Chapter 1: Measurement of Thickness and Length

1. Mechanical Instruments

- Principle of mechanical measurement
- Types of mechanical instruments:
  - ➢ Vernier caliper
  - ➢ Micrometer (screw gauge)

2. Pneumatic Instruments

- Principle of pneumatic measurement
- Types of pneumatic instruments:
  - ➢ Pneumatic comparators

3. Optical Instruments

- Principle of optical measurement
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4. Evaluation of Errors

- Types of measurement errors:
- Methods of correction and estimation of uncertainties

5. Conclusion and Chapter Summary

Chapter I: Measurement of Thickness and Length
Lecture one: Mechanical Instruments

I.1 Introduction

Good [morning/afternoon], everyone, It gives me great pleasure to welcome you all to the first lecture in our course on **Introduction to Mechanical Instruments**. Today marks the beginning of our journey into the fascinating world of precision measurement an essential part of engineering, manufacturing, and quality control. In this lecture, we will focus on two fundamental measuring tools: the **Vernier Caliper** and the **Micrometer**. These instruments are the backbone of mechanical measurement, known for their accuracy and reliability in determining dimensions such as length, diameter, and thickness.

I.2 Definition of Vernier Caliper

A **caliper** is a precision measuring instrument used to measure the **linear dimensions** of an object. It can be used to determine **external dimensions** (such as length, width, or outside diameter), **internal dimensions** (such as the diameter of a hole), and **depth**. Calipers are essential tools in fields such as mechanical engineering, metalworking, woodworking, and quality control.
There are several types of calipers, including **Vernier calipers**, **dial calipers**, and **digital calipers**, each offering varying levels of ease and precision in measurement.

Note: The term **"caliper"** is believed to have originated from a variation of the word **"caliber,"** historically used to describe the internal diameter of a firearm barrel. Over time, the term evolved to refer to instruments designed for fine measurement of various geometrical features.

The different parts of a caliper are illustrated below, each serving a specific function to ensure accurate and versatile measurement. These parts typically include:

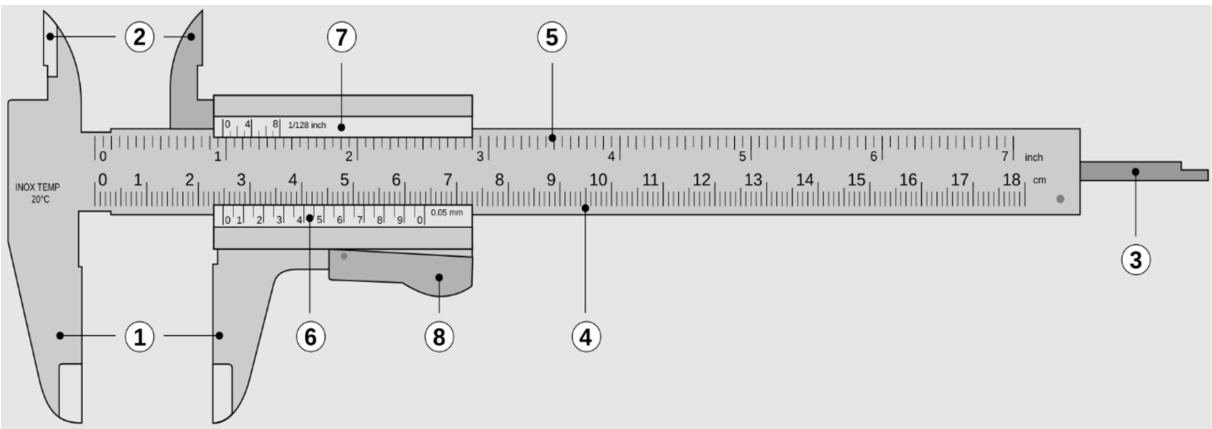


Figure I.1: Diagram of Vernier caliper.

The labelled parts are:

1) **Outside large jaws:** used to measure external diameter of an object (like a hollow cylinder) or width of an object (like a rod), diameter of an object (like a sphere);
2) **Inside small jaws:** used to measure the internal diameter of an object (like a hollow cylinder or pipe);
3) **Depth probe, or depth rod:** used to measure depths of an object (like a small beaker) or a hole;
4) **Main scale (metric):** marked every millimeter and helps to measure length correct up to 1 mm;
5) **Main scale (imperial):** marked in inches and fractions;
6) **Vernier scale (metric):** gives interpolated measurements to 0.1 mm or better;
7) **Vernier scale (imperial):** gives interpolated measurements in fractions of an inch;
8) **Retainer:** used to block movable part to allow the easy transferring of a measurement.

The calipers in the diagram show a primary reading on the metric scale of about 2.475 cm (2.4 cm read from the main scale plus about 0.075 cm from the Vernier scale).

I.3 Principle of Vernier Caliper

The graduations on the Vernier scale are such that the length of 'n' divisions on the Vernier scale is equal to (n-1) divisions of the main scale.

Generally, a Vernier has **10 divisions** and the length of these 10 divisions is equal to the length of 10 – 1 = 9 divisions of the main scale.

That is, 10 div of Vernier scale = 9 mm.

1 div of Vernier scale = **9/10** mm

Least Count of Vernier or Vernier Constant: The **Least Count (LC)** of a Vernier Caliper refers to the **smallest measurement it can accurately read**. It is the difference between one main scale division (MSD) and one Vernier scale division (VSD): **Least Count (LC) = Least Count (LC)=1MSD−1VSD**

It is defined as the difference between the values of one main scale division and one Vernier scale division.

L.C. = Value of one main scale division – Value of one Vernier scale division

= 1 mm – 9/10 mm = 1 mm – 0.9 mm = **0.1 mm or 0.01 cm**

OR

L.C. = Value of one main scale division / Total number of divisions on Vernier

= 1 mm / 10 = **0.1 mm or 0.01 cm**

The **three common types of Least Counts** found in Vernier Calipers are illustrate in table blew:

Vernier Scale Divisions	Corresponding MSD	Least Count (mm)
10	**9 MSD**	**0.1mm**
20	**19 MSD**	**0.05mm**
50	**49 MSD**	**0.02mm**

The **Least Count (LC)** of a Vernier Caliper depends on how many divisions are on the **Vernier Scale (VSD)** and how they relate to the **Main Scale Divisions (MSD)**. The formula is :

$$\text{Least Count} = \frac{1 \text{ Main Scale Division}}{\text{Number of Vernier Divisions}} = \frac{1 \text{ MSD}}{\text{Number of VSD}} = \text{Value of VSD} - \text{Value of 1 MSD}$$

1) **Vernier with 10 Divisions :**

- **10 VSD = 9 MSD**
- So, 1 VSD = 0.9 mm (if 1 MSD = 1 mm), Least Count= 1 - 0.9 = 0.1mm

2) **Vernier with 20 Divisions :**

- **20 VSD = 19 MSD**
- So, 1 VSD = 0.95 mm (if 1 MSD = 1 mm), Least Count= 1 - 0.95 = 0.05mm

3) **Vernier with 50 Divisions :**

- **50 VSD = 49 MSD**
- So, 1 VSD = 0.98 mm (if 1 MSD = 1 mm), Least Count= 1 - 0.98 = 0.02mm

I.4 How to read Vernier Caliper scales

1) The jaws are first gently closed on the object to be measured;

2) Note the main scale reading (M.S.R);

3) Note the division on Vernier scale which coincides with any division of the main scale. Multiply this number of Vernier division with the least count. This is the Vernier scale reading (V.S.R). Hence V.S.R = Vernier scale coincidence x Least count (L.C.);

4) Add the main scale reading to the Vernier scale reading. This gives the observed length.

Hence, Observed Reading = Main scale reading + Vernier scale reading

Observed reading = M.S.R + V.S.R

OR

Observed reading = M.S.R. + (Vernier scale coincidence * L.C.)

5) Accuracy of the Vernier caliper is half the smallest scale so:

Vernier caliper accuracy is: $\Delta x = (\pm 1/2) *$ Least count (L.C.).

Instrumental Uncertainty (Δx): Unless otherwise specified, we assume the uncertainty is ±½ **of the least count**, so: $\Delta X = \pm\frac{1}{2} * \text{Least Count (L.C.)}$

This comes from the idea that when you take a reading, you might be off by half a division due to limitations of human vision and instrument resolution.

The accuracy or uncertainty of a Vernier caliper is taken as ±½ of the least count

Term	Formula	Meaning
Least Count (L.C.)	$\frac{\text{Smallest Main Scale Division}}{\text{Number of Vernier Divisions}}$	**Instrument precision**
Uncertainty (Δx)	$\pm\frac{1}{2} * \text{Least Count (L.C.)}$	**Possible reading error**
Final reading	**Measurement ± Δx**	**Measured value with uncertainty**

For example, Let us observe the diagram given below

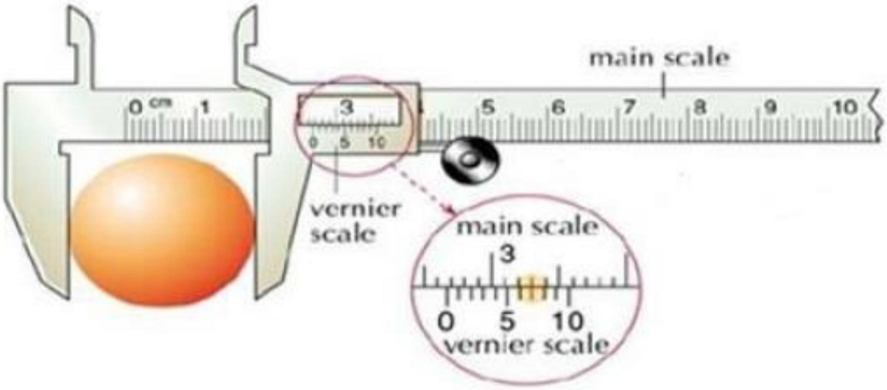


Figure I.2: Caliper scales reading.

Least count (L.C.) = 0.01 cm

M.S.R. = 2.6 cm

Vernier scale coincidence = 7

V.S.R. = Vernier scale coincidence x L.C. = 7 x 0.01 =**0.07 cm**

Observed reading = M.S.R + V.S.R = 2.6 cm + 0.07 cm **= 2.67 cm.**

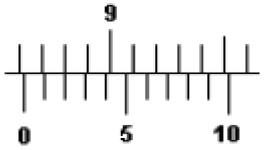
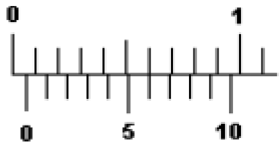
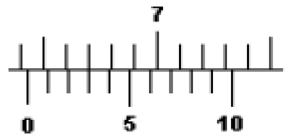
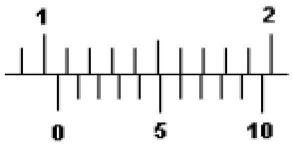
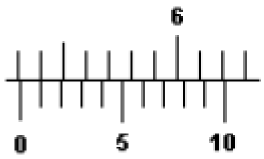
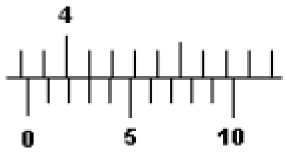
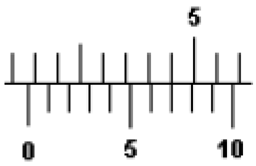
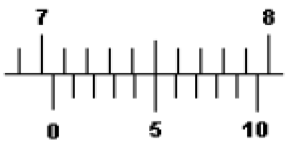
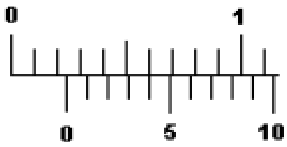
Vernier caliper accuracy is: Δx=1/2* Least count (L.C.)=1/2*0.01=0.005cm

Because Δx=0.005cm (three decimal places), then the results of measurement readings (xo) also must be expressed in 3 decimal places. Unlike the ruler, on a scale Vernier caliper, you can never estimate the last digit (decimal to-3) so that you can just give the value 0 for decimal to-3. So that the measurement results using can shove you report as:

Length, **L = xo ± Δx**

Example, **L = (2,670 ± 0,005) cm**

❖ **<u>Exercise 1:</u>** Find the readings of the Vernier calipers below.

………………………..  ………………………	………………………  ………………………	………………………  ………………………
………………………  ………………………	………………………  ………………………	………………………  ………………………
………………………  ………………………	………………………  ………………………	………………………  ………………………

I.5 Vernier Caliper Zero Error

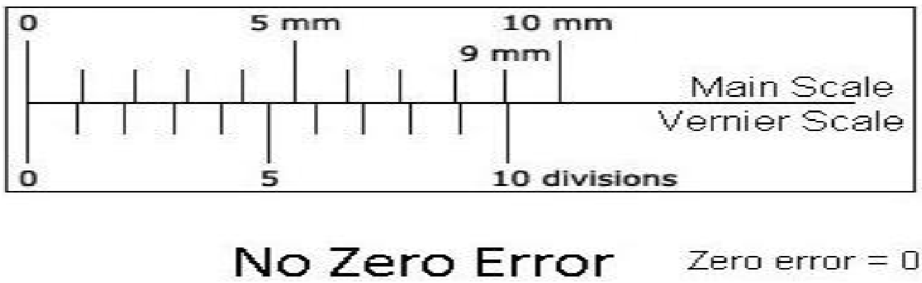
Zero error in the Vernier caliper is a mathematical error due to which, the zero of the Vernier scale does not coincide with the zero of the main scale.

Types of Zero Error:

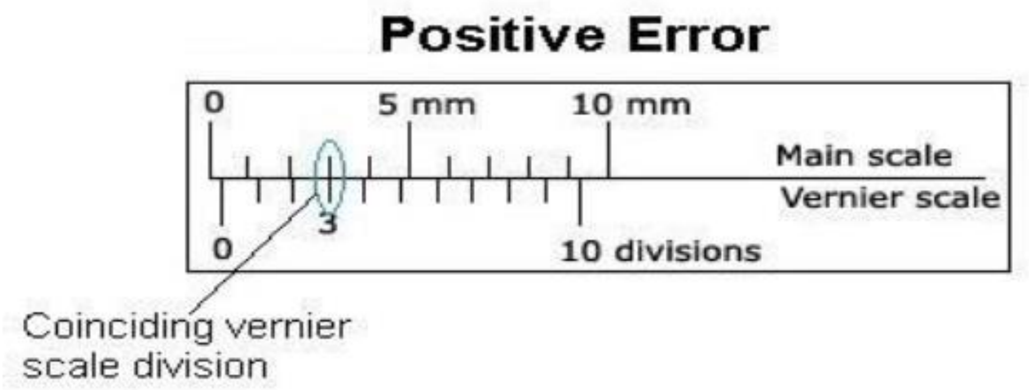
There are three types of zero error.

- No Zero Error
- Positive Zero Error
- Negative Zero Error

<u>No Zero Error:</u> In **no zero error**, when we bring two jaws together. You will see zero of the Main scale is coinciding with the zero of the Vernier scale. They are exactly in a straight line so this Vernier caliper is free from zero error or you can say there is no zero error in this Vernier caliper.



<u>Positive Zero Error</u>: In **positive zero error**, let's bring these jaws together. You see, the zero of Vernier scale is ahead of main scale zero. Alternatively, you can say zero of Vernier scale is at the right side of main scale zero.



Calculation of Positive error:

Coinciding vernier scale Div. = 3

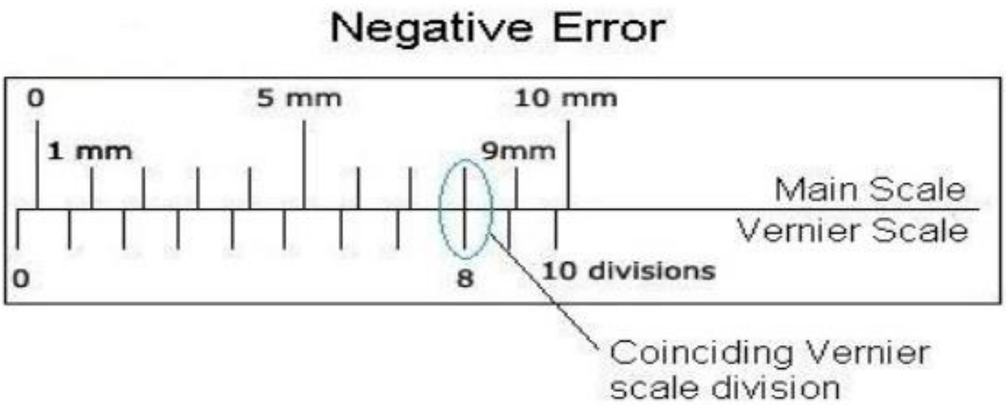
Zero Error = Coinciding V.S Div. X Least count

$= 3 \times 0.01cm$

$= +0.03cm$

Thus it is positive error it is indicated with "+".

<u>Negative Zero Error:</u> In **negative zero error**, we will bring the two jaws together. Here you can see zero of Vernier scale is the back side of main scale zero. On the other hand, to the left of main scale zero.



Calculation of Negative error:

Coinciding vernier scale div.= **8**

Difference = Total div. - Coinciding div.

= **10** - **8** = **2**

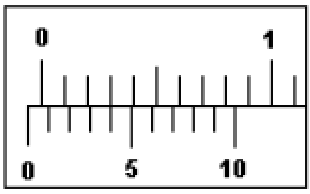
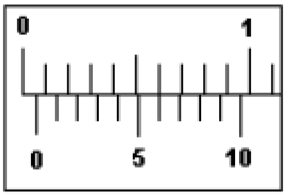
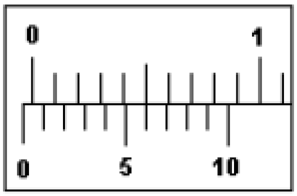
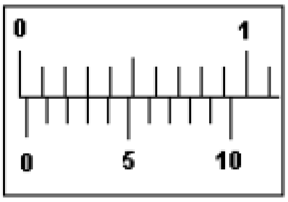
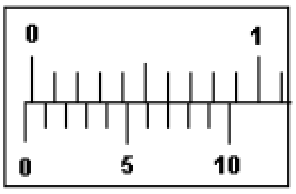
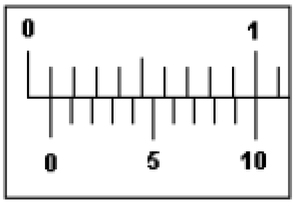
Now, **Zero error = Difference X Least count**

$= \mathbf{2 \times 0.01cm}$

$= \mathbf{-0.02\ cm}$

The minus sign indicates the negative error in vernier caliper.

<u>Exercise 2:</u> Assuming that the jaws of the calipers are tightly closed, find the zero error of the Vernier calipers below.

 …………………….. ……………………..	 …………………….. ……………………..	 …………………….. ……………………..
 …………………….. ……………………..	 …………………….. ……………………..	 …………………….. ……………………..

I.6 Types of Vernier calipers

Many types of calipers permit reading out a measurement on a ruled scale, a dial, or an electronic digital display. A common association is to calipers using a sliding Vernier scale.

- **<u>Flat Edge Vernier Caliper:</u>** This type of Vernier is used for normal functions. We can take outer measurement of a job's length, breadth, thickness, and diameter, etc.

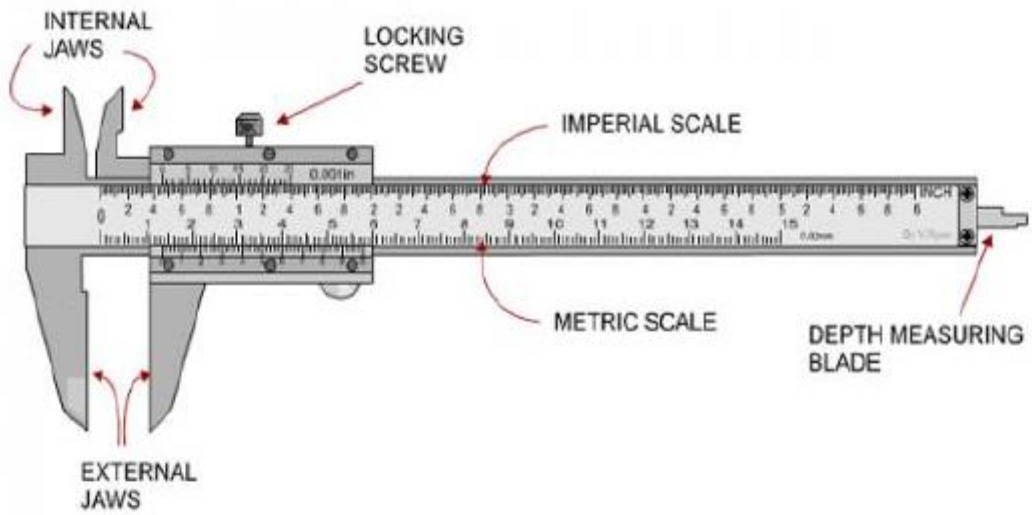


Figure I.3: Flat Edge Vernier Caliper.

- **Dial Vernier Caliper:** For this purpose, nowadays Vernier Dial calipers are being used. In place of the Vernier scale, it contains a graduation dial as shown in the figure.

Figure I.4: TESA Vernier Dial Caliper.

- **Digital Vernier Caliper: A Modern Alternative:** In addition to the traditional Vernier Caliper, there is also a digital version available in the market. A digital Vernier Caliper provides the same accuracy and precision as its traditional counterpart but with the added convenience of digital readings. Instead of reading the scales manually, the Digital Caliper displays the measurement on a digital screen. This makes it easier to read and eliminates the need for interpreting Vernier scales. Digital Vernier Calipers often come with additional features such as relative measurement, metric and imperial unit conversions, and zero setting options.

Figure I.5: Digital Vernier Caliper.

Digital Vernier Calipers can be a valuable tool for those who prefer a more user-friendly approach to measurement. They are especially useful in scenarios where quick and accurate measurements are required.

I.7 Micrometer Screw Gauge

A **micrometer** or **micrometer screw gauge** is a **precision measuring instrument** used to measure **small dimensions** with **high accuracy**, typically up to **0.01 mm**. It offers **greater precision than a Vernier caliper**, making it ideal for measuring **small parts** where dimensional accuracy is critical, such as in mechanical, manufacturing, or engineering applications.

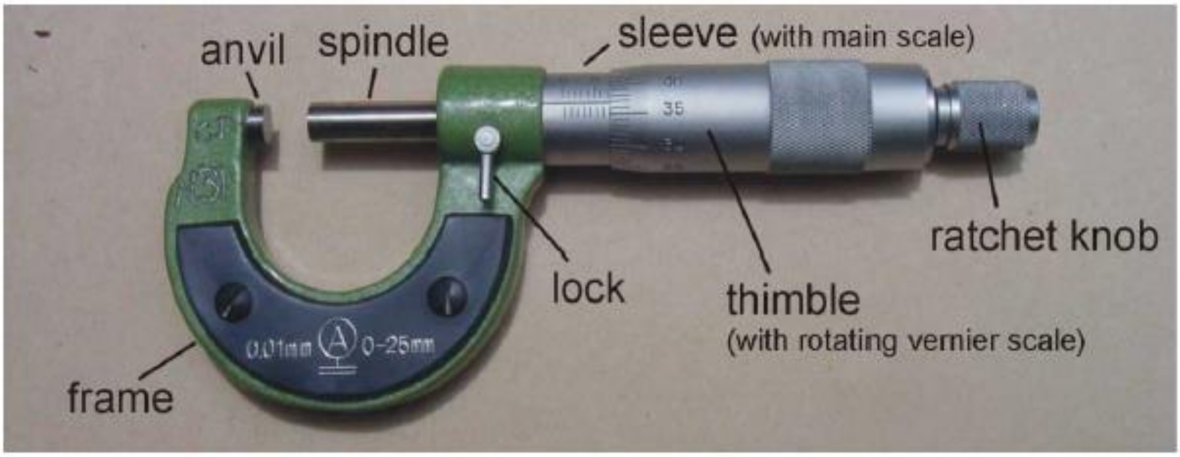


Figure I.6: Micrometer Screw Gauge.

When dealing with components where even a minor dimensional error can lead to failure, such as in aerospace, automotive, or fine instrument design, the micrometer screw gauge provides the necessary **precision and reliability**. It operates using a **finely threaded spindle**, and its main parts include the **anvil, spindle, sleeve (barrel), thimble**, and **ratchet stop**. These components work together to convert small rotary motion into precise linear movement, enabling highly accurate measurements.

The main parts of a micrometer: the frame, anvil, spindle, sleeve (barrel), thimble, and ratchet.

1) **Frame:** Micrometer frames are c-shaped and ensure the optimum positioning of the anvil and barrel. Frames may take a variety of shapes and sizes, allowing for desirable functionality of the micrometer. The hub-shaped frame is ideal for taking highly accurate measurements in confined spaces.
2) **Anvil:** The micrometer anvil should be noticeably shiny. It should ensure that the spindle gravitates towards the object, which is firmly secured. The anvil will be kept in consistent contact with the part and may chip unless a high level of care is taken. Quality models typically come complete with carbide-tipped micrometer anvils, which allow for an extended tool-life.
3) **Spindle:** The shiny cylindrical component spindle is inner most cylinder that move TO and FRO that causes to move toward the anvil while thimble is rotated and is used to grab and also to measure the object with referring to its backend threads. These moments eventually turns into numerical output of the movement of this cylinder.
4) **Sleeve (Barrel):** It has the scale markings over it and it also provide support to thimble shell that move over sleeve. the round micrometer sleeve or barrel is kept securely in place and features the linear scale. It is also quite common for Vernier markings to be found on this part of the micrometer. This scale allows highly accurate measurements to be taken in degrees of .0001.
5) **Thimble:** It is the outer shell of whole measuring mechanism and has 100 or fifty divisions make on one end depending on precision required. It is also called circular scale it acts as stationary nut that gives motion to inner bolt.

6) **Ratchet Knob:** Device on end of handle that limits applied pressure by slipping at a calibrated torque. It is use to move spindle with high accuracy and precision and save them from unwanted force that can cause damage to the screw gauge.

I.8 How to read Micrometer

Micrometers are the ideal tool for the measurement of cylindrical and spherical shaped objects. In order to use a micrometer, you should follow these steps:

1) Take time to acquaint yourself with the main technical terms;

2) Clean the micrometer, using a soft cloth to remove any marks and debris from between the anvil and spindle;

3) Begin by positioning the item being measured next to the anvil. It is important to keep the object stable and avoid any scratching. You may control the micrometer with your free hand, or alternatively, there is the option of using a stationary vise, leaving both of your hands free for control of the micrometer;

4) Spin the ratchet anti-clockwise, ensuring that the 0 mark on the thimble is positioned in accordance with the sleeve scale. Keep twisting until the spindle is within close contact of the object; three clicks is a good guide;

5) The thimble lock should be applied while the micrometer is within close proximity of the object. It should be possible to adjust the spindle as required. Once you are confident that the micrometer has fulfilled its function you can remove the object, taking care to avoid scratching the anvil and spindle surfaces;

6) Finally, record the reading, ensuring that the spindle is kept stable.

I.8.1 Example of reading a micrometer

To read a micrometer screw gauge, begin by observing the main scale on the sleeve, which shows measurements in millimeters. The visible part of the main scale before the rotating thimble gives the base reading. Some micrometers also have a half-millimeter line between the main divisions, which should be added if visible. Next, observe the thimble scale, which rotates around the sleeve and is marked with 50 or 100 divisions, each typically representing 0.01 mm. Find the line on the thimble that aligns exactly with the horizontal line on the sleeve. Multiply the aligned thimble division by the least count (usually 0.01 mm) and add it to the main scale reading. The sum gives the final measurement. For example, if the main scale reads 5.5 mm and the thimble scale aligns at 23, the total measurement is $5.5 + (23 \times 0.01) = 5.73$ mm.

Parts Involved in Reading a Micrometer:

1. **Sleeve (or Barrel):** Has the main scale (in mm or inches).
2. **Thimble:** Rotates around the sleeve and has a circular scale.
3. **Ratchet Stop:** Ensures consistent pressure for accurate measurement.

Steps to Read:

1. **Read the Main Scale (Sleeve):**

   Check the last visible mark on the sleeve before the thimble edge.

   Let's say you see **5.5 mm** on the sleeve (that includes one half mark after 5 mm).

2. **Read the Thimble Scale:**

   Look for the line on the thimble that lines up with the horizontal line on the sleeve.

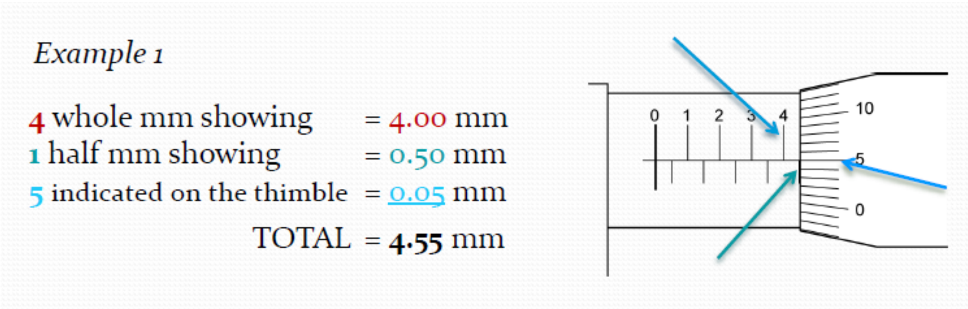
   Suppose it aligns at **23**.

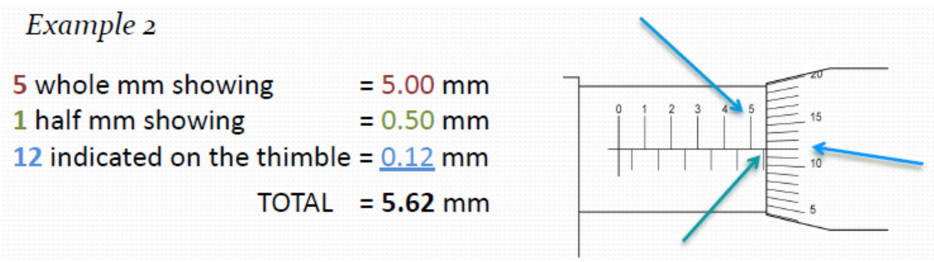
3. **Calculate the Total Reading:**

$$\text{Total} = \text{Main scale} + (\text{Thimble reading} \times \text{Least Count})$$

$$= 5.5 \text{ mm} + (23 \times 0.01 \text{ mm}) = 5.5 \text{ mm} + 0.23 \text{ mm} = \boxed{5.73 \text{ mm}}$$

Final Micrometer Reading: 5.73mm





I.8.2 Micrometer Accuracy

Micrometers are known for their high precision in measuring small dimensions, typically to the nearest **0.01 mm (10 microns)** or **0.001 inches**, depending on the type. This makes them significantly more accurate than tools like rulers or even Vernier calipers. The accuracy of a micrometer depends on factors such as:

- Build quality and calibration
- Proper use and handling
- Environmental conditions (e.g., temperature)
- Zero error or backlash

With careful use and regular calibration, micrometers provide highly reliable and repeatable measurements, making them ideal for applications in mechanical engineering, machining, and quality control.

The **Accuracy** and **uncertainty** of Micrometer are related but not exactly the same:

- **Accuracy** refers to how close a measurement is to the true or accepted value.

- **Uncertainty** refers to the possible range of error in the measurement, it tells you how much the value could vary.

➢ For **Vernier Calipers**, the uncertainty is usually taken as **±½ of the least count**. For example, if the least count is 0.02 mm, the uncertainty is ±0.01 mm.

➢ For **Micrometers**, the same idea applies. The uncertainty is **typically considered as ±½ of the least count** as well.

So if a micrometer has a least count of 0.01 mm, its **typical uncertainty is ±0.005 mm**.

- Vernier Caliper (least count 0.02 mm) → Uncertainty = ±0.01 mm
- Micrometer (least count 0.01 mm) → Uncertainty = ±0.005 mm

So, **they follow the same principle** in general, uncertainty is taken as ±½ of the least count unless otherwise specified or calibrated more precisely.

Term	Formula	Meaning
Range	–	The span of sizes the micrometer can measure (e.g., 0–25 mm, 25–50 mm).
Least Count (LC)	Pitch of screw ÷ number of divisions	The smallest value the micrometer can measure (usually 0.01 mm).
Pitch of Screw	–	Distance the spindle moves in one full rotation (usually 0.5 mm).
Main Scale Reading	–	The visible reading on the fixed scale (in mm).
Circular Scale Reading	No. of divisions × LC	Reading from the rotating scale (thimble).
Total Reading	Main Scale + Circular Scale	Final measured value from both scales.
Zero Error (ZE)	–	Error when the micrometer is fully closed but does not read 0.
Corrected Reading	Total Reading ± Zero Error	Actual value after accounting for zero error.
Uncertainty	±(½ × LC)	Possible error range in the measurement (typically ±0.005 mm).

I.9 Types of Micrometer

There are various different types of micrometer available, each suited to varying uses and applications. Outside micrometers are one of the most widely used varieties, but inside and depth micrometers are alternatives which may be more appropriate for use in certain scenarios. Below are some of the most common types of micrometers:

➢ **<u>Ball Micrometers:</u>** Ball micrometers have spherical anvils. They are used for purposes such as measuring the thickness of walls and establishing the distances between holes and edges. As opposed to tube micrometers, the ball variety can be used to correctly identify the measurement of alternative rounded surfaces.

Figure I.7: Ball micrometer.

- **<u>Digital Micrometers:</u>** Integrated with decoders for the effective identification of distance, these micrometers present measurements in a digital format.

Figure I.8: Digital Micrometer.

- **<u>Blade Micrometers:</u>** This type of micrometer comes complete with matching narrow tips, or blades. They are particularly helpful when it comes to the measurement of specifically shaped objects, such as those with O-ring grooves.

Figure I.9: Blade Micrometer.

- **<u>Tube Micrometers:</u>** Designed to measure the thickness of tubes, tube micrometers feature cylindrical anvils which are located perpendicular to the spindle. They allow for quick and accurate measurements when compared with alternative tools.

Figure I.10: Tube Micrometer.

I.10 Difference between a Micrometer and Caliper

Micrometers and Vernier caliper are both commonly used to establish the sizes of different objects. However, there is some contrast between the efficiency and usage of each of these tools. Calipers might be used to establish physical dimensions, interior measurements, exterior measurements and depths. However, micrometers are generally used for more specific purposes such as measuring exterior or inside dimensions. The expected accuracy of Vernier calipers is typically between ±0.001, with the accuracy of micrometers generally being ±0.00005.

I.11 Conclusion

In conclusion, understanding the proper use and functionality of the Vernier Caliper and Micrometer is essential for precision in mechanical measurements. Mastery of these tools not only ensures accurate readings but also builds a strong foundation for more advanced measurement techniques in engineering and manufacturing fields.