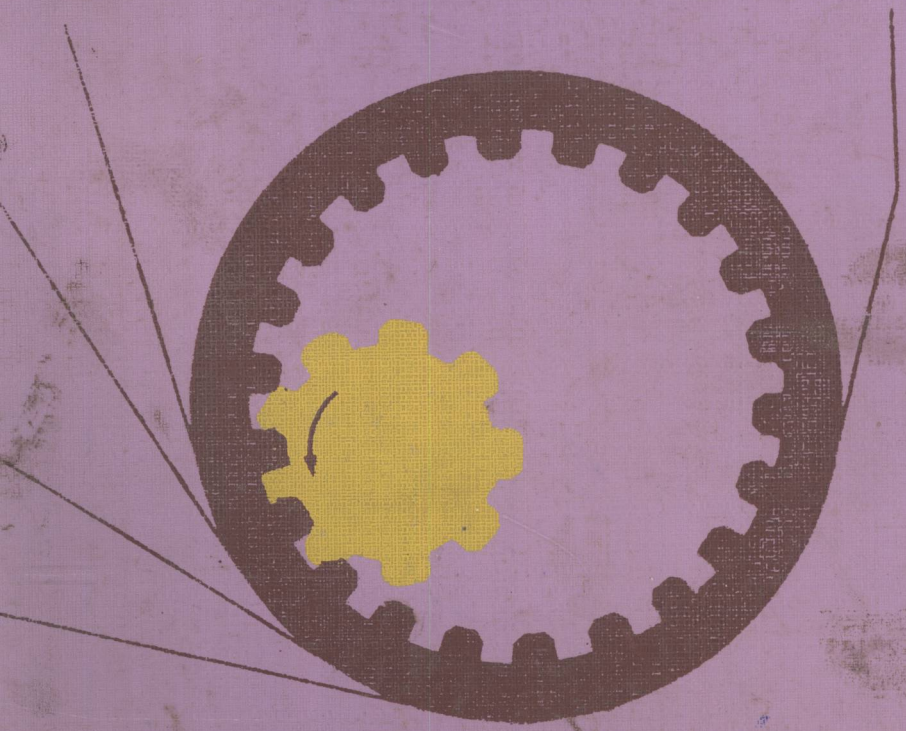
A TEXT BOOK OF

APPLIED MECHANICS

MKS and SI units



R. S. KHURMI

MECHANICS

[For the students of U.P.S.C. (Engg. Services); B.Sc. Engg. ; and Diploma courses.]

By

R. S. KHURMI

With a Foreword

by

Dr. S. P. LUTHRA

B.Sc. Engg. (Elect.), Ph.D. Engg. (Mech.), London
D.I.C. (Civil Engg.) London,
D.I.C. (Chem. Engg.) London, F.I.E. (India)
Formerly Director, Indian Institute of Technology, Hauz Khas, New Delhi-110029.

1977

S. CHAND & COMPANY LTD
RAM NAGAR, NEW DELHI-110055

S. CHAND & COMPANY LTD

Regd. Office. : Ram Nagar, New Delhi-110055

Show Room : 4/16-B, Asaf Ali Road New Delhi-110002

Branches :

Mai Hiran Gate, Jullundur-144008
Aminabad Park, Lucknow-226001
Blackie House,
103/5, Walchand Hirachand Marg,
Opp. G.P.O., Bombay-400001
35, Mount Road, Madras-600002
Khazanchi Road, Patna-800004
285/J, Bipin Behari Ganguly Street,
Calcutta-700012
Sultan Bazar, Hyderabad-500001
Gandhi Sagar East,
Nagpur-440002
KPCC Building, Race Course Road,
Bangalore-560009.

This book has been subsidised by the Government of India, through the National Book Trust, India for the benefit of students.

"Paper used for the printing of this book was made available by the Government of India at concessional rates."

First Published 1967

Subsequent Editions and Reprints 1969, 1970, 1971, 1972, 1973, 1974, 1975, 1976 (twice)

Eighth Edition 1977

Price : **Rs. 13.00**

Published by S. Chand & Company Ltd., Ram Nagar, New Delhi-110055 and printed at Rajendra Ravindra Printers (P.) Ltd., Ram Nagar, New Delhi-110055

A TEXT BOOK OF APPLIED MECHANICS

(MKS and SI Units)

A TEXT BOOK OF
APPLIED

(MKS and SI Units)

By the same author...

- A Text Book of Hydraulics
- A Text Book of Fluid Mechanics
- A Text Book of Hydraulic Machines
- Strength of Materials
- Theory of Structures
- Theory of Machines

To

My Revered Guru and Guide

Shree B.L. THERAJA

A well-known author, among Engineering students, both at home and abroad, to whom I am ever indebted for inspiration and guidance.

Foreword

In the text book on 'APPLIED MECHANICS' by Shri R.S. Khurmi, the author has dealt with the subject with great insight. The problems have been properly selected and well-graded. The book is a useful aid to technical students of Engineering Colleges, Polytechnics and professional examinations conducted by the Institution of Engineers (India), Institution of Telecommunication Engineers (India) and Aeronautical Society of India.

I have no doubt, that his venture will be success and will also encourage him further.

Feb. 23, 1967 *S.P. LUTHRA*

Acknowledgements

The author is thankful to the following Indian as well as foreign universities and examining bodies, whose examination papers have been included in the text of the subject by way of illustration. Moreover, their syllabi have also been kept in view while writing this treatise.

1. Agra University
2. Aligarh University
3. Allahabad University
4. Andhra University
5. Annamalai University
6. Banaras Hindu University
7. Bangalore University
8. Baroda University
9. Bhopal University
10. Bihar University
11. Bombay University
12. Calcutta University
13. Delhi University
14. Gauhati University
15. Gorakhpur University
16. Gujarat University
17. Indore University
18. Jabalpur Uuiversity
19. Jadavpur University
20. Jiwaji University
21. Jodhpur University
22. Kanpur University
23. Karnatak University
24. Kerala University
25. Madras University
26. Madurai University
27. Mysore University
28. Nagpur University
29. Osmania University
30. Patna University
31. Poona University
32. Panjab University
33. Punjabi University
34. Rajasthan University
35. Ranchi University
36. Roorkee University
37. Saurashtra University
38. Cambridge University
39. London University
40. Oxford University
41. Union Public Service Commission (Engg. Services).

Preface to the Eighth Edition

I feel very much elevated in presenting the eighth edition of this standard treatise. The favourable and warm reception, which the previous editions of this book have enjoyed all over India and abroad has been a matter of great satisfaction for me.

The eighth edition of this treatise has been rewritten in MKS and SI units. New chapters on Virtual Work, Kinetics of Motion of Rotation, Balancing of Rotating Bodies have been added. Lot of useful changes have been incorporated to widen the scope of this book and make it more useful. It is earnestly hoped that the book will continue to cater the long felt need of the teachers and students of all the Indian and foreign universities.

I wish to express my sincere thanks to the numerous professors and students for their valuable suggestions and recommending the book to their students and friends. I hope, that they will continue to patronise this standard treatise in the future also.

Any errors, omissions and suggestions for the improvement of this volume, brought to my notice, will be thankfully acknowledged and incorporated in the next edition.

R. S. KHURMI

Preface to the First Edition

I take an opportunity to present this standard treatise entitled as *A Text Book of Applied Mechanics* to the students of Degree, Diploma and A.M.I. E. (I) classes. The object of this book is to present the subject matter in a most concise, compact, to-the-point and lucid manner.

While writing this book, I have constantly kept in mind the requirements of all the students regarding the latest as well as the the changing trend of their examination. To make it more useful, at all levels, the book has been written in an easy style. All along the approach to the subject matter, every care has been taken to

arrange matter from simpler to harder, known to unknown with full details and illustrations. A large number of worked examples, mostly examination questions of Indian as well as foreign universities and professional examining bodies, have been given and graded in a systematic manner and logical sequence, to assist the students to understand the text of the subject. At the end of each chapter *Highlights* have been added, which summarise the main topics discussed in the chapter. Various definitions, laws and equations have been clearly restated for quick revision before the examination. At the end of each chapter, a few excercises have been added, for the students, to solve them independently. Answers to these problems have been provided, but it is too much to hope that these are entirely free from errors. In short, it is expected that the book will embrace the requirements of the students for which it has been designed.

I wish to express my deep gratitude to Dr. S.P. Luthra, a most learned and famous person for writing a foreword to this volume. I am also thankful to my publishers for excellent printing and nice get up, and at the same time making it available to the students at a moderate price, inspite of heavy cost of production.

Although every care has been taken to check mistakes and misprints, yet it is difficult to claim perfection. Any errors, omissions and suggestions, for the improvement of this volume, brought to my notice will be thankfully acknowledged, and incorporated in the next edition.

Feb. 24, 1967 *R.S. KHURMI*

Contents

1

Introduction

1. Definition. 2. Sub-divisions of Applied Mechanics. 3. Statics. 4. Dynamics. 5. Kinetics. 6. Kinematics. 7. Fundamental Units. 8. Derived Units. 9. System of Units. 10. C.G.S. Units. 11. F.P.S. Units. 12. M.K.S. Units. 13. S.I. Units. 14. Metre. 15. Kilogram. 16. Second. 17. Presentation of Units and their Values. 18. Useful Data. 19. Algebra. 20. Trigonometry. 21. Differential Calculus. 22. Integral Calculus. 23. Scalars and Vectors. 24. Binomial Theorem.

1·1. Definition

The present day engineers are vitally engaged in the planning, designing and construction of various types of structures and machines. In order to take up this job skilfully, an engineer must understand thoroughly the principles of Mechanics along with their application to engineering problems. A systematic study of different laws and principles of Mechanics alongwith their applications to engineering problems is known as Applied Mechanics*.

The knowledge of Applied Mechanics, coupled with the knowledge of other specialised subjects *e.g.* Strength of Materials, Theory of Structures, Theory of Machines, Machine Design etc. is very essential for an engineer to enable him in designing his all types of structures and machines.

1·2. Sub-divisions of Applied Mechanics

The subject of Applied Mechanics may be sub-divided into the following two main groups :

(*i*) Statics, and (*ii*) Dynamics.

*The word 'mechanics' was coined by Sir Issac Newton, the famous scientist. He used this word for the science which deals with the machines and the art of making them.

1·3. Statics

It is that branch of Applied Mechanics, which deals with the forces and their effects, while acting upon the bodies at rest.

1·4. Dynamics

It is that branch of Applied Mechanics, which deals with the forces and their effects, while acting upon the bodies in motion. Dynamics may be further sub-divided into the following two branches:

(*i*) Kinetics, and (*ii*) Kinematics.

1·5. Kinetics

It is that branch of dynamics, which deals with the bodies in motion due to the application of forces.

1·6. 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.

1·7. Fundamental Units

The measurement of physical quantities is one of the most important operations in engineering. Every quantity is measured in terms of some arbitrary, but internationally accepted units, called *fundamental units*. All the physical quantities, met with in Applied Mechanics, are expressed in terms of three fundamental quantities, *i.e.*

(*i*) length, (*ii*) mass, and (*iii*) time.

1·8. Derived Units

Sometimes, the units are also expressed in other units (which are derived from fundamental units) known as *derived units e.g.* units of area, velocity, acceleration, pressure etc.

1·9. System of Units

There are only three systems of units, which are commonly used and universally recognised. These are known as :

(*i*) C.G.S. units, (*ii*) F.P.S. units, and (*iii*) M.K.S. units.

1·10. C.G.S. Units

In this system, the fundamental units of length, mass and time are centimetre, gram and second respectively.

1·11. F.P.S. Units

In this system, the fundamental units of length, mass and time are foot, pound and second respectively.

1·12. M.K.S. Units

Strictly speaking, the fundamental units of this system are not separate ones, but are the multiples of C.G.S. units. The units of

length, mass and time, in this system are metre, kilogram and second respectively.

1·13. S.I. Units (International System of Units)

The eleventh General Conference* of Weights and Measures has recommended a unified and systematically constituted system of fundamental and derived units for international use. This system of units is now being used in about 20 countries. In India, the Standards of weights and measures act of 1956 (vide which we switched over to M.K.S. units) has been revised to recognise all the S.I. units in industry and commerce.

In this system of units, the **fundamental units are metre (m), kilogram (kg) and second (s) respectively. But there is a slight variation in their derived units. The following derived units will be used in this book.

Density (Mass density)	kg/in^3
Force	N (Newton)
Pressure	N/mm^2 or N/m^2
Work done (in joules)	J=Nm
Power in watts	W=J/s

International metre kilogram and second are discussed here.

1·14. Metre

The international metre may be defined as the shortest distance (at 0°C) between two parallel lines engraved upon the polished surface of a Platinum-Iridium bar, kept at the International Bureau of Weights and Measures at Sevres, near Paris.

1·15. Kilogram

The international kilogram may be defined as the mass of the Platinum-Iridium cylinder, which is also kept at the International Bureau of Weights and Measures at Sevres, near Paris.

1·16. Second

The fundamental unit of time for all the three systems is second, which is $\frac{1}{24\times60\times60}=\frac{1}{86,400}$ th of the mean solar day. A solar day may be defined as the interval of time between the instants at which the sun crosses the meridian on two consecutive days. This value varies throughout the year. The average of all the solar days, of one year, is called the mean solar day.

---

*It is known as General Conference of Weights and Measures (C.G.P.M.). It is an international organisation of which most of the advanced and developing countries (including India) are members. The conference has been entrusted the task of prescribing definitions of various units of weights and measures, which are the very basis of science and technology today.

**The other fundamental units are electric current, ampere (*A*), thermodynamic temperature, degree Kelvin (°*K*) and luminous intensity, candela (*cd*), These three units will not be used in this book.

1·17 Presentation of Units and their Values

The frequent changes in the present day life are facilitated by an international body known as International Standard Organisation (ISO). The main function of this body is to make recommendations regarding international procedures. The implementation of ISO recommendations in a country is assisted by its organisation appointed for the purpose. In India, Indian Standards Institution (ISI) has been created for this purpose.

We have already discussed in the previous articles the units of length, mass and time. It is always necessary to express all lengths in metres, all masses in kilograms and all times in seconds. According to convenience, we also use larger multiples or smaller fractions. As a typical example, although the metre is the unit of length yet a smaller length of one-thousandth of a metre proves to be more convenient unit especially in the dimensioning of drawings. Such convenient units are formed by using a prefix in front of the basic units to indicate the multiplier. The full list of these prefixes is given below :

Factor by which the unit is multiplied	*Standard form*	*Prefix*	*Abbreviation*
1 000 000 000 000	10^{12}	tera	T
1 000 000 000	10^{9}	giga	G
1 000 000	10^{6}	mega	M
1 000	10^{3}	kilo	k
100	10^{2}	hecto*	h
10	10^{1}	deca*	da
0·1	10^{-1}	deci*	d
0·01	10^{-2}	centi*	c
0·001	10^{-3}	milli	m
0·000 001	10^{-6}	micro	μ
0·000 000 001	10^{-9}	nano	n
0·000 000 000 001	10^{-12}	pico	p

At the time of writing this book, the author sought the advice of various international authorities regarding the use of units and

*These prefixes are generally becoming obsolete probably due to possible confusion. Moreover, it is becoming a conventional practice to use only those powers of ten which confirm to 10^{3n} where n is a positive or negative whole number.

their values, it was then decided to present* the units and their values as per the recommendations of ISO and ISI. Some of these values are given below :

4 500	not	4500	or	4,500
75 890 000	not	7589000	or	7,58,90,000
0· 012 55	not	0·01255	or	·01255
30×10^6	not	3,00,00,000	or	3×10^7

The above mentioned figures are meant for numerical values only. Now we shall discuss about the units. We know that the fundamental units in M.K.S. and S.I. units for length, mass and time are metre, kilogram and second respectively. While expressing these quantities, we find it time-consuming to write these units such as metres, kilograms and seconds, in full, every time we use them. As a result of this, we find it quite convenient to use the following standard abbreviations which are internationally recognised. We shall use :

m	for metre or metres
km	for kilometre or kilometres
kg	for kilogram or kilograms
t	for tonne or tonnes
rad	for radian or radians
rev	for revolution or revolutions
kg m	for kilograms × metres (*i.e.*, work done)
t m	for tonnes × metres

1·18. Useful Data

The following summarises the previous memory and formulae, the knowledge of which is very essential at this stage.

1·19. Algebra

1. $a^0=1,\ x^0=1$

   (*i.e. Anything raised to the power zero is one.*)

2. $x^m \times x^n = x^{m+n}$

   (*i.e. If the bases are same, in multiplication the powers are added.*)

3. $\dfrac{x^m}{x^n} = x^{m-n}$

   (*i.e. If the bases are same, in division the powers are subtracted.*)

4. If $ax^2+bx+c=0$

   then $$x=\frac{-b+\sqrt{b^2-4ac}}{2a}$$

   where a is the coefficient of x^2,
   b is the coefficient of x, and
   c is the constant term.

*In some question papers, standard values are not used. The auther has tried to avoid such questions in the text of the book, in order to avoid possible confusion. But at certain places such questions have been included keeping in view the importance of question from the reader's angle.

1·20. Trigonometry

In a right angled triangle *ABC*,

1. $\frac{b}{c} = \sin\theta$

2. $\frac{a}{c} = \cos\theta$

3. $\frac{b}{a} = \frac{\sin\theta}{\cos\theta} = \tan\theta$

4. $\frac{c}{b} = \frac{1}{\sin\theta} = \text{cosec}\,\theta$

5. $\frac{c}{a} = \frac{1}{\cos\theta} = \sec\theta$

6. $\frac{a}{b} = \frac{\cos\theta}{\sin\theta} = \frac{1}{\tan\theta} = \cot\theta$

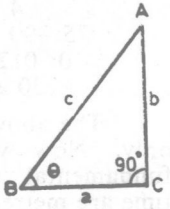


Fig. 1·1.

7. The following table shows the values of trigonometrical functions for some typical angles :

angle	0°	30°	45°	60°	90°
sin	0	$\frac{1}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{\sqrt{3}}{2}$	1
cos	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0
tan	0	$\frac{1}{\sqrt{3}}$	1	$\sqrt{3}$	∞

or in other words, for sin write :

0°	30°	45°	60°	90°
$\frac{\sqrt{0}}{2}$	$\frac{\sqrt{1}}{2}$	$\frac{\sqrt{2}}{2}$	$\frac{\sqrt{3}}{2}$	$\frac{\sqrt{4}}{2}$
0	$\frac{1}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{\sqrt{3}}{2}$	1

for cos write the values in reverse order ; for tan divide the value of sin by cos for the respective angle.

8. In the first quadrant (*i.e.* 0° to 90°) all the trigonometrical ratios are positive.