UNIT 5 LINEAR MEASURING DEVICES AND COMPARATORS

Structure

5.1 INTRODUCTION

Linear measurement includes the measurement of lengths, diameters, heights and thickness. The basic principle of linear measurement (mechanical type) is that of comparison with standard dimensions on a suitably engraved instrument or device. Linear measuring instruments are categorized depending upon their accuracy. The two categories are non-precision instruments and precision instruments. Non-precision instruments include steel rule, caliper divider, and telescopic gauge that are used to measure to the line graduations of a rule. Precision instruments include micrometers, vernier calipers, height gauges and slip gauges. A wide variety of electrical measuring devices is also available. Electric measuring devices are mainly transducers, i.e. they transform the displacement into suitable measurable parameter like voltage and current. Some of the displacement transducers are strain gauges, linear variable differential transformers (LVDT) and potentiometers. This unit will discuss different type of linear measuring devices and comparators.

Objectives

After studying this unit, you should be able to

- familiarise yourself with various type of linear measuring devices, and
- choose a suitable measuring device according to the precision required.

5.2 NON-PRECISION MEASURING INSTRUMENTS

Non-precision instruments are limited to the measurement of parts to a visible line graduation on the instrument used. There are several non-precision measuring devices. They are used where high measurement accuracy is not required. This section describes some of the non-precision measuring devices.

5.2.1 Steel Rule

It is the simplest and most common measuring instruments in inspection. The principle behind steel rule is of comparing an unknown length to the one previously calibrated. The rule must be graduated uniformly throughout its length. Rules are made in 150, 300, 500 and 1000 mm length. There are rules that have got some attachment and special features with them to make their use more versatile. They may be made in folded form so that they can be kept in pockets. The degree of accuracy when measurements are made by a steel rule depends upon the quality of the rule, and the skill of the user in estimating part of a millimeter.

5.2.2 Calipers

Calipers are used for measurement of the parts, which cannot be measured directly with the scale. Thus, they are accessories to scales. The calipers consist of two legs hinged at top, and the ends of legs span part to be inspected. This span is maintained and transferred to the scale. Calipers are of two types : **spring type** and firm **joint type**.

Spring Type

As the name explains, the two legs are attached with spring in this type of calipers. The working ends of each leg of a spring calipers should be identical in shape and have contact points equally distant from the fulcrum. The cross-section of the legs is either rectangular or circular in shape. The calipers are adjusted to set dimensions by means of either a knurled solid nut or a knurled quick action release nut operating in a finely threaded adjusting screw. The top portion of the legs are located in a flanged fulcrum roller and held in position by a spring in order to maintain the alignment of the working ends. The spring provides sufficient tension to hold the legs rigid at all points of the adjustment. A separate washer under the nut minimizes the friction between the adjusting nut and the leg.

Spring type calipers are of following types :

Outside Spring Calipers

These are designed to measure outside dimensions. The accuracy in caliper measurement depends upon the inspectors' sense of feel. The legs are held firmly against the end of the proper dimensions by adjusting nut with the thumb and forefinger. For accurate settings, the distance between the outside calipers may be set by slip gauges or by micrometer anvils. Figure 5.1 shows the diagrams of Outside spring calipers. A steel rule must be used in conjunction with them if a direct reading is desired.

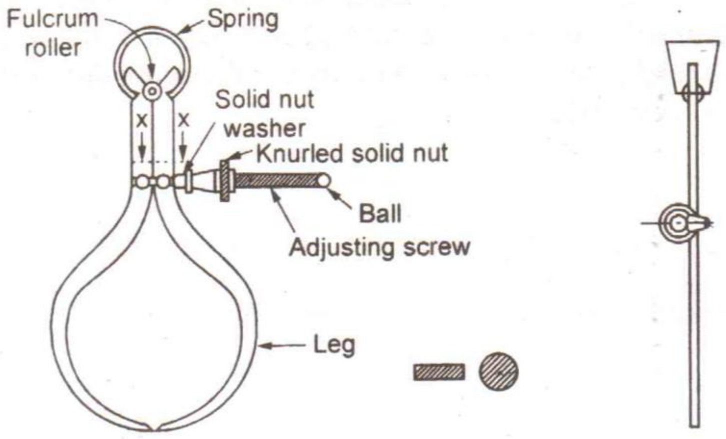

Figure 5.1 : Outside Spring Caliper

Inside Spring Calipers

They are designed to measure the inside dimensions. An inside spring caliper is exactly similar to an outside caliper with its legs bent outward as shown in Figure 5.2. Adjustment in them is generally made by knurled solid nut. They are used for comparing or measuring hole diameters, distances between shoulders, or other parallel surfaces of any inside dimensions. To obtain a specific reading, steel scale must be used as with the outside calipers.

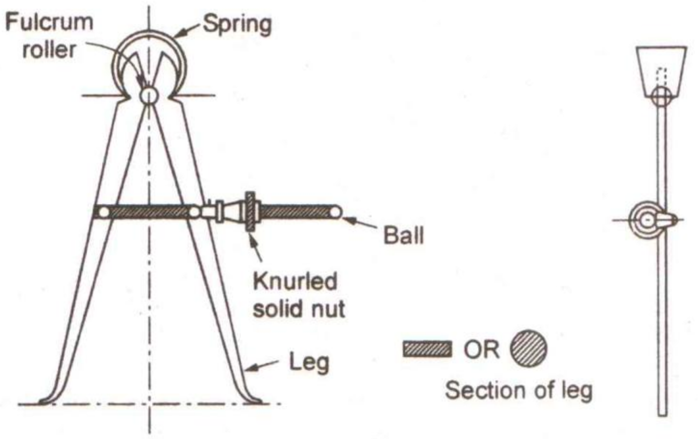

Figure 5.2 : Inside Spring Caliper

Firm Joint Type

They work on the friction created at the junction of the legs. The two legs are identical in shape with the contact points equally distant from the fulcrum and are joined together by a rivet. The component parts of the calipers should be free from seams, cracks and must have smooth bright finish. The distance between the rivet centre and the extreme working ends of the legs is known as *nominal size* and these calipers are available in the nominal size of 100, 150, 200 and 300 mm.

Firm joint calipers are of following types :

(i) Outside caliper

(ii) Inside caliper

(iii) Transfer caliper

(iv) Hermaphrodite caliper

Outside Firm Joint Caliper

Figure 5.3 shows the diagram of an outside firm joint caliper. Unlike spring type outside calipers, it does not have any spring. The construction is quite simple with two identical legs held firmly by the fulcrum. If direct reading is desired, a steel rule must be used in conjunction with them.

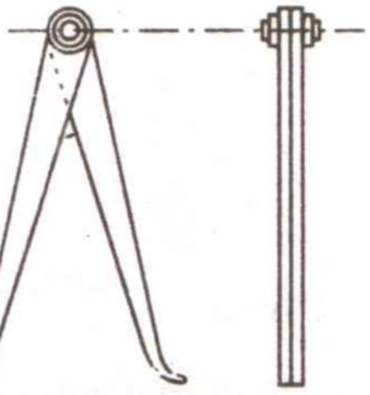

Figure 5.3 : Outside Firm Joint Caliper

Inside Firm Joint Caliper

Inside firm joint calipers are almost similar to inside firm joint caliper with the exception that it does not have any spring to hold the legs as shown in

Figure 5.4. Micrometers generally make adjustment in them. Like spring type inside calipers, they are also used for comparing or measuring hole diameters, distances between shoulders, or other parallel surfaces of any inside dimensions.

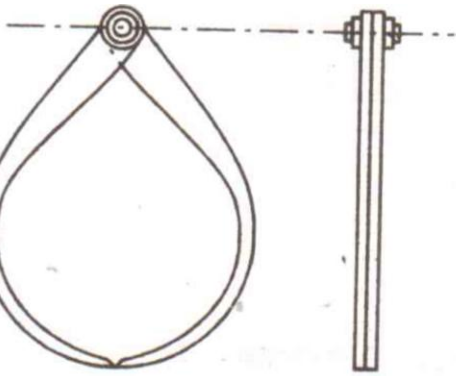

Figure 5.4 : Inside Firm Joint Caliper

Transfer Caliper

These are used for measuring recessed areas from which the legs of calipers can not be removed directly but must be collapsed after the dimension has been measured. Therefore, an auxiliary arm is provided with two legs so that it can preserve the original setting after the legs are collapsed. The nut *N* in Figure 5.5 is first locked and the caliper opened or closed against the work. The nut is then loosened and the leg is swung to clear the obstruction leaving the auxiliary arm in position. The leg can be moved back to the auxiliary leg, where it will show the size previously measured.

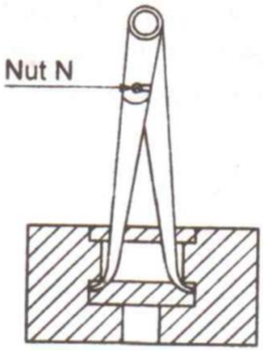

Figure 5.5 : Transfer Caliper

Hermaphrodite Caliper

It is also known as odd leg caliper consisting of one divider and one caliper leg. It is used for layout work like scribing lines parallel to the edge of the work and for finding the centre of a cylindrical work. It can be with two types of legs, viz. notched leg or curved legs.

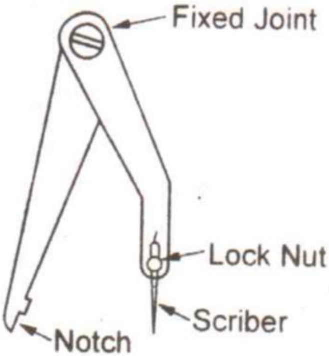

Figure 5.6 : Hermaphrodite Caliper

5.2.3 Divider

A divider is similar in construction to a caliper except that both legs are straight with sharp hardened points at the end as shown in Figure 5.8. These are used for scribing arcs and circles and general layout work. The distance between the fulcrum roller centre and the extreme working end of one of legs is known as the *nominal size* Dividers are available in the sizes of 100, 200, 300 mm. In practice, one point is placed in the centre position and the circle or arc may then be scribed on the job with the other point. A steel scale must be used with this instrument. Figure 5.7 shows a divider.

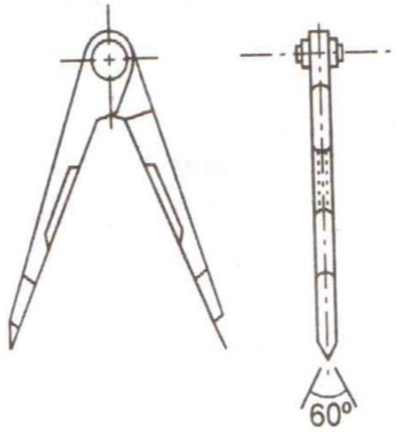

Figure 5.7 : Divider

5.2.4 Telescopic Gauge

The telescopic gauge shown in Figure 5.8 is used for the measurement of internal diameter of a hole during machining operation. It consists of a handle and two plungers, one telescopic into the other and both under spring tension. Ends of the plungers have spherical contacts. The plunger can be locked in position by turning a knurled screw at the end of the handle. To measure the diameter of a hole, the plungers are first compressed and locked in position. Next, the plunger end is inserted in the hole and allowed to expand the opposite edges. Finally, they are locked in place, taken out of the hole, and measured by an outside micrometer.

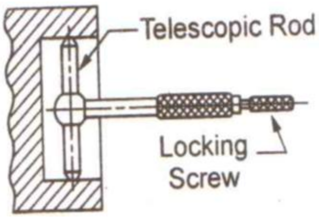

Figure 5.8 : Telescopic Gauge

5.2.5 Depth Gauge

This tool is used to measure the depth of blind holes, grooves, slots, the heights of shoulders in holes and dimensions of similar character. This is essentially a narrow steel rule to which a sliding head is clamped at the right angles to the rule as shown in Figure 5.9. The head forms a convenient marker in places where the rule must be held in a distance from the point being measured.

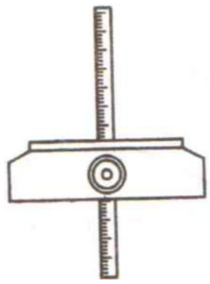

Figure 5.9 : Depth Gauge

5.3 PRECISION MEASURING INSTRUMENTS

Since modern production processes is concerned with interchangeable products, precise dimensional control is required in industry. Precision measurement instruments use different techniques and phenomena to measure distance with accuracy. We will discuss some of the precision measuring instruments in this section.

5.3.1 Vernier Calipers

Vernier calipers are precision measuring instruments that give an accuracy of 0.1 mm to 0.01 mm. The main scale carries the fixed graduations, one of two measuring jaws, a vernier head having a vernier scale engraved on. The vernier head carries the other jaw and slides on main scale. The vernier head can be locked to the main scale by the knurled screw attached to its head. Enlarged diagram of the metric vernier scale is shown in Figure 5.10.

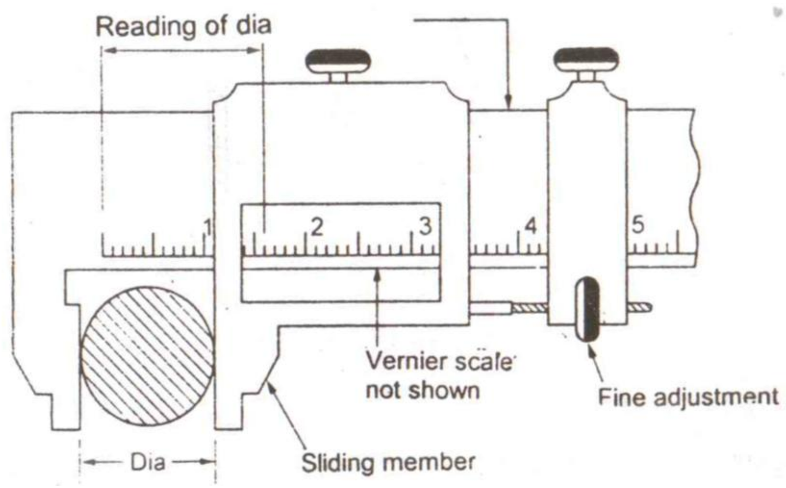

Figure 5.10 : Vernier Caliper

To understand the working principle of a vernier caliper, let us consider that the vernier scale has got 20 divisions which equals to 19 divisions of the main scale. Thus, one smallest division of the vernier scale is slightly smaller than the smallest division of the main scale. This difference is called vernier constant for that particular vernier caliper and when it is multiplied with the smallest unit of the main scale gives the least count of that vernier.

Now, 20 vernier scale divisions (VSD) = 19 main scale division (MSD)

$$\therefore \quad 1 \text{ VSD} = \frac{19}{20} \text{ MSD}$$

$$\therefore \quad \text{Vernier constant (VC)} = 1 \text{ MSD} - 1 \text{ VSD}$$

$$= 1 \text{ MSD} - \frac{19}{20} \text{ MSD}$$

$$= \frac{1}{20} \text{ MSD}$$

Now, if the smallest unit of the main scale be 1 mm, the least count of the vernier scale

$= VC \times$ one smallest unit of the main scale

$$= \frac{1}{20} \times 1 \text{ mm}$$

$$= 0.05 \text{ mm}$$

If the smallest unit in the main scale be 0.5 mm, the least count of the vernier scale is,

$$= \frac{1}{20} \times 0.5 \text{ mm}$$

$$= 0.025 \text{ mm}$$

To read a measurement from a vernier caliper, first the main scale reading up to the zero of the vernier scale is noted down. It will give accuracy up to the smallest division of the main scale. Now, vernier number of vernier scale division from its zero, which coincides exactly with the main scale is noted. This number when multiplied with the vernier constant gives the vernier scale reading. The actual length is obtained when the vernier scale reading is added to the main scale reading.

The caliper is placed on the object to be measured and the fine adjustment screw is adjusted until the jaws tightly fit against the Workpiece. There are vernier calipers that incorporate arrangements for measurement of internal dimensions and depth. The vernier calipers are designed to measure both internal and external dimensions. The lower jaws of a vernier scale are used for external measurement and the upper jaws for the measurement of internal dimensions. The rectangular rod carried by the movable jaw is used for the measurement of depth.

SAQ 1

(a) Describe different types of caliper for measuring the linear dimensions.

(b) A vernier scale consists of 25 divisions on 12 mm spacing and the main scale has 24 divisions on 12 mm. What is the least count?

5.3.2 Micrometers

Micrometer is one of the most widely used precision instruments. It is primarily used to measure external dimensions like diameters of shafts, thickness of parts etc. to an accuracy of 0.01 mm. The essential parts of the instruments shown in Figure 5.11, consist of

(a) Frame

(b) Anvil and spindle

(c) Screwed spindle

(d) Graduated sleeve or barrel

(e) Thimble

(f) Ratchet or friction stop

(g) Spindle clamp

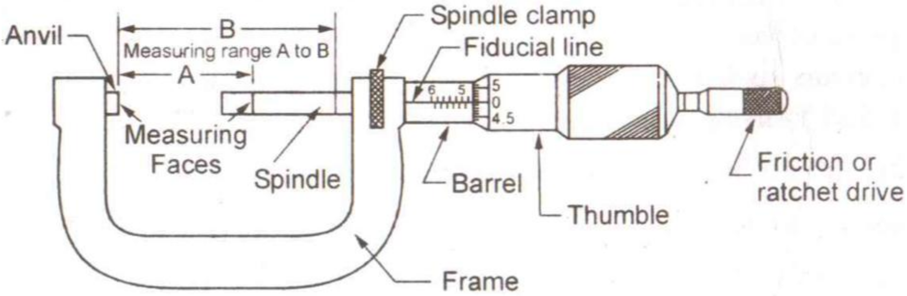

Figure 5.11 : Micrometer

The *frame* is made of steel, malleable cast iron or light alloy. The anvil shall protrude from the frame for a distance of at least 3-mm in order to permit the attachment of measuring wire support. The *spindle* does the actual measuring and possesses the threads of 0.5 mm pitch. The *barrel* has datum and fixed graduations *Thimble* is tubular cover fastened with the spindle. The beveled edge of the spindle is divided into 50 equal parts, every fifth being numbered. *The ratchet* is a small extension to the thimble. It slips when the pressure on the screw exceeds a certain amount. It produces uniform reading and prevents damage or distortion of the instruments. The *spindle clamp* is used to lock the instrument at any desired setting.

Procedure for Reading in a Micrometer

The graduation on the barrel is in two parts divided by a line along the axis of the barrel called the reference line. The graduation above the reference is graduated in 1 mm intervals. The first and every fifth are long and numbered 0, 5, 10, 15, etc. The lower graduations are marked in 1 mm intervals but each graduation shall be placed at the middle of the two successive upper graduations to be read 0.5 mm.

The thimble advances a distance of 0.5 mm in one complete rotation. It is called the pitch of the micrometer. The thimble has a scale of 50 divisions around its circumference. Thus, one smallest division of the circular scale is equivalent to longitudinal movement of $0.5 \times 1/50$ mm = 0.01mm. It is the least count of the micrometer.

The job is measured between the end of the spindle and the anvil that is fitted to the frame. When the micrometer is closed, the line marked zero on the thimble coincides with the line marked zero on the barrel. If the zero graduation does not coincide, the micrometer requires adjustment.

To take a reading from the micrometer, (1) the number of main divisions in millimeters above the reference line, (2) the number of sub-divisions below the reference line exceeding only the upper graduation, and (3) the number of divisions in the thimble have to be noted down. For example if a micrometer shows a reading of 8.78 mm when

8 divisions above the reference line	= 8.00 mm
1 division below the reference line	= 0.50 mm
28 thimble divisions	= 0.28 mm
	8.78 mm

The various important terms used in connection with micrometers are given below.

Backlash

It is the lack of motion or lost motion of the spindle when the rotation of thimble is changed in direction.

Measuring Range

It is the total travel of the measuring spindle for a given micrometer.

Cumulative Error

It is the deviation of measurement from the nominal dimension determined at any optional point of the measuring range. It includes the effect of all possible individual errors such as errors of the thread, errors of measuring faces etc. It can be determined by using slip gauges.

The following are the various types of micrometers.

Inside Micrometer Caliper

The measuring tips of inside micrometer are constituted by jaws with contact surface, which are hardened and ground to a radius. Unlike the conventional micrometer, an inside micrometer does not have any U-shape frame and spindle. One of the jaws is held stationary at the end and second one moves by the movement of the thimble. A locknut is provided to check the movement of the movable jaw. This facilitates the inspection of small internal dimension.

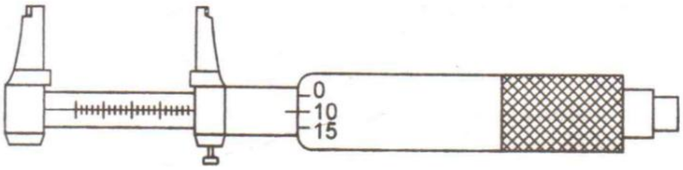

Figure 5.12 : Inside Micrometer Caliper

Inside Micrometer

The inside micrometer is intended for internal measurement to an accuracy of 0.001 mm. In principle, it is similar to an external micrometer and is used for measuring holes with a diameter over 50 cm. It consists of :

(a) measuring unit

(b) extension rod with or without spacing collar, and

(c) handle.

When the micrometer screw is turned in the barrel, the distance between the measuring faces of the micrometer can vary from 50 to 63 mm. To measure the holes with a diameter over 63 mm, the micrometer is fitted with extension rods. The extension rods of the sizes 13, 25, 50, 100, 150, 200 and 600 mm are in common use.

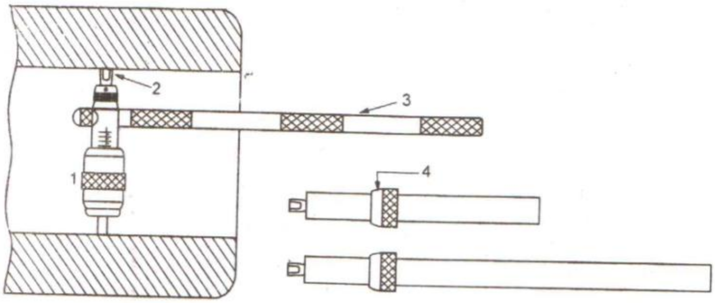

Figure 5.13 : Measuring the Inside Diameter of a Hole by an Inside Micrometer (1) Micrometer, (2) Anvil, (3) Handle and (4) Extension Rod

The measuring screw has a pitch of 0.5 mm. The barrel or sleeve is provided with a scale of 13 mm long and graduated into half-millimeter and millimeter divisions as in the external micrometer. A second scale is engraved on the beveled edge of the thimble. The beveled edge of the thimble is divided into 50 scale divisions round the circumference. Thus, on going through one complete turn, the thimble moves forward or backward by a thread pitch of 0.5 mm, and one division of its scale is, therefore, equivalent to a movement of $0.5 \times 1/50 = 0.01$ mm.

Stick Micrometers

Stick micrometers are used for measurement of longer internals length. A series of extension rods will permit continuous range of measurement up to the required length. It is connected with a 150 mm or 300 mm micrometer unit fitted with a micrometer of 25 mm range and having rounded terminal faces. Screw joints are used for joining the end-piece, extension rod and the measuring unit. The extension rod is generally hollow and has minimum external diameter of 14 mm. The accuracy of this instruments is in order of ± 0.005 mm. Figure 5.14 shows the parts of a stick micrometer.

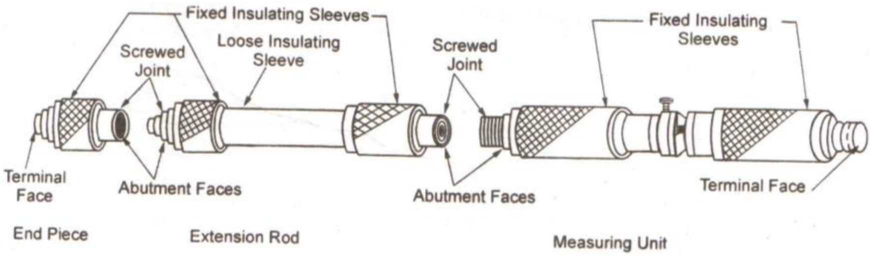

Figure 5.14 : Stick Micrometer

Screw Thread Micrometer Caliper

The shape of a Screw thread Micrometer is more or less like an ordinary micrometer with the difference that it is equipped with a pointed spindle and a double *V*-anvil, both correctly shaped to contact the screw thread of the work to be gauged. The angle of the *V*-anvil and the conical point at the end of the spindle correspond to the included angle of the profile of the thread. The extreme point of the cone is rounded so that it will not bear on the root diameter at the bottom of the thread, and similarly clearance is provided at the bottom of the groove in the *V*-anvil so that it will not bear on the thread crest. The spindle point of such a micrometer can be applied to the thread of any pitch provided the form or included angle is always same.

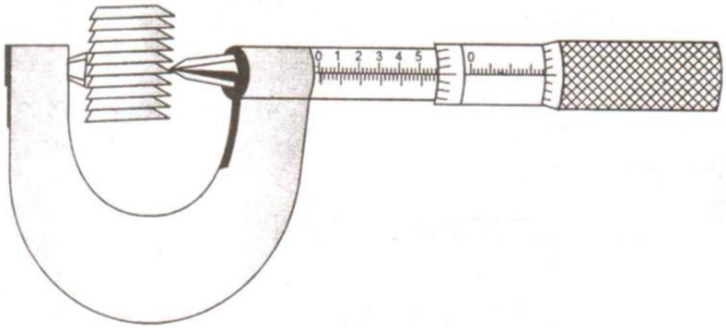

Figure 5.15 : Screw Thread Micrometer Caliper

V-anvil Micrometer Caliper

This is a special purpose micrometer used for checking out-of-roundness condition in centreless grinding and machining operations, odd-fluted taps, milling cutters, reamers etc. Use of special fixtures is eliminated in this type of micrometer. The *V* equals 60 degrees and the tip of the *Vee* coincides with axis of spindle. The zero reading of micrometer starts from a point where the two sides of the *V* meet. Figure 5.16 shows a *V*-anvil micrometer caliper.

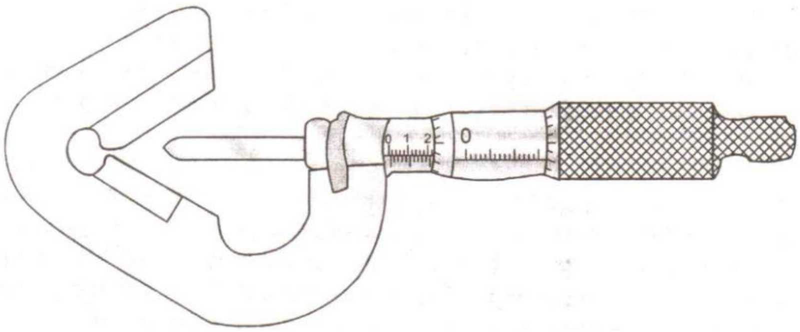

Figure 5.16 : *V*-anvil Micrometer Caliper

Blade Type Micrometer

It is ideally suited for fast and accurate measurement of circular formed tools, diameters and depth of all types of narrow grooves, slots, keyways, recesses etc. It has non-rotating spindle which advances to contact the work without rotation.

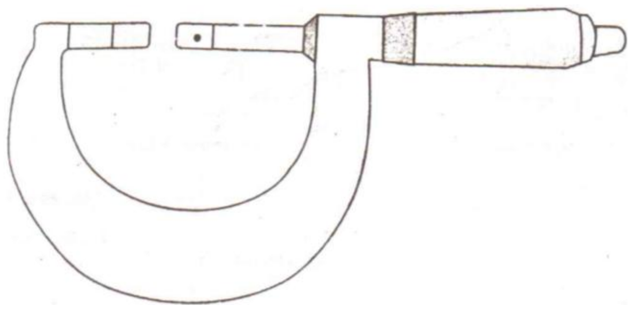

Figure 5.17 : Blade Type Micrometer

Bench Micrometer

A bench micrometer is a high precision micrometer with an anvil retractor device for repeated measurement. The worktable is adjustable and the indicator can measure up to 1 μm. The Anvil pressure is adjustable and linear friction transfer mechanism is used between anvil and indicator for high accuracy.

Groove Micrometer

It is used for measuring grooves, recesses and shoulders located inside a bore. Standard discs with diameter 12.7 mm and 6.35 mm are used to measure the locations inside a small bore. It is also capable of measuring an edge of a land and groove.

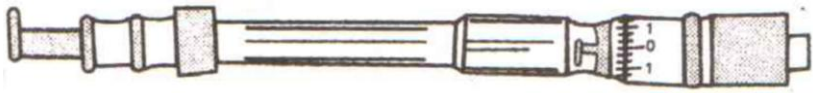

Figure 5.18 : Groove Micrometer

Digital Micrometer

Digital micrometer is capable of giving direct reading up to 0.001 mm. The spindle thread is hardened, ground and lapped in this type of micrometers. The positive locking clamp ensures locking of spindle at any desired setting. Operation is very simple with push button controls for “Zero” reset and indication “hold”.

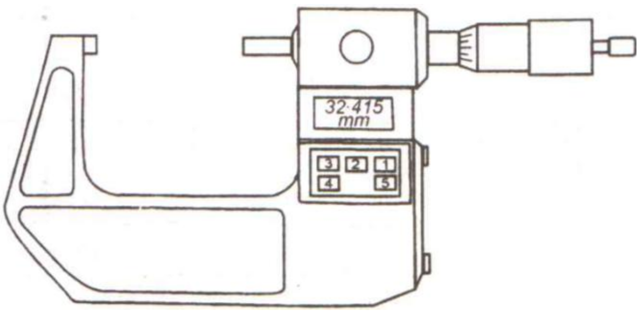

Figure 5.19 : Digital Micrometer

5.3.3 Height Gauge

This also uses the same principle of vernier caliper and is used especially for the measurement of height. It is equipped with a special base block, sliding jaw assembly and a removable clamp. The upper and lower surfaces of the measuring jaws are parallel to the base, which make possible to measure both over and under surfaces. A scribing attachment in place of measuring jaw can be used for scribing lines at certain distance above the surface. Specification of a vernier height gauge is made by specifying the range of measurement, type of scale required and any particular requirement in regard to the type of vernier desired.

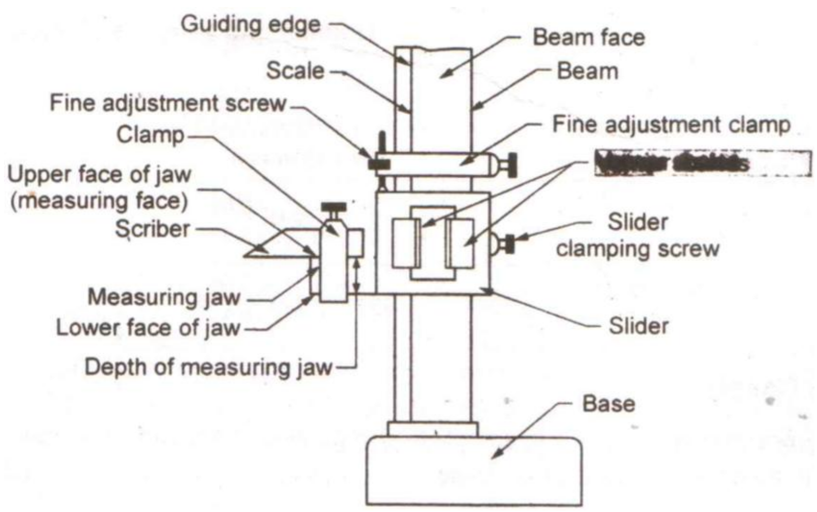

Figure 5.20 : Vernier Height Gauge

5.3.4 Slip Gauges

Slip gauges are rectangular blocks of steel having a cross-section of about 30 by 10 mm. The essential purpose of slip gauges is to make available end standards of specific lengths by temporarily combining several individual elements, each representing a standard dimension, into a single gauge bar. The combination is made by pressing the faces into contact and then imparting a small twisting motion while maintaining the contact pressure. This is called wringing. Wringing occurs due to molecular adhesion between a liquid film (thickness about 6 μm to 7 μm) and the mating surface. The combination made in that way can be used as reference for transferring the dimensions of the unit of length from the primary standard to gauge block of lower accuracy. It is also used for the verification and graduation of measuring apparatus and for direct measurement of linear dimensions of industrial components. For this purpose, control geometry of form such as flatness and parallelism of the surfaces and squareness of the gauging surfaces are essential. According to accuracy, the slip gauges can be graded into three categories, i.e. Grade 0, Grade I and Grade II. Generally, two sets of slip gauges are available.

Normal Set

Slip gauges of the following dimensions are available in this type of set.

Table 5.1 : Normal Set

Range	Step	Pieces
1.001 to 1.009	0.001	9
1.01 to 1.09	0.01	9
1.1 to 1.9	0.1	9
1 to 9	1	9
10 to 90	10	9
	Total	45

Special Set

Slip gauges of the following dimensions are available in this type of set.

Table 5.2 : Special Set

Range	Step	Pieces
1.001 to 1.009	0.001	9
1.01 to 1.49	0.01	49
0.5 to 9.5	0.5	19
10 to 90	10	9
	Total	86

The cross-section of most commonly used rectangular slip gauges are as shown below.

Normal Size	Cross-sectional Area ($w \times d$) in mm
Up to 10 mm	$30^{+0.0}_{-0.3} \times 9^{-0.05}_{-0.3}$
Above 10 mm	$35^{+0.0}_{-0.3} \times 9^{-0.05}_{-0.3}$

Selection of Slip Gauges

Standard procedure is followed in selecting slip gauges. It should be such that minimum number of slip gauges is chosen for combination of blocks depending on the type of set available. The procedure will be clear if we explain it with an example :

Let us consider the case where we have to arrange a dimension of 56.421 mm and normal sets of slip gauges are available.

Always the last decimal point is to be considered first, i.e. 0.001 mm. Since gauge of 0.001 mm is not available, 1.001 mm slip gauge is to be selected.

The dimension left now is 56.421 – 1.001 = 55.42 mm.

Now considering the second decimal place, slip gauge with 1.02 mm height is selected. The dimension left is 55.42 – 1.02 = 54.4 mm.

Next for 54.4 mm, slip gauge with 1.4 mm is to be chosen and then 3.0 mm gauge. Finally, 50 mm gauge is to be chosen.

Thus, we have 50.000 + 3.000 + 1.400 + 1.020 + 1.001 = 56.421 mm. All these five slip gauges are wrung properly to get the required dimension.

If special set of gauges be used, the combination in this case would have been 50.000 + 5.420 + 1.001 = 56.421 mm.

SAQ 2

(a) List various types of micrometers. Describe screw thread micrometer caliper.

(b) List the slip gauges to be wrung together to produce an over all dimension of 93.458 mm using both normal and special set of slip gauges without any protection slips.

5.4 ELECTRICAL MEASURING DEVICES

Electrical measuring devices give the most precise value of measurement among all the instruments discussed above. They use electrical transducers that transform a variety of physical quantities and phenomena into electrical signals. We will discuss some of the widely used electric devices in linear measurement in the following sections.

5.4.1 Strain Gauge

The most widely used pressure and force sensitive transducer is the strain gauge. The principle of the strain gauge is based on the resistive properties of electrical conductors. Electrical conductor possesses resistance based on the relationship

$$R = \rho \left(\frac{L}{A} \right)$$

where R is the resistance, ρ is the resistivity, L is the length and A is the area of cross-section.

When a metal conductor is stretched or compressed, its resistance changes because of the fact that both length and diameter of the conductor change. These effects, called piezoresistive effect, can be used for measurement of several variables like strain and associated stress in experimental stress analysis, and small dimensional changes. Figure 5.21 shows the influence of forces.

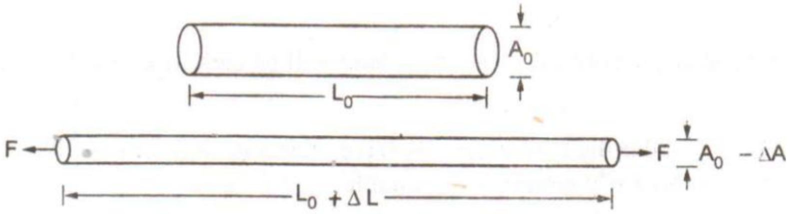

Figure 5.21

At the top of the figure, the conductor is unstressed. At the bottom of the figure, the conductor is in tension, increasing its length and reducing its area. The resistance of the strain gauge changes in proportion to its change in dimensions.

$$R_0 + \Delta R = \rho \frac{L_0 + \Delta L}{A_0 - \Delta A}$$

The gauge factor, *G*, of a strain gauge is the ratio of relative change in resistance to the relative change in length.

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

There are two primary constructions used in making strain gauges : bonded and unbonded. These are shown in Figure 5.22. In the unbonded strain gauge, the wire resistance element is stretched between two flexible supports. The wire stretches in accordance with the force applied to the diaphragm. The resistance of the wire changes due to these forces.

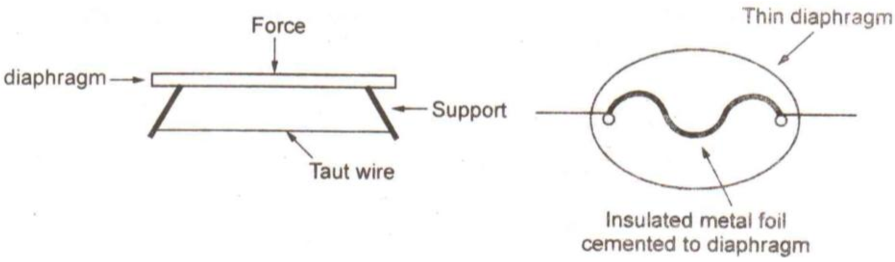

Figure 5.22 : (a) Unbonded; and (b) Bonded

In a bonded strain gauge, a wire metal foil is placed in a thin metal diaphragm. When the diaphragm is flexed, the element deforms and change in resistance occurs. Generally, bonded strain gauge is more durable than unbonded.

There are three types of strain gauges :

(a) Metallic resistance strain gauge made of metallic wires such as constantan (Cu-Ni alloy) Nichrome V or Platinum alloy.

(b) Foil strain gauge consists of a thin, 8-to 15 μm nitro-cellulose impregnated paper on which photo etched metal alloy filaments are attached as resistance material. For higher temperature, an epoxy backing is used instead of paper. The active length of the gauge is along the transverse axis. The gauge should be mounted with its transverse axis in the same direction as the direction of application of force or strain. Thus, the elongation of the gauge reduces the length and consequently the resistance.

(c) The third type is the semiconductor gauge. It depends on the piezoresistive properties of silicon and germanium. They have high sensitivities with gauge factor from 50 to 200. Their chief defects are fluctuations due to temperature and non-linear output. The p-type gauges increase resistance with applied tensile strain while n-type gauge resistance decreases. The gauge is generally bonded to the structure by epoxy adhesive or ceramic cement.

5.4.2 Potentiometer

A potentiometer consists of a resistive elements provided with a sliding contact. This sliding contact may move either in linear or rotational direction and accordingly the corresponding potentiometer is called a linear or rotary potentiometer respectively. Figure 5.23 shows the diagram for translational, single turn rotational, and multi-turn helix potentiometer.

Let e_i and e_0 = input and output voltage (V) respectively,

x_t = total length of translational potentiometer m,

x_i = displacement of wiper from its zero position, and

R_p = total resistance of the potentiometer.

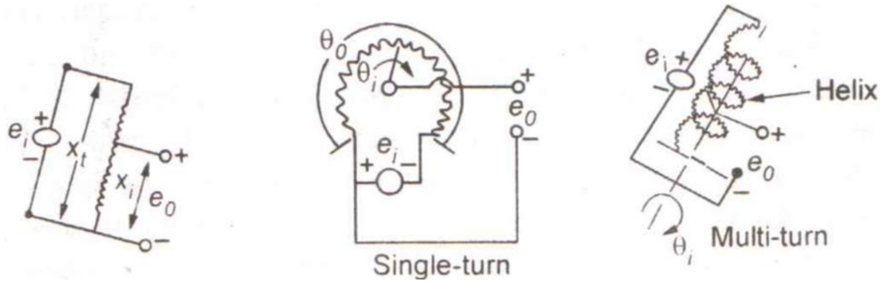

Figure 5.23

If the distribution of the resistance with respect to translational movement is linear, the resistance per unit length is R_p/x_p.

The output voltage under ideal condition is :

$$e_0 = \left(\frac{\text{Resistance at the Output Terminal}}{\text{Resistance at the Input Terminal}} \right) \times \text{Input Voltage}$$

$$= \left[\frac{R_p \left(x_i / x_t \right)}{R_p} \right] e_i = \frac{x_i}{x_t} \times e_i$$

Under ideal condition, the output voltage varies linearly with displacement.

5.4.3 Linear Variable Differential Transformer (LVDT)

LVDT is high-resolution contact transducer. As Figure 5.24 illustrates, it is connected with three coils, one primary and two secondary. A magnetic core sits within the coil.

If an alternating current is imposed on the primary coil, a voltage will be induced across the secondary coil. The magnitude of that voltage is a linear function of the position of the magnetic core. Deviation from the null position of the core can be translated into voltage reading by the equation

$$\Delta V_0 = K\, \Delta X$$

where, ΔV_0 is the change in output voltage, K is a proportionality constant, and ΔX is the change in position.

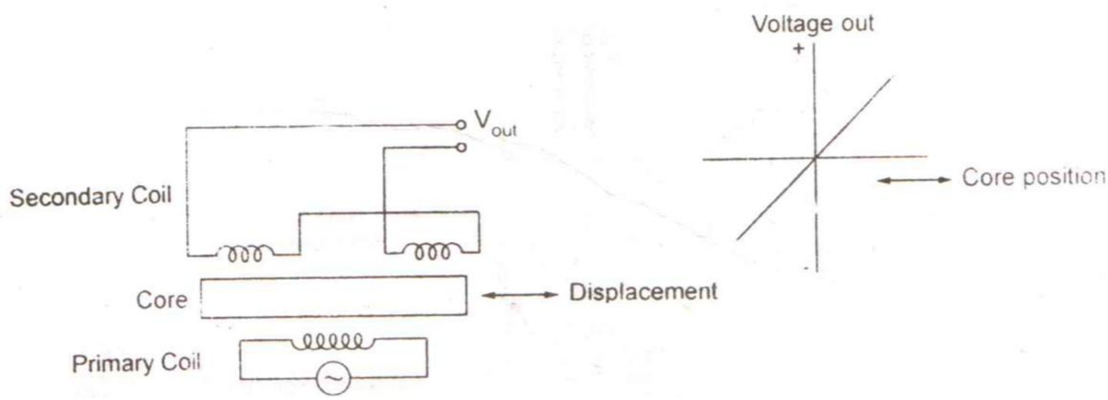

Figure 5.24 : LVDT

LVDTs come in various sizes. The resolution of an LVDT is excellent, easily able to measure displacement below 0.001 inch. Since this is an analog device, the limits of resolution are usually governed by the resolution of the A/D converters.

LVDT use alternating currents. Therefore, a requirement exists to transform the output voltage to DC before it is applied to the A/D converter. Manufacturers of LVDT serve this requirement with instrumentation packages that provide the required DC operation voltage.

It is apparent that the LVDT has an advantage over the potentiometer as a position measurement device. Since its core does not touch the coil, there is no mechanical wear that would result in deterioration of performance over time. On the other hand, it is a more expensive transducer. It is justifiable primarily where very high and repeatable accuracy is required.

5.5 COMPARATORS

Comparators are the instruments calibrated by means of end standards to measure unknown dimensions. The purpose of a comparator is to detect and display the small differences between the unknown linear dimensions and the length of the standard. The difference in lengths is detected as a displacement of a sensing probe. The important and essential function of the instruments is to magnify or amplify the small input displacement so that it is displayed on an analog scale. Comparators are classified on the basis of type of the amplification method used. Accordingly comparators are of following types or hybrid thereof.

(a) Mechanical comparators, (b) Optical Comparators.

(c) Pneumatic comparators, (d) Electrical comparators.

5.5.1 Mechanical Comparators

Conventional mechanical methods to obtain magnification are not suitable in construction of mechanical comparators as it causes backlash and friction. Also they require a large input force. Let us understand the mechanical comparators by studying a reed comparator which is strictly a mechanical comparator.

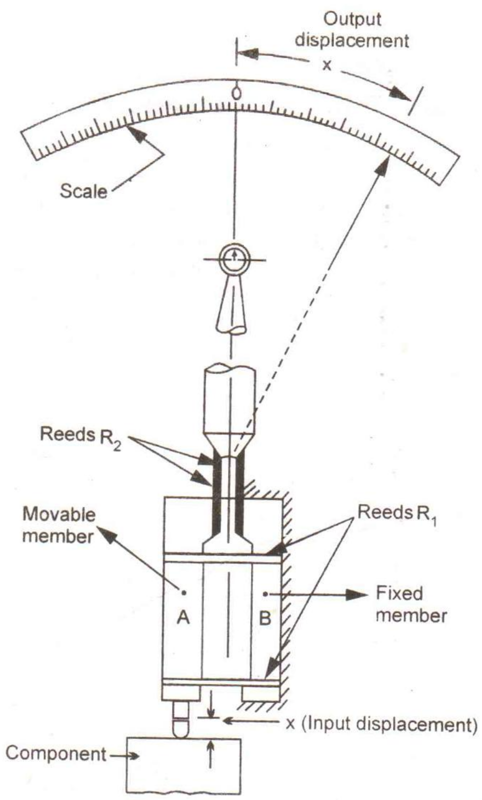

Figure 5.25 : Mechanical (Reed) Comparator

A spindle attached to the movable member is in contact with the component to be measured. Movable member moves through a distance *x*, in response to displacement with respect to fixed member. The movable member is constrained by flexture strips or reeds R_1, to move relative to the fixed member. The pointer is attached to reeds R_2. A small input displacement produces a large angular movement, *x*, of the pointer on account of their orientation relative to the motion. The scale is calibrated by means of gauge blocks and indicate the difference in displacement of the fixed and movable elements. There is no friction and the hysteresis effect is minimized by using suitable steel for the reeds. Comparators of this type have sensitivities of the order of 0.25×10^{-3} mm/scale division. There are many other systems which are used for mechanical comparators. However, there is a limit to magnification that can be achieved with purely a mechanical comparator.

5.5.2 Optical Comparators

Optical comparators are based on the principle of projection of image. A simple optical comparator for measurement of linear dimension is shown in Figure 5.26. The arrangement consists of mechanical system which causes a plane reflector to tilt about an axis so that the image of an index is projected on scale on the inner surface of a ground glass screen. The actual difference *x* between the two dimensions is amplified by a lever to give an angular displacement θ of a pivoted mirror. The reflected ray is deflected through an angle 2θ from the original line and gives a reading of *X* on the scale. The main advantage of an optical comparator is that it is capable of giving higher degree of magnification due to reduction of moving members and better wear resistance qualities.

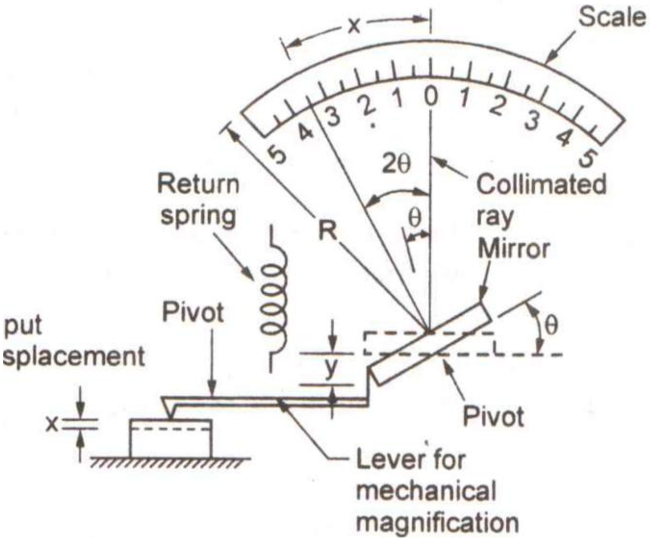

Figure 5.26 : Optical Comparator

5.5.3 Pneumatic Comparators

Pneumatic comparators are the widely used precision instruments which use the principle of obstructed nozzle. The schematic diagram of a pneumatic comparator is shown in Figure 5.27.

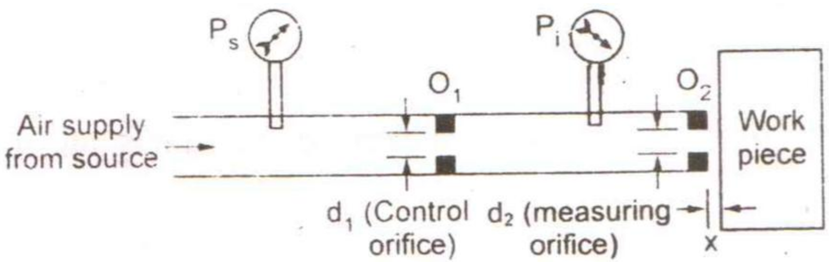

Figure 5.27 : Schematic Diagram of a Pneumatic Comparator

It has two orifices O_1 and O_2 with diameter d_1 and d_2 respectively. Through O_1, air is supplied at a constant pressure, P_s, which is the pressure of the source.

The area of orifice $O_1 = A_1 = (\pi / 4)\, d_1^2$. This area is fixed.

The area of the second orifice through which air can pass $O_2 = A_2 = \pi\, d_2\, x$.

Thus, the area of orifice O_2 is variable and depends upon the displacement of the workpiece x.

The intermediate pressure P_i between the fixed orifice and the outlet is dependent upon the source pressure P_s, and the pressure drops across the two orifices O_1 and O_2. Since area A_2 of the orifice O_2 varies with displacement x, the intermediate pressure, P_i, also changes with change in x. Thus, change of pressure is a function of displacement x and hence can be used as a measure of dimension x.

5.5.4 Electrical Comparators

Electrical comparators are used as a means of detecting and amplifying small movements of a work contacting elements. It may use any of the following transducers for magnification. They are

(a) strain gauges,

(b) variable inductance transducers, and

(c) variable capacitance transducers.

The transducer converts the displacement into a corresponding change in current and a meter recorder connected in the circuit to indicate the electrical change calibrated to show in terms of displacement. Generally, an amplifier is used to provide the requisite sensitivity and to match the characteristics of different parts of the circuit. There are different types of electrical comparators. One of them, called an electrolimit gauge, is used to check or measure the outside diameter of a roll. The object to be checked is placed on the anvil under overhanging gauging spindle. Movement of the spindle for its deviation from a standard dimension unbalances an electric circuit. The displacement is magnified electrically and shown on the dial meter.

There are a number of advantages of electrical comparators over the mechanical type. They have little or no moving parts and, therefore, they maintain their accuracy over long periods. In addition, the sensitivity of these comparators can be adjusted at will to suit the type of measurement being done. Electrical comparators can give magnification from 600 to 10,000 according to the meter. Figure 5.28 shows the basic parts of an electric comparator.

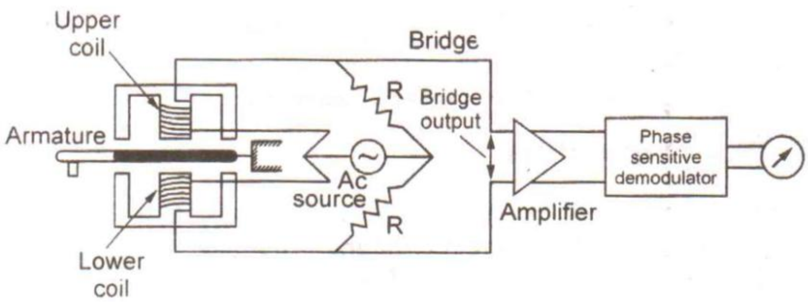

Figure 5.28 : Electric Comparator

SAQ 3

What are the advantages of electrical comparators over mechanical comparators?

5.6 SUMMARY

In this unit, linear measuring devices and comparators have been discussed. The unit begins with the description of non-precision measuring devices like scale (ruler), caliper, divider and telescopic gauge. Next, precision measuring devices, viz. vernier caliper, micrometer, height gauges and slip gauges are explained. The principles of electrical measuring devices like strain gauges, LVDTs, potentiometers have also been discussed. The four basic types of comparator viz. mechanical, optical, pneumatic and electrical are discussed.

5.7 KEY WORDS

Vernier Constant : It is defined as the difference between one small division of the vernier scale and one small division of the main scale.

Least Count : It is the minimum distance that can be measured by a vernier caliper or a micrometer accurately.

Wringing : It is the process of combining two slip gauges by application of pressure normal to the surface to be joined with sliding motion of one surface over the other.

Transducer : A transducer is a device which, when actuated, transform energy from one form to another.

Piezo-resistive Effect : It is defined as the phenomenon due to which resistivity of a conductor changes when it is subjected to strain.

Gauge Factor : The gauge factor of a strain gauge is the ratio of relative change in resistance to the relative change in length.

5.8 ANSWERS TO SAQs

SAQ 1

See preceding text for answer.

SAQ 2

(a) Least count of a vernier scale

= Main scale spacing – Vernier scale spacing

$$= \left(\frac{12}{24} - \frac{12}{25}\right) \text{ mm}$$

$$= \frac{1}{50} \text{ mm}$$

= 0.02 mm

(b) See preceding text for answer.

(c) By using the normal set

Original dimension	=	93.458
First Plate	=	1.008
		92.450
Second Plate	=	1.050

		91.000
Third Plate	=	1.400
		90.000
Fourth Plate	=	90.000

Therefore, combination = 1.008 + 1.05 + 1.40 + 90 mm
= 93.458 mm.

By Using the Special Set

Original dimension	=	93.458
First Plate	=	1.008
		92.450
Second Plate	=	1.45
		91.00
Third Plate	=	1.00
		90.00
Fourth Plate	=	90.00

Therefore, combination = 1.008 + 1.05 + 1.40 + 90 mm
= 93.458 mm.