MIT-WORLD PEACE UNIVERSITY, PUNE

First Year B. Tech

DEPARTMENT OF CIVIL ENGINEERING

ENGINEERING MECHANICS

Course Code:
Name of Student:
Division:
Batch:
Roll Number:

LABORATORY MANUAL

I N D E X

Sr. No.	Name of the Experiment	Page	Date	Remark of Batch Incharge
1.	Verification of law of parallelogram of forces/polygon of forces.			
2.	To find the member forces of Jib Crane.			
3.	To verify the law of moments by bell crank lever.			
4.	Force Table Apparatus to analyze equilibrium conditions for concurrent forces and finding out resultant.			
5.	To determine support reaction of simple and compound beams and verify the reaction by analytical (By Equilibrium Conditions) and graphical Methods.			
6.	To find Force transmitted by member of given truss/Simple roof Truss and verify the forces by analytical and graphical method.			
7.	Determination of coefficient friction of inclined plane and Determination of coefficient friction of belt (Flat Belt)			
8.	To determine forces in the members of space force system and verify with analytical Method.			
9.	Moment of Inertia of Flywheel.			
10.	To study the curvilinear motion and verify with analytical method.			
11.	Determination of coefficient of restitution between two colliding bodies for different materials (Rubber, Steel, Aluminum and wood).			
12.	To find the law of a simple lifting machine. (Worm-wheel and second system of pulley)			

CERTIFICATE

Certified that Mr./Ms.____

of Class **F.Y.B. Tech.**Division_________, Batch________Roll No.__________________

has completed the laboratory work in the subject **Engineering Mechanics** in during the Semester I/II of the academic year__________________________.

Signature and Name of Batch Incharge **Seal of the Head of the Department**

Name:______________________________. Class:_______________. Batch:_______________.

Roll No.:_______________ Expt. No. 1

Performed on:__________. Submitted on:____________. Teacher's Sign:________________.

VERIFICATION OF LAW OF POLYGON OF FORCES

Purpose of the experiment: -

The Law of Polygon of Forces, also known as the Parallelogram Law of Forces, is a fundamental principle in physics and engineering that deals with the addition of multiple concurrent forces acting on a single point. The purpose of the Law of Polygon of Forces experiment is to demonstrate and understand how multiple forces acting on a body at a point can be combined or resolved into a single resultant force.

Instruments: -

Gravesand's Apparatus, Paper Sheet, Weight Box, Thread, Drawing pins & Pencil, Mirror Strip Pans.

Theory: -

The **Law of Polygon of Forces** states that – if any number of coplanar concurrent forces can be represented in magnitude and direction by the sides of a polygon taken in order; then their resultant will be represented by the closing side of the polygon taken in opposite order".

Procedure: -

1. Fix the paper sheet with drawing pin on the board set in a vertical plane such that it should be parallel to the edge of board.
2. Pass a thread over two pulleys. Take a second thread and tie the middle of this thread to the middle of first thread. Pass the ends of the second thread over the other set of two pulleys.
3. Take a third thread and tie its one end to the point of first two threads.

4. Attach pans to the free ends of the threads as shown in Fig. 1.

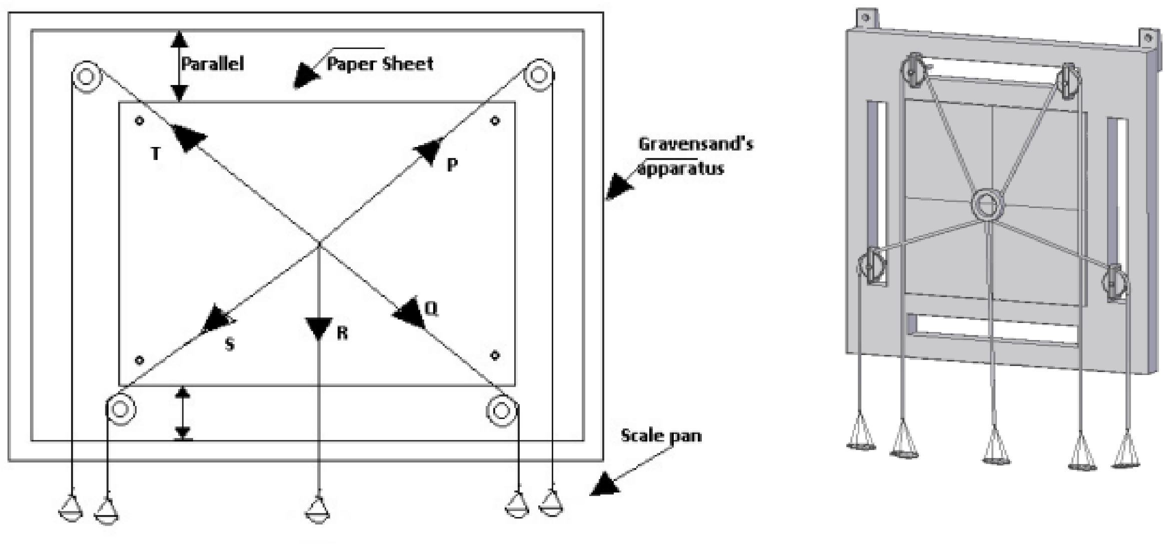


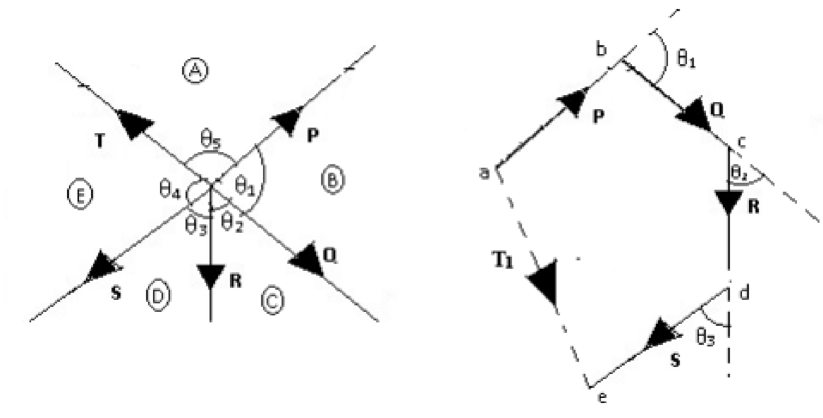
Fig 1. Gravesand's Apparatus

5. Add weights in the pan in such a manner that the knot comes approximately in the centre. Mark lines of forces represented by thread without disturbing the system and write the magnitude of forces i.e. Pan Weight + Added Weight.
6. Remove the paper from the board and produce the line to meet at O.
7. Select a suitable scale and draw the vector diagram as per graphical method (Fig. 2) by moving in one direction (i.e. clockwise or counter clockwise). Draw ab parallel to AB and cut it equal to force P; draw bc 5 parallel to BC and cut it equal to Q; Draw cd parallel to CD and cut it equal to force R; draw de parallel to DE and cut it equal to S. Vector ae will be the resultant force T1 taken in opposite direction and should be equal to force T which proves the law of polygon forces. If ae is not equal to T then percentage error is found as follows:

$$\text{Percentage error} = \frac{T - T_1}{T} * 100$$

Graphical Method

Fig. 2.2(b), draw ab parallel to force P in suitable scale with the use of set square and then from b draw bc parallel to force Q. From c draw cd parallel to R and then draw de parallel to S. The closing side of polygon represents the force T1 which should be equal to force T. Note, the difference between T1 and T shows the graphical error.



(a) Space diagram (b) Vector diagram

Fig 2. Graphical Method

Analytical Method

Draw a horizontal and vertical line at the point of concurrency of all the forces in Fig.2.2 (a) with the help of set square.

Resolve each force in x and y axis,

$$\sum F_x = 0; \qquad P_x + Q_x + R_x + S_x + T_x = 0$$

$$T_x = -(P_x + Q_x + R_x + S_x)$$

$$\sum F_y = 0; \qquad P_y + Q_y + R_y + S_y + T_y = 0$$

$$T_y = -(P_y + Q_y + R_y + S_y)$$

$$T_2 = \sqrt{(T_X{}^2 + T_y{}^2)}$$

Note that T is resultant from the experiment, T_1 is the resultant found from graphical method and T_2 is the resultant found from analytical method. The difference between T_2 and T shows the experimental error.

Observations and Calculations: -

1] Scale N: mm

Sr. No.	Force (Pan Weight + Added Weight)					% Graphical Error	% Analytical Error
	P	Q	R	S	Resultant T	$\left[\frac{T-T_1}{T}\right]*100$	$\left[\frac{T-T_2}{T}\right]*100$
1							
2							
3							
4							
5							

Precautions

1. Pans/weights should not touch the vertical board
2. There should be only one central knot on the thread which should be small
3. While calculating the total force in each case the weight of the pan should be added to the weight put into the pan
4. Make sure that all the pans are at rest when the lines of action of forces are marked E. All the pulleys should be free from friction

Space for Calculation

Conclusion: -

Questions: -

1. What is the purpose of verifying the Law of Polygon in mechanics, and what practical applications does it have in real-world scenarios?
2. Can you think of situations in daily life where understanding and applying the Law of Polygon could be beneficial?
3. Can you propose a real-life scenario where multiple forces act on an object, and the Law of Polygon helps in determining the net force and its effect?
4. How might the Law of Polygon be used to solve practical problems in engineering design or analysis?
5. What are some practical challenges you might face when conducting the experiment, and how would you overcome them?

Space for Question Answer

Name: ______________________________. Class: _______________. Batch: ____________.

Roll No.:_______________ Expt. No. 2

Performed on: __________. Submitted on: ____________. Teacher's Sign: ________________.

VERIFY LAMI'S THEOREM BY ANALYZING CONCURRENT FORCES ACTING ON A JIB CRANE SYSTEM

Purpose of the experiment: -

To understand and demonstrate the principles of equilibrium and balance on a jib crane by analyzing the loads and forces involved.

Instruments: -

Jib Apparatus, Weight, Meter Rod, Set Square, Pencil etc.

Theory: -

Lami's Theorem states that "If three coplanar concurrent forces are acting on a body and keeps the body in Equilibrium, then each force is proportional to the sine of the angle between the other two forces." Mathematically, if you have three forces F_1, F_2, and F_3 acting on a body at angles α, β and γ with respect to a reference axis, the theorem can be expressed as:

$$\frac{F_1}{\sin\alpha} = \frac{F_2}{\sin\beta} = \frac{F_3}{\sin\gamma}$$

The jib crane is an example of three concurrent forces. Jib crane is used to lift heavy loads. When it lifts load then jib member is subjected to compression & tie member is subjected to tension. The forces in the tie and the jib can be calculated experimentally. Analytically it can be found by making use of Lami's theorem. The apparatus consists of an inclined rod fitted with a compression spring called a jib which is pivoted and a hook is attached to the other end from which a chain hangs to carry a weight. The vertical tubular rod is fixed at the base and has a sliding adjustable hook. One end of the tie rod is fitted to the jib and other end is attached to one of the hooks of tubular rod. A spring balance in the tie. The vertical tubular rod is supported for rigidity. The tubular rod is fixed on a heavy base to avoid tilting.

Procedure: -

- Take the initial reading of forces in the compression spring balance of rod and tension spring balance of the tie rod.
- Suspend a known weight ‘w’ with the help of weight hanger.
- Take final reading of force in jib rod and tie rod of spring balance.
- From the final reading subtract the initial reading to get observed value of the forces in rod and tie rod.
- Measure the length of jib rod from the point on the platform, the position where string is attached, length of the tie rod and vertical height of the post.
- From the above measurement, draw the space diagram to a suitable scale and name the member by bow’s notation.
- Measure the internal angles contained between the two forces in vector diagram.
- Measure angle α, β and γ and apply Lami’s theorem to find out the forces in the member.
- Compare the calculated values of forces with observed values and determine the percentage error.
- Repeat the experiment either by changing the load or by varying the length of the vertical post.

Fig 1. Jib Crane Apparatus

Observations and Calculations: -

Sr. No.	Weight on Post (kg)	Length of the members of Jib Crane (m)			Initial Reading (kg)		Final Reading (kg)		Observed Force (kg)		Calculated Force (kg)		Percentage error in Force	
	W	Jib	Tie	Post	Jib	Tie	Jib	Tie	Jib	Tie	Jib	Tie	Jib	Tie
1														
2														
3														
4														
5														

Precautions

- Initial reading of the spring balance of tie rod and jib rod should be taken carefully.
- Weight should be suspended gently without any jerk.
- Measure the length of each member of jib crane with an extensible string.
- The spring balance should be sensitive to give correct reading.
- The space and force diagram should be drawn correctly.

Space for Calculation

Conclusion: -

1. Magnitude of observed forces and calculated forces are **_____________** (equal/ nearly equal/ not equal)
2. The difference in the above two forces is because of **_____________________** (error of manipulation/ instrument error/ error of observation)

Questions: -

1. Explain the significance of the jib crane apparatus in real-world applications.
2. How does the weight and position of the load affect the stability and equilibrium of the jib crane?
3. What factors should be considered when selecting the appropriate counterweight for the jib crane?
4. How does the length of the jib arm impact the mechanical advantage and lifting capacity of the crane?
5. How would you determine the maximum load that the jib crane can lift without tipping over?

Space for Question Answer

Name:_______________________________. Class:________________. Batch:________________.

Roll No.:________________ Expt. No. 3

Performed on:___________. Submitted on:_____________. Teacher's Sign:__________________.

VERIFICATION OF PRINCIPLE OF MOMENT USING BELL CRANK LEVER APPARATUS

Purpose of the experiment: -

The purpose of the experiment is to demonstrate and verify the principle of moments (also known as the principle of equilibrium) in mechanics. The principle of moments states that for a body to be in rotational equilibrium, the sum of the clockwise moments about any point must be equal to the sum of the counterclockwise moments about the same point.

Instruments: -

Bell Crank Lever apparatus, slotted weight, spirit meter, spring balance and pointer

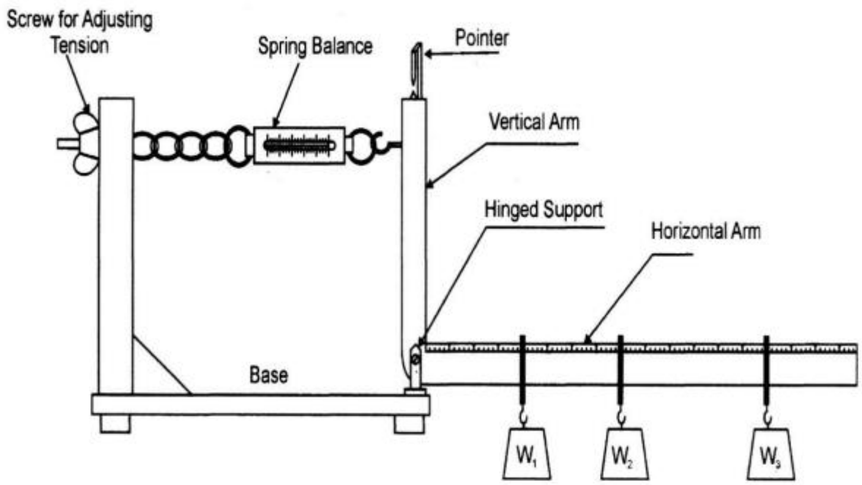
Theory: -

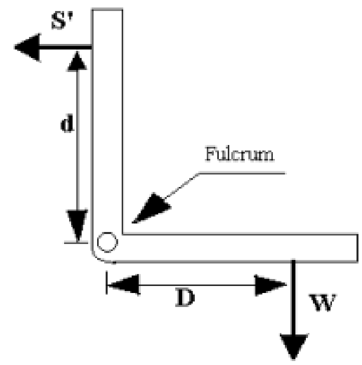
A bell crank lever is a simple mechanical device consisting of a lever arm pivoted at a fixed point. It converts a linear force into rotational motion or vice versa. The principle of moments is based on the law of equilibrium, which states that for a body in a state of equilibrium, the sum of the moments acting on the body is zero.

Procedure: -

1. Make the longer arm of the lever horizontal by adjusting with wing nut provided at the end of spring balance longer screw, by using a spirit meter when there is no load on longer arm.
2. Adjust the initial spring balance reading as zero.

3. Hang a small weight (W) on the hook fixed in the lever. This will make the longer arm move down ward and the spring balance will show some reading on balance
4. Note the final spring balance reading.
5. Change the position of load and repeat the steps B to D for different loads and calculate the moments.





Free Body Diagram

Fig. 1. Bell Crank Lever

Free body diagram of bell crank lever apparatus is shown in Fig.1. Here,

W is Force applied on lever, D is Varying distance on lever, S’ is Theoretical spring force, S is Experimental spring force, d is Fixed distance, measure from the fulcrum of equipment.

As the system is in equilibrium,

$$\sum M_O = 0,$$

$$W * D - S' * d = 0$$

Observations and Calculations: -

Sr. No.	Weight (W) N	Distance (D) mm	Moment (W x D) mm	Observed Spring Force (S) N	Actual Spring Force (S') $\left[\frac{W * D}{d}\right]$	% Error $\left[\frac{S' - S}{S'}\right] * 100$
1						
2						
3						
4						
5						

Precautions

1. There should minimal disturbance as long as the pointer is concerned.
2. Only one person must take all the readings, because eye-judgment for matching the pointer with the mark on the lever will vary from individual to individual.
3. Weights should not touch the table.
4. Add weights in the hanger gently.
5. The pointer should exactly coincide with the mark on the bell crank lever. F. The optimum starching of spring should be kept in mind.
6. The apparatus should be kept on smooth and leveled surface.
7. Proper lubrication of the joints of two arms of the lever should be done so as to reduce frictional force.
8. Zero error of spring should be properly noted.

Space for Calculation

Conclusion: -

From the values obtained above, it’s clear that the observed and calculated values of spring force are nearly equal and within the permissible experimental error limits. Hence the Law of Moments stating that “the moment of a force about an axis is equal to the sum of moment of its component about the same axis” has been verified.

Questions: -

1. What is the main principle being verified using the bell crank lever apparatus?
2. Can you explain the concept of the moment in mechanical systems, and how it applies to the bell crank lever?
3. What are the variables that could affect the accuracy of the results in this experiment, and how can they be controlled?
4. Can you identify any potential sources of error in the experiment, and suggest ways to minimize or eliminate them?
5. Suppose you were given another mechanical system, unrelated to the bell crank lever, and asked to devise an experiment to verify the principle of moment for that system. How would you approach this task, and what considerations would you take into account?

Space for Question Answer

Name:__________________________. Class:_________________________. Batch:____________.

Roll No.:________________ Expt. No.

Performed on:________________. Submitted on:_____________. Teacher's Sign.:_____________.

DETERMINATION OF FORCES IN A SPACE FORCE SYSTEM

Purpose of the experiment:-

To introduce the concept of a force as a vector in space, concept of equilibrium of concurrent space force system. To determine the non coplanar concurrent forces experimentally and verify them analytically.

Instruments:-

Space force apparatus, ropes, spring balances, weights, hangers.

Theory:-

This experiment is based upon the equilibrium of non-coplanar concurrent forces, i.e. the equilibrium of concurrent space forces. Like coplanar forces, this system of forces also can be resolved. The resolution of forces will be along three mutually perpendicular directions called as X, Y and Z axes.

Thus force can be expressed in the form of a vector such as

$$\bar{F} = F_x \hat{i} + F_y \hat{j} + F_z \hat{k}$$

Where F_x, F_y & F_z are the components of the force $\bar{F}$ in X, Y and Z directions respectively and $\hat{i}$, $\hat{j}$, $\hat{k}$ are the unit vectors along X, Y and z directions respectively.

If the force $\bar{F}$ is defined by the coordinates of two points M (x_1, y_1, z_1) and N (x_2, y_2, z_2) located on its line of action, then force F is defined as $\bar{F}$ = F. $\hat{\lambda}$

where, F is the magnitude and $\hat{\lambda}$ is the unit vector in the direction of $\bar{F}$

$$\text{Unit vector} = \lambda = \left[\frac{(x_2 - x_1)\hat{i} + (y_2 - y_1)\hat{j} + (z_2 - z_1)\hat{k}}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}} \right]$$

where l, m and n are the direction cosines of the line of action of the force and

$$l = \left[\frac{(x_2 - x_1)}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}} \right]$$

$$m = \left[\frac{(y_2 - y_1)}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}} \right]$$

$$n = \left[\frac{(z_2 - z_1)}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}} \right]$$

Also $l^2+m^2+n^2=1$

F_x = Fl =X component of the force, Fy = Fm = Y component of the force

F_z = Fn = Z component of the force

If the system of forces is in equilibrium, the algebraic sum of the components in three mutually perpendicular directions must be zero. i.e., $\sum F_x = 0, \sum F_y = 0, \Sigma F_z = 0$

These are the analytical conditions of equilibrium of concurrent force system in space.

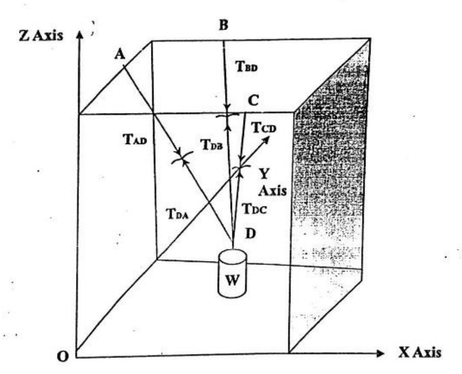


Fig. 1: Concurrent space force system

Procedure: - (Ref. Fig. 1):

1. Attach three strings AD, BD and CD with spring balances to the different points on the space force apparatus as shown in fig. 1. Ensure that the strings are just tight and that the spring balance reading is zero.

2. Suspend weight W at the point of concurrency (Pt. D) of the three ropes.

3. With respect to a fixed origin and observing the right-hand screw rule, decide the orientation of X, Y and Z axes Find the coordinates of A, B, C and D w.r.t this frame of reference.

4. Read the spring balances and get the experimental values of the tensions T_{DA}, T_{DB} and T_{DC}.

5. Using the conditions of equilibrium at D, find the analytical values of T_{DA}, T_{DB} and T_{DC}.

6. Repeat the procedure with different combinations of weight W and locations of A, B, C and D.

Observations and Calculations: -

Sr. No.	Weight (W) in N	Coordinates	Coordinates in (m)				Tensions in N						%Error		
							Experimental			Analytical					
			A	B	C	D	T_{DA}	T_{DB}	T_{DC}	T_{DA}	T_{DB}	T_{DC}	T_{DA}	T_{DB}	T_{DC}
1.		X													
		Y													
		Z													
2.		X													
		Y													
		Z													
3.		X													
		Y													
		Z													

Space for Calculation

Conclusion: -

Questions:-

1. How do you decide the orientation of coordinate access in a space force system?
2. What are the conditions of the equilibrium of non-coplanar concurrent force system?
3. What are the conditions of the equilibrium of non-coplanar parallel force system?
4. How to express a force as a vector quantity?
5. What do you mean by the direction cosines of a force vector?

Space for Question and answer

Name:______________________________. Class:________________. Batch:________________.

Roll No.:________________ Expt. No. 5

Performed on:___________. Submitted on:_____________. Teacher's Sign:__________________.

DETERMINATION OF SUPPORT REACTIONS OF SIMPLE AND COMPOUND BEAMS

Purpose of the experiment:-

To introduce and develop an understanding of the basic principles of static equilibrium, types of force systems, and various types of transverse loads on determinate beams. To introduce the analytical and experimental methods for determining the reactions of simple and compound beams.

Instruments:-

Beams with a spring balance, hangers, and weights.

Theory:-

The basic principles used in statics to analyze all the forces and moments acting on a rigid body are based on Newton's First Law. A body at rest is in static equilibrium under the combined action of all external forces acting on it. When all forces (active and reactive) are considered, we have a complete force system acting on that body.

Force Law of Equilibrium:

A structure is considered to be in equilibrium if, initially at rest, it remains at rest when subjected to a system of forces and couples. If a structure is in equilibrium then all its members and parts are also in equilibrium.

Equilibrium implies a balance of forces within a system. Therefore, in any direction, the algebraic sum of all forces acting on a body in static equilibrium is zero. This statement is known as the 'Force Law of Equilibrium' expressed as $\boxed{\sum \bar{F} = 0}$

To be assured of complete equilibrium, the algebraic sum of forces must be shown to be zero in at least two mutually perpendicular directions to each other. The two scalar equations of equilibrium are expressed in general as under,

$$\boxed{\sum F_x = 0 \,,\ \sum F_y = 0}$$

where F_x and F_y are the rectangular components of the forces in the given system.

Moment of a Force:

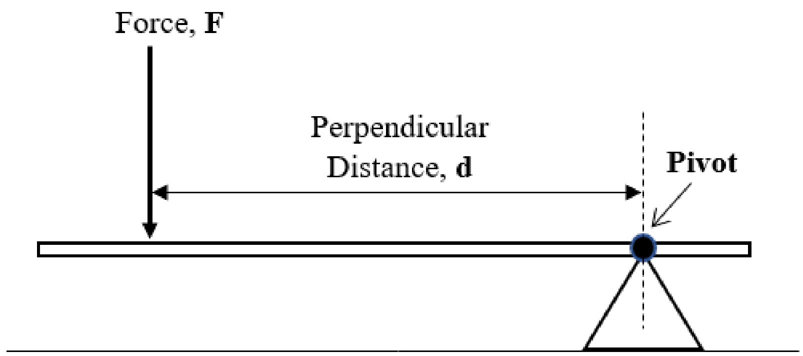
The effect of a force on a rigid body depends on its point of application, as well as its magnitude and direction. It is common knowledge that a small force can have a large turning effect or leverage. In Mechanics, the term 'moment' is used instead of 'turning effect'.
The moment of a force with a magnitude (F) about a turning point (O) is defined as:

$$\boxed{M = F \times d}$$

where d is the perpendicular distance from O to the line of action of force F. (Refer to Fig. 1) The distance d is often called the lever arm. The direction of a moment about a point or axis is defined by the direction of the rotation that the force tends to give to the body. An anticlockwise moment is usually considered as having a positive sign and vice versa.

Moment Law of Equilibrium:

Equilibrium also implies a balance of opposing moments of the forces within a system. Therefore, about any moment axis, the algebraic sum of the moments of all forces acting upon a body in static equilibrium is zero. This statement is known as the 'Moment Law of Equilibrium', and is stated as $\boxed{\sum \bar{M} = 0}$. Then about any axis, the sum of the clockwise moments must be equal to the sum of the anticlockwise moments for equilibrium.



Moment of force about Pivot = F x d

Fig.1. Moment of Force

Free-body Diagram:

The diagram of an isolated body with reprentationn of all external forces acting on it, it is called as free body diagram (FBD).

Reactions:

Structural components are usually held in equilibrium by being secured to rigid fixing points; these are often other parts of the same structure. The fixing points or supports will react against the tendency of the applied forces (loads) to cause the member to move. The forces generated by the supports are called reactions. In general, a structural member has to be held or supported at a minimum of two points (an exception to this is the cantilever). Anyone who has tried 'balancing' a long pole or a similar object will realize that, although only one support is theoretically necessary, two are needed to give satisfactory stability.

Resultant:

The resultant of a system of forces and couples is the simplest system that can replace the original force system without altering the external effect on the rigid body to which the forces are applied.

Equilibrium:

The equilibrium of a body is the condition in which the resultant of all forces acting on the body is zero. This condition is studied in statics. When the resultant of all forces on a body is not zero, the acceleration of the body is obtained by equating the force resultant to the product of the mass and acceleration of the body (Newton's Second law). This condition is studied in dynamics. Thus, the determination of the resultant is basic to both statics and dynamics.

Types of Coplanar Forces:

i) **Concurrent Forces:** Forces whose lines of action meet at one point are said to be concurrent. Coplanar forces lie in the same plane, whereas non-coplanar forces have to be related to three-dimensional space and require two items of directional data together with the magnitude. Two coplanar non-parallel forces will always be concurrent. For equilibrium, the vector sum of all the forces must be zero.

ii) **Parallel Forces:** Parallel forces are either collinear forces or parallel and non-concurrent. The sum of the forces must be zero and the sum of moments must also be equal to zero for the system to be in equilibrium.

iii) **Coplanar, non-concurrent, non-parallel forces:** These forces will be in equilibrium if the sum of the forces equals zero and the sum of the moments about a point in the plane equals zero.

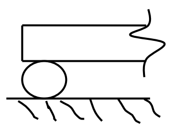
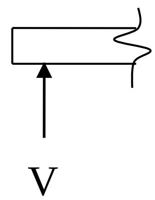
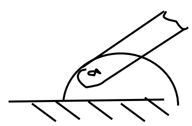
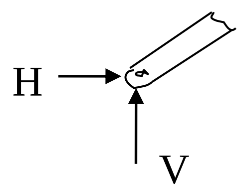
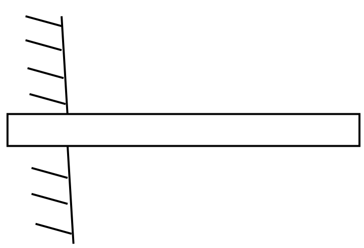
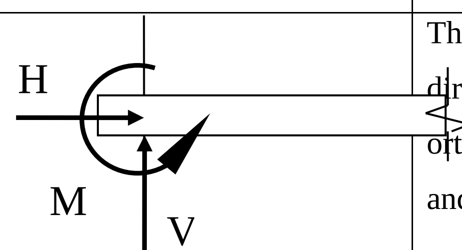
Types of Supports:

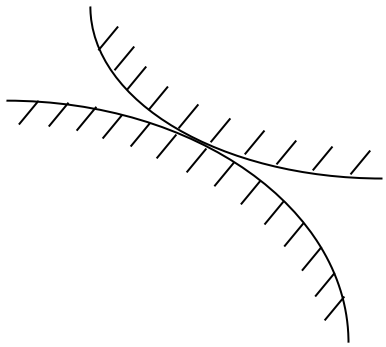
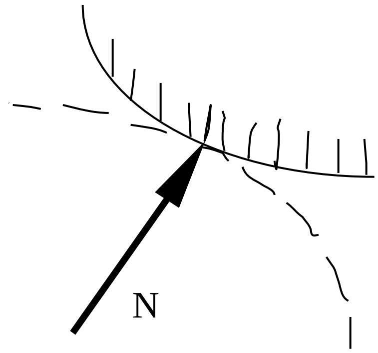
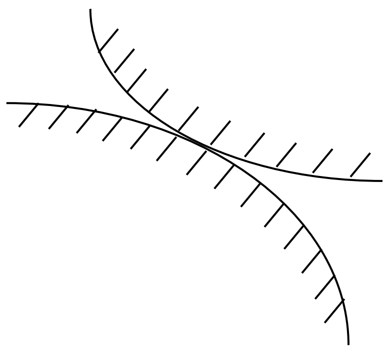
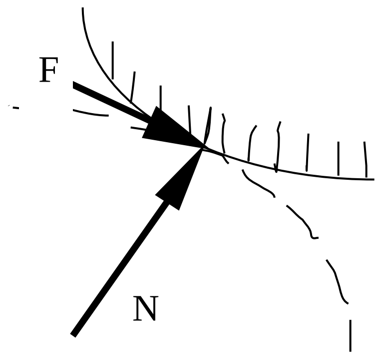
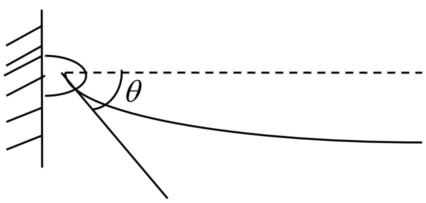
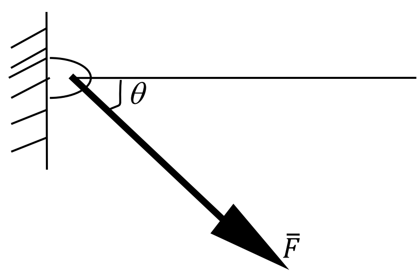
i) **Roller Support:** In the case of roller support translation is possible in all directions except against the surface on which the roller is resting. The reacting force at a roller support or smooth surface is always perpendicular to the supporting surface. There cannot be any component of beam reaction along the beam. Hence, the number of unknowns is equal to one i.e. magnitude of the reaction.

ii) **Hinge Support or Pin Support:** This support prevents translation completely but rotation in the plane of the forces is allowed. The reacting force at hinged support has no specific direction in relation to the supporting surface though it will be determined by loading on the beam, compatible with conditions of equilibrium. We generally say that the pin has two components of reaction that are along the two orthogonal directions. Thus the number of unknowns is two.

iii) **Fixed Support:** This support prevents translation as well as rotation completely and achieves perfect fixity. In the case of fixed support, the reacting components of forces are along two orthogonal directions and accompanied by a reacting moment. Thus the number of unknowns is three. Different types of supports and their support reactions are shown in Fig. 2

Fig. 2. Different Types of Supports and their Reactions.

Type of support	**FBD**	**Explanation**
Roller or Simple Support 		The reaction is normal to the supporting surface only
Hinge or Pin Support 		A hinged support is fixed in position, hence the two reaction components. But it is not restrained in direction hence it can rotate about the axis of the hinge.
Built Support or fixed support 		The body is fixed in position and direction also. Hence two orthogonal reaction components and reacting moment.

Smooth Surface 		The reaction is normal to the surface i.e. at right angles to the tangent at the contact point
Rough surfaces 		The rough surface is capable of supporting a tangential force as well as a normal reaction. The resultant reaction is the vectorial sum of these two components
Flexible cable or rope 		The force exerted by the cable or rope is always tensile, away from the fixing, in the direction of the tangent to the cable curve

Loading Systems:

Before any of the various load effects (tension, compression, bending, etc.) can be considered, the applied loads must be rationalized into ordered systems. Irregular loading is difficult to deal with exactly, but even the most irregular loads may be reduced and approximated to regular systems. These can be dealt with in mathematical terms using the principle of superposition to estimate the overall combined effect.

Concentrated Loads:

Concentrated loads are those that can be assumed to act at a single point, e.g. weight hanging from a ceiling or a person pushing against a box. Concentrated loads are represented by a single arrow drawn in the direction and through the point of application of the force. The magnitude of the force is always indicated.

Distributed Loads:

Uniformly distributed loads, written as UDL, are those that can be assumed to act uniformly over an area or along the length of a structural member e.g. roof loads, wind loads, or the effect of the weight of water on a horizontal surface. For calculation, UDL is normally considered in a plane.Distributed load with linear variation is another common load situation. These are called uniformly varying loads (UVL). The loading shape is triangular/ trapezoidal and is the result of such actions as the pressure of the water on dams and the pressure of soil on the retaining walls. The area of the load diagram is the magnitude of the total force represented by the diagram and its point of application is the centroid of the load diagram.

Procedure of Experiment:-

i) Place a wooden beam horizontally with one end resting on the pan balance as shown in the fig. 3.

ii) Note down the initial reading shown by the pan balance due to the self-weight of the beam.

iii) The external load (W) is attached to the hanger at a distance ‘x’ from the pin support.

iv) Note down the final reading shown by the pan balance due to self-weight and external load (W).

v) From the final reading, the initial reading is subtracted to get the reaction due to an external load (W) only.

vi) The value of the reaction is calculated analytically and compared with the experimental value.

vii) Above procedure is repeated for the arrangement of the compound beam as shown in the fig. 4.

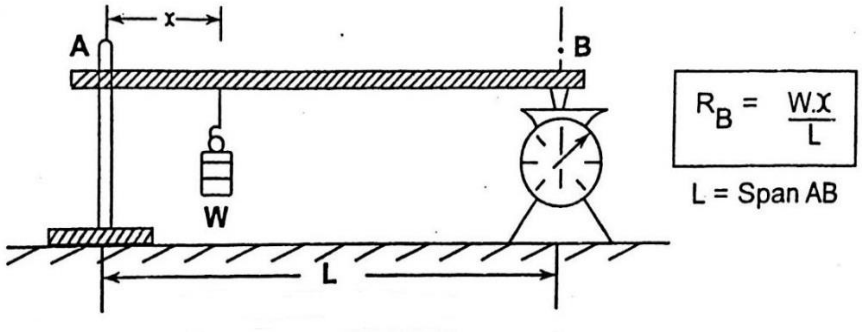


Fig. 3. Simple Beam

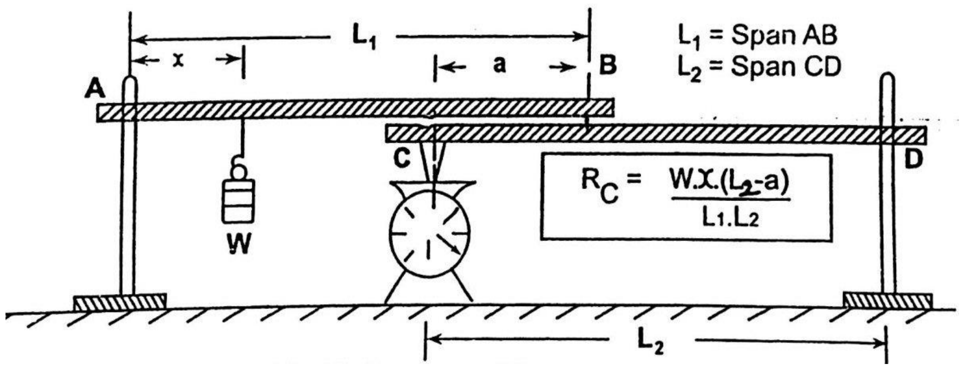


Figure 4. Compound Beam

Observations and Calculations:-

1] **Simple Beam:**

Span of the beam (L) = m

Sr. No.	Load 'W' (N)	Distance 'x' (m)	R_B Experimentally (N)			R_B Analytical (N) $(R_B)_{Ana}$ $= \frac{Wx}{L}$	% Error = $\left[\frac{(R_B)_{Exp} - (R_B)_{Ana}}{(R_B)_{Ana}}\right]100$
			Due to Self-Weight	Due to External Load + Self Weight	R_B due to External Load $(R_B)_{Exp}$		
1							
2							
3							
4							
5							

2] **Compound Beam**

Span of beam AB = L_1 = m

Span of beam CD = L_2 = m

Distance 'a' = 0.2 m

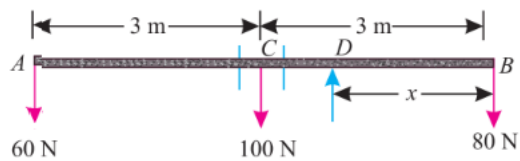
Sr. No.	Load 'W' (N)	Distance 'x' (m)	R_c Experimentally (N)			R_c Analytically (N) $(R_c)_{Ana}$ $\frac{Wx(L_2-a)}{L_1 L_2}$	% Error = $\left[\frac{(R_C)_{Exp}-(R_C)_{Ana}}{(R_C)_{Ana}}\right]100$
			Due to Self-Weight	Due to External Load + Self Weight	R_c due to External Load $(R_c)_{Exp}$		
1.							
2.							
3.							
4.							
5.							

Space for Calculation

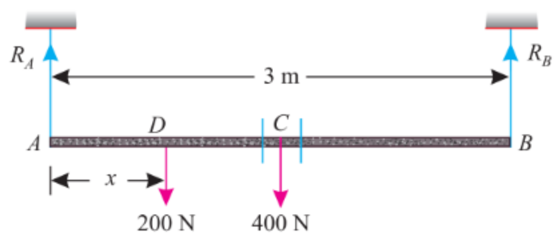
Conclusion:-

Questions:-

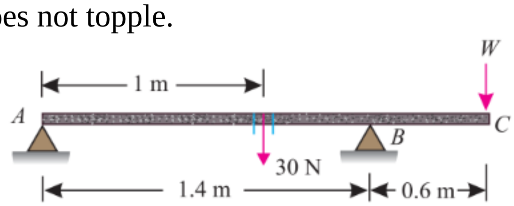
1. A uniform beam AB of weight 100 N and 6 m long had two bodies of weights 60 N and 80 N suspended from its two ends as shown in Fig. 4.5. Find analytically at what point the beam should be supported, so that it may rest horizontally.



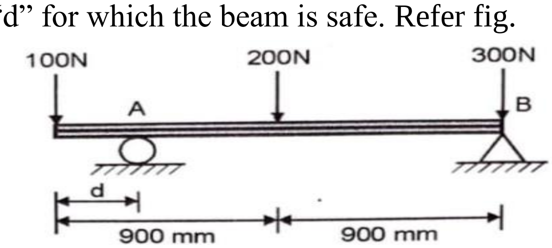
2. A beam 3 m long weighing 400 N is suspended in a horizontal position by two vertical strings, each of which can withstand a maximum tension of 350 N only. How far a body of 200 N weight be placed on the beam, so that one of the strings may just break ?



3. A uniform plank ABC of weight 30 N and 2 m long is supported at one end A and at a point B, 1.4 m from A as shown in Fig. Find the maximum weight W, that can be placed at C, so that the plank does not topple.



4. The maximum allowable value of each of the reactions is 360N, Determine range of values of distance "d" for which the beam is safe. Refer fig.



Space for Question Answer

Name: ______________________________. Class: _______________. Batch: ____________.

Roll No.:_______________ Expt. No. 6

Performed on: __________. Submitted on: _________ ___. Teacher's Sign: ________________.

VERIFY AXIAL FORCES ACTING ON LOADED SIMPLE ROOF TRUSS APPARATUS

Purpose of the experiment: -

To measure the forces in loaded frame and then compare them with theoretical values using simple roof truss apparatus.

Instruments: -

Simple roof truss Apparatus, Weight, Meter Rod, Set Square, Pencil etc.

Theory: -

A truss is a useful structure in construction consisting of elements that takes only tension (T) or compression (C) and no bending is induced what so ever. The members are connected with a gusset joint that is either riveted, bolted or welded in such a way that has only axial forces are induced in the structure. The reason behind axial forces is the reason that the external loads are applied in such a way that their effects are in the form of forces applying only on joints. When designing and analyzing a truss structure that is to be subjected to a given load the forces that each member and joint of the structure will undergo under the application of the load, must first be determined. Each truss member acts as a two force member and therefore the forces at the ends of the member must be directed along the axis of the member. If the force tends to pull away from the ends of the member it is a tensile force (T), meaning it undergoes tension. If the force tends to push into the member it is compressive force (C), meaning it undergoes compression.

Compression members must be made thicker than tension members because of the buckling of column effect that occurs when a member is in compression.

This experiment will be determining the forces possess of each member of the simple truss structure by applying the forces downward at joint B. After that, the reading from the compression spring balance of inclined compressions members and tension spring balance of the tie member will be used for determining the force at the joints respectively.

Procedure: -

- Take the initial reading of forces in the compression spring balance of inclined members and tension spring balance of the tie member.
- Suspend a known weight ‘w’ at joint B with the help of weight hanger.
- Take final reading of force in inclined compressions members and tie member of spring balance.
- From the final reading subtract the initial reading to get observed value of the forces in compression members and tie member.
- Measure the length of inclined compression members and length of the tie member.
- From the above measurement, draw the space diagram to a suitable scale and name the member by bow’s notation.
- Measure the internal angles contained between the two forces in vector diagram.
- Measure angle α between inclined member and compression member, β between two inclined member, apply method of joint to find out the forces in the member.
- Compare the calculated values of forces with observed values and determine the percentage error.
- Repeat the experiment either by changing the load or by varying the length of the tie member.
- For the theoretical method in determining the forces act on the joint, it is using the formula which are calculated by using method of joint.

$$F_{AC} = \frac{W}{2\tan\alpha}$$

$$F_{AB} = F_{BC} = \frac{W}{2\sin\alpha}$$

- At the end of the experiment, it will be observed that there is the relationship between measured forces in a loaded roof truss experimentally and theoretically.

Fig 1. Simple roof truss apparatus

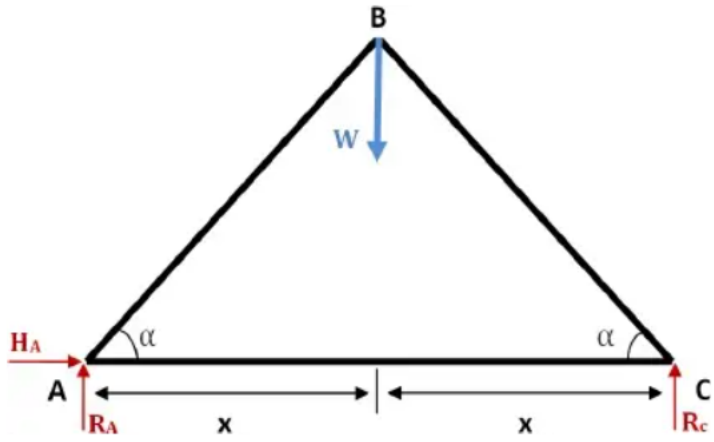


Fig 2. Free body diagram of simple roof truss apparatus

Observations and Calculations: -

- Initial Reading

1. AC (Tie Member): kg
2. AB (Compression Member): kg
3. BC (Compression Member): kg

Sr. No.	Weight on roof truss (kg)	Length of the roof truss members (m)			Observed Force (kg)			Calculated Force (kg)			Percentage error in Force (kg)		
	W	AC	AB	BC	AC	AB	BC	AC	AB	BC	AC	AB	BC
1													
2													
3													
4													
5													

Precautions

- Initial reading of forces in the compression spring balance of inclined members and tension spring balance of the tie member should be taken carefully.
- Weight should be suspended gently without any jerk.
- Measure the length of each member of simple roof truss with an extensible string.
- The spring balance should be sensitive to give correct reading.
- The free body diagram should be drawn correctly.

Space for Calculation

Conclusion: -

1. Magnitude of observed forces and calculated forces are _____________ (equal/ nearly equal/ not equal)
2. The difference in the above two forces is because of ____________________ (error of manipulation/ instrument error/ error of observation)

Questions: -

1. Explain the significance of the simple roof truss in real-world applications?
2. Explain how the method of joints can be employed to determine the internal forces in the members of the truss?
3. Explain the role of joints in a truss system and how they might influence the distribution of forces within the structure.?
4. How does the type of load (point load, distributed load, etc.) affect the analysis of a truss structure?
5. How does varying the angles and lengths of individual members in a roof truss affect the overall stability and load-bearing capacity of the structure?

Space for Question Answer

Name:____________________________. Class:____________________. Batch:_____________.

Roll No.:_____________ Expt. No. 7

Performed on:______________. Submitted on:_____________. Teacher's Sign.:____________.

DETERMINATION OF COEFFICIENT OF FRICTION BETWEEN FLAT BELT AND PULLEY

Purpose of the experiment:-

To introduce and develop the concept of Frictional force, Coulomb's laws of friction, and belt friction. To determine the coefficient of friction between a flat belt and pulley.

Instruments:-

Belt friction apparatus flat belt, weights, and hangers.

Theory:-

Friction: If two bodies are in contact with each other the property whereby a force is exerted between them at their point of contact preventing one from sliding over the other is called friction and the force that comes into play is called the force of friction. It is a passive self-adjusting force always opposing the motion or the impending motion. As much frictional force is called into play as is necessary to prevent motion.There is always a limit to the force of friction. This limiting frictional force bears a constant ratio to the normal reaction between the two bodies and depends purely on the nature of surfaces of contact and is independent of the extent or shape of the bearing surface.

The angle of Friction:

If the reaction normal to the surface is denoted by N, and the frictional force along the surface at the instant, motion is just impending is denoted by F_{max}, then the angle of friction is defined as $\Phi = \tan^{-1}\frac{(F_{max})}{N}$

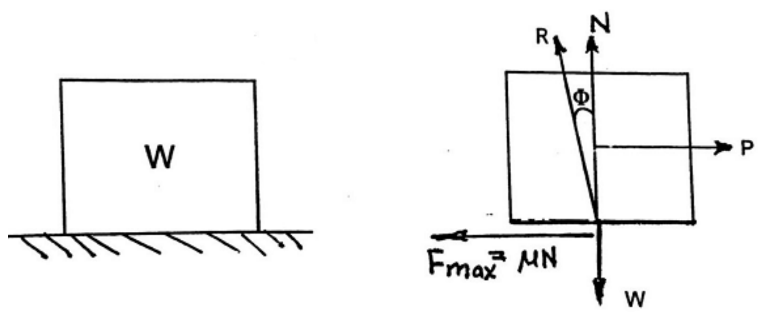


Fig. 1: Block resting on rough surface and its FBD

Coulomb's Law of Friction:

1. The frictional force F acts along the tangent plane at the surface of contact and opposes the movement of bodies in contact. The maximum frictional force that can be possibly developed is proportional to the normal reaction N at the surface of contact. Thus $F_{max} = \mu N$, where μ is termed as the coefficient of friction.

2. For a given value of normal reaction N, the coefficient of friction is independent of the areas in contact.

3. Once sliding occurs, the frictional force developed is independent of the velocity of sliding for low velocities. This frictional force, however, is less than the force just when sliding is about to occur.

Belt Friction:

To study the effect of friction on the tension in a belt when it passes over a rough cylindrical surface. [Ref. Fig. No. 2 (a), 2 (b).The pulley of radius 'r' is stationary. A belt passes around the pulley subtending an angle β, which is known as the 'Angle of Lap'. T_1 is the tension on the tight side and T_2 is the tension on the slack side. Both these forces are such that the motion of the belt is impending in the direction of T_1. We shall now investigate the relationship between T_1 and T_2 with β and μ. It should be noted that normal reaction in the belt increases from 0 to maximum at the center. Hence forces acting on a small infinitesimal element (fig. 2 (b)) have to be considered and their total effect over the entire arc has to be obtained.

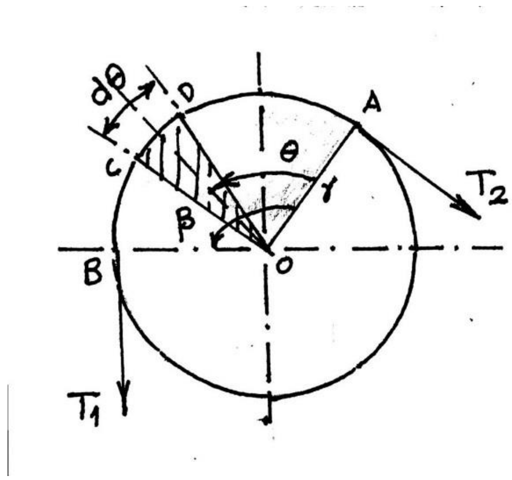


Fig. No. 2 (a)

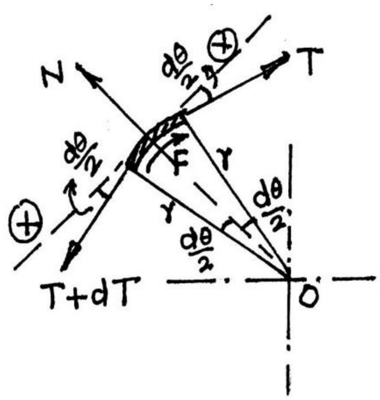


Fig. No. 2 (b)

Where, T_1 = Tension on tight side, T_2 = Tension on slack side, N = Normal reaction on element considered F = Frictional force = μN, β = Angle of lap

Resolve along X-X (tangential direction).

$$\left(T + dT\right)\cos\left(\frac{d\theta}{2} - T\cos\frac{d\theta}{2}\right) - \mu N = 0$$

$$\therefore dT\cos\left(\frac{d\theta}{2}\right) = \mu N$$

As $\left(\frac{d\theta}{2}\right)$ is very very small cos $\left(\frac{d\theta}{2}\right)$=1

$\therefore dT = \mu N$ …………………(1)

Resolve along Y-Y (Normal direction)

N-T sin $\left(\frac{d\theta}{2}\right)$-(T + dT) sin$\left(\frac{d\theta}{2}\right)$=0

As $\left(\frac{d\theta}{2}\right)$ is very very small sin $\left(\frac{d\theta}{2}\right)$= $\left(\frac{d\theta}{2}\right)$, and (dT x dθ) is neglected.

N – 2T $\left(\frac{d\theta}{2}\right)$= 0

N = T .dθ ………………….(2)

From equation (1) and (2), we get

dT = μ. T. dθ

$$\therefore \left(\frac{dT}{T}\right) = \mu\theta$$

$$\int_{T_2}^{T_1}\left(\frac{dT}{T}\right) = \int_0^{\beta}\mu.d\theta$$

$$\frac{T_1}{T_2} = e^{\mu\beta}$$

While deriving the above relationship, the mass of the belt is neglected.

Procedure:-

Case-1: Determination of coefficient of friction μ by maintaining the angle of lap β constant.

1. Adjust the angle β by rotating the graduated disc such that desired angle β is observed below the pointer. Then fix the handle tightly.
2. Clean the surfaces of the belt and pulley.
3. By holding the belt, place known weight T_2 on one side (slack side).
4. Adjust the weights T_1 on the tight side such that the belt just starts sliding over the pulley. (This may be ascertained by making a chalk mark on the belt and pulley).
5. Repeat the procedure for five different values of T_2 and tabulate the results.

Case-2: Determination of coefficient friction μ by maintaining T_2 i.e. tensions on slack side constant.

Experiment, in a similar manner as in case 1 except that instead of keeping the value of β constant, keep T_2 constant and vary the value of the angle of lap β.

Observations and Calculations:-

Sr. No.	Case -1, β =			Sr. No.	Case-2, T_2=			
	T_2(N)	T_1(N)	μ		β (deg)	β (rad)	T_1 (N)	μ (N)
1.								
2.								
3.								
4.								
5.								
		μ_{ave} =					μ_{ave} =	

Space for Calculation

Graphs:

Case-1: Draw a graph with values of T_2 on the X-axis and that of T_1 on Y axis. The scale chosen should be the same on both axes. The graph will be a straight line passing through the origin.
Coefficient of friction = [$\log_e$ (slope of straight line)]/β (rad)
Case-2: Draw a graph with the value of β (rad) on the X axis and $\log_e T_1$ on the Y axis. The graph will be a straight line, with Y intercept as $\log_e T_2$. The slope of the straight line will be the value of μ.
Coefficient of friction = μ = slope of straight line

Result:-

Case (1)		Case (2)	
μ (Experimental)	μ (Graphical)	μ (Experimental)	μ (Graphical)
The average value of μ =			

Hence the coefficient of friction between the given flat belt and pulley =____________

Questions:-

1. A body of weight W on an inclined plane of angle α with horizontal, is being pulled up the plane by horizontal force P. The motion impends when P=…………….. Take angle of friction as Ø
2. A block of weight 100 N is kept on a rough incline for which $\mu_S = 0.3$ and $\mu_K = 0.2$. The inclination of plane is 300 with horizontal. A force of 40N, up the plane, is applied to the block then the frictional force is ……….
3. A rope wrapped around a post holds a weight of 20 kN by exerting a force of 120 N at other end. If $\mu_S = 0.3$, The no turns of rope is……….
4. A rope wrapped around a post holds a weight of 20 kN by exerting a force of 120 N at other end. For $2\frac{1}{2}$ turns of rope, coefficient of static friction is……………

Space for question Answer

Name: ______________________________. Class: _______________. Batch: ____________.

Roll No.:_______________ Expt. No. 8

Performed on: __________. Submitted on: _________ ___. Teacher's Sign: ________________.

EQUILIBRIUM OF COPLANAR CONCURRENT FORCE SYSTEM

Purpose of the experiment: -

The purpose of the experiment using a "Force Table Apparatus" is to analyze equilibrium conditions for concurrent forces and find out the resultant force acting on an object. This experiment helps students understand the concept of vector addition and how multiple forces can combine to create equilibrium or a resultant force.

Instruments: -

Universal force table with four pulleys, strings, standard weights.

Theory: -

The state of equilibrium of a particle refers to the state of uniform velocity or rest. A particle is said to be in equilibrium under the action of forces if the vector summation of forces is zero. This experiment pertains to study the forces acting on a particle with the help of Universal force table as shown in Fig. 1. The apparatus consists of a circular table with a marked protractor and pulleys at its edges. Strings or ropes are attached to the pulleys, and weights can be hung from these strings.

Procedure: -

1. Level the force table with the help of spirit level and adjusting foot screw.

2. Apply weights and / or adjust pulleys such that the Centre of knot coincides with central pivot. Note down the angle made by strings on graduated circular scale and the value of weights.
3. Draw spaces diagram by drawing the angles as measured on forces and show the respective forces, give Bow's notations and draw force (vector) diagram with suitable scale to solve the problem graphically. The closing line of first and last point gives the error incurred due to manual observations and friction in the apparatus. Error is found by following the procedure of resolution of forces.
4. Apply four known weights and one unknown weights, repeat the steps 2 & 3 and find the value of unknown weights analytically as well as graphically assuming the system the system with zero error.

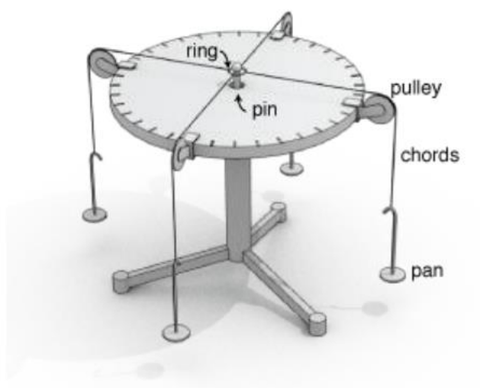


Fig 1. Universal Force Table

Graphical Method

Law of polygon is employed to find the value of unknown forces graphically. Resultant of more than two coplanar concurrent forces can be found with the help of this law and is stated as "When more than two coplanar concurrent forces acting at a point are represented by the sides of a polygon taken in order, in direction and magnitude, the closing line of polygon taken in order, in direction and magnitude, the closing line of polygon, taken in opposite order, represents the resultant in direction and magnitude." Thus, polygon law of forces follows graphical method of finding the resultant of given forces.

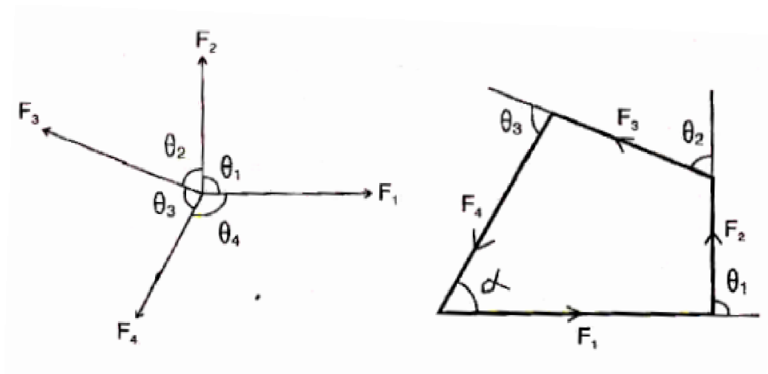


Fig 2. Graphical Method

Analytical Method

If P_1, P_2, P_3, & P_4, are five forces acting on a particle simultaneously on a horizontal plane at an inclination of θ_1, θ_2, θ_3, & θ_4 with positive X-axis measured in anticlockwise direction then the magnitude of the resultant is given be,

$$R = \sqrt{(\sum F_X{}^2 + \sum F_Y{}^2)}$$

Where,

$$\sum F_x = F_1 \cos\theta_1 + F_2 \cos\theta_2 + F_3 \cos\theta_3 + F_4 \cos\theta_4$$

(ΣF_x is the components of all forces along positive X-axis.)

$$\sum F_Y = F_1 \sin\theta_1 + F_2 \sin\theta_2 + F_3 \sin\theta_3 + F_4 \sin\theta_4$$

(ΣF_y is the components of all forces along positive Y-axis.)

and its direction given by,

$$\theta = \tan^{-1}\left(\frac{\sum F_x}{\sum F_y}\right)$$

If the forces are in equilibrium the value of the resultant (R) will be zero. This method of finding the resultant is called Resolution of forces.

Observations and Calculations: -

Sr. No.	Magnitude of Forces (N)				Anticlockwise angle w.r.t +ve X axis (degree)				ΣF_x	ΣF_y	Resultant	
	F_1	F_2	F_3	F_4	θ_1	θ_2	θ_3	θ_4			Analytically	Graphically
1												
2												
3												
4												
5												

Precautions

1. Pulleys are assumed to be frictionless.
2. Self-weight of the string is neglected.
3. Strings should be free of knots.
4. Rotations of pulley should be smooth.

Space for Calculation

Conclusion: -

1. Analytical Resultant = ……………….
2. Graphical Resultant = ……………….

Questions: -

1. If three forces are in equilibrium on the force table, what does this imply about their vector sum? Explain your answer.
2. In the force table experiment, why do we use the concept of equilibrium? How does it relate to the vector sum of forces?
3. Suppose you have three forces applied at different angles on the force table, but the system is not in equilibrium. What could be the possible reasons for this? How could you adjust the forces to achieve equilibrium?
4. If one of the force vectors is removed from the force table experiment while keeping all other forces constant, what impact would it have on the resultant force vector? Explain your reasoning.
5. Explain the significance of the force table experiment in real-world applications.

Space for Question Answer

Name:________________________________. Class:________________. Batch:___________.

Roll No.:_______________ Expt. No. 9

Performed on:_____________. Submitted on:______________. Teacher's Sign.:____________.

DETERMINATION OF MOMENT OF INERTIA OF FLYWHEEL

Purpose of the Experiment:-

To determine the moment of inertia of a Flywheel.

Instruments:-

Flywheel, string, stopwatch, weight, scale.

Theory:-

A flywheel is always necessarily connected to engine shaft (crank shaft). The reason behind it is that the torque generated by the engine is not constant throughout the rotation of the crank shaft .That is two complete rotations of the crank shaft are required for the completion of four strokes which are known as suction stroke, compression stroke, expansion stroke, and exhaust stroke .In the four stroke engine, the power is generated during the expansion stroke only. Thus the process of power generation takes place only during that part of rotation at which power stroke (expansion stroke) is going on. Thus if we do not use the flywheel, the speed of the engine will be excessive during power stroke and will be very less for remaining three strokes. Hence fluctuation of speed will be tremendous during one cycle.Thus the function of the flywheel is to act as an energy reservoir which will store energy during those periods of crank rotation when the turning moment applied by the engine is greater than load moment to be overcome and will restore the energy during those periods when the turning moment is less than load moment to be overcome. Absorption of energy is necessarily accompanied by increase of speed and restoration of energy is accompanied by decrease of speed. The mass moment of inertia of flywheel must be sufficient that these changes of speed do not exceed the permissible limits. That is the change in speed should not be greater than 5 to 10% of the mean speed. Hence it becomes necessary for an engineer to design a flywheel of such mass, that its moment of inertia will regulate the speed so as not to exceed the limit of 5 to 10% of the mean speed.

Moment of inertia of flywheel:

Moment of inertia or second moment of small element of mass ‘dm’ about any axis is defined as the product of the mass ‘dm’ and the square of the perpendicular distance of an element from the axis of rotation.

Moment of inertia of a rigid body about an axis passing through it, is defined as follows:

Moment of Inertia = $\int dm.\ r^2$

where the rigid body is split into number of small elements having infinitesimal small masses ‘dm and ‘r’ is its distance from the axis of rotation. Thus when the body is rotating it is its ‘moment of inertia’ which opposes angular acceleration of the body and not its mass according to the Newtons first law of motion.

Moment of Inertia of flywheel = $I = \int dm.\ r^2$……………….(1)

Kinetic Energy in Rotation:

Kinetic energy of mass ‘m’ having velocity ‘v’ is given as $\frac{1}{2}mv^2$. In rotation only velocity has to be replaced by the quantity ‘rω’ where ‘ω’ is angular speed and ‘r’ is distance of rotating mass from axis of rotation. When the flywheel is considered as divide into a number of infinitesimally small mass elements and its corresponding distances from axis of rotation ‘r’ then kinetic energy of flywheel is given as follows:

$$\text{Kinetic Energy of flywheel} = \int \frac{1}{2}\, dm\, (r\omega)^2 = \frac{1}{2}\omega^2 \int dm\, (r^2)$$

$$= \frac{1}{2} I\, \omega^2$$

Experimental Determination of Moment of Inertia of Flywheel.

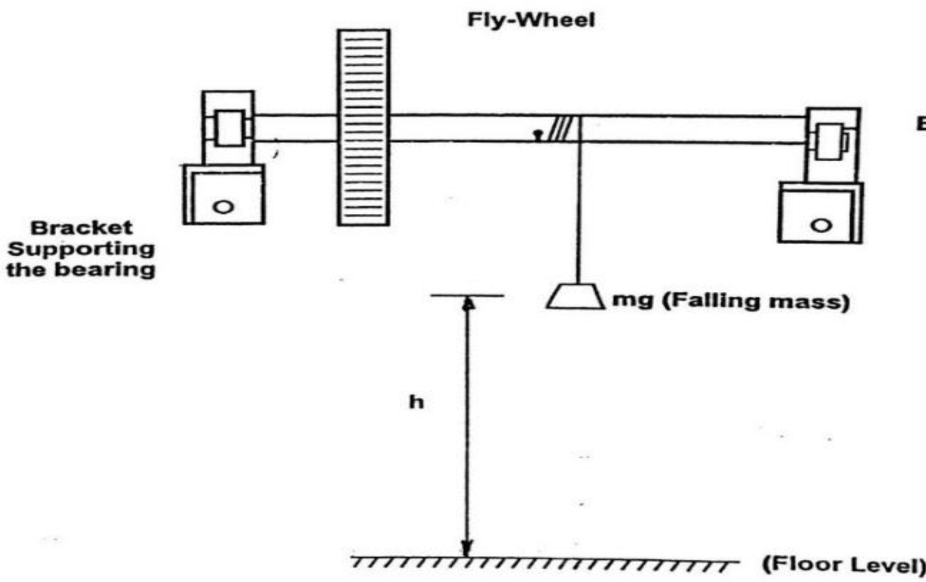


Fig. 1: Experimental setup to find M.I. of flywheel

To find out moment of inertia of fly wheel, a string is attached to the shaft, and it is wound on it for a certain number of turns and to the free end mass ‘m’ (kg) is attached at a height ‘h’(m) from the ground level as shown in the figure1. Then the system is released and the mass is allowed to fall to the ground and the time ‘t’ (sec) required for the fall is noted.

If N_1 = number of revolutions made by the flywheel till the mass strikes the ground.

N_2 = number of revolutions made by the flywheel from the instant mass strikes the ground till the flywheel stops,

m = the mass attached to the free end of the string,

h = height of mass from ground level,

v = the velocity (m/s) of the mass when it strikes the ground,

ω= angular velocity (rad/sec) of the flywheel at the instant the mass strikes the ground,

I = moment of inertia of flywheel (kgm^2),

then, loss in potential energy due to fall of mass ‘m’ through the height ‘h’ = P E

= Gain in kinetic energy of translation of the mass (KE1) + Gain in kinetic energy of rotation of the flywheel (KE2) + Work done against friction (WDF1)

That is, PE = KE1+ KE2+ WDF1 ……… equation (2) where PE = mgh

KE1 = $\frac{1}{2}mv^2$, v=velocity of mass when it is striking the ground.

KE2 = $\frac{1}{2} I\omega^2$

We have, by Kinematics,

$h = ut + \frac{1}{2} at^2$

where u=initial velocity

a=uniform acceleration at the instant at which mass touches the ground.

t=time required for mass to reach the ground

h=height

since the weight falls freely, u=0

$$h = \frac{1}{2}at^2$$

$$a = \frac{2h}{t^2} \text{ ....(3)}$$

Also we have the following kinematic equation for motion under uniform acceleration,

$v^2 = u^2+2ah$

$=2ah$ ....as u = 0

$$= 2\left(\frac{2h}{t^2}\right)h \text{ .... from equation (3)}$$

$$= \left(\frac{4h^2}{t^2}\right) \text{ ....(4)}$$

Also $\omega^2=v^2/r^2$ where 'r' is the radius of the shaft.

$$\omega^2 = \left(\frac{4h^2}{t^2}\right)/r^2 = \left(\frac{4h^2}{r^2t^2}\right) \text{ ....(5)}$$

$$KE1 = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{4h^2}{t^2}\right) = \left(\frac{2mh^2}{t^2}\right)$$ ………. from equation (4)

$$KE2 = \frac{1}{2}I\omega^2 = \frac{1}{2}I\left(\frac{4h^2}{r^2t^2}\right) = \left(\frac{2Ih^2}{r^2t^2}\right)$$ ………. from equation (5)

Kinetic Energy of rotation of the flywheel after mass is detached is KE2 and is consumed in overcoming the frictional couple which is assumed constant. It causes the retardation and brings the flywheel to come to rest.

So we have following equation:

KE 2 = WDF2 =Work done against friction

=frictional couple 'C' x Number of revolution (N_2) made by flywheel after the mass is detached x 2π

Hence, WDF2 = C.2 π N_2

Putting this value in equation (4),

K.E.2 = C .2 π N_2

$\frac{2Ih^2}{r^2t^2}$ = C (2π N_2) …………from equation (5)

$$C = \frac{2Ih^2}{r^2t^2(2\pi N_2)}$$ …………………..(6)

Work done against friction W.D.F1.

WDF1=C. (2π N_1) $= \frac{2Ih^2}{r^2t^2(2\pi N_2)} \times (2\pi N_1)$ ………………..from equation (6)

$$= \frac{2Ih^2}{r^2t^2} \times \frac{N_1}{N_2}$$ ……………………… (7)

Putting the corresponding values in equation 2 we get

$$mgh = \frac{2mh^2}{t^2} + \frac{2Ih^2}{r^2t^2} + \frac{2Ih^2}{t^2r^2}\frac{N_1}{N_2}$$

By rearranging the terms, we get.

$$I = \left(\frac{mr^2}{2h}\right)\left(gt^2 - 2h\right)\left(\frac{N_2}{N_1 + N_2}\right) \quad \text{.......kg.m}^2$$

Procedure:-

1) Measure the radius of axle ‘r’(m)of the axle of the flywheel.
2) Attach one end of the string on the axle .Then wind it on the axle after attaching the mass ‘m’(kg) at known height ‘h’ (m)from ground level.
3) Make a prominent chalk mark on the rim of the flywheel as a reference point for measuring its rotations.
4) Release the weight and start the stop watch at the same instant .Note the time ‘t’ (sec) for mass to reach .Count also the no. of rotations N_1 made by the flywheel before the mass reaches the ground .
5) Count the number of rotations N_2 made by the flywheel after the mass touches the ground till the flywheel comes to rest.
6) Repeat the above procedure three times with different combinations of ‘m’ and ‘h’ in such a way that the potential energy ‘mgh’ almost remains constant.

Observations and Calculations:-

1) Gravitational Acceleration = g = 9.81 m/sec^2 2) Radius of the axle = r = 0.03 m.

Sr. No.	Mass m (kg)	h meter	t seconds	N_1	N_2	I (kg-m^2)	Average I (kgm^2)
1.							
2.							
3.							
4.							
5.							
6.							

Space for Calculation

Conclusion:-

Questions:-

1. What are the practical applications of fly wheel?
2. What is the physical significance of moment of inertia?
3. What is radius of gyration?
4. What is the parallel axis theorem of M.I.?
5. What is the perpendicular axis theorem of M.I.?

Space for Question and Answer

Name:__________________________. Class:_________________________. Batch:___________.

Roll No.:________________ Expt. No. 10

Performed on:_________________. Submitted on:___________. Teacher's Sign.:____________.

STUDY OF CURVILINEAR MOTION

Purpose of the experiment:-

To demonstrate and study the curvilinear motion of a particle. To study the expression for position, velocity and acceleration of a particle using different frames of references. To develop the differential equations of curvilinear motion using Newton's second law.

Instruments:-

Smooth sphere, circular rim with smooth surface, meter scale, string, saw dust.

Theory:-

When a moving particle describes a curved path, it is said to have curvilinear motion. When the path of the particle is lying in one plane, then the motion is a two-dimensional motion (plane motion). When the path of the particle is not lying in one plane then it is, a three-dimensional motion (space motion). There are 3 different ways to express the position, velocity and acceleration of a particle subjected to curvilinear translation along a plane curve. These are as under:

1) Using Cartesian frame of reference i.e. rectangular coordinates:

Coordinates of a point; x, y (These are functions of time 't')

Position vector: $\bar{r} = x\hat{i} + y\hat{j}$ m

Velocity vector: $v = \dot{x}\hat{i} + \dot{y}\hat{j}$ m/s

$= v_x\hat{i} + v_y\hat{j} \ m/s$

Acceleration vector: $\bar{a} = \ddot{x}\hat{i} + \ddot{y}\hat{j} \quad m/s^2 = a_x\hat{i} + a_y\hat{j} \ m/s^2$

2)Using Polar frame of reference i.e., polar coordinates:

Coordinates of a point: r, θ (These are functions of time 't')

Position vector: $\overline{r} = r.\hat{e}_r$ m

Velocity vector: $v = \dot{r}\hat{e}_r + r\dot{\theta}\hat{e}_\theta$ m/s $= v_r\hat{e}_r + v_\theta\hat{e}_\theta$ m/s

Acceleration vector: $\overline{a} = a_r\,\hat{e}_r + a_\theta\,\hat{e}_\theta$ m/s^2 $\quad \bar{a} = \left(\ddot{r} - r\,\dot{\theta}^2\right)\hat{e}_r + \left(r\,\ddot{\theta} + 2\,\dot{r}\,\dot{\theta}\right)\hat{e}_\theta$

3) Using Path Variables:

Velocity vector : $\overline{v} = v.\hat{e}_t$ m/s

Acceleration vector : $a = \left(\frac{dv}{dt}\right).\hat{e}_t + \left(\frac{v^2}{\rho}\right)\hat{e}_n$ m/s^2 where ρ = radius of curvature

Differential equations of curvilinear motion:

If the resultant force acting on the particle varies in the direction as well as in the magnitude, the particle is subjected to curvilinear motion. In this case we can resolve the force acting on the particle along any two mutually perpendicular directions and we can write the differential equations of curvilinear motion using Newton's second law of motion.

i) Using Cartesian frame of reference

$\Sigma F_x = m.a_x = m\ddot{x}$ and $\Sigma F_x = m.a_y = m\ddot{y}$

ii) Using polar frame of reference

$\Sigma F_r = m.a_r = m\left(\ddot{r} - r\dot{\theta}^2\right)$ and $\Sigma F_\theta = m.a_\theta = m\left(r\ddot{\theta} + 2\dot{r}\dot{\theta}\right)$

iii) Using path variables:

$\Sigma F_t = m.a_t = m.\frac{dv}{dt}$ and $\Sigma F_n = m.a_n = \frac{m.v^2}{\rho}$

Referring fig. 1, if a small smooth sphere of mass 'm' starts from rest at A (the top of a frictionless circular rim) and slides in a vertical plane along the arc AB, the sliding sphere leaves the circular path at

B when it makes an angle $\Phi = 48.19^0$ at the center. After point B, the sphere travels along trajectory BC and strikes the horizontal plane CD at point C. The distance of point C, from the bottom of the rim is (1.46) r. Here, the motion of the sphere from A to C is a curvilinear motion. But for the path AB, the radius is constant, hence the motion of the sphere from A to B is circular motion. For the path BC, the only force acting on the spherical particle is its weight. Hence the motion of the particle form B to C is a projectile motion.

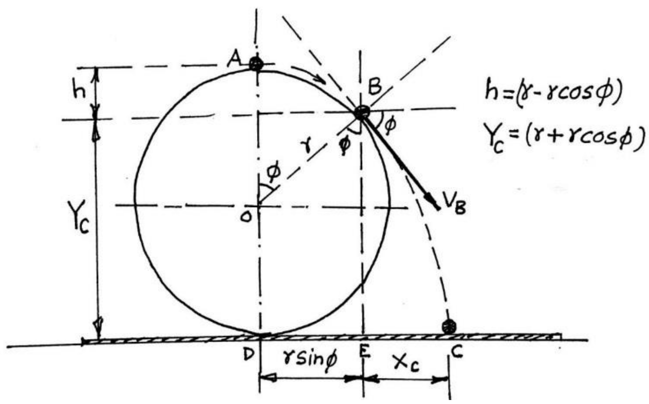


Fig. 1: curvilinear motion of the particle

For the circular motion of the particle from A to B:

applying Work-Energy principle,

(Work-done in travelling from A to B) = (Change in kinetic energy from A to B)

$$m(-g)[-r - r\cos\Phi] = \frac{1}{2}mV_B^2 - \frac{1}{2}mV_A^2$$

Since $V_A = 0$, $V_B^2 = 2.g.r(1-\cos\Phi)$ ------------------- (1)

Consider the free body diagram of the particle at position B, (Ref. Fig. 2)

Applying Newton’s second law of motion in the normal direction

we get $\Sigma F_n = m.a_n$, $mg\cos\Phi = (m.V_B^2)/r$

$V_B^2 = .r.\cos\Phi$ --------------------------(2)

Equating equations (1) and (2) We get,

$$V_B^2 = 2g.r.(1-\cos\Phi) = g.r.\cos\Phi$$

$\therefore \cos\phi = 0.7 \quad \therefore \cos\phi = \frac{2}{3} \boxed{\Phi = 48.19^0}$

$\therefore V_B^2 = (r)(9.81)(\cos 48.19^0)$

$V_B = (2.56)\sqrt{r}$

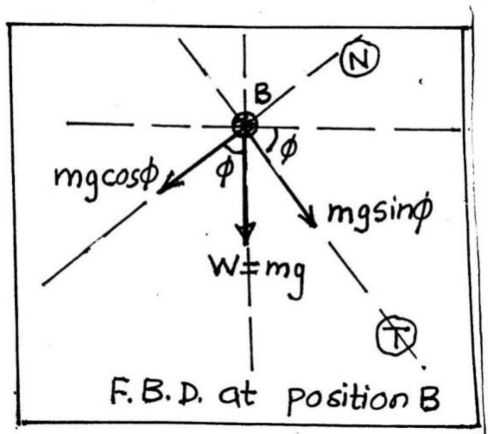


Fig. 2: FBD of particle at B

For the projectile motion of the particle from B to C:

Consider the origin of the frame of reference as point B (Ref. Fig. 3). Then for the vertical motion from B to C.

$-Y_c = -(V_B.\sin\Phi)t\left(\frac{1}{2}g.t^2\right)$, $\qquad Y_c = (V_B \sin\Phi)t + \left(\frac{1}{2}g.t^2\right)$

$r + r\cos\Phi = (V_B \sin\Phi)t + \frac{1}{2}g.t^2$, $\qquad (4.905)t^2 + 1.86(\sqrt{r}.)t - (1.966)r = 0$

$\boxed{t = (0.42)\sqrt{r}}$ --------- -------- (3)

For the horizontal motion from B to C

Xc = (V_B. cosΦ) t

$= (2.56)\sqrt{r}(\cos 48.19^0)(0.42)\sqrt{r} \quad = (0.72)r$

Therefore, distance CD = DE +EC = r sin Φ + X_c

= r (sin 48.19^0) + (0.72) r = (1.46) r =CD

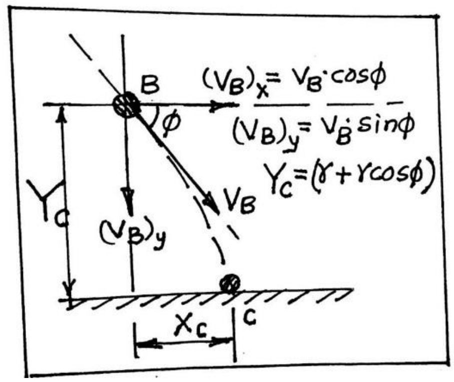


Fig. 3: Projectile motion of the particle

Procedure: -

1. Measure the radius of the rim.
2. Arrange the circular rim to rest in vertical position at the support.
3. Spread the saw dust on the table where the steel ball is likely to strike.
4. Place the smooth steel ball on the highest point A on the rim and allow it to roll along the groove.
5. Locate the point on the rim where the ball loses its contact with the rim. i.e., locate point B by visual observation.
6. Locate the point on the table where the ball strikes the horizontal plane. i.e., locate point C.
7. With the help of a thread, measure the arc length AB along the rim and also measure the distance CD on the table.
8. Determine Φ by using the relation arc length AB = r. Φ (where Φ is in Radians). Convert Φ to degrees.
9. Verify $\Phi = 48.19^0$, and CD = (1.46) r.

Observation and Calculations:-

1. Radius of the rim r =______________m.
2. Arc length AB =______________m.
3. Distance CD =______________m.
4. Angle Φ = ____________Radians =_______________degrees

Result: -

	Analytical	Experimental
Φ	48.18^0	
CD	1.46 r	______________r

Space for Conclusion: -

Questions: -

1. What are the different frames of references used in curvilinear motion?
2. What is the difference between velocity and speed?
3. What is centrifugal and centripetal acceleration?
4. “A particle is moving along a curve with constant velocity” Will there be any acceleration?
5. The tangential component of acceleration gives us the idea of the rate of change of ……………………….. (a) Velocity b) Speed c) Acceleration d) Displacement)

Space for question and Answer

Name:________________________________. Class:_________________. Batch:___________.

Roll No.:_______________ Expt. No. 11

Performed on:_____________. Submitted on:____________. Teacher's Sign.:____________.

DETERMINATION OF COEFFICIENT OF RESTITUTION BETWEEN TWO COLLIDING BODIES

Purpose of the experiment:-

To study the Impulse Momentum principle, the concept of direct central impact, and the coefficient of restitution. To demonstrate direct central impact and to determine the coefficient of restitution between two bodies by using the concept of collision with a body of infinite mass.

Instruments:-

Measuring scale, ball, steel plate, Aluminum plate, wooden cabinet of height 1 m attached with measuring scale.

Theory:-

Impulse Momentum Principle:

By Newton's 2nd Law of motion, we have

$$F = m\bar{a} = \frac{d\bar{v}}{dt}$$

$$Fdt = md\,\bar{v}$$

$$\int_{t_1}^{t_2} Fdt = \int_u^v md\bar{v}$$

$$\bar{F}(t_2 - t_1) = m(\bar{v} - \bar{u})$$

Let $t_2 - t_1 = t$

$$\left(\bar{F}.t\right) = m.\bar{v} - m.\bar{u}$$

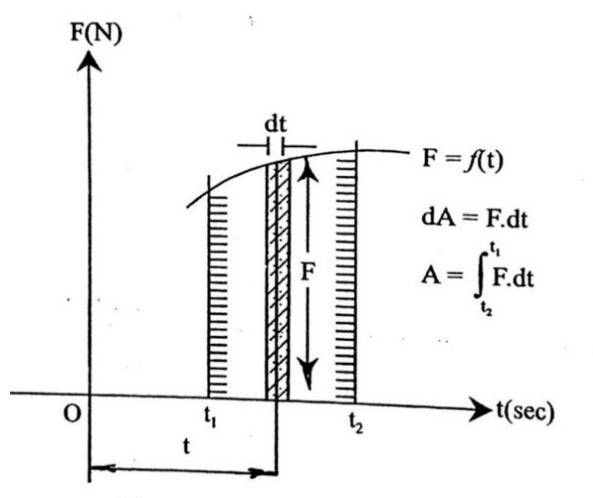


Fig. 1: F-t Diagram

'F.t' is called as impulse acting on a particle for time 't'. Thus, the impulse acting on the particle for time 't' is equal to the change in the linear momentum at that time. This is called as Impulse Momentum Principle. Here the force acting on the particle is constant for time 't'. If the force acting on the particle is changing and force F = f(t), then the area under the F-t diagram is the impulse acting on the particle for time 't'. (ref. fig. 1)

Direct Central Impact:

The collision of two bodies in which each body exerts tremendous pressure on the other for a very short interval of time is called as impact. When the mass centers of the colliding bodies are lying on the line of impact and their velocities are collinear to the line of impact then it is called are direct central impact (Ref fig. 2)

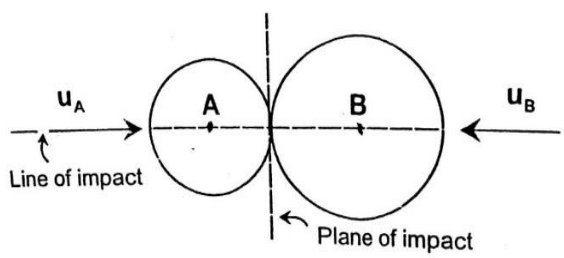


Fig. 2: Direct central impact

Impulse of Deformation:

When the two colliding bodies touch each other, initially they tend to push the other body. This stage is called as deformation stage. The impulse acting on the body during the deformation stage is called as impulse of deformation.

Impulse of Recovery:

After the deformation stage, the bodies develop the tendency to separate away from each other. This is called as Recovery stage. Recovery may be 100% or 0% or partial. The impulse acting on the body during the recovery stage is called as Impulse of recovery.

Time of impact (Δt) = time of deformation (Δt_d) + time of recovery (Δt_r) = $\Delta t = \Delta t_d + \Delta t_r$ (ref. fig 3)

Coefficient of restitution:

The ratio of the impulse of recovery to the impulse of deformation is called as coefficient of restitution between the two colliding bodies. The coefficient of restitution is considered as a constant for given geometries and a given combination of colliding materials. It also depends on the impact velocity, shape, and size of colliding bodies.

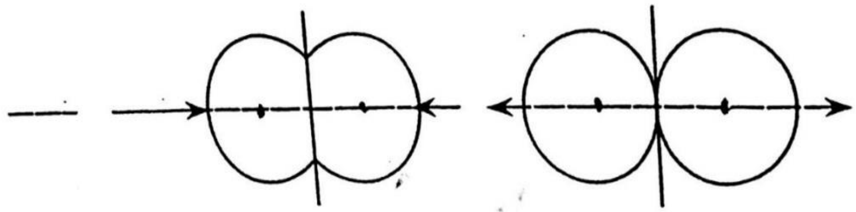


Fig. 3: Deformation and recovery stage during impact

Consider two colliding bodies (1&2) as under:

Before Impact

Let m_1 = mass of body 1,

m_2 = mass of body 2,

u_1 = Velocity of body 1 before impact,

u_2 = Velocity of body 2 before impact,

v_1 = Velocity of body 1 after impact,

v_2 = Velocity of body 2 after impact

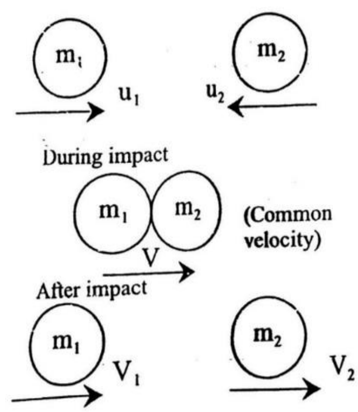


Fig. 4: Collision between two bodies

	Impulse of Deformation	Impulse of recovery
Body 1	$m_1v-m_1u_1$	$m_1v_1-m_1v$
Body 2	$m_2v-m_2u_2$	$m_2v_2-m_2v$

$$e=\frac{m_1v-m_1u}{m_1v-m_1u_1}=\frac{v_1-u}{v-u_1}$$ & $$e=\frac{m_2v_2-m_2v}{m_2v-m_2v_2}=\frac{v_2-v}{v-v_2}$$

$$e=\frac{v_1-v_2}{v-v_1}=\frac{v_2-v}{v-u_2}=\frac{v_1-v-v_2+v}{v-u_1-v+u_2}$$

$$\boxed{e=\left[\frac{v_1-v_2}{u_2-u_1}\right]}$$

$$e = \frac{v_1 - v_2}{u_2 - u_1} = \left[\frac{v_1 - v_2}{u_1 - u_2}\right] = \left[\frac{v_{\frac{1}{2}}}{u_{\frac{1}{2}}}\right]$$

$$e = -\left(\frac{relative\ velocity\ of\ 1\ wrt\ 2\ after\ impact}{relative\ velocity\ of\ 2\ wrt\ 1\ before\ impact}\right)$$

$$e = -\left(\frac{velocity\ of\ separation}{velocity\ of\ approach}\right)$$

i.e., mass will not have any effect on the coefficient of restitution.

Collision with a body of infinite mass: Consider the impact between the ball and the floor.

If a ball (body 1 of finite mass m) is released from height h1. It strikes the floor (body 2 of infinite mass) and rebounds to height h_2 after impact as shown in Fig. 5.

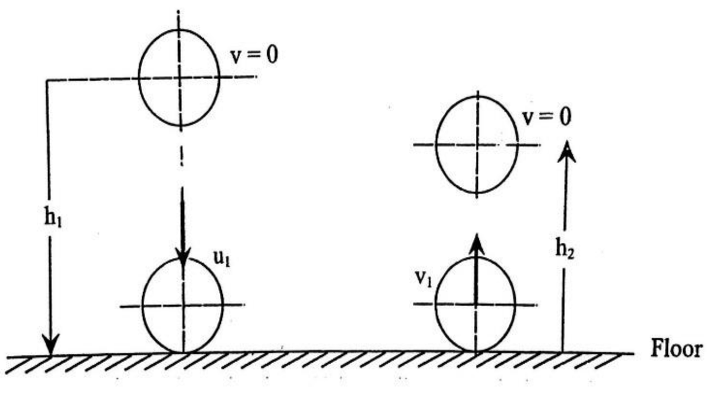


Fig. 5: Collision with a body of infinite mass

u_1 = striking velocity

$u_1 = \sqrt{2gh,}\ (\downarrow)$

v_1= Rebounding velocity

$u_1 = \sqrt{2gh_2}\ (\uparrow)$

For body 2, $u_2 = v_2 = 0$

$$\therefore e = \frac{v_1 - v_2}{u_1 - u_2} = \frac{v_1}{-u_1} = \frac{\sqrt{2gh_2}}{\sqrt{2gh_2}}$$

$$\boxed{e = \sqrt{\frac{h_2}{h_1}}}$$

Based on the coefficient of restitution the phenomenon of impact is classified into three: Elastic impact, semi-elastic impact, and plastic impact. The characteristics of these three types of impacts are as under:

Elastic Impact:

i) The two bodies separate after the impact.

ii) Coefficient of restitution, e = 1

iii) Linear momentum is conserved ($m_1u_1+m_2u_2=m_1 v_1+m_2v_2$).

iv) Kinetic energy is conserved.

(K.E. of the system before impact) = (K.E. of the system after impact).

$$\left(\frac{1}{2}m_1u_1^{\ 2}+\frac{1}{2}m_2u_2^{\ 2}\right)=\left(\frac{1}{2}m_1v_1^{\ 2}+\frac{1}{2}m_2v_2^{\ 2}\right)$$

v) Recovery is 100% and the two bodies regain their original shape and size

Semi-elastic Impact:

i) The two bodies separate after the impact.

ii) The coefficient of restitution varies between zero and one, $0 < e < 1$.

iii) Linear momentum is conserved ($m_1u_1+m_2u_2=m_1u_1+m_2v_2$).

iv) The kinetic Energy of the system is not conserved.

(K. E. of the system before impact) > (K.E. of the system after impact).

$$\left(\frac{1}{2}m_1u_1^{\ 2}+\frac{1}{2}m_2u_2^{\ 2}\right)>\left(\frac{1}{2}m_1v_1^{\ 2}+\frac{1}{2}m_2v_2^{\ 2}\right)$$

Energy lost in impact = (T_1-T_2)

$$\text{\% loss in energy} = \left(\frac{T_1-T_2}{T_1}\right)\times 100$$

v) The recovery is partial and there is same permanent damage of the bodies.

Plastic Impact:

i) The two bodies do not separate after the impact but they move with a common velocity 'v'.

ii) Coefficient of restitution $e=0$

iii) Linear momentum is conserved $(m_1u_1+m_2u_2) = (m_1+m_2)v$

iv) There is a great loss of Kinetic Energy and it is not conserved.

(K.E. of the system before impact) > (K.E. of the system after impact)

$$\left(\frac{1}{2}m_1u_1^2+\frac{1}{2}m_2u_2^2\right)>\left(\frac{1}{2}m_1v_1^2+\frac{1}{2}m_2v_2^2\right)$$

Energy lost in impact = (T_1-T_2)

% loss in energy = $\left(\frac{T_1-T_2}{T_1}\right)\times 100$

v) The recovery is partial and there is some permanent damage on the colliding bodies.

Procedure:-

1. Place the wooden cabinet of height 1 m on a horizontal plane surface.

2. Release a rubber ball from the central hole at the top of the cabinet i.e., from a height 'h_1'. (h_1= 1 m for the lab setup). The ball will fall vertically through 1 m height and strike the base of the cabinet. It will then rebound

3. Measure the height of rebound 'h_2' from two directions which are perpendicular to each other, with the help of the meter scale attached inside the cabinet on the two perpendicular sides of the cabinet. Take the average of these two readings. This is the final height of rebound 'h_2'.

4. Take three such readings.

5. Calculate the coefficient of restitution (between rubber and wood) using the formula.

$$e=\sqrt{\frac{h_2}{h_1}}$$

6. Place steel plate at the base of the cabinet. Repeat the above procedure and calculate the coefficient of restitution between rubber and steel

7. Now place the Aluminium plate at the base of the cabinet. Repeat the above procedure and calculate the coefficient of restitution between rubber and aluminium.

Observations and calculations:-

Sr. No.	Materials	Height h_1 cm	Height h_2 in cm (after impact)				Coeff. of Restitution $e = \sqrt{\frac{h_2}{h_1}}$
			1	2	3	h_2 average	
1.	Rubber and wood						
2.	Rubber and Steel						
3.	Rubber and Aluminium						

Space For Calculation

Results:-

Coefficient of restitution	Between Rubber and wood	Between Rubber and steel	Between Rubber and aluminium
e			

Questions:-

1. What is direct central impact?
2. What is conservation of linear momentum?
3. What is the expression for coefficient of restitution for collision of two bodies of finite masses?
4. What is the expression for coefficient of restitution for the collision of a body of finite mass with a body of infinite mass?
5. What is the difference between elastic, semi elastic and plastic impact?

Space for Question Answer

Name:_______________________________. Class:___________________. Batch:___________.

Roll No.:_______________ Expt. No. 12

Performed on:_____________. Submitted on:______________. Teacher's Sign.:____________.

TO FIND THE LAW OF MACHINE OF A SIMPLE LIFTING MACHINE

Purpose of the Experiment: -

To study the performance of simple lifting machines and to established the law of machine for the same.

Instruments: -

Lifting Machines (Work and Worm Wheel, Second System of Pulleys, Compound Wheel and Axle), weights, hangers, scale.

Theory: -

A mechanism is a system of rigid bodies connected together and capable of undergoing displacement.

A machine is a mechanism used for overcoming a resistance at one point by the application of a force at some other defined point in mechanism. The resistance to be overcome is called as load(W). The force which is required for overcoming the resistance is called as effort (P).

Definitions:

Mechanical Advantage

Lifting machines are used for overcoming a large resistance by application of small effort. The ratio $\frac{Load}{Effort}$ i.e.,$\frac{W}{P}$ is defined as 'Mechanical Advantage'.

Velocity Ratio

If the displacement of the effort is denoted by 'b' and the corresponding displacement of the load is denoted by 'a' during the same time interval 't',

then, the ratio = $\frac{Displacement\ of\ Effort\ in\ time\ t}{Displacement\ of\ Load\ in\ time\ t} = \frac{Velocity\ of\ Effort}{Velocity\ of\ Load} = \frac{b/t}{a/t} = \frac{b}{a}$ is defined as the 'velocity ratio' denoted by 'v'. This velocity ratio is constant for any given machine and depends purely on the geometrical configuration of load and effort exerting mechanism and is independent of the load or effort.

Efficiency of a Machine

The ratio of useful work got out of machine to the work put in by the effort is defined as the 'efficiency' (η) of the machine and is usually expressed as a percentage efficiency.

Efficiency = $\frac{Useful\ work\ got\ out\ of\ machine}{Work\ put\ in\ by\ Effort} = \frac{Output}{Input} = \frac{W.a}{P.b} = \frac{W}{P\frac{b}{a}} = \frac{W}{P.v} = \frac{W/P}{v} = \frac{Mechanical\ Advantage}{Velocity\ Ratio}$

Percentage efficiency (η %) = $\frac{W}{Pv}$ x100

This expression can be shown in various useful forms:

For a given load W for which actual effort is P, the ideal effort (if there were no friction) should have been $\frac{W}{v}$. (This can be easily proved by putting efficiency equal to 1 as there is no friction)

$\eta = \frac{W}{Pv} = \frac{W/v}{P} = \frac{Ideal\ Effort}{Actual\ Effort}$

Similarly with a given effort P, the ideal load that would have been lifted (if there were no friction) should have been Pv. Therefore, efficiency η = $\frac{Actual\ Load}{Ideal\ Load}$.

The measure of friction in the machine can be stated in two ways. If 'P' is the actual effort for a given load 'W', the ideal effort should have been $\frac{W}{v}$.

Therefore, effort lost in friction = $P - \frac{W}{v}$.

We may also say that for a given effort to lift a load 'W' the ideal load lifted should have been Pv. Frictional load = (Pv – W).

The mechanical advantage of the machine (and hence loss of effort due to friction) will depend upon the how well the machine is maintained by lubrication. The mechanical advantage of a machine is to be obtained experimentally by observing effort P required for a given load W to be lifted.

Law of Machine:

If efforts 'P' corresponding to various loads W are plotted, it will generally be found that the relationship between the two is a linear one, which can be expressed as P = mW + C ,

where m = slope of the load effort, graph and C = Intercept on effort axis.

Procedure:-

1) Study the arrangement of the machine (Refer Fig. 1, 2, 3). Measure the required dimensions and find out the velocity ratio v.

2) Note down the point of application of load and effort.

3) Apply known weight (Load) W and apply just that effort at which the effort moves with uniform velocity.

4) Observe such efforts ‘P’ for a number of loads ‘W’.

5) Plot graphs of:

   a) Load (W) against effort (P).

   b) Load against effort lost in friction (P_f).

   c) Load against efficiency.

Observations and Calculations: -

A) Worm and worm wheel: Velocity ratio v =

Sr. No.	Load W	Effort P	Frictional Effort P_f =P-(W/v)	Mechanical advantage (W/P)	Efficiency η = (W/Pv)
1.					
2.					
3.					
4.					
5.					

B) Second system of pulleys: Velocity ratio v=

Sr. No.	Load W	Effort P	Frictional Effort P_f =P-(W/v)	Mechanical advantage (W/P)	Efficiency η = (W/Pv)
1.					
2.					
3.					
4.					
5.					

Space for calculation

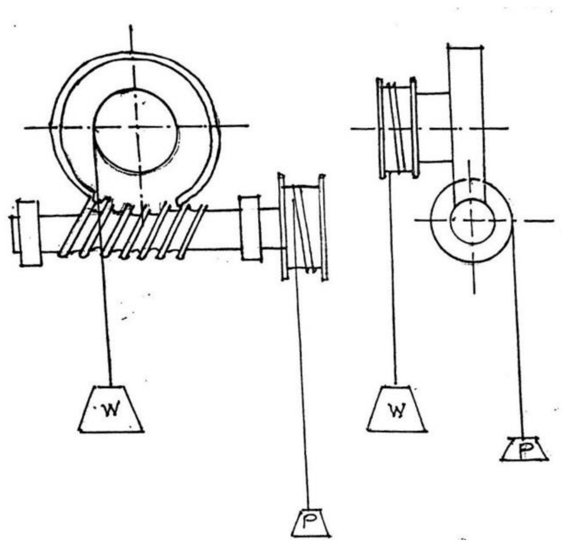


Fig. 1: Worm and Worm Wheel.

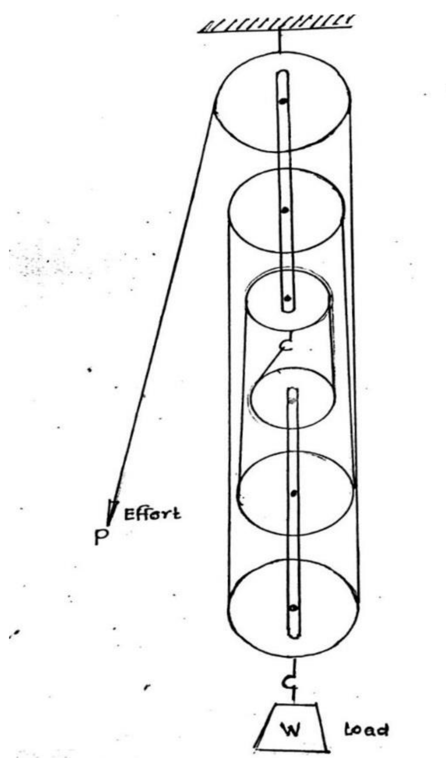


Fig. 2: Second System of Pulleys.

Conclusion: -

Machine	**Law of Machine**	**Max Efficiency**
Worm and Worm Wheel		
Second System of Pulleys		

Questions: -

1. The efficiency of a lifting machine is the ratio of……………..

   (a) Its output to input (b) Work done by it to the work done on it (c) Its mechanical advantage to its velocity ratio (d) All of the above.

2. If efficiency of a lifting machine is kept constant, its velocity ratio is directly proportional to its………..

   (a) Mechanical advantage (b) Effort applied (c) Machine friction (d) All of the above

3. In an ideal machine, the mechanical advantage is .... velocity ratio

   (a) Equal to (b) Less than (c) Greater than

4. A lifting machine having an efficiency less than 50% is known as……….

   (a) Reversible machine (b) non-reversible machine (c) Ideal machine (d) None of the above

5. 5. A weight of 1000 N can be lifted by an effort of 80 N. If the velocity ratio of the machine is 20, then the machine is………

   (a) Reversible (b) non-reversible (c) Ideal

6. The maximum mechanical advantage of a lifting machine is…………..

   (a) 1 + m (b) 1 – m (c) 1/ m (d) m

7. 7. The maximum efficiency of a lifting machine is………………

   (a) 1/ m (b) V. R./ m (c) m/ V. R. (d) 1/ (m × V. R.)

Space for Question and Answer