A Textbook of Engineering Mechanics

A textbook for B.Tech./B.E. students of Himachal Pradesh Technical University, (Hamirpur) written strictly according to the new syllabus (BE – 105) effective from 2012–13

Dr. Sadhu Singh

S. CHAND

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Dr. Sadhu Singh
Professor and Head, Mechanical Engineering Department *(Former)*
&
Dean, Faculty of Engineering & Technology, *(Former)*
G.B. Pant University of Agriculture & Technology,
Pantnagar – 263 145 (Uttarakhand)
and
Director (Colleges), (*Former*)
Punjab Technical University, Jalandhar

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Dedicated

to

my

wife

Smt. Manjit Kaur

Preface

Engineering Mechanics is a textbook for B.E. /B.Tech. students of Himachal Pradesh Technical University, Hamirpur. The book has been written according to the new syllabus BE-105 introduced from the session 2012–13. The book cotains nine chapters comprising of Force Systems and Moment; Centroid, Centre of Gravity and Moment of lnertia; Frames and trusses; Simple Stresses in Beams; Torsion of Circular Shafts; and Introduction to Friction. The book contains a large number of solved and unsolved problems. The special features of the book are: Multiple Choice Questions, Short Answer Type Questions and end of chapters Exercises.

The support and cooperation received from the staff of S. Chand and Company Pvt. Ltd., and in particular from Mr. P.J. Singh, Manager, Jalandhar office, and the Management team is highly acknowledged.

My grand children, Kanupreet Kaur and Amitoej Singh have been a source of great inspiration during the preparation of the man script. They kept my mood cheerful, which helped in improving the text. Mrs. Narinderpal Kaur, my daughter – in – law, took proper care during writing of the manuscript and otherwise. I have all appreciations for them.

It is hoped that book in its present form shall be quite useful to the students and teachers. Futher suggestions for the improvement of the book are invited by the publishers and the author.

Dr. Sadhu Singh

ENGINEERING MECHANICS (BE-105)

Course Code	BE – 105	L-3, T-1, P-0	
Name of the Course	Engineering Mechanics		
Lectures to be delivered	52 (1 Hr Each) (L = 39, T = 13, P = 0 for each semester)		
Semester End Examination	Max. Time = 3 hrs.	Mas. Marks: 100	Min. Pass Marks: 40
Continuous Assessment (based on sessional tests (2) 50% Tutorials/Assignments 30%, Quiz/Seminar 10%, Attendance 10%)			Max. Marks: 50

INSTRUCTIONS:

1. **For Paper Setters:** The question paper will consist of five sections A, B, C, D & E. Section E will be compulsory, it will consist of a single question with 10-20 subparts of short answer type, which will cover the entire syllabus and will carry 20% of the total marks of the semester end examination for the course. Section A, B, C and D will have two questions from the respective sections of the syllabus, and each question will carry 20% of the total marks of the semester end examination for the course.
2. **For candidates:** Candidates are required to attempt five questions in all selecting one question from each of the sections A, B, C and D of the question paper and all the subparts of the questions in Section E. Use of non-programmable calculators is allowed.

Section-A

Force, Moment, Center of gravity & Moment of Inertia: Idealization of Mechanics, Concept of Rigid Body and Elastic Body, Laws of Mechanics, Forces & System of Forces, Composition, Resolution & resultant of Forces, Laws of Forces, Lami's Theorem, Moment & Couples, Varignon's Theorem, Free Body Diagram, Centre of Gravity of a Lamina, Centroids of various Geometric Shapes, Moment of Inertia, Radius of Gyration, Parallel and Perpendicular Axis Theorem.

Frames and Trusses: Introduction, Perfect Frame, Redundant Frame, Reactions of Supports, Plane Trusses, Space Trusses, Method of Joints, Method of Section, Graphical Method-Maxwell Diagram.

Section-B

Simple Stresses and Strains: Stress and strain; Types of stresses and strains Elastic limit; Hooks law; Stress - strain diagram for ductile and brittle material, Factor of safety; Poisson's ratio; Elastic constants; Young's modulus, Shear modulus & Bulk modulus. Relationship between elastic constants. Thermal Stress & Strain.

Shear Force and Bending Moment: Concept of beams - statically determinate and indeterminate beams, Concept and definition of shear force and bending moment, Sign conventions, Types of load - concentrated, uniformly distributed, uniformly varying, Types of beams: Cantilever beam, simply supported beam, overhanging beam; Shear force and bending moment diagrams for the above beams subjected to different loadings and couples. Point of contraflexure, Relationship between load, Shear force and bending moment.

Section-C

Bending Stresses in Beams: Bending Stresses in Beams with derivation of bending equation and its application to beams of circular, rectangular I and T Section, Composite beams.

Shearing Stresses in Beams: Shearing stress at a section in a loaded beam, Shear stress distribution over different sections.

Section-D

Torsion of Circular Shaft: Introduction, Theory of Pure torsion - Derivation of torsion equation, assumptions made in theory of pure torsion, Maximum torque transmitted by Solid and hollow shafts, Polar modulus, Torsion rigidity, Power transmitted by a shaft, Comparison of hollow and solid shaft subjected to pure torsion,Close-coiled helical spring subjected to axial load and torque.

Introduction to Friction: Definition, Principles of friction, Friction between solid bodies, Coefficient of friction, Kinetic friction force, Definition and Determination of angle of friction, Laws of friction. Procedure for friction analysis, Equilibrium of rigid bodies subjected to frictional force of resistance, Friction at the ends of ladder, Wedge friction, Remedial measures in overcoming friction.

CONTENTS

1 CHAPTER

FORCE SYSTEMS AND MOMENT

1.1 IDEALIZATION OF MECHANICS

Engineering mechanics is the science which deals will the physical state of rest or motion of bodies under the action of forces. Depending upon the nature of the body involved, it can be further divided into mechanics of rigid bodies, mechanics of deformable or elastic bodies, and mechanics of fluids.

Matter is made up of atoms and molecules. The real picture of matter as atoms and molecules is very complex to deal with in this text. Therefore, to study the average measurable behaviour of bodies, it is assumed that the matter is continuously distributed. Such a description of matter is called a continuum. A continuum can be rigid or deformable (or elastic) depending upon the assumptions made. In the study of engineering mechanics, the continuum is assumed to be rigid or non- deformable.

1.2 BASIC CONCEPTS

Mechanics: The science which deals with the physical state of rest or of motion of rigid bodies under the action of external forces is called mechanics.

Engineering Mechanics: The science which deals with the physical state of rest or of motion of rigid under the action of external forces when applied to engineering problems is termed Engineering Mechanics or Applied Mechanics.

Statics: It is a science which deals with the action of forces on rigid bodies such that the forces are in equilibrium and the body is at rest.

Dynamics: It is science which deals with the action of forces on rigid bodies such that the body is in motion.

Matter: It is anything that occupies space and has physical existence. It possesses mass and offers resistance to external forces.

Particle: It is defined as an object whose mass is concentrated at point. It is infinitely small in size and mass is irrelevant to its motion.

Body: A body is a portion of matter which occupies finite space and consists of number of particles. It has definite mass.

Rigid Body: A rigid body is that which does not change its shape or size when subjected to external forces. In real situations, all bodies deform under the action of external forces, however small it may be. But if the deformation is so small that if can be neglected for all practical purposes, then it is considered as a rigid body.

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Deformable Body: A deformable body changes its shape or size under the action of external forces. Such bodies are also called elastic bodies. They regain their original shape after the external forces are removed.

Space: It is a region which extends in all directions in the universe and contains everything in it, e.g. stars and planets. The position of a point in space is defined by some frame of reference and co-ordinate system. In order to define the state of rest or of motion of a body, some datum or reference is required. A body can be considered to be at rest or in motion only with respect to some reference frame. This reference should be fixed in space preferably. As it is doubtful to locate any fixed references in the universe, so the earth's surface is usually employed as a reference frame. For example, a person sitting in a moving train is at rest with reference to the train but in motion with reference to the earth.

Time: It is a measure of succession of events. Concept of time is essential to relate the sequence of events, e.g. starting and stopping of the motion of a body. The unit of time is second (s) which is a fraction of the period by the earth's rotation, *i.e.* $\frac{1}{86400}$ of an average solar day.

Mass: It is the quantity of matter contained in a body. Its concept is essential to distinguish between the behavior of two bodies under the action of an identical force. The unit of mass is kg.

Force: It may be defined as a pull or push, which acting on body changes or tends to change, the state of rest or of uniform motion of body. The unit of fore is newton (N). One newton is the force which produces an acceleration of 1 m/s^2 in a mass of 1 kg.

Weight: It is the force by which earth attracts a body towards its centre of gravity. If m is the mass of a body and g the acceleration due to gravity, then weight, $W = m \times g$ N.

1.3 LAWS OF MECHANICS

There are six fundamental laws of mechanics as listed below:

1. Newton's three laws of motion.
2. Newton's law of gravitation.
3. Principle of transmissibility of force.
4. Parallelogram law of forces.

1. Newton's laws of motion

(*i*) *Newton's first law:* It states that everybody continues in its state of rest or of uniform motion in a straight line unless it is compelled to change that state by an external force impressed on it. This law helps us to define a force as the external ageney which changes or tends to change the state of rest or of uniform linear motion of the body.

Inertia is the tendency of a body to continue in its state of rest or of motion. Therefore, first law of motion may be considered as the law of inertia.

(ii) *Newton's second law*: It states that the time rate of change of momentum of a body is directly proportional to the impressed force and takes place in the direction of the straight line in which the force is acting on it. Thus

Force, $F \propto$ of change of momentum

$$\text{Now momentum} = \text{mass} \times \text{velocity} = m \times v$$

$$F \propto \frac{d}{dt}(mv)$$

$$\propto m\frac{dv}{dt} \text{ if } m \text{ is constant.}$$

$$\propto \text{mass} \times \text{acceleration}$$

$$\propto ma = kma$$

where k = constant of proportionality.

If F = 1N, m = 1 kg. and a = 1 m/s^2, then k = 1

$\therefore$ $F = ma$

This law helps us to measure force quantitatively.

(iii) *Newton's third law*: It states that to every action there is an equal and opposite reaction. It means that the forces of action and reaction between two bodies are equal in magnitude and opposite in direction.

2. **Newton's law of gravitation:** It states that the force of attraction between two bodies is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. Let m_1 and m_2 be the masses of two bodies and r the distance between them, then as shown in Fig. 1.1.

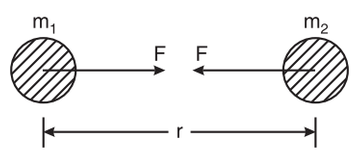

Fig. 1.1

Force of attraction, $F \propto \frac{m_1 \times m_2}{r^2} = G\frac{m_1\, m_2}{r^2}$

where G = constant of proportionality and is called the universal constant of gravitation.

Consider a body of mass m lying on the surface of the Earth of mass M and radius R. Then

$$F = G\frac{mM}{R^2}$$

$$= \text{weight of the body, } W = mg$$

$$g = \frac{GM}{R^2}$$

where g = acceleration due to gravity = 9.80665 m/s^2.

3. **Parallelogram law of forces:** This law states that if two forces acting at a point are represented in magnitude and direction by the two adjacent sides of a parallelogram then their resultant is represented in magnitude and direction by the diagonal of the parallelogram. The diagonal passes through the point of intersection of the two sides representing the forces. If P and Q are the two forces acting at a point O and represented by the sides OA and OB of a parallelogram respectively, as shown in Fig. 1.2, then their resultant R is represented by the diagonal OC.

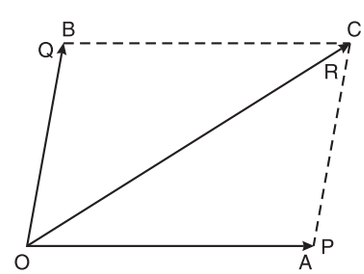

Fig. 1.2

4. **Principle of transmissibility of force:** This principle states that the state of rest or of motion of a rigid body remains unaltered if the point of application of the force acting on the rigid body is transmitted to act at any other point along the line of action of force.

   Let F be the force acting on a rigid body acting along line ab at point A, as shown in Fig. 1.3 (a). According to the principle of transmissibility of force, the force F may be deemed to act at point B on straight line ab, as shown in Fig. 1.3 (b). This will not change the effect of force F on the rigid body.

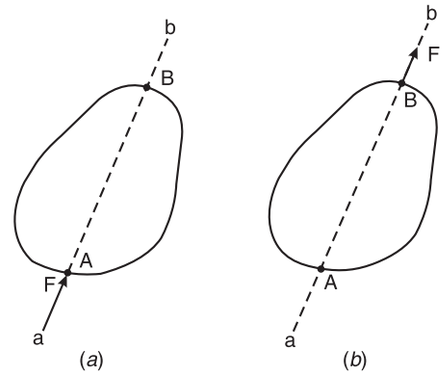

Fig. 1.3

1.4 FORCE AND ITS CHARACTERISTICS

A force may be defined as an agency which changes or tends to change the state of rest or of uniform motion of a body. The force may be either of the push type (Fig 1.4 a) or pull type (Fig. 1.4 b). The force can also produce twist in a body as shown in Fig. 1.4 (c).

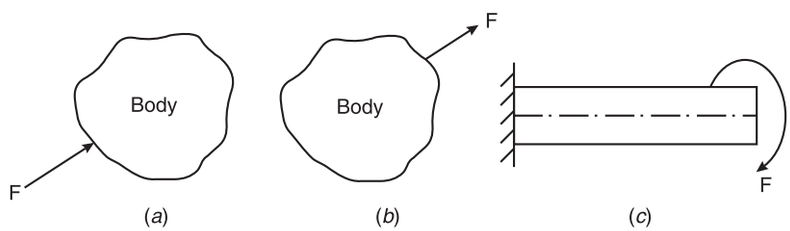

Fig. 1.4 Push and pull type forces

A force is a vector quantity and can be completely defined by the following characteristics (Fig. 1.5.)

1. Magnitude
2. Point of application
3. Line of action and
4. Direction.

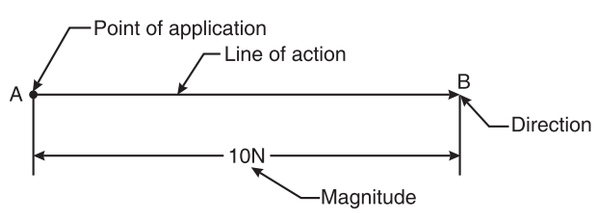

Fig. 1.5 Characteristics of a force.

The force is completely represented as shown in Fig. 1.5. A force of 10 N is represented as follows:

Magnitude = 10N, Point of application = A

Line of action = AB, Direction: A to B, represented by the arrow head.

1.5 SYSTEM OF FORCES

When many forces of different magnitude and direction act upon a body, they form a system of forces. The system of forces are of the following types:

1. Coplanar forces
   - (*i*) Parallel forces
     - (*a*) Like parallel forces (*b*) Unlike parallel forces
   - (*ii*) Concurrent forces
   - (*iii*) Non-coplanar forces
2. Non-coplanar forces
   - (*i*) Parallel forces (*ii*) Concurrent forces (*iii*) Non-concurrent forces
3. Collinear forces

1. Coplanar Forces: If all the forces in a system lie in the same plane, they are called coplanar forces. Some example of coplanar forces are:

(*i*) A system of vertical forces acting on a simply supported beam along with support reactions, as shown in Fig. 1.6.

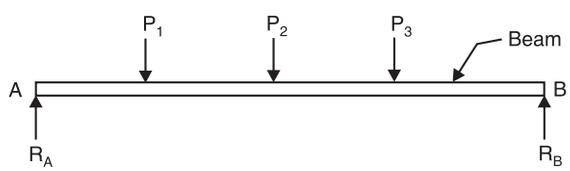

Fig. 1.6

(*ii*) The forces acting on rope-pulley system, as shown in Fig. 1.7.

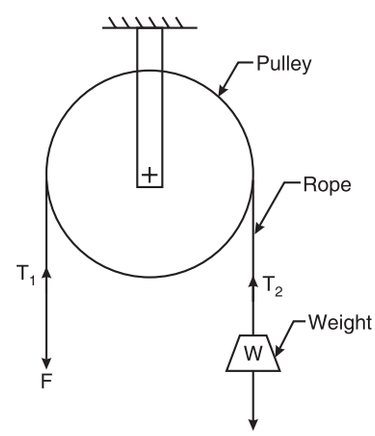

Fig. 1.7

Coplanar Parallel Forces: A system of coplanar forces which are parallel to each other are called coplanar parallel forces. For example, the forces shown acting on the beam AB in Fig. 1.6 are coplanar parallel forces as they all lie in the same vertical plane.

Coplanar Like Parallel Forces: A system of coplanar parallel forces acting in the same direction are called coplanar line parallel forces. For example, the forces P_1, P_2 and P_3 acting on the beam in Fig. 1.6 are coplanar like parallel forces. Similarly the tension $T_1 = T_2$ acting in the rope in Fig. 1.7 are coplanar like forces.

Coplanar Unlike Parallel Forces: A system of coplanar parallel forces having opposite directions are called coplanar unlike parallel forces. For example, the forces acting on an electric pole due to tension in the wires are unlike coplanar parallel forces, as shown in Fig. 18 (*a*). The forces acting on the body shown in Fig. 1.8 (*b*) is another example of such forces.

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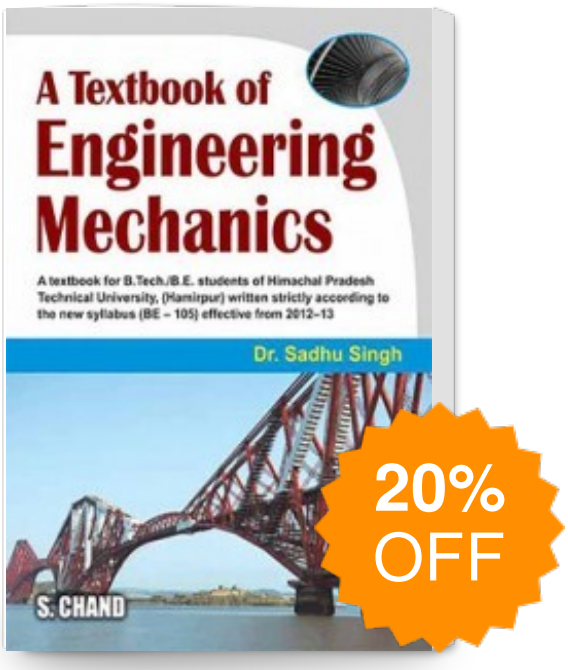

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