EXPERIMENTS IN MECHANICAL MEASUREMENT AND METROLOGY

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DEPARTMENT OF MECHANICAL ENGINEERING

SUBJECT : MECHANICAL MEASUREMENT AND METROLOGY

SUBJECT CODE: 141901

INDEX

PRACTICAL: 01 **Date:**

AIM: - To Study about different terminology related to Metrology

- **What is Metrology?**

Metrology is the scientific study of measurements. Measurements come in all forms. Gemstones can be measured for hardness or carat size. Pieces of wood can be measured for length. Electricity can be measured in amps, volts, and watts.

Mechanical metrology concentrates on standardizing acoustics, force/pressure, vibration, volume, density, and dimensions. As Asian companies begin sweeping the country in terms of inexpensive manufacturing, other companies are relying on mechanical metrology to help them compete. With a set of standards in place, customers can buy products from any country and know they will be getting parts with universal measurements. This helps keep repair costs competitive.

As early as the 1950s, businesses worldwide determined that there was a need to bring unity to measurement in the manufacturing process. As a result, the International Organization of Legal Metrology was created in 1955. Today, dozens of countries are members of the organization and share a common goal, to unify manufacturing and business throughout the world.

With so many countries competing for the market share of manufacturing business, metrology is essential to keep the market competitive. Having unified measurements can help with repair costs in the future and ensure that products can be used worldwide without difficulty. Many organizations hold international conventions where metrology members can share ideas and concerns, and compare notes. These metrology conventions are becoming a popular means for unifying the wide array of measurements used throughout the world.

Over the past decade, there has been an increased need for metrology in chemistry labs. Metrology of chemistry makes it possible to create strong processes for quality control of many goods manufactured worldwide. As pollution controls increase, there is an intense need to regulate worldwide emission controls. Metrology of chemistry helps ensure that different countries utilize chemicals in a manner that protects the environment. Chemistry metrology helps define standards to be used in gas/air mixtures, gas analyzers, inorganic materials, spectrometry, and microanalysis.

Quiz:

1) Define Metrology.
2) Give the objectives of Metrology.
3) Briefly explain following terms giving example
    1. Resolution.
    2. Accuracy.
    3. Threshold.
    4. Precision.
4) What do you mean by Standard? Explain different standards. Also differentiate between standard and standardization.
5) Describe the following types of errors and state how they can be taken care of.
    (i)Environmental error (ii) Error due to vibration
6) List and explain characteristics of measuring devices stating illustrations
7) State and explain five basic elements of measuring system

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PRACTICAL: 02 **Date:-**

AIM: - To study about linear measuring instruments

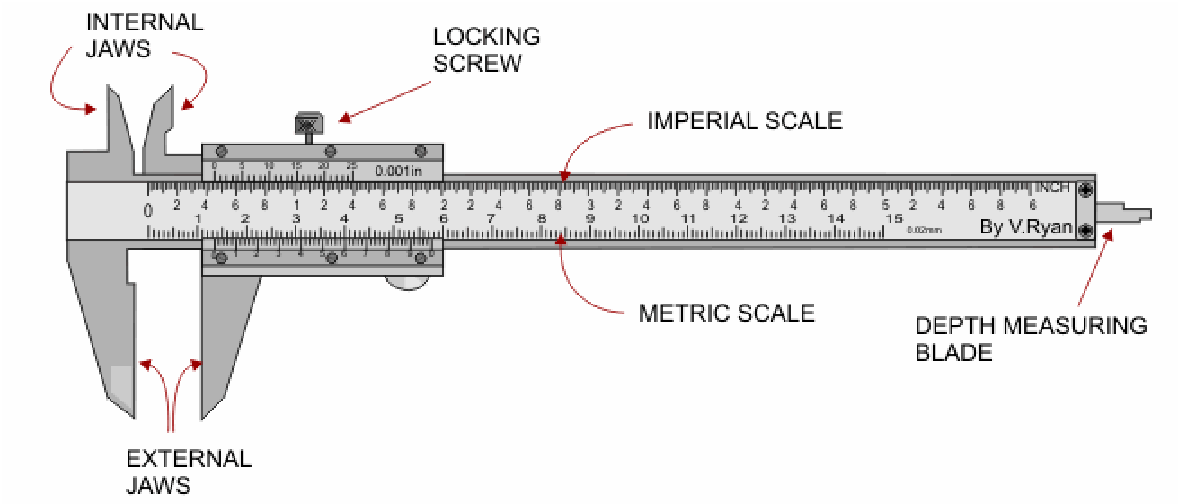
VERNIER CALIPERS:

TERM	BRIEF DEFINITION
Caliper	"A tool that can be used to measure outside dimensions, inside dimensions, or depths of holes."
Instrument least count	"The size of the smallest division on a scale." For the main scale on the common vernier caliper this is probably 0.1 cm. With the vernier scale the least count might be 0.002 cm.
Main Scale	"The scale on the larger, fixed portion of the caliper." It gives the most significant digits in the reading. Make the reading to the nearest least count of the main scale opposite the zero of the vernier.
Vernier scale	"The scale on the smaller sliding portion of the caliper." It gives the least significant digits in the reading, and sub-divides a mark on the main scale into 10, 20, or 50 subdivisions. Read the vernier scale at the point where a vernier line and a main scale line best line up. Combine the main scale reading with the vernier scale reading to get a final reading.

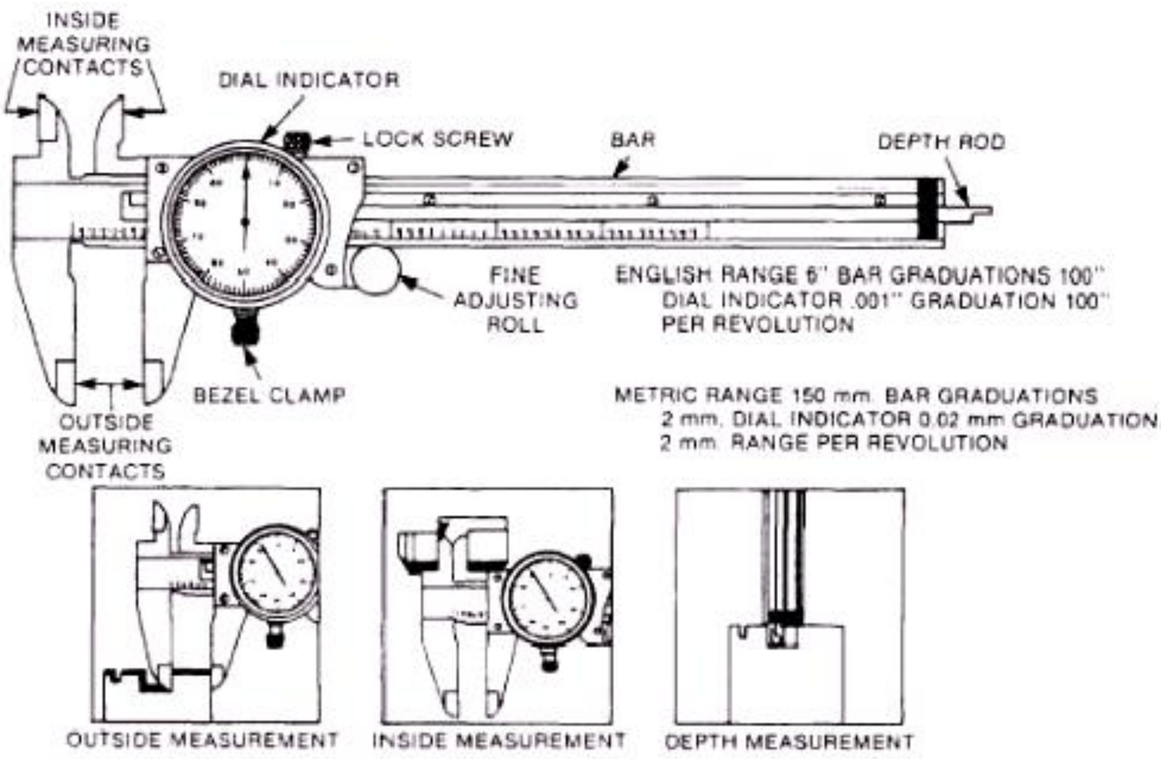
CONSTRUCTION:

The vernier caliper consists of two scales:

One is fixed while other is movable. The fixed scale called main scale is calibrated on L-shaped frame and carries a fixed jaw. The movable scale called vernier scale slides over the main scale and carries a movable jaw. In addition, an arrangement is provided to lock the sliding scale on the fixed main scale. For the precise setting of movable jaw, an adjustment screw is provided,



DIAL VERNIER:



CONSTRUCTION:

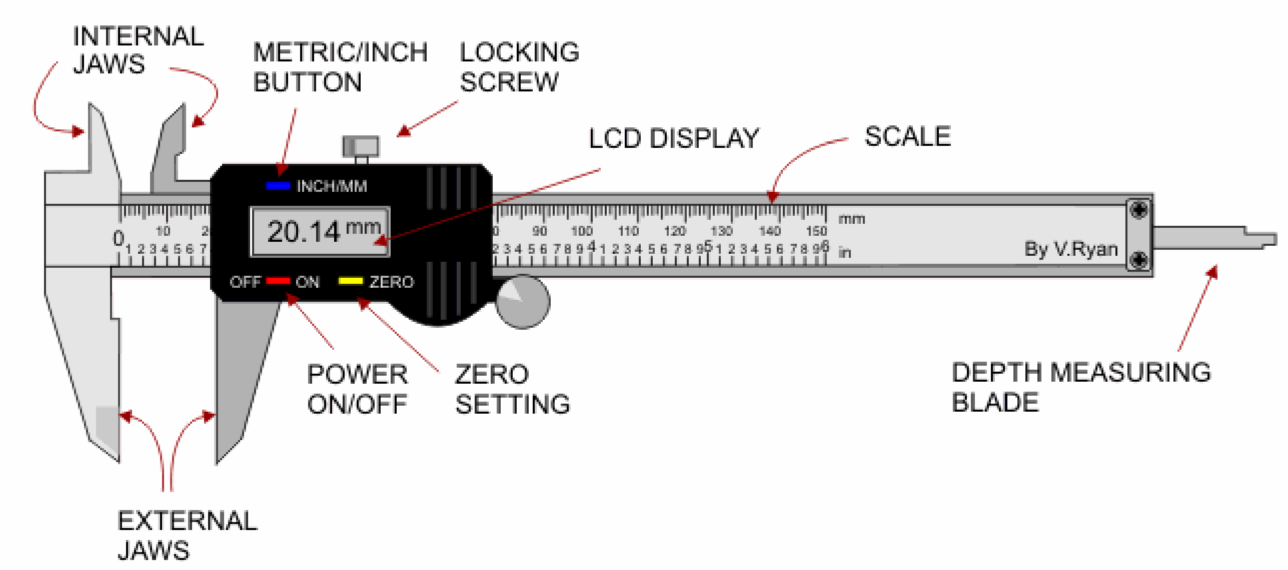
The Dial vernier itself suggests that dial is provided for measurement. Its construction is same as the vernier calipers. One fixed scale on which movable scale is provided. According to the movement of vernier scale the dial, indicate the reading.

DIGITAL VERNIER:

The Vernier Caliper is a precision instrument that can be used to measure internal and external distances extremely accurately. The example shown below is a digital vernier caliper as the distances are read from a LCD display.

The most important parts have been labeled. Earlier versions of this type of measuring instrument had to be read by looking carefully at the imperial or metric scale and there was a need for very good eyesight in order to read the small sliding scale. Manually operated vernier calipers can still be bought and remain popular because they are much cheaper than the digital version. Also, the digital version requires a small battery whereas the manual version does not need any power source.

Digital vernier calipers are easier to use as the measurement is clearly displayed and by pressing the inch/mm button, the distance can be read as metric or imperial.

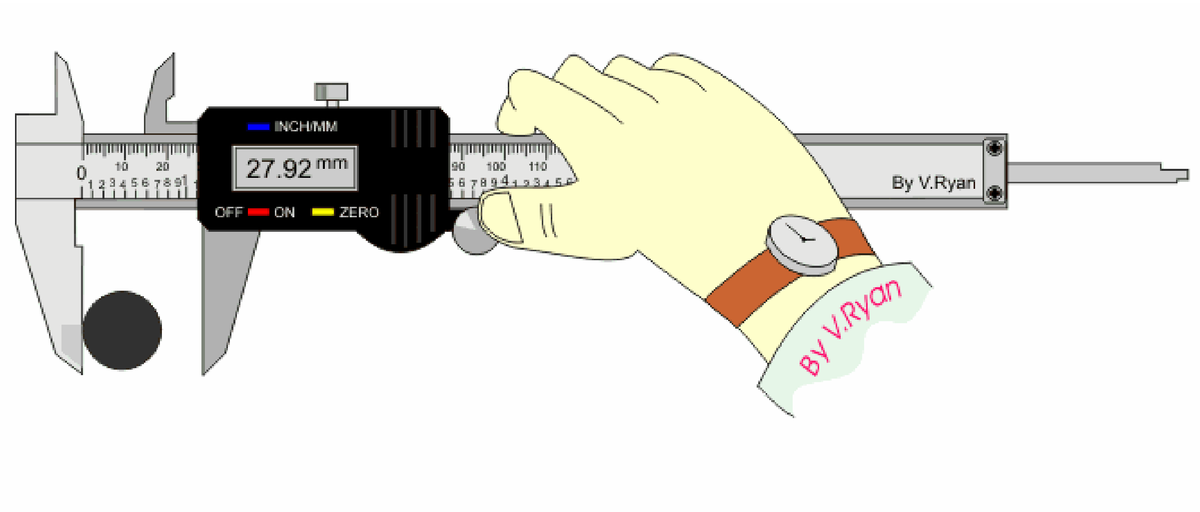


PROCEDURE OF MEASUREMENT:

The display is turned on with the on/off button. The external jaws should then be brought together until they touch and the zero buttons should be pressed. The vernier caliper can then be used to measure distances. Always go through this procedure when turning on the display for the first time.

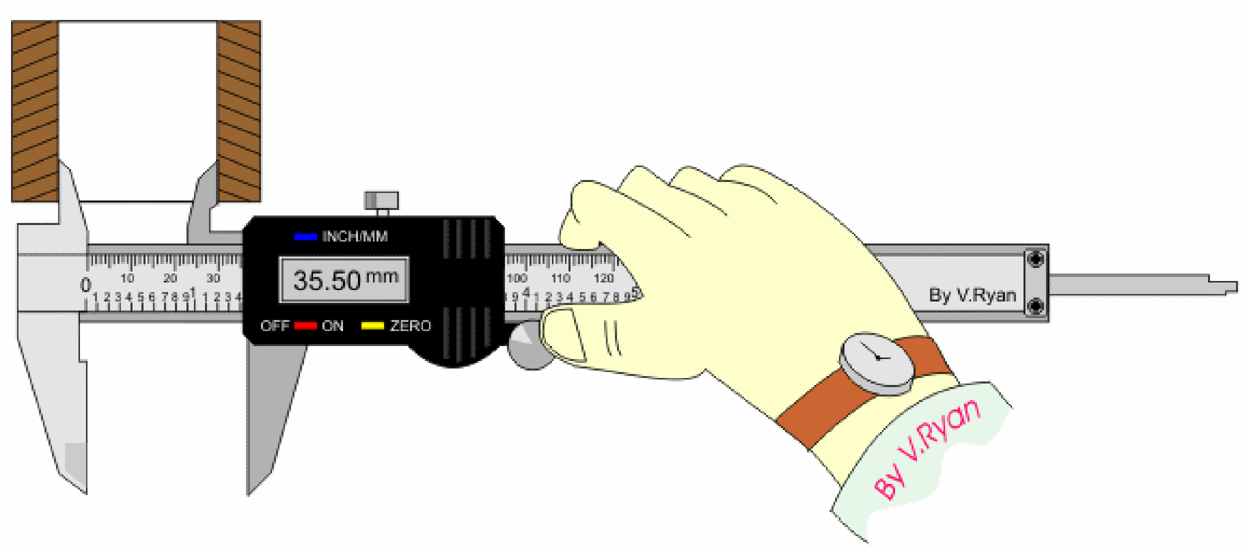
Measuring External Distances:

The material to be measured is placed between the external jaws and they are carefully brought together. The locking screw is tightened so that the jaws do not move apart. The digital display can then be read. The distance can be read by in metric and imperial by pressing the inch/mm button.



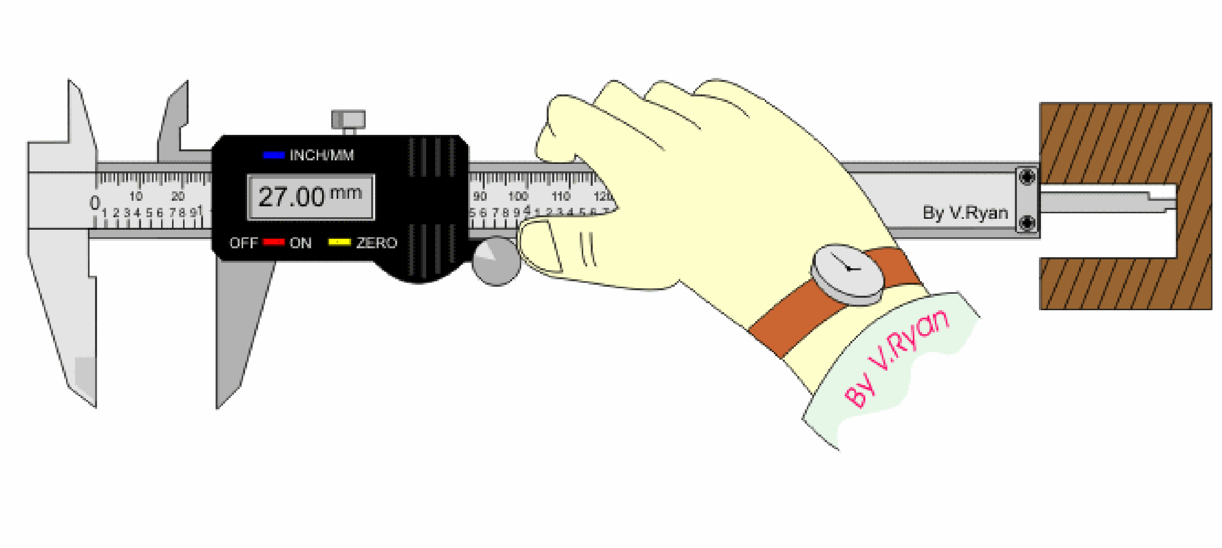
Measuring internal distance:

The example below shows a vernier calipers being used to measure the internal diameter of a piece of copper tube. The internal jaws are adjusted carefully until they touch the internal 'sides'. The locking screw is tightened so that an accurate measurement can be made even if the jaws are 'knocked' against the sides as the jaws are removed from the hole. The measurement is shown on the LCD display.



Measuring Depth:

Measuring the depth of a hole can be very difficult. However, using a vernier caliper makes this task easy. The base of the vernier caliper rests on the top of the hole and the depth-measuring blade is adjusted until it touches the bottom of the hole. The locking screw is tightened and the measurement can be read on the LCD display.



VERNIER HEIGHT GAUGE:

CONSTRUCTION:

A finely ground and lapped base, the base is massive and robust in construction to ensure rigidity and stability. A vertically graduated beam or column supported on a massive base. Attached beam is a sliding vernier and head the vernier scale and a clamping screw. The auxiliary head, which is also calculated to the beam above sliding vernier head. A measuring jaw or scriber attached to the front of sliding vernier. Procedure for vernier height gauge: It is same as vernier caliper but the vernier height gauge is measured height from the reference.

PRECAUTIONS:

- First clean vernier caliper by wiping of oil, dust, grit etc.
- Clean the two jaws with clean piece of papers.
- Set the zero reading of the instrument to be the measure between two jaws.
- While measuring dimensions of vernier caliper, it must move carefully.
- Hold the past whose dimension is to measure between two jaws.

INTRODUCTION OF MICROMETER: -

It is one of the most common & most popular forms of measuring instrument for precise measurement with **0.01 mm** accuracy. In addition, micrometer screw gauges are available with **0.001 mm** accuracy.

It classify as:-

- Outside micrometer
- Inside micrometer
- Screw thread micrometer
- Depth gauge micrometer.

PRINCIPLE OF MICROMETER: -

The micrometer works on the principle of "**screw & nut**". We know that when screw is turned through one revolution it advances by one pitch distance i.e. – one revolution of screw corresponds to a linear movement of a distance equal to pitch of the thread.

COMPONENTS AND THEIR FUNCTIONS: -

U-SHAPED STEEL FRAME: -

The outside micrometer has 'U' shaped & 'C' shaped frame. It holds all the micrometer parts together. It is made of steel C.I.

ANVIL AND SPINDLE: -

The micrometer has fixed anvil protruding **3mm** from the left hand side of frame. Its diameter is same as spindle.

LOCK NUT: -
The Lock provides on the micrometer spindle to lock. When micrometer is at correct, the Lock nut provides the tight holding of job as well as reading.

SLEEVE AND BASSEL: -
The sleeve divided accurately and marked correctly in **0.5mm** division along the length, which serves as a main scale.

- **THIMBLE: -**

The thimble can move over the parallel. It has 50 equal divisions around its circumference each division has a value of **0.01mm**.

- **RATCHET: -**

It provides on the end of the thimble. It used to assure accurate measurement & to prevent too much pressure applied to microscope.

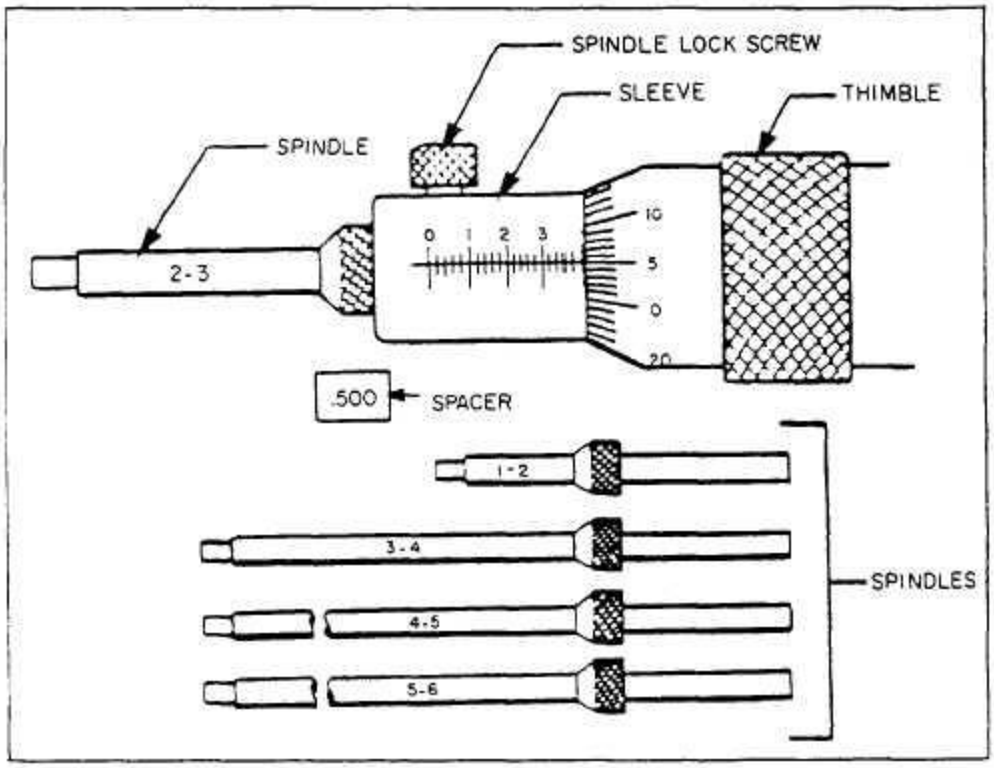
THE OUTSIDE MICROMETER

The micrometer is a precision measuring instrument, used by engineers. Each revolution of the rachet moves the spindle face 0.5mm towards the anvil face. The object to be measured is placed between the anvil face and the spindle face. The rachet is turned clockwise until the object is 'trapped' between these two surfaces and the rachet makes a 'clicking' noise. This means that the rachet can not be tightened any more and the measurement can be read.

INSIDE MICROMETER

The inside micrometer, as the name implies, is used for measuring inside dimensions, such as pump casing wearing rings, cylinders, bearings, and bushings. Inside micrometers usually come in a set that includes a micrometer head, various length spindles (or extension rods) that are interchangeable, and a spacing collar that is 0.500 inch in length. The spindles (or extension rods) usually graduate in 1-inch increments of range; for example, 1 to 2 inch, 2 to 3 inch (fig.).

The 0.500 spacing piece is used between the spindle and the micrometer head so the range of the micrometer can be extended. A knurled extension handle is usually furnished for obtaining measurements in hard-to-reach locations.



To read the inside micrometer, read the micrometer head exactly as you would an outside micrometer, then add the micrometer reading to the rod length (including spacing collar, when installed) to obtain the total measurement.

When the 1- to 2-inch spindle is used, and the sleeve and thimble scales are set to 0.00 inch, the distance between the face of the anvil and the face of the spindle is exactly 1.00 inch.

THE DEPTH GAUGE MICROMETER

The depth gauge micrometer is a precision measuring instrument, used by engineers to measure depths. Each revolution of the rachet moves the spindle face 0.5mm towards the bottom of the blind hole. The diagram below shows how the depth gauge is used. The ratchet is turned clockwise until the spindle face touches the

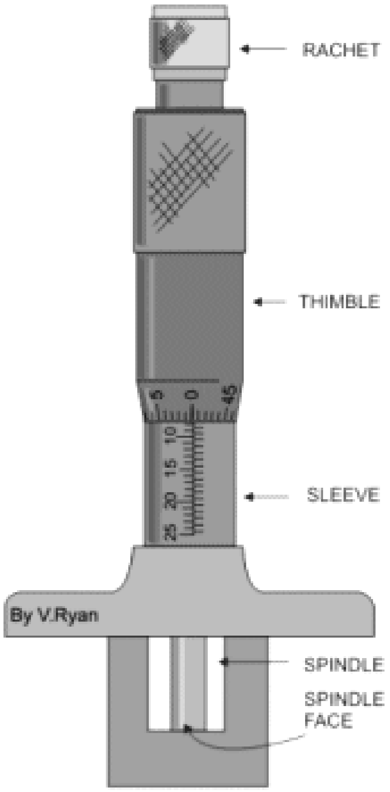


Fig. Depth gauge Micrometer

Bottom of the blind hole the scales are read in exactly the same way as the scales of a normal micrometer (see previous information sheets).

CONCLUSION:-

QUIZ:-

1. State the principal of Vernier instrument and explain briefly construction and use Of Vernier caliper with a neat sketch
2. Enlist different types of micrometers. What precaution should be observed while using the micrometer? Draw the sketch indicating reading of 23.78 mm and 18.36 mm
3. Describe with sketch the construction and working of a micrometer. Explain how Least count is found and reading is taken. What is zero error
4. Explain the following with construction and working in briefly Bore gauge, Telescopic gauge, Slip gauges, Dial indicator
5. Describe in brief the construction and working of SIGMA Mechanical comparator.
6. Explain pneumatic comparator and state the advantages and disadvantages.
7. Calibration of various linear measuring instruments
8. Applications, Advantages of linear measuring instrument
9. Discuss the constructions and working of vernier depth gauge with neat sketch.

Marks **Date:** **Faculty Sign**

PRACTICAL: 03 **Date:-**

AIM: - To measure the dimensions of given work piece using Vernier caliper and micrometer.

CONSTRUCTION:

The vernier caliper consists of two scales:

One is fixed while other is movable. The fixed scale called main scale is calibrated on L-shaped frame and carries a fixed jaw. The movable scale called vernier scale slides over the main scale and carries a movable jaw. In addition, an arrangement is provided to lock the sliding scale on the fixed main scale. For the precise setting of movable jaw, an adjustment screw is provided.

PROCEDURE:

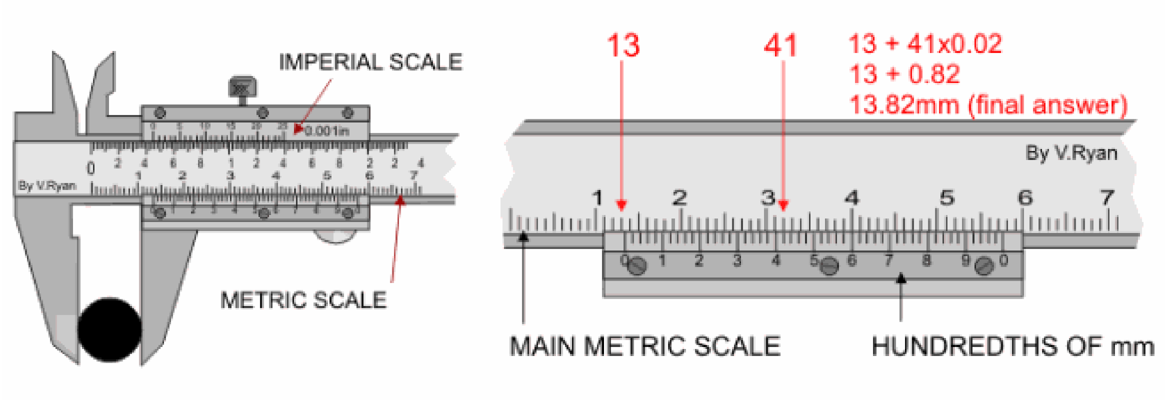
Before using the instrument, it should be checked for zero error. The zero line on vernier scale should coincide with zero on the main scale. Then take the reading in mm on main scale to the left of zero on the main scale.

Now count the number of division on the vernier scale from zero to a line, which exactly coincides, with any line on main scale. From the figure, we can observe that the 41st division exactly coincides the main scale.

The total reading is now = Main scale reading +No. of division that coincides the main scale ***** least count of vernier caliper

The total reading in mm = 13 + 41 * 0.02

= 13.82 mm



PRECAUTIONS:

- First clean vernier caliper by wiping of oil, dust, grit etc.
- Clean the two jaws with clean piece of papers.
- Set the zero reading of the instrument to be the measure between two jaws.
- While measuring dimensions of vernier caliper, it must move carefully.

- Hold the past whose dimension is to measure between two jaws.

OBSERVATION TABLE FOR VERNIER CALIPER :

Sr. No	Measured Part name	Instrument	Actual Measurement			Avg.
			X_1 mm	X_2 mm	X_3 mm	X mm

PROCEDURE OF MEASUREMENT WITH MICROMETER: -

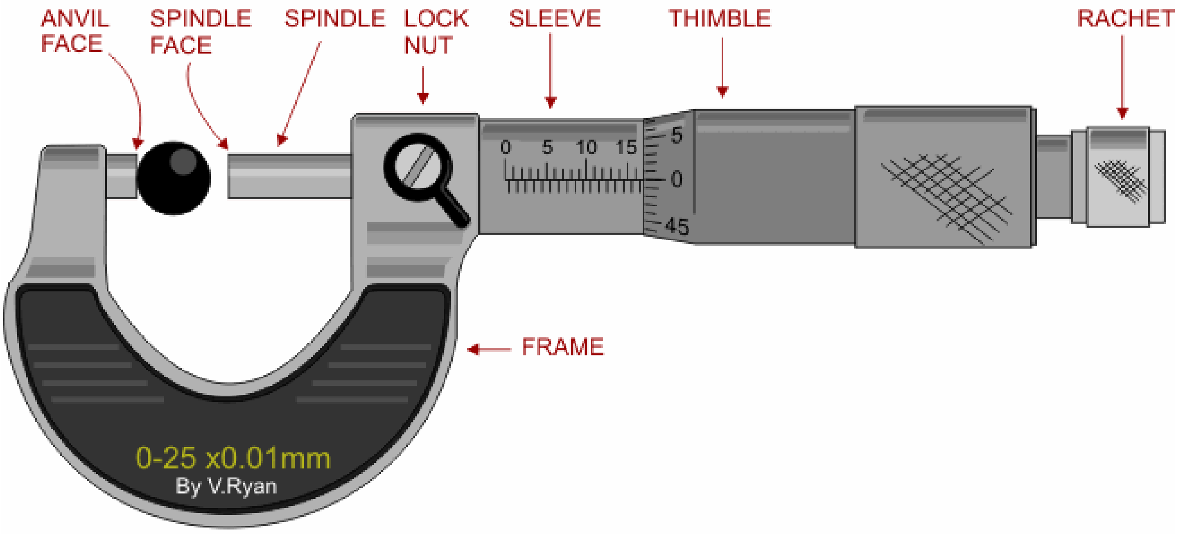
- Before a micrometer used to measure the dimension of a component, It is necessary to set zero.
- After setting the zero, again open the touched anvils and put the job between the anvils & take reading.
- First, of all take the main scale reading & then take vernier scale reading. Now add the reading of vernier scale multiplying with the least count value to main value. This is the accurate & final reading.

PRECAUTION IN USING THE MICROMETER: -

- First, clean the micrometer by wiping of oil, dirt, dust etc.
- Clean measuring face of anvil & spindle with clean piece of paper.
- Set the zero reading of instrument.
- While measuring dimensions of circular parts the micrometer must moved carefully over representative area to note maximum dimension only.

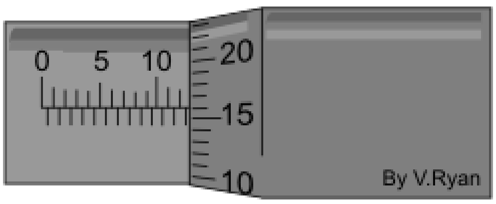
EXAMPLE MEASURE READINGS

Using the first example seen below:



1. Read the scale on the sleeve. The example clearly shows 12 mm divisions.
2. Still reading the scale on the sleeve, a further ½ mm (0.5) measurement can be seen on the bottom half of the scale. The measurement now reads 12.5mm.

3. Finally, the thimble scale shows 16 full divisions (these are hundredths of a mm). The final measurement is 12.5mm + 0.16mm = 12.66



SLEEVE READS FULL mm	=	12.00
SLEEVE READS ½ mm	=	0.50
THIMBLE READS	=	0.16
TOTAL MEASUREMENT	=	12.66mm

OBSERVATION TABLE FOR MICROMETER: -

Sr. No	Measured Part name	Instrument	Characteristic Dimension	Actual Measurement			Avg.
				X_1 mm	X_2 mm	X_3 mm	X mm

CONCLUSION:-

Marks **Date:** **Faculty Sign**

PRACTICAL: 04 **Date :**

AIM: To study about Measurement of given angle of given work piece with the help of combination set and bevel protractor.

a) To measure the angle between two faces of a given component using Bevel protractor.

b) To measure the taper angle of a given component using sine bar.

EQUIPMENT AND ACCESSORIES REQUIRED:

1) Bevel protractor with vernier and actual angle attachment (150/300 mm blades), 2) Sine bar (100 mm size), 3) Surface plate, 4) Slip gauges, 5) Dial gauge (0.01 mm least count), 6) Slotted angle plate, 7) Bolts for locking sine bar to angle plate, 8) Clamps for locking component to sine bar.

THEORY AND DESCRIPTION:

Bevel Protractor:

It is the simplest instrument for measuring angle between two faces of component. It consists of a base plate attached to the main body and an adjustable blade which is attached to a circular plate called turret containing vernier scale. The adjustable blade is capable of rotating freely about the centre of the main scale (graduated around a complete circle from 0° to 90°, 90° to 0° and 0° to 90°, 90° to 0°) engraved on the body of the instrument and can be locked in any position. An acute attachment is provided at the top as shown in fig (1.1) to measure acute angles. The base of the base plate is made flat so that it could be laid flat upon the work and any type of angle measured. It is capable of measuring from 0° to 360°.

The vernier scale has 24 divisions coinciding with 46 main scale divisions (23 on either side) as shown in fig (1.2). The vernier scale is graduated to the right and left of zero up to 60 minutes, each of the 12 graduations representing 5 minutes. Since both the protractor dial and vernier scale have graduations in both directions from zero, any angle can be measured,. If the zero graduation on the vernier scale coincides with a protractor graduation, the number of degrees read between the zeros on the 5 minutes, must be added to the number of degrees read between the zeros on the protractor dial and vernier scale. Magnified view of main scale is shown in fig (1.2a).

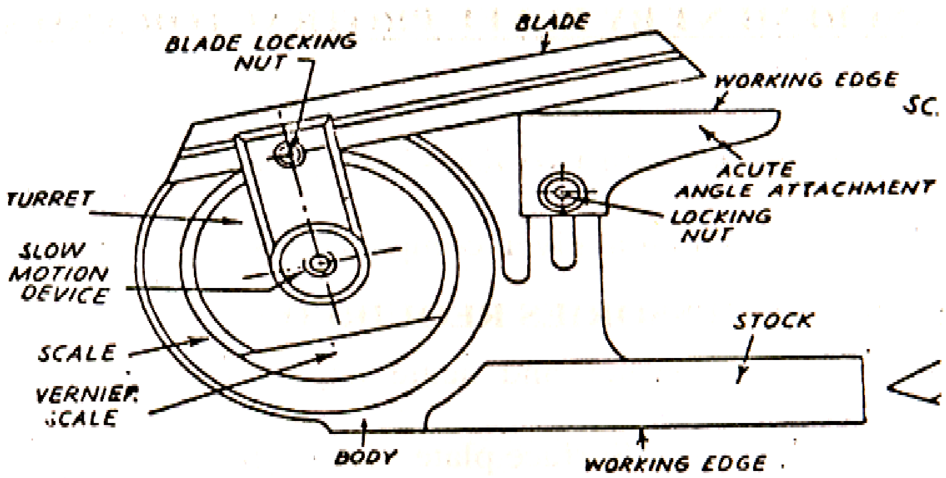


Fig (1.1). Bevel Protractor

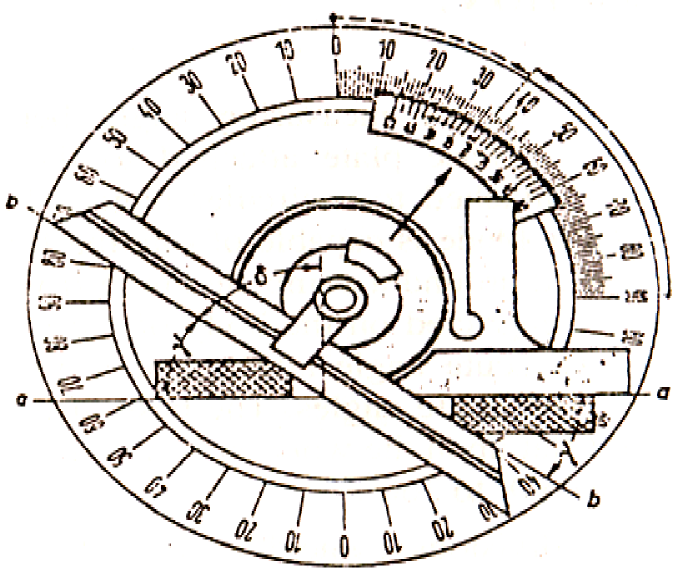


Fig (1.2a). Magnified view of Main Scale

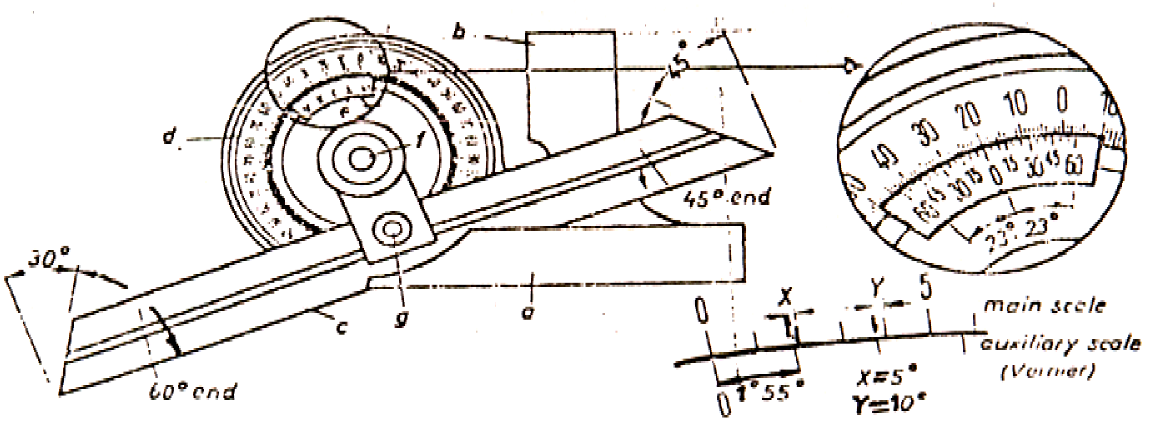


Fig (1.2). Magnified view of Vernier scale

PROCEDURE:

Angle measurement by Bevel protractor:

1) The base plate of the bevel protractor is placed on the top horizontal surface of the component.

2) Blade locking nut is loosened and by rotating the blade about the centre of the main scale, the working edge of the blade is made to coincide with the inclined surface of the component.

3) Blade is locked in that position by tightening the nut.

4) Vernier scale division coinciding with main scale division is noted.

Inclination of the surface with respect to horizontal is calculated as follows:

Angular reading = (Vernier scale division $*$ 5 minutes) + Main scale division in degrees.

QUIZ:

1. Differentiate vernier scale and main scale of a Bevel Protractor.
2. How do you measure the angle of a component using Bevel protractor?
3. What is the distance between the axes of two cylinders in British system and metric system?
4. Discuss the construction and working with application of vernier bevel protector with neat sketch.
5. What is clinometer? Describe how it can be used for measuring and setting of angle and illustrate your answer with neat sketch
6. What are the angle gauges? How they are used? Explain briefly with neat sketch.
7. Explain how angle of a work piece is measure with the help of angle dekkor and angle gauge.
8. Describe with sketch principle, construction and use of Autocollimator
9. Calculate the angle of taper and minimum diameter of internal taper from the following readings. Diameter of bigger ball = 10.25 mm. Diameter of smaller ball = 6.07 mm. Height of bigger ball form datum = 30.13 mm. Height of smaller ball from datum = 10.08 mm.

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PRACTICAL: 05 **Date :**

AIM:- To find unknown angle of a given component using sine bar

Sine Principle and Sine bar:

The Sine principle uses the ratio of two sides of a right angle triangle in deriving a given angle. The measurement is usually limited to 45° from loss of accuracy point of view. The accuracy with which the sine principle can be put to use is dependent in practice, on some form of linear measurement. The sine bar in itself is not a complete measuring instrument. Another datum such as surface plate is needed, as well as other auxiliary equipment, notably slip gauges, and indicating device to make measurements. Sine bars used in conjunction with slip gauges constitute a very good device for the precise measurement of angles. Sine bars are used either to measure angles very accurately or for locating any work to a given angle within very close limits.

Sine bars are made from high carbon, high chromium, corrosion resistance steel, hardened, ground and stabilized. Two cylinders of equal diameter are attached at the ends.

The axes of these two cylinders are mutually parallel to each other and also parallel to and at equal distance from the upper surface of the sine bar. The distance between the axes of the two cylinders is exactly 5 inches or 10 inches in British System and 100, 200 and 300 mm in metric system.

The various parts are hardened and stabilized before grinding and lapping. All the working surfaces and the cylindrical surfaces of the rollers are finished to surface finish of 0.2 μm Ra value or better. Depending upon the accuracy of the centre distance, sine bars are graded as of A grade or B grade of sine bars are guaranteed accurate up to 0.01 mm/m of length. There are several forms of sine bars, but the one shown in fig (1.3) is not commonly used. Some holes are drilled in the body of the bar to reduce the weight and to facilitate handling.

The accuracy of sine bar depends on its constructional features:

1) The two rollers must have equal diameter and true cylinders.

2) The rollers must be set parallel to each other and to the upper face.

3) The precise centre distance between the rollers must be known.

4) The upper face must have a high degree of flatness.

USE OF SINE BAR:

a) Measuring known angles or locating any work to a given angle:

For this purpose the surface plate is assumed to be having a perfectly flat surface so that its surface could be treated as horizontal.

One of the cylinders or rollers of sine bar is placed on the surface plat and other roller is placed on the slip gauges of height 'h' as shown in fig (1.4). Let the sine bar be set at angle θ. Then $\sin\theta = h/L$.

Where, L = Distance between the centre of rollers.

Thus knowing θ, h can be found out and any work could be set at this angle as the top face of sine bar is inclined at angle θ to the surface plat.

The use of angle plates and clamps could also be made in case of heavy components for better results; both the rollers could also be placed on slip gauges of height h_1 and h_2 respectively. Then $\text{Sine}\theta = (h_2 - h_1)/L$

b) Checking of unknown angles:

Many a times, angle of components to be checked is unknown. In such a case, it is necessary to first find the angle approximately with the help of a bevel protractor. Let the angle be θ.

Then the sine bar is set at an angle θ and clamped to an angle plate. Next, the work is placed on sine bar and clamped to an angle plate as shown in fig (1.5) and dial indicator is set at one end of the work and moved to the other, and deviation is noted. Again slip gauges are so adjusted that dial indicator reads zero across work surface.

If deviation noted by the dial indicator is δh over a length of L of work, then height of slip gauges by which is should be adjusted is equal to $\delta h * L/L^1$

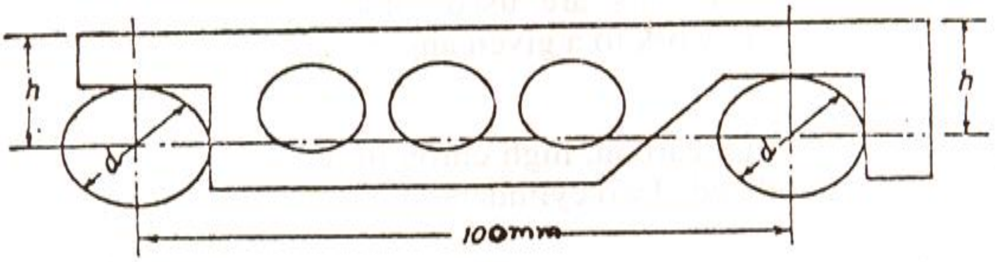


Fig (1.3). Sine bar

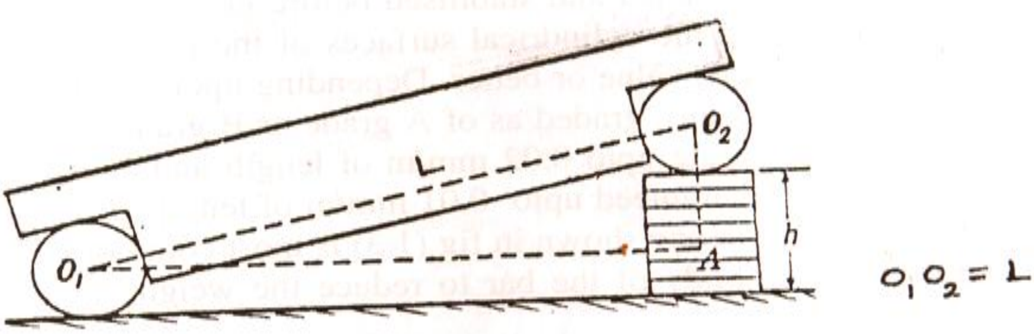
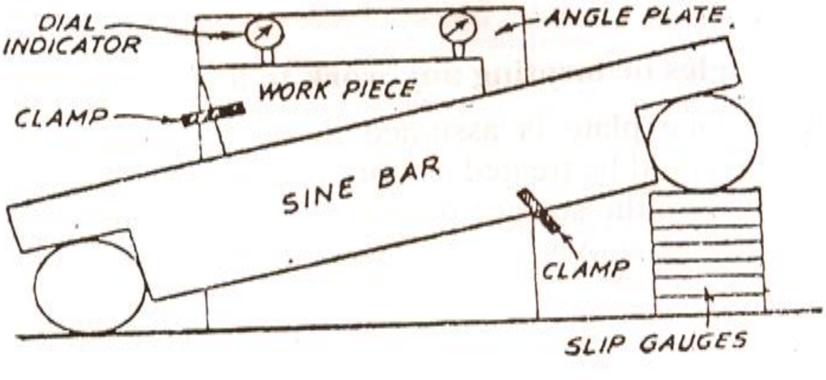


Fig (1.4). Use of Sine bar, $\sin\theta = \frac{h}{L}$



PROCEDURE:

Angular measurement by sine bar:

1) The sine bar is made to rest on surface plate with rollers contacting the datum (Surface plat)

2) Place the component on sine bar and lock it in position.

3) Lift one end (roller) of the sine bar and place a pack of slip gauges, underneath the roller. The height of the slip gauges (h) should be selected such that the top surface of component is parallel to the datum plate (Surface plat). The parallelism can be assessed by making the stylus of a dial indicator mounted on a dial gauges stand in contact with the upper surface of component and sliding the stylus along the component surface. If both the surfaces are perfectly parallel, the pointer on the dial gauges shows the same reading throughout the travel of the dial gauge stylus. If the surfaces are not parallel then the height of slip gauge back (h) can be altered and procedure for checking parallelism can be repeated.

Record the final height of slip gauge pack used for achieving parallelism

Calculate inclination $\theta = \text{Sine}^{-1}(h/L)$

PRECAUTIOS:

1) The sine bar should not be used for angle greater than 60° because any possible error in construction is accentuated at this limit.

2) Accuracy of sine bar should be ensured.

3) As far as possible longer sine bar should be used since many errors are reduced by using longer sine bar

.

Sr. No	**Measured Part name**	**Instrument**	**Actual Measurement**			**Avg.**
			θ_1	θ_2	θ_3	$\theta_{Average}$

Conclusion:-

QUIZ:

1) What is sine principle?

2) How do you measure the angle of a component using sine bar?

3) Why is a sine bar longer length preferable to the one of a shorter length?

4) What are the constructional features on which accuracy of sine bar depends?

5) Why are rollers preferred to support the sine bar?

6) Which material is used for sine bar?

7) Describe with sketch with application and limitations: Sine Center

Marks **Date:** **Faculty Sign**

PRACTICAL: - 06 **Date :**

AIM:-To study about pressure measuring devices

6.1 Pressure and its units of measurement
Pressure and temperature are among the most important physical variables. Pressure is defined as a force acting evenly over a given area. This force can be exerted by liquids, by gases or vapors, or by solid bodies. Surface compression takes place at the interface between two solid bodies, but for our purposes we can consider this additional force negligible.
The basic unit of force in the U.S. is the Poundforce (lbf) which is the force exerted by one pound of mass. If we take one square inch (in2) as the basic unit of area, then we can define pressure as: Pressure = lbs. per sq. inch (PSI)
Pressure can also be expressed in terms of metric (SI) units. The basic metric unit of force is the Newton (N) and the basic unit of pressure is the Pascal (Pa).

6.2 Types of pressure

The different types of pressure differ only with respect to their reference point.

6.2.1 **Absolute pressure**

The most definite reference point is absolute zero pressure. This is the pressure of empty space in the universe. When a pressure is based on this reference point, it is called absolute pressure. To distinguish it from other types of pressures it is accompanied by the suffix "a" or "abs" (from the Latin: absolutes = independent, separate from).

6.2.2 **Atmospheric pressure**

The most important pressure for life on earth is atmospheric air pressure p_{amb} ,It is produced by the weight of the atmosphere surrounding the earth up to an altitude of about 300 miles. Atmospheric pressure decreases continuously up to this altitude until it practically equals zero (full vacuum). Atmospheric air pressure undergoes climatic changes, as shown by the daily weather report. At sea level, p_{amb} has an average value of 29.90 inches of Mercury ("Hg). In high or low pressure weather zones it can fluctuate by as much as ± 5%.

6.2.3 **Differential pressure**

The difference between two pressures P1 and P2 is referred to as the pressure differenential $\Delta P = P1 - P2$. The difference between two independent pressures is called the differential pressure.

1.2.4 **Gauge Pressure and Vacuum**

The most common measurement of pressure is gauge pressure (Pg) which is the pressure difference between the measured pressure and ambient pressure. $pg = p_{meas.} - p_{amb}$
The term pressure is used if the measured pressure is higher than the atmospheric pressure. The term vacuum is used if the measured pressure is below atmospheric pressure. The use

of either of these terms automatically implies that the pressure being measured is with respect to ambient pressure (i.e. gauge pressure or vacuum). In order to distinguish absolute pressure measurements, the words "absolute pressure" must be used

6.3 Pressure measuring instruments using a liquid column (Liquid column manometers)

The measuring principle of a gauge using a liquid column, commonly referred to as a liquid column manometer, consists of comparing the pressure **p** being measured with the height **h** of a liquid column using the law $\Delta p = \Delta h \cdot \rho m \cdot g$.
The height of the liquid column h is read from a graduated scale. If higher precision is needed or if the measurement signal is to be processed further, the height difference is measured by a resistance wire inserted into the liquid or by the reflection of sound or light waves

6.3.1 Types of Manometer

1. U-tube manometer
2. inclined-tube manometer
3. multiple liquid manometer
4. Float-type manometer

6.3.1.1 U-tube manometer

Liquid column manometers come in various configurations to meet specific requirements. The basic types are described below. The simplest liquid column manometer is the U-tube manometer.

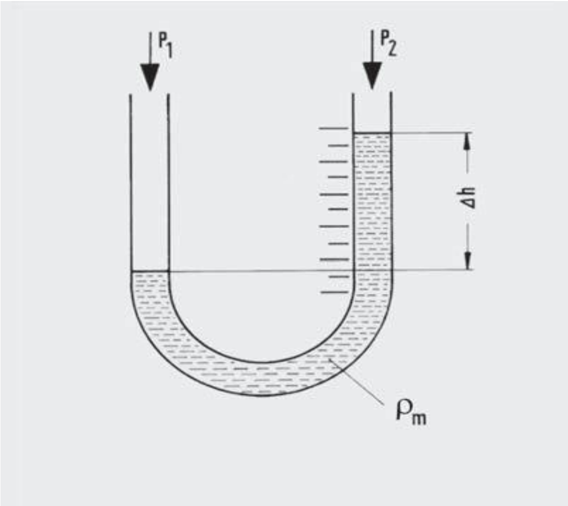
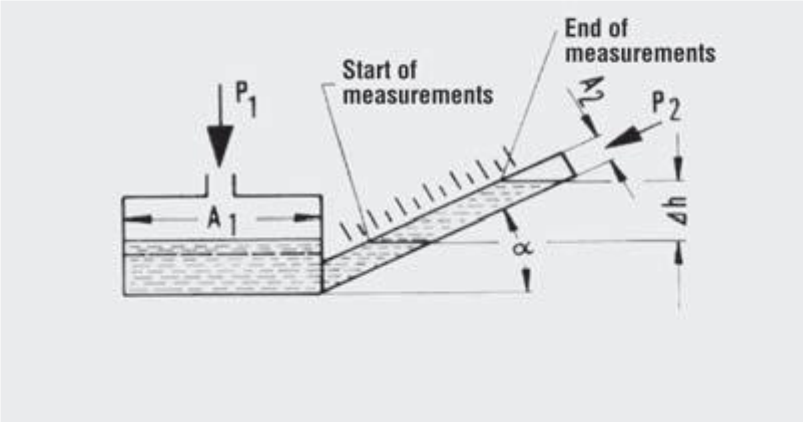


FIG: - U-Tube Manometer

When the pressures p1 and p2 are equal, the height difference Δh - and therefore Δp - is zero. With the same internal diameter, surface consistency and material, the capillary elevation has no effect...

6.3.1.2 Inclined tube manometer

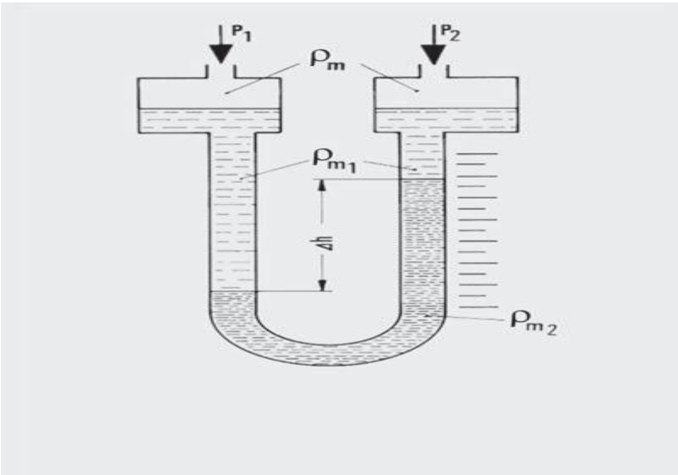
The inclined-tube manometer is used to measure very low pressures of up to about 4 "H2O. The sloping design of the tube stretches the graduation by an amount proportional to the angle of inclination α. For this reason, the angle of inclination of many inclined tube manometers can be adjusted. With unequal areas A1 and A2, the graduation will need to be corrected accordingly due to the changing level of liquid at A1. For high precision, the measurement must be made very carefully. Generally these instruments are equipped with a bubble leveler for precise horizontal adjustment.



[FIG: - INCLINED TUBE MANOMETER]

6.3.1.3 Multiple liquid manometers

A multiple liquid manometer allows magnification of the measuring range by a factor of 8 to 10 because the measurement is based solely on the difference of the two densities.

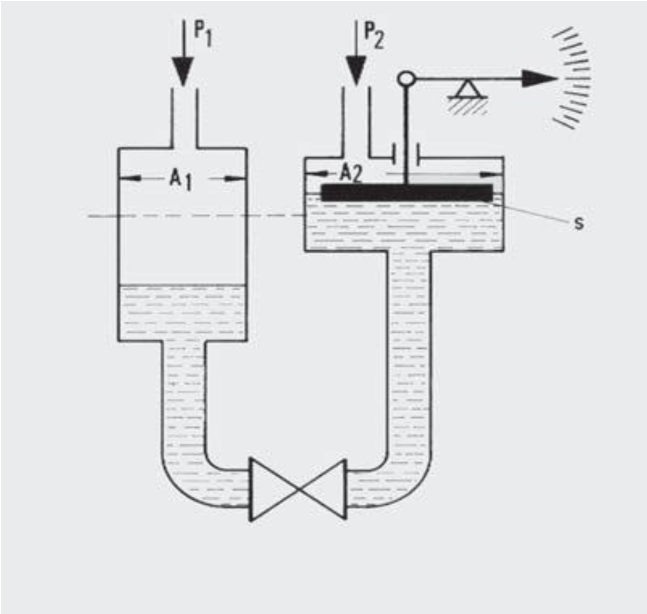


[**FIG: MULTIPLE LIQUID MANOMETERS]**

With multiple liquid manometers it is important that the separating liquids not mix with each other nor with the process fluid. If the process fluid density ρm and the separating liquid density ρm1 differ, the change of height of the upper liquid level must be taken into account. This is particularly important for the measurement of gas pressures.

6.3.1.4 Float-type manometer

The float-type manometer tries to combine the advantages of easy reading on a graduated scale with the advantages of a liquid column.



[**FIG :- Float-type manometer]**

A float **S** follows the height of the liquid column and relays this height to the outside. This design allows the instrument to be made of metal for operating pressures from 10"H2O to 6000PSI. The measuring range can be changed by reversing the ratio A1 : A2. The main problem with this type of instrument is that the friction occurring from the pressure-tight transmission of the measurement results adds error to the reading. Additional equipment can be added to the float-type manometer that determines the position of the float from the outside (i.e. ultrasonic’s) which then transmits the results to the graduated scale. However, even this additional equipment is not enough to maintain this instrument's former popularity

Conclusion :

Quiz:-

1. What are the Elements of Generalized measurement systems? Identify various elements of pressure actuated thermometer
2. Explain with sketch construction and working of Piezo meter & U-Tube Manometer stating application.
3. Describe with sketch construction and working of Dead Weight Pressure Gauge Tester. State sources of error and their remedies.
4. State advantages and limitations of manometers & state the ideal characteristics of manomatric liquid
5. Describe method of calibrating Bourdon tube pressure gauge and also describe the sources of errors in the method of calibration.
6. Explain the calibration of pressure measuring instrument briefly.
7. Classify the instrument for pressure measurement. Explain bourdon tube pressure gauge.
8. Explain briefly the following two gauges. Bourdon tube pressure gauge and diaphragm pressure gauge
9. In a pipeline water is flowing. A manometer is used to measure the pressure drop for flow through the pipe. The difference in level was found to be 20cm. If the manometric fluid in CCl4 find the pressure drop in S.I. units (density of CCl4 = 1.596 g/cm3). If the manometric fluid is changed to mercury (ρ = 13.6 gm/ cm3) what will be the difference in level ?
10.) A McLeod gauge has volume of bulb of measuring capillary equal to 110 x 10_6 m3 and measuring capillary diameter of 1.1 mm. Calculate
    (i) The pressure indicated when the reading of the measuring capillary is 28 mm in case approximate formula is used. (ii) What is the error if exact formula is used for pressure measurement?

Marks **Date:** **Faculty Sign**

PRACTICAL: - 07 **Date :**

AIM:- To measure the tooth thickness of a given spur gear using gear tooth Vernier caliper.

Sr. No	Measured Part name	Instrument	Actual Measurement			Avg.
			X_1 mm	X_2 mm	X_3 mm	X mm

Quiz:-

1. Calculate the chord length and its distance below the tooth tip for a gear ofmodule4 and 20 degree pressure angle.
2. List the various elements to be checked for the accuracy of gear and describe any two.
3. Describe with sketch the construction and use of Gear Tooth Vernier Caliper. How is the gear tooth thickness at PCD measured?

Marks **Date:** **Faculty Sign**

PRACTICAL: - 08 **Date :**

AIM: - To study about measurement of straightness, flatness, squareness and parallelism.

Quiz:-

1. Explain Surface Texture and Elements of Surface Roughness.
2. Discuss the measurement of straightness,flatness,squareness and parallelism with neat sketch.

Marks **Date:** **Faculty Sign**

PRACTICAL: - 09

AIM: - To study about measurement of surface finish

TITLE: - Surface Roughness Measurement

AIM:

(1) To measure the surface roughness of the given specimens using roughness tester

(3) To show the variation of surface roughness as a function of cutting conditions i.e., speed, feed, depth of cut and tool geometry etc.

MEASURING INSTRUMENTS AND MATERIAL RIQURIED:

a) Surface roughness tester (SJ- 201)

b) Precision roughness specimen, Test specimens, Calibration stage

c) Height gauge, Adapter for the height gauge, support

d) Nose Pieces, Digimatic data processor (DP-1 HS)

TERMINOLOGY AS PER INDIAN STANDARD

Surface roughness: It concerns all those irregularities which form surface relief and which are conventionally defined within the area where deviations of form and waviness are eliminated.

PRIMARY TEXTURE (ROUGHNESS):

It is caused due to the irregularities in the surface roughness which results from the inherent action of the production process. These are deemed to include transverse feed marks and the irregularities within them.

SECONDARY TEXTURE (WAVINESS)

It results from factors such as machine or work deflections, vibrations, chatter, heat treatment or warping strains, waviness is the component of surface roughness upon which roughness is superimposed.

CENTRE LINE: The line about which rough is measured.

LAY: it is the direction of the "predominant surface pattern: ordinarily determined by the method of production used.

TRAVERSING LENGTH: It is the length of the profile necessary for the evaluation of the surface roughness parameters.

SAMPLING LENGTH (I): Is the length of profile necessary for the evaluation of irregularities to be taken into account. This is also known as the cut –off length as regard to the measuring instruments. It is measured in a direction parallel to the general direction of profile.

THEORY:

Surface texture is deemed to include all those irregularities which, recurring many times across the surface, tend to form on it a pattern or texture. The irregularities in the surface texture which result from the inherent action of the production process is called roughness or primary texture. That component of surface texture upon which roughness is super imposed is called waviness or secondary texture. This may result from such factors as machine or work deflections, vibrations, chatter, heat treatment or warping strains. The direction of the predominant surface pattern, ordinarily determined by the production method used is called lay. The parameters of the surface are conveniently defined with respect to a straight reference line. The most widely used parameter is the arithmetic average departure of the

Filtered profile from the mean line. This is known as the CLA (Centre – Line – Average) or Ra (roughness average)

ARITHMETIC MEAN DEVIATION OF THE PROFILE, RA

R_a is the arithmetic mean of the absolute values of the profile deviations (Y_i) from the mean line.

$$R_a = 1/N \sum_{I=1}^{N} |Y_i|$$

ROOT –MEAN- SQUARE DEVIATION OF THE PROFILE, R_Q :

R_q is the square root of the arithmetic mean of the squares of profile deviations (Y_i) from the mean line.

$$\sqrt{\;} \; 1/N \sum_{I=1}^{N} Y_i^2$$

MAXIMUM HEIGHT OF THE PROFILE, RY:

R_y is the sum of height Y_p of the highest peak from the mean line and depth Y_v of the deepest valley from the mean line.

$$R_y = Yp + Y_v$$

OUTLINE OF SURF TEST SJ- 201

The surf test -201 is a shop-floor type surface roughness measuring instrument, which traces the surfaces of various machines parts, calculates their surface roughness based on roughness standards, and displays the results.

SURF TEST SJ-201 SURFACE ROUGHNESS MEASUREMENT PRINCIPLE:

A pick-up which is usually called as the "Stylus" attached to the detector unit of the surf test SJ- 201 will trace the minute irregularities of the work piece surface. The vertical stylus displacement during the trace is processed and digitally displayed on the liquid crystal display of the surf test SJ- 201. The measurement principle of surf test SJ- 201 is show in fig. The instrument consists of the display unit and drive/detector unit is designed to be removable from the display unit. Depending on the shape of the work piece, it may be easier to perform measurement without mounting the drive/detector unit to the display unit. Name of each part on the display unit is shown in fig. The detector in turn can be detached from the drive unit. Each time a measurement task has been completed with the surf test SJ-201, it is recommended that the detector be detached from the drive unit and stored in a safe place.

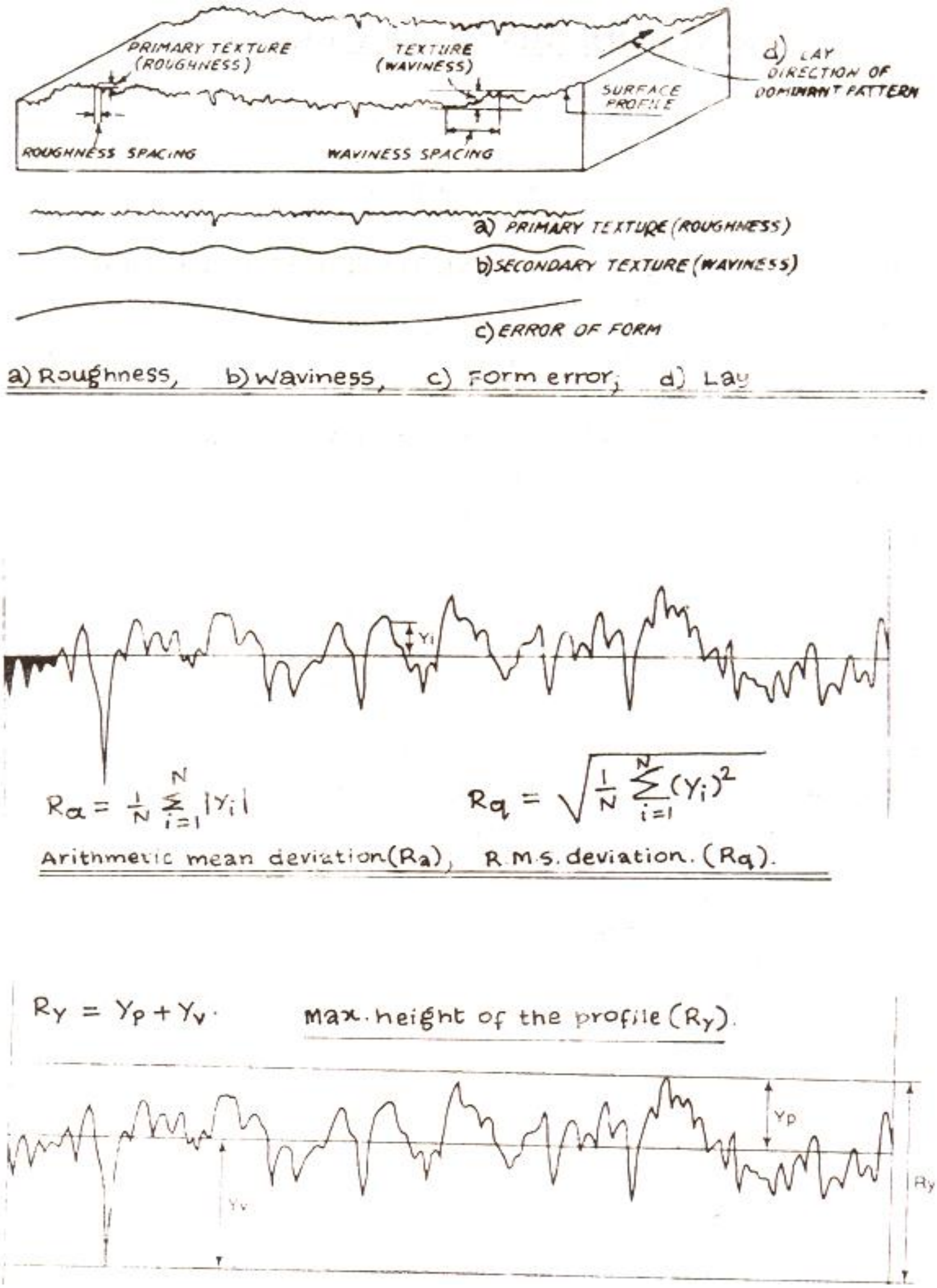


Fig. Terminology as per Indian Standard

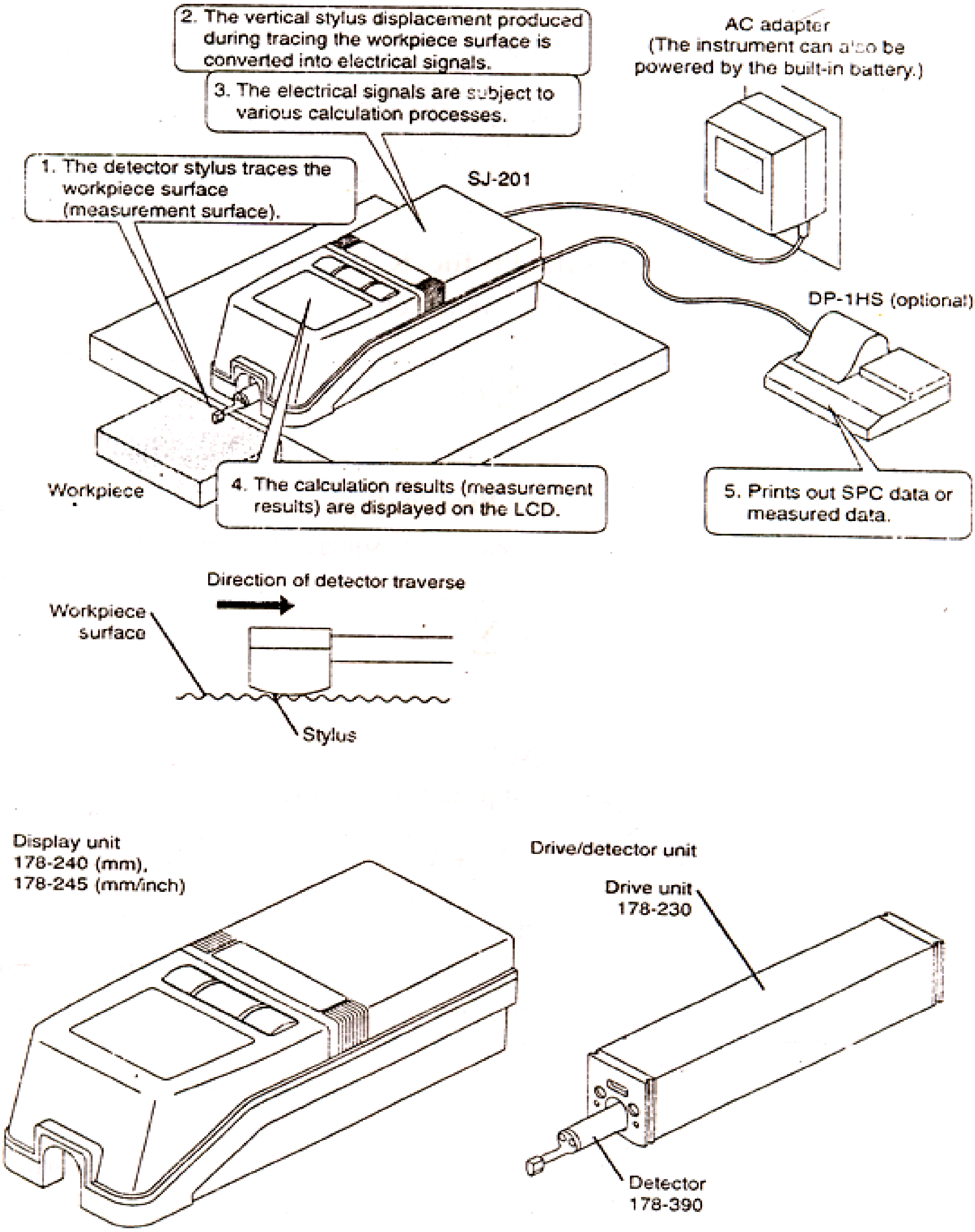


Fig. Measurement Principle of Surftest SJ-201

LIST OF SURF TEST SJ-201 OPERATION MODE:

The surf test SJ-201 has various operation modes including the measurement mode, calibration mode, condition setting mode, RS-232C communication mode, and detector retraction mode.

MEASUREMENT MODE:

Starts and stops measurement, calculates and selects measurements parameters to be displayed, and performs SPC output.

CALIBRATION MODE:

Sets the calibration value prior to measurement and performs calibration measurement.

CONDITION SETTING MODE:

Sets and modifies measurement conditions. This mode has 11 sub-modes as shown in chart.

RS – 232C COMMUNICATION MODE:

Used for communication with a personal computer.

DETECTOR RETRACTION MODE:

Retracts the detector as required.

Relationship between the operation modes and available keys is shown in Table.

MEASUREMENT OF SURFACE ROUGHNESS:

Surface roughness measurement with the surf test SJ-201 includes

i) Mounting/ dismounting the drive unit/ detector, and cable connection, etc. according to the feature of the work piece to be measured.

ii) Selection of power supply i.e., either the AC adaptor or built-in battery.

iii) Modifying the measurement conditions as necessary.

iv) Calibrating surf test SJ-201 to adjust the detector gain for correct measurements.

v) Measuring the roughness specimen and display the result.

vi)Outputting the measurement data or perform communication with a personal computer via the RS- 232C interface.

PROCEDURE:

MODIFYING MEASUREMENT CONDITIONS:

Table shows the measurement conditions that can be modified by the user. If they are not modified, then measurement will be performed according to the default values, measurement conditions are modified according to the surface roughness parameters, the amplitude of roughness, the conditions of the objective area of measurement, etc.

The surf test SJ-201 can obtain each roughness parameter based on the new JIS, old JIS, DIN ISO and ANSI standards. Evaluation according to any one of the standards may be obtained from Reference information (User's manual)

CALIBRATION OF MEASURING INSTRUMENT:

The process of calibration involves the measurement of a reference work piece (precision roughness specimen) and he adjustment of the difference (gain adjustment), if there is any between the measured value and the reference value(precision roughness specimen). With out properly calibrating the instrument, correct measurements cannot be obtained. Calibration of surf test SJ- 201 with the supplied precision roughness specimen must be performed with the default values mentioned in table.

i) Precision roughness specimen and calibration stage are placed on a level table.

ii) Surf Test SJ-201 is mounted on the calibration stage.

iii) Surf Test SJ-201 is set so that the detector traversing direction is perpendicular to the cutter mark of the precision roughness specimen. It should be confirmed that the detector is parallel to the measured surface as shown in fig.

iv) If [CAL/STD/RANGE] key is pressed in the measurement mode, the calibration mode is entered and current calibration value is displayed. In this stage the calibration value can be modified, if the displayed value is different from that marked on the precision roughness specimen.

v) [n/Ent] key is pressed after confirming the displayed value, so that the entered calibration value is set.

vi) [START/STOP] key is pressed to begin the calibration measurement. The symbol "— "is displayed while the detector is traversing and the measured value will be displayed when the measurement has been completed.

vii) [n/Ent] key is pressed so that the calibration factor is updated, completing the entire calibration operation.

viii) [MODE/ESC] is pressed. This restores the measurement mode and retains the calibration factor obtained in the previous operation.

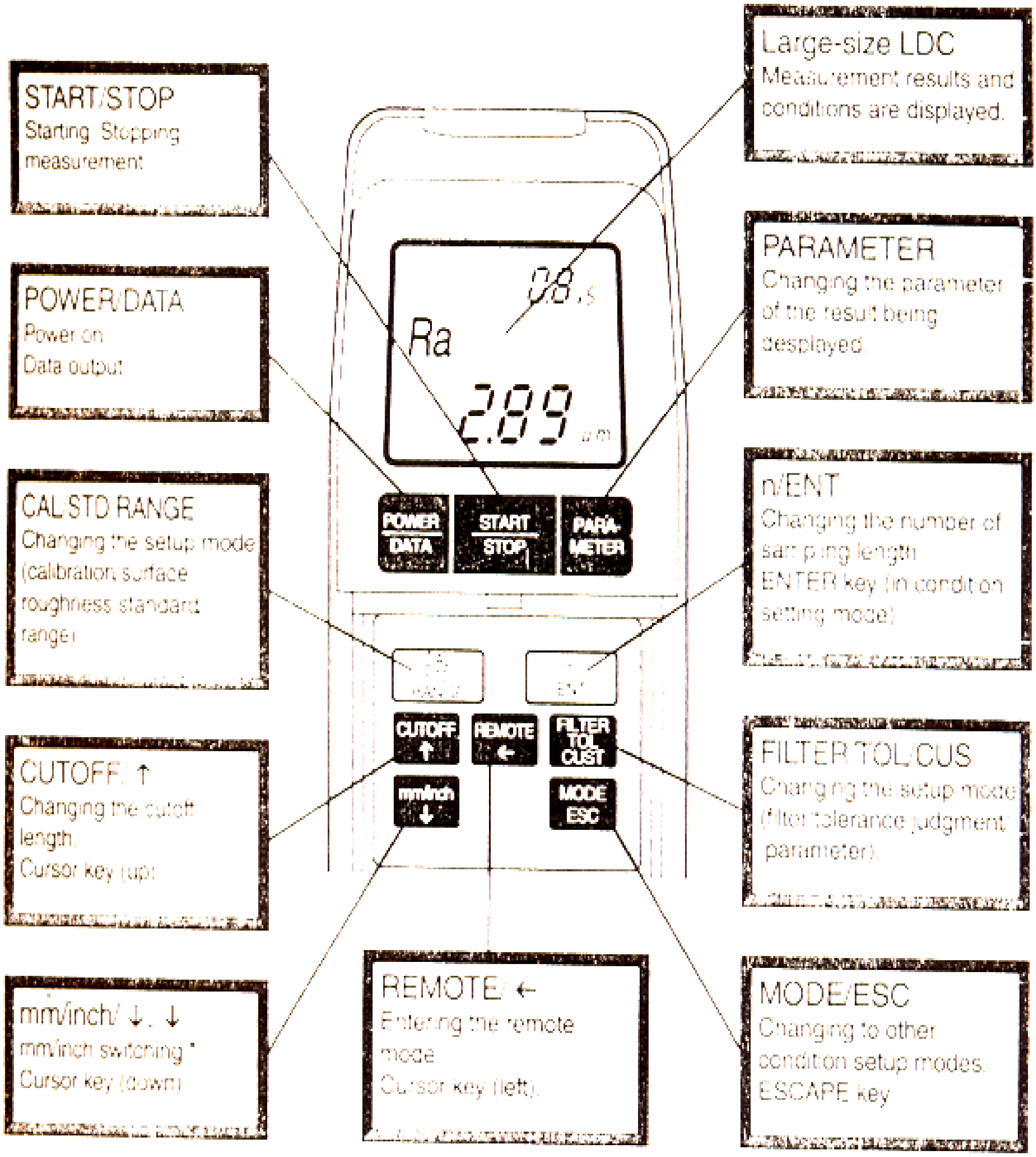


Fig. Name of each part on the display Unit

ACTUAL MEASUREMENT OF ROUGHNESS SPECIMEN:

Surf Test SJ-201 is placed on the work piece, if the work piece surface is large enough. For measurement to be successful, it should be performed on a firm base that is insulated as well as possible from all sources of vibration. If measurement is performed being subject to significant vibrations, results, may be un reliable.

i) Work piece is poisoned so that the measured surface is level.

ii) Surf Test SJ-201 is placed on the work piece, In this operation SJ-201 is supported by to reference surfaces at the bottom of driving unit. It must be confirmed that the stylus is in proper contact with the measured surface and the detector is parallel to the measured surface.

iii) [START/STOP] key is pressed in the measurement mode, the detector starts traversing to perform measurement.

iv) After the measurement has been completed, the measured value is displayed on the LCD.

v) [PARAMETER] key is pressed until the desired parameter value is displayed on the LCD.

OUTPUTTING MEASUREMENT RESULT:

(1) The Surf Test SJ-201 is connected to a Digimatic data processor (DP-1HS) to output the measurement results (including the unit of measurement) as SPC data.

(2) DP-1HS is turn to ‘ON’ position.

(3) [PARAMETER] key is pressed until the objective parameter for output is displayed.

(4) POWER/DATA] key is pressed so that the measurement result will be outputted from the Surf Test SJ-201 to the DP-1HS.

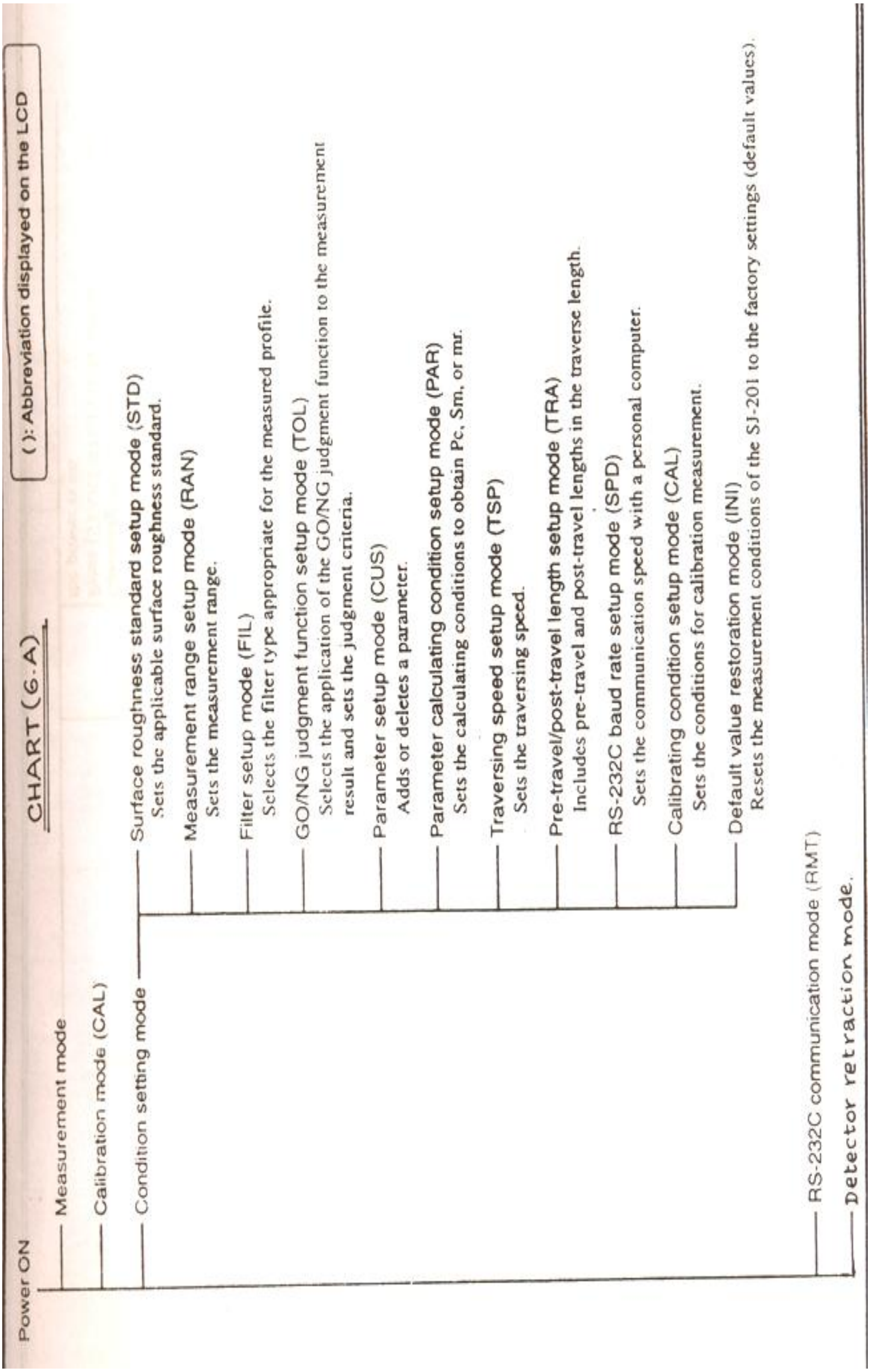


CHART (6.A)
( ): Abbreviation displayed on the LCD
Power ON
Measurement mode
Calibration mode (CAL)
Condition setting mode
Surface roughness standard setup mode (STD)
Sets the applicable surface roughness standard.
Measurement range setup mode (RAN)
Sets the measurement range.
Filter setup mode (FIL)
Selects the filter type appropriate for the measured profile.
GO/NG judgment function setup mode (TOL)
Selects the application of the GO/NG judgment function to the measurement result and sets the judgment criteria.
Parameter setup mode (CUS)
Adds or deletes a parameter.
Parameter calculating condition setup mode (PAR)
Sets the calculating conditions to obtain Pc, Sm, or mr.
Traversing speed setup mode (TSP)
Sets the traversing speed.
Pre-travel/post-travel length setup mode (TRA)
Includes pre-travel and post-travel lengths in the traverse length.
RS-232C baud rate setup mode (SPD)
Sets the communication speed with a personal computer.
Calibrating condition setup mode (CAL)
Sets the conditions for calibration measurement.
Default value restoration mode (INI)
Resets the measurement conditions of the SJ-201 to the factory settings (default values).
RS-232C communication mode (RMT)
Detector retraction mode.

OUTLINE OF THE SJ-201 FUNCTIONS AND KEY OPERATIONS

■ Relationship between the operation modes and available keys

TABLE(6.B)

Operation mode	Symbol (on LCD)	Key for mode switching
Calibration mode	CAL	[CAL/STD/RANGE]
Surface roughness standard setup mode	STD	[CAL/STD/RANGE]
Measurement range setup mode	RAN	[CAL/STD/RANGE]
Filter setup mode	FIL	[FILTER/TOL/CUST]
GO/NG judgment function setup mode	TOL	[FILTER/TOL/CUST]
Parameter setup mode	CUS	[FILTER/TOL/CUST]
Parameter calculating condition setup mode	PAR	[MODE/ESC]
Traversing speed setup mode	TSP	[MODE/ESC]
Pre-travel/post-travel length setup mode	TRA	[MODE/ESC]
RS-232C baud rate setup mode	SPD	[MODE/ESC]
Calibrating condition setup mode	CAL	[MODE/ESC]
Default value restoration mode	INI	Press [POWER/DATA] while simultaneously holding down [PARAMETER] and [START/STOP] during auto sleep.
RS-232C communication mode	RMT	Press [POWER/DATA] while holding down [REMOTE ←] during auto sleep.
Detector retraction mode	OFF ON	Retraction: Press [POWER/DATA] while holding down [START/STOP] during auto sleep. Canceling retraction: Press [START/STOP] if the detector is retracted and the power is on.

Table (6.C)

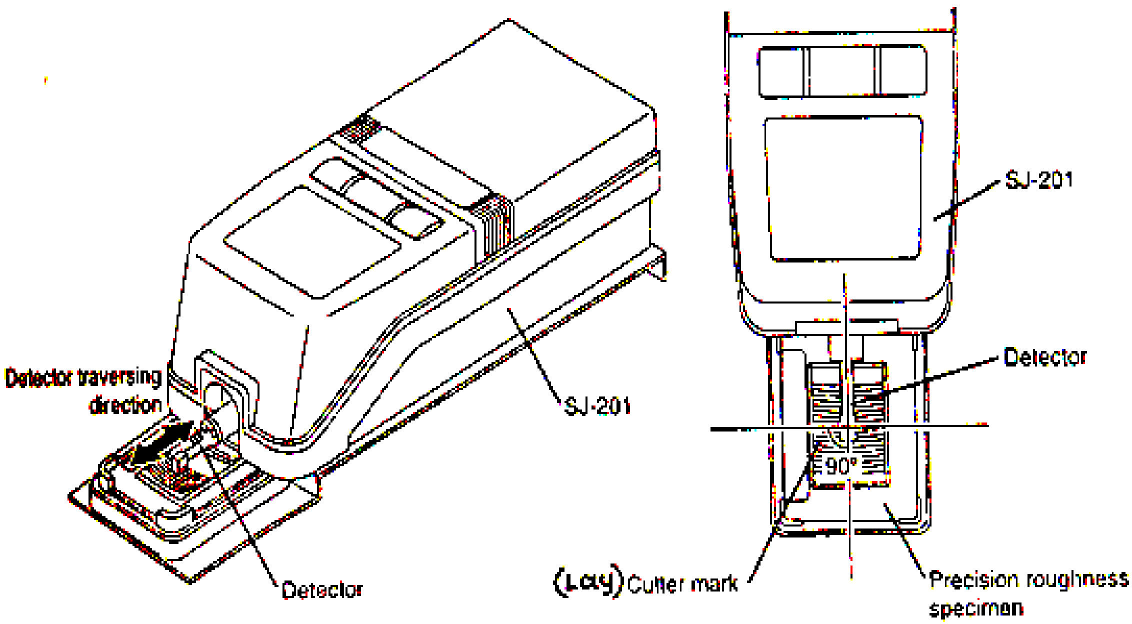
Measurement condition	Default value	Remark
Cutoff length (sampling length)	0.8 mm (.03 in)	
Number of sampling lengths	x 5	
Arbitrary evaluating length	None	If measurement is not performed with the cutoff length and the number of sampling lengths provided by the SJ-201, set an arbitrary length for traversing.
Surface roughness standard	*1	Set to the desired standard.
Measurement range	Auto	
Filter applied for measured profile	R-profile Pc50	
Application of GO/NG judgment and the range	None	Set the upper or lower roughness limit to discriminate between measured workpieces to be accepted or rejected.
Surface roughness parameter	Only Ra, Ry, Rz, Rq	Parameters to be yielded can be set on/off.
Traversing speed	0.5 mm/s (.02 in/s)	Default traversing speed can be modified.
To include pre-travel/post-travel length in the traversing length	ON	Since the existing surface roughness standards require the pre-travel/post-travel length to be included in the traversing length, the setting is usually set to "ON". However, if these lengths can not be traced due to the limited space, the setting can be changed to "OFF".
Calibration value	3.00 µm (118 µin)	Can be set according to the value of the precision reference specimen.
Unit of measurement	*2	Depending on the model/destination.
Baud rate	9600 bps	Set as required to communicate with the personal computer. Select either 9600 bps or 19200 bps.

*1, *2 :

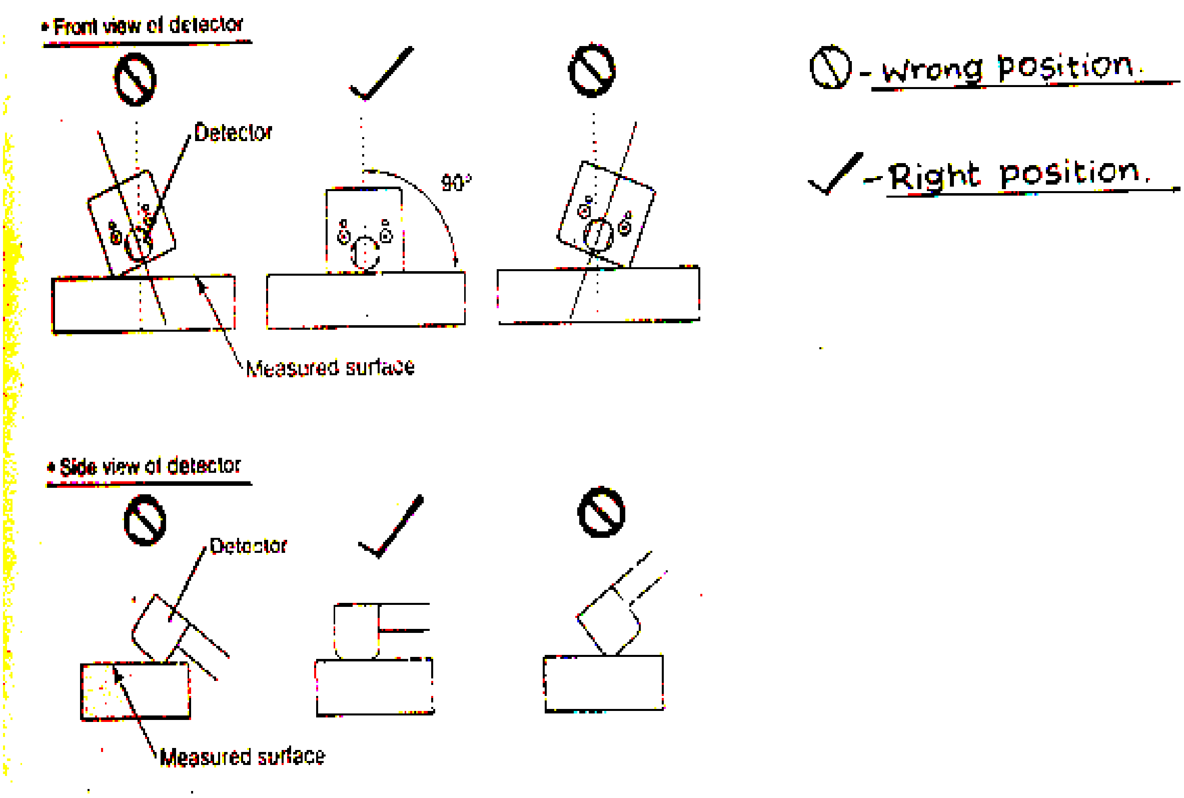
Measurement condition	Set No.						
	178-950K	178-950A	178-950D	178-950E	178-951	178-951A	178-951D
*1 Surface roughness standard	New JIS	ANSI	DIN	ISO	New JIS	ANSI	DIN
*2 Unit of measurement	mm	mm	mm	mm	inch	inch	inch

Table (6.D)

Calibrating condition setup item	Default value
Parameter	Ra
Cutoff length	2.5mm (.1")
Number of sampling lengths	5
Measurement range	Auto
Measured profile/filter	R-profile/Pc50(depends)
Pre-travel/post-travel length	ON



Fig(6.4). Detector traversing direction Perpendicular to Lay



PRECAUTIONS:

i) Never touch the stylus, otherwise it may be damaged.
ii) Do not hold the detector when detaching the drive/ detector unit. Otherwise, the detector may be damaged.
iii) Confirm that the detector is parallel to the measured surface.
iv) Confirm that the stylus is in proper contact with the measured surface.
v) Calibration of SJ-201 with the precision roughness specimen must be performed with the default values that have been used for calibrating the roughness specimen.

CONCLUSION:-

QUIZ:-

1. Explain the following terms used in surface finish. (i) Roughness (ii) Waviness (iii) Effective profile (iv) Centreline of profile and (v) Lay
2. Discuss the methods of measuring surface finish briefly With the help of a neat sketch explain the construction and working of the following. (i) Tomlinson's surface meter (ii) Profilometer
3. Explain numerical evaluation of surface texture with neat sketch.
4. Explian tysurf surface roughness tester with working and principle.
5. What is primary texture?
6. What is secondary texture?
7. What is Ley?
8. What do you mean by traversing length and sampling length?
9. Define $R_{a,}$ R_q R_y
10. What is calibration? And why is it necessary for roughness measurement?
11. How will you output the SPC data from surf test SJ-201 to DP-1HS printer?
12. What is the measurement principle of surf test SJ-201?
13. What are the various operation modes in surf test SJ-201?
14. How will you modify the measurement conditions?

Marks **Date:** **Faculty Sign**

PRACTICAL: - 10 **Date :**

AIM: - To study about Thread and Gear measurement.

SCREW THREAD MICROMETER

Screw thread micrometers measure the pitch of the thread directly. The screw thread micrometer has a 60-degree pointed spindle and a double V-shaped swiveling anvil (Figure).

Fig.3.4. Screw Thread Micrometer

The screw thread micrometer reading indicates the pitch diameter of the thread. When the micrometer is set at zero, the pitch line of the spindle and anvil coincide (Figure). When the micrometer is measuring the thread it is measuring along the pitch diameter of the thread (Figure).

Fig. The pitch line indicates the imaginary thread profile engagement.

Fixed anvil screw thread micrometers are those types of screw thread micrometers that can only measure thread pitches within a limited range. It is important to make sure that the screw thread micrometer that you will be using falls within the screw pitch range of a particular thread. With fixed anvil screw thread micrometers, seven micrometers will be needed to cover threads from 3 to 64 threads per inch.

Fig. Set of interchangeable anvils for an interchangeable anvil screw thread micrometer

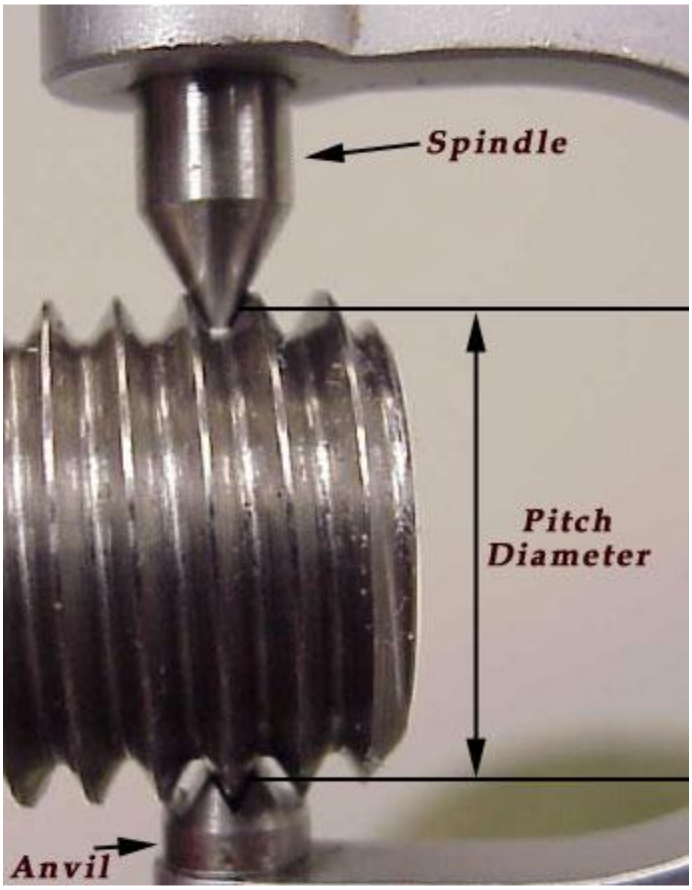


Fig. The pitch diameter of the thread is the most important dimension

The type of screw thread micrometer shown in Figure has interchangeable anvils to cover a wide range of thread pitches. Whenever you change the anvils on the thread pitch micrometer, check the micrometer for accuracy.

Fig. 1–2 inch screw thread micrometer with interchangeable anvils

<table>
<tr><th rowspan="2">Sr. No</th><th rowspan="2">Measured
Part name</th><th rowspan="2">Instrument</th><th colspan="3">Actual Measurement</th><th>Avg.</th></tr>
<tr><th>X_1 mm</th><th>X_2 mm</th><th>X_3 mm</th><th>X mm</th></tr>
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</table>

Conclusion:-

Quiz :-

1. Discuss the gear tooth terminology with neat sketch.
2. Discuss the elements of screw thread with neat sketch.
3. What is an effective diameter of threads? State its significance. Explain with sketch Measurement of Effective Diameter by Two Wire method stating limitation.
4. Explain with neat sketch three wire method of measuring effective diameter of screw thread.
5. Explain Parkinson gear tester with a neat sketch.

Marks **Date:** **Faculty Sign**

PRACTICAL: - 11 **Date :**

AIM: - To study about temperature measurement.

11.1 Introduction to thermometry

In the same way that the boy playing with a paper streamer .unconsciously learns about the physical quantity "pressure", temperature is a quantity that can be readily perceived by the human senses, by contact with the skin or by visually by eye. The concepts "warm", "cold", "ice cold" or at high temperatures "red hot" or "white hot" are familiar to everyone. Human beings are quite good at comprehending temperature differences, whether something is colder or warmer than another substance or object. However, the determination of an exact temperature is outside man's abilities. In technical measurements temperature can be determined by the material properties dependent on it. It is again necessary to rely on comparison of the thermal change detected at the measuring equipment with a known reference point, i.e. the temperature of melting ice, to allow its quantitative evaluation. Basically, all properties which can be influenced by temperature, such as the expansion behavior of gases, liquids and solid substances, the electrical resistance of metal conductors, the current flow through metal conductors, the current flow through a semiconductor, the radiation density of glowing materials, the resonant frequency of an oscillating crystal, etc. can be used for temperature measurement.

Temperature plays an important role in the reproducibility of product quality, the profitability of production processes and the operational reliability of industrial installations and equipment. Besides pressure it is the most frequently measured physical quantity in technology. In industrial production processes the temperatures that are commonly measured are usually between -450°F (-273 °C) and about 6000°F (3500 °C), but can reach substantially higher ranges in special processes. Temperatures even higher than 100 million°F occur in plasmas.

11.2 Principles and definitions of temperature measurement

From the physical point of view temperature can be described as a measure of the energy inherent in a body, which results from the unordered movement of its atoms or molecules. Temperature is a state variable, which together with quantities such as mass, heat capacity and others, describes the energy content of a body or system. Therefore temperature could be measured directly in energy units. However, the tradition of specifying the temperature in degrees had already been introduced far earlier and was well established in physics, so that for practical reasons it was not reasonable to discontinue the use of degrees.

If a body no longer possesses heat energy, its molecules are in the state of rest. This state, which cannot exist in reality, is designated absolute zero. Since there is no state with lower energy, the value O K (Kelvin) is assigned to it. The Kelvin temperature is always a positive quantity according to this convention.

Quiz :-

1. List and explain with sketch types of expansion thermometer stating application
2. Explain in brief the principles of thermocouple stating an illustration.
3. Compare bimetallic thermocouple and thermister as temperature measuring devices.
4. Discuss the construction and working of thermocouple with neat sketch
5. Compare the advantages of thermocouple and thermisters.
6. Explain the construction and working of a resistance thermometer and thermocouple with a neat sketch.
7. What are thermisters? What are their advantages?
8. Explain in brief the principles of thermocouple stating an illustration.
9. A Chromel-Alumel thrmocouple is assumed to have nearly linear operating range up to 1100º C with emf (reference 0º C) 45.14 mV at this temperature. The thermocouple is exposed to a temperature of 840 º C. The potentiometer is used as cold junction and its temperature is estimated to be 25 º C. Calculate the emf indicated on the potentiometer.

Marks **Date:** **Faculty Sign**