Unit-5

Measurement Of Force Torque And Pressure

MODULE 5

MEASUREMENTS OF FORCE, TORQUE AND PRESSURE

CONTENTS

OBJECTIVES

1. Is to get knowledge of force, pressure and temperature measuring devices and their applications.

5.1 Introduction

A force is defined as the reaction between two bodies. This reaction may be in the form of a tensile force (pull) or it may be a compressive force (push). Force is represented mathematically as a vector and has a point of application. Therefore the measurement of force involves the determination of its magnitude as well as its direction. The measurement of force may be done by any of the two methods.

- Direct method: This involves a direct comparison with a known gravitational force on a standard mass example by a physical balance.
- Indirect method: This involves the measurement of the effect of force on a body. For example.

a) Measurement of acceleration of a body of known mass which is subjected to force.

b) Measurement of resultant effect (deformation) when the force is applied to an elastic member.

Direct method

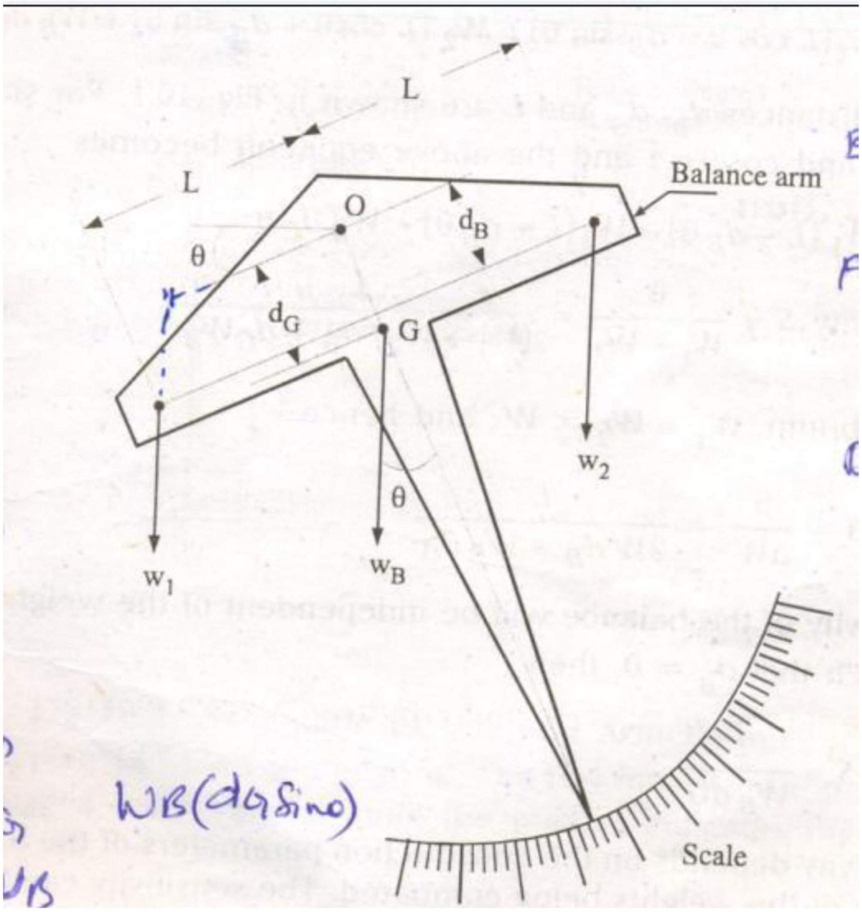
A body of mass "m" in the earth's gravitational field experiences a force F which is given by F = ma = W.

Where 'W' is the weight of the body 'a' is the acceleration due to gravity. Any unknown force may be compared with the gravitational force (ma) on the standard mass 'm'. The values of 'm' and 'a' should be known accurately in order to know the magnitude of the gravitation force.

Mass is a fundamental quantity and its standard kilogram is kept at France. The other masses can be compared with this standard with a precision of a few parts in109. On the other hand, 'a' is a derived quantity but still makes a convenient standard. Its value can be measured with an accuracy of 1 part in 106. Therefore any unknown force can be compared with the gravitational force with an accuracy of about this order of magnitude.

5.2 Analytical Balance : (Equal arm balance)

Direct comparison of an unknown force with the gravitational force can be explained with the help of an analytical balance. The direction of force is parallel to that of the gravitational force, and hence only its magnitude needs to be determined. The constructional details of an analytical balance are as shown in Fig.



The balance arm rotates about the point "O" and two forces W1 and W2 are applied at the ends of the arm. W1 is an unknown force and W2 is the known force due to a standard mass. Point G is the centre of gravity of the balance arm, and WB is the weight of the balance arm and the pointer acting at G. The above figure show the balance is unbalanced position when the force W1 and W2 are unequal. This unbalance is indicated by the angle θ which the pointer makes with the vertical.

In the balanced position $W_1 = W_2$, and hence θ is zero. Therefore, the weight of the balance arm and the pointer do not influence the measurements.

The sensitivity S of the balance is defined as the angular deflection per unit of unbalance is between the two weight W_1 and W_2 and is given by

$$S = \frac{\theta}{w_1 - w_2} = \frac{\theta}{\Delta W}$$

where, ΔW is the difference between W_1 and W_2. The sensitivity S can be calculated by writing the moment equation at equilibrium as follows:

$W_1 (L \cos\theta - d_B \sin\theta) = W_2 (L \cos\theta + d_B \sin\theta) + W_B d_G \sin\theta$

where the distances d_B, d_G and L are shown in Fig. For small deflection angles $\sin\theta = \theta$ and $\cos\theta = 1$ and the above equation becomes

$W_1 (L - d_B \theta) = W_2 (L + d_B \theta) + W_B d_G \theta$

$$\therefore \text{ The Sensitivity } \quad S = \frac{\theta}{w_1 - w_2} = \frac{L}{(w_1 + w_2) d_B + d_G W_B}$$

Near Equilibrium, $W_1 = W_2 = W$ and hence

$$S = \frac{\theta}{\Delta w} = \frac{L}{2W d_B + W_B d_G}$$

The sensitivity of the balance will be independent of the weight W Provided it is designed such that $d_B = 0$ then

$$S = \frac{L}{W_B d_G}$$

The sensitivity depends on the construction parameters of the balance arm and is independent of the weights being compared. The sensitivity can be improved by decreasing both d_G and W_B and increasing L. A compromise however, is to be struck between the sensitivity and stability of the balance.

5.3 UNEQUAL ARM BALANCE

An equal arm analytical balance suffers from a major disadvantage. It requires a set of weights which are at least as heavy as the maximum weight to be measured. In order that the heavier weights may be measured with the help of lighter weights, balances with unequal arms are used.

The unequal arm balance uses two arms. One is called the **load arm** and the other is called the **power arm.** The load arm is associated with load i.e., the weight force to be measured, while power arm is associated with power i.e, the force produced by counter posing weights required to set the balance in equilibrium.

Fig. shows a typical unequal arm balance. Mass 'm' acts as power on the beam and exerts a force of F_g due to gravity where $F_g = m \times g$. This force acts as counterposing force against the load which may be a test force F_t.

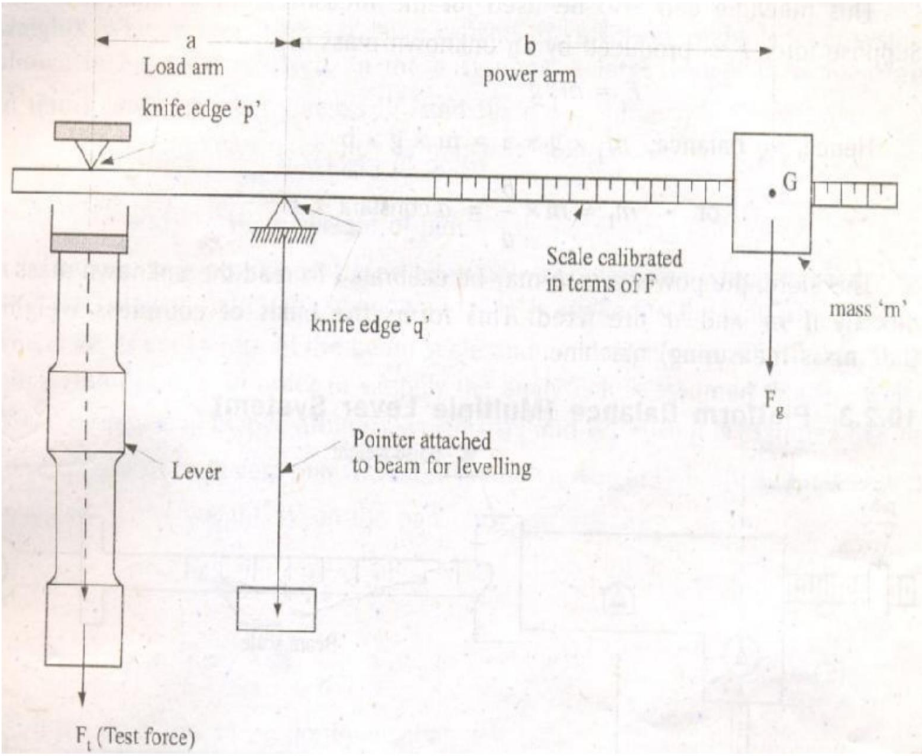


Fig. Schematic of Unequal Arm Balance

The beam is pivoted on a knife edge *'q'*. The test force F_t is applied by a screw or a lever through a knife edge *'p'* until the pointer indicates that the beam is horizontal.

For balance of moments, $F_t (a) = F_g (b)$

or test force $F_t = F_g (b/a)$

$= m \times g \times b/a$

$=$ constant $\times$ b (provided that g is constant).

Therefore the test force is proportional to the distance 'b' of the mass from the pivot. Hence, if mass 'm' is constant and the test force is applied at a fixed distance 'a' from the knife edge 'q' (i.e., the load arm is constant), the right hand of the beam (i.e., the power arm) may be calibrated in terms of force F_t. If the scale is used in different gravitational fields, a correction may be made for change in value of 'g'.

The set-up shown in Fig. is used for measurement of tensile force. With suitable modifications, it can be used for compression, shearing and bending forces.

This machine can also be used for the measurement of unknown mass. Suppose force F_t is produced by an unknown mass m_t.

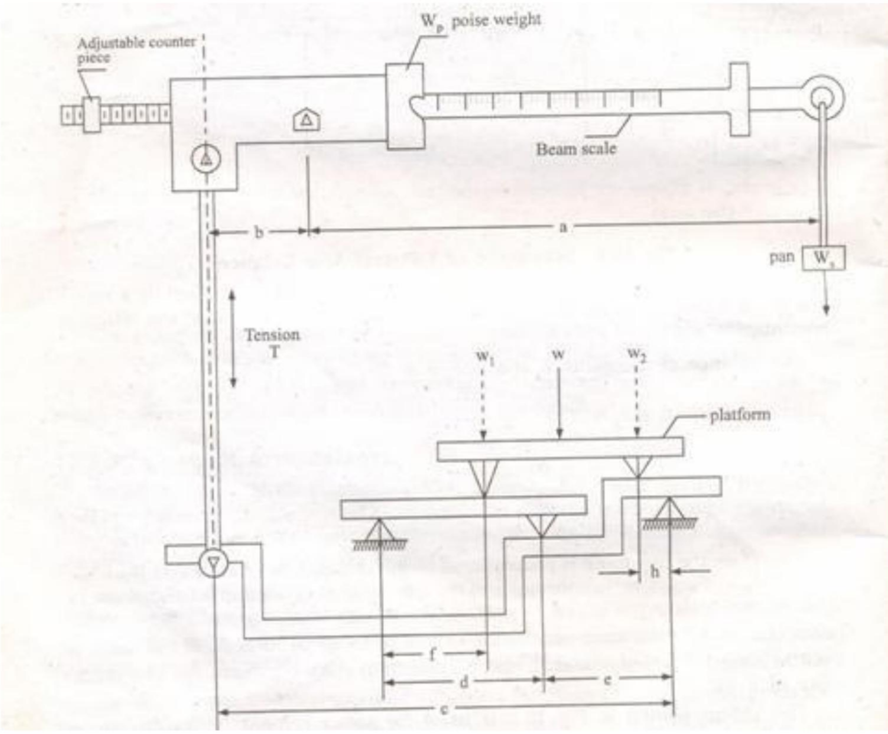
Therefore Ft = mt g

Hence, for balance, m1 x g x a = m x g x b

or m1 = m x b/a = a constant x b

Therefore, the power arm b may be calibrated to read the un known mass m1 directly if 'm' and 'a' are fixed. This forms the basis of countless weighing (i.e., mass measuring) machine.

5.4 Platform Balance (Multiple Lever System)



Schematic of Multiple Lever System

An equal and unequal arm balances are not suited for measurement of large weights. When measurement of large weights is involved, multiple lever systems shown in Fig. are used.

In these systems, a large weight W is measured in terms of two smaller weights Wp and Wg where, Wp = weight of poise and Ws = Weight of Pan

The system is provided with an adjustable counterpoise which is used to get an initial balance. Before the unknown load W is applied to the platform, the poise weight W_p is set at zero of the beam scale and counter piece is adjusted to obtain Initial zero balance.

In order to simplify the analysis it is assumed that the weight W can be replaced by two arbitrary weights W_1 and W_2. Also it is assumed that the poise weight W_p is at zero and when the unknown weight W is applied it is entirely balanced by the weight, W_s in the pan.

Therefore T x b = W_s x a ….(1)

and T x c = W_1 f/d e + W_2 h …(2)

If the links are so proportioned that h/e = f/d

We get : T x c = h (W_1 + W_2) hW ….(3)

From the above equation (3) it is clear that the weight W may be placed anywhere on the platform and its position relative to the two knife edges of the platform is immaterial.

T can be eliminated from equations. (l) and (3) to give

$$WS\frac{a}{b} = \frac{Wh}{d}$$

$$Unknown\ weight\ W = \frac{a}{b}\frac{c}{h}W_s$$

$$where\ m = \frac{a}{b}\frac{c}{h}\quad is\ called\ the multiplication\ ration\ of the\ scale$$

The multiplication ratio *M,* is indicative of weight that should be put in the pan to balance the weight on the platform. Suppose the scale has a multiplication ratio of 1000. It means that a weight of 1 kg put in the pan can balance a weight of 1000 kg put on the platform. Scales are available which have multiplication ratios as high as 10,000.

If the beam scale is so divided that a movement of poise weight Wp by 1 scale division represents a force of *x* kg, then a poise movement of y scale divisions should produce the same result as a weight W_p placed on the pan at the end of the beam. Hence,

$$Wp\ y = x\ y\ a$$

$$or\quad x = \frac{W_p}{a}$$

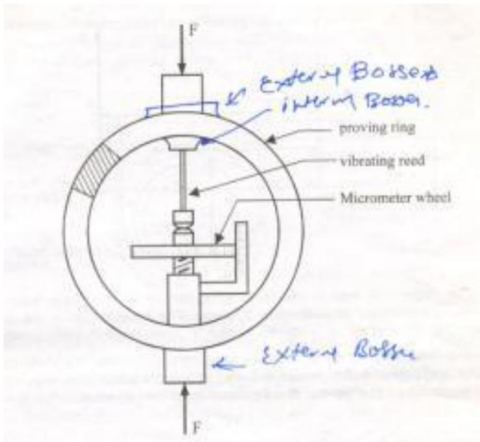
The above equation represents a relationship that determines the required scale divisions on the beam for any poise weight Wp.

5.5 Proving Ring

This device has long been the standard for calibrating tensile testing machines and is in general, the means by which accurate measurement of large static loads may be obtained. A proving ring is a circular ring of rectangular cross section as shown in the Fig. which may be subjected to tensile or compressive forces across its diameter. The force-deflection relation for a thin ring is

$$F=\frac{16}{\frac{\pi}{2}-\frac{4}{\pi}}\frac{EI}{d^3}y$$

where, *F* is the force, E is the young's modulus, I is the moment of inertia of the section about the centroidal axis of bending section. *D* is the outside diagram of the ring, y is the deflection. The above equation is derived under the assumption that the thickness of the ring is small compared to the radius. And also it is clear that the displacement is directly proportional to the force.



The deflection is small and hence the usefulness of the proving ring as a calibration device depends on the accuracy with which this small deflection is measured. This is done by using a precision micrometer shown in the figure. In order to obtain precise measurements one edge of the micrometer is mounted on a vibrating reed device which is plucked to obtain a vibratory motion.

The micrometer contact is then moved forward until a noticeable damping of the vibration is observed.

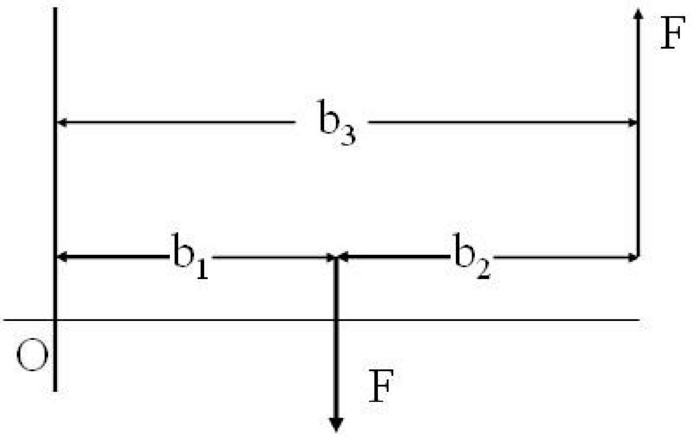
Proving rings are normally used for force measurement within the range of 1.5 KN to 1.5 MN. The maximum deflection is typically of the order of 1% of the outside diameter of the ring.

5.6 Torque Measurement

The force, in addition to its effect along its line of action, may exert a turning effort relative to any axis other than those intersecting the line of action as shown in Fig. Such a turning effect is called torque or couple

Torque or couple = $Fb_1 - Fb_3$

$= Fb_2$



The important reason for measuring torque is to obtain load information necessary for stress or deflection analysis. The torque T may be computed by measuring the force F at a known radius 'r' from the following relation T=Fr.

However, torque measurement is often associated with determination of mechanical power, either power required to operate a machine or power developed by the machine. The power is calculated from the relation.

$$P = 2\pi NT$$

where N is the angular speed in revolutions per second. Torque measuring devices used in this connection are commonly known as **dynamometers.**

There are basically three types of dynamometers.

1. Absorption dynamometers: They absorb the mechanical energy as torque is measured, and hence are particularly useful for measuring power or torque developed by power sources such as engines or electric motors.

2. Driving dynamometers: These dynamometers measure power or torque and as well provide energy to operate the devices to be tested. They are, therefore, useful in determining performance characteristics of devices such as pumps, compressors etc

3. Transmission dynamometers: These are passive devices placed at an appropriate location within a machine or in between machines to sense the torque at that location. They neither add nor subtract the transmitted energy or power and are sometimes referred to as **torque meters.**

The first two types can be grouped as mechanical and electrical dynamometers.

These dynamometers are of absorption type. The most device is the prony brake as shown in Fig.

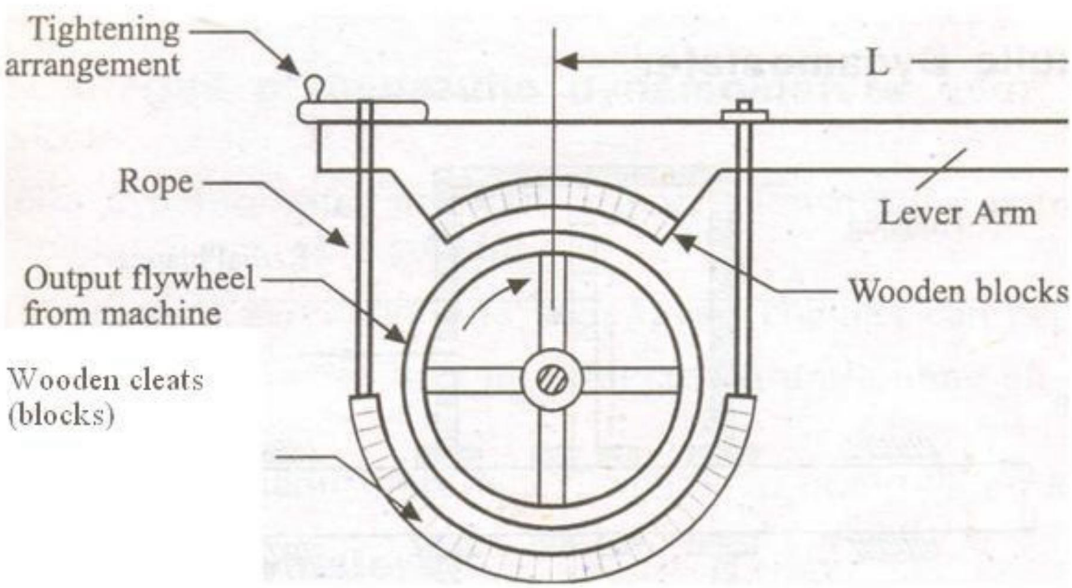


Fig. Schematic of Prony Brake

Two wooden blocks are mounted diametrically opposite on a flywheel attached to the rotating shaft whose power is to be measured. One block carries a lever arm, and an arrangement is provided to tighten the rope which is connected to the arm. The rope is tightened so as to increase the frictional resistance between the blocks and the flywheel. The torque exerted by the prony brake is T = F.L where force F is measured by conventional force measuring instruments, like balances or load cells etc. The power dissipated in the brake is calculated by the following equation.

$$P = \frac{2\pi\ NT}{60} = \frac{2\pi\ FLN}{60}\ Watts.$$

where force F is in Newtons, L is the length of lever arm in meters, N is the angular speed in revolution per minute, and P in watts. The prony brake is inexpensive, but it is difficult to adjust and maintain a specific load.

Limitation : The prony brake is inherently unstable. Its capacity is limited by the following factors.

i). Due to wear of the wooden blocks, the coefficient of friction varies between the blocks and the flywheel. This requires continuous tightening of clamp. Therefore, the system becomes unsuitable for measurement of large powers especially when used for long periods

ii) The use of prony brake results in excessive temperature rise which results in decrease in coefficient of friction leading to brake failure. In order to limit the temperature rise, cooling is required. This is done by running water into the hollow channel of the flywheel.

iii) When the machine torque is not constant, the measuring arrangement is subjected to oscillations. There may be changes in coefficient of friction and hence the reading of force F may be difficult to take.

Hydraulic Dynamometer

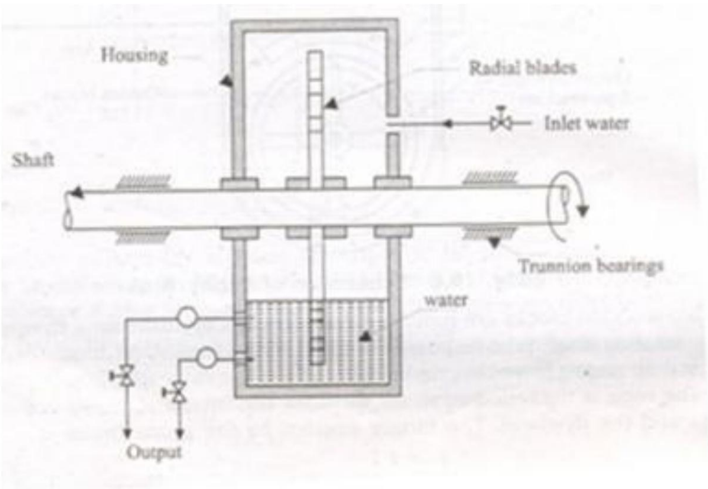


Fig. Section through a typical water brake

Fig. shows a hydraulic dynometer in its simplest form which acts as a water brake. This is a power sink which uses fluid friction for dissipation of the input energy and thereby measures the input torque-or power.

The capacity of hydraulic dynamometer is a function of two factors, speed and water level. The power consumed is a function of cube of the speed approximately. The torque is measured with the help of a reaction arm. The power absorption at a given speed may be controlled by adjustment of the water level in the housing. This type of dynamometer may be made in considerably larger capacities than the simple prony brake because the heat generated can be easily removed by circulating the water into and out of the housing. Trunnion bearings support the dynamometer housing, allowing it a freedom to rotate except for the restraint imposed by the reaction arm.

In this dynamometer the power absorbing element is the housing which tends to rotate with the input shaft of the driving machine. But, such rotation is constrained by a force-measuring device, such as some form of scales or load cell, placed at the end of a reaction arm of radius. By measuring the force at the known radius, the torque T may be computed by the simple relation.

Advantages of hydraulic dynamometers over mechanical brakes

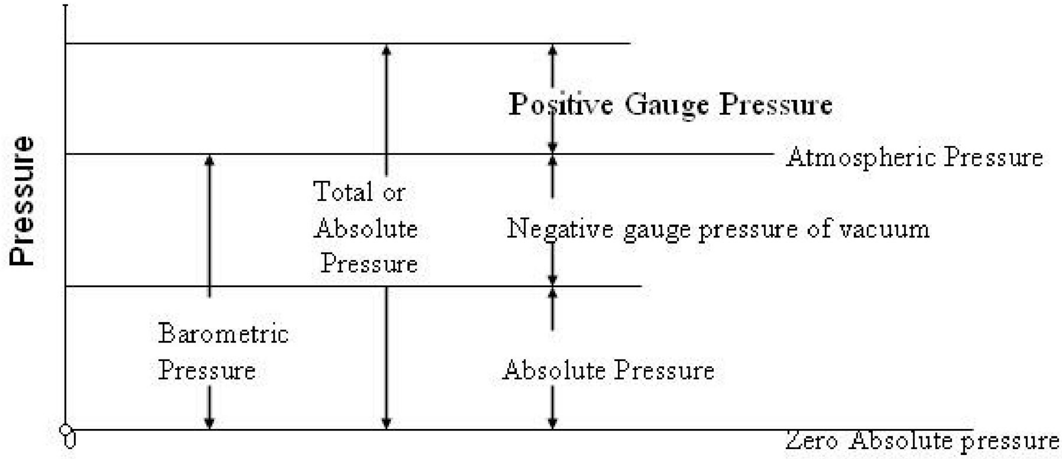
- In hydraulic dynamometer constant supply of water running through the breaking medium acts as a coolant.
- The brake power of very large and high speed engines can be measured.
- The hydraulic dynamometer may be protected from hunting effects by means of dashpot damper.
- In hydraulic dynamometer there is a flexibility in controlling the operation

5.7 Pressure Measurements

Introduction

Pressure is represented as a force per unit area exerted by a fluid on a container. The standard SI unit for pressure is Newton / Square meter (N/m2) or Pascal (Pa). High pressures can be conveniently expressed in KN/m2 while low pressure are expressed in terms of mm of water or mm of mercury.

Pressure is the action of one force against another over, a surface. The pressure P of a force F distributed over an area A is defined as: P = F/A.



Relationship between Pressure Terms

Absolute Pressure.

It refers to the absolute value of the force per unit are exerted on the containing wall by a fluid.

Atmospheric Pressure

It is the pressure exerted by the earth's atmosphere and is usually measured by a barometer. At sea level. Its value is close to 1.013 x 105 N/m2 absolute and decreases with altitude.

Gage Pressure

It represents the difference between the absolute pressure and the local atmosphere pressure

Vacuum

It is an absolute pressure less the atmospheric pressure i.e. a negative gage pressure.

Static and Dynamic pressures

If a fluid is in equilibrium, the pressure at a point is identical in all directions and independent of orientation is referred as pressure. In dynamic pressure, there exist a pressure gradient within the system. To restore equilibrium, the fluid flows from regions of higher pressure t regions of lower pressure.

Types of Pressure Measuring Devices

(i) Mechanical Instruments: These devices may be of two types. The first type includes those devices in which the pressure measurement is made by balancing an unknown pressure with a known force. The second types include those employing quantitative deformation of an elastic member for pressure measurements.

(ii) Electro-mechanical Instruments: this instrument employs a mechanical means for detecting the pressure and electrical means for indicating or recording the detected pressure.

(iii) Electronic Instruments: these instruments depend on some physical change which can be detected and indicated or recorded electronically.

Use of Elastic Members in Pressure Measurement

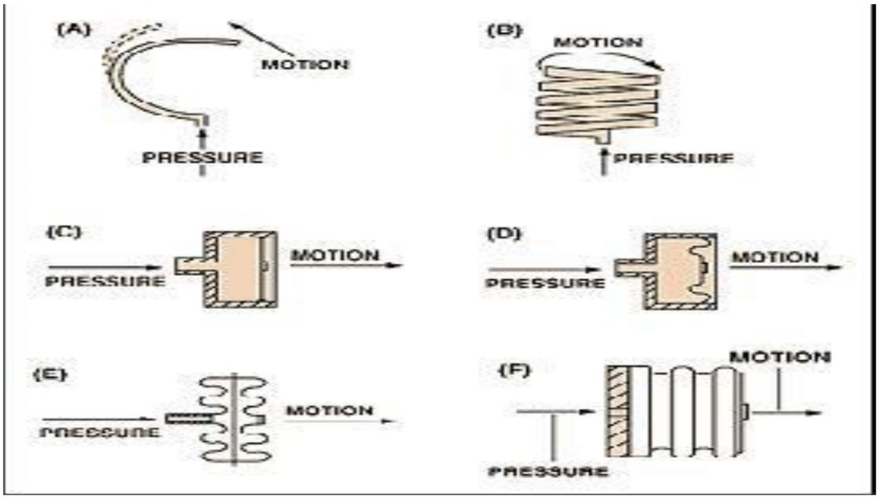
Application of pressure to certain materials causes elastic deformations. The magnitude of this elastic deformation can be related either analytically or experimentally to the applied pressure. Following are the three important elastic members used in the measurement of pressure.

(i) Bourdon tube,

(ii) Diaphragms and

(iii) Bellows

Sensing Elements



The basic pressure sensing element can be configured as a C-shaped Bourdon tube (A); a helical Bourdon tube (B); flat diaphragm (C); a convoluted diaphragm (D); a capsule (E); or a set of bellows (F).

The Bridgman Gage

The resistance of fine wires changes with pressure according to the following linear relationship. $R = R1 (1 + \alpha p)$

Where R1 Resistance at 1 atmosphere (100 KN/m2) in ohms

α Pressure coefficient of resistance in ohms/100 KN M-2

p gage pressure in KN/m2.

The above said resistance change may be used for measurement of pressures as high as 100,000 atm., 10.00KN/m2. A pressure transducer based on this principle is called a Bridgman gage. A typical gage uses a fine wire of manganin (84% Cu, 12% Mn, 4% Ni) wound in a coil and enclosed in a suitable pressure container. The pressure coefficient of resistance for this material is about 2.5x10-11 Pa-1. The total resistance of the wire is about 100Ω and conventional bridge circuits are employed for measuring the change in the resistance. Such gages are subjected to aging over a period of time, so that frequent calibration is required. However, when properly calibrated, the gage can be used for high pressure measurement with an accuracy of 0.1%. The transient response of the gage is exceedingly good. The resistance wire itself can respond of variations in the mega hertz range. Of course, the overall frequency response of the pressure-measurement system would be limited to much lower values because of the acoustic response of the transmitting fluid.

Low-Pressure measurement

In general, pressures below atmospheric may be called low pressures or vacuums. Its unit is micron, which is one-millionth of a meter (0.001 mm) of mercury column. Very low pressures may be defined as that pressures which are below 1 mm (1 torr) of mercury. An Ultra low pressure is one which has pressure less than a millimicron(10-3 micron). An ultralow pressure is one which has pressure less than a millimicron (10-3 micron). Following are the two methods of measuring low pressure.

Direct Method: In this, direct measurement resulting in displacement caused by the action of pressure. Devices used in this method are Bourdon tubes, flat and corrugated-diaphragms, capsules and various forms of manometers. These devices are limited to a lowest pressure measurement of about 10mm of mercury.

Indirect or Inferential method: In this pressure is determined through the measurement of certain other pressure-controlled properties, such as volume, thermal conductivity etc.

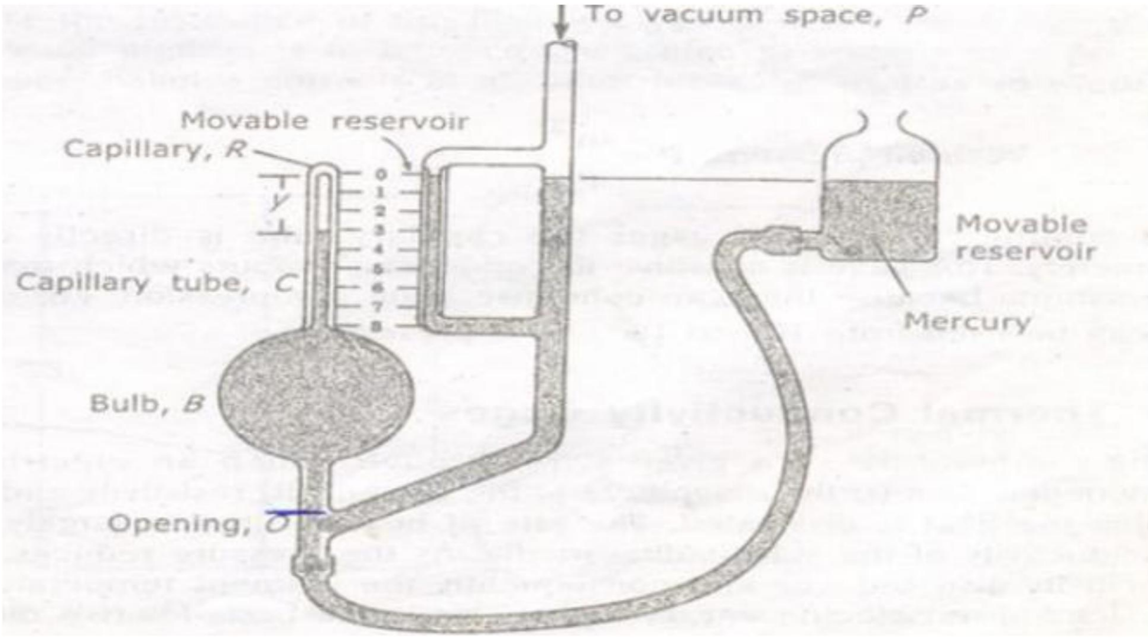
The Mcleod Gage

The operation of McLeod gage is based on Boyle's law.

$$p_1 = \frac{p_2 \, v_2}{v_1}$$

Where, p1 andp2 are pressures at initial and conditions respectively, and v1 and v2 are volumes at the corresponding conditions. By compressing a known volume of low pressure gas to a higher pressure and measuring the resulting volume and pressure we can calculate the initial pressure.

The McLeod gage is a modified mercury manometer as shown in the Fig. 11.2. The movable reservoir is lowered until the mercury column drops below the opening O.



The Bulb B and capillary tube C are then at the same pressure as that of the vacuum pressure P. The reservoir is subsequently raised until the mercury fills the bulb and rises in the capillary tube to a point where the level in the reference capillary R is located at the zero point. If the volume of the capillary tube per unit length is 'a' then the volume of the gas in the capillary tube is Vc = ay----(1).

Where 'y' is the length of gas occupied in capillary tube.

If the volume of capillary tube, bulb and the tube down to the opening is VB. Assuming isothermal Compression, the pressure of the gas in the capillary tube is

$$P_C = P\frac{V_B}{V_C} \qquad \text{-------(2)}$$

The pressure indicated by the capillary tube is

Pc - P = --------(3)

Where, we are expressing the pressure in terms of the height of the mercury column. And combining equations (1), (2) and (3)

$$P = \frac{ay^2}{V_B - ay}$$

Usually ay << VB

$$\therefore\ Vacuumpressur,\ P = \frac{ay^2}{V_B}$$

In commercial McLeod gages the capillary tube is directly calibrated in micrometers. This gage is sensitive to condensed vapours which may be present in the sample because they can condense upon compression. For dry gases the gage can be used from 10^{-2} to 10^{2} µm of pressure.

Thermal Conductivity Gages

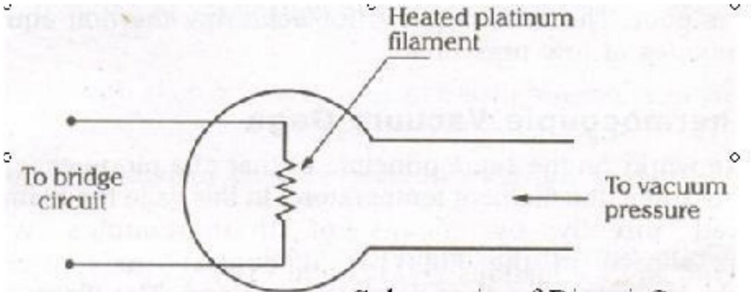
The temperature of a given wire through which an electric current is flowing depend, on (i) the magnitude of the current (ii) resistivity and (iii) the rate at which the heat is dissipated. The rate of heat dissipation largely depends on the conductivity of the surrounding media. As the pressure reduces, the thermal conductivity also reduces and consequently the filament temperature becomes higher for a given electric energy input. This is the basis for two different forms of gages to measure low pressures.

i). Pirani thermal conductivity gage

ii). Thermocouple vacuum gage

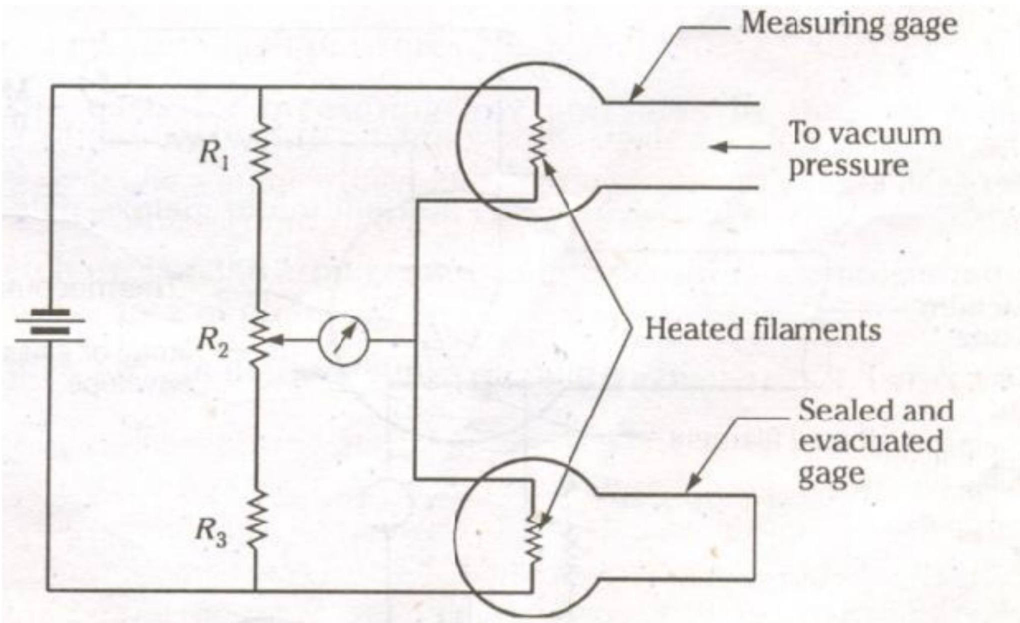
Pirani Thermal Conductivity Gages

The pirani gage as shown in the Fig. operates on the principle that if a heated wire is placed in a chamber of gas, the thermal conductivity of the gas depends on pressure. Therefore the transfer of energy from the wire to the gas is proportional to the gas pressure. If the supply of heating energy to the filament is kept constant and the pressure of the gas is varied, then the temperature of the filament will alter and is therefore a method of pressure measurement.



Schematic of Pirani Gage

To measure the resistance of the filament wire a resistance bridge circuit is used. The usual method is to balance the bridge at some datum pressure and use the out-of-balance currents at all other pressures as a measure of the relative pressures.



Pirani gage arrangement to compensate for ambient temperature Changes

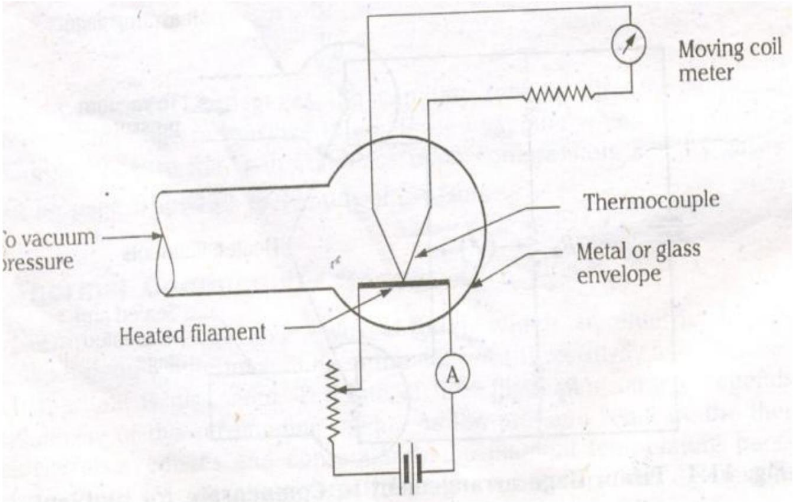
The heat loss from the filament is also a function of ambiet temperature and compensation for this effect may be achieved by connecting two gages in series as shown in Fig. The measuring gage is first evacuated and both the measuring and sealed gages are exposed to the same environment conditions. The bridge circuit is then adjusted through the resistor *R2* to get a null condition. When the measuring gage is exposed to the test vacuum pressure, the deflection of the bridge from the null position will be compensated for changes in environment temperature.

Pirani gages require calibration and are not suitable for use at pressures below l) lm and upper limit is about 1 torr. For higher pressures, the thermal conductivity changes very little with pressure. It must be noted that the heat loss from the filament is also a function of the conduction losses to the filament supports and radiation losses to the surroundings. The transient response of the pirani gage is poor. The time required for achieving thermal equilibrium may be of several minutes at low pressures.

Thermocouple Vacuum gage

This gage works on the same principle as that of a pirani gage, but differs in the means for measuring the filament temperature. In this gage the filament temperature is measured directly by means of thermocouples welded directly to them as shown in the Fig. 11.5. It consists of heater filament and thermocouple enclosed in a glass or metal envelope.

The filament is heated by a constant current and its temperature depends upon the amount of heat lost to the surroundings by conduction and convection. At low pressures, the temperature of the filament is a function of the pressure of surrounding gas. Thus, the thermocouple provides an output voltage which is a function of temperature of the filament and consequently the pressure of the surrounding gas. The moving coil instrument may be directly calibrated to read the pressure.



Thermocouple Vacuum Gage

5.8 Temperature Measurements

Introduction

Temperature measurement is the most common and important measurement in controlling any process. Temperature may be defined as an indication of intensity of molecular kinetic energy within a system. It is a fundamental property similar to that of mass, length and time, and hence it is difficult to define. Temperature cannot be measured using basic standards through direct comparison. It can only be determined through some standardized calibrated device.

Change in temperature of a substance causes a variety of effects such as:

i) Change in physical state,

ii) Change in chemical state,

iii) Change in physical dimensions,

iv) Change in electrical properties and

v) Change in radiating ability.

The change in physical and chemical states cannot be used for direct temperature measurement. However, temperature standards are based on changes in physical state. A change in physical dimension due to temperature shift forms the basis of operation for liquid in- glass and bimetallic thermometers. Changes in electrical properties such as change in electrical conductivity and thermoelectric effects which produce electromotive force forms the basis for thermocouples. Another temperature-measuring method using the energy radiated from a hot body forms the basis of operation of optical radiation and infrared pyrometers.

Temperature Measurement by Electrical Effects

Electrical methods of temperature measurement are very convenient because they provide a signal that can be easily detected, amplified, or used for control purposes. In addition, they are quite accurate when properly calibrated and compensated. Several temperature-sensitive electrical elements are available for measuring temperature. Thermal emf and both positive and negative variations in resistance with temperature are important among them.

Thermo resistive Elements

The electrical resistance of most materials varies with temperature. Resistance elements which are sensitive to temperature are made of metals and are good conductors of electricity. Examples are nickel, copper, platinum and silver. Any temperature-measuring device which uses these elements is called resistance thermometers or resistance temperature detectors (RTD). If semiconducting materials like combination of metallic oxides of cobalt, manganese and nickel having large negative resistance co- efficient are used then such devices are called thermistors.

The differences between these two kinds of devices are:

Sl. No	Resistance Thermometer	Thermistor
1	In this resistance change with temperature shift is small and positive.	In this resistance change with temperature shift is relatively large and negative
2	Provides nearly a linear temperature-resistance relation	Non-linear temperature resistance relation.
3	Practical operating temperature range is -250 to 1000°C	Practical operating temperature range is -100 to 275°C.
4	More time-stable hence provide better reproducibility with low hysteresis	Not time-stable

Electrical Resistance Thermometers

The desirable properties of resistance-thermometer materials are:

i) The material should permit fabrication in convenient sizes.

ii) Its thermal coefficient of resistivity should be high and constant

iii) They must be corrosion-resistant and should not undergo phase changes with in the temperature ranges.

iv) Provide reproducible and consistent results.

Electrical Resistance Thermometers

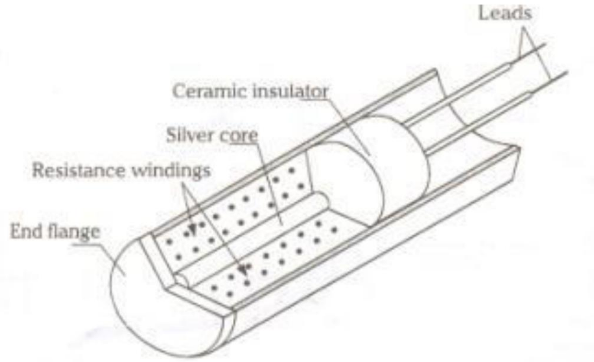
Unfortunately, there is no universally acceptable material and the selection of a particular material depends on the compromises. Although the actual resistance-temperature relation must be determined experimentally, for most metals the following empirical equation may be used.

$$R_t = R_o (1 + aT + bT_2)$$

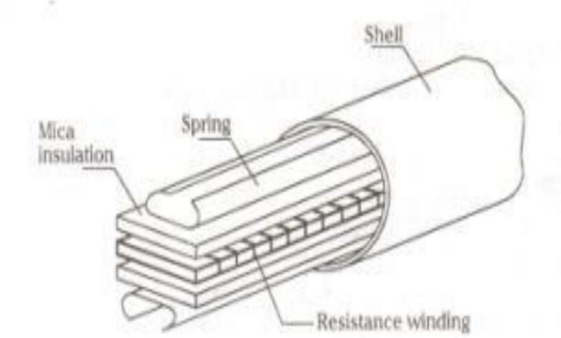
Where, Rt is the resistance at temperature T, Ro is the resistance at the reference temperature, T is the temperature and a and b are constants depending on the material.

Usually platinum, nickel and copper are the most commonly used materials, although others like tungsten, silver and iron can also be used.

Fig. shows the construction of two forms of resistance thermometer In Fig. (a) the element consists of a number of turns of resistance wire wrapped around a solid silver core. Heat is transmitted quickly from the end flange through the core to the windings.



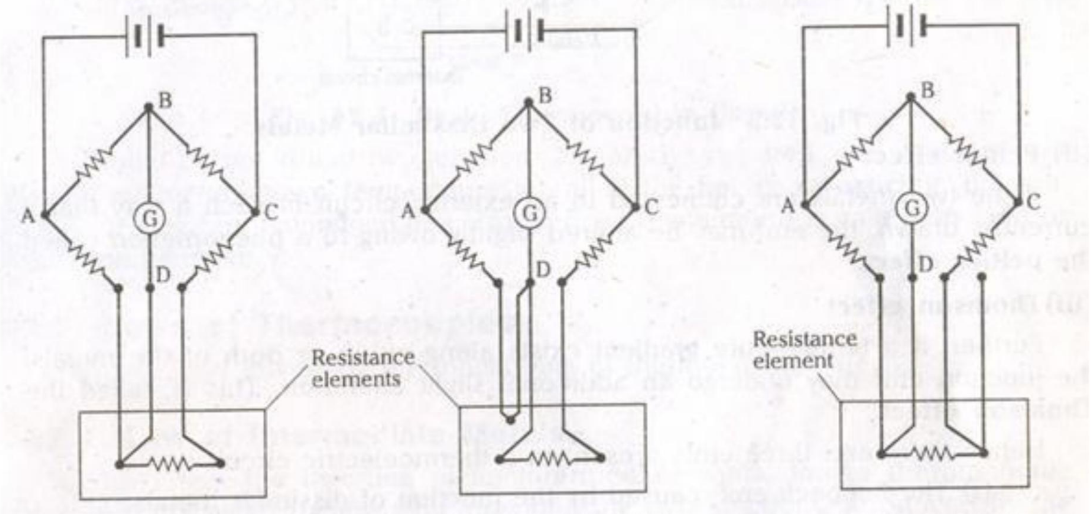
Another form of construction is shown in Fig. (b) in which the resistance wire is wrapped around a mica strip and sandwiched between two additional mica strips. These resistance thermometers may be used directly. But, when permanent installation with corrosion and mechanical protection is required a well or socket may be used.



Instrumentation for Resistance Thermometers

Some type of bridge circuit is normally used to measure resistance change in the thermometers. Leads of appropriate length are normally required, and any resistance change in them due to any cause affects the measurement. Hence, the lead resistance must be as low as possible relative to the element resistance.

Three methods of compensating lead resistance error are as shown in the Fig. The arms AD and DC each contain the same length of leads. If the leads have identical properties and are at identical ambient conditions, then the effects introduced by one arm will be cancelled by the other arm.



(a) Siemen's three lead arrangement (b) Callender's Four lead arrangement (c) Floating-potential arrangement

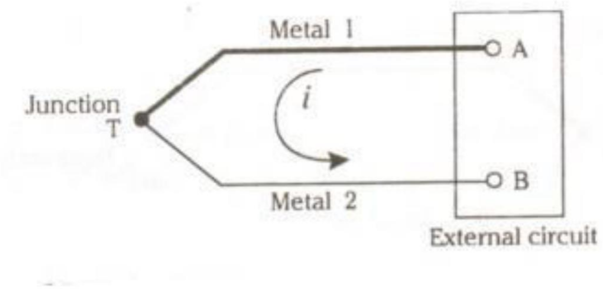
Methods of Compensating Lead Resistance Error

The Siemen's three-lead arrangement is the simplest corrective circuit. At balance conditions the centre lead carries no current, and the effect of the resistance of the other two leads is cancelled out. The Siemen's three-lead arrangement is the simplest corrective circuit. At balance conditions the centre lead carries no current, and the effect of the resistance of the other two leads is cancelled out. The calendar's four-lead arrangement solves the problem by inserting two additional lead wires in the adjustable leg of the bridge so that the effect of the lead wires on the resistance thermometer is cancelled out. The floating-potential arrangement is same as the Siemens' connection, but with an extra lead. This extra lead may be used to check the equality of lead resistance. The thermometer reading may be taken in the position shown, followed by additional readings with the two right and left leads interchanged, respectively. By averaging these readings, more accurate results may be obtained.

Usually, null-balance bridge is used but is limited to static or slowly changing temperatures. While the deflection bridge is used for rapidly changing temperatures.

1. See beck Effect:

When two dissimilar metals are joined together as shown in the Fig. an electromotive force (emf) will exists between the two points A and B, which is primarily a function of the junction temperature. This phenomenon is called the **see beck effect.**



Junction of Two Dissimilar Metals

2. Peltier effect

If the two metals are connected to an external circuit in such a way that a current is drawn, the emf may be altered slightly owing to a phenomenon called the **peltier effect.**

3.Thomson effect

Further, if a temperature gradient exists along either or both of the metals, the junction emf may undergo an additional slight alteration. This is called the **Thomson effect**.

Hence there are, three emfs present in a thermoelectric circuit:

i) The Seebeck emf, caused by the junction of dissimlar metals

ii) The Peltier emf, caused by a current flow in the circuit and

iii) The Thomson emf, resulting from a temperature gradient in the metals.

The Seebeck emf is important since it depends on the junction temperature.

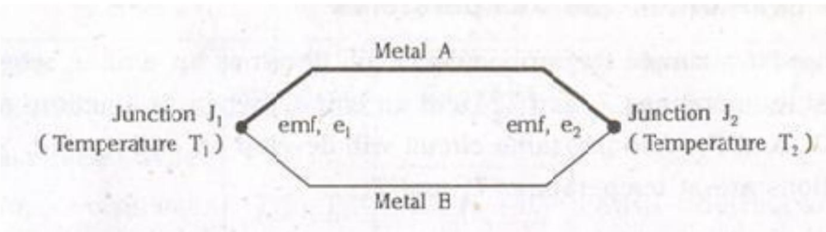
If the emf generated at the junction of two dissimilar metals is carefully measured as a function of temperature, then such a junction may be used for the measurement of temperature.

The above effects forms the basis for a thermocouple which is a temperature measuring element.

Thermocouple

If two dissimilar metals are joined an emf exists which is a function of several factors including the temperature.When junctions of this type are used to measure temperature, they are called thermocouples.

The principle of a thermocouple is that if two dissimilar metals *A* and *B are* joined to form a circuit as shown in the Fig. It is found that when the two junctions J_1 and J_2 are at two different temperatures T_1 and T_2, small emf's e_1 and e_2 are generated at the junctions. The resultant of the two emf's causes a current to flow in the circuit. If the temperatures T_1 and T_2 are equal, the two emf's will be equal but opposed, and no current will flow. The net emf is a function of the two materials used to form the circuit and the temperatures of the two junctions. The actual relations, however, are empirical and the temperature-emf data must be based on experiment. It is important that the results are reproducible and therefore provide a reliable method for measuring temperature.



Basic Thermocouple Circuit

It should be noted that two junctions are always required, one which senses the desired or unknown temperature is called the **hot** or **measuring** junction. The other junction maintained at a known fixed temperature is called the **cold** or **reference** junction.

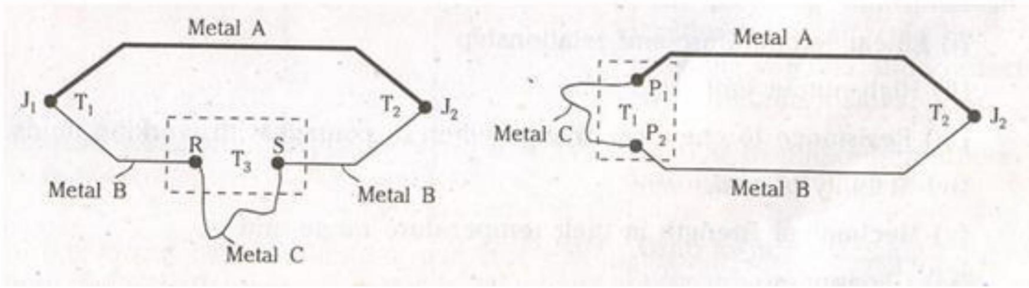
Laws of Thermocouples

The two laws governing the functioning of thermocouples are:

i) Law of Intermediate Metals:

It states that the insertion of an intermediate metal into a thermocouple circuit will not affect the net emf, provided the two junctions introduced by the third metal are at identical temperatures.

Application of this law is as shown in Fig. In Fig. (a), if the third metal C is introduced and the new junctions R and S are held at temperature T3, the net emf of the circuit will remain unchanged. This permits the insertion of a measuring device or circuit without affecting the temperature measurement of the thermocouple circuit

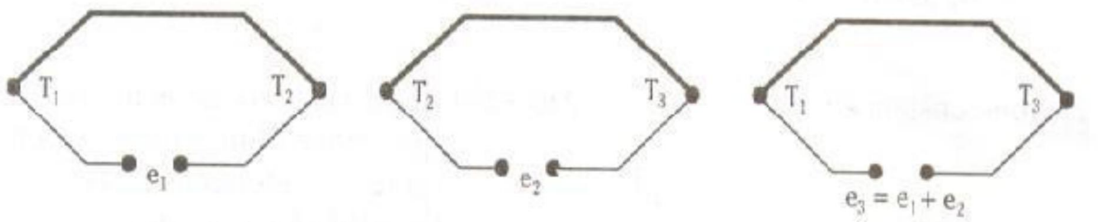


Circuits illustrating the Law of Intermediate Metals

In the Fig. (b) the third metal is introduced at either a measuring or reference junction. As long as junctions P_1 and P_2 are maintained at the same temperature T_P the net emf of the circuit will not be altered. This permits the use of joining metals, such as solder used in fabricating the thermocouples. In addition, the thermocouple may be embedded directly into the surface or interior of a conductor without affecting the thermocouple's functioning.

i) Law of Intermediate Temperatures:

It states that "If a simple thermocouple circuit develops an emf, e_1 when its junctions are at temperatures T_1 and T_2, and an emf e_2, when its junctions are at temperature T_2 and T_3. And the same circuit will develop an emf $e_3 = e_1 + e_2$, when its junctions are at temperatures T_1 and T_3.

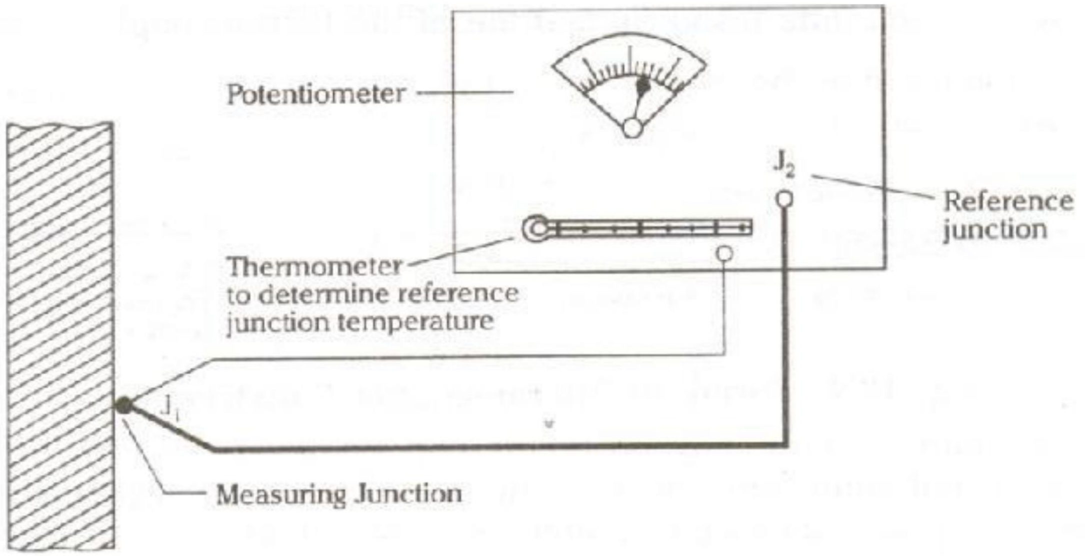


Circuits illustrating the Law of Intermediate Temperatures

This is illustrated schematically in the above Fig. This law permits the thermocouple calibration for a given temperature to be used with any other reference temperature through the use of a suitable correction. Also, the extension wires having the same thermo-electric characteristics as those of the thermocouple wires can be introduced in the circuit without affecting the net emf of the thermocouple.

Measurement of Thermal emf

The magnitude of emf developed by the thermocouples is very small (0.01 to 0.07 millivolts/^{0}C), thus requires a sensitive devices to measure. Measurement of thermocouple output may be obtained by various ways. like millivolt meter or voltage-balancing potentiometer etc. Fig. shows a simple temperature-measuring system using a thermocouple as the sensing element and a potentiometer for indication. The thermoelectric circuit consists of a measuring junction J_1 and reference junction J_2, at the potentiometer. By the law of intermediate metals the potentiometer box may be considered to be an intermediate conductor. Assuming the two potentiometer terminals to be at identical temperature, the reference junction can be formed by the ends of the two thermocouple leads as they attach to the terminals. The reference temperature is determined using liquid-in-glass thermometer placed near the terminals. The value of the emf developed by the thermocouple circuit is measured using the potentiometer. Then using the table (values of emf Vs temperature) the temperature of the measuring junction can be determined.



Temperature measuring Arrangement using Thermocouple

Advantages and Disadvantages of Thermocouples

Advantages

1. Thermocouples are cheaper than the resistance thermometers.
2. Thermocouples follow the temperature changes with small time lag thus suitable for recording rapidly changing temperatures.
3. They are convenient for measuring the temperature at a particular point.

Disadvantages

1. Possibility of inaccuracy due to changes in the reference junction temperature hence they cannot be used in precision work.

2. For long life, they should be protected to prevent contamination and have to be chemically inert and vacuum tight.

3. When thermocouples are placed far from the measuring systems, connections are made by extension wires. Maximum accuracy is obtained only when compensating wires are of the same material as that of thermocouple wires, thus the circuit becomes complex.

Principles used for Radiation Temperature Measuring Devices

1. Total Radiation Pyrometry:

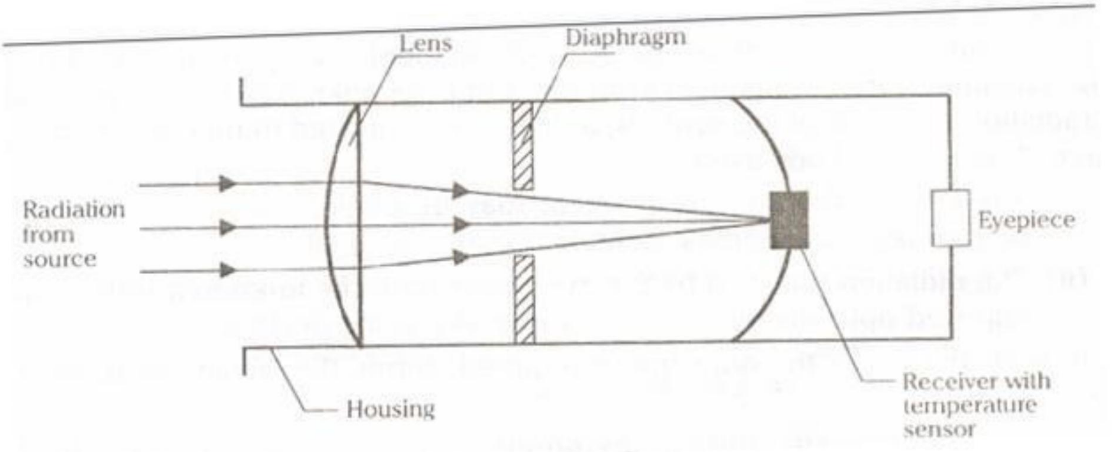
In this case the total radiant energy from a heated body is measured. This energy is represented by the area under the curves of above Fig. and is given by Stefen – Boltzmann law. The radiation pyrometer is intended to receive maximum amount of radiant energy at wide range of wavelengths possible.

2. Selective Radiation Pyrometry:

This involves the measurement of spectral radiant intensity of the radiated energy from a heated body at a given wavelength. For example, if a vertical line is drawn in Fig. the variation of intensity with temperature for given wavelength can be found. The optical pyrometer uses this principle.

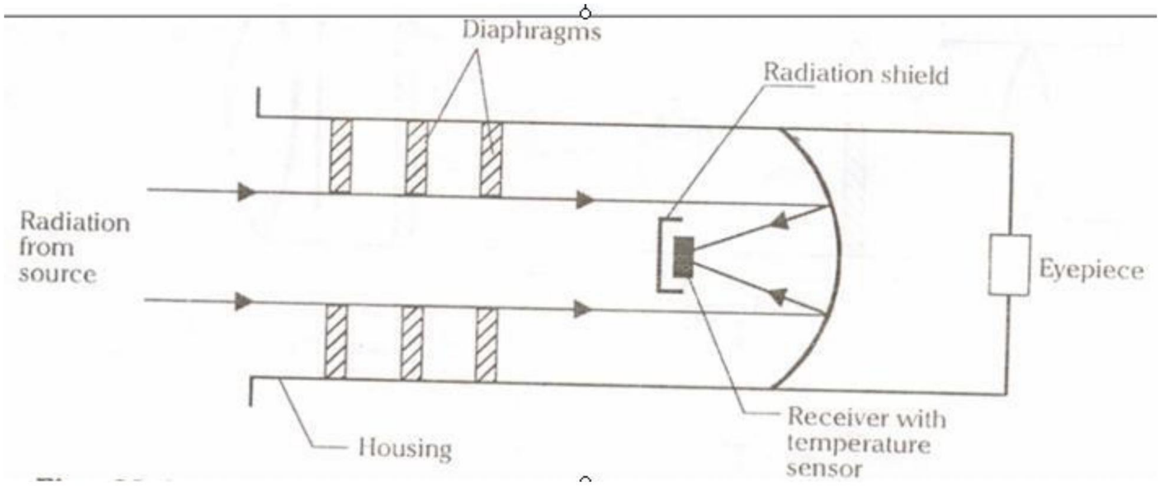
Total Radiation Pyrometers

The total radiation pyrometers receives all the radiations from a hot body and focuses it on to a sensitive temperature transducer like thermocouple, resistance thermometer etc. It consists of a radiation-receiving element and a measuring device to indicate the temperature. The most common type is shown in the Fig. A lens is used to concentrate the total radiant energy from the source on to the temperature sensing element. The diaphragms are used to prevent reflections. When lenses are used, the transmissibility of the glass determines the range of frequencies passing through. The transmission bands of some of the lens materials are shown in the Fig. The radiated energy absorbed by the receiver causes a rise of temperature. A balance is established between the energy absorbed by the receiver and that dissipated to the surroundings. Then the receiver equilibrium temperature becomes the measure of source temperature, with the scale established by calibration.



Schematic of Lens Type Radiation Receiving Device

The mirror type radiation receiver is another type of radiation pyrometer as shown in the Fig. Here the diaphragm unit along with a mirror is used to focus the radiation onto a receiver. The distance between the mirror and the receiver may be adjusted for proper focus. Since there is no lens, the mirror arrangement has an advantage a absorption and reflection effects are absent.



Mirror Focussing Type Radiation Receiving Device

Although radiation pyrometers may theoretically be used at any reasonable distance from a temperature source, there are practical limitations.

i) The size of target will largely determine the degree of temperature averaging, and in general, the greater the distance from the source, the greater the averaging.

ii) The nature of the intervening atmosphere will have a decided effect on the pyrometer indication. If smoke, dust or certain gases present considerable energy absorption may occur.

This will have a particular problem when such absorbents are not constant, but varying with time. For these reasons, minimum practical distance is recommended.

Optical pyrometers

Optical pyrometers use a method of matching as the basis for their operation. A reference temperature is provided in the form of an electrically heated lamp filament, and a measure of temperature is obtained by optically comparing the visual radiation from the filament with that from the unknown own source. In principle, the radiation from one of the sources, as viewed is adjusted to match with that from the other source. The two methods used are :

i) The current through the filament may be controlled electrically with the help of resistance adjustment or

ii) The radiation received by the pyrometer from the unknown source may be adjusted optically by means of some absorbing devices.

In both the cases the adjustment required, forms the means of temperature measurement. The variable intensity optical pyrometer is, as shown in the Fig. The pyrometer is positioned towards an unknown temperature such that the objective lens focuses the source· in the plane of the lamp filament.

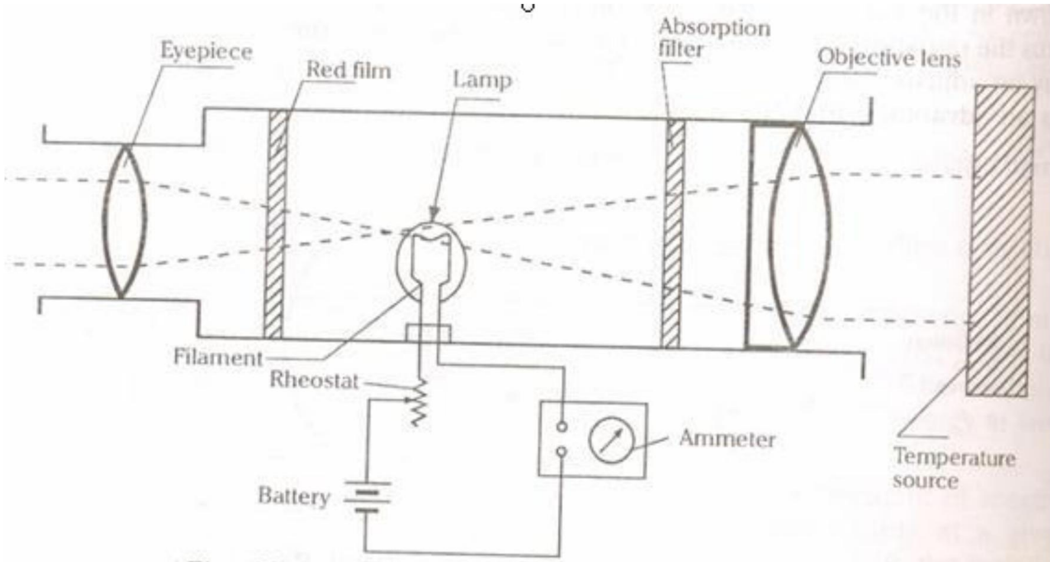
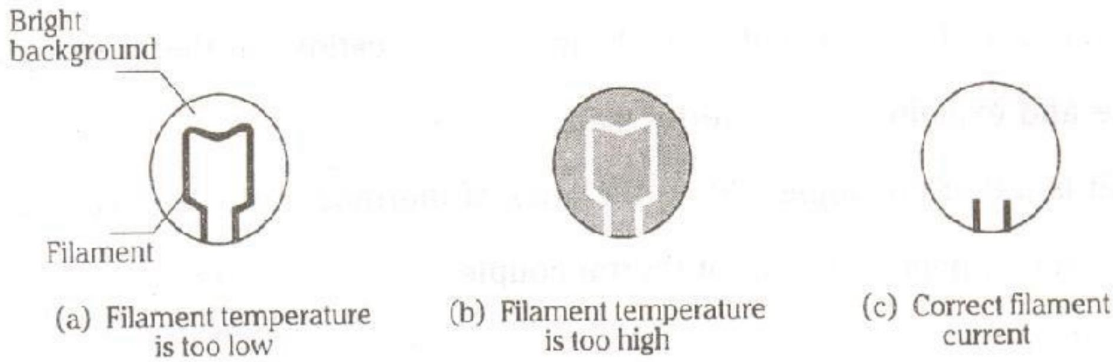


Fig. 12.13 Schematic of an Optical Pyrometer

The eyepiece is then adjusted such that the filament and the source appear superimposed. The filament may appear either hotter or colder than the unknown source as shown in the Fig.The current through the filament is adjusted by means of rheostat.



Filament Appearance

When the current passing through the filament is too low, the filament will emit radiation of lesser intensity than that of the source, it will thus appear dark against a bright background as in Fig. (a). When the current is too high it will appear brighter than the background as in Fig. (b). But when correct current is passed through the filament. The filament "disappears" into the background as in Fig. because it is radiating at the some intensity as the source. In this way the current indicated by the ammeter which disappears the filament may be used as the measure of temperature. The purpose of the red filter is to obtain approximately monochromatic conditions, while an absorption filter is used so that the filament may be operated at reduced intensity.

5.9 Strain Measurements

When a system of forces or loads act on a body, it undergoes some deformation. This deformation per unit length is known as **unit strain** or simply a strain mathematically

Strain € = δl /l where, δl = change in length of the body

l= original length of the body.

If a net change in dimension is required, then the term, **total strain** will be used. Since the strain applied to most engineering materials are very small they are expressed in **"micro strain"**

Strain is the quantity used for finding the stress at any point. For measuring the strain, it is the usual practice to make measurements over shortest possible gauge lengths. This is because, the measurement of a change in given length does not give the strain at any fixed point but rather gives the average value over the length. The strain at various points might be different depending upon the strain gradient along the gauge length, then the average strain will be the point strain at the middle point of the gauge length. Since, the change in length over a small gauge length is very small, a high magnification system is required and based upon this, the strain gauges are classified as follows:

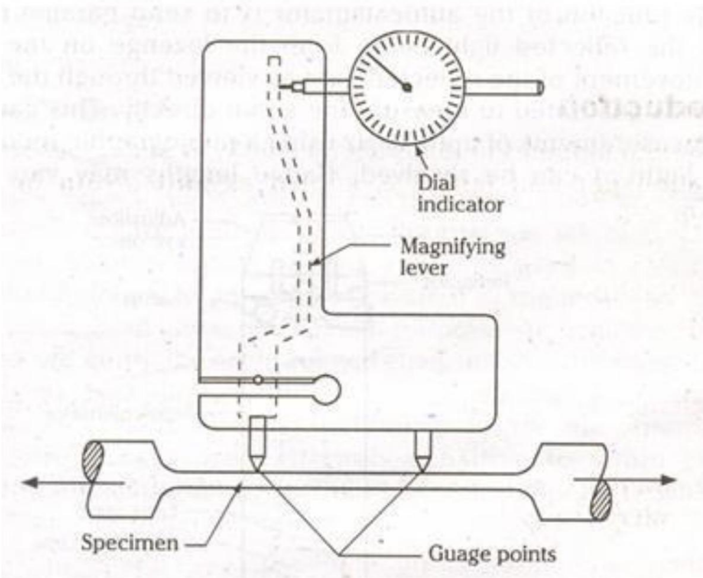
i) Mechanical strain gauges

ii) Optical strain gauges

iii) Electrical strain gauges

Mechanical Strain Gauges

This type of strain gauges involves mechanical means for magnification. Extensometer employing compound levers having high magnifications was used. Fig. shows a simple mechanical strain gauge. It consists of two gauge points which will be seated on the specimen whose strain is to be measured. One gauge point is fixed while the second gauge paint is connected to a magnifying lever which in turn gives the input to a dial indicator. The lever magnifies the displacement and is indicated directly on the calibrated dial indicator. This displacement is used to calculate the strain value. The most commonly used mechanical strain gauges are Berry-type and Huggen berger type. The Berry extensometer as shown in the Fig. is used for structural applications in civil engineering for long gauge lengths of up to 200 mm.



Mechanical Strain Gauge (Berry Extensometer)

Advantages

1. It has a self contained magnification system.
2. No auxiliary equipment is needed as in the case of electrical strain gauges.

Disadvantages

1. Limited only to static tests.
2. The high inertia of the gauge makes it unsuitable for dynamic measurements and varying strains.
3. The response of the system is slow and also there is no method of recording the readings automatically.
4. There should be sufficient surface area on the test specimen and clearance above it in order to accommodate the gauge together with its mountings.

OUTCOME

Students will be able to

1. Learn the concepts of force, torque, pressure, temperature measuring devices.

SELF-ASSESSMENT QUESTIONS

1. With a neat sketch explain force measuring devices.
2. With a neat sketch explain torque measuring devices.
3. With a neat sketch explain pressure measuring devices.
4. With a neat sketch explain temperature measuring devices.

FURTHER READING

1. Jain R. K., 1997, Engineering Metrology, Khanna Publishers.
2. Shawne A. K., 1998, Mechanical Measurement and Instrumentation, Dhanpat Rai and Co. (P) Ltd.
3. Hazra Chowdhury, 1995, Workshop Technology, Media Promoters and Publishers Pvt. Ltd