LECTURE HANDOUTS

L - 01

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : I-Basics and Statics of Particles

Topic of Lecture: Introduction, Units, Dimensions

Introduction :

- Mechanics is the area of physics concerned with the motions of physical objects. Forces applied to objects result in displacements, or changes of an object's position relative to its environment.
- This branch of physics has its origins in Ancient Greece with the writings of Aristotle and Archimedes During the early modern period, scientists such as Galileo, Kepler, and Newton laid the foundation for what is now known as classical mechanics.
- It is a branch of classical physics that deals with particles that are either at rest or are moving with velocities significantly less than the speed of light.
- It can also be defined as a branch of science which deals with the motion of and forces on bodies not in the quantum realm. The field is today less widely understood in terms of quantum theory.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)

- Basic Science
- Basic Knowledge in Mathematics

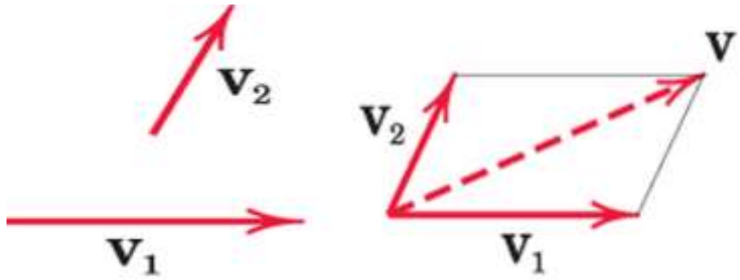
Detailed content of the Lecture:

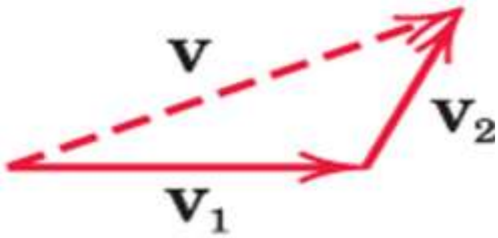
- STATICS It is that branch of Engineering Mechanics, which deals with the forces and their effects, while acting upon the bodies at rest.
- DYNAMICS It is that branch of Engineering Mechanics, which deals with the forces and their effects, while acting upon the bodies in motion. The subject of Dynamics may be further sub-divided into the following two branches: 1. Kinetics, and 2. Kinematics.
- KINETICS It is the branch of Dynamics, which deals with the bodies in motion due to the application of forces.
- KINEMATICS It is that branch of Dynamics, which deals with the bodies in motion, without any reference to the forces which are responsible for the motion.

Units

Length (Space): needed to locate position of a point in space, &describe size of the physical system
Distances, Geometric Properties
Time: measure of succession of events basic quantity in Dynamics
Mass: quantity of matter in a body measure of inertia of a body (its resistance to change in velocity)
Force: represents the action of one body on another characterized by its magnitude, direction of its action, and its point of application
Force is a Vector quantity.
Scalars: only magnitude is associated.
Ex: time, volume, density, speed, energy, mass
Vectors: possess direction as well as magnitude, and must obey the

Ex: displacement, velocity, acceleration, force, moment, momentum
Parallelogram law of addition (and the triangle law).
Equivalent Vector: $V = V_1 + V_2$ (Vector Sum)





In order to determine the effects of a force, acting on a body, we must know the following characteristics of a force : 1. Magnitude of the force (i.e., 100 N, 50 N, 20 kN, 5 kN, etc.) 2. The direction of the line, along which the force acts (i.e., along OX, OY, at 30° North of East etc.). It is also known as line of action of the force. 3. Nature of the force (i.e., whether the force is push or pull). This is denoted by placing an arrow head on the line of action of the force. 4. The point at which (or through which) the force acts on the body.

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=K4u5S76OYR4

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics-R.S.Khurmi 8-13

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LECTURE HANDOUTS

L-02

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : I- Basics and Statics of Particles

Topic of Lecture:
Laws of Mechanics, Lami's theorem, Parallelogram and triangular Law of forces

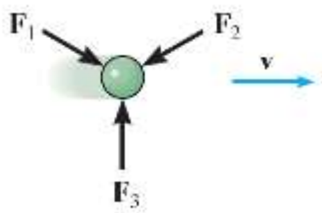
Introduction :

- In classical mechanics, Newton's laws of motion are three laws that describe the relationship between the motion of an object and the forces acting on it
- The first law states that an object either remains at rest or continues to move at a constant velocity, unless it is acted upon by an external force.
- The second law states that the rate of change of momentum of an object is directly proportional to the force applied, or, for an object with constant mass, that the net force on an object is equal to the mass of that object multiplied by the acceleration.
- The third law states that when one object exerts a force on a second object, that second object exerts a force that is equal in magnitude and opposite in direction on the first object.

Prerequisite knowledge for Complete understanding and learning of Topic:
(Max. Four important topics)
Newton's First Law, Second Law, Third Law

Detailed content of the Lecture:
Basis of formulation of rigid body mechanics.
First Law: A particle originally at rest, or moving in a straight line with constant velocity, tends to remain in this state provided the particle is not subjected to an unbalanced force.

First law contains the principle of the equilibrium of forces main topic of concern in Statics



Equilibrium

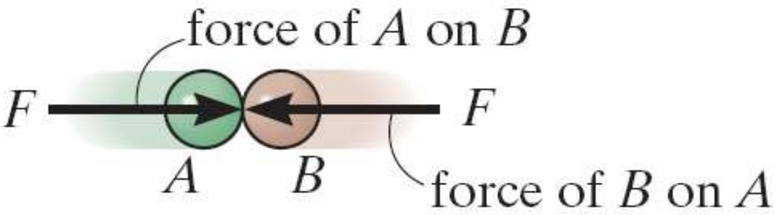
Second Law: A particle of mass "m" acted upon by an unbalanced force "F" experiences acceleration "a" that has the same direction as the force and a magnitude that is directly proportional to the force.

Accelerated motion

F = ma

Second Law forms the basis for most of the analysis in Dynamics

Third Law: The mutual forces of action and reaction between two particles are equal, opposite, and collinear.

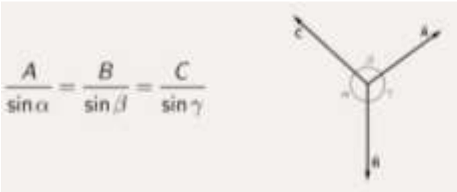


Action – reaction

Third law is basic to our understanding of Force, Forces always occur in pairs of equal and opposite forces.

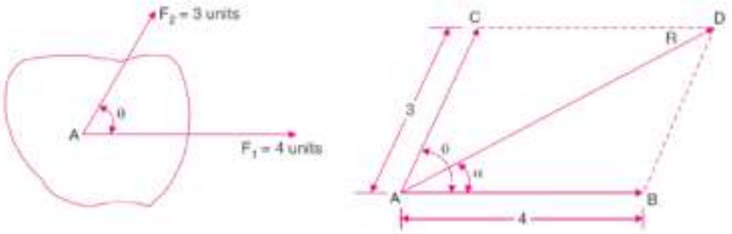
Lami's Theorem

Lami's Theorem states, "When three forces acting at a point are in equilibrium, then each force is proportional to the sine of the angle between the other two forces".

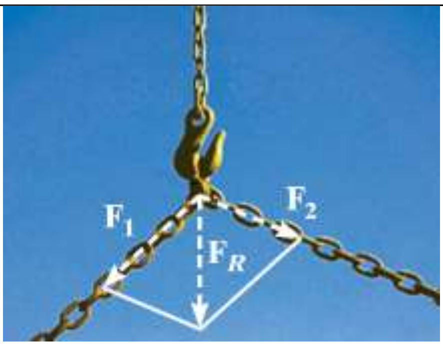


Parallelogram Law (Graphical)

It states that if two forces acting simultaneously on a body at a point are represented by the two adjacent sides of a parallelogram, their resultant is represented in magnitude and direction by the diagonal of the parallelogram which passes through the point of intersection of the two sides representing the forces.

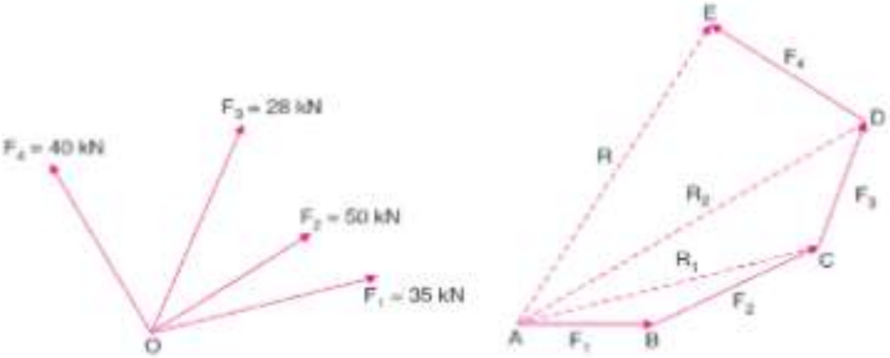


Resultant Force (diagonal) Components (sides of parallelogram)

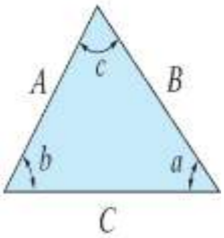


The Triangle Law of Forces states that if two forces acting on a body are represented one after another by the sides of a triangle, their resultant is represented by the closing side of the triangle taken from first point to the last point.

Polygon of law of forces states that if a number of concurrent forces acting simultaneously on a body are represented in magnitude and direction by the sides of a polygon, taken in a order, then the resultant is represented in magnitude and direction by the closing side of the polygon, taken from first point to last point.



Resultant Force and Components from Law of Cosines and Law of Sines



Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=YzxUZzMrlfQ&list=PLF_7kfnwLFCGcF1IhVgTiZ-Sf0pnKIOub

Important Books/Journals for further learning including the page nos.:

- A text of Engineering Mechanics - R.S.Khurmi 12-19

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LECTURE HANDOUTS

L-03

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : I- Basics of Statics and Particles

Topic of Lecture: : Vectorial Representation of forces

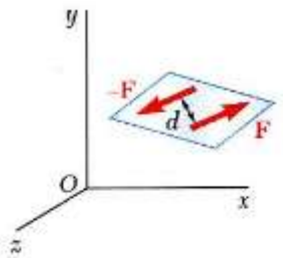
Introduction :

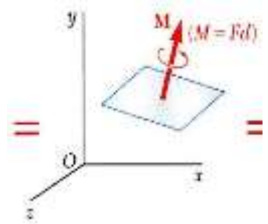
- Components of a Force are not necessarily equal to the Projections of the Force unless the axes on which the forces are projected are orthogonal (perpendicular to each other).
- A force vector is a representation of a force that has both magnitude and direction. This is opposed to simply giving the magnitude of the force, which is called a scalar quantity. A vector is typically represented by an arrow in the direction of the force and with a length proportional to the force's magnitude
- A major feature of force vectors is that they can be broken into components, according to the application of the force. Vector components are usually perpendicular to each other, although they also can be in a parallelogram configuration.

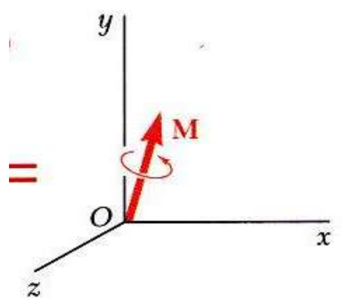
Prerequisite knowledge for Complete understanding and learning of Topic:

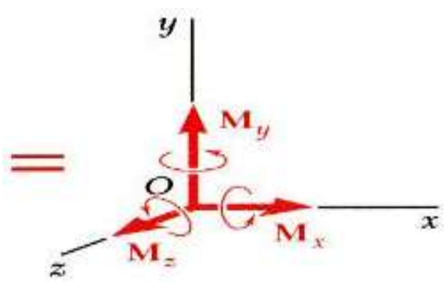
- Vector Operations
- Basics of Mathematics

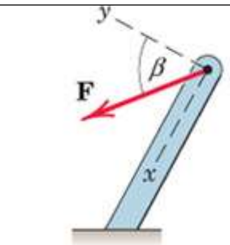
Detailed content of the Lecture:





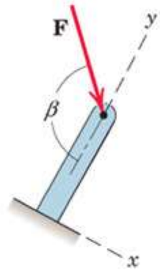






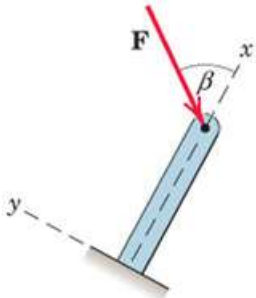
$F_x = F \sin \beta$

$F_y = F \cos \beta$



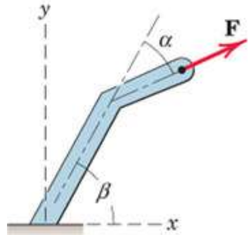
$F_x = F \sin(\pi - \beta)$

$F_y = -F \cos(\pi - \beta)$



$F_x = -F \cos \beta$

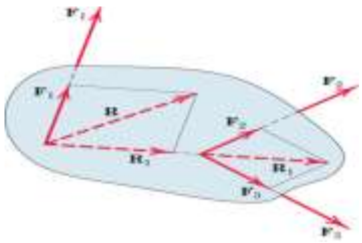
$F_y = -F \sin \beta$



$F_x = F \cos(\beta - \alpha)$

$F_y = F \sin(\beta - \alpha)$

Vector



Magnitude and direction of the resultant force R is obtained by forming the force polygon where the forces are added head to tail in any sequence

$$\mathbf{R} = \mathbf{F}_1 + \mathbf{F}_2 + \mathbf{F}_3 + \cdots = \Sigma\mathbf{F}$$

$$R_x = \Sigma F_x \qquad R_y = \Sigma F_y \qquad R = \sqrt{(\Sigma F_x)^2 + (\Sigma F_y)^2}$$

$$\theta = \tan^{-1}\frac{R_y}{R_x} = \tan^{-1}\frac{\Sigma F_y}{\Sigma F_x}$$

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=0zGykVWkPZg

Important Books/Journals for further learning including the page nos.:

- A text Book of Engineering Mechanics - R.S.Khurmi 68-73

LECTURE HANDOUTS

L-04

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : I-Basics and Statics of Particles

Topic of Lecture:
Vector Operations of Forces -Additions, Subtraction, Dot Product, Cross Product

Introduction:

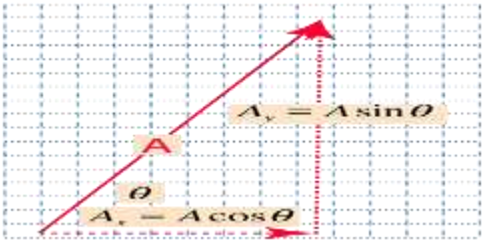
- Vector addition is the operation of adding two or more vectors together into a vector sum.
- To subtract two vectors, you put their feet (or tails, the non-pointy parts) together; then draw the resultant vector, which is the difference of the two vectors, from the head of the vector you're subtracting to the head of the vector you're subtracting it from.
- Algebraically, the dot product is the sum of the products of the corresponding entries of the two sequences of numbers.
- In mathematics, the cross product or vector product is a binary operation on two vectors in three-dimensional space, and is denoted by the symbol.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Basics of Scalars and Vectors
- Basics of Mathematics

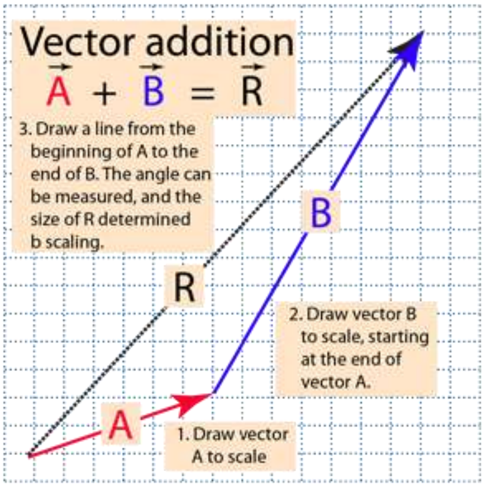
Detailed content of the Lecture:

Vectors are resolved into components by use of the triangle trig relationships. You may change the length or angle of the polar form of the vector, and the components will be calculated below.



Vector Addition, Two Vectors

Adding two vectors A and B graphically can be visualized like two successive walks, with the vector sum being the vector distance from the beginning to the end point. Representing the vectors by arrows drawn to scale, the beginning of vector B is placed at the end of vector A. The vector sum R can be drawn as the vector from the beginning to the end point.



To **subtract two vectors**, you put their feet (or tails, the non-pointy parts) together; then draw the resultant **vector**, which is the difference of the **two vectors**, from the head of the **vector** you're **subtracting** to the head of the **vector** you're **subtracting** it from.

Multiplying a Vector by a Vector (Dot Product and Cross Product) How **do we multiply** two **vectors** together? There is more than **one** way! The scalar or Dot Product (the result is a scalar).

$$\vec{A} \cdot \vec{B} = \vec{B} \cdot \vec{A}$$

$$\vec{A} \cdot (\vec{B} + \vec{c}) = \vec{A} \cdot \vec{B} + \vec{A} \cdot \vec{C}$$

$$(k\vec{A}) \cdot \vec{B} = k(\vec{A} \cdot \vec{B})$$

Cross Product

The cross product of two vectors $\vec{A}$and $\vec{B}$is a vector orthogonal to both vectors and is given by

$$\vec{A} \times \vec{B} = -\vec{B} \times \vec{A}$$

$$(k\vec{A}) \times \vec{B} = \vec{A} \times (k\vec{B}) = k(\vec{A} \times \vec{B})$$

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=KBSCMTYaH1s

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics - R.S.Khurmi 56-62

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LECTURE HANDOUTS

L-05

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : I- Basics and Statics of Particles

Topic of Lecture: Coplanar Forces

Introduction :

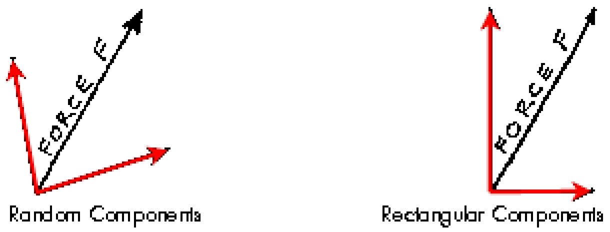
- Coplanar force system refers to the number of forces which remain in same plane.
- When all forces are acting in the same plane, they are called coplanar whereas when forces act at the same time and at the same point, they are called concurrent/forces.

Prerequisite knowledge for Complete understanding and learning of Topic:

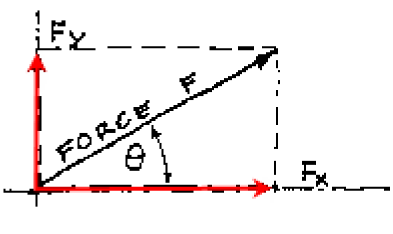
- Basics of Mathematics
- Fundamentals of Vectors
- Basics of Physics

Detailed content of the Lecture:

- **Coplanar Force** Systems. **Coplanar force** system refers to the number of **forces** which remain in same plane. It is also stated as the number of **forces** in a system which remains in single plane. This **force** system can be **concurrent**, parallel and non-**concurrent** and non-parallel.
- The **resultant** of any number of **concurrent forces** can be found by resolving each **force** into its rectangular components and then adding the components algebraically. Remember, the sum of Fx = 0 and Fy = 0. The resulting numbers will be the components of the **resultant**.
- A force can be resolved into an infinite number of combinations of components by the parallelogram method. The most useful components are the two components that are parallel to the X and Y axes. These are known as the **rectangular components**.



- The solution of many problems is greatly simplified by using the rectangular components. These are usually noted as F_x, for forces parallel to the X axis, and F_y, for forces parallel to the Y axis. They are also known simply as H, for horizontal, and V, for vertical.
- The rectangular components may be determined graphically, where the force is shown as a vector, or algebraically. In order to resolve a vector into its components, F_x = F cos or F_y = F sin, one must know at least two items of the six geometric descriptors of a triangle (the lengths of the sides and the three angles).



- Conversely, if the magnitude of the rectangular components are known, the resultant can be found with the Pythagorean Theorem, F = SQRT (F_x^2 + F_y^2). The direction of the resultant may be determined by trigonometry knowing that the tan is = opposite side / adjacent side.
- The solutions to many problems are greatly simplified by resolving multiple forces into a resultant or by finding the rectangular components of a force system. This tool will be used extensively throughout the course.

In summary:

Fx = F cos

Fy = F sin

F = SQRT (Fx^2 + Fy^2)

tan = Fx / Fy = opposite side / adjacent side

The resultant of any number of concurrent forces can be found by resolving each force into its rectangular components and then adding the components algebraically. Remember, the sum of F_x = 0 and F_y = 0. The resulting numbers will be the components of the resultant.

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=DqZBnX47e7M

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi 28-32

LECTURE HANDOUTS

L- 06

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : I-Basics and Statics of Particles

Topic of Lecture: Equilibrium of a Particle

Introduction :

- A particle is in equilibrium if the vector sum of the external forces acting on it is zero.
- Hence a particle is in equilibrium if: **1. It is at rest and remains at rest − Static Equilibrium 2. It moves with constant velocity − Dynamic Equilibrium**
- If there are only two forces acting on a particle that is in equilibrium, then the two forces must be equal (in magnitude) and opposite in direction to each other. If three forces act on a particle that is in equilibrium, then when the three forces are placed end to end they must form a triangle.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Basics of Physics
- Definition of Equilibrium
- Applications of Newton Law's

Detailed content of the Lecture:

- The resultant force will produce the same effect as produced by all the given forces. A little consideration will show that if the resultant of a number of forces, acting on a particle is zero, the particle will be in equilibrium. Such a set of forces, whose resultant is zero, are called equilibrium forces.
- The force, which brings the set of forces in equilibrium, is called an equilibrant. As a matter of fact, the equilibrant is equal to the resultant force in magnitude, but opposite in direction.

Principles of Equilibrium: Though there are many principles of equilibrium, yet the following three are important from the subject point of view :

1. Two force principle. As per this principle, if a body in equilibrium is acted upon by two forces, then they must be equal, opposite and collinear.
2. Three force principle. As per this principle, if a body in equilibrium is acted upon by three forces, then the resultant of any two forces must be equal, opposite and collinear with the third force.
3. Four force principle. As per this principle, if a body in equilibrium is acted upon by four forces, then the resultant of any two forces must be equal, opposite and collinear with the resultant of the other two forces.

Methods for the Equilibrium of Coplanar Forces:

Though there are many methods of studying the equilibrium of forces, yet the following are important from the subject point of view: 1. Analytical method. 2. Graphical method

Example 5.1. *An electric light fixture weighting 15 N hangs from a point C, by two strings AC and BC. The string AC is inclined at 60° to the horizontal and BC at 45° to the horizontal as shown in Fig. 5.3*

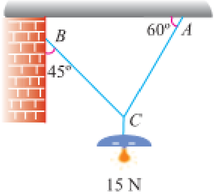


Fig. 5.3.

Using Lami's theorem, or otherwise, determine the forces in the strings AC and BC.

Solution. Given : Weight at $C = 15$ N

Let T_{AC} = Force in the string AC, and

T_{BC} = Force in the string BC.

The system of forces is shown in Fig. 5.4. From the geometry of the figure, we find that angle between T_{AC} and 15 N is 150° and angle between T_{BC} and 15 N is 135°.

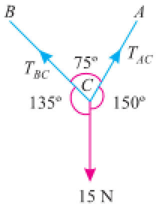


Fig. 5.4.

$\therefore \quad \angle ACB = 180° - (45° + 60°) = 75°$

Applying Lami's equation at C,

$$\frac{15}{\sin 75°} = \frac{T_{AC}}{\sin 135°} = \frac{T_{BC}}{\sin 150°}$$

or

$$\frac{15}{\sin 75°} = \frac{T_{AC}}{\sin 45°} = \frac{T_{BC}}{\sin 30°}$$

$$\therefore \quad T_{AC} = \frac{15 \sin 45°}{\sin 75°} = \frac{15 \times 0.707}{0.9659} = 10.98 \text{N} \quad \textbf{Ans.}$$

and

$$T_{BC} = \frac{15 \sin 30°}{\sin 75°} = \frac{15 \times 0.5}{0.9659} = 7.76 \text{N} \quad \textbf{Ans.}$$

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=WDegKaZ22IA

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi 28-32

Course Faculty

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LECTURE HANDOUTS

L-07

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : I- Basics and Statics of Particles

Topic of Lecture: Forces in Space

Introduction:

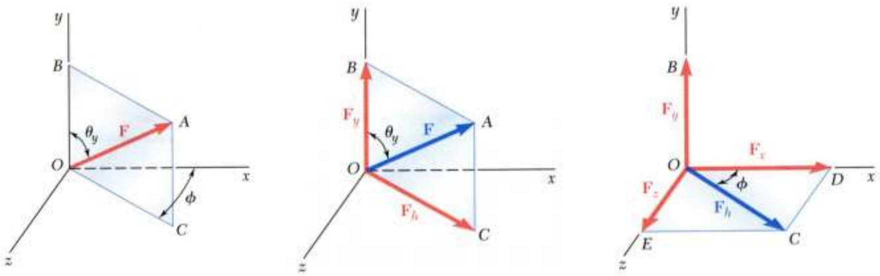
- Space – 3-D geometrical region, where objects (particles, bodies) are placed and move (i.e. change positions). The measure of the size of a physical system and of the distances between objects is known as a length
- Force, in mechanics, any action that tends to maintain or alter the motion of a body or to distort it
- The magnitude of the acceleration is directly proportional to the magnitude of the external force and inversely proportional to the quantity of matter in the body.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Application of Forces
- Resolution of Forces
- Scalars and Vectors

Detailed content of the Lecture:

Rectangular Components in Space



- The vector $\vec{F}$ is contained in the plane $OBAC$.

- Resolve $\vec{F}$ into horizontal and vertical components.

$$F_y = F\cos\theta_y$$

$$F_h = F\sin\theta_y$$

- Resolve F_h into rectangular components

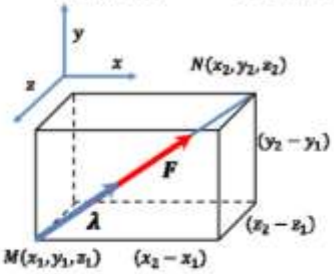
$$F_x = F_h\cos\phi = F\sin\theta_y\cos\phi$$

$$F_z = F_h\sin\phi = F\sin\theta_y\sin\phi$$

Rectangular Components in Space

Direction of the force is defined by the location of two points

$M(x_1, y_1, z_1)$ and $N(x_2, y_2, z_2)$



$\boldsymbol{d}$ is the vector joining M and N

$$\boldsymbol{d} = d_x\boldsymbol{i} + d_y\boldsymbol{j} + d_z\boldsymbol{k}$$

$$d_x = (x_2 - x_1) \qquad d_y = (y_2 - y_1)$$

$$d_z = (z_2 - z_1)$$

$$\boldsymbol{F} = F\boldsymbol{\lambda}$$

$$= F\left(\frac{d_x\boldsymbol{i} + d_y\boldsymbol{j} + d_z\boldsymbol{k}}{d}\right)$$

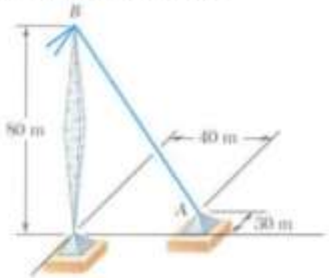
$$F_x = F\frac{d_x}{d} \qquad F_y = F\frac{d_y}{d} \qquad F_z = F\frac{d_z}{d}$$

Rectangular Components in Space

Example: The tension in the guy wire is 2500 N. Determine:

a) components F_x, F_y, F_z of the force acting on the bolt at A,

b) the angles q_x, q_y, q_z defining the direction of the force



SOLUTION:

- Based on the relative locations of the points A and B, determine the unit vector pointing from A towards B.
- Apply the unit vector to determine the components of the force acting on A.
- Noting that the components of the unit vector are the direction cosines for the vector, calculate the corresponding angles.

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=GOZfbU6tLVk

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi 45-52

Course Faculty

LECTURE HANDOUTS

L-08

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : I-Basics and Statics of Particles

Topic of Lecture: Equilibrium of Particle in Space

Introduction:

- More generally in conservative systems, equilibrium is established at a point in configuration space where the gradient of the potential energy with respect to the generalized coordinates is zero.
- If a particle in equilibrium has zero velocity, that particle is in static equilibrium.
- According to Newton's first law, a particle is said to be in equilibrium, if there is no net force acting on it. This does not mean that no forces act on the particle, but rather that the resultant of all the forces which do act on the particle is zero.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Equilibrium
- Equilibrant
- Resultant Force
- Laws of Statics

Detailed content of the Lecture:

When a particle (or a rigid body) is in space, the forces acting on the rigid body (or on the particle) may be concurrent or non-concurrent. If the forces acting are concurrent, then the equation of equilibrium are

$\Sigma F_x = 0, \quad \Sigma F_y = 0 \quad \text{and} \quad \Sigma F_z = 0$

i.e., the resultant force in x, y and z directions are zero.

But if forces acting are non-concurrent then the resultant force in x, y and z directions should be zero also the resultant moment about x, y and z axis should be zero. i.e.,

$\Sigma F_x = 0, \quad \Sigma F_y = 0 \quad \text{and} \quad \Sigma F_z = 0$

Also $\Sigma M_{xy} = 0, \quad \Sigma M_{xz} = 0 \quad \text{and} \quad \Sigma M_{yz} = 0$

Moment is the cross product of position vector and force vector

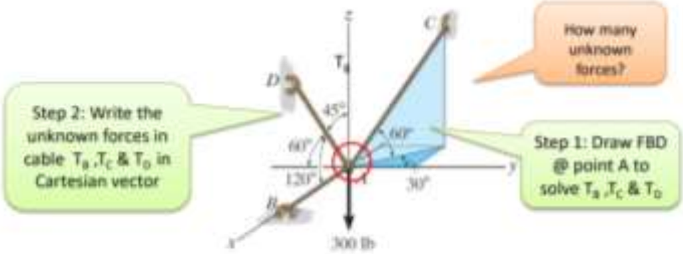
$\mathbf{M} = \mathbf{r} \times \mathbf{F}$

Thus there will be six equations of equilibrium, three equations of equilibrium will be for force and three equations of equilibrium will be for moment. In vector form, these equations can be written as

$\Sigma \mathbf{F} = 0, \quad \Sigma \mathbf{M} = 0$

Example 3.4

This is an example of a 3-D or coplanar force system. If the whole assembly is in equilibrium, determine the tension developed in each cables

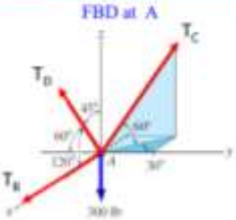


Solution Example 3.4

$\boldsymbol{T_B} = T_B\, \boldsymbol{i}$

$\boldsymbol{T_C} = -(T_C \cos 60°) \sin 30°\, \boldsymbol{i} + (T_C \cos 60°) \cos 30°\, \boldsymbol{j} + T_C \sin 60°\, \boldsymbol{k}$

$\boldsymbol{T_C} = T_C\,(-0.25\, \boldsymbol{i} + 0.433\, \boldsymbol{j} + 0.866\, \boldsymbol{k})$



$\boldsymbol{T_D} = T_D \cos 120°\, \boldsymbol{i} + T_D \cos 120°\, \boldsymbol{j} + T_D \cos 45°\, \boldsymbol{k}$

$\boldsymbol{T_D} = T_D\,(-0.5\, \boldsymbol{i} - 0.5\, \boldsymbol{j} + 0.7071\, \boldsymbol{k})$

$\boldsymbol{W} = -300\, \boldsymbol{k}$

Solution Example 3.4

- Applying equilibrium equations:

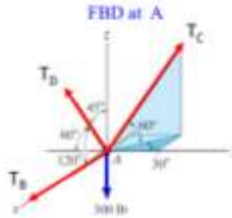
$\Sigma \boldsymbol{F_R} = 0 = T_B\, \boldsymbol{i} + T_C\,(-0.25\, \boldsymbol{i} + 0.433\, \boldsymbol{j} + 0.866\, \boldsymbol{k}) + T_D\,(-0.5\, \boldsymbol{i} - 0.5\, \boldsymbol{j} + 0.7071\, \boldsymbol{k}) - 300\, \boldsymbol{k}$

Equating the respective *i*, *j*, *k* components to zero,

$\Sigma F_x = T_B - 0.25\, T_C - 0.5\, T_D = 0$ (1)

$\Sigma F_y = 0.433\, T_C - 0.5\, T_D = 0$ (2)

$\Sigma F_z = 0.866\, T_C + 0.7071\, T_D - 300 = 0$ (3)



Using (2) and (3), $T_C = 203$ lb, $T_D = 176$ lb
Substituting T_C and T_D into (1), $T_B = 139$ lb

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=GOZfbU6tLVk

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi 45-52

LECTURE HANDOUTS

L-09

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : I- Basics and Statics of Particles

Topic of Lecture: Equivalent systems of Forces –Principle of Transmissibility

Introduction:

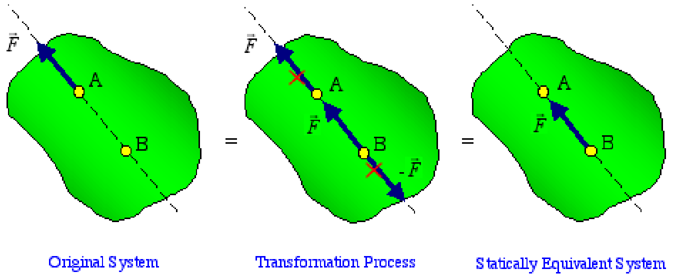
- The principle of transmissibility states that the point of application of a force can be moved anywhere along its line of action without changing the external reaction forces on a rigid body.
- The state of rest or of motion of a rigid body is unaltered if a force acting on the body is replaced by another force of the same magnitude and direction but acting anywhere on the body along the line of action of the applied forces.
- Any force that has the same magnitude and direction, and which has a point of application somewhere along the same line of action will cause the same acceleration and will result in the same moment. Therefore, the points of application of forces may be moved along the line of action to simplify the analysis of rigid bodies.
- When analyzing the internal forces (stress) in a rigid body, the exact point of application does matter. This difference in stresses may also result in changes in geometry which will in turn affect reaction forces. For this reason, the principle of transmissibility should only be used when examining external forces on bodies that are assumed to be rigid.

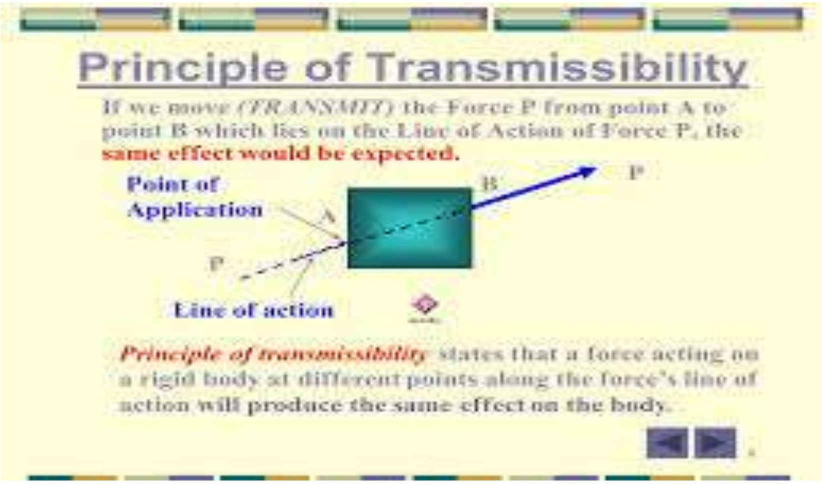
Prerequisite knowledge for Complete understanding and learning of Topic:

- Application of Force
- Basics of Physics

Detailed content of the Lecture:

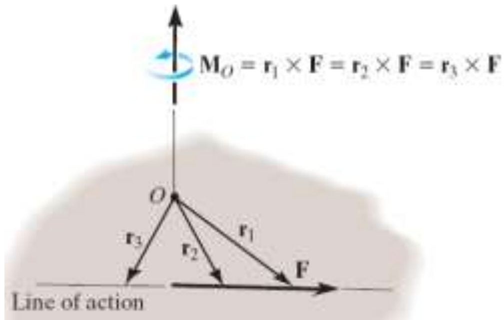
- If force acting on a body is represented (or replaced) by another force or a force-moment system (at a different point on the body) such that the resulting rigid-body effects (i.e., translation and rotation) remain unchanged, the two systems are said to be statically equivalent. We are interested in this concept because in many statics problems, it may be more convenient to replace the existing force with another equivalent force or force-moment system.
- Notice that although it is possible to keep the rigid-body effects the same, it is impossible to keep the internal effects such as stresses the same when we move the force from one location to another. So the idea of equivalent systems is only to help with the statics of a rigid body. We examine the topic of equivalent systems by looking at three different cases as described below.
- **Case 1:** Equivalent Force at an Arbitrary Point along the Same Line of Action: Let's represent (replace) the force acting at point A by a statically equivalent system at point B. In this case, point B is along the line of action of the force at A. The statically equivalent system is found by adding two equal and opposite forces at point B such that each has the same magnitude as the original force and is parallel to it as shown below. Since the two equal and opposite forces shown at point B cancel each other, there is no net change to the loading system in the transformation process. Canceling the force Fat A with -Fat B gives the statically equivalent force at B.





Principle of Transmissibility

Any force that has the same magnitude and direction as **F**, is *equivalent* if it also has the same line of action and therefore, produces the moment.



$$P_1\, r\,\frac{[(K-1)(r^{\gamma-1}-1)]}{[(\gamma-1)(r-1)]}$$

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=HjFunNWJplI

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi 25-29

LECTURE HANDOUTS

L-10

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : II- Equilibrium of Rigid Bodies

Topic of Lecture: Free body diagram

Introduction:

- Free-body diagrams are diagrams used to show the relative magnitude and direction of all forces acting upon an object in a given situation.
- They depict a body or connected bodies with all the applied forces and moments, and reactions, which act on the body (ies).
- The body may consist of multiple internal members (such as a truss), or be a compact body (such as a beam). A series of free bodies and other diagrams may be necessary to solve complex problems.
- The body may consist of multiple internal members (such as a truss), or be a compact body (such as a beam). A series of free bodies and other diagrams may be necessary to solve complex problems.
- Free body diagrams are used to visualize the forces and moments applied to a body and to calculate the resulting reactions in many types of mechanics problems.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Basics of Scalars and Vectors
- Fundamentals of Forces

Detailed content of the Lecture:

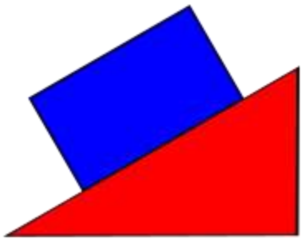
- A free body diagram is not meant to be a scaled drawing. It is a diagram that is modified as the problem is solved. There is an art and flexibility to the process. The iconography of a free body diagram, not only how it is drawn but also how it is interpreted, depends upon how a body is modeled.

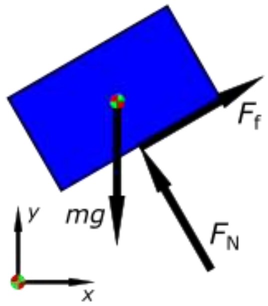
Free body diagrams consist of:

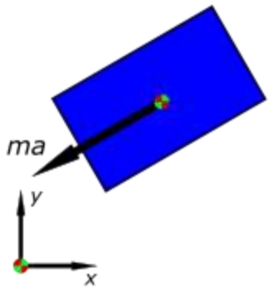
- A simplified version of the body (often a dot or a box)
- Forces shown as straight arrows pointing in the direction they act on the body
- Moments shown as curved arrows pointing in the direction they act on the body
- A coordinate system
- Frequently reactions to applied forces are shown with hash marks through the stem of the arrow
  - The number of forces and moments shown in a free body diagram depends on the specific problem and the assumptions made; common assumptions are neglecting air resistance and friction, and assuming rigid bodies.
  - In statics all forces and moments must balance to zero; the physical interpretation of this is that if the forces and moments do not sum to zero the body is accelerating and the principles of statics do not apply. In dynamics the resultant forces and moments can be non-zero.

An FBD represents the body of interest and the external forces on it.

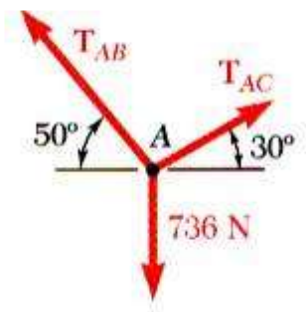
- The body: This is usually sketched in a schematic way depending on the body—particle/extended, rigid/non-rigid—and on what questions are to be answered. Thus if rotation of the body and torque is in consideration, an indication of size and shape of the body is needed. For example, the brake dive of a motorcycle cannot be found from a single point, and a sketch with finite dimensions is required.
- The external forces: These are indicated by labelled arrows. In a fully solved problem, a force arrow is capable of indicating
  - the direction and the line of action
  - the magnitude
  - the point of application
  - a reaction as opposed to an applied load if a hash is present through the arrow







A sketch showing the physical condition of the problem.



Free-Body Diagram:

A sketch showing only the forces on the selected particle. A portion of the body of interest or– A full body of interest or– A group of bodies of interest– Body forcesυOn the boundary of the FBD– “Replacement” forces/distribution of forces $R_x = \Sigma F_x = 0$ $R_y = \Sigma F_y = 0$ Two-dimensions, $\Sigma F_x = 0$ $\Sigma F_y = 0$
Video Content / Details of website for further learning (if any): • https://www.youtube.com/watch?v=aCrHpnvZp1E
Important Books/Journals for further learning including the page nos.: • A Text Book of Engineering Mechanics R.S.Khurmi 78-95

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LECTURE HANDOUTS | **L-11**

MECH | **II/III**

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : II-Equilibrium of Rigid Bodies

Topic of Lecture: Types of supports –Action and Reaction Forces –Stable Equilibrium

Introduction:

- A support reaction is the reaction force/forces that are attributed to a support for the system, i.e if the system is a chair, and the external inputs that exert significant forces on the chair are the Earth (gravitational force) and the floor ("Normal" force; Normal here is being used to describe a force perpendicular
- Structural support is a part of a building or structure providing the necessary stiffness and strength in order to resist the internal forces (vertical forces of gravity and lateral forces due to wind and earthquakes) and guide them safely to the ground.
- External loads (actions of other bodies) that act on buildings cause internal forces (forces and couples by the rest of the structure) in building support structures.
- Supports can be either at the end or at any intermediate point along a structural member or a constituent part of a building and they are referred to as connections, joints or restraints

Prerequisite knowledge for Complete understanding and learning of Topic:

- Importance of Load Carrying Member
- Laws of Statics
- Statically Determinant Beam

Detailed content of the Lecture:

Types of Supports and Connections in Structural Analysis

- Fixed **Support**. A fixed **support** is the most rigid **type of support** or connection.
- Pinned **Support**. A pinned **support** is a very common **type of support**
- Roller **Support**
- Simple **Support**

Fixed Support and Reactions and Applications in a Structure

- Fixed supports are also called as rigid supports. Fixed supports are restrained against both rotation and translation so they can resist any type of force or moment.
- In structural analysis, there are three unknowns to find for fixed support which can satisfy all the three equations of equilibrium.
- To provide good stability to the structure, at least one rigid support should be provided. Beam fixed in wall is a good example for fixed support.

Pinned Support and Reactions in a Structure

- Pinned support or hinged support can resists both vertical and horizontal forces but they cannot resist moment. It means hinged support is restrained against translation.
- Using equations of equilibrium, one can find out the components of horizontal and vertical forces.
- **Best example for hinged support is door leaf which only rotates about its vertical axis without any horizontal or vertical movement.**
- The rotation of pinned support or hinged support is allowed in only one direction and is resisted in other direction.
- Hinged supports are also used in three hinged arched bridges with two supports at ends and third hinge is provided at the center of the arch which is called as internal hinge.

Roller Support and Reactions and Applications in a Structure

- Roller supports only resists perpendicular forces and they cannot resist parallel or horizontal forces and moment. It means, the roller support will move freely along the surface without resisting horizontal force.
- This type of support is provided at one end of bridge spans. The reason for providing roller support at one end is to allow contraction or expansion of bridge deck with respect to temperature differences in atmosphere.
- If roller support is not provided then it will cause severe damage to the banks of bridge. But this horizontal force should be resisted by at least one support to provide stability so, roller support should be provided at one end only not at both ends.

Rocker Support and Reactions and Applications in a Structure

- Rocker support is similar to roller support. It also resists vertical force and allows horizontal translation and rotation.

Link Support and Reactions in a Structure

- Link is support allows rotation and translation perpendicular to the direction of link only. It does not allow translation in the direction of link. It has single linear resultant force component in the direction of link which can be resolved into vertical and horizontal components.

Simple Supports in a Structure and Their Reactions

- Simple support is just a support on which structural member rests. They cannot resists lateral movement and moment like roller supports. They only resist vertical movement of support with the help of gravity.
- The horizontal or lateral movement allowed is up to a limited extent and after that the structure loses its support. It's just like a brick resting longitudinally on two bricks.
- This type of support is not commonly used in structural purposes. However, in the zones of frequent seismic activity simple supported structures can be seen.
- Link is support allows rotation and translation perpendicular to the direction of link only. It does not allow translation in the direction of link. It has single linear resultant force component in the direction of link which can be resolved into vertical and horizontal components.

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Video Content / Details of website for further learning (if any)

- https://www.youtube.com/watch?v=xLPbqH8Yk5c

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi 105-112

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LECTURE HANDOUTS

L-12

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : II-Equilibrium of Rigid Bodies

Topic of Lecture: Moments and Couples – Moment of a force about a point and about an axis – Vectorial representation of moments and couples

Introduction: A couple consists of two parallel forces that are equal in magnitude, opposite in sense and do not share a line of action. It does not produce any translation, only rotation. The resultant force of a couple is zero. BUT, the resultant of a couple is not zero; it is a pure moment.

Prerequisite knowledge for Complete understanding and learning of Topic:

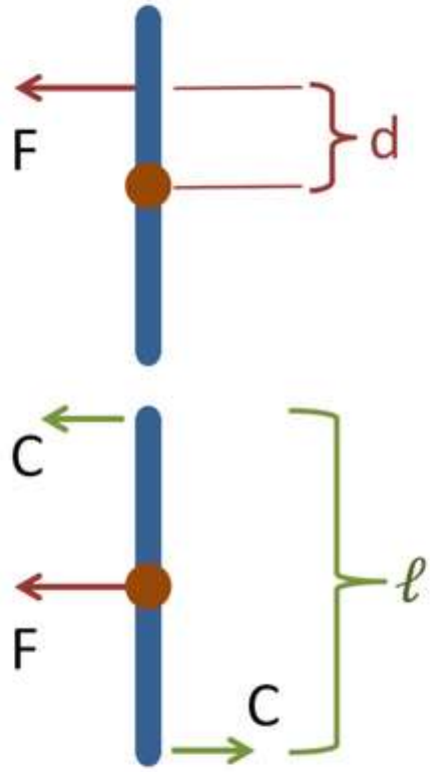
- Impact of Rotation
- Basics of Levers
- Basics of theorem of Moments

Detailed content of the Lecture:

- The Moment of a force is a measure of its tendency to cause a body to rotate about a specific point or axis. This is different from the tendency for a body to move, or translate, in the direction of the force. In order for a moment to develop, the force must act upon the body in such a manner that the body would begin to twist. This occurs every time a force is applied so that it does not pass through the centroid of the body.
- A moment is due to a force not having an equal and opposite force directly along its line of action.
- In mechanics, a couple is a system of forces with a resultant (a.k.a. net or sum) moment but no resultant force.
- A better term is force couple or pure moment.
- Its effect is to create rotation without translation, or more generally without any acceleration of the centre of mass. In rigid body mechanics, force couples are free vectors, meaning their effects on a body are independent of the point of application.
- The resultant moment of a couple is called a torque. This is not to be confused with the term torque as it is used in physics, where it is merely a synonym of moment.
- A couple is a pair of forces, equal in magnitude, oppositely directed, and displaced by perpendicular distance or moment.
- The simplest kind of couple consists of two equal and opposite forces whose lines of action do not coincide. This is called a "simple couple"
- The forces have a turning effect or moment called a torque about an axis which is normal (perpendicular) to the plane of the forces. The SI unit for the torque of the couple is newton metre
- If the two forces are F and −F, then the magnitude of the torque is given by the following

formula: F.d

- The magnitude of the torque is equal to F • d, with the direction of the torque given by the unit vector, which is perpendicular to the plane containing the two forces and positive being a counter-clockwise couple.



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Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=hYNgGKIKT8w

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi 115-119

LECTURE HANDOUTS

L-13

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : II- Equilibrium of Rigid Bodies

Topic of Lecture: Scalar Component about a Moment

Introduction:

- The moment of a force about a point provides a measure of the tendency for rotation (sometimes called a torque).
- In a 2-D case, the magnitude of the moment is Mo = F d
- In 2-D, the direction of M_O is either clockwise (CW) or counter-clockwise (CCW), depending on the tendency for rotation.

Prerequisite knowledge for Complete understanding and learning of Topic:

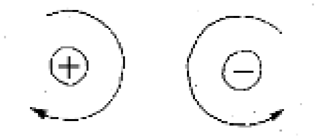
- Basics of Moments
- Basics of Mathematics

Detailed content of the Lecture:

- **Moment of a force** with respect to a **point** (centre of rotation also known as **moment** centre) is the turning effect (rotating effect) the **force** produces with respect to the **point**. It is measured as the product of **force** and the perpendicular distance of the **force** from the centre of rotation. It's unit in SI system is Nm.
- The **Moment** of a force is a measure of its tendency to cause a body to rotate about a specific point or axis. This is different from the tendency for a body to move, or translate, in the direction of the force. In order for a moment to develop, the force must act upon the body in such a manner that the body would begin to twist. This occurs every time a force is applied so that it does not pass through the centroid of the body. A moment is due to a force not having an equal and opposite force directly along it's line of action.
- Imagine two people pushing on a door at the doorknob from opposite sides. If both of them are pushing with an equal force then there is a state of equilibrium. If one of them would suddenly jump back from the door, the push of the other person would no longer have any opposition and the door would swing away. The person who was still pushing on the door created a moment. Elements of a Moment
- The magnitude of the moment of a force acting about a point or axis is directly proportional to the distance of the force from the point or axis. It is defined as the product of the force (F) and the moment arm (d). The **moment arm** or **lever arm** is the perpendicular distance between the line of action of the force and the center of moments.

Moment = Force x Distance or **M = (F)(d)**

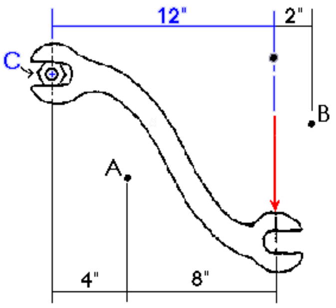
- The **Center of Moments** may be the actual point about which the force causes rotation.
- It may also be a reference point or axis about which the force may be considered as causing rotation. It does not matter as long as a specific point is always taken as the reference point. The latter case is much more common situation in structural design problems. A moment is expressed in units of foot-pounds, kip-feet, newton-meters, or kilonewton-meters.
- A moment also has a sense; A clockwise rotation about the center of moments will be considered a positive moment; while a counter-clockwise rotation about the center of moments will be considered negative. The most common way to express a moment is



- The example shows a wrench being applied to a nut. A 100 pound force is applied to it at point C, the center of the nut. The force is applied at an x- distance of 12 inches from the nut. The center of moments could be point C, but could also be points A or B or D.

Moment about C

The moment arm for calculating the moment around point C is 12 inches. The magnitude of the moment about point C is 12 inches multiplied by the force of 100 lbs to give a total moment of 1200 inch-lbs (or 100 ft-lbs).



Moment Arm (d) = 12 inches

Magnitude (F) = 100 lbs

Moment = M = 100 lbs x 12 in. = 1200 in-lbs

Similarly, we can find the moments about any point in space

- A moment causes a rotation about a point or axis. If the moment is to be taken about a point due to a force F, then in order for a moment to develop, the line of action cannot pass through that point. If the line of action does go through that point, the moment is zero because the magnitude of the moment arm is zero. Such was the case for point D in the previous wrench problem. The total moment was zero because the moment arm was zero as well. let us assume that 200 pound force is applied to the wrench as indicated. The moment of the 200 pound force applied at C is zero because:

M = F x d = 200 lbs x 0 in = 0 in-lbs

In other words, there is no tendency for the 200 pound force to cause the wrench to rotate the nut. One could increase the magnitude of the force until the bolt finally broke off (shear failure).

The moment about points X, Y, and Z would also be zero because they also lie on the line of action.

- A moment can also be considered to be the result of forces detouring from a direct line drawn between the point of loading of a system and its supports. In this case, the blue force is an eccentric force. In order for it to reach the base of the column, it must make a detour through the beam. The greater the detour, the greater the moment. The most efficient structural systems have the least amount of detours possible. This will be discussed in more detail in and later courses.

- There are cases in which it is easier to calculate the moments of the components of a force around a certain point than it is to calculate the moment of the force itself. It could be that the determination of the perpendicular distance of the force is more difficult than determining the perpendicular distance of components of the force. The moment of several forces about a point is simply the algebraic sum of their component moments about the same point. When adding the moments of components, one must take great care to be consistent with the sense of each moment. It is often prudent to note the sense next to the moment when undertaking such problems.

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=kH52e5VDeXI

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi 89-95

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LECTURE HANDOUTS

L-14

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : II- Equilibrium of Rigid Bodies

Topic of Lecture: Varignon's Theorem

Introduction:

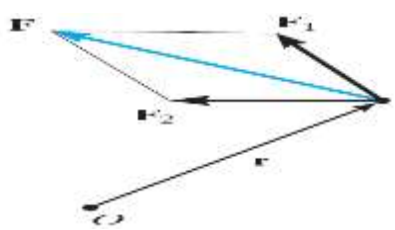
- Varignon's theorem is a theorem by French mathematician Pierre Varignon (1654-1722), published in 1687 in his book Projet d'une nouvelle mécanique.
- The application of varignon's theorem practically is to find the position of the resultant from any point of the body.
- Varignon's theorem also called Law of Moment.

Prerequisite knowledge for Complete understanding and learning of Topic:

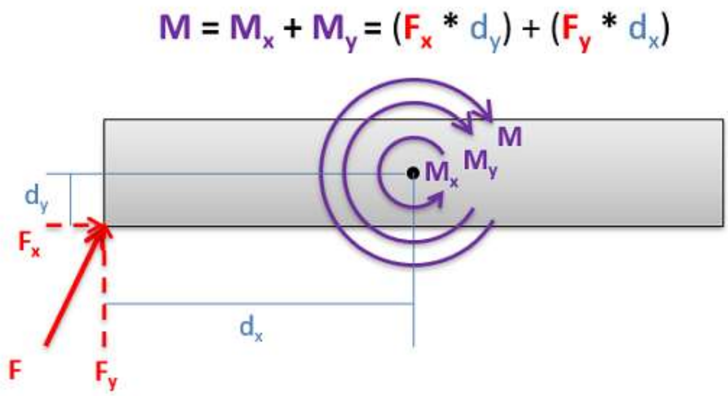
- Vector Addition
- Representation of Vectors in 3D Plane

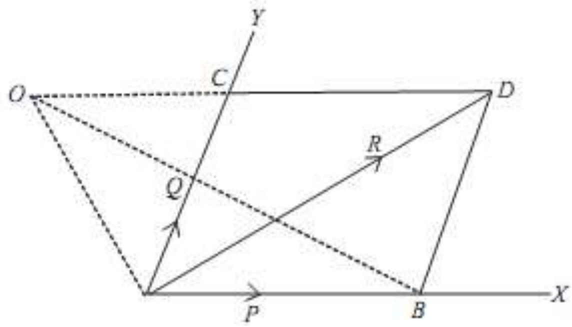
Detailed content of the Lecture:

Moment of a Force about a point is equal to the sum of the moments of the force's components about the point.



Varignon's Theorem, also often called the **principle of moments**, is a very useful tool in scalar moment calculations. In cases where the perpendicular distance is hard to determine, Varignon's Theorem offers an alternative to finding that distance. On its surface this doesn't seem that useful, but in practice we will often use this Theorem in reverse by breaking down a force into components (the components being a set of concurrent forces). We can solve for the moment exerted by each component (where perpendicular distance d is easier to find) and then simply add together the moments from each component to find the moment from the original force.





Proof: Let us consider, two concurrent forces P and Q represented in magnitude and direction by AB and AC as shown in the figure given below.

Let 'O' be the point, about which moment are taken, through O draw line OD parallel to direction of force P, to meet line of action of force Q at point C. Now with AB and AC as the two adjacent sides, complete Parallelogram ABDC as shown in the figure given below. Join the diagonal AD of the parallelogram and OA and OB. From parallelogram law of forces, we know that diagonal AD represents in the magnitude and direction, resultant of two forces P and Q. Now we see that moment of the force P about O: = 2. Area of triangle AOB

Likewise, moment of the force Q about O: = 2. Area of ΔAOC ...(ii)

And moment of resultant force R about O: = 2.Area of ΔAOD ...(iii)

But from the geometry of the figure, we find that

Area of ΔAOD = Area of ΔAOC + Area of ΔACD

But the Area of ΔACD = Area of ΔABD = Area of ΔAOB

(As the two "AOB and ADB are on same base AB and between same // lines)

Now Area of triangle AOD = Area of triangle AOC + Area of triangle AOB

Multiply both the side by 2 we obtain;

2. Area of triangle AOD = 2.Area of triangle AOC + 2. Area of triangle ACD, that gives

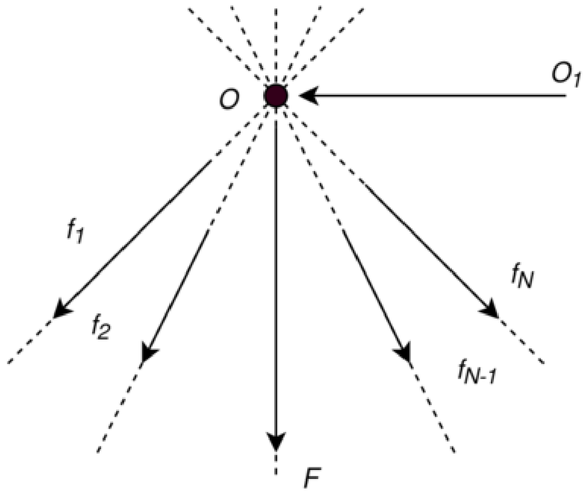
Moment of force R about O = Moment of force P about O + Moment of force Q about O or,

Where R. d = $\sum M$

$\sum M$ = Sum of moment of all the forces

d = Distance between resultant force and point where moment of all the forces are taken. This principle can be extended for any number of the forces.

The application of varignon's theorem practically is to find the position of the resultant from any point of the body.



Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=UABd38mEzsw

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi 118-113

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LECTURE HANDOUTS

L-15

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : II- Equilibrium of Rigid Bodies

Topic of Lecture: Single Equivalent Force

Introduction:

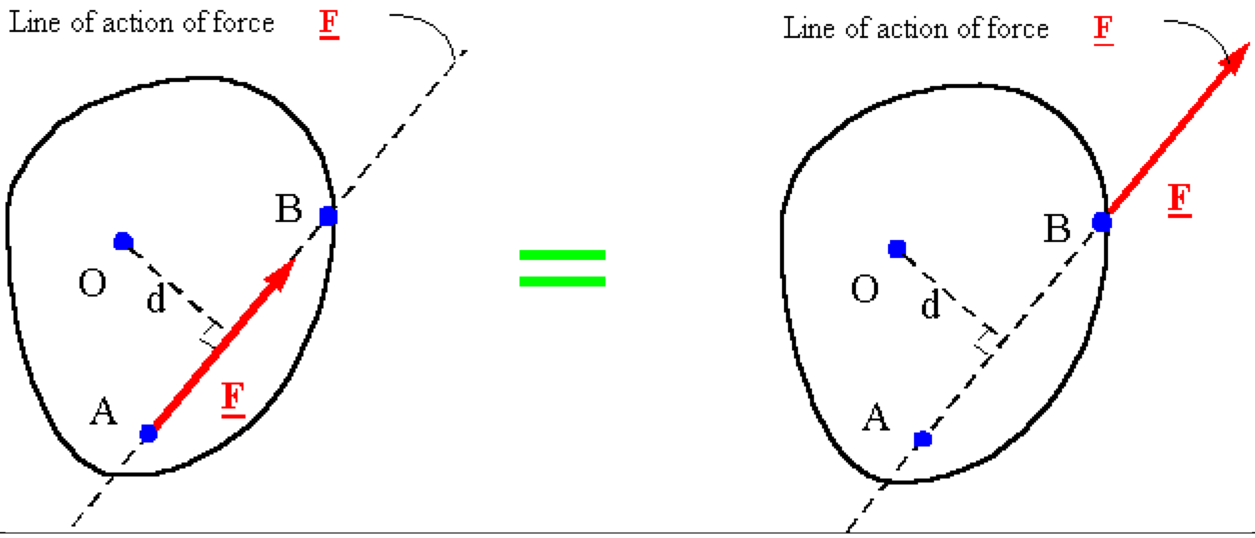
- Every set of forces and moments has an equivalent force couple system. This is a single force and pure moment (couple) acting at a single point that is statically equivalent to the original set of forces and moments
- Two force systems are equivalent if they result in the same resultant force and the same resultant moment.
- The single force passing through O is equal to the resultant force of the original system, and the couple is equal to the resultant moment of the original system around point O.

Prerequisite knowledge for Complete understanding and learning of Topic:

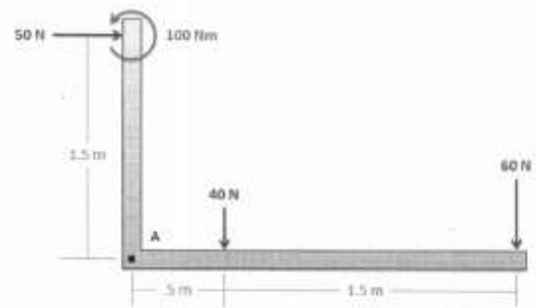
- Moment and Couple
- Principle of Transmissibility
- Basics of Forces and it's Applications

Detailed content of the Lecture:

- In physics and engineering, a resultant force is the single force and associated torque obtained by combining a system of forces and torques acting on a rigid body.
- The defining feature of a resultant force, or resultant force-torque, is that it has the same effect on the rigid body as the original system of forces.
- Two forces are said to be equivalent if they have the same magnitude and direction (i.e. they are equal) and produce the same moment about any point O (i.e. same line of action).



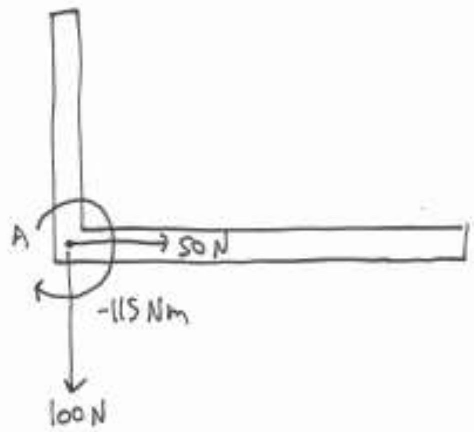
Find the equivalent force couple system for the forces shown below about point A.



$$\sum F_x = 50\,N = 50\,N$$

$$\sum F_y = -40\,N - 60\,N = -100\,N$$

$$\sum M_A = 100\,Nm - (50N)(1.5m) - (40N)(.5m) - (60N)(2m) = -115\,Nm$$



Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=0Xil3raraZw

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi 103-105

LECTURE HANDOUTS

L-16

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : II- Equilibrium of Rigid Bodies

Topic of Lecture: Equilibrium of Rigid bodies in Two Dimensions

Introduction:

- When a rigid body is in equilibrium, both the resultant force and the resultant couple must be zero.
- Forces and moments acting on a rigid body could be external forces/moments or internal forces/moments.
- The weight of a body is also an external force.
- If the resultant of all external forces acting on a rigid body is zero, then the body is said to be in equilibrium. Therefore, in order for the rigid body to be in equilibrium, both the resultant force and the resultant couple must be zero.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Rigid Body
- Principle of Equilibrium
- Basics of Scalars and Vectors

Detailed content of the Lecture:

This means that a rigid body in a two dimensional problem has three possible equilibrium equations; that is, the sum of force components in the x and y directions, and the moments about the z axis. The sum of each of these will be equal to zero.

These equations are the three scalar equations of equilibrium. They are valid for any point in equilibrium and allow you to solve for up to three unknowns. When a particle is in equilibrium, the vector sum of all the forces acting on it must be zero.

These equations are the three scalar equations of equilibrium. They are valid for any point in equilibrium and allow you to solve for up to three unknowns. When a particle is in equilibrium, the vector sum of all the forces acting on it must be zero

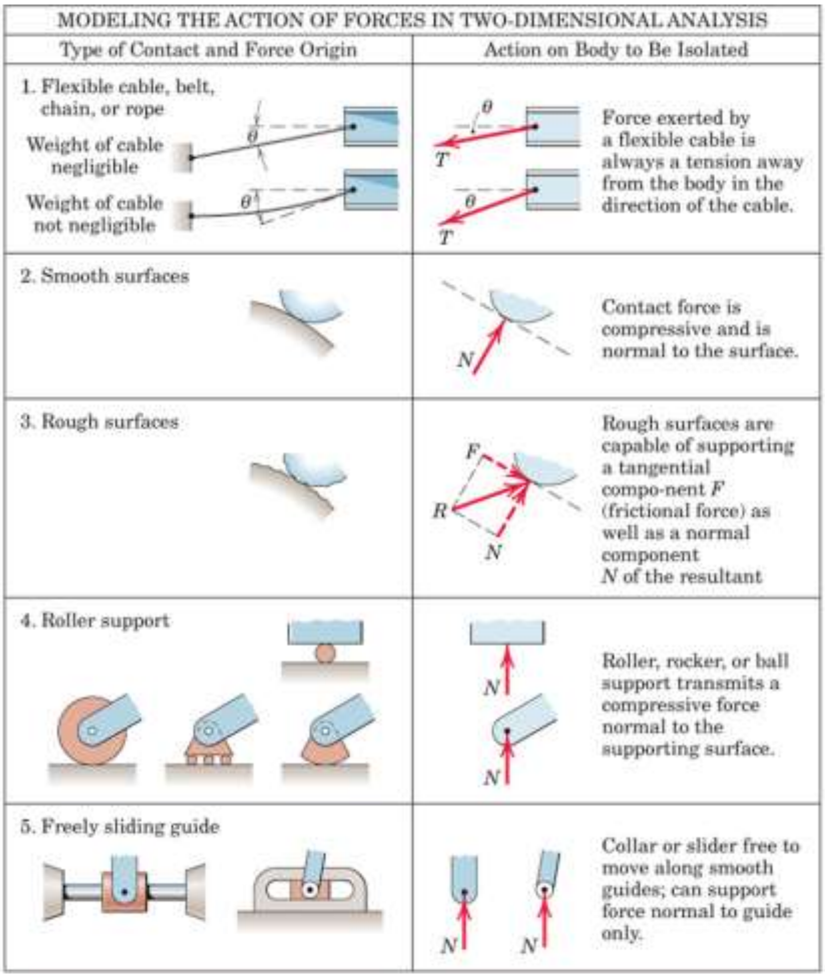
Principles Of Equilibrium

Though there are many principles of equilibrium, yet the following three are important from the subject point of view :

1. Two force principle. As per this principle, if a body in equilibrium is acted upon by two forces, then they must be equal, opposite and collinear.
2. Three force principle. As per this principle, if a body in equilibrium is acted upon by three forces, then the resultant of any two forces must be equal, opposite and collinear with the third force.
3. Four force principle. As per this principle, if a body in equilibrium is acted upon by four forces, then the resultant of any two forces must be equal, opposite and collinear with the resultant of the other two forces.

Lami's Theorem

It states, "If three coplanar forces acting at a point be in equilibrium, then each force is proportional to the sin of the angle between the other two.



Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=62rI-7FG1MI

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.KHURMI 89-95

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LECTURE HANDOUTS | **L-17**

MECH | **II/IV**

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : II- Equilibrium of Rigid Bodies

Topic of Lecture: : Equilibrium of Rigid Bodies in Three Dimensions

Introduction :

- Classical physics theories describe three physical dimensions: from a particular point in space, the basic directions in which we can move are up/down, left/right, and forward/backward. Movement in any other direction can be expressed in terms of just these three.
- Universe is three dimensional: space, and all of the objects which exist inside it, have a width, a breadth, and a height.
- A surface such as a plane or the surface of a cylinder or sphere has a dimension of two (2D) because two coordinates are needed to specify a point on it – for example, both a latitude and longitude are required to locate a point on the surface of a sphere.
- The inside of a cube, a cylinder or a sphere is three-dimensional (3D) because three coordinates are needed to locate a point within these spaces.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Rigid Body
- Difference Between 2D, 3D

Detailed content of the Lecture:

Six scalar equations are required to express the conditions for the equilibrium of a rigid body in the general three-dimensional case, those equations are listed below:

$$\Sigma F_x = 0 \qquad \Sigma F_y = 0 \qquad \Sigma F_z = 0$$
$$\Sigma M_x = 0 \qquad \Sigma M_y = 0 \qquad \Sigma M_z = 0$$

These equations can be solved for no more than six unknowns, which generally will represent reactions at supports or connections. During solving the most of the problems, the above scalar equations will be more conveniently obtained if we first expressed in vector form the conditions for the equilibrium of the rigid body considered. We write and express the forces 'F' and position vectors 'r' regarding scalar components and unit vectors. Next, we compute all vector products, either by direct calculation or using determinants.

$$\Sigma \mathbf{F} = 0 \qquad \Sigma \mathbf{M}_O = \Sigma(\mathbf{r} \times \mathbf{F}) = 0$$

Students will be able to solve 3-D particle equilibrium problems by
a) Drawing a 3-D free body diagram, and,
b) Applying the three scalar equations (based on one vector equation) of equilibrium.

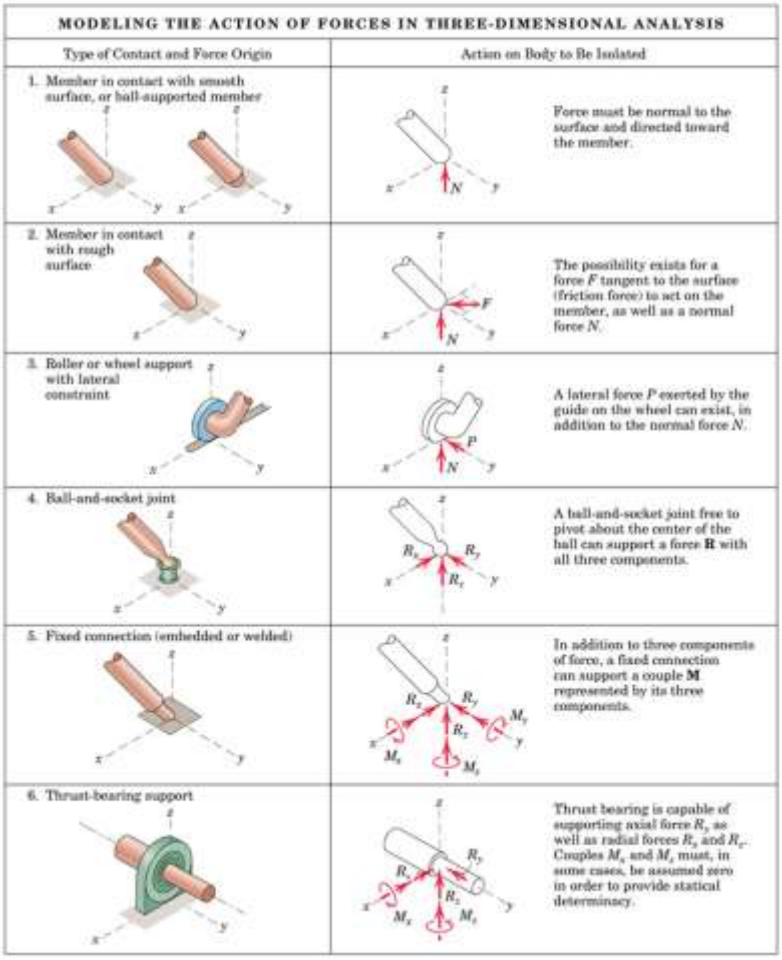
When a particle is in equilibrium, the vector sum of all the forces acting on it must be zero ($\boldsymbol{F} = 0$) . This equation can be written in terms of its x, y and z components. This form is written as follows.

$(F_x)\,\boldsymbol{i} + (F_y)\,\boldsymbol{j} + (F_z)\,\boldsymbol{k} = 0$

This vector equation will be satisfied only when

$F_x = 0$, $F_y = 0$, $F_z = 0$

These equations are the three scalar equations of equilibrium. They are valid at any point in equilibrium and allow you to solve for up to three unknowns.



MODELING THE ACTION OF FORCES IN THREE-DIMENSIONAL ANALYSIS

Type of Contact and Force Origin	Action on Body to Be Isolated
1. Member in contact with smooth surface, or ball-supported member	Force must be normal to the surface and directed toward the member.
2. Member in contact with rough surface	The possibility exists for a force F tangent to the surface (friction force) to act on the member, as well as a normal force N.
3. Roller or wheel support with lateral constraint	A lateral force P exerted by the guide on the wheel can exist, in addition to the normal force N.
4. Ball-and-socket joint	A ball-and-socket joint free to pivot about the center of the ball can support a force $\mathbf{R}$ with all three components.
5. Fixed connection (embedded or welded)	In addition to three components of force, a fixed connection can support a couple $\mathbf{M}$ represented by its three components.
6. Thrust-bearing support	Thrust bearing is capable of supporting axial force R_y as well as radial forces R_x and R_z. Couples M_x and M_z must, in some cases, be assumed zero in order to provide statical determinacy.

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=JcDM1sSjbRk

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi 66-79

LECTURE HANDOUTS | **L-18**

MECH | **II/III**

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : II- Equilibrium of Rigid Bodies

Topic of Lecture: Problems

Introduction:

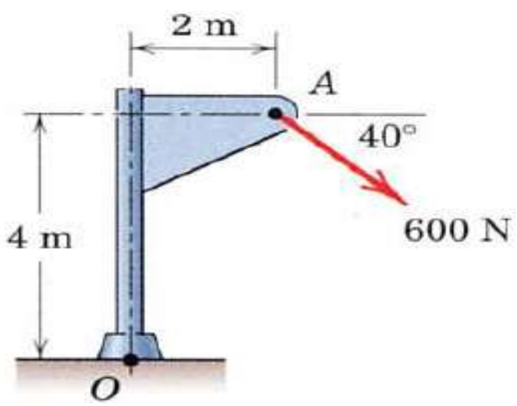
The systematic steps involved in solving a problem in mechanics are:

- Draw a free body diagram.
- Choose convenient coordinate system.
- Consider all the forces acting on the body.
- Resolve the forces in the chosen coordinate system.
- Apply Newton's Laws of Motion.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Resolution of Forces
- Moments

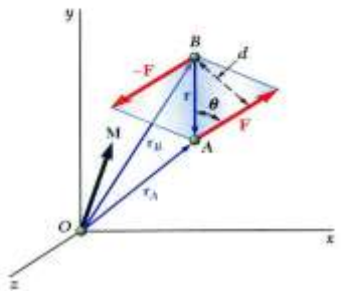
Detailed content of the Lecture:



Moment of a Couple

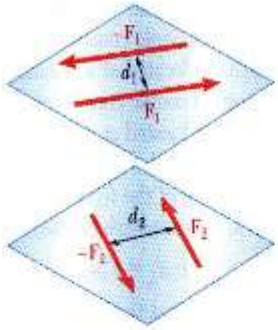
Moment produced by two equal, opposite and non-collinear forces is called a couple.

Magnitude of the combined moment of the two forces about O: The moment vector of the couple is independent of the choice of the origin of the coordinate axes, i.e., it is a free vector that can be applied at any point with the same effect.

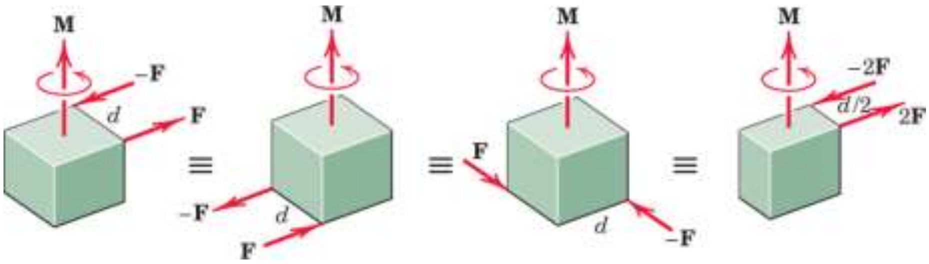


Moment of a Couple

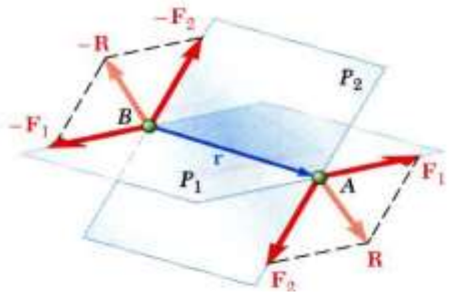
The two couples lie in parallel planes .The two couples has the same sense or the tendency to cause rotation in the same direction.



Examples:



Addition of Couples



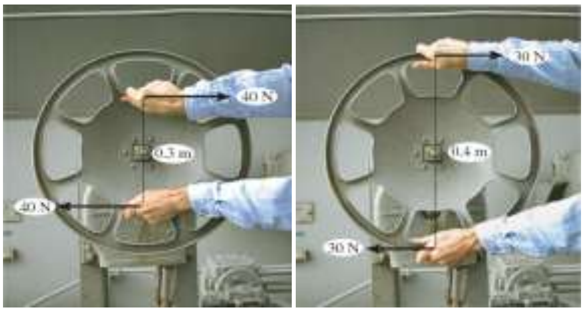
Sum of two couples is also a couple that is equal to the vector sum of the two couples

Moment required to turn the shaft connected at center of the wheel = 12 Nm

Case I: Couple Moment produced by 40 N forces = 12 Nm

Case II: Couple Moment produced by 30 N forces = 12 Nm

If only one hand is used? Force required for case I is 80N Force required for case II is 60N What if the shaft is not connected at the center of the wheel?



Video Content / Details of website for further learning (if any): Nil

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi 87-92

LECTURE HANDOUTS

L-19

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : III- Properties of Surfaces and Solids

Topic of Lecture: Centroids and Centre Of mass– Centroids of Lines and Areas - Rectangular, Circular, Triangular Areas by Integration

Introduction:

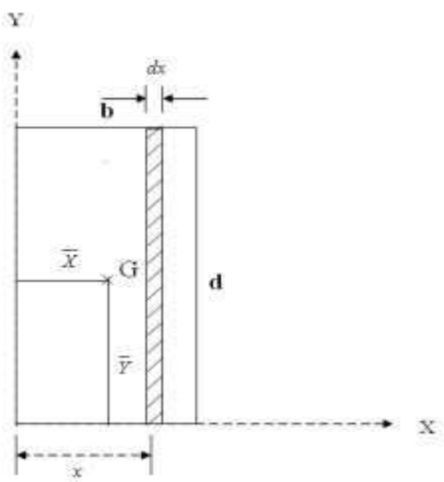
- The center of gravity is the average location of the weight of an object. We can completely describe the motion of any object through space in terms of the translation of the center of gravity of the object from one place to another and the rotation of the object about its center of gravity if it is free to rotate.
- Centre of mass is the point at which the distribution of mass is equal in all directions, and does not depend on gravitational field.
- The centroid of an area can be thought of as the geometric center of that area.
- The location of the centroid is often denoted with a 'C' with the coordinates being $\bar{x}$ and $\bar{y}$, denoting that they are the average x and y coordinate for the area.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Importance of CG
- Concepts of 2D and 3D
- Basics of Physics

Detailed content of the Lecture:

The **center of mass** is the mean position of the **mass** in an object. Then there's the **center of gravity**, which is the point where **gravity** appears to act. For many objects, these two points are in exactly the **same** place. But they're only the **same** when the gravitational field is uniform across an object.



$$\bar{X} = \frac{\int_0^b x.dA}{A}$$

$$A = b \cdot d$$

$$dA = dx \cdot d$$

$$\bar{X} = \frac{\int_0^b x.(dx.d)}{b.d}$$

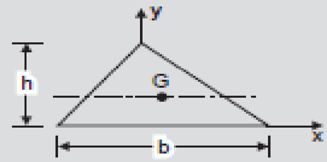
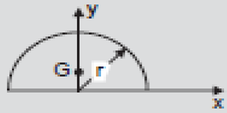
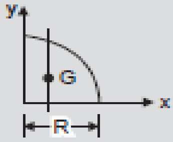
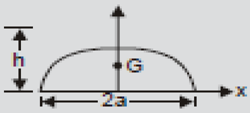
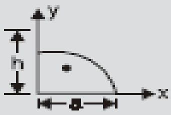
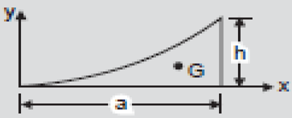
$$\bar{X} = \frac{1}{d} \cdot \int_0^b x.dx$$

$$\bar{X} = \frac{1}{b} \cdot \left[\frac{x^2}{2}\right]_0^b$$

$$\bar{X} = \frac{1}{b} \cdot \left[\frac{b^2}{2}\right]$$

$$\bar{X} = \frac{b}{2}$$

Centroid of Some Common Figures

Shape	*Figure*	$\bar{x}$	$\bar{y}$	*Area*
Triangle		—	$\frac{h}{3}$	$\frac{bh}{2}$
Semicircle		0	$\frac{4R}{3\pi}$	$\frac{\pi R^2}{2}$
Quarter circle		$\frac{4R}{3\pi}$	$\frac{4R}{3\pi}$	$\frac{\pi R^2}{4}$
Sector of a circle		$\frac{2R}{3\alpha}$ sin *a*	0	αR^2
Parabola		0	$\frac{3h}{5}$	$\frac{4ah}{3}$
Semi parabola		$\frac{3a}{8}$	$\frac{3h}{5}$	$\frac{2ah}{3}$
Parabolic spandrel		$\frac{3a}{4}$	$\frac{3h}{10}$	$\frac{ah}{3}$

Video Content / Details of website for further learning (if any):

- https://www.intmath.com/applications-integration/5-centroid-area.php

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi- 620-623

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IQAC

LECTURE HANDOUTS

L-20

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : III- Properties of Surfaces and Solids

Topic of Lecture: Centroids for T section, I section, Angle section, Hollow section by Using Standard Formula

Introduction:

- A T-beam (or tee beam), used in construction, is a load-bearing structure of reinforced concrete, wood or metal, with a T-shaped cross section.
- The top of the T-shaped cross section serves as a flange or compression member in resisting compressive stresses
- The web (vertical section) of the beam below the compression flange serves to resist shear stress and to provide greater separation for the coupled forces of bending.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Aptitude Skills
- Imagination Skills
- Concept of Centroid

Detailed content of the Lecture:

Example 6.1. *Find the centre of gravity of a 100 mm × 150 mm × 30 mm T-section.*

Solution. As the section is symmetrical about *Y-Y* axis, bisecting the web, therefore its centre of gravity will lie on this axis. Split up the section into two rectangles *ABCH* and *DEFG* as shown in Fig 6.10.

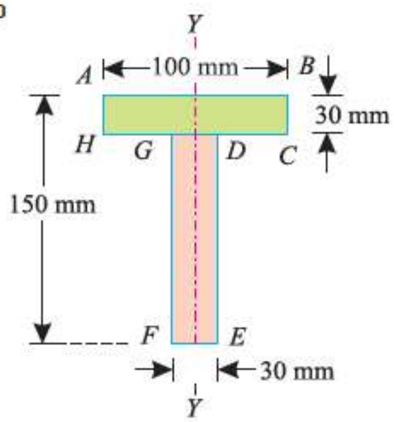


Fig. 6.10.

Let bottom of the web *FE* be the axis of reference.

(*i*) *Rectangle ABCH*

$$a_1 = 100 \times 30 = 3000 \text{ mm}^2$$

and $$y_1 = \left(150 - \frac{30}{2}\right) = 135 \text{ mm}$$

(*ii*) *Rectangle DEFG*

$$a_2 = 120 \times 30 = 3600 \text{ mm}^2$$

and $$y_2 = \frac{120}{2} = 60 \text{ mm}$$

We know that distance between centre of gravity of the section and bottom of the flange *FE*.

$$\bar{y} = \frac{a_1 y_1 + a_2 y_2}{a_1 + a_2} = \frac{(3000 \times 135) + (3600 \times 60)}{3000 + 3600} \text{ mm}$$

$$= 94.1 \text{ mm} \quad \textbf{Ans.}$$

Example 6.4. *Find the centroid of an unequal angle section 100 mm × 80 mm × 20 mm.*

Solution. As the section is not symmetrical about any axis, therefore we have to find out the values of $\bar{x}$ and $\bar{y}$ for the angle section. Split up the section into two rectangles as shown in Fig. 6.13.

Let left face of the vertical section and bottom face of the horizontal section be axes of reference.

(*i*) *Rectangle* 1

$$a_1 = 100 \times 20 = 2000 \text{ mm}^2$$

$$x_1 = \frac{20}{2} = 10 \text{ mm}$$

and $$y_1 = \frac{100}{2} = 50 \text{ mm}$$

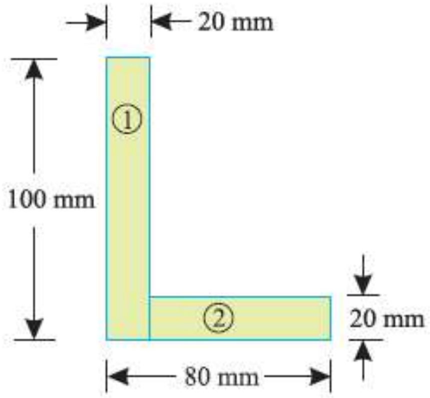


Fig. 6.13.

(*ii*) *Rectangle* 2

$$a_2 = (80 - 20) \times 20 = 1200 \text{ mm}^2$$

$$x_2 = 20 + \frac{60}{2} = 50 \text{ mm}$$

and $$y_2 = \frac{20}{2} = 10 \text{ mm}$$

We know that distance between centre of gravity of the section and left face,

$$\bar{x} = \frac{a_1 x_1 + a_2 x_2}{a_1 + a_2} = \frac{(2000 \times 10) + (1200 \times 50)}{2000 + 1200} = 25 \text{ mm} \quad \textbf{Ans.}$$

Similarly, distance between centre of gravity of the section and bottom face,

$$\bar{y} = \frac{a_1 y_1 + a_2 y_2}{a_1 + a_2} = \frac{(2000 \times 50) + (1200 \times 10)}{2000 + 1200} = 35 \text{ mm} \quad \textbf{Ans.}$$

Video Content / Details of website for further learning (if any):

- https://www.engineersedge.com/material_science/moment-inertia-gyration-7.htm

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi 512-518

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : III- Properties of Surfaces and Solids

Topic of Lecture: Theorems of Pappus

Introduction

- In mathematics, Pappus's centroid theorem (also known as the Guldinus theorem, Pappus–Guldinus theorem or Pappus's theorem) is either of two related theorems dealing with the surface areas and volumes of surfaces and solids of revolution.
- The theorems are attributed to Pappus of Alexandria and Paul Guldin.
- These theorems enable us to work out the volume of a solid of revolution if we know the position of the centroid of a plane area, or vice versa; or to work out the area of a surface of revolution if we know the position of the centroid of a plane curve or vice versa. It is not necessary that the plane or the curve be rotated through a full 360o.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Basics of Mathematics
- Basics of 2D,3D
- Basics of Surface Volume

Detailed content of the Lecture:

Theorem 1 :

It states that the area of a surface of revolution is the product of the length of the generating curve and the distance travelled by the centroid of the curve, while the surface is being generated

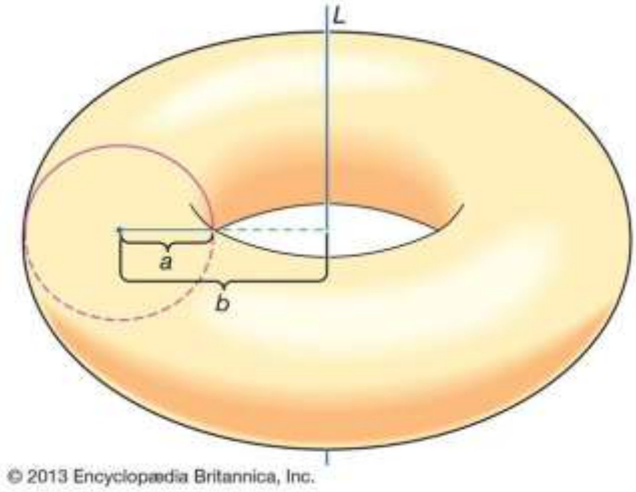
Theorem 2 :

- It states that the volume of a body of revolution is obtained from the product of the generating area and the distance travelled by the centroid of the area, while the body is being generated

Pappus's theorem, in mathematics, theorem named for the 4th-century Greek geometer Pappus of Alexandria that describes the volume of a solid, obtained by revolving a plane region D about a line L not intersecting D, as the product of the area of D and the length of the circular path traversed by the centroid of D during the revolution.

- To illustrate Pappus's theorem, consider a circular disk of radius a units situated in a plane, and suppose that its centre is located b units from a line L in the same plane, measured perpendicularly, where b > a. When the disk is revolved through 360 degrees about L, its centre travels along a circular path of circumference 2πb units (twice the product of π and the radius of the path). Since the area of the disk is πa2 square units (the product of π and the square of the radius of the disk), Pappus's theorem declares that the volume of the solid torus obtained is $(\pi a^2) \times (2\pi b) = 2\pi^2 a^2 b$ cubic units.
- Pappus stated this result, along with a similar theorem concerning the area of a surface of revolution, in his Mathematical Collection, which contained many challenging geometric ideas and would be of great interest to mathematicians in later centuries. Pappus's theorems are sometimes also known as Guldin's theorems, after the Swiss Paul Guldin, one of many Renaissance mathematicians interested in centres of gravity.

- Guldin published his rediscovered version of Pappus’s results in 1641.



Video Content / Details of website for further learning (if any):

- https://en.wikipedia.org/wiki/Pappus%27s_centroid_theorem
- https://www.britannica.com/science/Pappuss-theorem

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics- R.S. Khurmi 630-635

MUTHAYAMMAL ENGINEERING COLLEGE
(An Autonomous Institution)
(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)
Rasipuram - 637 408, Namakkal Dist., Tamil Nadu

LECTURE HANDOUTS

L-22

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : III-Properties of Surfaces and Solids

Topic of Lecture: : Area Moments of Inertia of Plane Areas – Rectangular, Circular, Triangular Areas by Integration

Introduction:

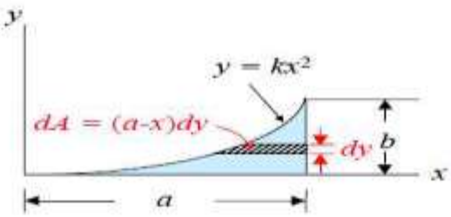
- In engineering practice, use of sections which are built up of many simple sections is very common. Such sections may be called as built-up sections or composite sections.
- To locate the centroid of composite sections, one need not go for the first principle (method of integration). The given composite section can be split into suitable simple figures and then the centroid of each simple figure can be found by inspection or using the standard formulae listed in the table above.
- Assuming the area of the simple figure as concentrated at its centroid, its moment about an axis can be found by multiplying the area with distance of its centroid from the reference axis.
- After determining moment of each area about reference axis, the distance of centroid from the axis is obtained by dividing total moment of area by total area of the composite section.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Moment
- 2D Plane Area
- Basics of Cross Section

Detailed Content of the Lecture:

• **Moment of Inertia I_x.**



Substituting $x = a$ and $y = b$

$$y = kx^2$$

$$b = ka^2$$

$$k = \frac{b}{a^2}$$

$$y = \frac{b}{a^2}x^2 \quad or \quad x = \frac{a}{b^{1/2}}y^{1/2}$$

$$I_x = \int_A y^2 dA$$

$$= \int_0^b y^2(a-x)dy$$

$$= \int_0^b y^2\left(a - \frac{a}{b^{1/2}}y^{1/2}\right)dy$$

$$= a\int_0^b y^2 dy - \frac{a}{b^{1/2}}\int_0^b y^{5/2}dy$$

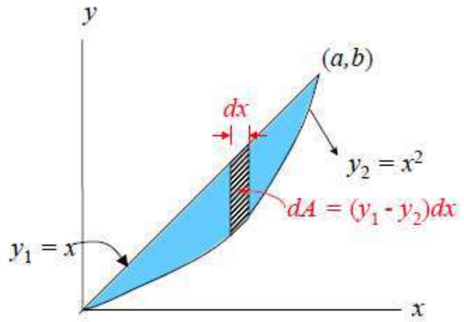
$$= \frac{ay^3}{3}\Big|_0^b - \frac{a}{b^{1/2}}\left(\frac{2}{7}y^{7/2}\right)\Big|_0^b$$

$$= \frac{ab^3}{3} - \frac{a}{b^{1/2}}\left(\frac{2}{7}b^{7/2}\right)$$

$$= \frac{ab^3}{3} - \frac{2ab^3}{7}$$

$$= \frac{ab^3}{21}$$

• **Moment of Inertia I_y.**



$$
\begin{aligned}
I_y &= \int_A x^2 dA \\
&= \int_0^a x^2 (y_1 - y_2) dx \\
&= \int_0^a x^2 (x - x^2) dx \\
&= \int_0^a (x^3) dx - \int_0^a (x^4) dx \\
&= \left. \frac{x^4}{4} \right|_0^a - \left. \frac{x^5}{5} \right|_0^a \\
&= \frac{a^4}{4} - \frac{a^5}{5}
\end{aligned}
$$

The second moment of area, also known as area moment of inertia, is a geometrical property of an area which reflects how its points are distributed with regard to an arbitrary axis. The unit of dimension of the second moment of area is length to fourth power, L^4, and should not be confused with the mass moment of inertia. If the piece is thin, however, the mass moment of inertia equals the area density times the area moment of inertia.

Video Content / Details of website for further learning (if any):

- https://en.wikipedia.org/wiki/List_of_second_moments_of_area

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi- 592-601

LECTURE HANDOUTS

L-23

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : III- Properties of Surfaces and Solids

Topic of Lecture: MI of T section, I section, Angle section, Hollow Section by Using Standard Formula

Introduction:

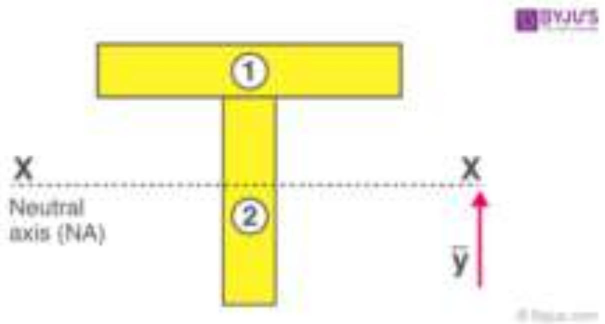
- The moment of inertia, otherwise known as the mass moment of inertia, angular mass or rotational inertia, of a rigid body is a quantity that determines the torque needed for a desired angular acceleration about a rotational axis; similar to how mass determine the force needed for a desired acceleration. It depends on the body's mass distribution and the axis chosen, with larger moments requiring more torque to change the body's rate of rotation.
- It is an extensive (additive) property: for a point mass the moment of inertia is simply the mass times the square of the perpendicular distance to the axis of rotation.
- The moment of inertia of a rigid composite system is the sum of the moments of inertia of its component subsystems (all taken about the same axis). Its simplest definition is the second moment of mass with respect to distance from an axis.
- For bodies constrained to rotate in a plane, only their moment of inertia about an axis perpendicular to the plane, a scalar value, and matters. For bodies free to rotate in three dimensions, their moments can be described by a symmetric 3 × 3 matrix, with a set of mutually perpendicular principal axes for which this matrix is diagonal and torques around the axes act independently of each other.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Importance of Cross Sections
- Resisting Property of the Material
- Principles of Inertia
- Principle of Moment

Detailed content of the Lecture:

- Moment of Inertia is the quantity that expresses an object’s resistance to change its state of rotational motion. The moment of inertia of a T section is calculated by considering it as 2 rectangular segments. The moment of inertia is separately calculated for each segment and put in the formula to find the total moment of inertia.



Step 1: The beam sections should be segmented into parts

The T beam section should be divided into smaller sections. The moment of inertia must be calculated for the smaller segments. Here the section is divided into two rectangular segments.

Step 2: Mark the neutral axis

The neutral axis is the horizontal line passing through the centre of mass. The centre of mass is calculated using the following formula

$Y_c = \Sigma Y_i A_i / \Sigma A_i$

Y_i is the centre of mass of the individual rectangle

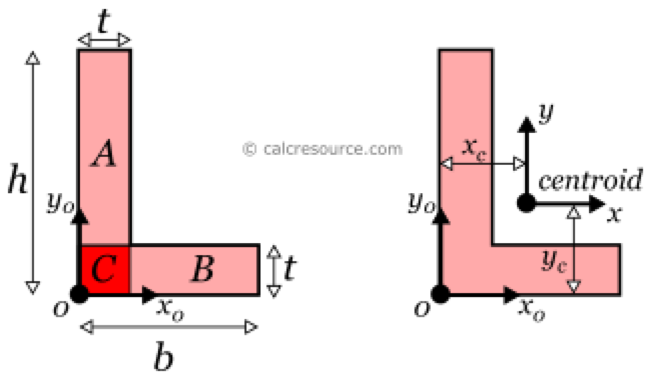
A_i is the area of the individual rectangle

Step 3: Calculating the Moment of Inertia

Apply the Parallel Axis Theorem

L Section:

The moment of inertia of an angle cross section can be found if the total area is divided into three, smaller ones, A, B, C, as shown in the figure below. The final area may be considered as the additive combination of A+B+C. However, a more straightforward calculation can be achieved by the combination (A+C) + (B+C)-C. Also, the calculation is better done around the non-centroidal x0, y0 axes, followed by application of the Parallel Axes Theorem.



Video Content / Details of website for further learning (if any):

- https://en.wikipedia.org/wiki/Moment_of_inertia
- https://byjus.com/jee/moment-of-inertia-of-t-section/

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi- 670-676

LECTURE HANDOUTS

L-24

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : III- Properties of Surfaces and Solids

Topic of Lecture: Parallel Axis Theorem and Perpendicular Axis Theorem

Introduction:

- The parallel axis theorem, also known as Huygens–Steiner theorem, or just as Steiner's theorem, named after Christiaan Huygens and Jakob Steiner, can be used to determine the moment of inertia or the second moment of area of a rigid body about any axis, given the body's moment of inertia about a parallel axis through the object's center of gravity and the perpendicular distance between the axes.
- The parallel axis theorem allows us to figure out the moment of inertia for an object that is rotating around an axis that doesn't go through the center of mass.
- If the value of the moment of Inertia about these two axes is known, then we can easily calculate the Moment of Inertia about the third axis by applying Perpendicular Axis theorem

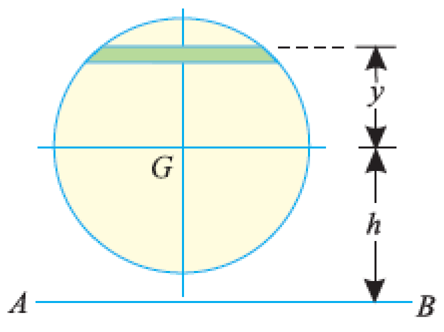
Prerequisite knowledge for Complete understanding and learning of Topic:

- Basics of Mathematics
- Basics of Physics
- Importance of Cetroid and CG
- Difference between 2D and 3D Figure

Detailed content of the Lecture:

Parallel axis theorem

It states that " the moment of inertia of a plane area about any axis parallel to centroidal axis is the sum of moment of inertia of the area about the centroidal axis and the product of the area and square of the distance between the two parallel axes



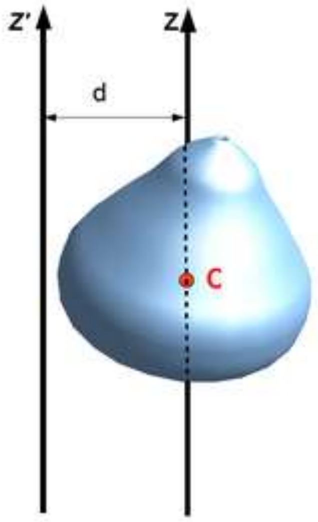
$$I_{AB} = I_G + ah^2$$

where I_{AB} = Moment of inertia of the area about an axis AB,

I_G = Moment of Inertia of the area about its centre of gravity

a = Area of the section, and

h = Distance between centre of gravity of the section and axis AB.



Perpendicular Axis Theorem

It states that "the moment of inertia of a plane lamina about an axis perpendicular to the lamina and passing through the centroid is equal to the sum of the moment of inertia of the lamina about two mutually perpendicular axes passing through the centroid and in the plane of the lamina.

$$I_{ZZ} = I_{XX} + I_{YY}$$

The moment of inertia Izz is also known as Polar moment of inertia. It is denoted by J

- **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=dJcx5bp3CmU

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics -R.S Khurmi 568-572

LECTURE HANDOUTS

L-25

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : III-Properties of Surfaces and Solids

Topic of Lecture: Principal Moments of Inertia of Plane Areas, Principal Axes of Inertia

Introduction

- A principal axis of rotation (or principal direction) is an eigenvector of the mass moment of inertia tensor (introduced in the previous section) defined relative to some point (typically the center of mass).
- The corresponding Eigen values are called the principal moments of inertia.
- The axes at which the product of inertia is zero are called Principal Axes. The moment of inertia about the principal axes are called Principal Moment of Inertia.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Moment of Inertia
- Torque
- Twisting Moment

Detailed Content of the Lecture:

- The axes at which the product of inertia is zero are called Principal Axes. The moment of inertia about the principal axes are called Principal Moment of Inertia.
- There will be always be two principal axes at the given point in the area and they will be mutually perpendicular to each other. The moment of inertia about one of the axis will be maximum and the other will be minimum. The maximum moment of inertia is called major principal moment of inertia and the minimum moment of inertia is called minor principal moment of inertia
- In principal axes, that are rotated by an angle θ relative to original centroidal ones x,y, the product of inertia becomes zero. Because of this, any symmetry axis of the shape is also a principal axis. The moments of inertia about principal axes, are called principal moments of inertia, and are the maximum and minimum ones, for any angle of rotation of the coordinate system. If Ix, Iy and Ixy are known for the arbitrary centroidal coordinate system x,y, then the principal moments of inertia and the rotation angle θ of the principal axes can be found, through the next expressions
- The area moment of inertia is a property of a two-dimensional plane shape which characterizes its deflection under loading.
- It is also known as the second moment of area or second moment of inertia. The area moment of inertia has dimensions of length to the fourth power.
- Area Moment of Inertia or Moment of Inertia for an Area - also known as Second Moment of Area - I, is a property of shape that is used to predict deflection, bending and stress in beams.
- In structural engineering, the second moment of area of a beam is an important property used in the calculation of the beam's deflection and the calculation of stress caused by a moment

applied to the beam. In order to maximize the second moment of area, a large fraction of the cross-sectional area of an I-beam is located at the maximum possible distance from the centroid of the I-beam's cross-section.

- The planar second moment of area provides insight into a beam's resistance to bending due to an applied moment, force, or distributed load perpendicular to its neutral axis, as a function of its shape.
- The polar second moment of area provides insight into a beam's resistance to torsional deflection, due to an applied moment parallel to its cross-section, as a function of its shape.
- For more complex areas, it is often easier to divide the area into a series of "simpler" shapes. The second moment of area for the entire shape is the sum of the second moment of areas of all of its parts about a common axis.
- This can include shapes that are "missing" (i.e. holes, hollow shapes, etc.), in which case the second moment of area of the "missing" areas are subtracted, rather than added. In other words, the second moment of area of “missing” parts is considered negative for the method of composite shapes.

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=vLe7lHcRpu8

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics –R.S Khurmi- 592-601

LECTURE HANDOUTS

L-26

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : III-Properties of Surfaces and Solids

Topic of Lecture: Mass moment of Inertia

Introduction:

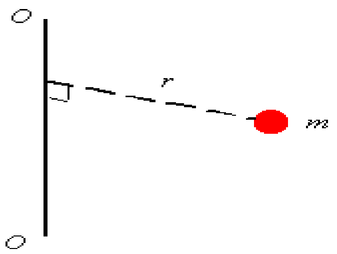
- The Mass Moment of Inertia of a solid measures the solid's ability to resist changes in rotational speed about a specific axis.
- The larger the Mass Moment of Inertia the smaller the angular acceleration about that axis for a given torque.
- The moment of inertia, otherwise known as the mass moment of inertia, angular mass or rotational inertia, of a rigid body is a quantity that determines the torque needed for a desired angular acceleration about a rotational axis; similar to how mass determine the force needed for a desired acceleration.
- It depends on the body's mass distribution and the axis chosen, with larger moments requiring more torque to change the body's rate of rotation.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Concepts of 3D Lamina
- Torque
- Basics of Physics

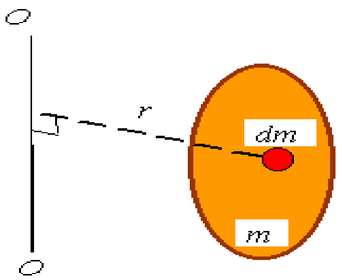
Detailed content of the Lecture:

$$I_O = r^2 m$$



Where O-O is the axis around which one is evaluating the mass moment of inertia, and r is the perpendicular distance between the mass and the axis O-O. As can be seen from the above equation, the mass moment of inertia has the units of mass time's length squared. The mass moment of inertial should not be confused with the area moment of inertia which has units of length to the power four. Mass moments of inertia naturally appear in the equations of motion, and provide information on how difficult (how much inertia there is) it is rotating the particle around given axis.

Mass moment of inertia for a rigid body: When calculating the mass moment of inertia for a rigid body, one thinks of the body as a sum of particles, each having a mass of dm. Integration is used to sum the moment of inertia of each dm to get the mass moment of inertia of body. The equation for the mass moment of inertia of the rigid body is



$$I = \sum r^2 dm = \int_m r^2 dm$$

The integral is actually a triple integral. If the coordinate system used is rectangular then $dV=dxdydz$. If the coordinates uses are cylindrical coordinates then $dV = rdrd\theta\, dz$.

For a two dimensional body like a plate or a shell one can use density ρ per unit area (units of mass per length squared) to change the integration using the relation

$$dm = \rho\, dA$$

where A is the surface are and dA differential element of area. For example, for rectangular coordinates $dA=dxdy$ and for polar coordinates $dA = rdrd\theta$. After this substitution one gets the equation to calculate the mass moment of inertia as

$$I = \int_A r^2 \rho\, dA$$

If the body is a rod like object then one can use the relation

$$dm = \rho\, dl$$

to get

$$I = \int_l r^2 \rho\, dl$$

Where l is a coordinate along the length of the rod and the density ρ is in units of mass per unit length.

Radius of gyration: Sometime in place of the mass moment of inertia the radius of gyration k is provided. The mass moment of inertia can be calculated from k using the relation

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=YQVF6A3Od44

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics-R.S.Khurmi-592-601

Course Faculty

LECTURE HANDOUTS | **L-27**

MECH | **II/III**

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : III- Properties of Surfaces and Solids

Topic of Lecture: Problems

Introduction:

- The first step to calculate moment of inertia for a mass, whether in textbook or real-world problems is to establish the location of the X, Y, and Z axes.
- The accuracy of the calculations (and later on the accuracy of the measurements to verify the calculations) will depend entirely on the wisdom used in choosing the axes.
- Theoretically, these axes can be at any location relative to the object being considered, provided the axes are mutually perpendicular.
- However, in real life, unless the axes are chosen to be at a location that can be accurately measured and identified, the moment of inertia calculations are meaningless

Prerequisite knowledge for Complete understanding and learning of Topic:

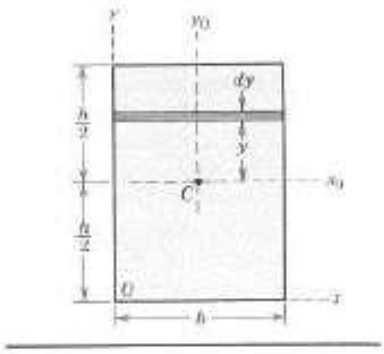
- Basic Mathematical Skills
- Aptitude Skills

Detailed content of the Lecture:

Example 1:

Sample Problem A/1

Determine the moments of inertia of the rectangular area about the centroidal x_0- and y_0-axes, the centroidal polar axis z_0 through C, the x-axis, and the polar axis z through O.



Solution. For the calculation of the moment of inertia $\bar{I}_x$ about the x_0-axis, a horizontal strip of area $b\,dy$ is chosen so that all elements of the strip have the same y-coordinate. Thus,

$$[I_x = \int y^2\,dA] \qquad \bar{I}_x = \int_{-h/2}^{h/2} y^2 b\,dy = \frac{1}{12}bh^3 \qquad \textit{Ans.}$$

By interchanging symbols the moment of inertia about the centroidal y_0-axis is

$$\bar{I}_y = \frac{1}{12}hb^3 \qquad \textit{Ans.} \quad ①$$

① If we had started with the second-order element $dA = dx\,dy$, integration with respect to x holding y constant amounts simply to multiplication by b and gives us the expression $y^2b\,dy$, which we chose at the outset.

The centroidal polar moment of inertia is

$$[I_z = I_x + I_y] \qquad \bar{I}_z = \frac{1}{12}(bh^3 + hb^3) = \frac{1}{12}A(b^2 + h^2) \qquad \textit{Ans.}$$

By the parallel-axis theorem the moment of inertia about the x-axis is

$$[I_x = \bar{I}_x + Ad_x^2] \qquad I_x = \frac{1}{12}bh^3 + bh\left(\frac{h}{2}\right)^2 = \frac{1}{3}bh^3 = \frac{1}{3}Ah^2 \qquad \textit{Ans.}$$

We also obtain the polar moment of inertia about O by the parallel-axis theorem, which gives us

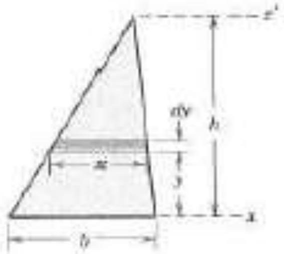
$$[I_z = \bar{I}_z + Ad^2] \qquad I_z = \frac{1}{12}A(b^2 + h^2) + A\left[\left(\frac{b}{2}\right)^2 + \left(\frac{h}{2}\right)^2\right]$$

$$I_z = \frac{1}{3}A(b^2 + h^2) \qquad \textit{Ans.}$$

Example 2:

Sample Problem A/2

Determine the moments of inertia of the triangular area about its base and about parallel axes through its centroid and vertex.



Solution. A strip of area parallel to the base is selected as shown (1) in the figure, and it has the area $dA = x\,dy = [(h - y)b/h]\,dy$. By (2) definition

$$[I_x = \int y^2\,dA] \qquad I_x = \int_0^h y^2 \frac{h-y}{h} b\,dy = b\left[\frac{y^3}{3} - \frac{y^4}{4h}\right]_0^h = \frac{bh^3}{12} \qquad Ans.$$

By the parallel-axis theorem the moment of inertia $\bar{I}$ about an axis through the centroid, a distance $h/3$ above the x-axis, is

$$[\bar{I} = I - Ad^2] \qquad \bar{I} = \frac{bh^3}{12} - \left(\frac{bh}{2}\right)\left(\frac{h}{3}\right)^2 = \frac{bh^3}{36} \qquad Ans.$$

A transfer from the centroidal axis to the x'-axis through the vertex gives

$$[I = \bar{I} + Ad^2] \qquad I_{x'} = \frac{bh^3}{36} + \left(\frac{bh}{2}\right)\left(\frac{2h}{3}\right)^2 = \frac{bh^3}{4} \qquad Ans.$$

(1) Here again we choose the simplest possible element. If we had chosen $dA = dx\,dy$, we would have to integrate $y^2\,dx\,dy$ with respect to x first. This gives us $y^2x\,dy$, which is the expression we chose at the outset.

(2) Expressing x in terms of y should cause no difficulty if we observe the proportional relationship between the similar triangles.

- Moment of inertia is similar to inertia, except it applies to rotation rather than linear motion. Inertia is the tendency of an object to remain at rest or to continue moving in a straight line at the same velocity. Inertia can be thought of as another word for mass. Moment of inertia is, therefore, rotational mass. Unlike inertia, MOI also depends on the distribution of mass in an object.
- The greater the distance the mass is from the center of rotation, the greater the moment of inertia.
- A formula analogous to Newton's second law of motion can be written for rotation:
- F = Ma (F = force; M = mass; a = linear acceleration)
- T = IA (T = torque; I = moment of inertia; A = rotational acceleration)

Video Content / Details of website for further learning (if any):

- https://www.space-electronics.com/KnowHow/calculating-moment-of-inertia

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S. Khurmi - 592-601

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LECTURE HANDOUTS

L-28

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : IV- Dynamics of Particles

Topic of Lecture: Velocity, Displacement, Acceleration and Their Relationship

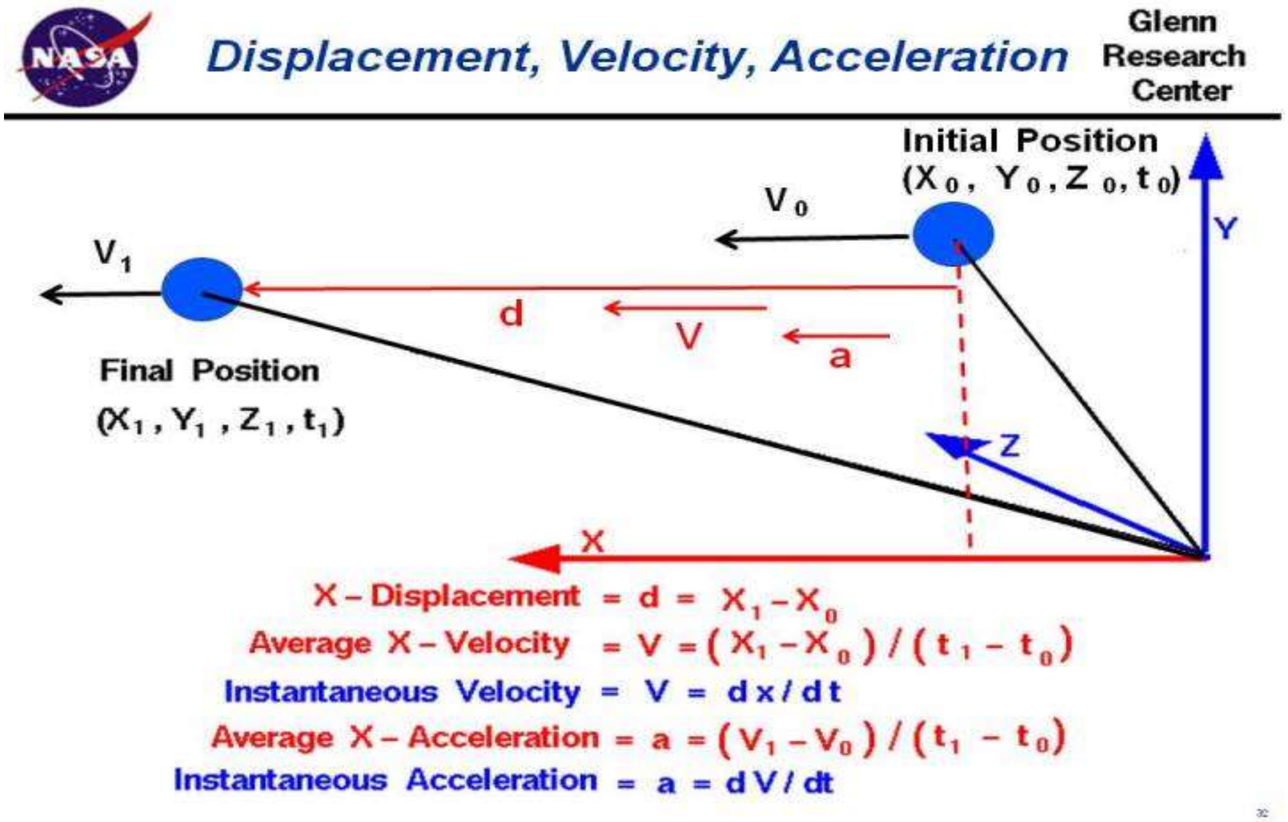
Introduction:

- The velocity of an object is the rate of change of its position with respect to a frame of reference, and is a function of time.
- Velocity is equivalent to a specification of an object's speed and direction of motion (e.g. 60 km/h to the north).
- Displacement is a vector quantity that refers to "how far out of place an object is"; it is the object's overall change in position.
- In mechanics, acceleration is the rate of change of the velocity of an object with respect to time. Accelerations are vector quantities (in that they have magnitude and direction). The orientation of an object's acceleration is given by the orientation of the net force acting on that object.

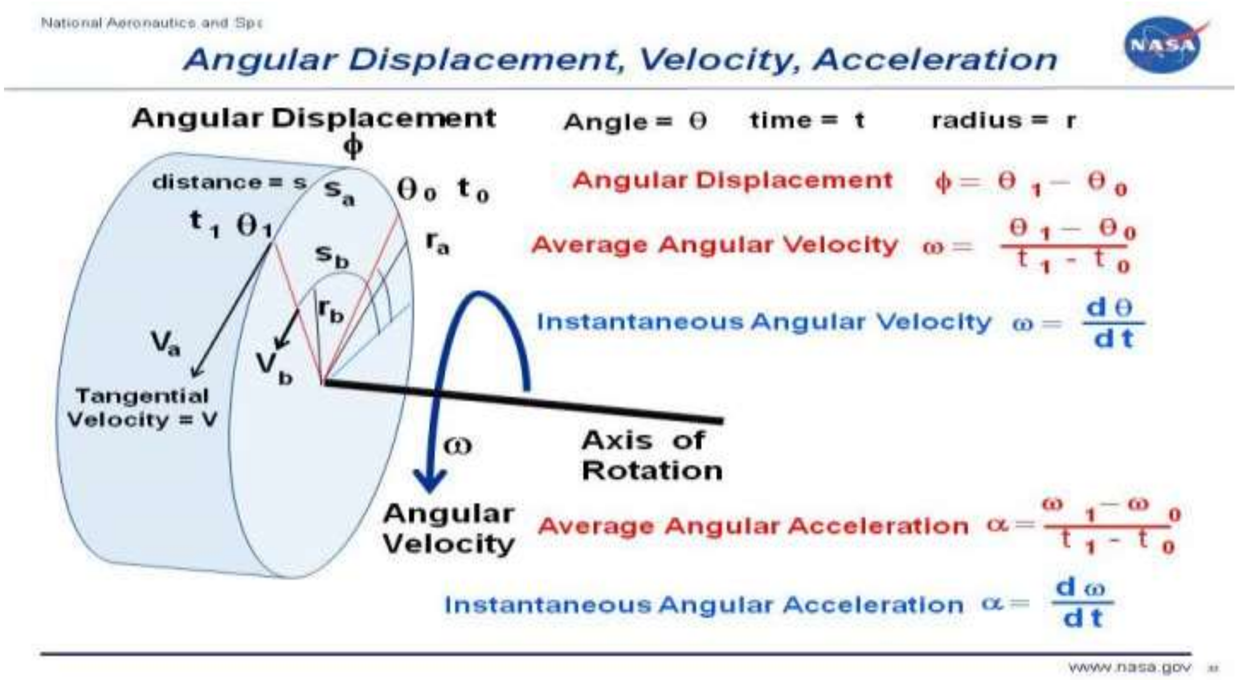
Prerequisite knowledge for Complete understanding and learning of Topic:

- Basics of Mathematics
- Basics of Physics

Detailed content of the Lecture:



Type of Formula	Linear	Angular
Velocity	$v = \frac{\Delta s}{\Delta t}$	$\omega = \frac{\Delta \theta}{\Delta t}$
Acceleration	$a = \frac{\Delta v}{\Delta t}$	$\alpha = \frac{\Delta \omega}{\Delta t}$
Displacement	$s = v_i t + \frac{1}{2} a t^2$	$\theta = \omega_i t + \frac{1}{2} \alpha t^2$
Motion with time canceled out	$v_f^2 - v_i^2 = 2as$	$\omega_f^2 - \omega_i^2 = 2\alpha\theta$



Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=0sq6H6ebPig

Important Books/Journals for further learning including the page nos.: Khurmi .R.S.pg 699-702

- A Text Book of Engineering Mechanics-R.S.Khurmi-699-702

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LECTURE HANDOUTS

L-29

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : IV-Dynamics of Particles

Topic of Lecture: Relative Motion

Introduction:

- The laws of physics which apply when you are at rest on the earth also apply when you are in any reference frame which is moving at a constant velocity with respect to the earth.
- For example, you can toss and catch a ball in a moving bus if the motion is in a straight line at constant speed.
- The concept of reference frames was first introduced to discuss relative motion in one or more dimensions. When we say an object has a certain velocity, then this velocity is with respect to some frame that is known as the reference frame.
- The motion observed by the observer depends on the location (frame) of the observer. This type of motion is called relative motion.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Imagination Skills
- Analytical Skills
- Basics of Solar System

Detailed content of the Lecture:

The laws of physics which apply when you are at rest on the earth also apply when you are in any reference frame which is moving at a constant velocity with respect to the earth. For example, you can toss and catch a ball in a moving bus if the motion is in a straight line at constant speed.

The motion may have a different appearance as viewed from a different reference frame, but this can be explained by including the relative velocity of the reference frame in the description of the motion

Relative Velocity

One must take into account relative velocities to describe the motion of an airplane in the wind or a boat in a current. Assessing velocities involves vector addition and a useful approach to such relative velocity problems is to think of one reference frame as an "intermediate" reference frame in the form:

Put into words, the velocity of A with respect to C is equal to the velocity of A with respect to B plus the velocity of B with respect to C. Reference frame B is the intermediate reference frame. This approach can be used with the airplane or boat examples. A boat in current is a good example of relative velocity.

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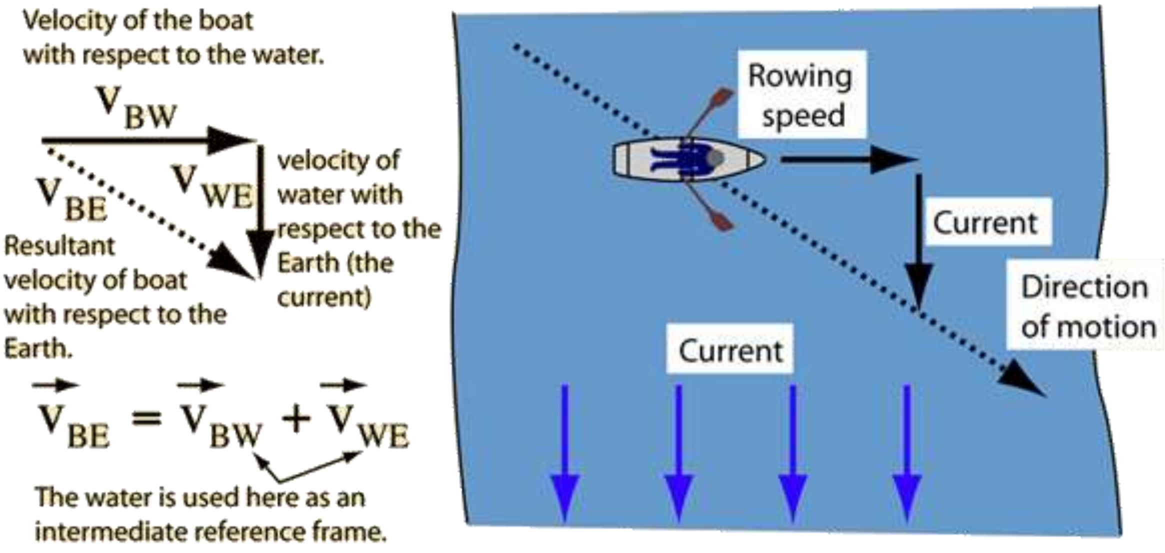

$$v_{BE} = \sqrt{v_{BW}^2 + v_{WE}^2}$$

$$\theta = \tan^{-1}\frac{v_{WE}}{v_{BW}}$$

$$\vec{V}_{AC} = \vec{V}_{AB} + \vec{V}_{BC}$$

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=nOKb2Fh63Zc

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics –R.S. Khurmi- 420

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LECTURE HANDOUTS

L-30

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : IV-Dynamics of Particles

Topic of Lecture: Rectilinear Motion and Curvilinear Motion

Introduction:

- Motion is one of the most common phenomena we come across in our daily lives. For example, a moving car, a kid running on the road or a fly moving in the air are all said to be in motion. So, in general terms, a body is said to be in motion if it changes its position with respect to a reference point and time.
- Depending upon the path taken by the particle the motion can be of different types like projectile motion, rectilinear motion, rotational motion, etc. For now, we will only focus on the rectilinear motion which is also known as linear motion.
- Curvilinear motion is defined as motion that occurs when a particle travels along a curved path. The curved path can be in two dimensions (in a plane), or in three dimensions. This type of motion is more complex than rectilinear (straight-line) motion.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Displacement
- Velocity
- Acceleration

Detailed content of the Lecture:

A body/ object is said to be in **linear motion** when it travels along a straight line or along a curve **in a** plane. Example- Athlete running along a straight path. **Rectilinear motion** (is also a type of **linear motion**) which can be described by by a moving body/object that travels only straight path

We have an origin O, measurements to the right of O are taken as positive while to the left are taken as negative. Suppose a person who starts from origin O reaches point A,

Distance = OA

Displacement = OA

Now he turns and reaches point B,

Distance = OA + AB

Displacement = -OB

Displacement is negative since it is measured to the left of origin. From the above example, we can infer that distance is always positive while displacement can either be positive or negative.

Speed and Velocity

These terms are used to describe rate of change of position. Speed is the rate of change of distance while velocity is the rate of change of displacement. Comparing from above as distance can never be negative so speed is never negative while velocity can be both positive and negative. In mathematical terms, these are defined as follows:

Speed = Distance Travelled Time Taken

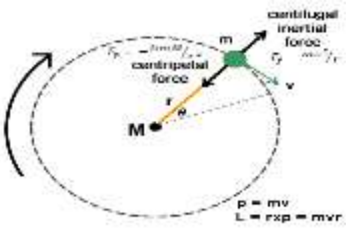
Velocity =(Final position–Initial position)Time Taken

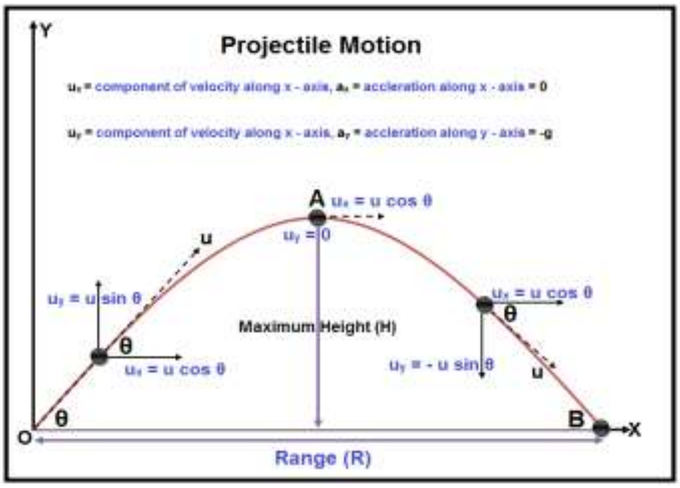
Examples for Rectilinear Motion

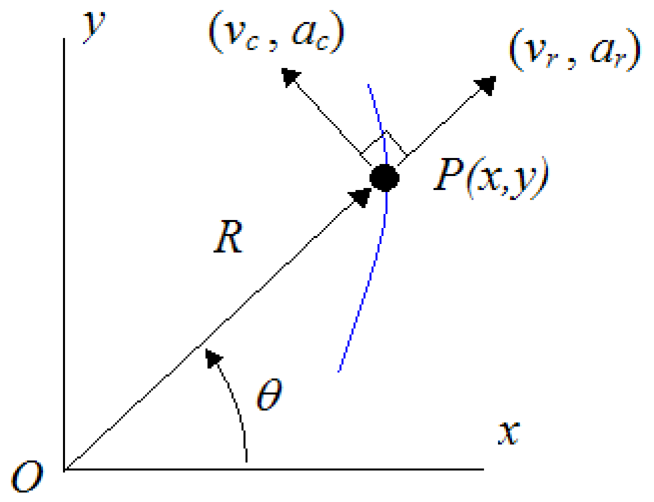
- Use of elevators in public places is an example of rectilinear motion.
- Gravitational forces acting on objects resulting in free fall is an example of rectilinear motion.
- A kid sliding down from a slide is a rectilinear motion.
- Motion of planes in the sky is a rectilinear motion.

Curvilinear motion is defined as motion that occurs when a particle travels along a curved path. The curved path can be in two dimensions (in a plane), or in three dimensions. This type of motion is more complex than rectilinear (straight-line) motion.

- The motion of an object moving in a curved path is called curvilinear motion. Some of the examples of curvilinear motion:
- Throwing a rocket or a dart in circular motion.
- When we sneeze our head moves in a curvilinear motion.
- Throwing a short put ball or a javelin throw also serves as examples of curvilinear motion.







Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=ihlO4IekC4A

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics -R.S.Khurmi 486-490

LECTURE HANDOUTS

L-31

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : IV-Dynamics of Particles

Topic of Lecture: Newton's Law of Motion

Introduction:

- In classical mechanics, Newton's laws of motion are three laws that describe the relationship between the motion of an object and the forces acting on it.
- The first law states that an object either remains at rest or continues to move at a constant velocity, unless it is acted upon by an external force.
- The second law states that the rate of change of momentum of an object is directly proportional to the force applied, or, for an object with constant mass, that the net force on an object is equal to the mass of that object multiplied by the acceleration.
- The third law states that when one object exerts a force on a second object, that second object exerts a force that is equal in magnitude and opposite in direction on the first object.
- The three laws of motion were first compiled by Isaac Newton in his Philosophiæ Naturalis Principia Mathematica (Mathematical Principles of Natural Philosophy), first published in 1687. Newton used them to explain and investigate the motion of many physical objects and systems, which laid the foundation for Newtonian mechanics

Prerequisite knowledge for Complete understanding and learning of Topic:

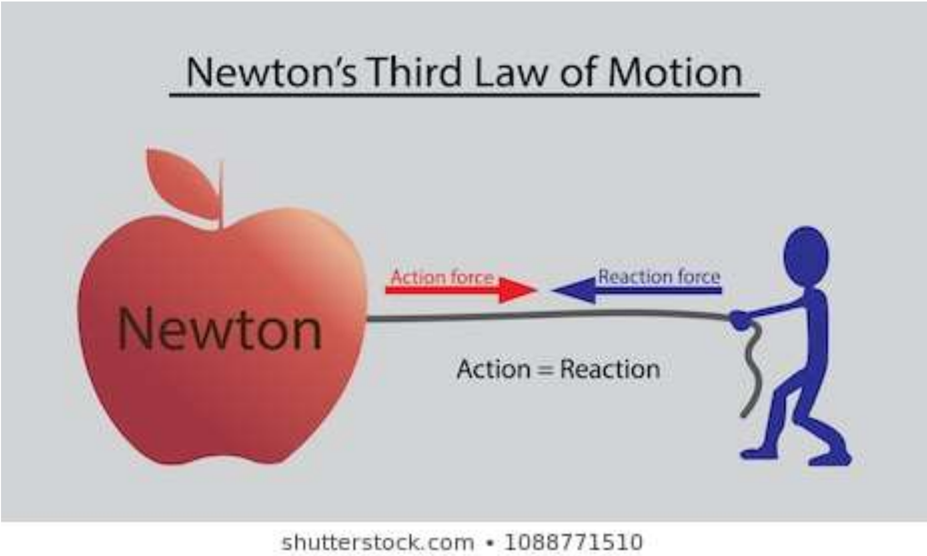
- Fundamentals of Forces
- Basics of Physics

Detailed content of the Lecture:

- The motion of an aircraft through the air can be explained and described by physical principals discovered over 300 years ago by Sir Isaac Newton. Newton worked in many areas of mathematics and physics.
- He developed the theories of gravitation in 1666, when he was only 23 years old. Some twenty years later, in 1686, he presented his three laws of motion in the "Principia Mathematica Philosophiae Naturalis." The laws are shown above, and the application of these laws to aerodynamics is given on separate slides.
- Newton's first law states that every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force. This is normally taken as the definition of inertia. The key point here is that if there is no net force acting on an object (if all the external forces cancel each other out) then the object will maintain a constant velocity. If that velocity is zero, then the object remains at rest. If an external force is applied, the velocity will change because of the force.
- The second law explains how the velocity of an object changes when it is subjected to an external force.
- The law defines a force to be equal to change in momentum (mass times velocity) per change in time. Newton also developed the calculus of mathematics, and the "changes" expressed in the

second law are most accurately defined in differential forms. (Calculus can also be used to determine the velocity and location variations experienced by an object subjected to an external force.) For an object with a constant mass m, the second law states that the force F is the product of an object's mass and its acceleration a: **F = m*a**

- For an external applied force, the change in velocity depends on the mass of the object. A force will cause a change in velocity; and likewise, a change in velocity will generate a force. The equation works both ways.
- The third law states that for every action (force) in nature there is an equal and opposite reaction. In other words, if object A exerts a force on object B, then object B also exerts an equal force on object A. Notice that the forces are exerted on different objects. **The third law can be used to explain the generation of lift by a wing and the production of thrust by a jet engine.**



Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=YzxUZzMrlfQ&list=PLF_7kfnwLFCGcF1IhVgTiZ-Sf0pnKIOub

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics - R.S Khurmi -720-725

LECTURE HANDOUTS | **L-32**

MECH | **II/III**

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : IV-Dynamics of Particles

Topic of Lecture: Work Energy Equation

Introduction:

- In physics, work is the energy transferred to or from an object via the application of force along a displacement. In its simplest form, it is often represented as the product of force and displacement.
- A force is said to do positive work if (when applied) it has a component in the direction of the displacement of the point of application. A force does negative work if it has a component opposite to the direction of the displacement at the point of application of the force.
- The work-energy theorem also known as the principle of work and kinetic energy states that the total work done by the sum of all the forces acting on a particle is equal to the change in the kinetic energy of that particle.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Simple Mathematical Concepts
- Lateral Thinking Skills
- Imagination Skills
- Basics of Science

Detailed content of the Lecture:

- Work, energy and power are the most used terms in Physics. They are probably the first thing you learn in your Physics class. Work and energy can be considered as two sides of the same coin. In this article, we will learn all about the concept of work, power and energy.
- Work done is generally referred in relation to the force applied while energy is used in reference to other factors such as heat. Power is defined as work done per unit time.
- The work W done by a constant force of magnitude F on a point that moves a displacement s in a straight line in the direction of the force is the product **W = F*S**
- The work 'W' done by the net force on a particle is equal to the change in the particle's kinetic energy (KE).

$$d = \frac{v_f^2 - v_i^2}{2a}$$

- Let us consider a case where the resultant force 'F' is constant in both direction and magnitude and is parallel to the velocity of the particle. The particle is moving with constant acceleration along a straight line. The relationship between the acceleration and the net force is given by the equation "F = ma" (Newton's second law of motion), and the particle's displacement 'd', can be determined from the equation:

$$v_f^2 = v_i^2 + 2ad$$

$$W = \Delta KE = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

- The work of the net force is calculated as the product of its magnitude (F=ma) and the particle's displacement. Substituting the above equations yields:

$$W = Fd = ma\frac{v_f^2 - v_i^2}{2a} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = KE_f - KE_i = \Delta KE$$

- The SI unit of work is the joule (J), named after the 19th-century English physicist James Prescott Joule, which is defined as the work required to exert a force of one newton through a displacement of one metre.
- The dimensionally equivalent Newton-metre (N·m) is sometimes used as the measuring unit for work, but this can be confused with the measurement unit of torque. Usage of N·m is discouraged by the SI authority, since it can lead to confusion as to whether the quantity expressed in newton metres is a torque measurement, or a measurement of work.
- Non-SI units of work include the newton-metre, erg, the foot-pound, the foot-poundal, the kilowatt hour, the litre-atmosphere, and the horsepower-hour. Due to work having the same physical dimension as heat, occasionally measurement units typically reserved for heat or energy content, such as theorem, BTU and calorie, are utilized as a measuring unit.
- Work is a scalar quantity so it has only magnitude and no direction. Work transfers energy from one place to another or one form to another.

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=MFS3rWIHmxA
- https://byjus.com/physics/derivation-of-work-energy-theorem/

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics -R.S.Khurmi 588-592

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LECTURE HANDOUTS

L-33

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : IV-Dynamics of Particles

Topic of Lecture: Work Energy Equation Problems

Introduction:

- In physics, work is the energy transferred to or from an object via the application of force along a displacement. In its simplest form, it is often represented as the product of force and displacement.
- A force is said to do positive work if (when applied) it has a component in the direction of the displacement of the point of application. A force does negative work if it has a component opposite to the direction of the displacement at the point of application of the force.
- The work-energy theorem also known as the principle of work and kinetic energy states that the total work done by the sum of all the forces acting on a particle is equal to the change in the kinetic energy of that particle.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Work-Energy Principle
- Basics of Mathematics

Detailed content of the Lecture:

Work and Kinetic Energy

Work

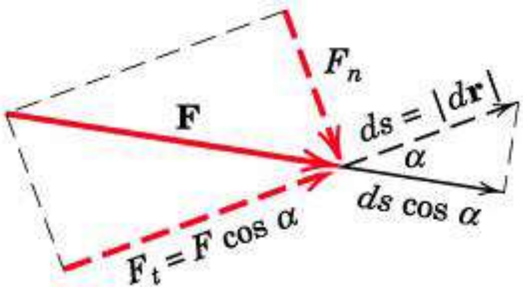
Work done by the force **F** during the displacement $d\mathbf{r}$

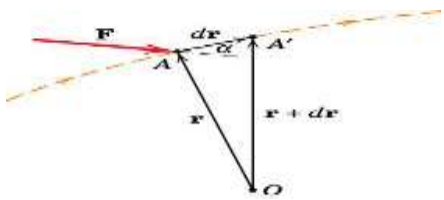
$dU = F \cdot dr$

$dU = F\, ds \cos\alpha$

The normal component of the force: $F_n = F \sin\alpha$ does no work.

Units of Work: Joules (J) or Nm



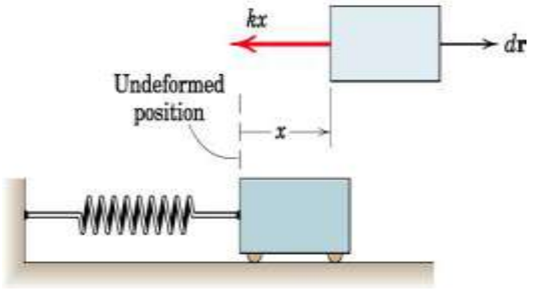


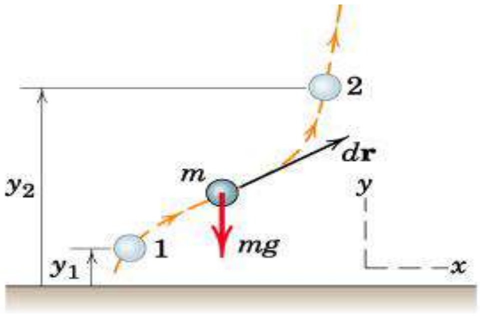
Work associated with a constant external force

Work done by the constant force *P* on the body while it moves from position 1 to 2:

Examples of Work (b) Work associated with a spring force
Force required to compress or stretch a linear spring of stiffness k is proportional to the deformation x.
Work done by the spring force on the body while the body moves from initial position *x*1 to final position *x*2:
Force exerted by the spring on the body:

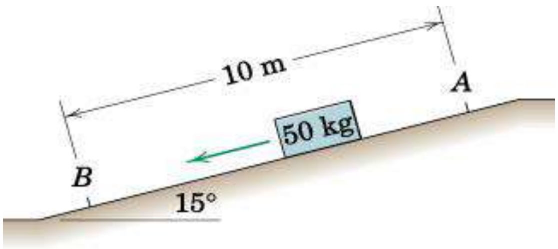
F = - kxi (this is the force exerted on the body)





Advantages of Work Energy Method
No need to compute acceleration; leads directly to velocity changes as functions of forces, which do work.
•Involves only those forces, which do work, and thus, produces change in magnitudes of velocities.
Calculate the velocity of the 50 kg box
when it reaches point B if it is given an
initial velocity of 4 m/s down the slope at A.

μk = 0.3. Use the principle of work.



Video Content / Details of website for further learning (if any):
- https://www.youtube.com/watch?v=-VzjEAq1Su8

Important Books/Journals for further learning including the page nos.:
- A Text Book of Engineering Mechanics R.S Khurmi - 730-736

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LECTURE HANDOUTS

L-34

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : IV-Dynamics of Particles

Topic of Lecture: Impulse Momentum Equation

Introduction:

- In classical mechanics, impulse is the integral of a force, F, over the time interval, t, for which it acts. Since force is a vector quantity, impulse is also a vector quantity.
- Impulse applied to an object produces an equivalent vector change in its linear momentum, also in the same direction. The SI unit of impulse is the newton second (N·s), and the dimensionally equivalent unit of momentum is the kilogram meter per second (kg·m/s).
- The corresponding English engineering unit is the pound-second (lbf·s), and in the British Gravitational System, the unit is the slug-foot per second.
- A resultant force causes acceleration and a change in the velocity of the body for as long as it acts. A resultant force applied over a longer time therefore produces a bigger change in linear momentum than the same force applied briefly: the change in momentum is equal to the product of the average force and duration. Conversely, a small force applied for a long time produces the same change in momentum—the same impulse—as a larger force applied briefly.

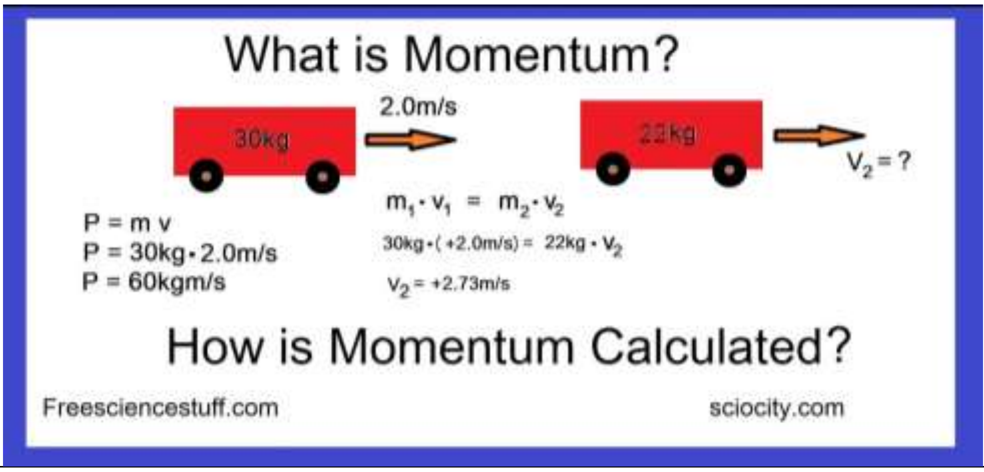
Prerequisite knowledge for Complete understanding and learning of Topic:

- Basics of Physics
- Basics of Mathematics

Detailed content of the Lecture:

Following are the practical application of momentum equation:

(1) Flow though bend pipes
(2) Jet propulsion and propellers
(3) Fluid flow though stationary and moving plates or vanes.
(4) Non-uniform flow through sadden enlarged pipes.
(5) Hydraulic jump in open channels

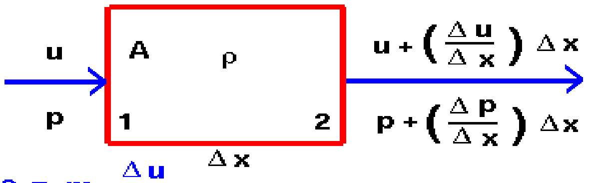


Conservation of Momentum
1 Dimension, Steady Flow

Glenn Research Center

x = distance
u = velocity
a = acceleration
t = time
m = mass

ρ = density
A = area
F = force
p = pressure



$$F = m\,a = m\,\frac{\Delta u}{\Delta t}$$

$$-\left[(pA)_2 - (pA)_1\right] = m\,\frac{u_2 - u_1}{\Delta t}$$

$$-\left[\left(p + \left(\frac{\Delta p}{\Delta x}\right)\Delta x\right)A - pA\right] = m\,\frac{u + \left(\frac{\Delta u}{\Delta x}\right)\Delta x - u}{\Delta t}$$

$$m = \rho\,\Delta x\,A \qquad -\left(\frac{\Delta p}{\Delta x}\right)\Delta x\,A = m\left(\frac{\Delta u}{\Delta x}\right)\frac{\Delta x}{\Delta t} \qquad \frac{\Delta x}{\Delta t} = u$$

$$-\frac{\Delta p}{\Delta x} = \rho\,u\,\frac{\Delta u}{\Delta x}$$

Differential Form: $$-\frac{dp}{dx} = \rho\,u\,\frac{du}{dx}$$

Impulse - Momentum Example

A 1.3 kg ball is coming straight at a 75 kg soccer player at 13 m/s who kicks it in the exact opposite direction at 22 m/s with an average force of 1200 N. How long are his foot and the ball in contact?

answer: We'll use $F_{net}\,t = \Delta p$. Since the ball changes direction, $\Delta p = m\Delta v = m(v_f - v_0)$
$= 1.3\,[22 - (-13)] = (1.3 \text{ kg})(35 \text{ m/s})$
$= 45.5 \text{ kg}\cdot\text{m/s}$. Thus, $t = 45.5 / 1200$
$= 0.0379$ s, which is just under 40 ms.

During this contact time the ball compresses substantially and then decompresses. This happens too quickly for us to see, though. This compression occurs in many cases, such as hitting a baseball or golf ball.

Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=c8x5pL0T4Y8

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics -R.S Khurmi- 461-462

LECTURE HANDOUTS

L-35

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : IV-Dynamics of Particles

Topic of Lecture: Impulse Momentum Problems

Introduction:

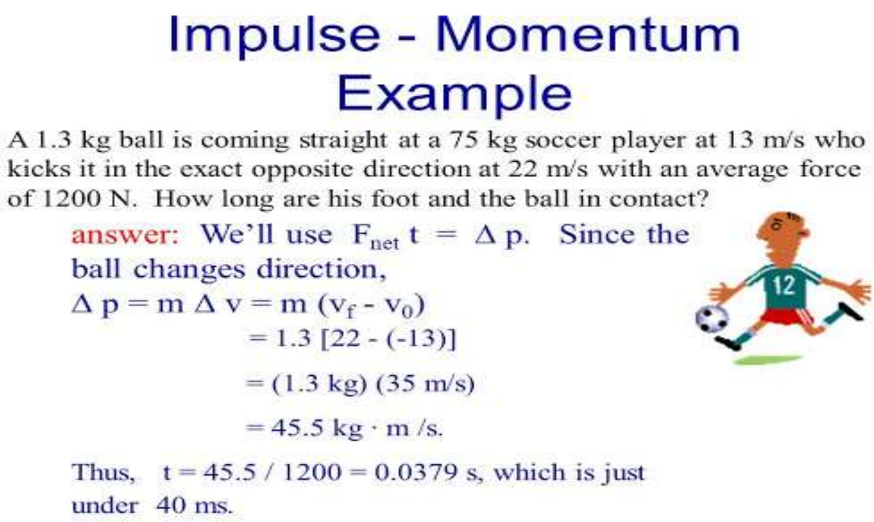
- In classical mechanics, impulse is the integral of a force, F, over the time interval, t, for which it acts. Since force is a vector quantity, impulse is also a vector quantity.
- Impulse applied to an object produces an equivalent vector change in its linear momentum, also in the same direction. The SI unit of impulse is the newton second (N·s), and the dimensionally equivalent unit of momentum is the kilogram meter per second (kg·m/s).
- The corresponding English engineering unit is the pound-second (lbf·s), and in the British Gravitational System, the unit is the slug-foot per second.
- A resultant force causes acceleration and a change in the velocity of the body for as long as it acts. A resultant force applied over a longer time therefore produces a bigger change in linear momentum than the same force applied briefly: the change in momentum is equal to the product of the average force and duration. Conversely, a small force applied for a long time produces the same change in momentum—the same impulse—as a larger force applied briefly.
- Momentum is a commonly used term in sports.

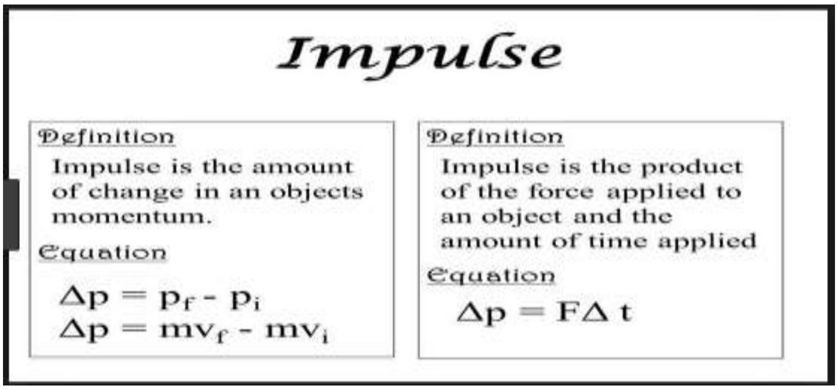
Prerequisite knowledge for Complete understanding and learning of Topic:

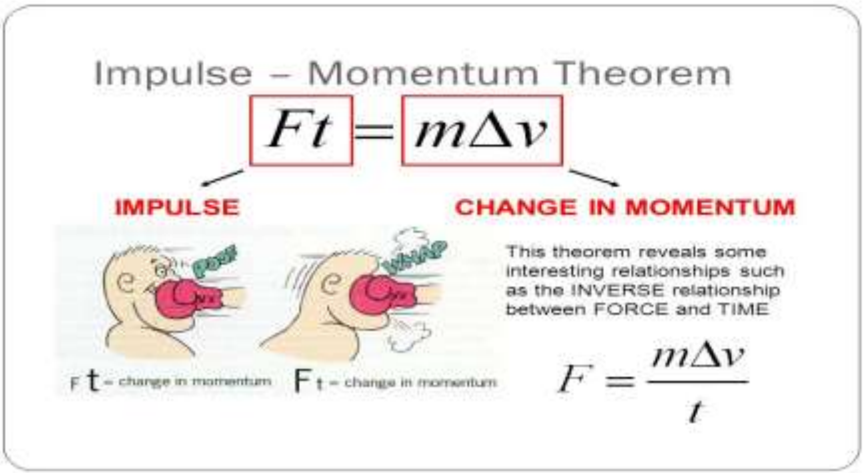
- Impact of Elastic Bodies
- Basics of Physics
- Basic Mechanics Terms

Detailed content of the Lecture:

- When a sports announcer says that a team has the momentum they mean that the team is *really on the move* and is going to be *hard to stop*. The term *momentum* is a physics concept. Any object with momentum is going to be hard to stop. To stop such an object, it is necessary to apply a force *against* its motion for a given period of time.
- The more momentum that an object has, the harder that it is to stop. Thus, it would require a greater amount of force or a longer amount of time or both to bring such an object to a halt. As the force acts upon the object for a given amount of time, the object's velocity is changed; and hence, the object's momentum is changed.
- Force acting for a given amount of time will change an object's momentum. Put another way, an unbalanced force always accelerates an object - either speeding it up or slowing it down. If the force acts opposite the object's motion, it slows the object down.
- If a force acts in the same direction as the object's motion, then the force speeds the object up. Either way, a force will change the velocity of an object. And if the velocity of the object is changed, then the momentum of the object is changed.







Video Content / Details of website for further learning (if any): Nil

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S Khurmi - 745-751

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IQAC

LECTURE HANDOUTS

L-36

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : IV- Dynamics of Particles

Topic of Lecture: Impact of Elastic Bodies

Introduction:

- In a center of momentum frame at any time the velocities of the two bodies are in opposite directions, with magnitudes inversely proportional to the masses.
- In an elastic collision these magnitudes do not change. The directions may change depending on the shapes of the bodies and the point of impact.
- Whenever two elastic bodies collide with each other, they tend to compress each other. Immediately after this, the two bodies attempt to regain its original shape, due to their elasticity. This process, of regaining the original shape, is called restitution.
- During the collision of small objects, kinetic energy is first converted to potential energy associated with a repulsive force between the particles (when the particles move against this force, i.e. the angle between the force and the relative velocity is obtuse), then this potential energy is converted back to kinetic energy (when the particles move with this force, i.e. the angle between the force and the relative velocity is acute).

Prerequisite knowledge for Complete understanding and learning of Topic:

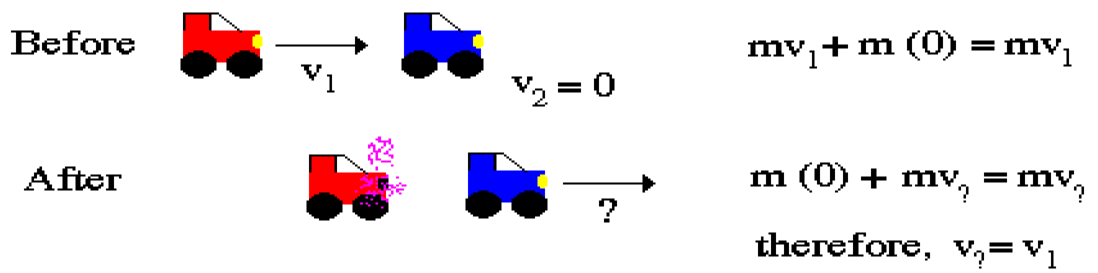
- Energy Principle
- Basics of Physics and Mathematics

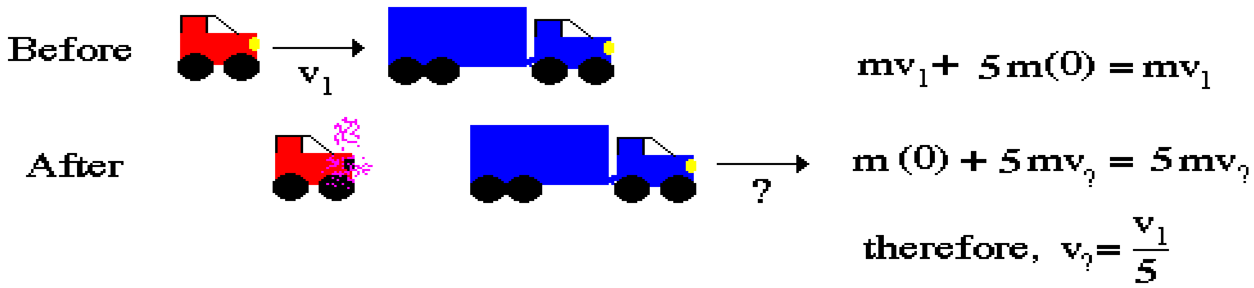
Detailed content of the Lecture:

- A useful special case of elastic collision is when the two bodies have equal mass, in which case they will simply exchange their momenta.
- The *molecules*—as distinct from atoms—of a gas or liquid rarely experience perfectly elastic collisions because kinetic energy is exchanged between the molecules' translational motion and their internal degrees of freedom with each collision. At any instant, half the collisions are, to a varying extent, *inelastic collisions* (the pair possesses less kinetic energy in their translational motions after the collision than before), and half could be described as "super-elastic" (possessing *more* kinetic energy after the collision than before). Averaged across the entire sample, molecular collisions can be regarded as essentially elastic as long as Planck's law forbids black-body photons to carry away energy from the system.
- Impact means the collision of two bodies which occurs in a very small interval of time and during which the two bodies exert very large force on each other. The important types of impacts are:
- Direct impact
- Indirect (oblique) impact.

Direct Impact of Two Bodies:

- The two bodies A and B are moving in a horizontal line before collision with velocities u_1 and u_2 in the same direction i.e., along x-axis as shown in Fig (a).
- If u1 > u2, the body A will strike the body B and collision will take place. Let C is the point of collision of the two bodies as shown in Fig (b). The point C is also known as the point of contact. The line joining the centres of these two bodies and passing through the point of contact is known as line of impact. Hence here the line O1-C-O2 is called line of impact.
- The collision between two bodies is known as direct impact if the two bodies before impact, are moving along the line of impact.





Video Content / Details of website for further learning (if any): nil

- https://www.youtube.com/watch?v=F79oakORGc0

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S Khurmi - 486-491

LECTURE HANDOUTS

L-37

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : V-Friction

Topic of Lecture: Frictional Force

Introduction:

- Friction is a force between two surfaces that are sliding, or trying to slide, across each other. For example, when you try to push a book along the floor, friction makes this difficult.
- Friction always works in the direction opposite to the direction in which the object is moving, or trying to move
- The amount of friction depends on the materials from which the two surfaces are made. The rougher the surface, the more friction is produced. Friction also produces heat. If you rub your hands together quickly, you will feel them get warmer.
- Friction can be a useful force because it prevents our shoes slipping on the pavement when we walk and stops car tyres skidding on the road. When you walk, friction is caused between the tread on shoes and the ground. This friction acts to grip the ground and prevent sliding**.**

Prerequisite knowledge for Complete understanding and learning of Topic:

- Basics of Science
- Basics of Mathematics

Detailed content of the Lecture:

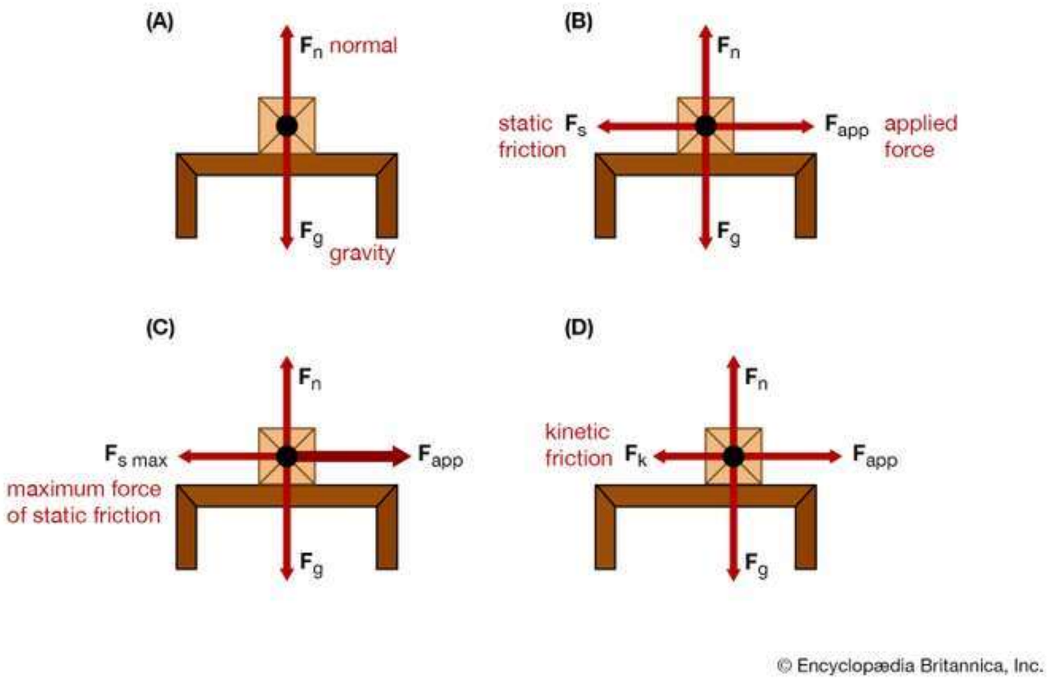
- Friction is the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other.

Types of Friction:

- **Dry friction** is a force that opposes the relative lateral motion of two solid surfaces in contact. Dry friction is subdivided into static friction ("stiction") between non-moving surfaces, and kinetic friction between moving surfaces. With the exception of atomic or molecular friction, dry friction generally arises from the interaction of surface features, known as asperities
- **Fluid friction** describes the friction between layers of a viscous fluid that are moving relative to each other
- **Lubricated friction** is a case of fluid friction where a lubricant fluid separates two solid surfaces.
- **Internal friction** is the force resisting motion between the elements making up a solid material while it undergoes deformation.
- When surfaces in contact move relative to each other, the friction between the two surfaces converts kinetic energy into thermal energy (that is, it converts work to heat).
- This property can have dramatic consequences, as illustrated by the use of friction created by rubbing pieces of wood together to start a fire.
- Kinetic energy is converted to thermal energy whenever motion with friction occurs, for example when a viscous fluid is stirred.

- Another important consequence of many types of friction can be wear, which may lead to performance degradation or damage to components. Friction is a component of the science of tribology.
- Friction is desirable and important in supplying traction to facilitate motion on land. Most land vehicles rely on friction for acceleration, deceleration and changing direction. Sudden reductions in traction can cause loss of control and accidents.
- Friction is not itself a fundamental force. Dry friction arises from a combination of inter-surface adhesion, surface roughness, surface deformation, and surface contamination.
- The complexity of these interactions makes the calculation of friction from first principles impractical and necessitates the use of empirical methods for analysis and the development of theory.
- Friction is a non-conservative force - work done against friction is path dependent. In the presence of friction, some kinetic energy is always transformed to thermal energy, so mechanical energy is not conserved.

Friction forces



Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=LckOqpEkPZQ

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi - 775-781

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LECTURE HANDOUTS

L-38

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : V-Friction

Topic of Lecture: Laws of sliding Friction

Introduction:

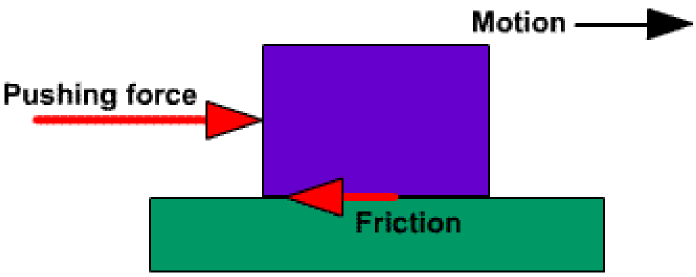
- The elementary property of sliding (kinetic) friction were discovered by experiment in the 15th to 18th centuries and were expressed as three empirical laws
- Amontons' First Law: The force of friction is directly proportional to the applied load.
- Amontons' Second Law: The force of friction is independent of the apparent area of contact.
- Coulomb's Law of Friction: Kinetic friction is independent of the sliding velocity.

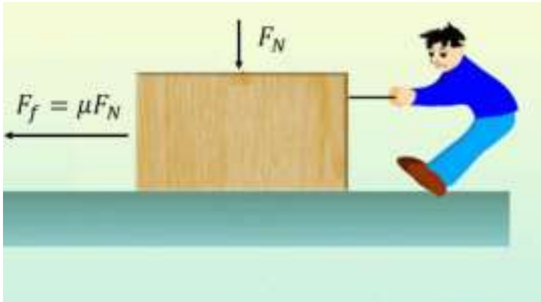
Prerequisite knowledge for Complete understanding and learning of Topic:

- Basics of Friction
- Basics of Science

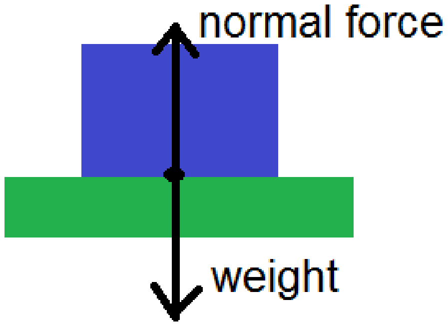
Detailed content of the Lecture:

1. When an object is moving, the friction is proportional and perpendicular to the normal force (N)
2. Friction is independent of the area of contact so long as there is an area of contact.
3. The coefficient of static friction is slightly greater than the coefficient of kinetic friction.
4. Within rather large limits, kinetic friction is independent of velocity.
5. Friction depends upon the nature of the surfaces in contact.





- The normal force is defined as the net force compressing two parallel surfaces together, and its direction is perpendicular to the surfaces. In the simple case of a mass resting on a horizontal surface, the only component of the normal force is the force due to gravity, where N=mg. In this case, the magnitude of the friction force is the product of the mass of the object, the acceleration due to gravity, and the coefficient of friction. However, the coefficient of friction is not a function of mass or volume; it depends only on the material.
- For instance, a large aluminum block has the same coefficient of friction as a small aluminum block. However, the magnitude of the friction force itself depends on the normal force, and hence on the mass of the block.
- If an object is on a level surface and the force tending to cause it to slide is horizontal, the normal force N, between the object and the surface is just its weight, which is equal to its mass multiplied by the acceleration due to earth's gravity, g.
- If the object is on a tilted surface such as an inclined plane, the normal force is less, because less of the force of gravity is perpendicular to the face of the plane. Therefore, the normal force, and ultimately the frictional force, is determined using vector analysis, usually via a free body diagram. Depending on the situation, the calculation of the normal force may include forces other than gravity.



Video Content / Details of website for further learning (if any):

- https://www.youtube.com/watch?v=OsQfoeVHZyE
- https://www.youtube.com/watch?v=8GG_Or5m3hA

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics- R.S Khurmi.pg 784-789

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : V-Friction

Topic of Lecture: Equilibrium Analysis of Simple Systems with Sliding Friction

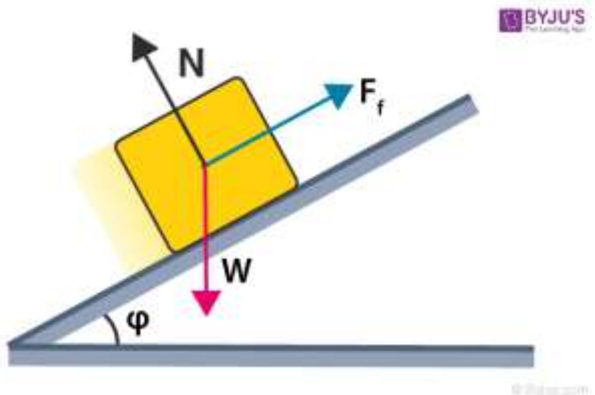
Introduction:

- The term sliding friction refers to the resistance created by two objects sliding against each other. This can also be called kinetic friction. Sliding friction is intended to stop an object from moving
- The amount of sliding friction created by objects is expressed as a coefficient which takes into consideration the various factors that can affect the level of friction. These various factors that can impact sliding friction include the following:
- The surface deformation of objects
- The roughness/smoothness of the surface of the objects
- The original speed of either object
- The size of object
- The amount of pressure on either object

Prerequisite knowledge for Complete understanding and learning of Topic:

- Meaning of Friction
- Understanding of Friction Laws

Detailed content of the Lecture:

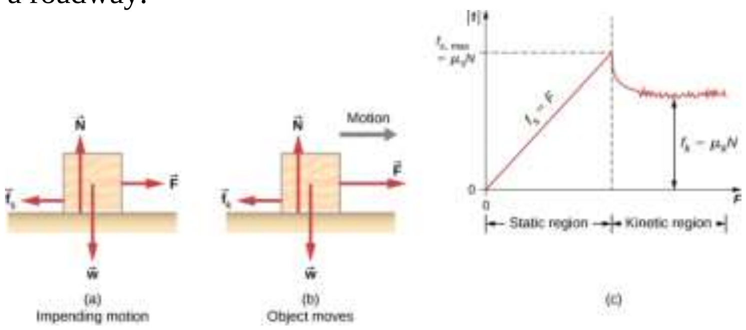


Factors affecting sliding friction

- The surface deformation of objects.
- The roughness or smoothness of the surface of the objects.
- The original speed of either object.
- The size of the object.
- Finally, the amount of pressure on either object.

Examples of Sliding Friction

- Rubbing both the hands together to create heat.
- A child sliding down through a slide in a park.
- A coaster sliding against a table.
- A washing machine pushed along with the floor.
- The frame and the edge of the door sliding against one another.
- A block being slid across the floor.
- Two cards in a deck sliding against each other.
- A couch sliding against the steps when being moved
- A dresser's legs on the carpet when being slid to another part of the room
- The rope and the pulley on a set of blinds or curtains
- The friction between two books when sliding one into place on a bookshelf
- The friction between the bottom of a book and the shelf when being slid into place
- A vegetable drawer sliding against the holder in the fridge
- A check being slid across the counter at the bank
- A paper sliding against the paper holder once emitted from a copy machine
- A paper on the roller as it slides through a fax machine
- The bottom of a chair leg and the floor when a chair is moved out
- The bottom of the coffee pot when slid out from the maker
- The sliding of the brew basket of the coffee maker against the internal parts when it is removed
- The tube on a lotion bottle and the opening to the lotion when it is pushed down to let out lotion
- A rag and the counter it is being used to clean
- Jeans on your legs when putting them on
- A card and an envelope when the card is being slid into the envelope
- Sliding can occur between two objects of arbitrary shape whereas the rolling friction is the frictional force that is associated with the rotational movement.
- The rolling friction is usually less than the one associated with sliding kinetic friction. The values for the coefficient of rolling friction are quite less than that of sliding friction. It usually produces greater sound and thermal bi-products. For example- Movement of braking motor vehicle tires on a roadway.



Video Content / Details of website for further learning (if any):

- https://byjus.com/physics/sliding-friction/

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S.Khurmi- 892-898

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L-40

LECTURE HANDOUTS

MECH & BT

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr.D.Velmurugan

Unit : V-Friction

Topic of Lecture: Problems

Introduction:

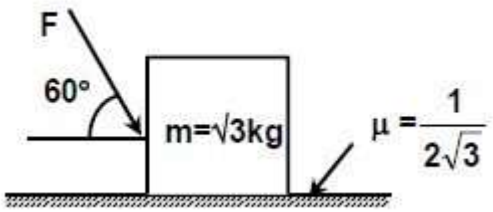
- Friction is a force between two surfaces that are sliding, or trying to slide, across each other. For example, when you try to push a book along the floor, friction makes this difficult.
- Friction always works in the direction opposite to the direction in which the object is moving, or trying to move
- The amount of friction depends on the materials from which the two surfaces are made. The rougher the surface, the more friction is produced. Friction also produces heat. If you rub your hands together quickly, you will feel them get warmer.
- Friction can be a useful force because it prevents our shoes slipping on the pavement when we walk and stops car tyres skidding on the road. When you walk, friction is caused between the tread on shoes and the ground. This friction acts to grip the ground and prevent sliding.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Basics of Science
- Basics of Mathematics

Detailed content of the Lecture:

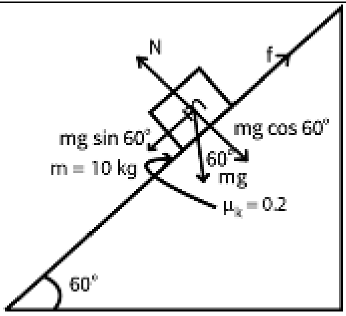
FRICTION ACTING AT ONE FIXED HORIZONTAL SURFACE - EXAMPLE



The maximum value of the force F such that the block shown in the arrangement, does not move is given by:
Block does not move till the horizontal force on it becomes more than the maximum static frictional force.

$F_{max}\cos 3\pi=\mu mgN\mu(mg+F_{max}\sin 3\pi)=231\times(3\times10+23F_{max})\Rightarrow F_{max}=20$ N

FRICTION AT FIXED INCLINED SURFACE - DEFINITION



A plane surface is inclined at an angle of 600. A body of mass 10 kg is placed on it. If the value of coefficient of friction μK, between the body and the inclined surface is 0.2, calculate the downward acceleration of the body, along the inclined plane surface. (Take g=10ms−2) At angles greater than the critical angle of inclination, the block slides down the incline with uniform acceleration a.
The frictional force is μKN.
Here N is the normal reaction.
The net force acting on the body in a direction along the plane is:
Fx=mgsinθ−μKmgcosθ=ma
Hence, the acceleration a of the body is related to θ, μK by the equation:
a=g(sinθ−μkcosθ)
On substituting the respective values:
a=10(23−0.2×21)
a=7.66 ms−2

RETARDATION DUE TO FRICTION - EXAMPLE

A car of mass 1000 kg moving with a velocity of 10ms−1 is acted upon by a forward force of 1000 N due to engine and retarding force of 500 N due to friction. It's velocity after 10 s is:

For a body in equilibrium,
Equating forces along Y-axis,
Normal reaction N=mg
Equating forces along X-axis,
ma+μN=F
ma+μmg=F
ma=F−μmg
a=mF−μmg
a=10001000−500
∴a=0.5m/s2
Now,
v=u+at
∴v=u+a×t
∴v=10+0.5×10
∴v=15 m/s

Video Content / Details of website for further learning (if any): Nil

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics R.S Khurmi - 892-898

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LECTURE HANDOUTS

L-41

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : V

Topic of Lecture: Ladder Friction

Introduction:

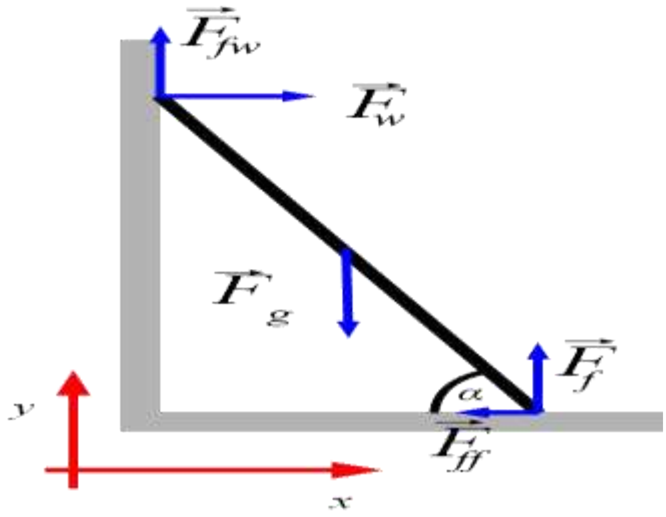
- If a ladder is placed against a rough horizontal floor and a vertical wall (smooth or roughly) then ladder is subjected to non-concurrent force system.
- Ladder can be analyzed by applying conditions for equilibrium of Non-concurrent force system.
- A ladder is an arrangement used for climbing on the walls.
- It essentially consists of two long uprights of wood or iron and connected by a number of cross bars. These cross bars are called rungs and provide steps for climbing.

Prerequisite knowledge for Complete understanding and learning of Topic:

- Friction
- Applications of Friction

Detailed content of the Lecture:

- If a **ladder** is placed against a rough horizontal floor and a vertical wall (smooth or roughly) then **ladder** is subjected to non-concurrent force system. **Ladder** can be analyzed by applying conditions for equilibrium of Non-concurrent force system.
- A ladder is leant against the wall. The coefficient of the static friction μ_{sw} between the ladder and the wall is 0.3 and the coefficient of the static friction μ_{sf} between the ladder and the floor is 0.4. The centre of mass of the ladder is in the middle of it. Find the minimum angle that the ladder can form with the floor not to slip down.



- The affecting forces keep the ladder in balance. It means that the resultant force affecting the ladder has to equal zero as well as the resultant moment of the forces has to equal zero, too (due to a random point).
- There are two types: rigid ladders that are self-supporting or that may be leaned against a vertical surface such as a wall, and rollable ladders, such as those made of rope or aluminium that may be hung from the top. The vertical members of a rigid ladder are called stringers or rails (US) or stiles (UK).
- Rigid ladders are usually portable, but some types are permanently fixed to a structure, building, or equipment. They are commonly made of metal, wood, or fiberglass, but they have been known to be made of tough plastic.
- Ladders are ancient tools and technology. A ladder is featured in a Mesolithic rock painting that is at least 10,000 years old, depicted in the Spider Caves in Valencia, Spain. The painting depicts two humans using a ladder to reach a wild honeybee nest to harvest honey. The ladder is depicted as long and flexible, possibly made out of some sort of grass.

Rigid ladders are available in many forms, such as:

- Accommodation ladder are portable steps down the side of a ship for boarding.
- Assault ladder, used in siege warfare to assist in climbing walls and crossing moats.
- Attic ladder, pulled down from the ceiling to allow access to an attic or loft.
- Bridge ladder, a ladder laid horizontally to act as a passage between two points separated by a drop.
- Boarding ladder, a ladder use to climb onto a vehicle. May be rigid or flexible, also boarding step(s), and swim ladder
- Cat ladder (US chicken ladder), a lightweight ladder frame used on steep roofs to prevent workers from sliding.
- Christmas tree ladder, a type of boarding ladder for divers which has a single central rail and is open at the sides to allow the diver to climb the ladder while wearing swim fins.
- Counterbalanced ladder, a fixed ladder with a lower sliding part. A system of counterweights is used to let the lower sliding part descend gently when released.
- Extension ladder or "telescopic ladder", a fixed ladder divided into two or more lengths for more convenient storage; the lengths can be slid together for storage or slid apart to expand the length of the ladder; a pulley system may be fitted so that the ladder can be easily extended by an operator on the ground then locked in place using the dogs and pawls. 65 ft (20 m), 50 ft (15 m) and some 35 ft (10 m) extension ladders for fire service use "bangor poles", "tormentor poles" or "stay poles" to help raise, pivot, steady, extend, place, retract and lower them due to the heavy weight.

Video Content / Details of website for further learning (if any):

- https://en.wikipedia.org/wiki/Ladder

Important Books/Journals for further learning including the page nos.:

- A Text Book of Engineering Mechanics- R.S.Khurmi - 832-838

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LECTURE HANDOUTS

L-42

MECH

II/III

Course Name with Code : 19GES28 & Engineering Mechanics

Course Faculty : Dr S.Sudhagar

Unit : V-Friction

Topic of Lecture: Ladder Friction Problem

Introduction:

- If a ladder is placed against a rough horizontal floor and a vertical wall (smooth or roughly) then ladder is subjected to non-concurrent force system.
- Ladder can be analyzed by applying conditions for equilibrium of Non-concurrent force system.
- A ladder is an arrangement used for climbing on the walls.
- It essentially consists of two long uprights of wood or iron and connected by a number of cross bars. These cross bars are called rungs and provide steps for climbing

Prerequisite knowledge for Complete understanding and learning of Topic:

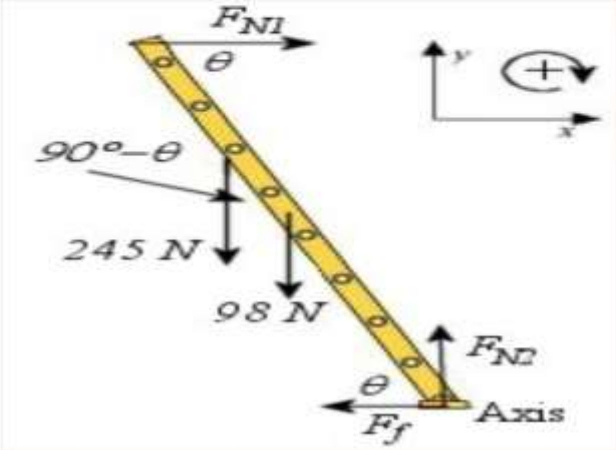
- Ladder Friction
- Free Body Diagram
- Line of Application of Force

Detailed content of the Lecture:

- The uniform ladder is 2-m long. The coefficient of static friction at A is A = 0.6 and at B is B = 0.4. Determine the smallest angle, for which the ladder can remain in the position?

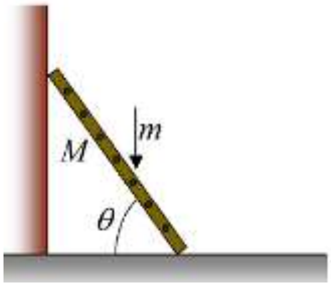
- A ladder rests against a smooth wall. There is no friction between the wall and the ladder, but there is a frictional force between the floor and the ladder. What is the minimum angle q required between the ground and the ladder so that the ladder does not slip and falls to the ground?

The forces on the ladder are:
1) The weight of the ladder (98 N downwards)
2) The tension force of the rope tied to the box (equal to the weight of the box (245 N))
3) The normal force exerted by the wall (towards the right)
4) The normal force exerted by the ground (upwards)
5) The friction force exerted by the ground



The direction of the friction force is not known. It can be towards the right or towards the left. We'll suppose here that this force is towards the left. If a positive value is obtained, this is the correct direction. If a negative value is obtained, then the force is instead directed towards the right point of contact with the ground as the axis of rotation (because this is where there is the largest number of unknown forces exerted).

A uniform ladder of length L is leaning against the side of a building, as shown. A person of mass m = 75 kg is standing on it. The mass of the ladder is M = 10 kg. The coefficient of static friction between the ground and ladder is μs1 = 0.5, and the coefficient of static friction between the wall and ladder is μs2 = 0.3. What is the minimum angle θ so that the ladder doesn't slip?



This is a good static equilibrium problem. It is particularly interesting because almost everyone has stood on a ladder before, but little thought is usually given to the minimum angle to avoid slipping. It is something you just sense intuitively. The minimum angle θ must correspond to the case where the person is standing at the very top of the ladder, since this produces a limiting condition where ladder slip is most likely. Use the following sign convention: The upward and rightward direction is positive. The downward and leftward direction is negative. Counterclockwise rotation is positive. Clockwise rotation is negative. Apply the condition of rotational equilibrium. Take the sum of the moments about the base of the ladder.

This gives us: mgLcosθ+Mg(L/2)cosθ−N2sinθL−F2cosθL = 0, where N2 is the (horizontal) normal force at the wall, F2 is the (vertical) friction force at the wall, and L/2 (in the second term) corresponds to the midpoint of the ladder and is the point at which the gravitational force acts, since the ladder is uniform. Call this equation

(1). Apply the condition of horizontal equilibrium: N2 = F1, where F1 is the (horizontal) friction force at the ground. Call this equation

(2). Apply the condition of vertical equilibrium: -Mg−mg+F2+N1 = 0, where N1 is the (vertical) normal force at the ground. Call this equation (3). The maximum allowable friction force at the wall is: F2 = μs2N2. Call this equation (4). The maximum allowable friction force at the ground is: F1 = μs1N1. Call this equation (5). Combine equations (1)-(5) to obtain an equation for θ. Note that the length of the ladder L cancels out.

We have: $\tan\theta = (2m+M-M\mu_{s1}\mu_{s2})/(2\mu_{s1}m+2\mu_{s1}M)$.

We can then substitute the known values to calculate θ, which is the minimum angle to prevent slipping.

Answer: **θ_{min} = 61.8°**

Video Content / Details of website for further learning (if any): Nil

Important Books/Journals for further learning including the page nos:

- A Text Book of Engineering Mechanics R.S. Khurmi- 832-838