CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information

# Fundamentals of Machine Design
# Volume I

Machine design is a part of Engineering Design. *Fundamentals of Machine Design* is compiled in two volumes. Vol. I provides extensive coverage and comprehensive discussion on the fundamental concepts and processes of machine design. Unit 1 of this volume starts by giving a background to the subject and then discusses the types of materials, their properties and their selection criteria for designing. Unit 2 covers different types of stresses including direct stress, bending stress, torsional stress and combined stress in detail. Unit 3 covers different types of temporary and permanent joints including pin joint, cotter joint, threaded joint, riveted joint and welded joint. The final unit covers the design procedure for keys, cotters, couplings, shafts, levers and springs in detail. It discusses applications of different types of joints used in boilers, bridges, power presses, automobile springs, screw jacks and couplings.

The chapters in the book are rich in pedagogical features like outcomes in beginning of a chapter summary at its end, many solved examples, review questions, multiple choice questions, design problems and questions of previous competition examinations are also provided. This textbook is primarily meant for undergraduate students of mechanical engineering for an introductory course on machine design. Design engineers will also find it useful. It is accompanied with teaching resources including a solutions manual for instructors.

**Ajeet Singh** was Professor and retired as Head at the Department of Mechanical Engineering, from Motilal Nehru National Institute of Technology (MNNIT), Allahabad. In addition to teaching, he worked in many administrative positions like Dean Academic, Dean Research and Consultancy etc. He has about three decades of teaching experience at undergraduate, graduate and doctoral level in India and 15 years abroad. He taught courses in machine drawing, machine design, internal combustion engines, tribology, computer aided design and engineering processes. He has been consultant to industries like BHEL, TEW etc. Besides publishing several papers in national and international journals, he has published three textbooks: *Working with AutoCAD 2000 with updates to AutoCAD 2000i* (2002), *Machine Drawing: Includes AutoCAD 2005* (2005) and *Machine Drawing; Includes AutoCAD 2010* (2012).

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information

# Fundamentals of Machine Design
## Volume I

Ajeet Singh

CAMBRIDGE
UNIVERSITY PRESS

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom
One Liberty Plaza, 20th Floor, New York, NY 10006, USA
477 Williamstown Road, Port Melbourne, vic 3207, Australia
4843/24, 2nd Floor, Ansari Road, Daryaganj, Delhi – 110002, India
79 Anson Road, #06–04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781316630402

© Cambridge University Press 2017

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

First published 2017

Printed in India

*A catalogue record for this publication is available from the British Library*

ISBN 978-1-316-63040-2 Paperback

Additional resources for this publication at www.cambridge.org/9781316630402

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party internet websites referred to in this publication, and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information

*Dedicated to my wife Mrs Kanwaljeet*

*Daughters Preety, Dileet and Maneet*

*and our grand children*

*Gaganjit, Karanjit, Ananya, Neha, Tanvi and Simar*

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information

# Contents

*Preface* *xxiii*
*Acknowledgment* *xxvii*

## Unit 1 - Concepts of Design

### 1. Introduction to Machine Design

1.1 Introduction 1
1.2 Stages in Design 2
1.3 Design Considerations 3
1.4 Types of Design 4
1.5 Units 5
1.6 Standardization 8
1.6.1 Objectives of standardization 9
1.6.2 Advantages of standardization 9
1.7 Use of Standards in Design 10
1.8 Standard Mechanical Component Designations 11
1.9 Preferred Numbers 12

### 2. Engineering Materials

2.1 Introduction 21
2.2 Material Properties 21
2.3 Classification of Engineering Materials 22
2.4 Ferrous Metals 23

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE
Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



2.5 Wrought Iron 24
2.6 Carbon Steels 24
2.6.1 Bureau of Indian Standards designation of steels 24
2.6.2 Applications of steels 26
2.6.3 Selecting a steel 28
2.7 Cast Iron 28
2.7.1 Code designation for ferrous castings 29
2.7.2 Types of cast iron 30
2.7.3 Applications of cast iron 31
2.7.4 Effects of impurities on properties of cast iron 32
2.8 Alloy Steels 32
2.8.1 Alloy steels designation 32
2.8.2 Properties of alloy steels 33
2.8.3 Applications of alloy steel 34
2.8.4 Guidelines for selecting alloy steel 35
2.9 Stainless Steels 35
2.10 Steels for High Temperatures 36
2.11 High Speed Steels 36
2.12 Spring Steels 37
2.13 Non-Ferrous Metals 37
2.14 Aluminum and its Alloys 38
2.14.1 Aluminum designation 38
2.14.2 Applications of aluminum alloys 38
2.14.3 Mechanical properties of aluminum alloys 39
2.15 Copper and its Alloys 40
2.16 Tin 41
2.17 Zinc Alloys 41
2.18 Nickel Alloys 41
2.19 Bearing Materials 42
2.20 Lead 42
2.21 Non Metals 43
2.22 Elastomers (Rubber) 44
2.23 Wood 44
2.24 Selecting a Material 45

**3. Limits, Tolerances and Fits**

3.1 Introduction 55
3.2 Terminology 55
3.3 International Tolerance Grade (IT Grade) 57

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



3.4 Tolerances and Manufacturing Processes 59
3.5 Fundamental Tolerances 60
3.5.1 Letter symbol for holes 60
3.5.2 Letter symbol for shafts 61
3.6 Indication of Tolerance on a Drawing 67
3.7 Fits 70
3.8 Systems of Fits 70
3.8.1 Hole basis 70
3.8.2 Shaft basis 70
3.9 Specifying a Fit 71
3.10 Types of Fits 71
3.11 Selection of Fits 72
3.12 Interchangeability 74

**4. Manufacturing Aspects in Design**

4.1 Introduction 82
4.2 Manufacturing Processes 83
4.3 Selection of Processes 83
4.4 Shaping Processes 86
4.4.1 Sand casting 86
4.4.2 Design considerations in sand castings 87
4.4.3 Factors controlling casting tolerances 90
4.4.4 Die casting 91
4.5 Forging Processes 92
4.5.1 Hot and cold forging 93
4.5.2 Forging in dies 93
4.5.3 Rolling 94
4.5.4 Drawing 94
4.5.5 Extrusion 94
4.5.6 Design aspects in forging 94
4.6 Joining Processes 98
4.6.1 Design considerations for welded parts 99
4.7 Material Removal Processes 100
4.7.1 Design considerations in machining 101
4.8 Jigs 102
4.9 Fixtures 102
4.10 Chemical Processes 103
4.11 Computerized Machines 103
4.11.1 CNC machines 103
4.11.2 Rapid prototyping 104

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



4.12 Heat Treatment Processes 104
4.13 Surface Finishing Processes 105
4.14 Design for Assembly 106
4.14.1 Approaches to design for assembly 107
4.14.2 Assembly methods 107
4.14.3 Cost of design for assembly 108
4.14.4 Guidelines for design for assembly 109

## Unit 2– Designing for Strength

### 5. Simple Stresses

5.1 Introduction to Design 117
5.2 Types of Loads 118
5.3 Tensile Stress 119
5.4 Strength and Stiffness 119
5.5 Tensile Strain – Linear / Lateral 119
5.6 Stress - Strain Curve 120
5.7 Factor of Safety 121
5.7.1 Factor of ignorance 121
5.8 Poisson's Ratio 122
5.9 Young's Modulus of Elasticity 123
5.10 Compressive Stresses 127
5.11 Compressive Stresses in Long Columns 129
5.11.1 Euler's formula 129
5.11.2 Rankine's formula 130
5.12 Bearing Stresses 133
5.13 Shear Stresses 134
5.14 Shear Strain 138
5.15 Shear Modulus of Rigidity 138
5.16 Bulk Modulus 139
5.17 Resilience 139
5.18 Thermal Stresses 140
5.19 Stresses due to Impact 143
5.20 Hertz Stresses 146
5.20.1 Sphere to sphere contact 146
5.20.2 Cylinder to cylinder contact 147
5.21 Hoop Stress 148
5.21.1 Thin wall 148
5.21.2 Thick-walled vessels 149

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE
Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



## 6. Bending Stresses

6.1 Bending Stresses 160
6.2 Flexural Strength 161
6.3 Bending Moment 161
6.4 Moment of Area 167
6.5 Beam Supports 169
6.6 Shear Stress in Beams 169
6.6.1 Shear force diagram 170
6.7 Bending Moment Diagram 171
6.8 Deflection of Beams 173
6.9 Eccentric Loading 178
6.10 Curved Beams 179
6.11 Neutral and Central Axis 180
6.12 Analysis of Curved Beam 182
6.13 C - Clamp 183
6.14 Machine Frame 185

## 7. Torsional Stresses

7.1 Torsional Shear Stresses 198
7.2 Design for Rigidity 200
7.3 Design of a Hollow Shaft 201
7.4 Torsion of Non-Circular Shafts 204
7.5 Torsion in Thin Sections 205
7.5.1 Closed thin sections 205
7.5.2 Open thin sections 208

## 8. Combined Stresses

8.1 Introduction to Combined Stresses 214
8.2 Bending with Axial Load 214
8.3 Principal Stresses 216
8.4 Torsion with Axial Load 219
8.5 Bending with Torsion 221
8.6 Torsion and Bending Combined with Axial Load 224
8.7 Mohr's Circle 226
8.7.1 Two-dimensional stresses 226
8.7.2 One-dimensional stress 228
8.7.3 Three-dimensional stresses 230

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



8.8 Theories of Failure 233
8.8.1 Maximum principal strain theory 233
8.8.2 Maximum shear stress theory 234
8.8.3 Maximum strain energy theory 236
8.8.4 Maximum distortion energy theory 237
8.8.5 Maximum principal stress theory 244
8.9 Summary of Failure Theories 247

**9. Stress Concentration**

9.1 Introduction 255
9.2 Stress Concentration Areas 255
9.3 Parameters Causing Stress Concentration 256
9.4 Stress Concentration Factor 256
9.5 Localized Stress Concentration with an Elliptical Hole 257
9.6 Stress Concentration with a Circular Hole 258
9.7 Axial Loads on Flats with Holes 258
9.7.1 Axial loads on flats with circular holes 258
9.7.2 Axial load with two circular holes 260
9.8 Axial Loads on Flats with a Fillet 263
9.9 Axial Loads on Flats with a Notch 265
9.10 Axial Loads on Cylinders 266
9.10.1 Cylinder with a fillet or a shoulder 266
9.10.2 Cylinder with a notch 267
9.11 Stress Concentration in Bending 268
9.12 Cylinder with a Notch 272
9.13 Stress Concentration in Torsion 274
9.14 Stress Concentration due to Keyway in a Shaft 276
9.15 Stress Concentration in Screw Threads 277
9.16 Stress Concentration in Gears 277
9.17 Methods of Reducing Stress Concentration 277
9.18 Actual Stress Concentration 278
9.19 Notch Sensitivity 278
9.19.1 Notch factor 280

**10. Endurance Strength**

10.1 Variable Loads 286
10.2 Endurance Strength 287
10.3 Fatigue Strength Testing 288
10.4 S-N Curve 288

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



10.5 Endurance Limit for Reversed Stresses 289
10.6 Number of Cycles and Fatigue Strength 290
10.7 Endurance Strength for Given Number of Cycles 292
10.8 Endurance Strength Modifying Factors 294
10.8.1 Load factor ($K_{load}$) 294
10.8.2 Size factor ($K_{size}$) 294
10.8.3 Reliability factor ($K_{rel}$) 295
10.8.4 Surface finish factor ($K_{surf}$) 295
10.8.5 Temperature factor ($K_{temp}$) 296
10.8.6 Notch factor ($K_{notch}$) 297
10.8.7 Miscellaneous factor ($K_m$) 297
10.9 Approximate Endurance Strength 297
10.10 Cumulative Design 302

**11. Fluctuating Stresses**

11.1 Designing for Fluctuating Loads 312
11.2 Safe and Unsafe Zones 313
11.2.1 Soderberg line 314
11.2.2 Goodman line 314
11.2.3 Modified Goodman line 314
11.2.4 Gerber parabola 315
11.2.5 ASME elliptical curve 316
11.3 Axial Fluctuating Loads 316
11.4 Bending Fluctuating Loads 321
11.5 Modified Goodman Line for Torsional Shear Stresses 324
11.6 Torsional Varying Loads 325
11.7 Axial and Bending Fluctuating Loads 328
11.8 Torsional and Axial Fluctuating Loads 333
11.9 Torsional and Bending Fluctuating Loads 335
11.10 Fatigue Design under Combined Loads 338
11.11 Two Dimensional Varying Loads 341

**Unit 3 - Joints**

**12. Cotter Joints**

12.1 Cotter Joint 352
12.2 Types of Cotter Joints 352
12.3 Cotter 353

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



12.4 Sleeve and Cotter Joint 353
12.5 Design Procedure of Sleeve and Cotter Joint 354
12.6 Socket and Spigot Joint 359
12.7 Design Procedure for Socket and Spigot Joint 360
12.8 Gib and Cotter Joint 369
12.9 Design of a Gib and Cotter Joint 370

**13. Pin Joints**

13.1 Introduction to Pin Joints 378
13.2 Knuckle Joint 378
13.3 Design Procedure for a Knuckle Joint 378

**14. Riveted joints**

14.1 Introduction 391
14.2 Rivets 391
14.3 Making a Riveted Joint 392
14.4 Rivet Materials 393
14.5 Rivet Heads 393
14.6 Classification of Riveted Joints 394
14.6.1 According to arrangement of plates 394
14.6.2 According to number of rows of rivets (Single / Double / Triple) 395
14.6.3 According to number of cover plates (Single / Double-Equal / Unequal) 396
14.6.4 According to arrangement of rivets (Chain / Zigzag) 396
14.7 Failures of a Riveted Joint and Strength 397
14.7.1 Failure of rivets 397
14.7.2 Failure of plates 398
14.8 Joint Efficiency 400
14.9 Design of Riveted Joints 401
14.9.1 Selection of rivet size 401
14.9.2 Rivet hole size 401
14.9.3 Rivet length 402
14.9.4 Joint proportions 402
14.9.5 Thickness of cover plates 402
14.9.6 Width of cover plates 403
14.9.7 Calculate strength in different modes of failure 403
14.9.8 Calculate joint efficiency 404
14.10 Diamond Riveting 409
14.10.1 Design procedure for diamond riveted joint 410

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



14.11 Boiler Joints 412
14.11.1 Longitudinal boiler joints 412
14.11.2 Circumferential boiler joints 417

**15. Welded joints**

15.1 Introduction 435
15.2 Welded versus Riveted Joint 435
15.3 Welded Joints versus Castings 436
15.4 Types of Welding Processes 436
15.4.1 Arc welding 437
15.4.2 Gas welding 437
15.4.3 Thermit welding 437
15.4.4 Pressure welding 437
15.5 Types of Welded Joints 438
15.6 Edge Preparation 439
15.7 Weld Symbols 439
15.7.1 Groove symbols 439
15.7.2 Contour symbols 440
15.7.3 Surface finish symbols 440
15.7.4 Additional welding symbols 440
15.8 Specifying a Welded Joint 441
15.8.1 Arrow line 441
15.8.2 Reference line 441
15.8.3 Weld size (a) 442
15.8.4 Welding symbol 443
15.8.5 Length of weld 443
15.8.6 Blank length 443
15.9 Spot Welds 444
15.10 Seam Welds 444
15.11 Plug Welds 444
15.12 Strength of a Butt Weld 445
15.13 Fillet Welds 449
15.14 Throat Size 449
15.15 Transverse Fillet Weld 450
15.16 Maximum Shear Stresses in Transverse Fillet Welds 452
15.17 Von-Mises Stresses in Transverse Fillet Welds 453
15.18 Parallel Fillet Weld (Axial Loading) 454
15.19 Maximum Shear Stresses in Parallel Fillet Welds 455

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



15.20 Combination of Transverse and Parallel Fillet Weld 457
15.21 Stress Concentration in Welds 458
15.22 Asymmetrical Parallel Welds 459
15.23 Welds in Bending 461
15.24 Welds in Torsion 461
15.24.1 Torsion of circular fillet 461

**16. Bolted joints**

16.1 Introduction 472
16.2 Advantages / Disadvantages of Threaded Joints 472
16.3 Terminology 473
16.4 Classification of Threads 474
16.5 Thread Profile 475
16.5.1 Metric threads 475
16.5.2 British standard Whitworth threads 475
16.5.3 Square threads 475
16.5.4 Acme threads 476
16.5.5 Buttress threads 476
16.5.6 Knuckle threads 476
16.6 Pitch of Threads 476
16.7 Thread Designation 477
16.8 Specifications of Threads 478
16.9 Bolts and Nuts 479
16.10 Bolt Materials 480
16.11 Bolt Manufacturing 481
16.12 Locking Devices 481
16.12.1 Lock nut 482
16.12.2 Locking with pin 482
16.12.3 Slotted nut 483
16.12.4 Castle nut 483
16.12.5 Sawn nut 483
16.12.6 Ring and groove nut 484
16.12.7 External locking devices 484
16.13 Screws 485
16.13.1 Bolt versus screws 485
16.13.2 Types of screws 485
16.14 Types of Threaded Joints 488
16.15 Stresses in Threaded Joints 489
16.15.1 Initial stresses 489
16.15.2 Stresses due to external forces 492

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE
Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



16.16 Design of Nut 494
16.17 Design of Turnbuckle 495
16.17.1 Design procedure for turnbuckle 497
16.18 Bolts of Uniform Strength 500
16.19 Design of Cylinder Cover Joint 501
16.20 Stiffness of Threaded Joints 505
16.20.1 Stiffness of bolt 506
16.20.2 Stiffness of components 508
16.21 Load Sharing by bolt and Components 510
16.22 Loads while Tightening Nut 512
16.23 Maximum Load on a Bolt 512
16.24 Gaskets in Threaded Joint 514
16.24.1 Soft gasket 515
16.24.2 Hard gasket 515
16.25 Variable Loading 518
16.26 Design Procedure for Variable Loading 521

**17. Eccentric Loading of Joints**

17.1 Eccentric Loading 540
17.2 Eccentrically Loaded Riveted Joints 541
17.2.1 Eccentricity in plane of rivets 541
17.3 Inclined Load 552
17.4 Load Parallel and Offset to Plane of Fasteners 555
17.5 Eccentrically Loaded Bolted Joints 555
17.5.1 Eccentric load in plane of bolts 555
17.5.2 Eccentric load parallel to plane of bolts 557
17.5.3 Eccentric load with rectangular base 557
17.5.4 Eccentric load parallel to circular base 561
17.6 Eccentrically Loaded Welds 570
17.6.1 Eccentric load in plane of welds 570
17.6.2 Eccentric load parallel and offset to plane of welds 576
17.6.3 Welding all around 581

**Unit 4 – Design of Machine Elements**

**18. Power screws**

18.1 Introduction 591
18.2 Types of Power Screws 592

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



18.3 Torque for Raising Load 593
18.4 Torque for Lowering Load 595
18.5 Efficiency of Square Threads 595
18.6 Maximum Efficiency of Square Threads 597
18.7 Torque for Raising Load using Acme Threads 597
18.8 Self Locking Screws 598
18.9 Screw and Nut Materials 599
18.10 Coefficient of Friction 600
18.11 Stresses in Power Screws 600
18.11.1 Direct axial compressive stress 600
18.11.2 Shear stress at the root of the threads 601
18.11.3 Torsional shear due to friction 601
18.11.4 Bearing pressures 602
18.12 Design of Thrust Collar 602
18.13 Lead Screw 605
18.14 Screw Jack 606
18.14.1 Construction and working of screw jack 606
18.14.2 Stresses in screw 607
18.15 Design of Screw Jack 608
18.15.1 Design of screw 608
18.15.2 Design of nut 611
18.15.3 Design of cup 611
18.15.4 Design of body 612
18.16 Hand Press 617
18.17 Screw of a Vice 621
18.18 Screw of Pipe Vice 623
18.19 Screw of a Broaching Machine 625
18.20 Differential Screw 628
18.21 Compound Screw 629
18.22 Design of Toggle Jack 630

**19. Shafts and Keys**

19.1 Introduction 644
19.2 Types of Shafts 645
19.3 Shaft Manufacturing 645
19.4 Shaft Materials 645
19.5 Standard Rod / Shaft Sizes 646
19.6 Shaft Design on Strength Basis 646
19.7 Shaft Design for Torsion only 647

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE
Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



19.8 Shaft Design for Bending 649
19.9 Shaft Design for Combined Torsion and Bending 650
19.10 Power Transmission using Pulley and Belt 654
19.11 Power Transmission through Gears 657
19.12 Long Shafts 664
19.13 Axial Load Combined with Torsion and Bending 665
19.14 Shaft Design with Varying Loads 673
19.15 Shaft Design for Rigidity 677
19.15.1 Torsional rigidity 677
19.15.2 Lateral rigidity 678
19.16 Stepped Shafts 679
19.16.1 Shafts in series 679
19.16.2 Shafts in parallel 680
19.17 Critical Speeds for Shafts 682
19.18 Keys 684
19.18.1 Key materials and allowable stresses 685
19.19 Keyways 686
19.20 Types of Keys 686
19.21 Saddle Keys 686
19.22 Taper Sunk Keys (IS 2048 - 1983) 687
19.23 Parallel Sunk Keys (IS 2048 - 1975) 688
19.24 Design of Sunk Keys 689
19.25 Round Keys 694
19.26 Tangent Keys (IS 2291) 696
19.27 Woodruff Key (IS 2294) 698
19.28 Set Screws 701
19.29 Splines 701

**20. Couplings**

20.1 Couplings 720
20.2 Types of Couplings 721
20.3 Rigid Flange Couplings 721
20.3.1 Marine coupling 721
20.3.2 Muff coupling 724
20.3.3 Split muff coupling 727
20.3.4 Half lap muff coupling 730
20.3.5 Rigid flange coupling 730
20.3.6 Protected flange coupling 736
20.4 Flexible Couplings 739

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE
Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



20.5 Oldham Coupling 746
20.5.1 Design of Oldham coupling 747
20.6 Universal Coupling 750
20.6.1 Construction of universal coupling 751
20.6.2 Joint proportions 752
20.6.3 Designing for strength 753

**21. Levers**

21.1 Introduction 763
21.2 Uses of Levers 763
21.3 Types of Levers 764
21.4 Design of a Lever 765
21.5 Design of a Hand Lever 766
21.6 Foot Lever 768
21.7 Cranking Lever 771
21.8 Safety Valve Lever 775
21.9 Bell Crank Lever 778
21.10 Cross Lever 782
21.11 Rocker Arm 783
21.12 Compound Lever 785

**22. Helical Springs**

22.1 Introduction 797
22.2 Classification of Springs 798
22.3 Helical Spring Terminology 799
22.4 Materials 800
22.5 Helical Springs 803
22.5.1 Compression spring 803
22.5.2 Tension spring 804
22.5.3 Torsion spring 805
22.5.4 Spiral spring 805
22.6 Conventional and Symbolic Representation of Springs 805
22.7 Stresses in Springs 805
22.8 Deflection and Number of Turns 808
22.9 Buckling of Spring 809
22.10 Design Force and Operating Force 810
22.11 Selection of Spring Index 810
22.12 Design Procedure for Helical Spring 810
22.13 Spring of a Safety Valve 814

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



22.14 Spring of an Internal Combustion Engine 815
22.15 Springs of Non-Circular Cross-Section 816
22.16 Spring of a Spring Balance 819
22.17 Spring Design for Impact Load 820
22.18 Spring for a Clutch 821
22.19 Natural Frequency of Helical Springs 822
22.20 Surge in Springs 824
22.21 Multiple Springs 824
22.22 Concentric or Composite Springs 827
22.23 Design of Spring with Varying Loads 832
22.24 Design of Helical Extension Springs 838
22.25 Helical Torsion Springs 841
22.26 Spiral Spring 844
22.27 Belleville Spring 846

**23. Leaf Springs**

23.1 Introduction 862
23.2 Spring Materials 863
23.3 Sizes of Spring Components 864
23.4 Shapes of Leaf Springs 864
23.5 Analysis of Leaf Spring 865
23.6 Graduated Leaves 866
23.7 Nipping 869
23.8 Length of Leaves 870
23.9 Energy Stored in a Spring 871
23.10 Design Procedure 871

*Appendix 1* 889
*Appendix 2* 890
*Appendix 3* 893
*References* 897
*Index* 899

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information

# Preface

Subject of *Machine Design* is a combination of engineering and art. The engineering part is important for the functional working of a machine, so that all the *machine elements* when assembled as a machine, work properly e.g. as an automobile, sewing machine, a lathe etc. The engineering may also include ergonomics, to cause minimum fatigue, if the machine has to be handled by human beings for a long time. The art part is adding aesthetic for appealing shapes, selecting suitable colors etc. which attract the customers.

*Fundamentals of machine design* considers the concepts of design for each element separately like for a shaft, bearing, pulley etc. Loads on a part/component are assessed, checked for the stresses, whether it is within the safe strength of the selected material. Deflection also should not be beyond a certain limit. The subject should not be confused with strength of materials as the designer has to selecting a suitable material and consider the production aspects also.

*Course content* is limited to topics, included in the syllabi of the universities and colleges. The subject is so wide that it is covered in two semesters, for mechanical engineering students in most of the universities. Hence the book is also divided in *two volumes*.

*English language* used in this book is direct and simple, so that an average student can understand easily. The sequence of the chapters is arranged in such a way that the concepts described in earlier chapters become useful for subsequent chapters.

*Symbols* used for mathematical derivations have been so assigned, that they are easy to remember. There is no list of symbols in the beginning of the book, they are defined wherever they have been used in the text.

*Volume - I* is for the first course on *Machine Design*, covering first semester topics offered by most colleges. The main objective of this volume is to provide rules for the design of general-purpose machine elements. This volume has four units.

*Unit 1* of the book is on *fundamentals* and has four chapters. The first chapter introduces *basic fundamentals* and types of machine design. Chapter 2 is on the selection of engineering *materials*, which will be useful for every part to be designed. Although manufacturing a part

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE
Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



is the job of a production engineer, however a designer should know the advantages and disadvantages of the different manufacturing processes. Hence a brief summary of various *manufacturing processes*, *limits and tolerances,* and *surface finish* are described in chapters 3 and 4. The tolerances and other production need to be specified on the working drawings, to be sent to shop floor.

*Unit 2* is on *design for strength* and has seven chapters. This unit is the backbone of the concepts of the subject, as the theory described here is applicable to the design of any machine member. Different types of stresses, like *direct, bending, torsion* are described in chapters 5, 6 and 7. Chapters 8 to 11 describe *principal stresses, stress concentration, fatigue failure* and *endurance strength* for *fluctuating loads.*

*Unit 3* is on design of *joints*, which is covered in six chapters. Chapter 12 is on *cotter* joints chapter 13 on *pin* joints, chapter 14 on *riveted* joints, chapter 15 on *welded* joints, chapter 16 on *bolted* joints and lastly chapter 17 on *eccentric loading,* which happens to any joint like rivet, weld or bolted.

*Unit 4* describes *design of simple machine elements* in six chapters. Chapter 18 is on *power screws*, chapter 19 on *shafts and keys*, chapter 20 on *couplings*, chapter 21 on *levers,* chapter 22 on *helical springs* and the last chapter 20 on *leaf springs*.

*Pedagogy features* of the book are excellent. Before starting a chapter, an *outcome* given in the beginning, gives an idea as to what a student is going to learn in that chapter. Each chapter is followed by theory questions, multiple choice questions, design problems. An effort has been made to explain theory with *490 figures.* To make the book further illustrative, license free *68 pictures* are pasted from the Internet and referenced in the text, wherever necessary. Students face a lot of difficulty in solving design problems, hence *238 solved examples* and *226 unsolved* design problem are given. Solution to the unsolved examples will be put in *solution manual* on the internet in due course of time. To practice for small quiz type questions, *270 multiple choice* questions have been given.

*Summary* is given at the end of each chapter for quick revision of the course and formulas at the time of examination.

*Competition examinations* questions of past 3-4 years from Engineering services examinations and *GATE* examinations are given at the end of chapter, to help students preparing for such examinations.

*S.I. units* have been used for mathematical calculations and design problems**.** *Indian Standards* and other standards have also been mentioned, wherever necessary.

*Volume - 2* is for the second course of the same subject. This volume has twenty chapters in four units. *Unit 1* covers mainly design of *drives* like belt, rope, chain and gears of various types, *Unit 2* is on sleeve and rolling bearings. *Unit 3* is on the deign of I.C. engine parts and *unit 4* covers miscellaneous parts like levers, clutches, brakes and pressure vessels.

After successful completion of the course, the student will be able to understand various aspects of the machine design process, and will be encouraged to seek opportunities for its satisfactory working. The mastering of the course is a pre-condition to a successful design.

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information



*Audience* – This book can be easily recommended as a text book of the subject for undergraduate students. The book can also be used by practicing engineers, students appearing for competition examinations and for graduate admission tests.

Although every effort is made to minimize the errors, but a human being is likely to commit mistakes. Also, there is always a possibility of improving the book. Any errors, omissions or suggestions for the improvement of the book may please be written to the publisher or emailed to the author at ajeet41@yahoo.com.

© in this web service Cambridge University Press www.cambridge.org

CAMBRIDGE

Cambridge University Press
978-1-316-63040-2 — Fundamentals of Machine Design
Ajeet Singh
Frontmatter
More Information

# Acknowledgements

Many books on the subject of machine design have been consulted and the author feels the need to thank the publishers and authors of these books. The author thanks Gauravjeet Singh Reen, commissioning editor at Cambridge University Press, who has been very helpful and prompt in interaction for any of my queries or doubts. I am thankful to the *reviewers* for giving encouraging remarks in their reviews and appreciating my effort in preparing the book. Thanks are due to the editorial and production staff of M/S Cambridge University Press, for their cooperation and help in the publication of the book. I wish to acknowledge my gratitude to Indian Standards Institution, for the extracts of some of standards used in this book. Lastly, I thank all my family members for their moral support in the preparation of the book.

© in this web service Cambridge University Press www.cambridge.org