To Determine Young's Modulus of Elasticity of the Material of a Given Wire

Aim

To determine Young's modulus of elasticity of the material of a given wire.

Apparatus

Searle's apparatus, two long steel wires of same length and diameter, a metre scale, a screw gauge, eight 1/2 kg slotted weights and a 1 kg hanger.

Description of Searle's Apparatus

Construction. Searle's apparatus consists of two metal frames F_1 and F_2. Each frame has torsion head at the upper side and hook at the lower side. These frames are suspended from two wires AB and CD of same material, length and cross-section. The upper ends of the wires are screwed tightly in two torsion heads fixed in same rigid support.
A constant weight of 1 kilogram is suspended from the hook of the frame F_2 attached to the auxiliary wire CD, which keeps the wire taut. A hanger H of 1 kilogram weight is suspended from the hook of the other frame F_1. The experimental wire AB can be loaded by slipping slotted weights on the hanger.
A spirit level rests horizontally with its one end hinged in the frame F_2. The other end of the spirit level rests on the tip of a spherometer screw fitted in the frame F_1. The spherometer screw can be rotated up and down along a vertical pitch scale marked in millimeter. The two frames are kept together by cross bars $E_1$and E_2.
Working. To perform the experiment, kinks are removed from the wire AB by loading and unloading it two or three times. All the weights are then removed from the hanger. The wire AB is kept taut under the weight of the hanger alone.
The spherometer screw is then rotated till the bubble comes in the middle of the spirit level. The spherometer disc reading is recorded for zero load.
A half kilogram weight is now slipped in the hanger. The wire AB extends and the frame F: moves down. The levelling is disturbed. The bubble is again brought in the middle by rotating the screw upwards. The distance by which screw is turned upwards gives the elongation of the wire due to half kilogram weight. A number of observations are taken by increasing the load on the hanger in steps of half kilogram each. The observations are then repeated by decreasing the load in the same order till all the weights are removed from the hanger. The mean of these observations is taken.
A graph is plotted between load M and mean extension l. It is a straight line. From the graph, mean increase in length l for a load M kg is found.
The measurements of length and radius of the wire are taken and value of Y is calculated from the relation,

$$Y = \frac{MgL}{\pi r^2 l} \text{ Nm}^{-2}.$$

Theory

If a wire of length L and radius r be loaded by a weight Mg and if l be the increase in length.

$$\text{Then, Normal stress} = \frac{Mg}{\pi r^2}$$

$$\text{and} \quad \text{Longitudinal strain} = \frac{l}{L}$$

$$\text{Hence, Young's modulus} = \frac{\text{Normal stress}}{\text{Longitudinal strain}}$$

$$\text{or} \qquad Y = \frac{Mg / \pi r^2}{l / L}$$

$$\text{or} \qquad Y = \frac{MgL}{\pi r^2 l}$$

Knowing L and r, and finding l for known Mg, Y can be calculated.

Diagram

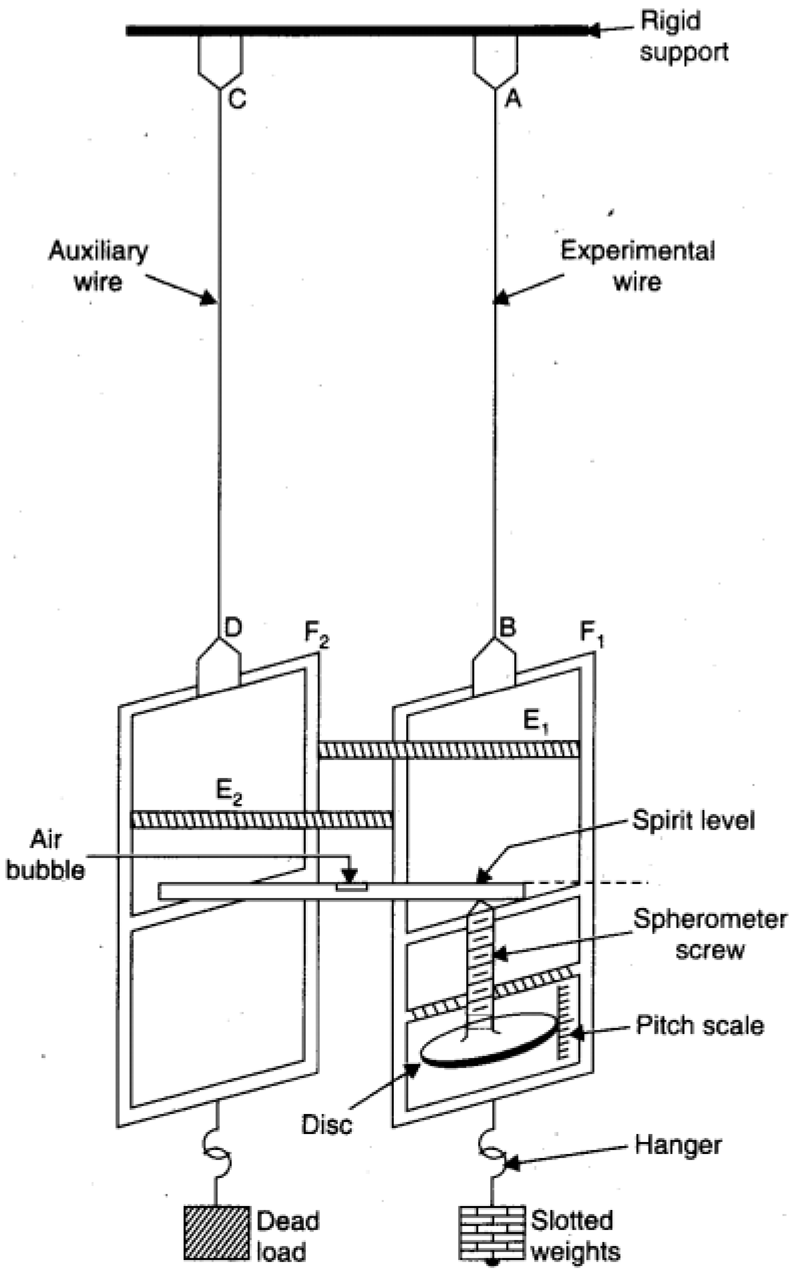

Fig. Searle's apparatus.

Procedure

1. Take two steel wires of same length and diameter and tight their ends in torsion screws A, B and C, D as shown in diagram. Wire AB becomes experimental wire and wire CD becomes auxiliary wire.

2. Suspend a 1 kg dead load from hook of frame F_2.
3. Suspend a 1 kg hanger and eight 1/2 kg slotted weights from hook of frame F_1. The experimental wire becomes taut.
4. Remove kinks from experimental wire by pressing the wire between nails of right hand thumb and first finger (through a handkerchief) and moving them along the length of the wire.
5. Remove all slotted weights from hanger. Now each wire is equally loaded with 1 kg weight.
6. Measure length of experimental wire from tip A to tip B using a metre scale.
7. Find the pitch and the least count of the screw gauge.
8. Measure diameter of the experimental wire at five different places, equally spaced along the length (near two ends, two quarter distance from ends and middle). At each place, measure diameter along two mutually perpendicular directions. Record the observations in the table.
9. Note the breaking stress for steel from table of constants. Multiply that by the cross section area of the wire to find breaking load of the wire. The maximum load is not to exceed one-third of the breaking load.
10. Find the pitch and the least count of the spherometer screw attached to frame F_1.
11. Adjust the spherometer screw such that the bubble in the spirit level is exactly in the centre. Note the reading of the spherometer disc. This reading is recorded against zero load.
12. Gently slip a 1/2 kg slotted weight in the hanger and wait for two minutes to allow the wire to extend fully. Bubble moves up from the centre.
13. Rotate the spherometer screw to bring the bubble back to centre. Note the reading of the spherometer disc. This reading is recorded against 1 kg load in load increasing column.
14. Repeat steps 12 and 13 till all the eight 1/2 kg slotted weights have been used (now total load on experimental wire is 5 kg which must be one-third of the breaking load).
15. Now remove one slotted weight (load decreasing), wait for two minutes to allow the wire to contract fully. Bubble moves down from the centre.
16. Repeat step 13. The reading is recorded against load in hanger in load decreasing column.
17. Repeat steps 15 and 16 till all the eight slotted weights are removed (now load on experimental wire is 1 kg the initial load).
    (Observations for same load in load increasing and in load decreasing column must not differ much. Their mean is taken to eliminate the error.)
18. Record your observations as given below.

Observations

Length of experimental wire AB, L = ……….cm
= ………..m.
Measurement of diameter of wire
Pitch of the screw gauge (p) = 0.1 cm
Number of divisions on the circular scale = 100
Least count of screw gauge (L.C.) =0.1/100 =0.001 cm.

Zero error of screw gauge (e) = …….cm.
Zero error of screw gauge (e) = -e =…….cm.

Table 1. Diameter of experimental wire

Serial No. of Obs.	Linear Scale Reading N (cm)	Circular Scale Reading		Total Reading N + n × (L.C.) d (cm)
		No. of division on reference line (n)	Value n × (L.C.) (cm)	
1. ⊖ ⊕				d_1 = d_2 =
2. ⊖ ⊕				d_3 = d_4 =
3. ⊖ ⊕				d_5 = d_6 =
4. ⊖ ⊕				d_7 = d_8 =
5. ⊖ ⊕				d_9 = d_{10} =

Measurement for extension of wire

Breaking stress for steel (from table), $B = \ldots\ldots \text{ N m}^{-2}$

Area of cross-section of wire, $\pi r^2 = \ldots\ldots \text{ cm}^2 = \ldots\ldots \text{ m}^2$

Breaking load, $= B\pi r^2 = \ldots\ldots \text{ N}$

$$= \frac{B \,.\, \pi r^2}{9.8} = \ldots\ldots \text{ kg} \quad (\because \quad 1 \text{ kg} = 9.8 \text{ N})$$

1/3rd of breaking load $= \ldots\ldots$ kg

Pitch of spherometer screw, (p) $= 0.1$ cm

Number of divisions in the disc $= 100$

Least Count of spherometer (L.C.) $= \frac{0.1}{100} = 0.001$ cm.

Table 2. load and extension

Serial No. of Obs.	Load on hanger M (kg)	Spherometer Screw Reading			Extension for load 2.5 kg
		Load increasing x (cm)	Load decreasing y (cm)	Mean $z = \frac{x+y}{2}$ (cm)	l (cm)
1.	0.0			$z_1 =$	
2.	0.5			$z_2 =$	
3.	1.0			$z_3 =$	
4.	1.5			$z_4 =$	
5.	2.0			$z_5 =$	
6.	2.5			$z_6 =$	$l_1 = (z_6 - z_1) =$
7.	3.0			$z_7 =$	$l_2 = (z_7 - z_2) =$
8.	3.5			$z_8 =$	$l_3 = (z_8 - z_3) =$
9.	4.0			$z_9 =$	$l_4 = (z_9 - z_4) =$

Calculations

From Table 1

Mean observed diameter of the wire,

$$d_0 = \frac{d_1 + d_2 + \ldots\ldots + d_{10}}{10} = \ldots\ldots \text{ cm.}$$

Mean corrected diameter of the wire,

$$d = (d_0 + c) = \ldots\ldots \text{ cm} = \ldots\ldots \text{ m.}$$

Mean radius of wire, $$r = \frac{d}{2} = \ldots\ldots \text{ m.}$$

From Table 2

Mean extension for 2.5 kg load

$$l = \frac{l_1 + l_2 + l_3 + l_4}{4} = \ldots\ldots \text{ cm} = \ldots\ldots \text{ m.}$$

From formula, $$Y = \frac{MgL}{\pi r^2 l} = \frac{2.5 \times 9.8 \times L}{\pi r^2 \times l} \text{ N m}^{-2}.$$

Calculation of M/l from graph
If we plot a graph between M and z taking M along X-axis and z along Y-axis, the graph comes to be a straight line. From it l for a known value of M can be calculated.
The same value can be used to get a single average value of Young's modulus Y.

Result

1. The Young's modulus for steel as determined by Searle's apparatus
$$= \ldots\ldots \text{ N m}^{-2}.$$
2. Straight line graph between load and extension shows that stress ∝ strain. This verifies Hooke's Law.

Percentage Error

Actual value of Y for steel (from tables)
$$= \ldots\ldots \text{ N m}^{-2}$$
Difference in values $= \ldots\ldots \text{ N m}^{-2}$

$$\text{Percentage error} = \frac{\text{Difference in values}}{\text{Actual value}} = \ldots\ldots \%.$$

It is within limits of experimental error.

Precautions

1. Both the wires (experimental and auxiliary) should be of same length, material and cross-section.
2. Both the wires should be supported from same rigid support.
3. Kinks should be removed from experimental wire before starting experiment.
4. Diameter of wire should be measured at different places and along two mutually perpendicular directions at every place.
5. Slotted weights should be added and removed gently.
6. Two minutes wait should be made after adding or removing a weight.
7. Load should be increased or decreased in regular steps.

Sources of error

1. Experimental wire may not have uniform cross-section throughout.
2. The slotted weights may not have standard weight.