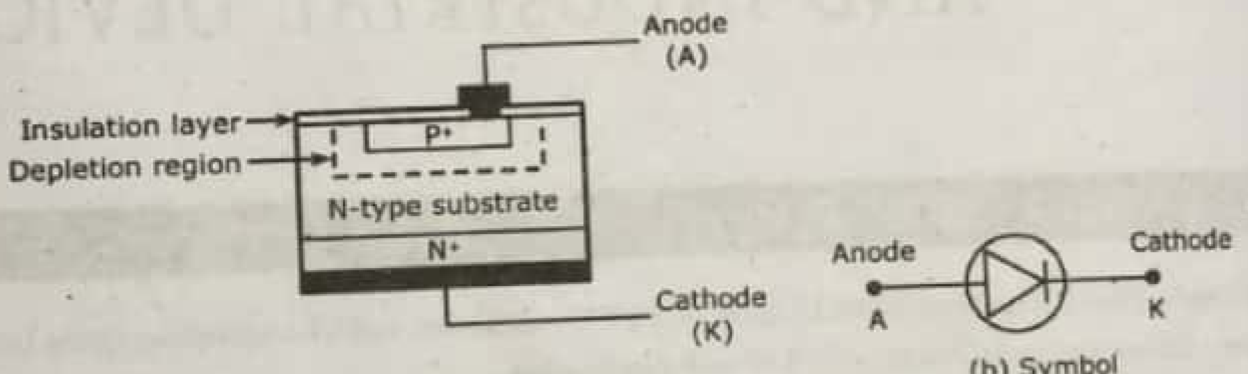
Photodiodes are semiconductor light sensor that generate a current or voltage when the P-N junction in the semiconductor is illuminated by light. Photodiodes operates by absorption of photons or charged particles and generates a flow of current in an external circuit proportional to the incident power. Photodiodes can be classified by function and construction as follows,

(1) PN photodiode.
(2) PIN photodiode.
(3) Schottky type photodiode.
(4) Avalanche photodiode (APD).

All of these photodiode types are widely used for the detection of the intensity, position, color and presence of light.

10.1.1 Construction

The basic structure and symbol of photodiode is shown in Fig. 10.1.1



(a) Basic Structure

(b) Symbol

Fig. 10.1.1 Photodiode Cross Section

The P-layer material at the active surface and the N-layer material at the substrate form a PN junction which operates as a photoelectric converter. The usual P-layer for a Si photodiode is formed by selective diffusion of boron, to a thickness of approximately 1μm or less and the neutral region at the junction between the P- and N-layers is known as the depletion layer. By controlling the thickness of the outer P-layer, substrate N-laye and bottom N^+ layer as well as the doping concentration, the spectral response an frequency response can be controlled.

10.1.2 Principle of Operation

When light strikes a photodiode, the electron within the structure becom stimulated. If the light energy greater than the band gap energy E_g i.e., $h\nu > E_g$ strik the material then its photon energy is acquired by an electron and thereby electro are pulled into the conduction band, leaving behind vacant space (hole) in the valen band as shown in Fig. 10.1.2. This mechanism of generating electron-hole pairs is kno as photoelectric effect.

These electron-hole pairs occur throughout the P-layer, depletion layer and N-layer materials. In the depletion layer the electric field accelerates these electrons toward the N-layer and the holes toward the P-layer. Of the electron-hole pairs generated in the N-layer, along with electrons that have arrived from the P-layer, are left in the N-layer conduction band. The holes at this time are being diffused through the N-layer up to the depletion layer while being accelerated and collected in the P-layer valence band. In this manner, electron-hole pairs which are generated in proportion to the amount of incident light are collected in the N and P-layers. This results in a positive charge in the P-layer and a negative charge in the N-layer. If an external circuit is connected between the P and N-layers, electrons will flow away from the N-layer and holes will flow away from the P-layer towards the opposite respective electrodes. These electrons and holes generating a current flow in a semiconductor are called the carriers.

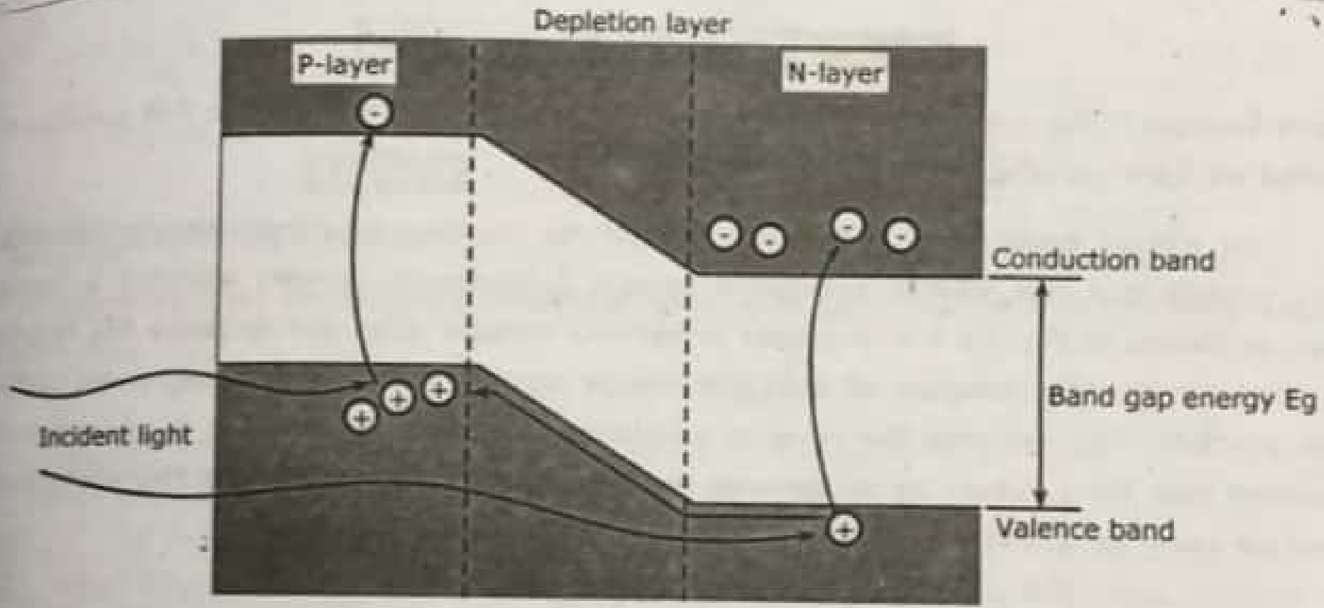


Fig. 10.1.2 Photodiode P-N Junction State

PHOTODIODE CHARACTERISTICS

When the P-N junction is reverse-biased, a reverse saturation current flows due to thermally generated holes and electrons being swept across the junction as the minority carriers. With the increase in temperature of the junction more and more hole-electron pairs are created and so the reverse saturation current I_0 increases. The same effect can be handled by illuminating the junction. When light energy bombards a P-N junction, it dislodges valence electrons. The more light striking the junction the larger the reverse current in a diode. It is due to generation of more and more charge carriers with the increase in level of illumination. This is clearly shown in Fig. 10.1.3 for different intensity levels.

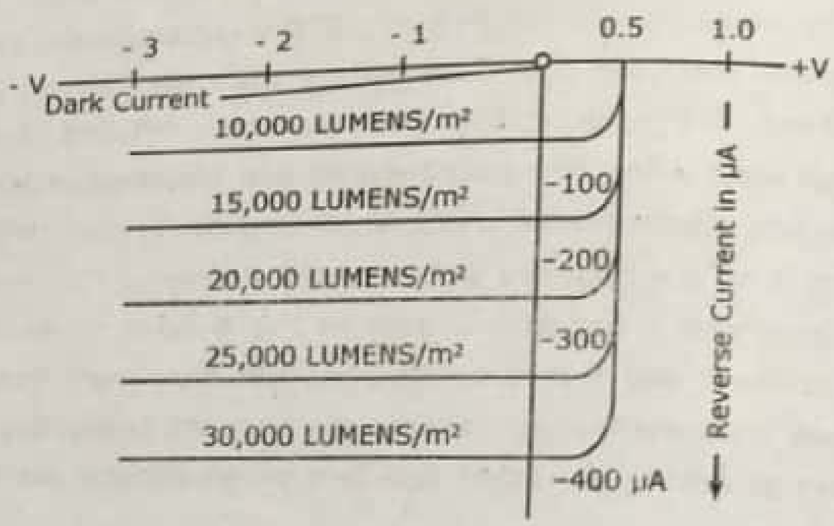


Fig. 10.1.3 Photodiode Characteristics

Dark Current : The current that exists when no light is incident on the P-N junction is called as dark current.

The almost equal spacing between the curves for the same increment in luminous flux reveals that the reverse saturation current I_0 increases linearly with the luminous flux as shown in Fig. 10.1.4. Increase in reverse voltage does not increase the reverse current significantly, because all available charge carriers are already being swept across the junction. For reducing the reverse saturation current I_0 to zero, it is necessary to forward bias the junction by an amount equal to barrier potential. Thus the photodiode can be used as a photoconductive device.

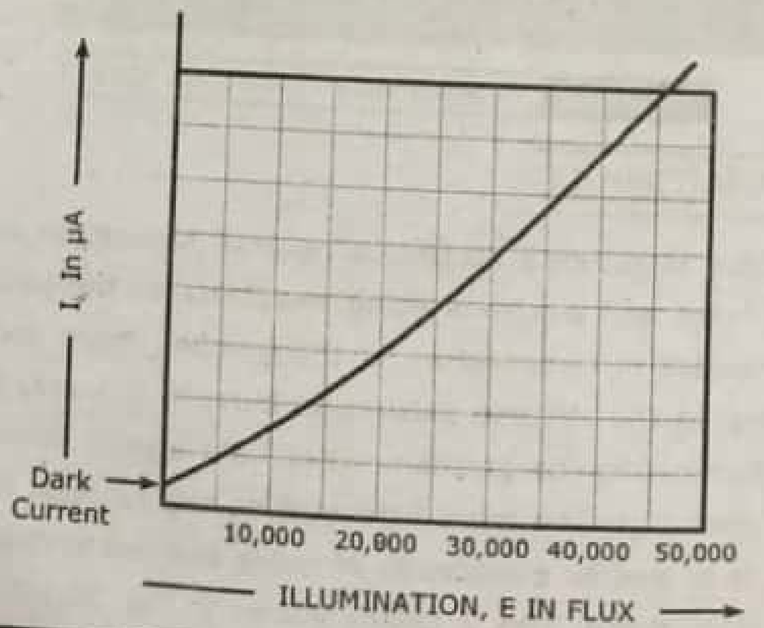


Fig. 10.1.4 Dark Current Vs Illumination Characteristics

10.2 PHOTO TRANSISTOR

Photo transistor is just like an ordinary BJT, except with no base terminal. Instead of base current, input to the transistor is provided in the form of light.

10.2.1 Circuit Symbol

Fig. 10.2.1 shows the standard symbol of a phototransistor, which can be regarded as a conventional transistor housed in a case that enables its collector-base junction to be exposed to external light.

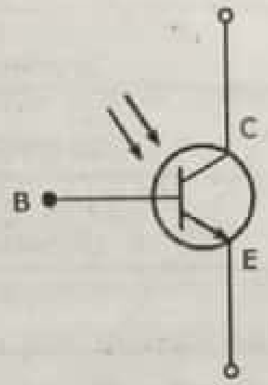


Fig. 10.2.1 Standard Symbol of Phototransistor

10.2.2 Working Operation

We know that an ordinary transistor with open base will have a collector current given by,

$$I_C = (h_{fe} + 1)I_{CO}$$

Where,

I_{CO} = Reverse saturation current of base collector junction J_C.

Now, if light falls on the junction J_C, as shown in Fig. 10.2.2, additional carriers will be generated by the photons. This will result in photocurrent I_P through the junction J_C. Due to transistor action, there would be current amplification and therefore the total collector current will be,

$$I_C = (h_{fe} + 1)(I_{CO} + I_P) \quad \text{... (10.2.1)}$$

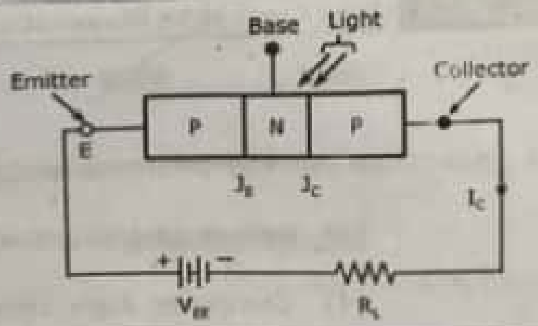


Fig. 10.2.2 Light f 'ling on collector junction of a phototransistor

10.2.3 Characteristics

Typical output characteristics are shown in Fig. 10.2.3, which are similar to tho of an ordinary transistor except that illumination level is substituted for base currer

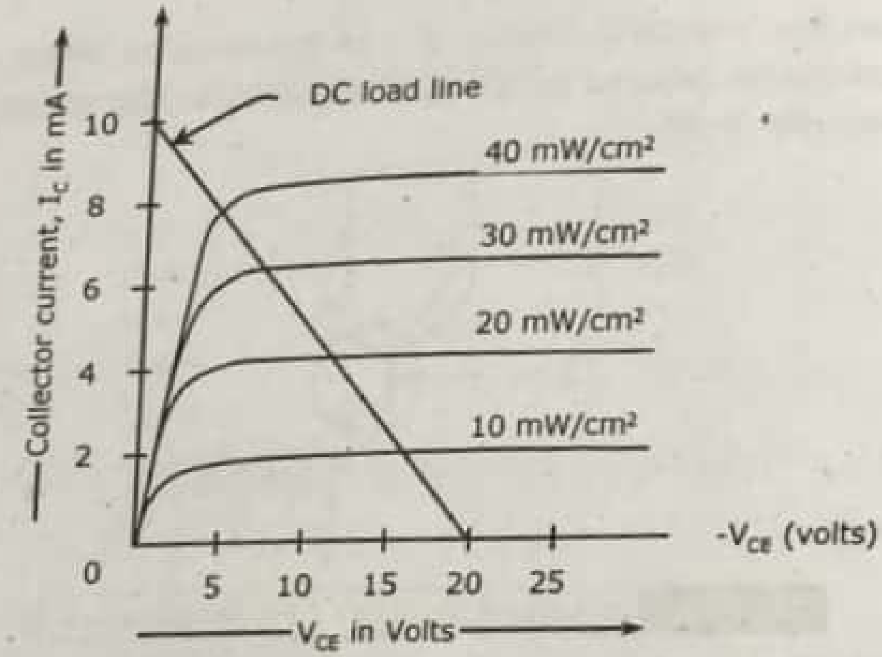


Fig. 10.2.3 V_{CE}-I_C characteristics of a Phototransistor

A curve of base current versus illumination level is shown in Fig. 10.2.4,

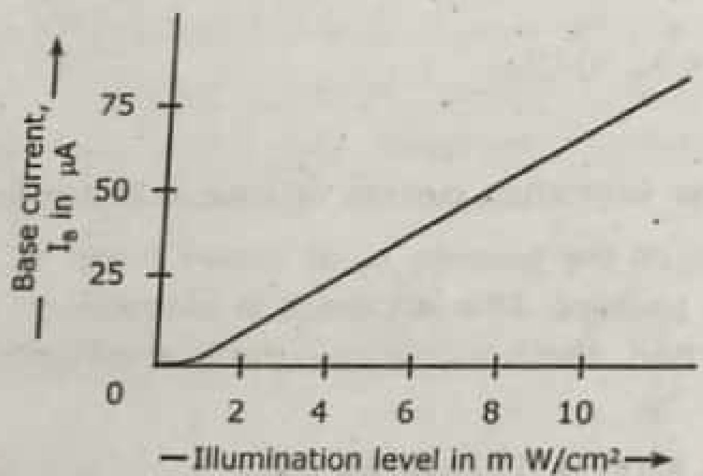


Fig. 10.2.4 Base Current Vs Illumination Level

.4 Applications

Some of the areas of application for the phototransistor include:

evel indication.

(2) Relays and counting system.

unch-card readers.

(4) Computer, logic circuitry.

ghting contract (highways).

10.2.5 Comparision between Photodiode and Phototransistor

(1) The basic difference between a photodiode and a phototransistor is the current gain β_{DC} or h_{fe}. With the same amount of light striking both devices, produces β_{DC} times more current in a phototransistor than in a photodiode.

(2) A phototransistor has typical output current in milliamperes but switches ON or OFF in micro seconds, whereas a photodiode has typical output current in micro amperes but switches ON or OFF in nano seconds.

(3) Photodiodes are faster than phototransistors.

(4) Phototransistors have high sensitivity over a photodiode, which is a big advantage of phototransistor.

10.3 LIGHT EMITTING DIODE (LED)

Light emitting diodes (LEDs) are semiconductor P-N junction device that operates in a forward biased condition and are capable of emitting spontaneous radiations in the visible region (0.33 μm-0.77 μm).

CIRCUIT SYMBOL

Fig. 10.3.1 shows the LED symbol.

Fig. 10.3.1 Symbol of LED

In Figure, arrow pointing away from the LED represents the radiation, i.e., light emitted by diode, which is being transmitted away from the junction.

CONSTRUCTION

The basic structure of a light emitting diode (LED) is shown in Fig. 10.3.2,

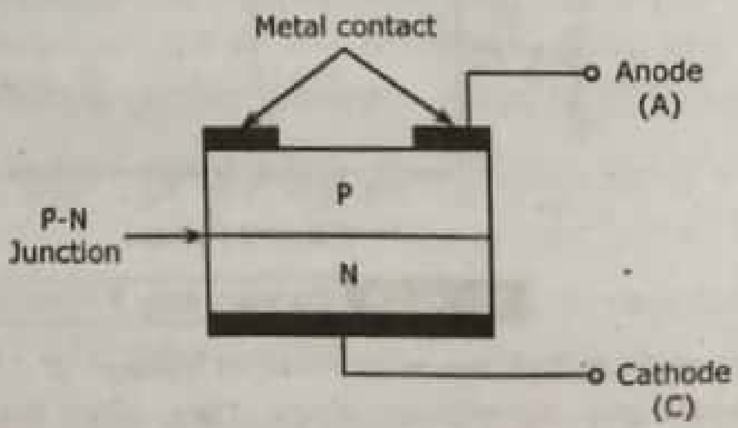


Fig. 10.3.2 Structure of LED

Here an N-type layer is grown upon a P-type substrate by a diffusion process. Then a thin P-type layer is grown on N-type layer. The metal connections are made to both the layers to make anode and cathode terminals as shown in Fig. 10.3.2.

Light Generating Mechanism in LEDs : When a light emitting diode is forward biased, electrons from N-side flow across the space-charge region and then recombine with the holes in the P-region. This recombination causes the light to be emitted as shown in Fig. 10.3.3. This spontaneous emission of light from the diode structure is called as *Electro luminescence.*

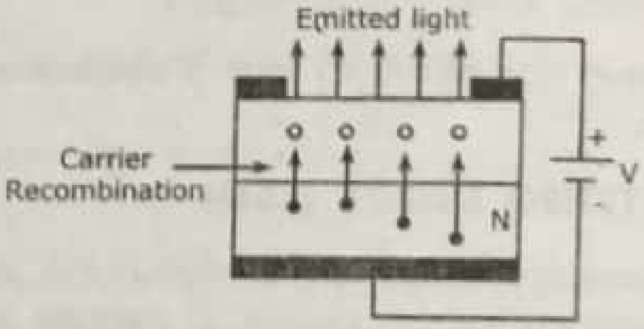


Fig. 10.3.3 Light Generating Mechanism in LEDs

As we know that electrons on N-side are in conduction band (higher energy levels), while hole on P-side are in valence (lower energy levels). Hence, electrons are at higher energy levels than holes. So, whenever an electron recombines with a hole they must give some energy. Typically the energy is given either in the form of heat or light.

Characteristics of LED : LEDs possess two curves to determine LED operating characteristics,

(1) **Forward Bias Characteristics :** Fig. 10.3.4 shows the forward bias characteristic for a typical LED.

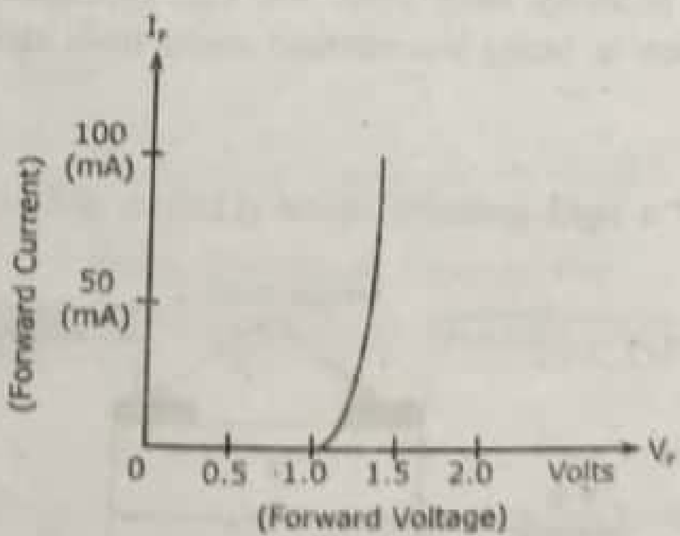


Fig. 10.3.4 Forward bias V-I curve

It is observed from the figure that cut-in voltage of LED is about 1V, which is considerably larger than an ordinary diode. Thus, when the P-N junction is forward biased with a voltage greater than about 1V, electron-hole recombination takes place.

(2) **Output Characteristics :** Fig. 9.3.5 provides radiant power forward current curve. The radiant output power is rather small and indicates a very low efficiency of electrical to radiant energy conversion.

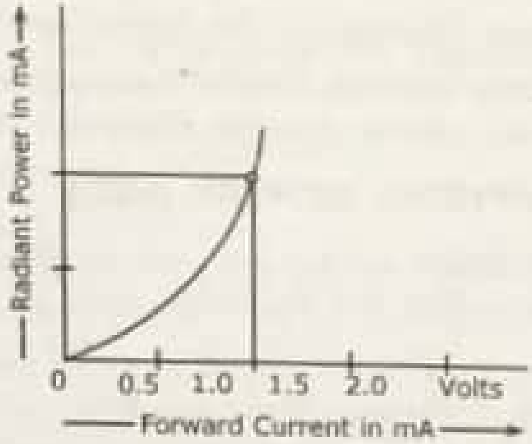


Fig. 10.3.5 Output Characteristic Curve

Advantages and Disadvantages

Advantages

Following are the advantages of LEDs,

(1) **Simple Fabrication :** There are no mirror facets and in certain structures no stripe geometry.

(2) **Cost :** The simple construction of the LED leads to much reduced cost.

(3) **Reliability :** LED does not exhibit catastrophic degradation and has proved far less sensitive to gradual degradation than the injection laser. It is also free from modal noise problems.

(4) **Less Temperature Dependence :** Light output versus current characteristic is less affected by temperature than the corresponding characteristics for the injection laser. LED is not a threshold device and therefore raising the temperature does not increase the threshold current above the operating point and hence halt operation.

(5) **Simpler Drive Circuitry :** This is due to lower drive currents and reduced temperature dependence.

(6) **Linearity :** Light output characteristics are linear as compared to the characteristics of injection laser. This proves advantageous where analog modulation is concerned.

(7) **Multimode Source :** LED supports many optical modes within its structure and is therefore often used as a multimode source.

Disadvantages : Following are the disadvantages of LEDs,

(1) LED cannot with stand over voltage or over current and may get damaged.

(2) LEDs are not suitable for large area display because of their high cost.

(3) Their temperature depends on the radiant output power and wavelength.

(4) The semiconducting materials used for manufacturing light emitting diodes are gallium arsenide (Ga As)), gallium arsenide phosphide (Ga As P).

10.4 LIQUID CRYSTAL DISPLAY (LCD)

(1) Liquid Crystal Displays (LCDs) are used for display of numeric and alphanumeric character in dot matrix and segmental displays.

(2) In general two types of liquid crystal materials are used in display technology. They are nematic and cholesteric whose schematic arrangement of molecules is shown in 10.4.1,

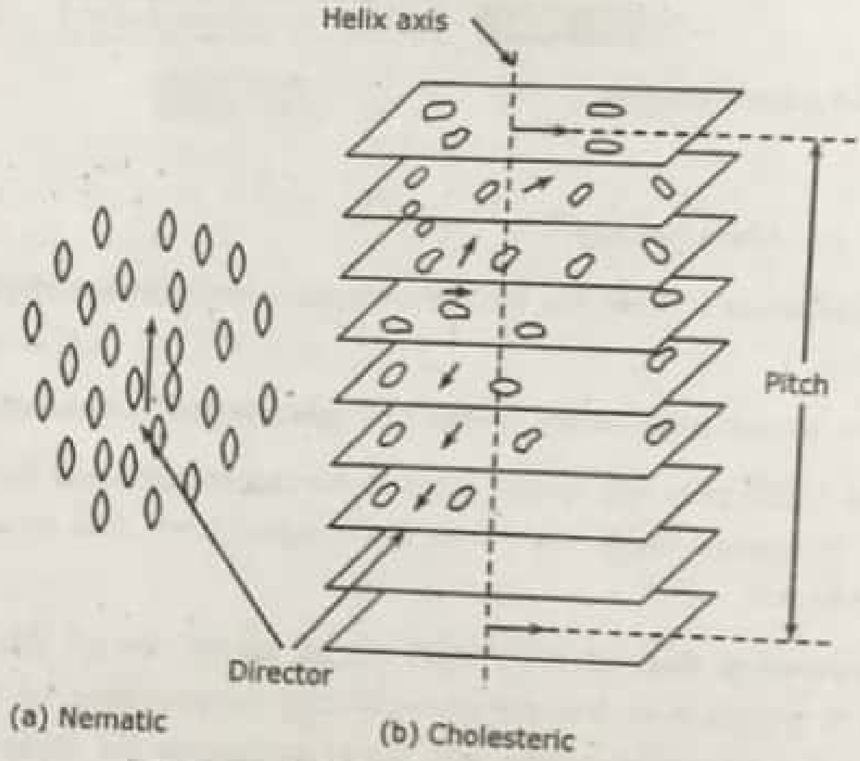


Fig. 10.4.1 Schematic Arrangement of Molecules

(3) Of the both liquid crystal materials, Nematic Liquid Crystal (NLC) is most popularly used in liquid crystal displays. In NLC, all the molecules are aligned almost parallel to a unique axis (director), while retaining the complete translational freedom.

(4) The liquid crystal displays are in general transparent. However where subjected to a strong electric field, the well ordered crystal structure gets disrupted causing the liquid crystal to polarize and turn opaque. With no external bias, the liquid crystal will again regain its original form and it then becomes transparent.

CLASSIFICATION OF LCDS

One important categorization of LCDs is based on the construction. Accordingly we have two types of LCDs. They are dynamic scattering type LCD and field effect type LCD.

(1) **Dynamic Scattering Type LCD :** Fig. 10.4.2 shows the construction of a dynamic scattering liquid crystal cell,

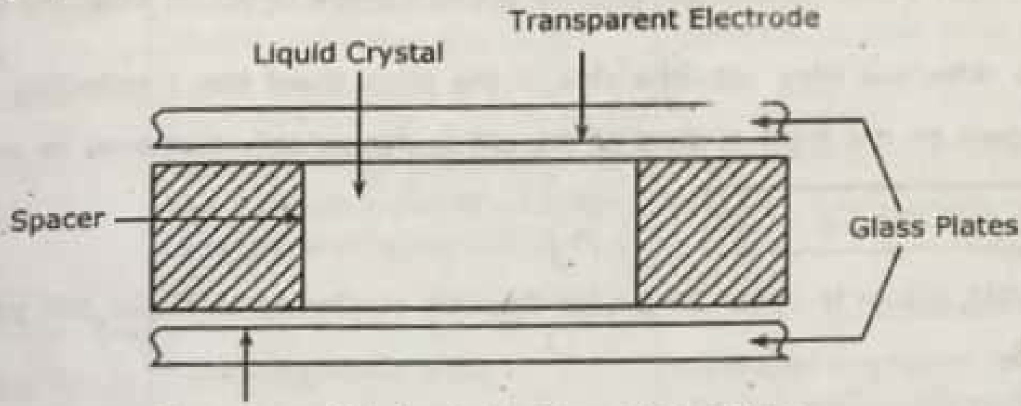


Fig. 10.4.2 Construction of a Dynamic Scattering LCD

It can be noticed from Fig. 9.4.2, this type of LCD consists of two glass plates, each inner surface of glass plate is coated with a very thin and transparent layer of tin oxide (SnO_2). This layer permits light to pass through it and at the same time acts as conducting electrode. The transparent electrodes are separated by a liquid crystal layer, 5 to 50 μm thick.

When the liquid crystal is subjected to an electric field, all the molecules align themselves in the direction of the field. If the applied voltage increases beyond a certain threshold value, the disruption of the well ordered crystal structure takes place and the appearance will get changed. As the voltage increases further, the liquid crystal becomes optically inactive. In this inactive state, the liquid crystal scatters light, thus becomes transparent. However, in an active state, the molecular turbulence causes light to be scattered in all directions and the liquid crystal appears to be bright. This phenomenon is called dynamic scattering.

(2) **Field Effect Type LCD :** The constructional details of field effect LCD differs from dynamic scattering LCD in only one aspect that is two thin polarizing optical filters are placed inside of each glass sheet. In this type LCD material is made up of crystal elements which twist and untwist at varying degrees to allow light to pass through. When the LCD material is not energized, twisting of light takes place and the liquid crystal appears to be bright. When the LCD material is energized, no twisting of light takes place and liquid crystal appears to be dull.

CATEGORIES OF LIQUID CRYSTAL CELLS

Liquid crystal cells are categorized as two types, namely, transmitive type and reflective type.

(1) In transmittive type cell, both glass plates (see Fig. 10.4.2) are transparent so that light from a rear source is scattered in the forward direction when the cell is activated.

(2) In a reflective type .ell, one side of the glass sheet has a reflecting surface. A light incident on the front surface of the cell is dynamically scattered by an activated cell.

SPECIFICATIONS OF LCDS

(1) Current drawn is about 25 μA for dynamic scattering cells and 300 μA for field effect cells.

(2) LCDs require A.C voltage supply.

(3) Voltage supply is 30 V peak-to-peak with 50 Hz for dynamic scattering LCDs.

(4) Liquid crystals consume small amount of energy.

Advantages of LCDs : Following are the advantages of LCDs,

(1) LCDs require very little current and hence power their operation.

(2) They are of very low cost.

(3) We can construct very small as well as very large displays using LCDs.

(4) Colour displays are possible using dyes.

(5) Very thin LCDs are possible.

(6) Better contrast ratio than many other displays except CRT.

(7) Requires no turn on time like CRTs.

Disadvantages of LCDs : Following are the disadvantages of LCDs,

(1) LCDs are very slow devices. The turn ON and turn OFF times are quite large. The turn ON time is typically of the order of a few ms, while the turn OFF time is 10 ms.

(2) Viewing angle of LCDs is limited. LCDs give best performance when viewed directly from its front. From sides, the view is limited.

Comparision of LED and LCD : Table 10.4.1 lists the comparision of LED and LCD.

Table 10.4.1 Comparison between LED and LCD

S.No.	Basic of Comparison	LED	LCD
(1)	Power Requir-ement	Consumes more power-requires 10-250 mW power per digit.	Consumes very less power req-uires 10-200 μW power per dig-it.
(2)	Mode of Driving	Because of high power require-ment, it requires external inter-face circui-try when driven from ICs.	Can be driven directly from IC chips.
(3)	Brightness	Good brightness level.	Moderate brightness level.
(4)	Temperature Range	Operable within the temperatu-re range -40 to 85°C	Temperature range limited to - 20 to 60°C.
(5)	Durability	Life time is around 100,000 hou-rs.	Life time is limited to 50,000 ho-urs due to chemical degradati-on.
(6)	Visibility	Emits light in red, orange, yell-ow, green blue and white.	Invisible in darkness – requires external illumination.
(7)	Operating Vo-ltage	1.5 to 5 V D.C.	3 to 20 V A.C.
(8)	Response Time	50 to 500 ns.	50 to 200 ms
(9)	Viewing Angle	150°	100°

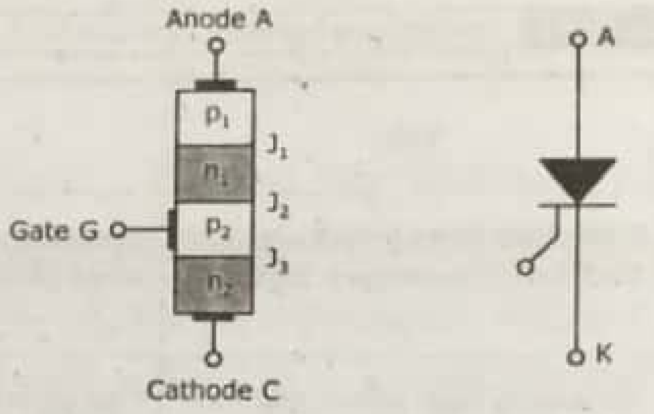
10.5 SILICON CONTROLLED RECTIFIER (SCR)

A Silicon Controlled Rectifier (SCR) is a three terminal semiconductor switching device. An SCR acts like a true electronic switch (a bidirectional switch).

CONSTRUCTION

When a p-n junction is added to a junction transistor, the resulting three p-n junction (J_1, J_2 and J_3) device is called SCR.

Fig. 10.5.1 shows its construction and symbol,



(a) SCR Structure (b) Symbol

Fig. 10.5.1 Silicon Controlled Rectifier

It is clear that, it is essentially an ordinary rectifier (PN) and a junction transistor (NPN) combined in one unit to form a PNPN device. The three terminals are anode, cathode and gate. SCR provides conduction of current in one direction only. Therefore it is also named as unidirection reverse-blocking thyristor. It can be switched from OFF to ON state by applying a positive trigger pulse to the gate. That is why it is also called a *controlled rectifier*.

In normal operation of SCR, anode is made high (positive) with respect to cathode and gate is made less positive with respect to cathode.

10.5.1 Working Operation

In an SCR, load is connected in series with anode. The anode is always kept at positive potential with respect to cathode. The working operation of SCR can be studied under following two cases,

Case I (When Gate is Open) : Fig. 10.5.2 shows the SCR circuit with gate open, i.e., $V_G = 0$.

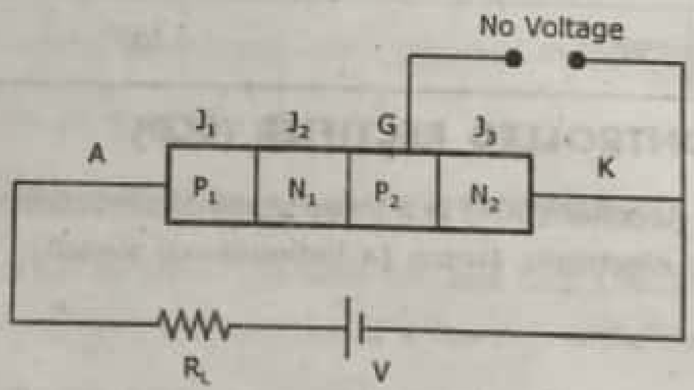


Fig. 10.5.2 The Circuit of "When no Gate Voltage"

Under this condition junctions J_1 and J_3 are forward biased while junction J_2 is reverse biased. Hence, the situation in junctions J_1 and J_3 is like that of an NPN transistor with base open. Consequently, no current flows through the load R_L and the SCR is in cut-off. However, if the applied voltage (i.e., anode voltage) is gradually increased, a threshold value is reached, where the junction J_2 breaksdown. Now, the SCR conducts heavily and is said to be in the ON state.

The applied voltage at which SCR conducts heavily without gate voltage is called 'break-over voltage' V_{BO}.

Case II (When Gate is Positive with respect to Cathode) : The SCR can be made to conduct heavily at smaller applied voltage by applying a small positive potential to the gate as in Fig. 10.5.3,

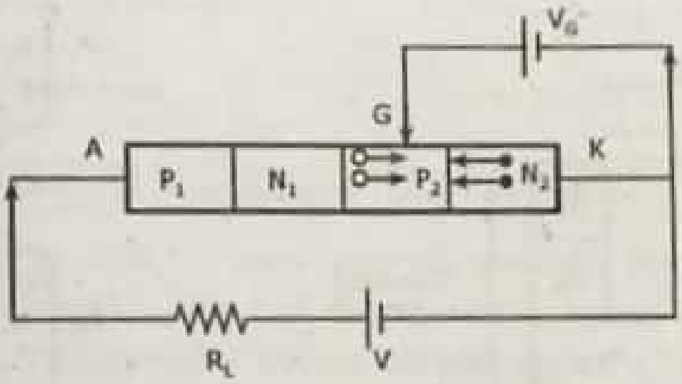


Fig. 10.5.3 With Gate Voltage V_G

Now, junction J_3 is forward biased and junction J_2 is reverse biased. Electrons from N-side start moving across J_3 towards left, whereas holes from P-side move towards right. Consequently, the electrons from J_3 are attracted across J_2 and gate current start flowing. Then anode current increases, which in turn makes more number of electrons available at J_2. Within an extremely small time the junction J_2 breaks down and the SCR starts conducting heavily.

Once SCR starts conducting, the gate losses all the control. Even if the gate voltage is removed, the anode current does not decrease at all. The only way to stop SCR conducting (OFF) is to reduce the applied voltage to zero.

Few important conclusions about SCR,

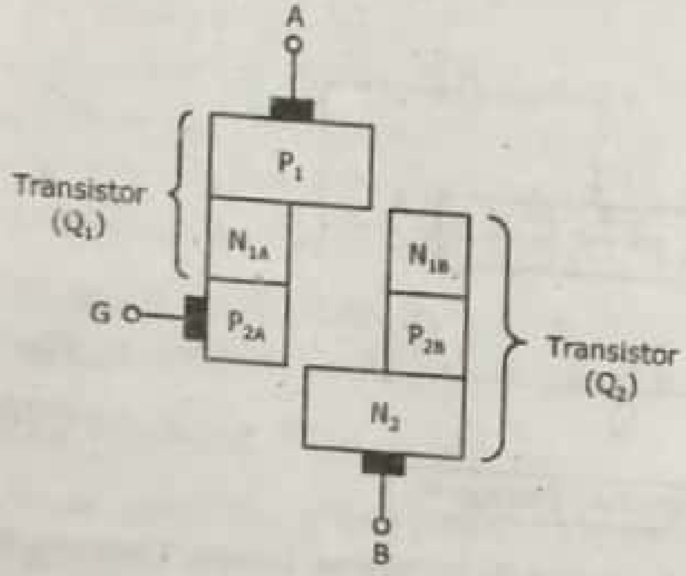
(1) **SCR Acts Like a Switch :** SCR can either conduct heavily or non-conducts, but there is no state in between. Hence SCR acts like a switch.

(2) **SCR is a unidirectional Device :** If the potential at anode is made negative with respect to potential at cathode, then the SCR gets blocked because of two reverse biased junctions J_1 and J_3. If the applied voltage is increased then at some critical point (break down voltage) SCR gets destroyed. This shows that SCR is a uni-directional device.

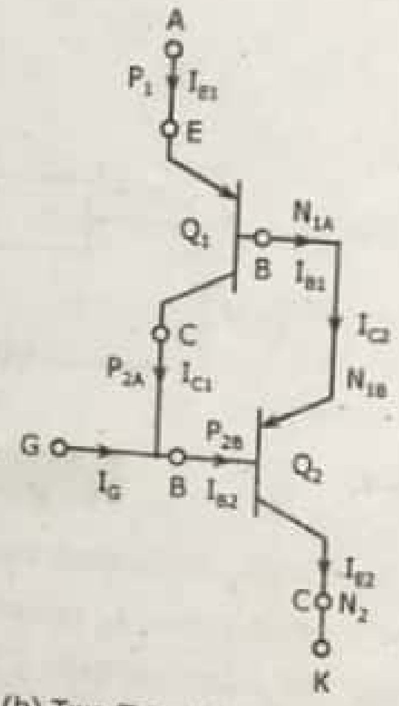
(3) To make the SCR non-conducting from conducting state, the supply voltage is reduced to zero.

10.5.2 Two Transistor Analogy of SCR

To understand the working operation of SCR more effectively, it is necessary to imagine SCR as two transistors, PNP and NPN as shown in Fig. 10.5.4,



(a) Two Transistor Construction

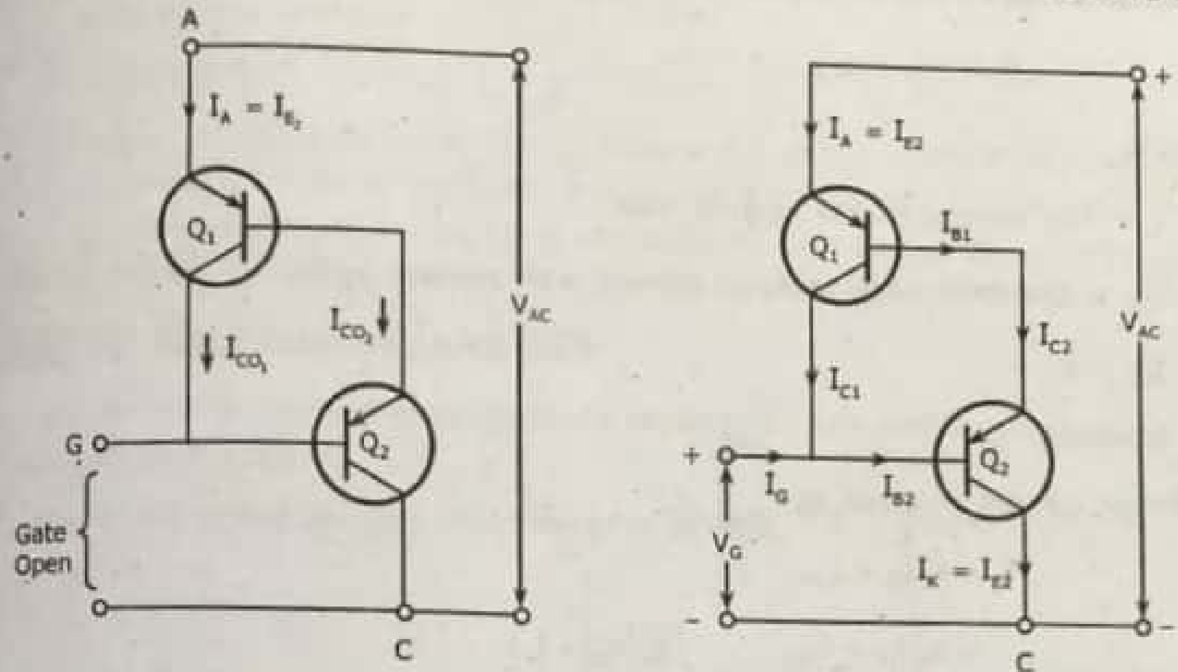


(b) Two-Transistor Equivalent Circuit

Fig. 10.5.4 Two Transistor Analogy of SCR

From Fig. 10.5.4(a) it is now possible to think layers P_1 N_{1A} and P_{2A} as a PNP transistor, whereas layers N_{1B}, P_{2B} and N_2 as a NPN transistor. Fig. 10.5.4(b) shows the two transistor equivalent circuit by replacing block represents. From Fig. 10.5.4(b), it can be noticed that collector of transistor Q_1, is connected to base of transistor Q_2. Also emitter terminal of Q_1 acts as anode, junction of Q_1 collector and Q_2 base acts as gate and emitter of transistor Q_2 acts as the cathode terminal. The working operation of SCR is studied for following two cases in forward-bias mode.

Fig. 10.5.5 shown that the two transistor equivalent circuit of SCR in forward-mode.



(a) Two-Transistor Equivalent Circuit

(b) SCR Turns ON with Gate Current

Fig. 10.5.5 Illustration of SCR Operation Using Two Transistor Analogy

CASE I (When Gate is Open) : With the gate terminal open, only small leakage currents (I_{CO_1}, I_{CO_2}) flows which is too small to turn both the transistors. Hence, both the transistors are in OFF state. Fig. 10.5.5(a) shows the leakage currents since the junction J_2 is reverse biased. The anode current is just the sum of leakage currents i.e.,

$$I_A = I_{E1} = I_{CO_1} + I_{CO_2}$$

CASE II (When Positive Gate Voltage is Applied) : When a small gate voltage is applied as shown in Fig. 10.5.5(b), then the positive gate cathode voltage forward biases the base-emitter junction of Q_2 resulting in a gate current ($I_G = I_{B2}$) to flow and thereby produces a collector current I_{C_2} . Since I_{C_2} is the same as I_{B1}, Q_1 also switches ON and hence I_{C1} starts to flow producing base current I_{B2}.

Both these collector currents provides much more base currents needed by the transistors (to bring them into ON state). Hence even if the gate terminal is open (i.e., $I_G = 0$), the transistors will remain in ON state and conducts heavily even with a small anode-to-cathode voltage. This property of SCR to hold in 'ON' state even if the gate (triggering) current is opened is called as latching.

COMMENT : *To switch 'ON' SCR, only a gate pulse current is required. Once it gets switched ON gate terminal has no further control and hence SCR remain "ON" until Anode-to-Cathode voltage drops to zero volts.*

Mathematical Analysis : From transistor analysis we have collector currents as,

$$I_C = \alpha I_E + I_{CO} \quad \text{--- (10.5.1)}$$

Where,

α = The common base current gain.

I_{CO} = Common base leakage current with emitter open.

I_{CO} = C

For transistor Q_1,

Collector current is given by,

$$I_{C_1} = \alpha_1 I_{E1} + I_{CBO_1}$$

$$= \alpha_1 I_A + I_{CBO_1} \qquad (\because I_{E1} = I_A)$$

For transistor Q_2,

Collector current,

$$I_{C_2} = \alpha_2 I_{E2} + I_{CBO_2}$$

$$= \alpha_2 I_K + I_{CBO_2} \qquad (\because I_{E2} = I_K)$$

The external circuit current i.e., the anode current is equal to the sum of two collector currents.

$$I_A = I_{C_1} + I_{C_2}$$

$$= \alpha_1 I_A + I_{CBO_1} + \alpha_2 I_K + I_{CBO_2}$$

$$= \alpha_1 I_A + I_{CBO_1} + \alpha_2 (I_A + I_G) + I_{CBO_2}$$

On simplification, we get,

Anode current,

$$I_A = \frac{\alpha_2 I_G + I_{CBO_1} + I_{CBO_2}}{1 - (\alpha_1 + \alpha_2)}$$

For negligible common base leakage current, we have anode current,

$$I_A = \frac{\alpha_2 I_G}{1 - (\alpha_1 + \alpha_2)} \quad \text{... (10.5.2)}$$

Here $(\alpha_1 + \alpha_2)$ is called as loop again. For unity loop gain the anode current becomes infinity turns ON the device.

From Eq. (10.5.2), we have $I_A \alpha I_G$

Therefore, as the gate current is increases the anode current also increases and the device conduct for lower voltages. Also, when gate current (I_G) is zero, the anode current (I_A) is zero. Hence, it can be known that the SCR works as a current controlled device or switch.

10.5.3 V-I Characteristics of SCR

It is the curve between anode-cathode voltage (V) and anode current (I) of an SCR at constant gate current.

Fig. 10.5.6 shows the V-I characteristics of SCR,

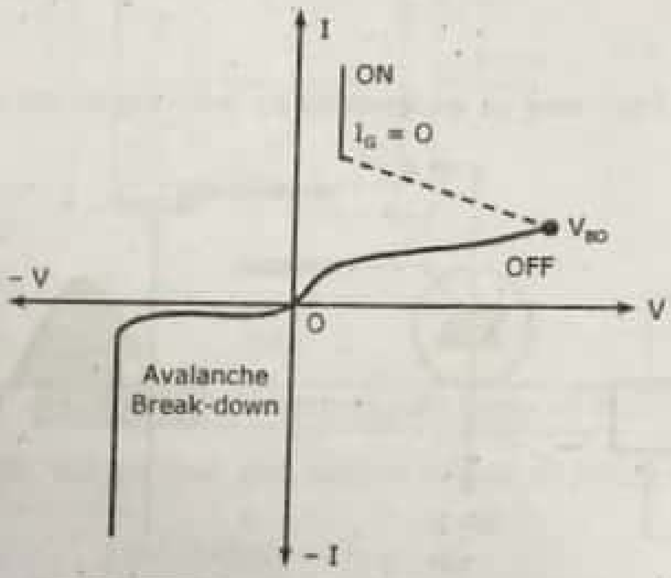


Fig. 10.5.6 V-I Characteristics of SCR

Forward Characteristics : When anode is positive with respect to cathode, the curve between V and I is called the forward characteristic. The forward characteristic shown below with $I_G = 0$. If the supply voltage is increased from zero and when a point (V_{BO}) is reached, the SCR starts conducting. Under this condition, the voltage across SCR drops suddenly as shown by the dotted line and most of supply voltage appears across the load resistance R_L. If proper gate current is made to flow, SCR can close at much smaller supply voltage.

Reverse Characteristics : When the anode is made negative with respect to cathode, the curve between V and I is called the reverse characteristic. The reverse voltage does come across SCR, when it is operated with AC supply. If the reverse voltage is gradually increased, at first, the anode current remains small (leakage current) and at some reverse voltage, avalanche breakdown occurs and the SCR, starts conducting heavily in the reverse direction. This maximum reverse voltage at which SCR starts conducting heavily is called reverse breakdown voltage.

TRIAC

The major drawback of an SCR is that it can conduct current in one direction only. Therefore, an SCR can only control D.C power or forward biased half-cycles of A.C in a load. However, in an A.C system, it is often desirable and necessary to exercise control over both positive and negative half-cycles. For this purpose, a semiconductor device called triac is used.

A triac is a three terminal semiconductor switching device which can control alternating current in a load.

Triac is an abbreviation for triode A.C switch. 'Tri' indicates that the device has three terminals and A.C means that the device controls alternating current or can conduct current in either direction.

The key function of a triac may be understood by referring to the simplified Fig. 10.6.1.

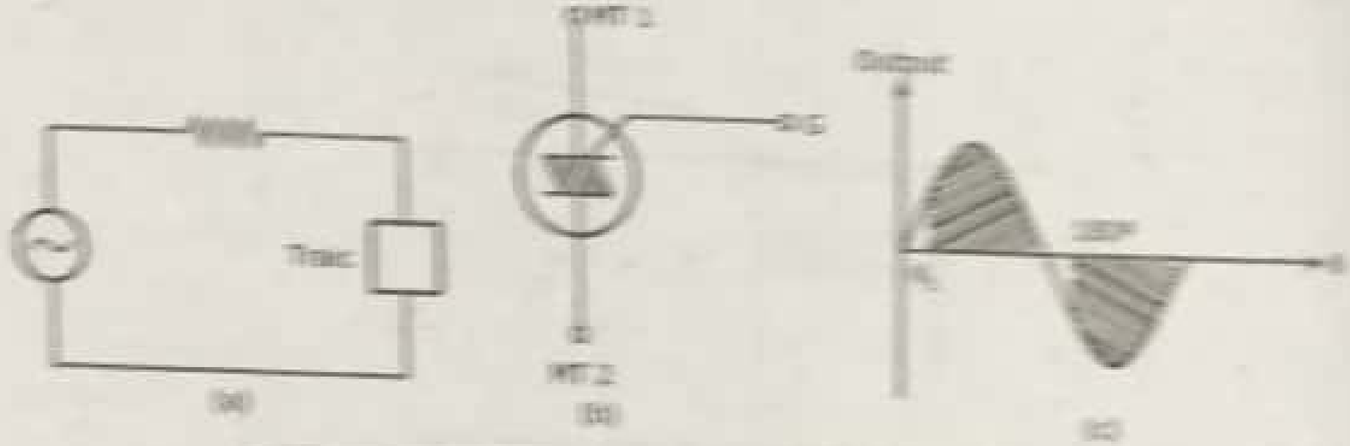


Fig. Symbol, Control Circuit and Output of a TRIAC

The control circuit of triac can be adjusted to pass the desired portions of positive and negative half cycles of A.C supply through the load R_L. Thus, referring to Fig. 10.6.1(b), the triac passes the positive half-cycle of the supply from α_1 to 180° i.e., the shaded portion of the positive half-cycle. Similarly, the shaded portion of negative half-cycle will pass through the load. In this way, alternating current and hence A.C power flowing through the load can be controlled.

Since a triac can control conduction of both positive and negative half-cycles of A.C supply, it is sometimes called a bidirectional semi-conductor triode switch. The above action of a triac is certainly not a rectifying action (as in an SCR) so that the triac makes no mention of rectification in its name.

10.6.1 Triac Construction

A triac is a bidirectional switch having three terminals. Fig. 10.6.2(a) shows the basic structure of a triac. Referring to Fig. 10.6.2(b), the basic structure can be shown to be consisting of two halves. Each half may be considered as pnpn SCR with the gates combined as shown in Fig. 10.6.2(c). The equivalent circuit of triac shown in Fig. 10.6.2(c) indicates that a triac corresponds to two separate SCRs connected in inverse parallel (i.e., anode of each connected to the cathode of the other) with the gates combined.

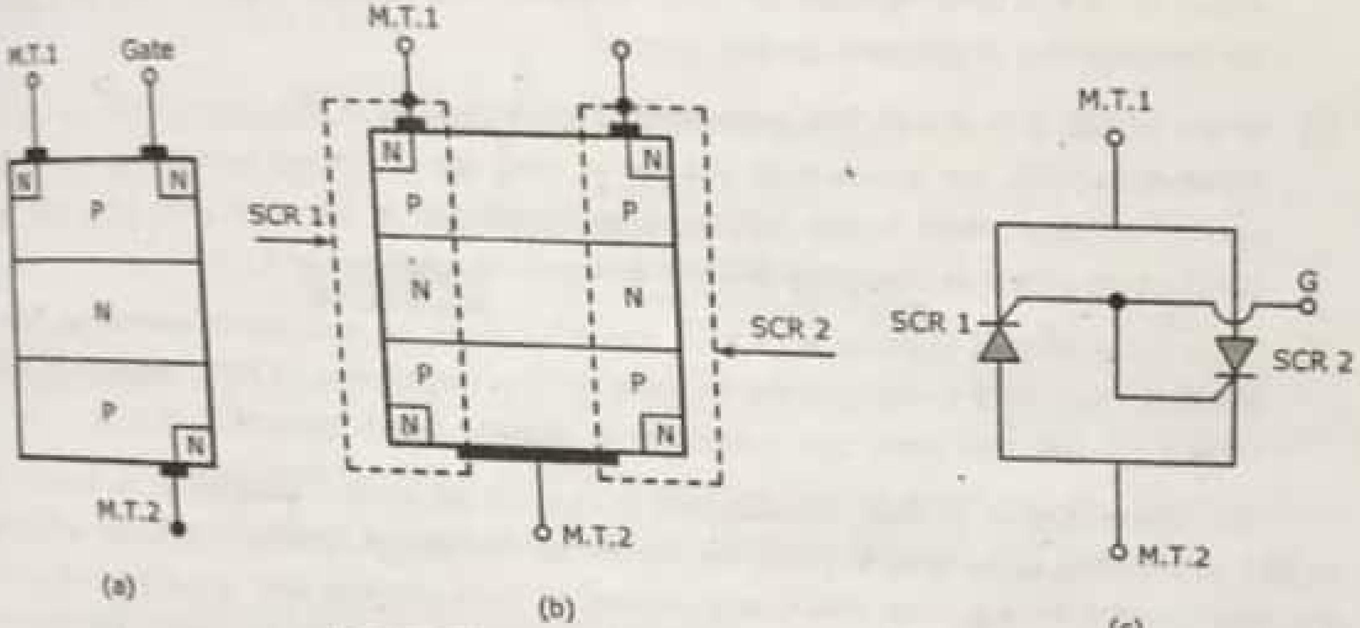


Fig. 10.6.2 Constructional Details of TRIAC

Fig. 10.6.3 shows the symbol and simple circuit of triac,

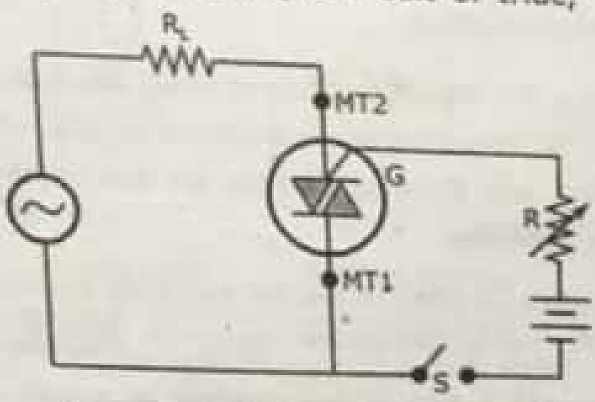


Fig. 10.6.3 Simple Traic Circuit

The control terminal as with SCR is called the gate G. The other two terminals are MT1 and MT2 respectively called main terminal 1 and main terminal 2. With a proper gate current, the triac can be made to conduct when MT2 is either positive or negative with respect to MT1. It can be seen that even symbol of triac indicates that it can conduct for either polarity of voltage across the main terminals. The gate provides control over conduction in either direction.

10.6.2 Triac Operation

The A.C supply to be controlled is connected across the main terminals of triac through a load resistance R_L. The gate circuit consists of battery, a current limiting resistor R and a switch S. The circuit action

(1) When switch S is open, there will be no gate current and the triac is cut off. Even with no gate current, the triac can be turned on provided the supply voltage becomes equal to break over voltage of triac. However, the normal way to turn on a triac is by introducing a propers guage current.

(2) When switch S is closed, the gate current starts flowing in the gate circuit. In a similar manner to SCR, the break over voltage of triac can be varied by making proper gate current to flow. With a few milliamperes introduced at the gate, the triac will start conducting whether terminal MT2 is positive or negative w.r.t MT1.

(3) If terminal MT2 is positive w.r.t MT1, the triac turns on and the conventional current will flow from MT2 to MT1. If the terminal MT2 is negative w.r.t MT1, the triac is again turned on but this time the conventional current flows from MT1 to MT2.

The above action of triac reveals that it can act as an A.C contractor to switch ON or OFF alternating current to a load. The additional advantage of triac is that by adjusting the gate current to a proper value, any portion of both positive and negative half-cycles of A.C supply can be made to flow through the load. This permits to adjust the transfer of A.C power from the source to the load.

10.6.3 Triac Characteristics

Fig. 10.6.4 shows the V-I characteristics of triac. Because the triac essentially consists of two SCRs of opposite orientation fabricated in the same crystal, its operating characteristics in the first and third quadrants are the same except for the direction of applied voltage and current flow.

(1) The V – I characteristics for triac in the 1st and IIIrd quadrants are essentially identical to those of an SCR in the 1st quadrant.

(2) The triac can be operated with either positive or negative gate control voltage but in no normal operation usually gate voltage is positive in quadrant I and negative in quadrant III.

(3) The supply voltage at which the triac is turned ON depends upon the gate current. The greater the gate current, the smaller the supply voltage at which the triac is turned on. This permits to use a triac to control A.C power in a load from zero to full power in a smooth and continuous manner with no loss in the controlling device.

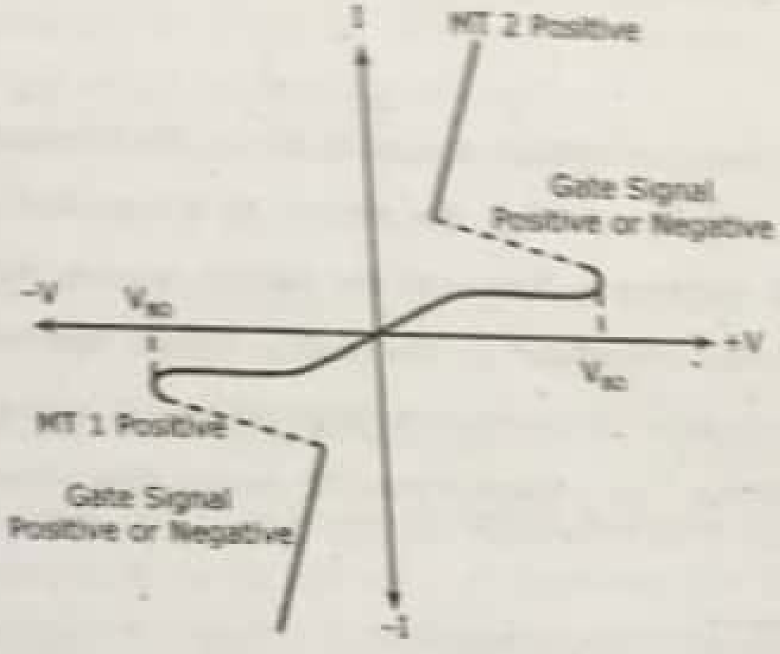


Fig. 10.6.4 V-I Characteristics of Triac

10.7 DIAC

A diac is a two terminal, three layer bidirectional device which can be switched from its OFF state to ON state for either polarity of applied voltage.

Fig. 10.7.1 shows the basic structure of diac.

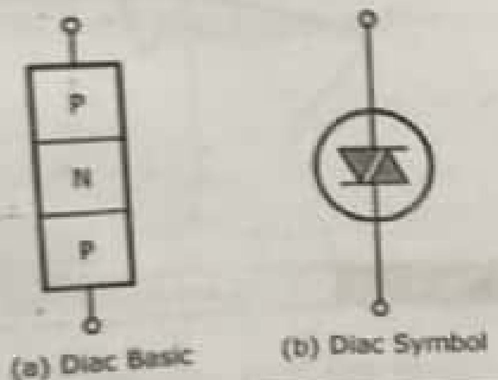


Fig. 10.7.1 Structure and Symbol of DIAC

The two leads are connected to p-regions of silicon separated by an n-region. The structure of the diac is somewhat like a transistor with the following basic differences,

(1) There is no terminal attached to the base layer.

(2) The doping concentrations are identical (unlike a bipolar transistor) to give the device symmetrical properties.

OPERATION

When a positive or negative voltage is applied across the terminals of a diac, only a small leakage current I_{BO} will flow through the device. As the applied voltage is increased, the leakage current will continue to flow until the voltage reaches the breakover voltage V_{BO}. At this point, avalanche breakdown on the reverse biased junction occurs and the device exhibits negative resistance i.e., current through the device increases with the decreasing values of applied voltage. The voltage across the device then drops to 'breakback' voltage V_W.

V-I CHARACTERISTICS

Fig. 10.7.2 shows the V-I characteristics of a diac.

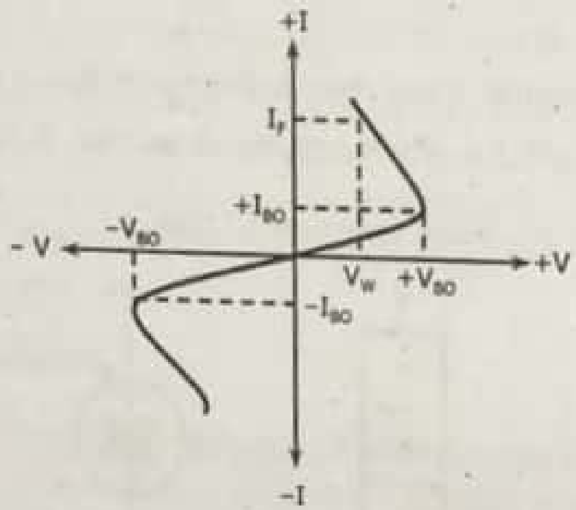


Fig. 10.7.2 VI_Characteristics of Diac

For applied positive voltage less than $+V_{BO}$ and negative voltage less then $-V_{BO}$, a small leakage current $(+I_{BO})$ flows through device. Under such conditions, the diac blocks flows the of current and effectively behaves as an open circuit. The voltage $+V_{BO}$ and $-V_{BO}$ are the breakdown voltages and usually have a range of 30 to 50 volts.

Applications of Diac : When the positive or negative applied voltage is equal to or greater than the breakdown voltage, diac begins to conduct and the voltage drop across it becomes a few volts:

Diacs are used primarily for triggering of triacs in adjustable phase control of A.C main power. Some of the circuit applications of diac are,

(1) Light dimming.

(2) Heat control.

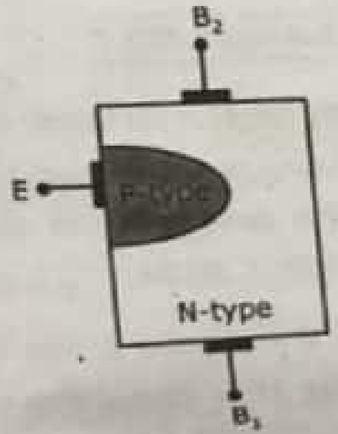
(3) Universal motor speed control.

10.8 UNI-JUNCTION TRANSISTOR (UJT)

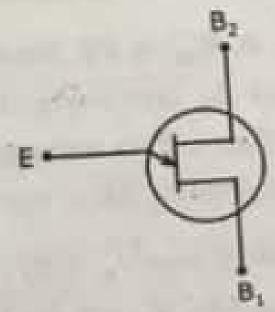
Uni-junction Transistor (UJT) is a 3-terminal device, it is quite different from the bipolar and field effect transistors as far as operation is concerned. The device input, called the Emitter, has a resistance which rapidly decreases when the input voltage reaches a certain level. This is called a negative resistance characteristic and this characteristics makes the UJT useful in a number of applications.

10.8.1 Construction of UJT

Fig. 10.8.1(a) shows the basic structure of Unijunction Transistor (UJT) in which a heavily doped P-type material is alloyed with a lightly doped N-type silicon bar to its one side closer to B_2 for producing single PN junction. The end terminals of the bar are termed as Base 1 (B_1) and Base 2 (B_2), and the P-type region is called Emitter E.



(a) Basic Structure of UJT



(b) UJT Circuit Symbol

Fig. 10.8.1 Structure and Symbol of UJT

Fig. 10.8.1(b) depicts the symbol of UJT. The emitter arrow show in the circuit symbol is inclined and points toward B_1 and it gives the conventional direction of current for a forward biased P-N junction.

10.8.2 UJT Characteristics

Fig. 10.8.2 shows the graph plotted between emitter current and emitter voltage which depicts the UJT characteristics,

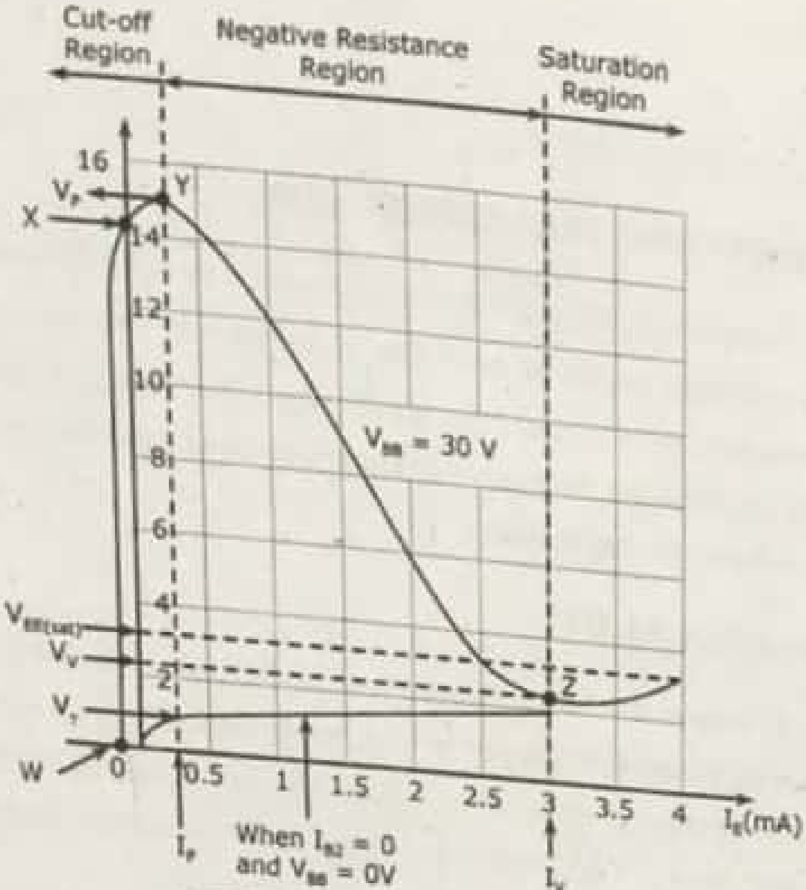


Fig. 10.8.2 UJT Characteristics

Case 1 (When, I_{B2} = 0, V_{BB} = 0V, Small V_E) : With base 2 terminal open and no voltage applied across B_1 and B_2 terminals, If emitter voltage is applied then diode becomes forward biased and after cut-in voltage diode starts conducting as shown in Fig. 10.8.2. This characteristics is similar as a normal PN junction diode.

Case 2 (When V_{BB} Applied and V_{EE} = 0) : If V_{BB} = 30 V is applied across B_1 and B_2 terminals, then voltage across R_{B2} i.e., V_1 will be approximately 15 V (for η = 0.5). At this instance, diode remains reverse biased and a small reverse current flows as shown by point 'W' in Fig. 10.8.2.

Case 3 (When V_{EE} is Applied) : If the emitter voltage (V_{EE}) is increased upto V_P (here 15 V) then I_E becomes zero shown by point 'X' on the characteristics in Fig. 10.8.2. With further increase in V_{EE} makes the diode forward biased and this indicates peak point shown by point 'Y' on characteristics. Voltage at this point is termed as peak voltage (V_P) and current as peak current (I_P).

If emitter voltage (V_{EE}) is further increased, then more carriers injected into N-type silicon bar reduces the resistivity of Base 2 region as explained earlier. As resistance decreases with increase in voltage, this region is called as negative resistance region. When V_{EE} falls to the valley voltage (V_V) shown by point 'Z' on characteristic in Fig. 10.8.2 then I_E increases upto I_V. If I_E is increased further, then device enters into saturation region.

When V_{BB} is reduced below 30 Volts, then peak voltage (V_P) is also reduced and the UJT will switch on at a lower value of peak voltage. Thus, using the different values of V_{BB}, a family of V_E-I_E characteristics for a given UJT can be plotted as shown in Fig. 10.8.3,

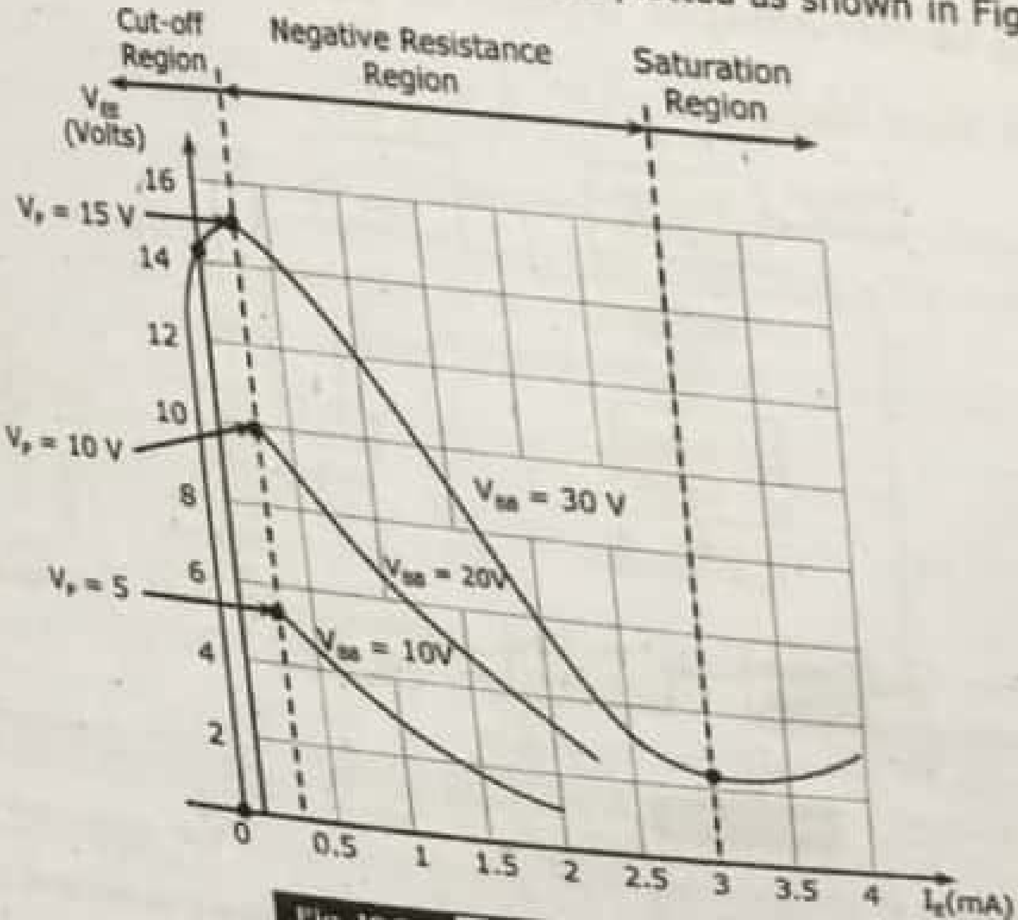


Fig. 10.8.3 UJT Characteristics

10.9 DISPLAY SYSTEMS

Information display is a key element in the advancement of electronics technology. In industrial, the display systems are widely used for measurements of amplitude, frequency, time period etc. Some of the display systems are CRO, LCD, LED etc. LCD and LED's are already discussed in previous sections. Now, we will discuss only CRO (Cathod Ray Oscilloscope).

10.10 CATHODE RAY OSCILLOSCOPE (CRO)

The Cathode Ray Oscilloscope (CRO) is the most useful and the most versatile laboratory instrument used to display waveforms of alternating currents and voltages. With the help of CRO, an electronics engineer can see the amplitude of electrical signals as a function of time on the screen at the different parts of the circuit.

The oscilloscope depends on movement of electron beam which is made visible by allowing the beam to impinge on the screen surface to produce a visible spot. The electron beam is deflected in two axes and luminous spot can be used to create two dimensional display. The x-axis is deflected at a constant rate relative to time and y-axis is deflected in response to input stimulus, such as voltage. This produces a time dependent variation of input voltage.

10.10.1 Constructional Details of C.R.O

The block diagram of a CRO is as shown in Fig. 10.10.1,

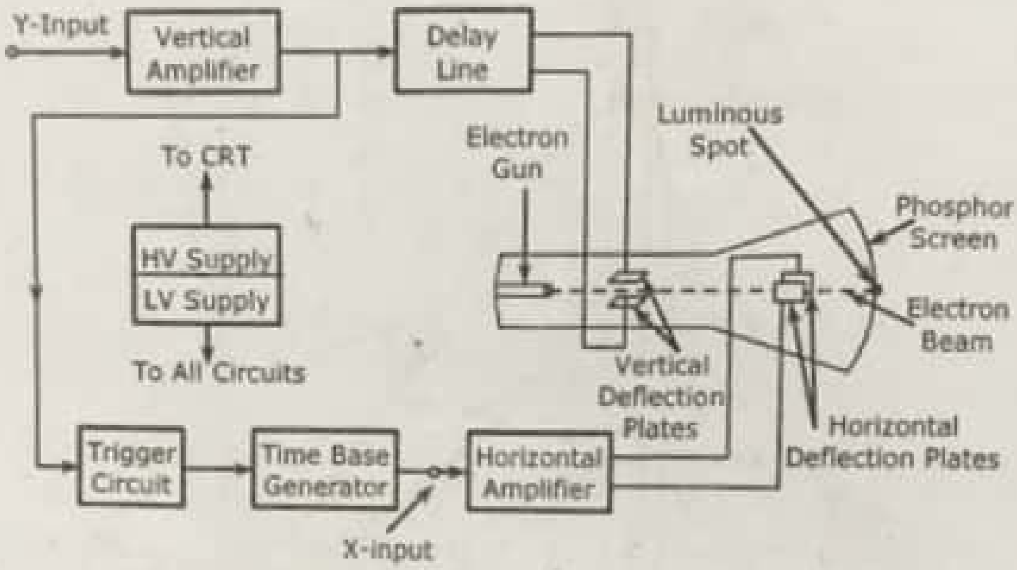


Fig. 10.10.1 Block Diagram of a General Purpose (CRO)

It consists of the following main subsystems which are explained below,

(1) **Cathode Ray Tube (CRT) :** The heart of the oscilloscope is a cathode ray tube whose function is to,

(i) Generate the electrons.

(ii) Accelerate the electrons to high velocity.

(iii) Deflection of the beam to create a visible spot on the phosphorus screen.

(2) **Vertical Deflection System :** The signal to be displayed is fed to the Y-input. Before applying to the vertical deflection plates of the CRT, it is first amplified by the vertical amplifier, which raises potential of the input signal to a level that will provide usable deflection of the electrons.

(3) **Horizontal Deflection System :** The horizontal deflection system consists of a timebase generator, synchronization circuit and a number of amplifier stages.

(ii) **Time Base Generator :** The time base generator is used to display the input signal as a function of time, on the screen at a uniform rate. The time base generator has a linear sawtooth oscillator, which generates sawtooth signal. This sawtooth voltage is amplified by horizontal amplifier whose gain can be controlled by a calibrated attenuator. This attenuator is marked as 'μs/div' or 'ms/div'. A different setting of this attenuator expands or contracts the time scale on the screen. With the help of markings on this attenuator, we can read the time period of the displayed waveform.

(iii) **Trigger Circuit :** A triggering circuit is provided for synchronizing two types of deflections so that horizontal signal each time it sweeps.

(4) **Power Supply :** Low voltage supply is required for the heater of the electron gun for generation of electron beam and high voltage, of the order of few thousand volts, is required for cathode ray tube to accelerate the beam. Normal voltage supply, say a few hundred volts, is required for other control circuits of the oscilloscope.

10.10.2 Applications

A general purpose CRO is used as a versatile test equipment in an electronics laboratory. It has following important applications,

(1) **Study of Waveforms :** The A.C voltage, sinusoidal or otherwise whose waveform is to be studied, is fed to the Y-input of the CRO. The size for the figure displayed on the screen can be adjusted suitably by adjusting the gain controls. By adjusting the timebase frequency, we can accommodate one, two, or more cycles of the Y-input signal.

(2) **Measurement of Voltages :** A D.C voltage can be measured by applying it to vertical deflection plate, and then by measuring the displacement of the spot on the screen. Multiplying this displacement by the deflection sensitivity of the CRO, we get the magnitude of the D.C voltage.

To measure an A.C (sinusoidal) voltage, it is applied to the vertical deflection plates. We then measure the length of the straight line trace obtained on the screen. Multiplying this length with the deflection sensitivity (given in V/cm) gives the peak-to-peak value of the A.C voltage. Dividing this value by $2\sqrt{2}$ gives the r.m.s value of the unknown A.C voltage.

(3) **Measurement of Current :** Basically, a CRO is a voltage indicating device. However, a current can be measured directly with the help of a CRO. The unknown current is passed through a suitable known resistor. Using CRO, we can measure the voltage developed across this resistor as explained above. Dividing this voltage by the resistance value gives the current.

(4) **Measurement of Frequency :** The simplest way to measure the frequency of an A.C voltage (whether sinusoidal, square, triangular, or any other periodic type) is to display it on the CRO and measure its time period, using the calibrated timebase. The frequency is then the inverse of this time period.

The above method of measuring frequency, though quite simple, is not very accurate. Another method, using Lissajous patterns, is more accurate.

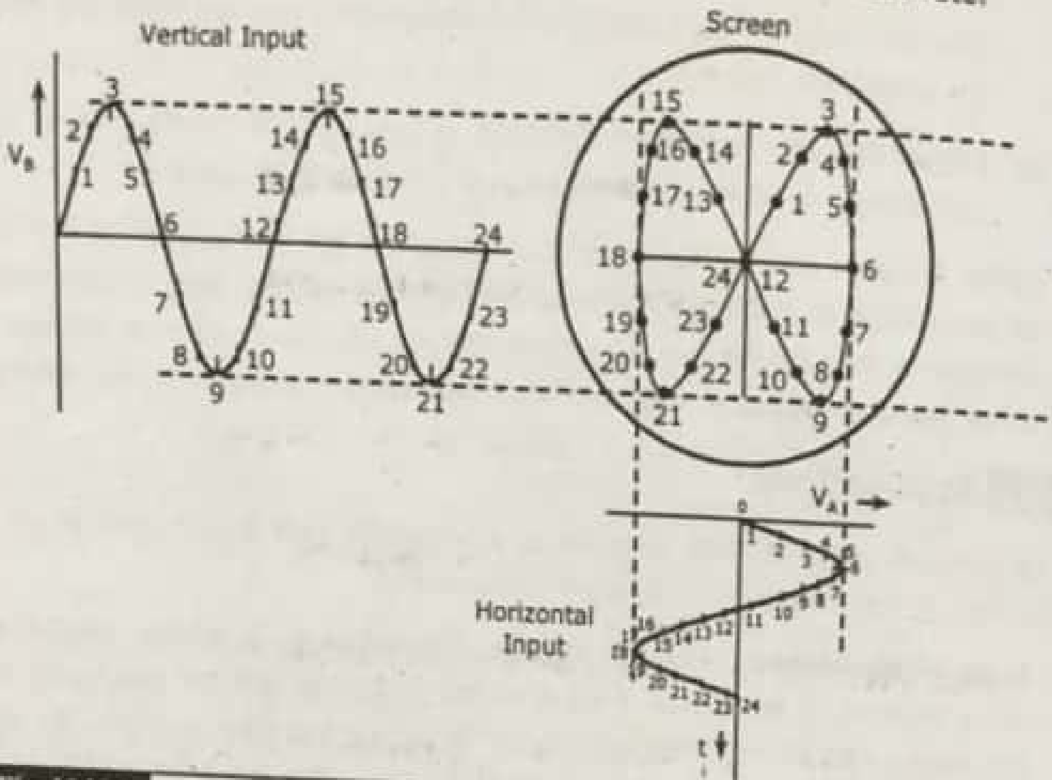


Fig. 10.10.2 Formation of Lissajous Pattern when the Ratio of Frequencies is 1 : 2

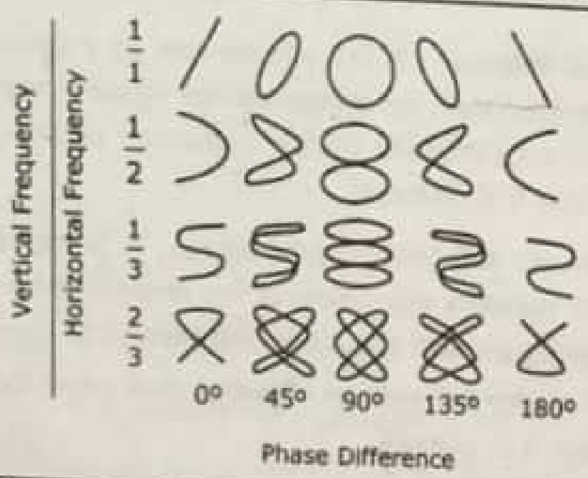


Fig. 10.10.3 Lissajous Pattern Different Frequency Ratios and Phase Differences

When two different sinusoidal signals are applied simultaneously to an oscilloscope without internal sweep, one to the horizontal deflection plates and the other to the vertical deflection plates, the resulting pattern is called a Lissajous pattern.

The type of pattern produced depends on,

(i) The ratio of the frequencies.

(ii) The relative phase of the two sine-wave voltages.

Fig. 10.10.2 illustrates the formation of the Lissajous pattern having a shape of 'figure of 8', when the two voltages applied to the two sets of deflection plates have frequencies in the ratio of 1 : 2. Fig. 10.10.3 shows some typical cases of Lissajous patterns for various frequency ratios and phase differences.

To measure the frequency of a given sinusoidal voltage, it is applied to one set of deflection plates (say, Y-input). To other set (say, X-input) another sinusoidal voltage obtained from a standard variable-frequency oscillator is applied. The frequency of this oscillator is varied till a suitable stable pattern is obtained on the screen. This frequency of the oscillator is noted. Once you recognize the pattern obtained, it is easy to determine the unknown frequency.

(3) **Measurement of Phase Difference :** The phase difference between two sine-wave voltages (of the same frequency) can be determined by using a CRO. The two voltages are simultaneously applied to the two sets of deflection plates. The resultant Lissajous pattern on the screen is an ellipse, as shown in Fig. 10.10.4. By adjusting the X-shift and Y-shift controls, the figure is centered on the origin. Then by measuring the y-intercept (Y_1) and the maximum deflection in y-direction (Y_2), the phase difference θ can be calculated from the following relation.

$$\sin \theta = \frac{Y_1}{Y_2}$$

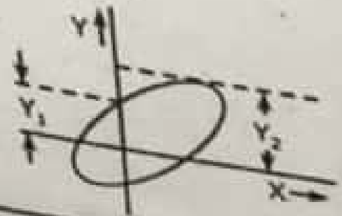


Fig. 10.10.4 Measurement of Phase Difference between Two Sine-wave Voltages

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