MECHANICS OF MATERIALS-II

LABORATORY MANUAL

UET

DEPARTMENT OF MECHANICAL ENGINEERING

UNIVERSITY OF ENGINEERING & TECHNOLOGY
LAHORE (KSK CAMPUS)

ENGR.SHEERAZ ALI
(BSc. Mechanical Engineering UET, Lahore (City Campus))
(MSc. Thermal Power Engineering UET, Lahore (City Campus))

Submitted by:

Name =
Registration No =

Submitted to:

Preface

The Mechanics of materials Laboratory Manual is written to describe the experiments in Mechanics of Material Lab course. Each experiment procedure is explained thoroughly along with related background. The experiments are selected to apply some concepts from mechanics of materials such as analysis of materials properties based on tension, bending, and torsion. Some complementary topics are also presented such as using of some measuring tools. The use of these tools will help students to understand how to measure objects precisely, which is a crucial skill in lab. Experimental data analysis techniques, such linear regression, are also presented to help student to determine mathematical models based on data obtained.

Data Sheet is developed for each experiment to help student learn how to manage experimental data obtained and make it handy during calculations. The data sheet provides tables listing parameters and variable needed to be measured or obtained through experimental work. In addition, Post-Lab Assignments are given to enhance student understanding of concepts being applied practically.

Part of this manual is developed based on information obtained from books referenced at the last section of the manual. A sincere appreciation and credit should be given to authors of these books. Students are encouraged to check these resources for more information or interest in any topic.

General Instructions to Students

- The purpose of this laboratory is to reinforce and enhance your understanding to the strength of materials. The experiments here are designed to demonstrate the applications of the basic mechanics of materials principles and to provide a more intuitive and physical understanding of the theory. The main objective is to introduce a variety of classical experimental and diagnostic techniques, and the principles behind these techniques. This laboratory exercise also provides practice in making engineering judgments, estimates and assessing the reliability of your measurements, skills which are very important in all engineering disciplines.
- Read the lab manual and any background material needed before you come to the lab. You must be prepared for your experiments before coming to the lab. In many cases you may have to go back to your fluid mechanics textbooks to review the principles dealt with in the experiment.
- Actively participate in class and don't hesitate to ask questions. Utilize the teaching assistants. You should be well prepared before coming to the laboratory, unannounced questions may be asked at any time during the lab.
- Carelessness in personal conduct or in handling equipment may result in serious injury to the individual or the equipment. Do not run near moving machinery. Always be on the alert for strange sounds. Guard against entangling clothes in moving parts of machinery.
- Students must follow the proper dress code inside the laboratory. To protect clothing from dirt, wear a lab apron. Long hair should be tied back.
- Calculator, graph sheets and drawing accessories are mandatory.
- In performing the experiments, proceed carefully to minimize any water spills, especially on the electric circuits and wire.
- Make your workplace clean before leaving the laboratory. Maintain silence, order and discipline inside the lab.
- Cell phones are not allowed inside the laboratory.
- Any injury no matter how small must be reported to the instructor immediately.
- Wish you a nice experience in this lab

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3	To verify the relationship among load on spiral spring, number of turns and degree of rotation of a coil spring
4	To determine the deflection at mid span of a propped cantilever beam and compare with the theoretical values.
5	To determine what levels of combined bending and torsion cause elastic failure in different material and to compare them with various theories of failure.
6	To find out the horizontal and vertical deflection of a quarter circular beam loaded by vertical load, using the Curved Bar Apparatus.
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Lab Session 1

1.1 Objective:

To determine how the stiffness of a compression spring is affected by the physical dimensions of the springs.

1.2 Apparatus:

- Compression of Spring Apparatus
- Hangers
- Weights

Figure 1- 1 Compression spring apparatus

1.3Summery of Theory:

1.3.1 Spring:

A spring is an object that can be deformed by a force and then return to its original shape after the force is removed. Its sole purpose is to store and utilize the energy.

1.3.2 Deformations in springs:

There are broadly two types of deformation:

1.3.2.1 Elastic deformation:

When the stress is removed the material returns to the dimension it had before the load was applied. The deformation is reversible, non-permanent.

1.3.2.2 Plastic deformation:

This occurs when a large stress is applied to a material. The stress is so large that when removed, the material does not spring back to its previous dimension. There is a permanent, irreversible deformation. The minimum value of the stress which produces plastic deformation is known as the elastic limit for the material.

Any spring should be designed so that it only experience upto elastic deformation mostly for efficient working.

1.3.3 Hooke’s law:

Hooke's law states that the force (F) needed to extend or compress a spring by some distance x is proportional to that distance. That is,

$$F = kx$$

Where F is the force, x is the length of extension/compression and k is a constant of proportionality known as the spring constant which is usually given in N/m.

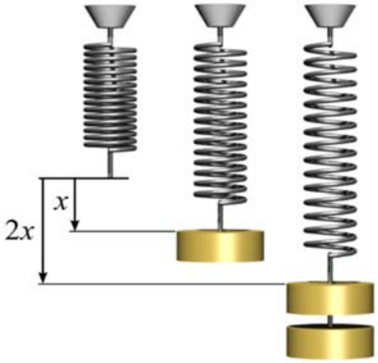


Figure 1- 2Hooke’s law visual representation

1.3.4 Material of spring:

Steel alloys are the most commonly used spring materials. The most popular alloys include high-carbon (such as the music wire used for guitar strings), oil-tempered low-carbon, chrome silicon, chrome vanadium, and stainless steel.

Other metals that are sometimes used to make springs are beryllium copper alloy, phosphor bronze, and titanium. Rubber or urethane may be used for cylindrical, non-coil springs. Ceramic material has been developed for coiled springs in very high-temperature environments. One-directional glass fiber composite materials are being tested for possible use in springs.

1.3.5 Types of springs according to loading conditions:

Springs can be classified depending on how the load force is applied to them:

1.3.5.1 Tension/extension spring

The spring is designed to operate with a tension load, so the spring stretches as the load is applied to it.

Figure 1- 3Extension spring

1.3.5.2 Compression spring

It is designed to operate with a compression load, so the spring gets shorter as the load is applied to it.

Figure 1- 4Compression spring

1.3.5.3 Torsion spring

The load applied to a torsion spring is a torque or twisting force, and the end of the spring rotates through an angle as the load is applied.

Figure 1- 5Torsion spring

1.3.5.3 Constant spring

In this the supported load will remain constant throughout the deflection of spring.

Figure 1- 6Constant spring

1.3.5.4 Variable spring:

In this, the resistance of the coil to load varies during compression.

Figure 1- 7Variable spring

1.3.6 Types of springs according to shapes:

1.3.6.1 Coil spring:

This type is made of a coil or helix of round wire.

Figure 1- 8Coil Spring

1.3.6.2 Flat spring:

This type is made of a flat spring steel.

Figure 1- 9Flat Spring

1.3.6.3 Machined spring:

This type of spring is manufactured by machining bar stock with a lathe and/or milling operation rather than a coiling operation. Since it is machined, the spring may incorporate features in addition to the elastic element. Machined springs can be made in the typical load cases of compression/extension, torsion, etc.

Figure 1- 10Machined Spring

1.3.6.4 Serpentine spring

A zig-zag of thick wire - often used in modern upholstery/furniture.

Figure 1- 11Serpentine Spring

1.4 Derivation of stiffness formula:

A spring may be defined as an elastic member whose primary function is to deflect or distort under the action of applied load; it recovers its original shape when load is released. Springs are energy absorbing units whose function is to store energy and to restore it slowly or rapidly depending on the particular application. In order to derive a necessary formula which governs the behavior of springs, consider a closed coiled spring subjected to an axial load W.

Let,

W = axial load

D = mean coil diameter

d = diameter of spring wire

N = number of active coils

G = modulus of rigidity

Δ = deflection of spring

Φ = Angle of twist

l = length of spring wire = πDN ---- (i)

In 1879, Alberto Castiglione' an Italian railroad engineer, published a book in which he outlined a method for determining the displacement / deflection & slope at a point in a body. This method which referred to Castiglione's Theorem is applied to the bodies, having constant temperature & material (homogeneous) with linear elastic behavior.

It states that **"The derivative of the strain energy with respect to the applied load gives the deformation corresponding to that load"**.

For a helical spring, the partial derivative of the strain energy w.r.t. the applied load gives the deflection in the spring i.e. $\partial U / \partial W$ = deflection.

Consider a helical compression spring made up of a circular wire and subjected to axial load W as shown in the figure above.

Strain Energy is given by:

$U = \frac{1}{2} T * \Phi$ ----- (ii)

Whereas,

$T = \frac{1}{2} W * D$ ----- (iii)

$\Phi = T\,l / JG$ ----- (iv)

(From Torsion formula) putting the values from eqs. # (i), (iii) & (iv) in eq. # (ii) and simplifying, we get;

$T = 4\,W^2 D^3 N / d^4 G$ ----- (v)

Now applying the Castiglione' theorem by taking the partial derivative of the strain energy with respect to the applied load

$\partial U / \partial W = \Delta = 8\,W D^3 N / d^4 G$ ----- (vi)

$W / \Delta = d^4G / 8 D^3N$

Stiffness = $K = d^4G / 8 D^3N$

1.5 Experimental Procedure:

1. A compression spring is already fitted to the apparatus on arrival.
2. To fit a new compression spring, remove the load hanger base by unscrewing the grip knob and base from the rod thread.
3. Loosen or remove the grip knob on the marker and pull the load hanger down until the top can be swung out from the slot by the 50 mm scale.
4. Withdraw the rod upward. The rod can now be threaded through the central hole in a compression spring and reverse the above procedure to return the apparatus to full working condition.
5. Clamp the marker so that the horizontal line is in line with the zero reading of the displacement scale.
6. Load the spring by 5N increments to a maximum of 55N,recording the change in length of the spring at each interval.

1.6 Observations and Calculations:

Spring Data			
	A	B	C
Wire diameter (d), mm			
Spring O/D, mm			
Spring Length (l), mm			
Number of active turns			

$$Stiffness = \frac{W}{\Delta} = \frac{d^4\,G}{8N\,D^3}$$

Where d = Wire diameter
N = Number of turns
D = mean diameter of spring coil (O/D – d)
G = Modulus of rigidity (77 KN/ mm^2 for spring steels)

Stiffness of Spring A=

Stiffness of Spring B=

Stiffness of Spring C=

1.6.1 Graph:

Deflection vs Load (Compression springs A, B & C)

1.6.2 Slope from Graph:

$$Slope \ = \frac{y_2 - y_1}{x_2 - x_1}$$

$Slope_A \ = $ ________ N/mm

$Slope_B \ = $ _________ N/mm

$Slope_c \ = $ _________ N/mm

Table 1.1 Calculations of deflections of different compression springs

Sr#	Load (N)	Deflection (mm)		
		Spring A	Spring B	Spring C
1				
2				
3				
4				
5				
6				

Average Percentage Error of Spring A= ________ %

Average Percentage Error of Spring A= ________ %

Average Percentage Error of Spring A= ________ %

1.7 Industrial Applications:

1.8 Statistical Analysis:

1.9 Conclusion:

Lab Session 2

2.1 Objective:

To measure the stiffness of an Extension spring and compare it with theoretical values.

2.2 Apparatus:

- Extension of spring apparatus
- Hangers
- Weights

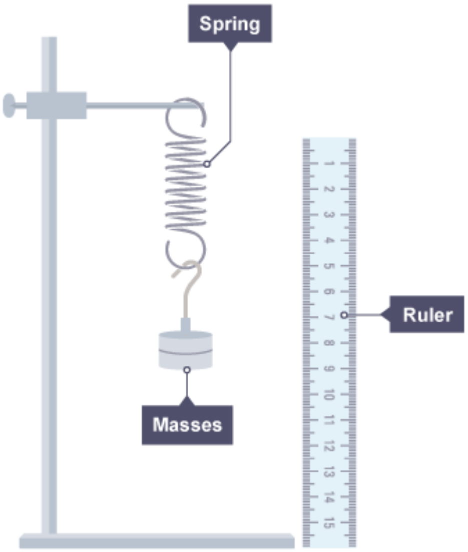


Figure 2- 1Extension Spring Apparatus

2.3 Summary of Theory:

- Refer to Lab Session 1

2.4 Procedure:

i Measure the diameter of wire and outer diameter of spring with the help of Vernier caliper.
ii Fit the extension spring in the spring support.
iii To fit compression spring, remove the load hanger base by unscrewing the grip knob and base from the rod thread.
iv . Loosen or remove the grip knob on the marker and pull the load hanger down until the top can be swung out from the slope.
v Withdraw the rod upward, insert the new spring and reverse the above procedure to return the apparatus to full working condition.
vi Load the spring by 10N increments recording the change in length of the spring up to the greatest readable deflection or the max load of 50N.
vii Record the spring dimensions Repeat the same process for other springs and record the readings.

2.5 Observations & Calculations:

Extension Springs Data			
	A	B	C
Wire diameter (d), mm			
Spring O/D, mm			
Spring Length (l), mm			
Number of active turns			

$$Stiffness = \frac{W}{\Delta} = \frac{d^4\,G}{8N\,D^3}$$

Where d = Wire diameter
N = Number of turns
D = mean diameter of spring coil (O/D – d)
G = Modulus of rigidity (77 KN/ mm^2 for spring steels)

Stiffness of Spring A=

Stiffness of Spring B=

Stiffness of Spring C=

2.5.1 Graph:

Deflection vs Load (Extension springs A, B & C)

2.5.2 Slope from Graph:

$$Slope \ = \frac{y_2 - y_1}{x_2 - x_1}$$

$$Slope_A \ = \ \_\_\_\_\_\_\_\_\_ \ N/mm$$

$$Slope_B \ = \ \_\_\_\_\_\_\_\_\_\_ \ N/mm$$

$$Slope_c \ = \ \_\_\_\_\_\_\_\_\_\_ N/mm$$

Table 2.1Calculations of deflections of different extension springs

Sr#	Load (N)	Deflection (mm)		
		Spring A	Spring B	Spring C
1				
2				
3				
4				
5				
6				

Average Percentage Error of Spring A= ________ %

Average Percentage Error of Spring A= ________ %

Average Percentage Error of Spring A= ________ %

2.6 Statistical Analysis:

2.7 Industrial Applications:

2.8 Conclusion:

Lab Session No. 3

3.1 Objective:

To verify the relationship among load on spiral spring, number of turns and degree of rotation of a coil spring

3.2 Apparatus:

- Coil Spring Apparatus
- Hanger
- Weights
- Two masses on the arm unit

Figure 3- 1Coil Spring Apparatus

3.3 Summary of Theory:

3.3.1 Spring:

Springs are elastic bodies, also termed as a resilient member (generally metal), that can be twisted, pulled or stretched by some force. They can return to their original shape when the force is released.

3.3.2 Helical spring

Helical spring is made of a wire coiled in the form of helix. Its cross sectional area is circular, square or rectangular. As shown above, helical spring are further classified on the basis of force that they experience.

3.3.3 Helical Tension Springs:

3.3.3.1 Characteristics:

a) It stretches apart to create load.
b) The gap between the successive coils is small.
c) The wire is coiled in a sequence that the turn is at right angles to the axis of the spring.
d) The spring is loaded along the axis.
e) By applying load, the spring elongates in action as it mainly depends upon the end hooks as shown in figure below.

3.3.3.2 Applications:

a) Garage door assemblies
b) Vise-grip piles
c) Carburetors

3.3.4 Helical Compression Springs

3.3.4.1 Characteristics:

a) The gap between the successive coils is larger.
b) It is made of round wire and wrapped in cylindrical shape with a constant pitch between the coils.
c) By applying the load, the spring contracts in action.

There are mainly four forms of compression springs as shown in figure. They are as follows:

a) Plain end
b) Plain and ground end
c) Squared end
d) Squared and ground end

Among the four types, the plain end type is less expensive to manufacture. It tends to bow sideways when applying a compressive load.

3.3.4.2 Applications:

a) Ball point pens
b) Pogo sticks
c) Valve assemblies in engines

3.3.5 Torsion Springs:

3.3.5.1 Characteristics:

a) It is also a form of helical spring, but it rotates about an axis to create load.
b) It releases the load in an arc around the axis as shown in figure.
c) Mainly used for torque transmission
d) The ends of the spring are attached to other application objects, so that if the object rotates around the center of the spring, it tends to push the spring to retrieve its normal position.

3.3.5.2 Applications:

a) Mouse tracks
b) Rocker switches
c) Door hinges
d) Clipboards
e) Automobile starters

3.3.6 Spiral Springs

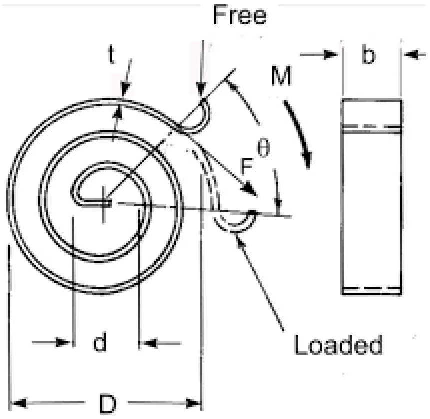


Figure 3- 2Spiral Spring Configuration

It is made of a band of steel wrapped around itself a number of times to create a geometric shape as shown in figure.

3.3.6.1 Applications

a) Alarm Time-Piece
b) Watch
c) Automotive Seat Recliners

3.4 Procedure:

i. Clamp the spring to give a number of active turns from 3 to 8 inclusive.
ii. Note the initial scale reading with the load hanger on the cord.
iii. Then add a weight and note the scale reading.
iv. Tabulate your results.

3.5 Observations & Calculations:

Wire diameter ____________ mm

Spring O/D ____________ mm

Modulus of rigidity ____________ N/ mm^2

Radius of the pulley ____________ mm

Width of the spring ____________ mm

Spring Thickness ____________ mm

Table 3.1Deflection variation on different number of active turns

Sr. No	**NO.OF ACTIVE COILS (N)**	**LOAD P**	**DEFLECTION ϴ^{o}**		
		(N)	*Lading*	*Unloading*	*Mean*
1					
2					
3					
4					
5					
1					
2					
3					
4					
5					
1					
2					
3					
4					
5					
1					
2					
3					
4					
5					

3.6 Statistical Analysis:

3.7 Industrial Applications:

3.8 Conclusions:

Lab Session 4

4.1 Objective:

To determine the deflection at mid span of a propped cantilever beam and compare with the theoretical values.

4.2 Apparatus:

- Propped cantilever beam apparatus
- Weights
- Dial gauge
- Vernier Caliper
- Specimen
- Hangers
- Spanner

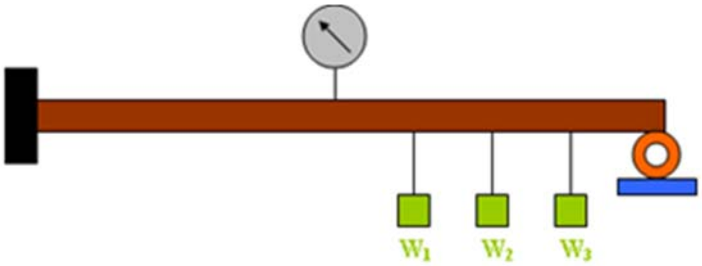


Figure 4- 1Propped Cantilever Beam

4.3Summery of Theory:

A beam is a structural element that is capable of withstanding load primarily by resisting bending.

4.3.1Classification of beams :

The beams may be classified in several ways, but the commonly used classification is based on support conditions. On this basis the beams can be divided into six types:

(1) Cantilever beams (2) Simply supported beams (3) Overhanging beams
(4) Propped beams (5) Fixed beams (6) Continuous beams

4.3.1.1Cantilever beam:

A beam having one end fixed and the other end free is known as cantilever beam, figure shows a cantilever with end ‘A’ rigidly fixed into its supports, and the other end ‘B’ is free. The length between A and B is known as the length of cantilever.

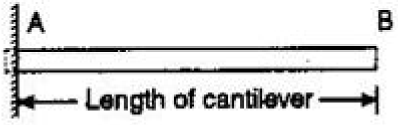


Figure 4- 2Cantilever beam

4.3.1.2Simply supported beam:

A beam having both the ends freely resting on supports is called a simply supported beam. The reaction act at the ends of effective span of the beam. Figure show simply supported beams. For such beams the reactions at the two ends are vertical. Such a beam is free to rotate at the ends, when it bends.

4.3.1.3Overhanging beams:

A beam for which the supports re not situated at the ends and one or both ends extend over the supports, is called an overhanging beam. Figure represents overhanging beams.

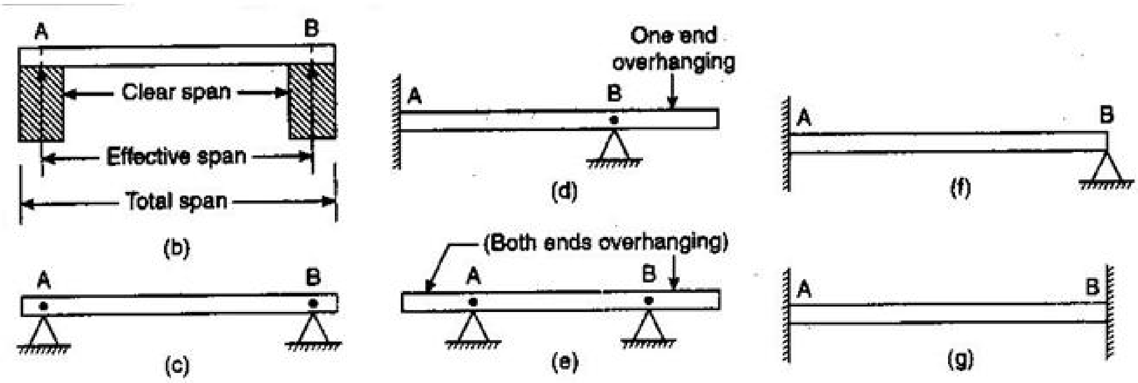


Figure 4- 3Overhanging beams

4.3.1.4Propped cantilever beams:

A cantilever beam for which one end is fixed and other end is provided support, in order to resist the deflection of the beam, is called a propped cantilever bema. A propped cantilever is a statically indeterminate beam. Such beams are also called as restrained beams, as an end is restrained from rotation.

4.3.1.5Fixed beams:

A beam having its both the ends rigidly fixed against rotation or built into the supporting walls, is called a fixed beam. Such a beam has four reaction components for vertical loading (i.e., a vertical reaction and a fixing moment at both ends) figure shows the fixed beam.

4.3.1.6Continuous beam:

A beam having more than two supports, is called as continuous beam. The supports at the ends are called as the end supports, while all the other supports are called as intermediate support. It may or may not have overhang. It is statically indeterminate beam. In these beams there may be several spans of same or different lengths figure shows a continuous beam.

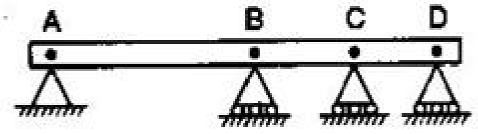


Figure 4- 4Continuous beam

4.3.2Derivation of formula for deflection at mid span.

(Derive the formula as for experiment conditions)

4.4Procedure:

i. Measure the width and depth of the beam with the help of scale to find the moment of inertia of the beam.
ii. Set the apparatus and put the required hangers at different points.
iii. Measure the distances of each hanger from the reference end.
iv. Set the deflection dial gauge at zero after putting the hangers.
v. Take the reading of deflection after putting the loads in the hangers
vi. Repeat the process for different loads
vii. Find the theoretical deflection and compare with the experimental values by showing on a graph

4.5 Observations and Calculations:

Width of Beam = b = ________ mm
Depth of beam = d = _________ mm
Moment of Inertia for rectangular metal bar = I = $bd^3/12$
Modulus of Elasticity = E =

Table 4.1Variation in deflection with loads

Obs.No	***LOADS (N)***			δ **exp**	δ **th**	***%age Error***
	W_1	W_2	W_3			
1						
2						
3						
4						
5						
6						

4.5.1 Graph:

On graph, plot the deflection against load for the theoretical & practical results. Draw the best-fit straight lines through the points

Deflection vs Load

4.6 Industrial Applications:

4.7 Statistical Analysis:

4.8 Conclusion:

Lab Session 5

5.1 Objective:

To determine what levels of combined bending and torsion cause elastic failure in different material and to compare them with various theories of failure.

5.2 Apparatus:

- Combined bending and torsion
- Weight
- Dial gauge
- Vernier Caliper
- Specimen
- Hanger
- Spanner

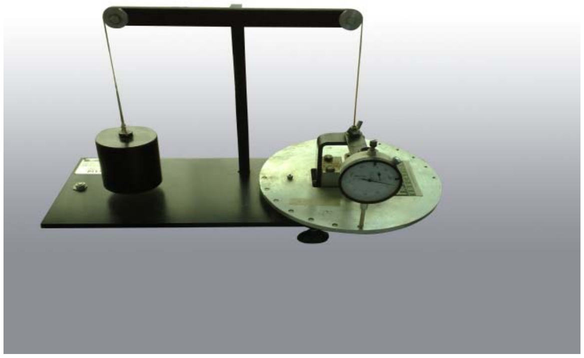


Figure 5- 1Combined Bending and Torsion Apparatus

5.3Summery of Theory:

5.3.1Theories of Elastic Failures:

1. Maximum Principal Stress Theory (Rankine, Lamé)
2. Maximum Principal Strain Theory (Saint-Venant)
3. Maximum Shear Stress Theory (Tresca, Guest, Coulomb)
4. Total Strain Energy Theory (Beltrami-Haigh)
5. Maximum Distortion Energy Theory (Huber-Henky-von Mises)
6. Mohr's Fracture Criterion

Many experiments have been conducted under complex stress system to study the behavior of different materials & it has been shown that:

1. Materials does not fail under hydrostatic stress system i.e $\sigma_1 = \sigma_2 = \sigma_3$
2. None of the theories agrees with the test perform for all types of materials and combinations of loads.
3. There is a good agreement between the maximum distortion energy theory and experimental result for ductile materials.
4. The max. principal stress theory appears to be the best for brittle materials
5. Max. Shear stress or max. Strain energy theories give the good approximation for ductile materials but the max. Shear stress criterion is somewhat more conservative.
6. The max. Strain theory should not be used in general as it only gives the reliable results in particular cases.
7. If the brittle material has a stress strain diagram, that is different in tension and compression, then the MOHR'S Failure Criterion may be used to predict the failure.

5.4 Procedure:

i. Record the material and neck diameter for the test specimen being used into table 5.1.

ii. Place the apparatus near the corner of a worktop with the circular loading plate overhanging the edge. The dial gauge side should face the other edge of the corner.

iii. Record the weight the of the load hanger. Put the first specimen in the apparatus and clamp it as described above. Set the dial gauge diametrically opposite the zero degrees load point and use the adjustable bezel to zero the outer ring against the large pointer.

iv. Put the load hanger on the zero degree dimples and enter the dial gauge reading in the column marked DTI rdg in table 5.1. This will be the zero load reading. Add 4Nto the load hanger and again enter the dial reading in table 1a. In the column diff in table 1a, fill in the difference, this should be similar to one before for linear elasticity.

v. Repeat the 4n increments while carefully watching for a trend to increasing differences as the linearity limit is reached. As the end of the linearity approaches reduce the load increments to 2N and then 1N, reckoning the differences between successive load in proportion. Try to stop adding more load before there is a 10% increase in the differences.

vi. As soon as non-linearity is determined unload the hanger and remove it move the dial gauge round by 15°and re-zero. Then repeat the above procedure. Carry on doing this until the loading at 90° has been completed.

vii. Unclamp the specimen and replace it with a new one of the same material. The whole of the foregoing procedure can then be followed, but starting at 90° position and working back by 15° interval to the 0° position. The results should be recorded in table 1b.

5.5 Observations and Calculations:

Table 5.1 Variation of Torque and Moment

Material	**Steel**	T_{max}=____________	T =0.1 W_l Cos Ø
Neck diameter ,mm	________________	M_{max}=____________	M=0.1 W_l Sin Ø
Hanger weight(N)	**4.6**		

Added Load	0°		15°		30°		45°		60°		75°		90°	
(N)	Rgd	Diff	Rgd	Diff	Rgd	Diff	Rgd	Diff	Rgd	Diff	Rgd	Diff	Rgd	Diff
1														
2														
3														
4														
5														
6														
7														
8														
T														
M														

5.6 Graph:

Torque Vs Moment

5.7 Statistical Analysis:

5.8 Conclusion:

Lab Session No. 6

6.1 Objective:

To find out the horizontal and vertical deflection of a quarter circular beam loaded by vertical load, using the Curved Bar Apparatus.

6.2 Apparatus

- Curved Bar Apparatus
- Weight
- Quarter circular beam apparatus
- Dial gauge
- Vernier Caliper.

Figure 6- 1Quarter Circular Curved Bar Apparatus

6.3 Summary of Theory:

- Beams/ Types
- Curved bars / deflection of curved bars
- Derivation of formulae

6.4 Procedure:

i. Adjust the quarter circular bar .
ii. Attach two dial gauges for finding vertical as well as horizontal deflection
iii. Load the bar for number of times by an equal amount of 1N each time and note the corresponding readings from dial gauges attached to the apparatus, for vertical and horizontal deflection.
iv. Multiply those observations with the least count of the dial gauges and note out the final deflections

6.5 Observations & Calculations:

Radius of curved bar = R =

Width of the bar = b =

Thickness of the bar = d =

Modulus of Elasticity = E=

Moment of Inertia= I=

6.5.1 Specimen calculations

Table 6.1Calculation of horizontal and vertical deflection with load

Sr. No.	**LOAD W (N)**	**Dial Gauge Reading**		**Experimental Deflection (mm)**		**Theoretical Deflection (mm)**	
		H	*V*	δH	δV	$\delta H = WR^3/2EI$	$\delta V == \Pi WR^3/4EI$
1							
2							
3							
4							
5							
6							
7							

6.5.2 Graph: On graph plot the deflection against load for horizontal & vertical deflection for the theoretical & practical results. Draw the best fit straight lines through the points.

6.6 Statistical Analysis:

6.7 Industrial Applications:

6.8 Conclusions:

Lab Session No. 7

7.1 Objective:

To find out the horizontal and vertical deflection of a Semicircular beam loaded by vertical load, using the Curved Bar Apparatus.

7.2 Apparatus

- Curved Bar Apparatus
- Weight
- Semicircular beam apparatus
- Dial gauge
- Vernier Caliper.

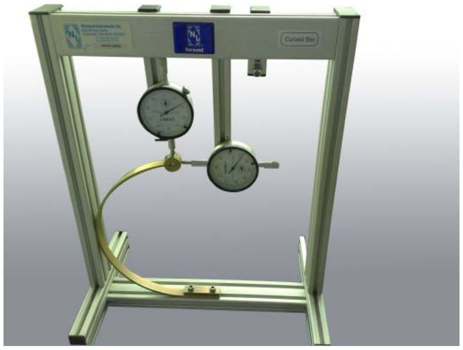


Figure 7- 1Semi Circular Curved Bar Apparatus

7.3 Summary of Theory:

- Beams/ Types
- Curved bars / deflection of curved bars
- Derivation of formulae

7.4 Procedure:

i. Adjust the semicircular bar .
ii. Attach two dial gauges for finding vertical as well as horizontal deflection
iii. Load the bar for number of times by an equal amount of 1N each time and note the corresponding readings from dial gauges attached to the apparatus, for vertical and horizontal deflection.
iv. Multiply those observations with the least count of the dial gauges and note out the final deflections

7.5 Observations & Calculations:

Radius of curved bar = R =

Width of the bar = b =

Thickness of the bar = d =

Modulus of Elasticity = E=

Moment of Inertia= I=

7.5.1 Specimen calculations:

Table 7.1Variation of deflection with load of a semi-circular beam

Sr. No.	**LOAD W (N)**	**Dial Gauge Reading**		**Experimental Deflection (mm)**		**Theoretical Deflection (mm)**	
		H	V	δH	δV	$\delta H = 7WR^3/4EI$	$\delta V == \Pi WR^3/2EI$
1							
2							
3							
4							
5							
6							
7							

7.5.2 Graph: On graph plot the deflection against load for horizontal & vertical deflection for the theoretical & practical results. Draw the best fit straight lines through the points.

7.6 Statistical Analysis:

7.7 Industrial Applications:

7.8 Conclusions:

Lab Session No. 8

8.1 Objective:

To determine experimentally the deflection at two points on a simply-supported beam carrying point loads and to check the results by Macaulay's method.

8.2 Apparatus

- Beam deflection apparatus
- steel beam
- two dial test-indicators and stands
- micrometre
- rule
- two hangers
- weights.

8.3 Summary of Theory:

Consider the simply-supported beam loaded as shown in fig.8.1.

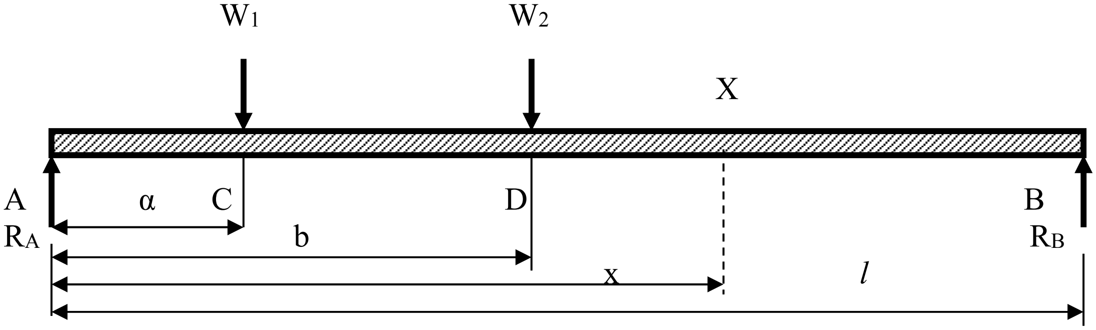


Figure 8- 1Free Body diagram of simply supported beam

For values of x between b and l

$$M_{XX} = R_A x - W_l(x-a) - W_2(x-b) \qquad \text{(i)}$$

For values of x between a and b

$$M_{XX} = R_A x - W_l(x-a) \qquad \text{(ii)}$$

For values of x between o and a

$$M_{XX} = R_A x \qquad \text{(iii)}$$

Eqn. (i) gives the bending moment at any section of the beam provided bracketed terms are discarded when they become negative. For this reason, the bracketed terms are known as the "Macaulay Ghost Terms".

Since $$EI\frac{d^2y}{dx^2} = M$$

$$\mathrm{EI}\frac{d^2y}{dx^2} = R_A x - W_1(x-a) - W_2(x-b) \qquad \text{(iv)}$$

In Macauley's method, the bracketed terms are intergraded as a whole. This is justified since

$$\int_{x_x}^{x_1}(x-a)dx = \qquad \int_{x_2}^{x_1}(x-a)d(x-a)$$

$$\mathrm{EI}\frac{dy}{dx} = R_A\frac{x^2}{2} - \frac{W}{2}(x-a)^2 - \frac{W2}{2}(x-b)^2 + A \qquad \text{(v)}$$

$$\mathrm{EIy} = R_A\frac{x^3}{6} - \frac{W1}{6}(x-a)^3 - \frac{W2}{6}(x-b)^3 + AX + B \qquad \text{(vi)}$$

By integrating the bracketed quantities as a whole, the constants A and B have the same values for all values of x.

This may be shown to be the case as follows:

Put x = a in eqn. (v) and omit the term in (x-b) since it is then negative.

Then, $$EI\frac{dy}{dx} = R_A\frac{a^2}{2} - \frac{WI}{2}(a-a)^2 + A$$

$$= R_A\frac{a^2}{2} + A$$

For values of x between o and a

$$\mathrm{EI}\frac{d^2y}{dx^2} = R_A x$$

Integrating

$$\mathrm{EI}\frac{dy}{dx} = R_A\frac{x^2}{2} + A_1$$

Putting x = a

$$\mathrm{EI}\frac{dy}{dx} = R_A\frac{a^2}{2} + A_1$$

Since the two equations concern the slope dy/dx at the same point that the constants A and A_1 must be equal. Similarly by putting x = b it may be shown that the constant is again A.

The actual values of the constants A and B are obtained from the boundary conditions, that is, in eqn. (vi):
y = o when x = o and

y = o when x = 1

In the particular case considered, B = o.

8.4 Procedure:

8.4.1 Procedure (Experimental)

Assemble the apparatus as shown in fig. 8.2 with the beam simply supported at its ends A and B. Place load hangers at point C and D distant a and b

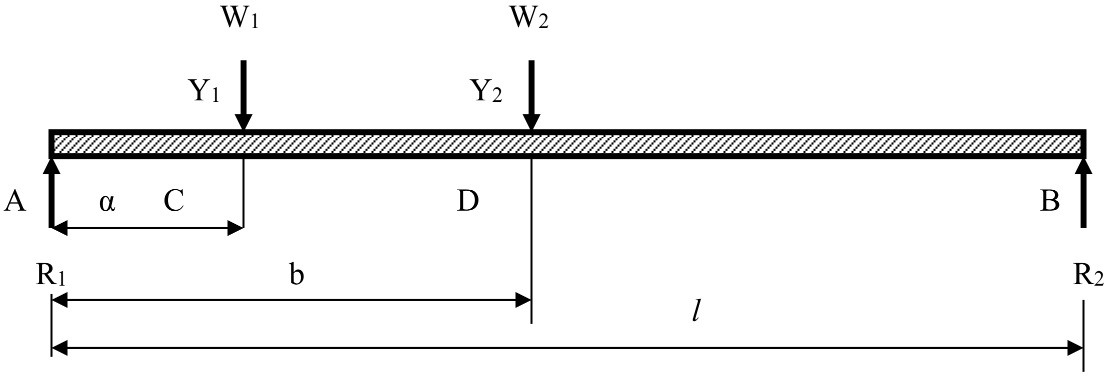


Figure 8- 2

Respectively from end A. Select two points X and Y approximately in positions shown in the figure and set up the dial gauges to bear at these points on the upper surface of the beam. Zero the dial gauges with the hangers in position.

Apply suitable loads W_1 and W_2 at C and D respectively and note the deflections at X and Y as indicated by the dial gauges. Record the values of W_1 and W_2 and the corresponding deflections at X and Y. Sketch the arrangement and indicate on the sketch the distances a, b, and l. Also the distances of points X and Y from end A.

Measure the cross-sectional dimensions of the beam, using a micrometer.

Calculate the deflections at X and Y, using Macaulay's method and compare the values with the observed results.

8.4.2Procedure (Calculations)

1. Set up an expression for the bending moment for any section in the extreme right-hand panel of the beam, measuring x from the left-hand end. Put in square brackets, the 'ghost'
2. Integrate to obtain the slope equation and again to obtain the deflection equation and again to obtain the deflection equation, adding the constants A and B respectively at each stage. Integrate the 'ghost' terms as a whole.

3. Calculate the constants A and B from the condition that the deflection y is zero at the two values of x corresponding with the supports. Omit negative 'ghost' terms.
4. To determine slope or deflection at a particular point on the beam substitute the corresponding value of x in the appropriate expression and omit any 'ghost' term which may become negative.

8.5 Observation & Calculations:

Table 8.1 Observation table

Width of beam, b (m)	
Thickness of beam, d (m)	
Span, l (m)	
Load W_1 (g)	
Load W_2 (g)	
Distance a (m)	
Distance b (m)	
Deflection at Y_1 (mm)	
Deflection at Y_2 (mm)	
Young's Modulus, E = 210 GPa (assumed)	

8.5.1Specimen calculations:

Second moment of area of beam cross-section $I = \frac{bd^3}{12} = m^4$

Reaction R_A =…………………… Reaction R_B =……………………..

Flexural rigidity EI =
By means of Macaulay's method calculate the deflection at the points X and Y using the appropriate values of x and tabulate the results, as follows:

Point	Observed Deflection	Calculated Deflection
1		
2		

8.5.2 Graph:

8.6 Statistical Analysis:

8.7 Conclusions:

Lab Session No.9

9.1Objective:

To examine the Rockwell Hardness testing machine and perform the Rockwell hardness test.

9.2 Apparatus:

- Rockwell hardness testing machine
- Specimen of mild steel/ cast iron etc.

9.3 Theory:

A large number of different definitions exist for the term “hardness”. Wear resistance, deformation behavior, tensile strength, as well as modulus of elasticity are, among others, associated with the term “hardness”. Hardness testing is almost nondestructive and serves in many cases for the determination of characteristic quantities or parameters which can be used for distinguishing and describing materials. Hardness values give e.g. information about the mechanical properties (i.e. strength) of the material at low cost.
In general, the technical hardness is to be understood as **the resistance of a material to the penetration of an indenter made of a harder material.**

Hardness is consequently no fundamental quantity of a material but the material’s responseto a certain load or test method. A hardness value is then calculated from this response of the material to the specific test. This means that, depending on the test method, other numerical values are determined which are defined or characterized by the shape and material of the indenter, as well as by the type and size of test load.

9.3.1Why hardness testing?

Within the production and assembly, hardness of materials or components is mainly tested for two reasons: Firstly, in order to define characteristic features of new materials and, secondly, for reasons of quality assurance by conforming to the required specifications.
The most common **uses for hardness tests** is to verify the heat treatment of a part and to determine if a material has the properties necessary for its intended use. Establishing a correlation between the hardness result and the desired material property allows this, making hardness tests very useful in industrial and R&D applications
Five Determining Factors
The following five factors can be used to determine the correct hardness test for application.

- **Material** - grain size, metal, rubber, etc.
- **Approximate Hardness** - hardened steel, rubber, etc.
- **Shape** - thickness, size, etc.
- **Heat Treatment** – through or casehardened, annealed, etc.
- **Production Requirements** - sample or 100%

9.3.2Hardness testing diamond indenter:

An indenter used in hardness testing apparatus to penetrate hard metals and other materials consists of a shank body having at its end a conical frustum with a cylindrical recess extending axially from that end, and a cone of polycrystalline diamond bonded to a hard metal rod which, in turn is bonded in the cylindrical recess concentrically with the axis of the body.

The various **<u>Test Methods Classification</u>** may be subdivided into two classes:

a) Static test methods

Figure 9- 1Rockwell Hardness Testing Machine

In these methods, the load is applied statically or quasi-statically. The hardness value is defined by means of the permanent test indentation after removing the test load as the quotient of test load and the surface or projection surface of the permanent indentation · It invovlves

- Rockwell Hardness Test
- Brinell Hardness Test
- Vickers Hardness Test
- Knoop Hardness Test
- Meyers Hardness Test

9.3.3Rockwell Hardness Test:

The Rockwell method **measures the permanent depth of indentation** produced by a force on an indenter. First, a preliminary test force (pre-load or minor load) is applied to a sample using a diamond indenter. This is the zero or reference position that breaks through the surface to reduce the effects of surface finish. Then, an additional test force (or major load) is applied to reach the total required test force. This force is held for a predetermined amount of time to allow for elastic recovery. The additional test force is then released and the final position is measured against the preliminary position and converted to a hardness number. Preliminary test forces range from 3 kg (used in "Superficial" Rockwell scale) to 10 kilograms (used in "Regular" Rockwell scale) to 200 kilograms (macro scale - not part of ASTM E-18; see ASTM E-1842). Total test forces range from 15 through 150 kilograms (superficial & regular) to 500 through 3000 kilograms (macro). A variety of indenters may be used: a conical diamond with a round tip for harder metals, and ball indenters ranging from 1/16" to 1/2" for softer and softer materials

A. Depth reached by indenter after application of preliminary test force (minor load).
B. Position of indenter under total test force.
C. Final position reached by indenter after elastic recovery of the material.
D. Position at which measurement is taken.

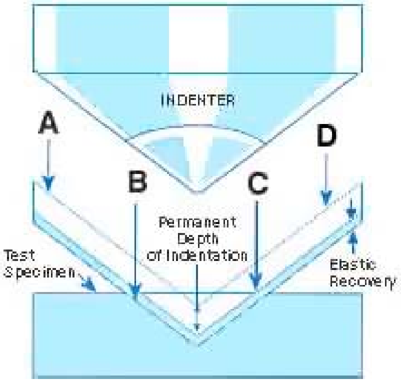


Figure 9- 2Indenter

In bench Rockwell hardness testing systems, all can handle large parts, however the **Versitron** can usually test large parts more quickly and accurately, when compared to other bench testers which require external support stands or fixtures. The **Indentron**, on the other hand, is much easier to use on small, awkward parts.

Selecting a Rockwell scale, the operator should select the scale that specifies the largest load and smallest indenter possible to do the job without exceeding defined operating conditions and accounting for conditions that influence the test result. These influencing conditions include test specimens which are below the minimum thickness for the depth of indentation

Indentron Rockwell Hardness Testing System

The Indentron uses a cantilevered indenter and a unique, low friction, semi-automatic loading system.

- Provides the highest level of repeatability due to a technology that has virtually frictionless operation.
- Cantilevered indenter can test inside diameters and other difficult configurations without special setup.
- Many electronic capabilities for data storage, printing reports and SPC.
- Semi automatic or automatic operation.
- Six models from which to choose.

Figure 9- 3Indentron Rockwell Hardness Testing Machine

9.3.4Common problems in rockwell hardness testing:

Problems related to accuracy, repeatability, and/or correlation usually
Can be traced to one or more of five **causes**:

- Machine
- Operator
- Environment
- Sample prep
- Calibration.

Bad indenter

The most common problem we hear is, “machine is reading high.” This always raises the “bad indenter” flag. In the case of testing hardened steels, diamond indenters are required to penetrate the material. Diamonds are used because of their hardness and ability to maintain their geometrical form. However, the very trait that enables diamonds to penetrate steel — high hardness — is also their Achilles’ heel. A diamond’s hardness renders it brittle, and an impact or shock can cause it to break, changing its dimensional form from a radiuses tip to a flat or other non-spheroconical shape.

Deflections

Machine deflection caused by dirt, grease, burrs, and other sources is also a significant contributor to machine errors. Most Rockwell-scale testers are unable to compensate for deflection (or movement) under load. (The Newage Versitron is an exception.)

Anvils

An often overlooked source of error is the anvil. Rough gouged anvil surfaces, anvil surfaces that have been inadvertently hardness tested, and anvil surfaces that are worn or ground to a taper can all spell disaster. In conventional Rockwell testers. These surfaces should be lapped together every few service visits to ensure that they are flat.

Surface preparation-related causes

Though the Rockwell method begins its hardness measurement beneath the surface of the part, the inherent variability of a rough surface can and will cause inconsistent results. Surface coatings or hardened layers also can provide deceptive results. If you want to test the hardness of a coating or surface layer, use a load/indenter combination that will ensure that the measurement is taken in the coating or layer

9.3.5 Test Specifications:

Scale Name	Indenter	Major Load	Minor Load	Applications
Regular Rockwell Scales				
A	Diamond	60 kg	10 kg	Cemented carbides, thin steel and shallow case hardened steel
B	1/16" ball	100 kg	10 kg	Copper alloys, soft steels, aluminum alloys, mealleable iron
C	Diamond	150 kg	10 kg	Steel, hard cast irons, pearlitic malleable iron, titanium, deep case-hardnened steel and the materials harder than HRB100
D	Diamond	60 kg	10 kg	Thin steel and medium case-hardnened steel and pearlitic malleable iron
E	1/8" ball	100 kg	10 kg	Cast iron, aluminum and magnesium alloys, bearing metals
F	1/16" ball	60 kg	10 kg	Annealed copper alooys, thin soft wheet metals.
G	1/16" ball	150 kg	10 kg	Phosphor bronze, beryllium copper, malleabel irons. Upper limit is HRG 92 to avoid possible flattening of the ball.
H	1/8" ball	100 kg	10 kg	Aluminum, Zinc, Lead
K	1/8" ball	150 kg	10 kg	Bearing metals and otehr very soft or thin materials. Use samllest ball and heaviest load that do not give an anvil effect
L	1/4" ball	60 kg	10 kg	[Same as K]
M	1/4" ball	100 kg	10 kg	[Same as K]
P	1/4" ball	150 kg	10 kg	[Same as K]
R	1/2" ball	60 kg	10 kg	[Same as K]
S	1/2" ball	100 kg	10 kg	[Same as K]
V	1/2" ball	150 kg	10 kg	[Same as K]

9.3.6Brinell Hardness Test:

Widely used on castings and forgings, the Brinell method applies a predetermined test force (F) to a hard steel or carbide ball of fixed diameter (D) which is held for a predetermined time and then removed. The resulting indentation is measured across at at least two diameters - usually at right angles to each other and averaged (d). A chart is then used to convert the averaged diameter measurements to a Brinell hardness number. Test forces range from 500 to 3000 kilograms

Also available in optical, digital as well as computerized models. In computerized Model, Brinell indentation can be automatically measured and hardness value is displayed on the screen .Strictly confirms IS 2281 & BS 240

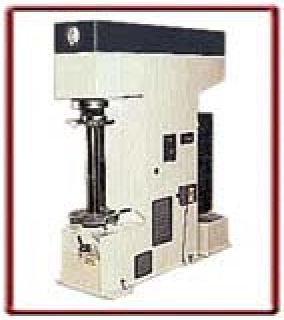
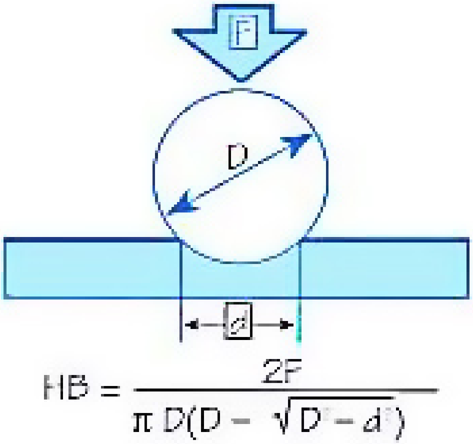


Figure 9- 4Brinell Hardness Testing Machine

Brinell Measurement Calculation
D = ball diameter
d = impression diameter
F = load
HB = Brinell Result



9.3.7 Vickers Hardness Test

These machines are designed for very high accuracy, reliability and ease of operation.

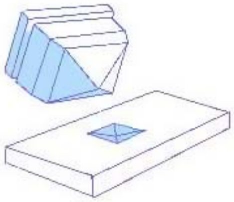
Wide Testing range – From soft to hard material, very thin to big samples. Built in projection screen with Micrometer (L.C. 0.001 mm) to get accurate results. Max.Magnification – 140 X Also available with Brinell loads. Test loads – From 1 kgf to 250 kgf in computerized Model, Vickers indentation can be automatically measured and hardness value is displayed on the screen. Strictly confirms IS 1754 for Vickers and IS 2281 & BS 240 for Brinell loads.

Figure 9- 5Vicker hardness testing machine

Mostly used for small parts, thin sections, or case depth work, Vickers and Knoop methods are based on an optical measurement system. The new Computer Assisted Measurement System (C.A.M.S.), now available from Newage Testing Instruments, Inc., has improved productivity, accuracy and repeatability of these labor intensive methods. To perform a test, a predetermined test force is applied with a pyramidal shaped diamond indenter. After a dwelt time, the force is removed. Then, in the Vickers method, the indentation length of vertical and horizontal axis is measured and averaged. In the Knoop method, only the tong axis is measured. A chart is used to convert the measurements to corresponding Vickers or Knoop hardness numbers, Test forces range from 1 to 2000 grams, Vickers does offer higher force capabilities - up to 150 kgs.

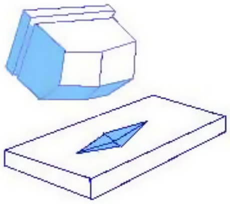
Vickers Test

opposing indenter faces are set at a 136 degree angle to each other



Knoop(Test)

Long side faces are set at a 172 degree, 30 minute angle to each other. Short side faces are set at a 130 degree angle to each other



9.3.8 Scratch Test

In this form of test a stylus is traversed across the surface of a flat specimen with either constant or increasing load. The experimental set-up for in-plan scratch testing is shown in Figure. Specimen preparation is minimal and the only limitation is that the specimen should be large enough to clamp without interfering with the movement of the stylus parallel to the plane of the traverse table.

The test parameters that must be monitored are the normal (applied) load and horizontal displacement. It is also desirable to monitor cracking events using acoustic emission (AE) and/or the horizontal (frictional) load to aid in the correlation of forces with inspection of the scratch path.

The significant result derived from the scratch test is the critical load for scale failure. This parameter is derived from visual inspection of the scratch track in conjunction with the vertical and horizontal load traces

Failure of the oxide/coating during scratch testing may occur by one of a number of mechanisms. The most important of these in terms of their relevance to spallation are buckling and wedge failures and quantitative interpretation of scratch testing is limited to the latter . The analysis , which applies to failure by initial wedge cracking in the surface layer, requires that the critical load for failure is measured as a function of oxide/coating thickness and residual stress. A straight line fit is used and the fracture stress is defined as the intercept ie failure when the imposed stress is zero; the gradient of the line, a, defines the relationship between the critical load in the scratch test and the imposed stress. This can be represented analytically by the expression:-

$$\sigma_F = \sigma_R + aL_c$$

L_c is the critical load measured in the scratch test

aL_c is equivalent to s_s.

Advantages

- The highest precision and accuracy is guaranteed by the digital measuring system
- Automatic test, for hardness measurements on moulded parts, with complicated and uneven shapes, and plate materials in all durometer and IRHD ranges
- Operating mode Hysteresis (data logging in connection with PC), for observation of the flow and recovery characteristics of a test object under load and after removing the load.
- Plug-in system: The measuring devices will only be plugged into the pick-up bracket, the measuring devices are identified automatically, and therefore there is no need to adjust the measuring distance.
- Through a short recess time and easy operation and handling of this intelligent system, results can be obtained quickly and reliably. There is no need to do any preselections.
- Temperature does not have any influences on the measuring devices, and therefore there is no need to adjust the measuring distance.
- Measuring devices can be integrated into production lines, or automatic manufacturing processes

Hardness represents the resistance of material surface to abrasion, scratching and cutting, hardness after gives clear indication of strength. In all hardness tests, a define force is mechanically applied on the piece, varies in size and shape for different tests. Common indenters are made of hardened steel or diamond. Rockwell hardness tester presents direct reading of hardness number on a dial provided with the m/c. principally this testing is similar to Brinell hardness testing. It differs only in diameter and material of the indenter and the applied force. Although there are many scales having different combinations of load and size of indenter but commonly ‘C’ scale is used and hardness is presented as HRC. Here the indenter has a diamond cone at the tip and applied force is of 150 kgf. Soft materials are often tested in ‘B’ scale with a 1.6mm dia. Steel indenter at 60kgf.