MIT-WORLD PEACE UNIVERSITY, PUNE

First Year B.Tech

DEPARTMENT OF CIVIL ENGINEERING

APPLIED MECHANICS

Course Code: CE -101

LABORATORY MANUAL

2017-18

Preface

Applied Mechanics

The laboratory work for the subject Applied Mechanics for F.Y. B. Tech. students of MIT-World Peace University covers experiments based on equilibrium of coplanar and space force system, study of belt friction, curvilinear motion and impact of elastic bodies. These are included in the laboratory work to familiarize the students with the principles of statics and dynamics and its various applications in the field of engineering. The safety precautions to be followed in the laboratory are included in this manual. In order to help the students to properly grasp the principles of Applied Mechanics, questions based on each experiment have been included. We hope that this course will provide hands on experience and lifelong learning to the students.

General Instructions to students

1. To enter the lab I-card is necessary.
2. Follow your time table strictly.
3. Always carry write-up of respective experiment of scheduled practical with you.
4. Always carry a rough notebook to record the results and to do calculations.
5. Be punctual in your laboratory work and submission.
6. Follow proper dress code in laboratory.
7. Do not eat food, drink beverages or chew gum in laboratory.
8. Do not litter the laboratory. Keep the laboratory premises clean and tidy.

Safety Instructions to be followed in Applied Mechanics Laboratory

Applied Mechanics Laboratory is associated with several heavy equipments and instruments with potential hazards and therefore certain precautions should be taken to minimize the probability of an accident. The awareness of hazards is the most important factor to avoid accidents and hence safety in the laboratory.

1. Perform the experiment in the presence of a laboratory assistant.
2. Do not touch any equipment or any other material unless you are told to do so.
3. Follow the instructions carefully and handle the instruments to avoid its breakage or damage.
4. Have only your notebook on the table and other things should be kept in the rack.
5. Before you leave the laboratory the instruments should be kept in proper location.
6. Record all observations in your note book.
7. Report all accidents / mishaps to your teacher immediately even if you think it is a minor one.

APPLIED MECHANICS
I N D E X

Sr. No.	Name of the Experiment	Page	Date	Signature of Batch I/C
1.	To find the reactions of simple and compound beams.			
2.	Determination of coefficient of friction between flat belt and pulley.			
3.	To find the law of machine of a simple lifting machine.			
4.	Determination of forces in a space force system.			
5.	Study of curvilinear motion.			
6.	Determination of Moment of Inertia of flywheel.			
7.	Determination of coefficient of restitution between two colliding bodies.			
8.	Graphic Statics 1			
9.	Graphic Statics 2			
10.	Graphic Statics 3			
11.	Graphic Dynamics 1			
12.	Graphic Dynamics 2			

CERTIFICATE

Certified that Mr./Ms.____ of Class **F.Y.B. Tech.** Division _____ Roll No.___________ has completed the laboratory work in the subject **Applied Mechanics** in during the trimester I/II/III of the academic year____________________________.

Signature of the Faculty **Seal of the Head of the Department**

Dr. Vishwanath Karad MIT WORLD PEACE UNIVERSITY | PUNE

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

Roll No.:_______________ Expt. No. 1

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

DETERMINATION OF SUPPORT REACTIONS OF SIMPLE AND COMPOUND BEAMS

Purpose of the experiment:-

To introduce and develop 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 spring balance, hangers and weights.

Theory:-

The basic principles used in statics to analyse all the forces and moments acting on a rigid body is 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 'Force Law of Equilibrium' expressed as $\boxed{\sum \bar{F} = 0}$

To be assured of the 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.

In particular, when the two directions are horizontal and vertical, the force equilibrium equations are expressed as, $\boxed{\sum H = 0 \;, \sum V = 0}$

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 a common knowledge that a small force can have a large turning effect or leverage. In Mechanics, the term <u>‘moment’</u> is used instead of ‘<u>turning effect’</u>.

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 fig. 1) The distance d is often called <u>lever arm</u>. 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.

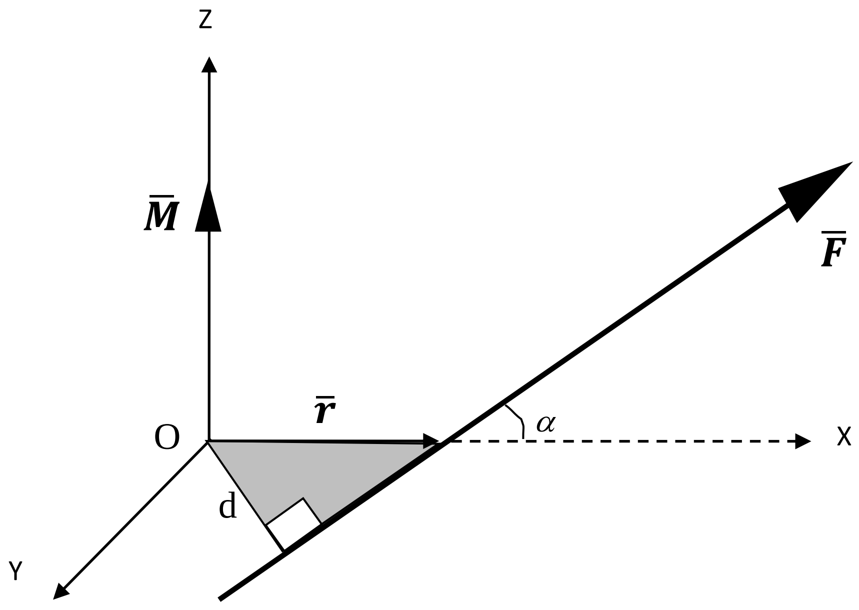


Fig 1. Moment of force $\bar{F}$

Free-body Diagram:

A mechanical system is defined as a body or group of bodies which can be conceptually isolated from all other bodies. A system may be a single body or a combination of connected bodies. The bodies may be rigid or non-rigid. The system may also be an identifiable fluid mass either liquid or gas, or a combination of fluids and solids. In statics we study primarily forces which act on rigid bodies at rest, although we also study forces acting on fluids in equilibrium.

Once we decide which body or a combination of bodies to analyze, we then treat this body or combination as a single body isolated from all surrounding bodies. This isolation is accomplished by means of the free-body diagram (FBD), which is a diagrammatic representation of the isolated system treated as a single body. The diagram shows all forces applied to the system by mechanical contact with other bodies, which are imagined to be removed. If appreciable body forces are present, such as gravitational or magnetic attraction, then these forces must also be shown on the free-body diagram of the isolated system. Only after such a diagram has been carefully drawn should the equilibrium equations be written. Because of its critical importance, we emphasize here that the free-body diagram is the most important step in the solution of problems in mechanics. Two common engineering problems are:

i) To determine the external forces, called support reactions at the supports of a structure that are caused by the external loads it carries.

ii) To determine the internal forces, called stresses, which the external forces produce on various members or parts of the structure.

Construction of Free-Body diagram:

The full procedure for drawing a free-body diagram which isolates a body or a system consists of the following steps.

Step 1. Decide which system to isolate. The system chosen should usually involve one or more of the desired unknown quantities.

Step 2. Isolate the chosen system by drawing a diagram which represents its complete external boundary. This boundary defines the isolation of the system from all other attracting or contacting bodies, which are considered as removed. This step is often the most crucial of all. Make certain that you have completely isolated the system before proceeding with the next step.

Step 3. Identify all forces which act on the isolated system as applied by the removed contacting and attracting bodies, and represent them in their proper positions on the diagram of the isolated system. Make a systematic traverse of the entire boundary to identify all contact forces. Include the body forces such as weights, wherever appreciable. Represent all known forces by vector arrows, each with its proper magnitude, direction, and sense. Each unknown force should be represented by a vector arrow with the unknown magnitude or direction indicated by a symbol. If the sense of the vector is also unknown, you must arbitrarily assign a sense. The subsequent calculations with the equilibrium equations will yield a positive quantity if the correct sense was assumed and a negative quantity if the incorrect sense was assumed. It is necessary to be consistent with the assigned characteristics of unknown forces throughout all the calculations. If you are consistent, the solution of the equilibrium equations will reveal the correct sense.

Step 4. Show the choice of the coordinate axes directly on the diagram. Pertinent dimensions may also be represented for convenience. Note, however, that the free-body diagram serves the purpose of focusing attention of the action of the external forces, and therefore the diagram should not be cluttered with excessive extraneous information. Clearly distinguish force arrows from arrows representing quantities other than forces. For this purpose a colored pencil may be used.

The free-body diagram method is extremely important in Mechanics because it ensures an accurate definition of a mechanical system and focuses attention on the exact meaning and application of the force laws of statics and dynamics.

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 which can replace the original force system without altering the external effect on the rigid body to which the forces are applied.

Equilibrium:

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 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 a 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 case of roller support translation is possible in all the 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 unknown 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 is along the two orthogonal directions. Thus the number of unknowns are 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 are three.

Different types of supports and their support reactions are shown in fig.2

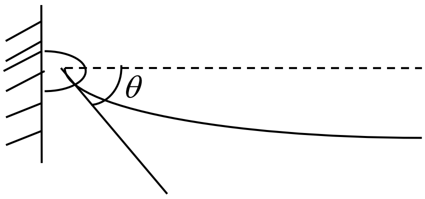
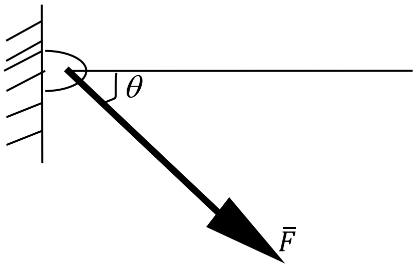
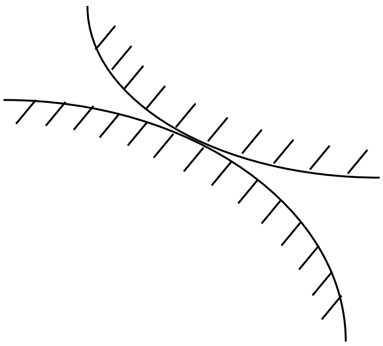
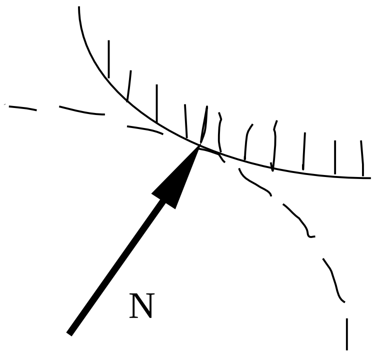
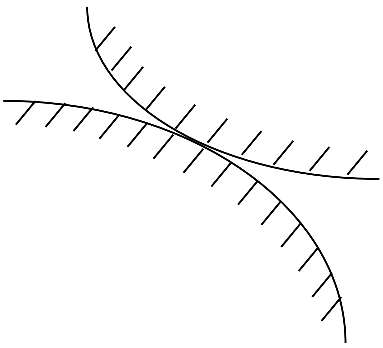
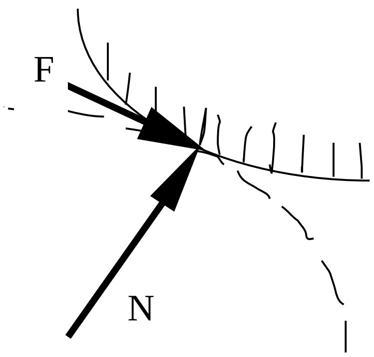
Loading Systems:

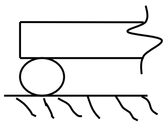
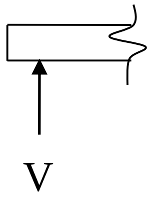
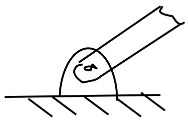
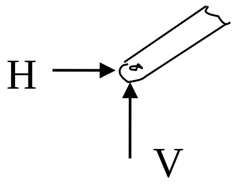
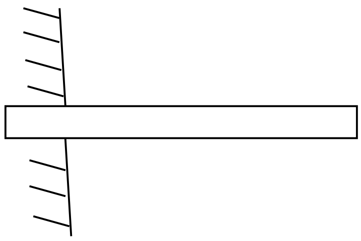
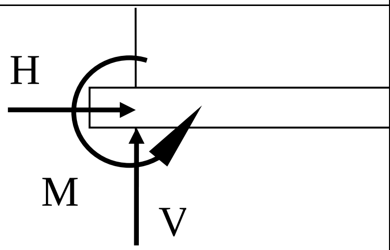
Before any of the various load effects (tension, compression, bending etc.) can be considered, the applied loads must be rationalized into a number of ordered systems. Irregular loading is difficult to deal with exactly, but even the most irregular loads may be reduced and approximated to a number of regular systems. These can then be dealt with 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.

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

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

Roller support 		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 hinge.
Built in Support or fixed support 		The body is fixed in position and direction also. Hence two orthogonal reaction components and reacting moment.

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 the purpose of calculation, a udl is normally considered in a plane.

Distributed load with linear variation is another common load situation. These are called as 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:-

i) Place a wooden beam horizontally with its 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 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, initial reading is subtracted to get the reaction due to external load (W) only.

vi) Value of 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.

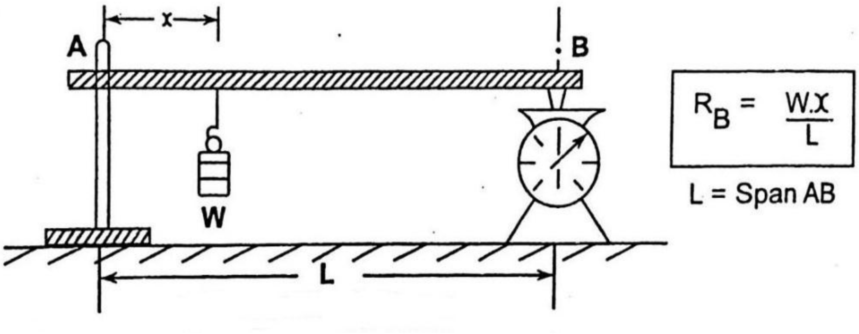


Fig. 3. Simple Beam

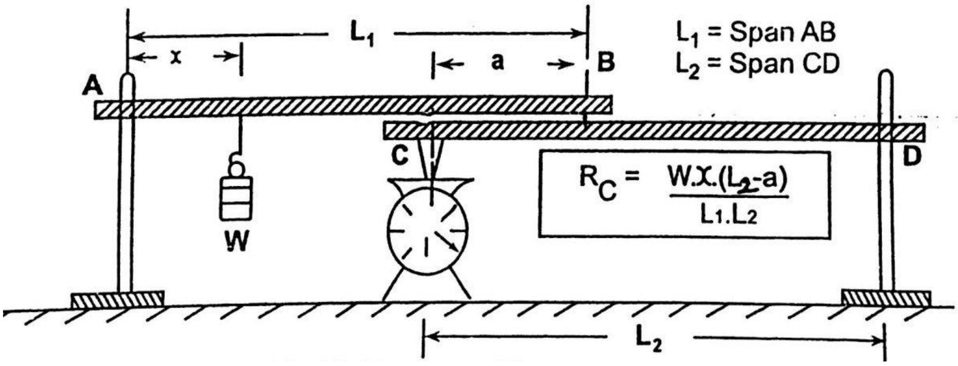


Figure 4. Compound Beam

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 (N)	Due to External Load + Self Weight (N)	R_B due to External Load (N) $(R_B)_{Exp}$		
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 Analytical (N) $(R_c)_{Ana}$ $\frac{Wx(L_2-a)}{L_1 L_2}$	% Error = $\left[\frac{(R_B)_{Exp}-(R_B)_{Ana}}{(R_B)_{Ana}}\right]100$
			Due to Self Weight (N)	Due to External Load + Self Weight (N)	R_c due to External Load (N) $(R_c)_{Exp}$		
1.							
2.							
3.							
4.							
5.							

Note: Students are instructed to do all the necessary calculations on separate sheets.

Conclusion:-

Questions:-

1. What is meant by equilibrium of a force system? What are the physical and analytical conditions of equilibrium?
2. What are the different types of supports and their corresponding reactions?
3. What do you mean by udl & uvl?
4. What is a compound beam? Illustrate by an example.
5. What is meant by F.B.D. of a body?

R101

Dr. Vishwanath Karad MIT World Peace University

F.Y. B.Tech. Academic Year 2017-18 Trimester:

SCIENCE & ENGG LABORATORY CONTINUOUS ASSESSMENT RUBRIC

COURSE: **EXPT NO.:**

EVALUATOR: **DATE:**

STUDENT:

DIMENSION	SCALE					SCORE
	1	2	3	4	5	
Regularity and punctuality	Did not Perform/ submit	Performed and submitted later than scheduled date with permission	Performed on schedule; submitted two weeks late	Performed on schedule; submitted one week late	Performed and submitted as per schedule	
Understanding the Objective	Neither shows any understanding of the objective nor can relate it to theory	States the objective very vaguely	Can only state the objective but shows poor understanding	Understands objective but cannot place it in context of a theory topic	Understands objective and can relate it to an appropriate theory topic	
Understanding of Procedure	Cannot follow the procedure and do any work	Follows the procedure half-heartedly	Follows right procedure; but cannot analyze data and interpret it	Follows right procedure, can analyze data but cannot interpret it	Follows right procedure, can analyze data and interpret it with justification	
Experiment Skills	Does not participate in the experiment	Performs the experiment only with the help from supervisor/others and is confused and untidy.	Performs the experiment with some supervisory help, forgets some crucial readings. Is confused and untidy.	Performs experiment on own without supervisor's help; records all the readings properly but is untidy.	Performs experiment on own without supervisor's help and records all the readings properly. Keeps the set-up clean and tidy.	
Ethics	Copies the results from others	Completes the result analysis with help from others but forgets to acknowledge the help.	Completes the result analysis with help from others and acknowledges the help.	Produces his own result analysis but blames others for any inadequacy found during the examination	Produces his own result analysis faithfully and owns up the results without any manipulation	
					Total	

Teacher's Signature with Date: Student's Signature with Date :

Name:____________________________. Class:_____________________. Batch:______________.

Roll No.:______________ Expt. No. 2

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, 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 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 extent or shape of bearing surface.

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 $\Phi = \tan^{-1} \frac{(F_{max})}{N}$.

(Ref. Fig.1)

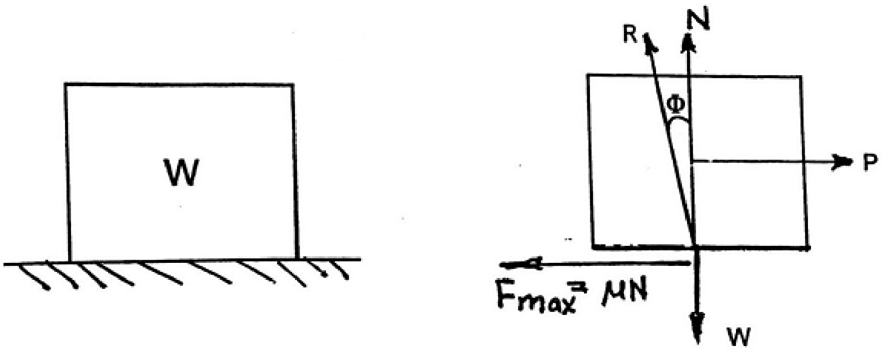


Fig. 1: Block resting on rough surface and its FBD

Coulomb's Law of Friction:

1. The frictional force F acts along the tangent plane at the surface of contact and opposes 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 'Angle of Lap'. T_1 is the tension on tight side and T_2 is the tension on 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 in relation to β and μ. It should be noted that normal reaction in the belt increases from 0 to maximum at centre.

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..

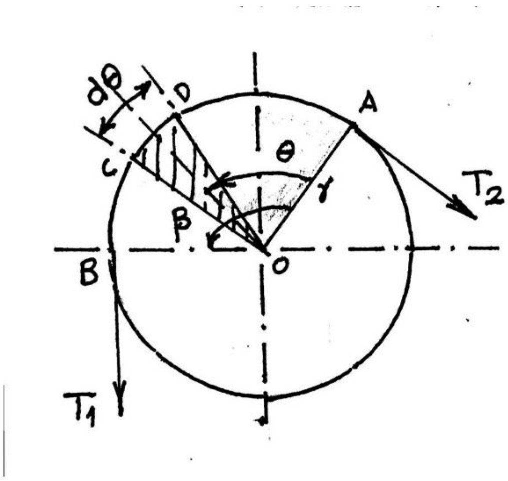


Fig. No. 2 (a)

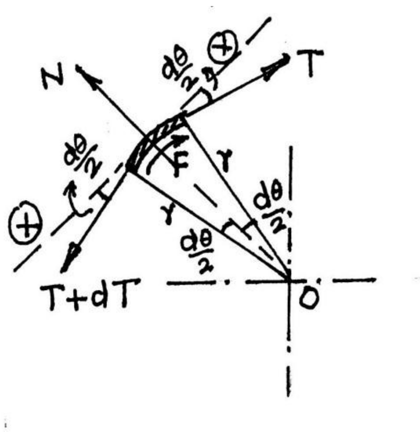


Fig. No. 2 (b)

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).

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

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

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

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

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

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

Procedure:-

Case-1: Determination of coefficient of friction μ by maintaining 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 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 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.

Perform the experiment, in a similar manner as in case 1 except that instead of keeping the value of β constant, keep T_2 as constant and vary the value of 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} =	

Note: Students are instructed to do all the necessary calculation on separate sheets and record the result.

Graphs: Case-1: Draw a graph with values of T_2 on X axis and that of T_1 on Y axis. The scale chose should be the same on both the axes. The graph will be a straight line passing through origin.

Coefficient of friction = [$\log_e$ (slope of straight line)]/β (rad) =

Case-2**:** Draw a graph with value of β (rad) on X axis and $\log_e T_1$ on 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 =

Note: Students are instructed to draw the graphs on separate paper and record the result.

Result:-

Case (1)		Case (2)	
μ (Experimental)	μ (Graphical)	μ (Experimental)	μ (Graphical)
Average value of μ =			

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

Questions:-

1. State the laws of friction?
2. What is the difference between Static friction and dynamic friction?
3. Define the coefficient of the friction, and angle of friction.
4. What do you mean by angle of lap?
5. What is the relationship between tight tension and slack tension for a flat belt passing over a stationary pulley?

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F.Y. B.Tech. Academic Year 2017-18 Trimester:

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STUDENT:

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Teacher's Signature with Date: Student's Signature with Date :

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Name:________________________________. Class:____________________. Batch:____________.

Roll No.:________________ Expt. No. 3

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 $\eta = \frac{Actual\ Load}{Ideal\ Load}$.

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) Compound Wheel and Axle: 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) 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.					

C) 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.					

Note: Students are instructed to do all the necessary calculation on separate sheets Separate graph papers should be used for each machine

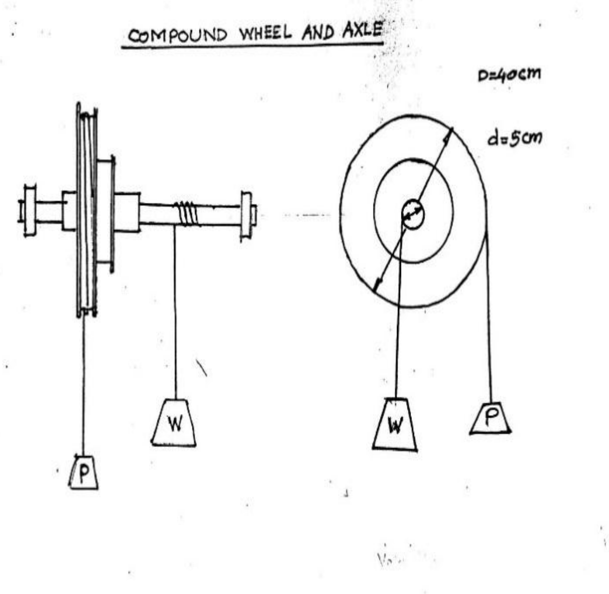

Fig. 1: Compound Wheel and Axle.

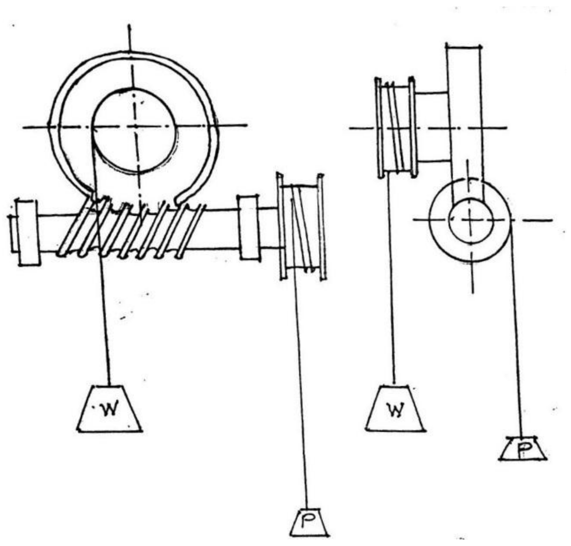

Fig. 2: Worm and Worm Wheel.

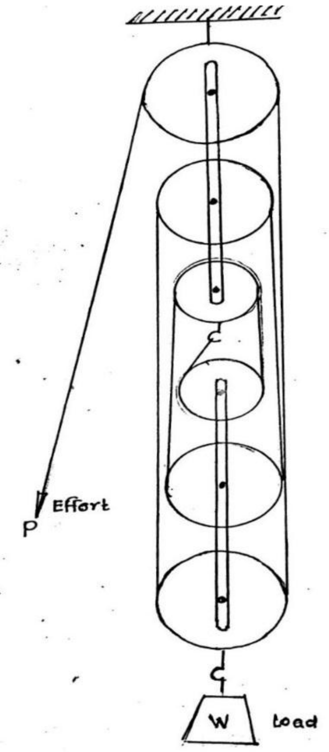

Fig. 3: Second System of Pulleys.

Conclusion:-

Questions:-

1. Define the following terms: a) Mechanical Advantage b) Velocity Ratio c) efficiency of machine.
2. What is the difference between reversible and irreversible machine?
3. What is the law of a machine?
4. State the practical applications where simple lifting machines are commonly used.
5. Why is the efficiency of the machine less than one?

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F.Y. B.Tech. Academic Year 2017-18 Trimester:

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Teacher's Signature with Date: Student's Signature with Date :

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

Roll No.:________________ Expt. No. 4

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

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

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 $\bar{F}$

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

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 , F_y = 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. $\boxed{\sum F_x = 0, \sum F_y = 0, \Sigma F_z = 0}$

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

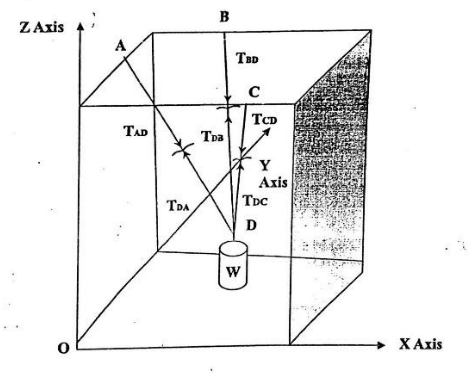

Fig. 1: Concurrent space force system

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. Wrt 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 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												

Note: Students are instructed to do all the necessary calculations on separate sheets.

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?

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F.Y. B.Tech. Academic Year 2017-18 Trimester:

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

Roll No.:_______________ Expt. No. 5

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

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

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

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

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

Position vector: $\bar{r} = r.\hat{e}_r$ 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: $\bar{a} = a_r\,\hat{e}_r + a_\theta\,\hat{e}_\theta$ m/s^2

$$\bar{a} = \left(\ddot{r} - r\,\dot{\theta}^2\right)\hat{e}_r + \left(r\,\ddot{\theta} + 2\,\dot{r}\,\dot{\theta}\right)\hat{e}_\theta \text{ m/s}^2$$

3) Using Path Variables:

Velocity vector : $\bar{v} = v.\hat{e}_t$ 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.

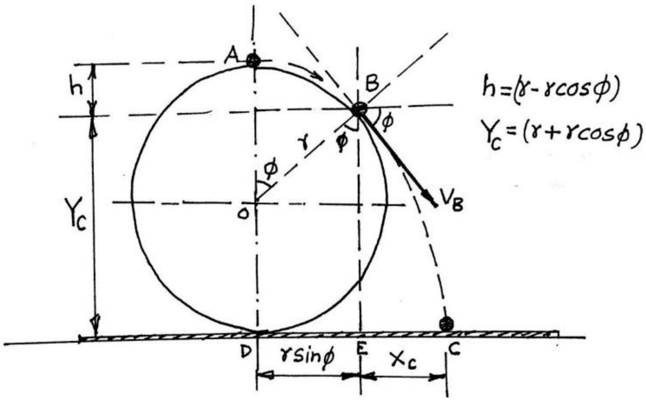

Fig. 1: curvilinear motion of the particle

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

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

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

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

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

$\therefore V_B^2=(r)(9.81)\left(\cos 48.19^0\right)$ $V_B=(2.56)\sqrt{r}$

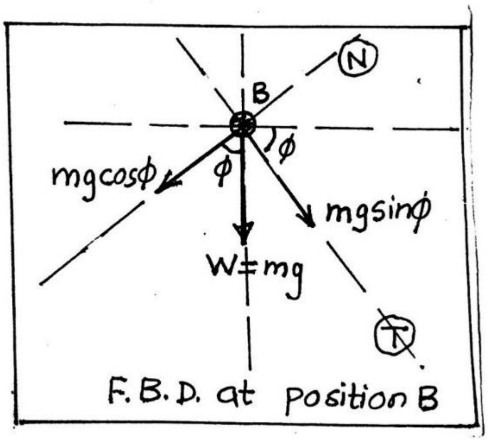

Fig. 2: FBD of particle at B

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

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

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

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

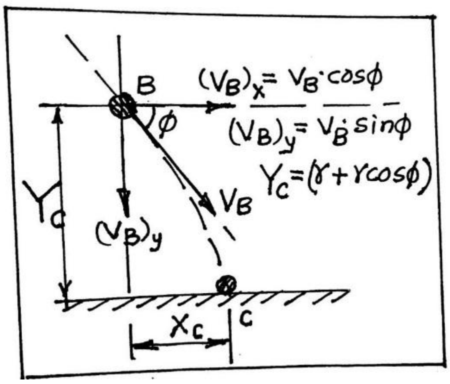

Fig. 3: Projectile motion of the particle

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 looses 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= ______________r
4. Angle Φ = ____________Radians =_______________degrees

Result:-

	Analytical	Experimental
Φ	48.18^0	
CD	1.46 r	______________r

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. What is Coriollis component of acceleration in polar coordinate system?
5. The tangential component of acceleration gives us the idea of the rate of change of …………………………
   (a) Velocity b) Speed c) Acceleration d) Displacement)
6. "A particle is moving along a curve with constant velocity" Will there be any acceleration?

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Dr. Vishwanath Karad MIT World Peace University

F.Y. B.Tech. Academic Year 2017-18 Trimester:

SCIENCE & ENGG LABORATORY CONTINUOUS ASSESSMENT RUBRIC

COURSE: **EXPT NO.:**

EVALUATOR: **DATE:**

STUDENT:

DIMENSION	SCALE					SCORE
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Teacher's Signature with Date: Student's Signature with Date :

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

Roll No.:_______________ Expt. No. 6

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 $= \int dm \cdot r^2$

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 = $I = \int dm \cdot r^2$………………..(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.

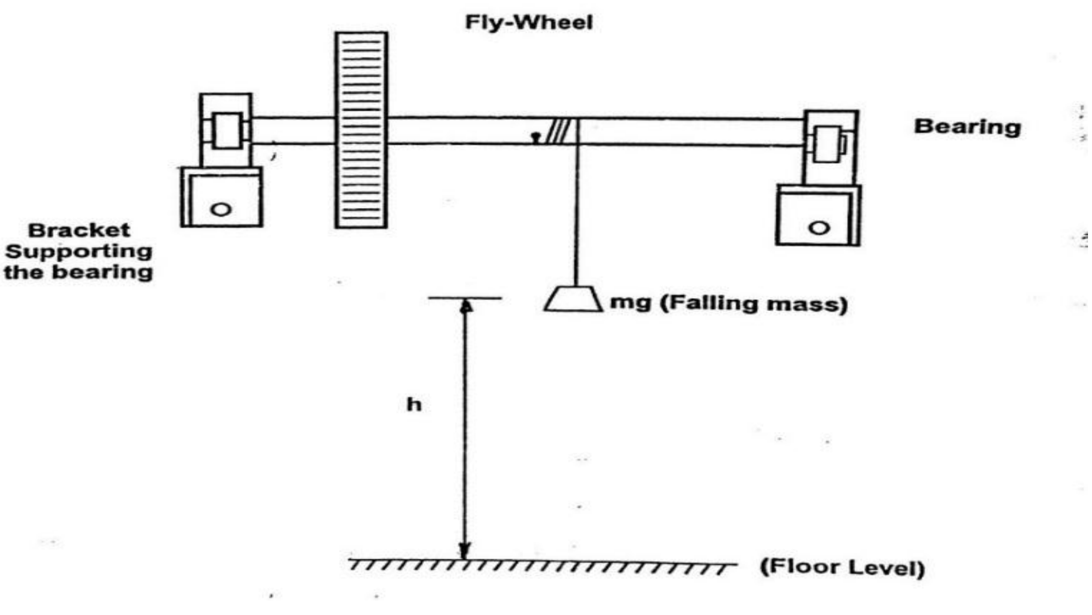

Fig. 1: Experimental setup to find M.I. of flywheel

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

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

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

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

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

$=2ah$ ……………..as u = 0

$= 2\left(\dfrac{2h}{t^2}\right)h$ ……………………from equation (3)

$= \left(\dfrac{4h^2}{t^2}\right)$ ……………………(4)

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

$\omega^2 = \left(\dfrac{4h^2}{t^2}\right)/r^2 \quad = \left(\dfrac{4h^2}{r^2t^2}\right)$ …………………(5)

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

$KE2 = \dfrac{1}{2}I\omega^2 \quad = \dfrac{1}{2}I\left(\dfrac{4h^2}{r^2t^2}\right) \quad = \left(\dfrac{2Ih^2}{r^2t^2}\right)$ ………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

$\dfrac{2Ih^2}{r^2t^2} = C\,(2\pi N_2)$ …………from equation (5)

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

Work done against friction W.D.F1.

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

$= \dfrac{2Ih^2}{r^2t^2} \times \dfrac{N_1}{N_2}$ ……………………… (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.

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

$I = \left(\frac{m.r^2}{2h}\right) \left(g.t^2 - 2.h\right) \left(\frac{N_2}{N_1 + N_2}\right)$ in kg.m^2

Note: Students are instructed to do all the necessary calculation on separate sheets:

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.?

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Roll No.:_______________ Expt. No. 7

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, concept of direct central impact and coefficient Type equation here.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

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

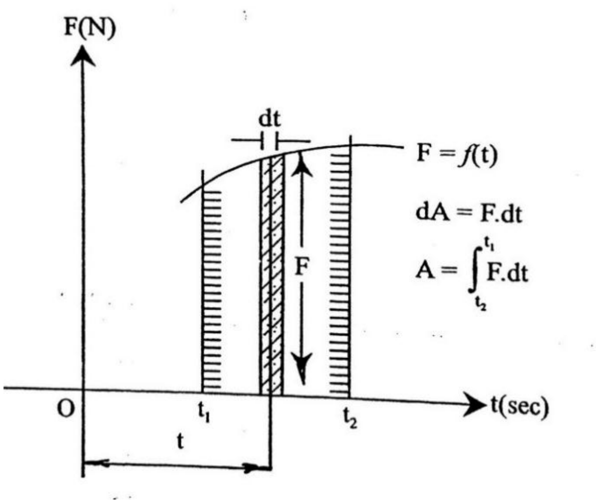


Fig. 1: F-t Diagram

'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 in 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:

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)

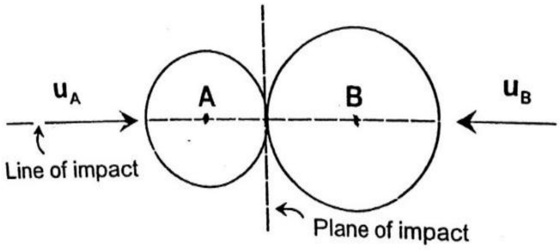


Fig. 2: Direct central impact

Impulse of Deformation:

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

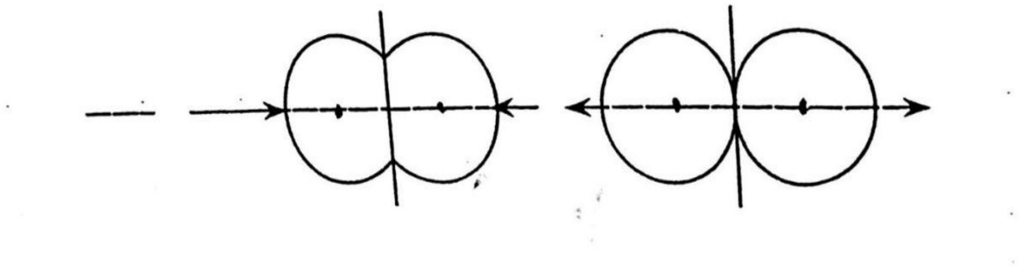
Impulse of Recovery:

After the deformation stage, the bodies develop the tendency of separating 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 recovery stage is called as Impulse of recovery.

Time of impact (Δt) = time of deformation (Δt_d) + time of recovery (Δt_r) (ref. fig 3)

Coefficient of restitution:

The ratio of 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 for a given combination of colliding materials. It also depends on the impact velocity, shape and size of colliding bodies.

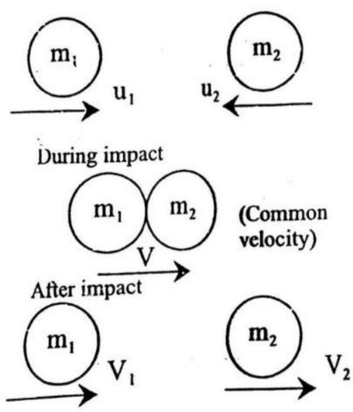


$\Delta t = \Delta t_d + \Delta t_r$

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	$m_2v-m_2u_2$	$m_2v_2-m_2v$

$$e = \frac{m_1 v - m_1 u}{m_1 v - m_1 u_1} \quad = \frac{v_1 - u}{v - u_1} \quad \& \quad e = \frac{m_2 v_2 - m_2 v}{m_2 v - m_2 v_2} \quad = \frac{v_2 - v}{v - v_2}$$

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

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

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

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

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

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

If a ball (body 1 of finite mass m) be 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.

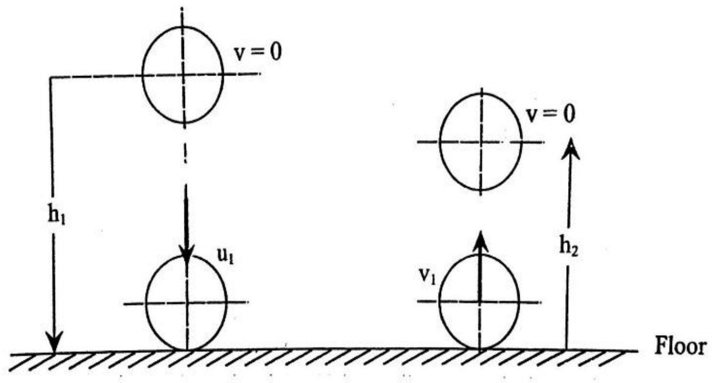


Fig. 5: Collision with a body of infinite mass

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

$$\therefore e = \frac{v_1 - v_2}{u_1 - u_2} = \frac{v_1}{-u_1} = \frac{\sqrt{2gh_2}}{\sqrt{2gh_2}} \qquad \boxed{e = \sqrt{\frac{h_2}{h_1}}}$$

Based on 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) 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) Kinetic Energy of 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)

% 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 (cm)	
1.	Rubber and wood						
2.	Rubber and Steel						
3.	Rubber and Aluminium						

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?

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