MEASUREMENT OF LENGTH, MASS AND TIME

AIM: To familiarize with measuring instruments.

APPARATUS: Metal blocks with holes, sheet of plain paper, stop watch, triple beam balance, vernier calipers and micrometer screw gauge 30 or 10 centimeter rule.

THEORY

Physics is a quantitative experimental science and as such, it is largely a science of measurements. Length, mass and time are fundamental basic physical quantities upon which the study of mechanics is based. If the dimensions of a regular geometrical object and its mass are measured, such things like its area, volume and density can be calculated. A measurement is only considered accurate to half the smallest division on the instrument. This is known as the limit of precision of the instrument.

The Vernier Calipers

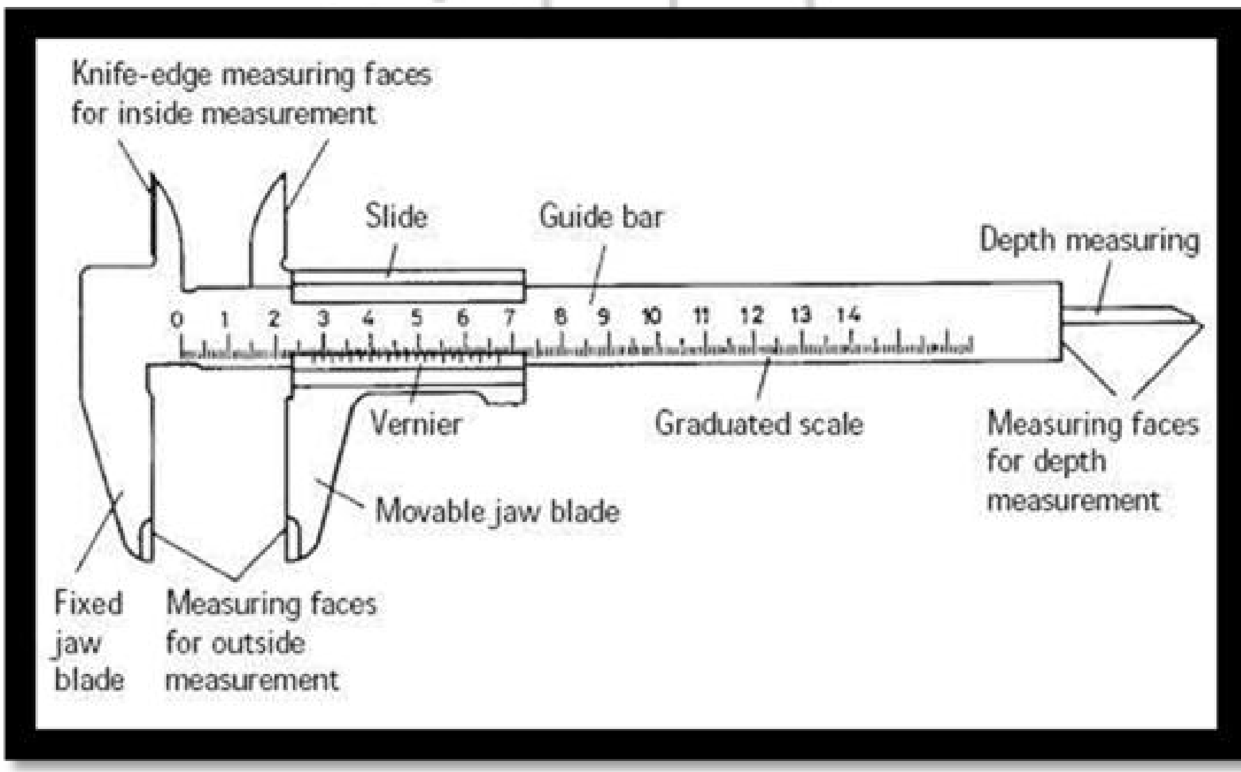

Figure 2.1 The vernier calipers

A vernier calipers can be used to measure the external length, the internal diameter and the depth of a hole at position A are used for internal measurements for object such as tubes, cylinders etc. The jaws at position B measure external lengths of objects. The right edge of the venier calipers has a movable blade C that is used to measure depth. A measuring demonstration will be done in the lab. This instrument has two scales: the main scale (MS) and the venier scale (VS). The smallest reading that can be taken accurately with this instrument is called the least count of the instrument. For a venier calipers, the least (LC) is given by

$$\text{Least count} = \frac{\text{value of the smallest reading on the main scale}}{\text{total number of divisions on the venier scale}} \tag{2.1}$$

This value sets the number of decimal places to which you can state the value of the instrument reading. For most vernier calipers the value of the smallest division on the main scale in 1mm. Some venier calipers may have 10 divisions on the venier scale whereas others may have 20 divisions. The latter is more accurate.

The main scale reading (MSR) in millimeters are read at the zero mark on the venier scale, and the tenths and twentieths of a millimeter are obtained by finding which venier line coincides best with a line on the main scale. Let N be the number of a venier line that coincides best with a line on the main scale.

$$\text{Instrument reading} = \text{MSR} + (\text{N} \times \text{LC})$$

When the jaws are in contact and the reading is zero then there is no zero error. If it does not read zero, a zero error correction must be performed for any reading taken with the instrument. The zero error can be *negative* or *positive.* It is negative if the zero mark of the vernier scale is to the left of the zero mark of the main scale, and positive if the zero mark of the vernier scale is to the right of the zero mark of the main scale. The negative zero correction has to be *added* to any measurement made using this vernier caliper, while the positive zero correction is to be *subtracted* from any measurement made.

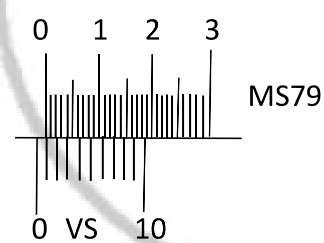

Figure 2.1 Negative Zero Error

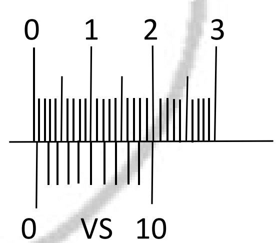

Figure 2.2 Positive Zero Error

2.3 The Micrometer Screw Gauge

A micrometer measures smaller distances to the order of micron (10μm). The principle of the micrometer is that as a screw is turned by one revolution it advances a distance equal to the pitch of the screw. A fraction of a rotation advances the screw by a corresponding fraction of the pitch. The micrometer you will use has a pitch of 0.5mm and the number of divisions on the circular scale is 50. The least count of the micrometer screw gauge is given by

$$\text{Least count} = \frac{\text{pitch of the screw}}{\text{total number of divisions on the circular scale}} \qquad (2.3)$$

The least count of the micrometer shown below is 0.01mm

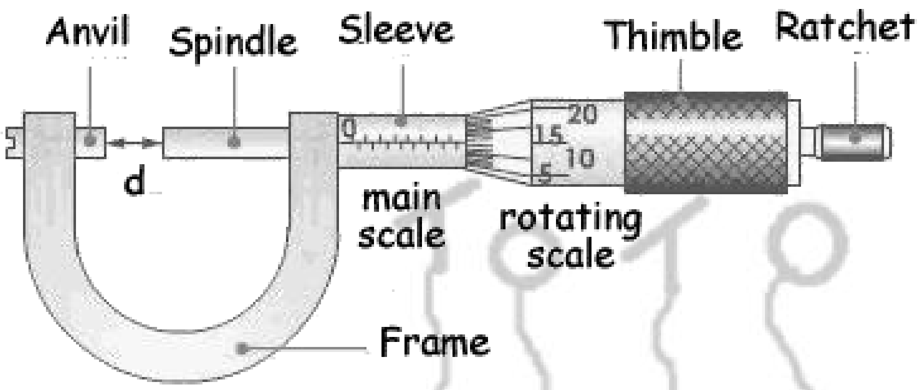

Figure 2.3 Micrometer Screw gauge

The micrometer reading is given as the sum of the sleeve reading (SR) and the product of the circular (or thimble) reading (CR) and least count (LC)

Reading = SR + (CR X LC) (2.4)

To safeguard the micrometer, do not close it by forcing, use the ratchet. When it clicks, it means that the spindle has reached the limit. At this point you can lock the micrometer using a knob provided on it so that the reading can be taken without possible shift of the divisions. This feature of a micrometer screw gauge is not shown in figure 2.3.

When the spindle is closed to make contact with the anvil and the reading is zero then there is no zero error. If it does not read zero, a zero error correction must be performed for any reading taken with the instrument. The zero error can be negative or positive. It is negative if the zero mark of the circular scale is below the reference line when anvil and spindle are in contact, and is positive if the zero mark of the thimble is above the reference line when anvil and spindle are closed. The negative error has to be *added* to any measurement using this micrometer, while the positive error is to be subtracted from any measurement made.

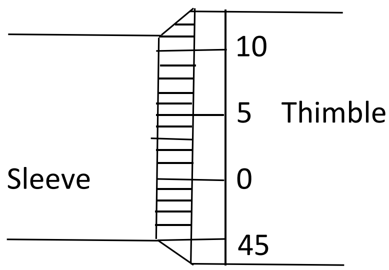

Figure 2.3 Negative Zero Error (-0.03mm)

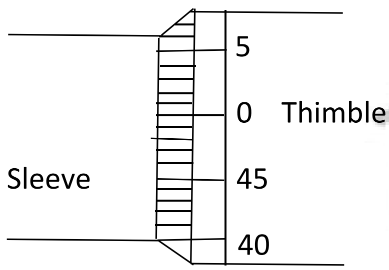

Figure 2.4 Positive Zero Error (+0.02mm)

PROCEDURE

(A) Vernier Calipers

1. The vernier calipers was examined and the smallest reading on the main scale and the number of divisions on the vernier scale were taken note of.
2. The vernier calipers was used to measure the diameter, height of the metal block and the depth of the hole in it.
3. With the help of the instructor, the mass of the block was measured.

(B) Micrometer Screw Gauge

1. Micrometer was wiped with a soft dry piece of cloth. It was examined and the magnitude of the smallest division on the sleeve and the number of divisions on the thimble were noted.
2. Reading that was indicated by it was taken and it was rotated through one revolution. The reading was taken again.
3. Using the micrometer, the thickness of a white sheet of plane paper was measured at five different positions.
4. Using a 30cm rule, the lateral dimensions of the paper was measured accurately.
5. The mass of the paper was measured using a beam balance.

DATA ANALYSIS

PART (A): VERNIER CALIPERS

1. (i) Smallest reading on the main scale = 1mm or 0.1cm
   (ii) Number of divisions on the vernier scale = 10

$$\text{Least count} = \frac{\text{value of the smallest reading on the main scale}}{\text{total number of divisions on the venier scale}}$$

$$\text{Least count} = \frac{0.1\text{cm}}{10}$$

$$\textbf{Least count} = \mathbf{0.01cm}$$

2. (i) Diameter
   MSR = 7.5cm, N = 6, LC = 0.01

$$\text{Instrument reading} = \text{MSR} + (\text{N} \times \text{LC})$$

$$\text{Instrument reading} = 7.5\text{cm} + (6 \times 0.01\text{cm})$$

$$\textbf{Instrument reading} = \mathbf{7.56cm}$$

(ii) Height
MSR = 8.6cm, N = 1, LC = 0.01cm

$$\text{Instrument reading} = \text{MSR} + (\text{N} \times \text{LC})$$

$$\text{Instrument reading} = 8.6 + (1 \times 0.01)$$

$$\textbf{Instrument reading} = \mathbf{8.61cm}$$

(iii) Depth of the smaller Hole

MSR = 4.64cm, N = 4, LC = 0.01cm

$$\text{Instrument reading} = \text{MSR} + (\text{N} \times \text{LC})$$

$$\text{Instrument reading} = 4.64\text{m} + (4 \times 0.01\text{cm})$$

$$\textbf{Instrument reading} = \mathbf{4.64cm}$$

(iv) Depth of the bigger Hole

MSR = 4.8cm, N = 2, LC = 0.01cm

$$\text{Instrument reading} = \text{MSR} + (\text{N} \times \text{LC})$$

$$\text{Instrument reading} = 4.8\text{cm} + (2 \times 0.01\text{cm})$$

$$\mathbf{Instrument\ reading = 4.82cm}$$

(v) Diameter of the smaller Hole

MSR=0.7cm N=4 LC=0,01cm

Instrument reading= MSR + (N×LC)

Instrument reading=0.7cm + (0.01cm×4)

Instrument reading= 0.74cm

(VI) Diameter of the bigger Hole

MSR=1.3cm N=1 LC=0,01cm

Instrument reading= MSR + (N×LC)

Instrument reading=1.3cm + (0.01cm×1)

Instrument reading =1.31 cm

(VII) <u>VOLUME OF SMALLER HOLE</u>

$$\text{Volume} = \pi r^2 h$$
$$\text{Volume} = \pi(0.37\text{cm})^2 \times 4.64\text{cm}$$
$$\mathbf{Volume = 2.00cm^3}$$

(VIII) VOLUME OF BIGGER HOLE

$\text{Volume} = \pi r^2 h$

$\text{Volume} = \pi(0.655\text{cm})^2 \times 4.82\text{cm}$

$\textbf{Volume} = \mathbf{6.50cm^3}$

TOTAL VOLUME OF THE HOLES

$\text{Total Volume} = V_1 + V_2$

$\text{Total Volume} = 2.21\text{CM} + 9.16\text{CM}$

$\textbf{Total Volume} = \mathbf{8.50cm^3}$

VOLUME OF METAL BLOCK

$\text{Volume} = \pi r^2 h$

$\text{Volume} = \pi(3.78\text{cm})^2 \times 8.61\text{cm}$

$\underline{\textbf{Volume} = \mathbf{386cm^3}}$

VOLUME OF THE MATERIAL

$\text{Volume} = \text{Volume of Metal Block} - \text{Total Volume of holes}$

$\text{Volume} = \underline{386\text{cm}^3} \ \underline{- 8.50\text{cm}^3}$

$\textbf{Volume} = \mathbf{378cm^3}$

3. **Mass = 1004g**

4. $\boldsymbol{Density} = \frac{Mass}{Volume}$

$$\text{Density} = \frac{1004\text{g}}{378\text{cm}^3}$$

$$\textbf{Density} = \mathbf{2.66 \approx 2.7g}/\boldsymbol{cm^3}$$

According to the Density found, the closest material is Aluminium which has a density of 2.70g/cm³

5. $\%\text{Error} = \frac{\text{Absolute Error}}{\text{True Value}}$

$\%\text{Error} = |\dfrac{2.66 - 2.70}{2.70}|\text{X}100\%$

$\%\textbf{Error} = \ \mathbf{1.5}\%$

ANSWERS TO QUESTIONS

1. The percentage errors obtained could have been due to;

- ❖ Mechanical vibrations in the experiment set up.
- ❖ Friction between parts of the instrument
- ❖ Rounding off digits in measurements.

2. Ways of minimizing errors

- ❖ Maintaining the mechanical vibrations by locking the vernier caliper and taking reading.
- ❖ Oiling the instrument
- ❖ Ensuring the vernier caliper instrument is kept well and cleaned before use.

The Volume of the largest metal block whose dimensions can be measured using tat vernier caliper is:

The largest reading that can be taken using the instrument is 12.5cm, thus tee it of the block will be 12.5cm,its radius 6.25cm

$\text{Volume} = \pi r^2 h$

V0lume= $\pi \times 6.25^2 \times 12.5$

Volume=1534cm^3

The largest block is made from aluminium this means that its density is $2.70\text{g}/cm^3$

Mass= density $\times$ volume

Mass= 2.70 $\times$ 1534

Mass= 4142 g

PART (B): MICROMETER SCREW GAUGE

1. (i) Magnitude of the smallest Division on the sleeve = 0.5mm

   (ii) Number of divisions on the thimble = 50

2. (i) First Reading = 0mm

   Second Reading (after one revolution) = 1mm

   Pitch = 1mm

$$\text{Least Count} = \frac{\text{Pitch of Screw}}{\text{Total Number of Divisions of the circular scale}}$$

$$\text{Least Count} = \frac{0.5}{50}$$

$$\mathbf{Least\ Count = 0.01mm}$$

3. Thickness of white sheet of paper
   (i) First position (thickness t_1) = O.08-(-0.02)=0.1mm
   (ii) Second position (thickness t_2) = 0.07-(0.02)=0.09mm
   (iii) Third Position (thickness t_3) = 0.08-(-0.02)=0.1mm
   (iv) Fourth Position (thickness t_4) = 0.08-(-0.02)=0.1mm
   (v) Fifth position (thickness t_5) = 0.07-(-0.02)=0.09mm

a) $\text{Mean thickness } \bar{\mathrm{t}} = \frac{1}{N}\sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{t_i}$

$$\text{Mean thickness } \bar{\mathrm{t}} = \frac{1}{5}\ (0.1\text{mm} + 0.1\text{mm} + 0.09\text{mm} + 0.09\text{mm} + 0.1\text{mm})$$

$$\text{Mean thickness } \bar{\mathrm{t}} = \frac{1}{5}(\ 0.48)\text{mm}$$

$$\mathbf{Mean\ thickness\ \bar{t} = 0.096}\boldsymbol{mm}$$

b) $\text{Mean Deviation } \delta\mathrm{t} = \frac{1}{N}\sum |(t_i - \bar{t})|$

$$\text{Mean Deviation } \overline{\delta t} = \frac{1}{5}|(0.1 - 0.096| + |0.1 - 0.096| + |0.09 - 0.096| + |0.1 - 0.096| + |0.09 - 0.096|$$

$$\text{Mean Deviation } \overline{\delta t} = \frac{1}{5}(0.004 + 0.004 + 0.004 + 0.006 + 0.006)$$

$$\text{Mean Deviation } \overline{\delta t} = \frac{1}{5}(0.024)mm$$

$$\mathbf{Mean\ Deviation\ \overline{\boldsymbol{\delta t}} = 0.0048mm}$$

c) %Error $= \frac{\overline{\delta t}}{\bar{t}} \times 100\%$

$$\%\text{Error} = \frac{0.0048\cancel{mm}}{0.096\cancel{mm}} \times 100\%$$

$\%\mathbf{Error} = \mathbf{5}\%$

d) Standard Deviation $\sigma = \sqrt{\frac{1}{N-1}\sum (t_i - \bar{t})^2}$

Standard Deviation $\sigma = \sqrt{\frac{1}{5-1}[0.004^2)}$3 + (0.006²)2

Standard Deviation $\sigma = \sqrt{\frac{1}{4}[1.6 \times 10^5)}$3+(3.6× 10^{-5})2

Standard Deviation $\sigma = \sqrt{\frac{1}{4}[4.8 \times 10^5)}$+(7.2× 10^{-5})

Standard Deviation $\sigma = \sqrt{[3 \times 10^{-5})}$

Standard Deviation $\boldsymbol{\sigma} = \mathbf{0.00548mm}$

4. (i) Width of A4 paper = 210mm = 21.0cm
   (ii) Length of A4 paper = 296mm = 29.6cm

5. Volume = Length × Width × Thickness
   Volume = 29.6cm × 21.0cm × 0.0096cm
   Volume = 5.97cm³

6. ` **Mass = 5.1g**
7. Density $= \frac{\text{Mass}}{\text{Volume}}$
   Density $= \frac{5.1\text{g}}{5.97cm^3}$
   Density $= \mathbf{0.854}\boldsymbol{g/cm^3}$

ANSWERS TO QUESTIONS

1. **Aspen Wood**
2. 100 reams arranged horizontally on a flat surface
   the ream is:
   500 X 0.0096cm = 4.8cm
   Assuming the 100 reams are arranged length wise then the total length is:
   100X 4.8cm = 480cm
   Total distance the ant would have to cover = 2960cm + 10cm =2970cm

$$\text{Time} = \frac{\text{Distance}}{\text{Speed}}$$

$$\text{Time} = \frac{480}{0.5\text{cm/s}}$$

<u>Time = 960s</u>

∴ the ant would take 960 seconds to traverse 100 compact reams of this paper arranged horizontally length wise.

DISCUSSION

Before measurements are obtained on the vernier caliper or micrometer screw gauge, it's vital that the instruments you zero the readings, completely when closed to avoid errors. In this case the vernier caliper ad no errors but the micrometer screw gauge indicated an error, a negative error of 0.02. Using the vernier calipers the diameter, height of the metal block and the depth and the diameter of the holes in it. From these measurements the volume of the small holes and the actual volume of the material were calculated, the actual volume was 378c$cm^3. Te\ mass\ of\ te\ block\ was\ determined\ (1004)$.Usin tat mass and the volume calculated earlier the density was calculated and found to be $2.66\text{g}/cm^3$ .Using the micrometer screw gauge the thickness of the paper was found to be 0.096mm.Usin a 30 cm rule the lateral dimension of the paper were calculated. Using the thickness of the paper and the lateral dimension the volume of the paper was found to be $5.97\text{cm}^3, usin\ tis\ volume\ and\ te\ mass\ measured\ usin\ te$ beam the density of the paper was calculated and found to be 0.854g/cm^3.

CONCLUSION

The experiment was a success in tat the vernier caliper was used to measure the external lent, the internal diameter and the dept ole successfully. And the micrometer screw gauge was successfully used to measure smaller distances to the order of micron ($10\mu m$).

REFERENCES

P.C. Simpemba, J. Simfukwe and Mr. siatubi *PH 110 Laboratory Manual*, (2016), School of Mathematics and Natural Sciences, Department of Physical Sciences, Copperbelt University, Kitwe, Zambia.