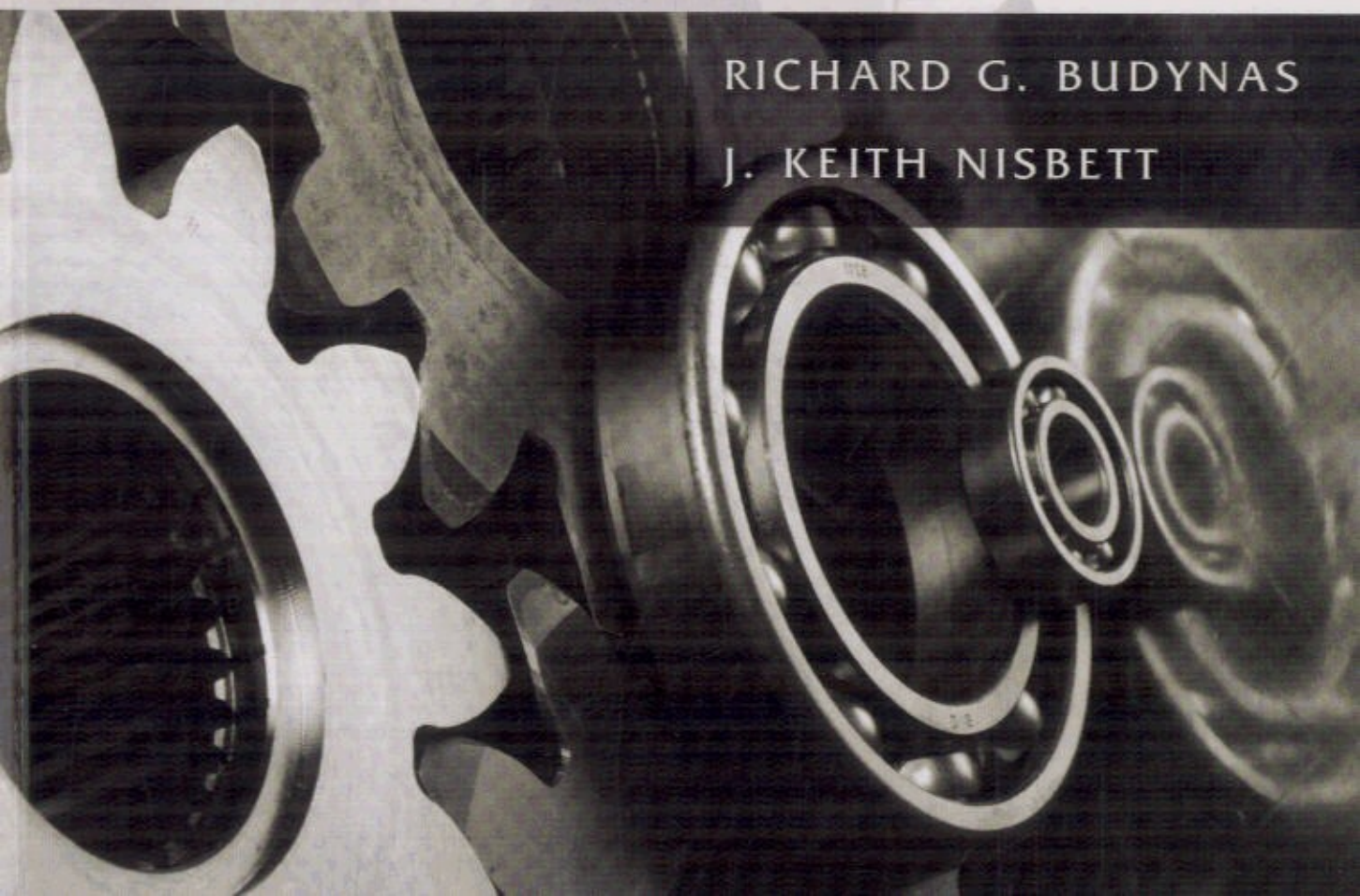


EIGHTH EDITION IN SI UNITS

Shigley's Mechanical Engineering Design

RICHARD G. BUDYNAS

J. KEITH NISBETT



Contents

Preface xv

Part 1 Basics 2

1 Introduction to Mechanical Engineering Design 3

- 1-1** Design 4
- 1-2** Mechanical Engineering Design 5
- 1-3** Phases and Interactions of the Design Process 5
- 1-4** Design Tools and Resources 8
- 1-5** The Design Engineer's Professional Responsibilities 10
- 1-6** Standards and Codes 12
- 1-7** Economics 12
- 1-8** Safety and Product Liability 15
- 1-9** Stress and Strength 15
- 1-10** Uncertainty 16
- 1-11** Design Factor and Factor of Safety 17
- 1-12** Reliability 18
- 1-13** Dimensions and Tolerances 19
- 1-14** Units 21
- 1-15** Calculations and Significant Figures 22
- 1-16** Power Transmission Case Study Specifications 22
- Problems** 24

2 Materials 27

- 2-1** Material Strength and Stiffness 28
- 2-2** The Statistical Significance of Material Properties 32
- 2-3** Strength and Cold Work 33
- 2-4** Hardness 36
- 2-5** Impact Properties 37
- 2-6** Temperature Effects 39
- 2-7** Numbering Systems 40

- 2-8** Sand Casting 41
- 2-9** Shell Molding 42
- 2-10** Investment Casting 42
- 2-11** Powder-Metallurgy Process 42
- 2-12** Hot-Working Processes 43
- 2-13** Cold-Working Processes 44
- 2-14** The Heat Treatment of Steel 44
- 2-15** Alloy Steels 47
- 2-16** Corrosion-Resistant Steels 48
- 2-17** Casting Materials 49
- 2-18** Nonferrous Metals 51
- 2-19** Plastics 54
- 2-20** Composite Materials 55
- 2-21** Materials Selection 56
- Problems** 63

3 Load and Stress Analysis 67

- 3-1** Equilibrium and Free-Body Diagrams 68
- 3-2** Shear Force and Bending Moments in Beams 71
- 3-3** Singularity Functions 73
- 3-4** Stress 75
- 3-5** Cartesian Stress Components 75
- 3-6** Mohr's Circle for Plane Stress 76
- 3-7** General Three-Dimensional Stress 82
- 3-8** Elastic Strain 83
- 3-9** Uniformly Distributed Stresses 84
- 3-10** Normal Stresses for Beams in Bending 85
- 3-11** Shear Stresses for Beams in Bending 90
- 3-12** Torsion 95
- 3-13** Stress Concentration 105
- 3-14** Stresses in Pressurized Cylinders 107
- 3-15** Stresses in Rotating Rings 110
- 3-16** Press and Shrink Fits 110

- 3-17** Temperature Effects 111
- 3-18** Curved Beams in Bending 112
- 3-19** Contact Stresses 117
- 3-20** Summary 121
- Problems 121

- 4 Deflection and Stiffness** 141
- 4-1** Spring Rates 142
- 4-2** Tension, Compression, and Torsion 143
- 4-3** Deflection Due to Bending 144
- 4-4** Beam Deflection Methods 146
- 4-5** Beam Deflections by Superposition 147
- 4-6** Beam Deflections by Singularity Functions 150
- 4-7** Strain Energy 156
- 4-8** Castigliano's Theorem 158
- 4-9** Deflection of Curved Members 163
- 4-10** Statically Indeterminate Problems 168
- 4-11** Compression Members—General 173
- 4-12** Long Columns with Central Loading 173
- 4-13** Intermediate-Length Columns with Central Loading 176
- 4-14** Columns with Eccentric Loading 176
- 4-15** Struts or Short Compression Members 180
- 4-16** Elastic Stability 182
- 4-17** Shock and Impact 183
- 4-18** Suddenly Applied Loading 184
- Problems 186

- Part 2 Failure Prevention** 204

- 5 Failures Resulting from Static Loading** 205
- 5-1** Static Strength 208
- 5-2** Stress Concentration 209
- 5-3** Failure Theories 211
- 5-4** Maximum-Shear-Stress Theory for Ductile Materials 211
- 5-5** Distortion-Energy Theory for Ductile Materials 213
- 5-6** Coulomb-Mohr Theory for Ductile Materials 219
- 5-7** Failure of Ductile Materials Summary 222
- 5-8** Maximum-Normal-Stress Theory for Brittle Materials 226
- 5-9** Modifications of the Mohr Theory for Brittle Materials 227
- 5-10** Failure of Brittle Materials Summary 229
- 5-11** Selection of Failure Criteria 230
- 5-12** Introduction to Fracture Mechanics 231
- 5-13** Stochastic Analysis 240
- 5-14** Important Design Equations 246
- Problems 248

- 6 Fatigue Failure Resulting from Variable Loading** 257
- 6-1** Introduction to Fatigue in Metals 258
- 6-2** Approach to Fatigue Failure in Analysis and Design 264
- 6-3** Fatigue-Life Methods 265
- 6-4** The Stress-Life Method 265
- 6-5** The Strain-Life Method 268
- 6-6** The Linear-Elastic Fracture Mechanics Method 270
- 6-7** The Endurance Limit 274
- 6-8** Fatigue Strength 275
- 6-9** Endurance Limit Modifying Factors 278
- 6-10** Stress Concentration and Notch Sensitivity 287
- 6-11** Characterizing Fluctuating Stresses 292
- 6-12** Fatigue Failure Criteria for Fluctuating Stress 295
- 6-13** Torsional Fatigue Strength under Fluctuating Stresses 309
- 6-14** Combinations of Loading Modes 309
- 6-15** Varying, Fluctuating Stresses; Cumulative Fatigue Damage 313
- 6-16** Surface Fatigue Strength 319
- 6-17** Stochastic Analysis 322
- 6-18** Roadmaps and Important Design Equations for the Stress-Life Method 336
- Problems 340

Part 3 Design of Mechanical Elements 346

7 Shafts and Shaft Components 347

- 7-1 Introduction 348
- 7-2 Shaft Materials 348
- 7-3 Shaft layout 349
- 7-4 Shaft Design for Stress 354
- 7-5 Deflection Considerations 367
- 7-6 Critical Speeds for Shafts 371
- 7-7 Miscellaneous Shaft Components 376
- 7-8 Limits and Fits 383
Problems 388

8 Screws, Fasteners, and the Design of Nonpermanent Joints 395

- 8-1 Thread Standards and Definitions 396
- 8-2 The Mechanics of Power Screws 400
- 8-3 Threaded Fasteners 408
- 8-4 Joints—Fastener Stiffness 410
- 8-5 Joints—Member Stiffness 413
- 8-6 Bolt Strength 417
- 8-7 Tension Joints—The External Load 421
- 8-8 Relating Bolt Torque to Bolt Tension 422
- 8-9 Statically Loaded Tension Joint with Preload 425
- 8-10 Gasketed Joints 429
- 8-11 Fatigue Loading of Tension Joints 429
- 8-12 Bolted and Riveted Joints Loaded in Shear 435
Problems 443

9 Welding, Bonding, and the Design of Permanent Joints 457

- 9-1 Welding Symbols 458
- 9-2 Butt and Fillet Welds 460
- 9-3 Stresses in Welded Joints in Torsion 464
- 9-4 Stresses in Welded Joints in Bending 469

- 9-5 The Strength of Welded Joints 471
- 9-6 Static Loading 474
- 9-7 Fatigue Loading 478
- 9-8 Resistance Welding 480
- 9-9 Adhesive Bonding 480
Problems 489

10 Mechanical Springs 499

- 10-1 Stresses in Helical Springs 500
- 10-2 The Curvature Effect 501
- 10-3 Deflection of Helical Springs 502
- 10-4 Compression Springs 502
- 10-5 Stability 504
- 10-6 Spring Materials 505
- 10-7 Helical Compression Spring Design for Static Service 510
- 10-8 Critical Frequency of Helical Springs 516
- 10-9 Fatigue Loading of Helical Compression Springs 518
- 10-10 Helical Compression Spring Design for Fatigue Loading 521
- 10-11 Extension Springs 524
- 10-12 Helical Coil Torsion Springs 532
- 10-13 Belleville Springs 539
- 10-14 Miscellaneous Springs 540
- 10-15 Summary 542
Problems 542

11 Rolling-Contact Bearings 549

- 11-1 Bearing Types 550
- 11-2 Bearing Life 553
- 11-3 Bearing Load Life at Rated Reliability 554
- 11-4 Bearing Survival: Reliability versus Life 555
- 11-5 Relating Load, Life, and Reliability 557
- 11-6 Combined Radial and Thrust Loading 559
- 11-7 Variable Loading 564
- 11-8 Selection of Ball and Cylindrical Roller Bearings 568
- 11-9 Selection of Tapered Roller Bearings 571
- 11-10 Design Assessment for Selected Rolling-Contact Bearings 582

- 11-11** Lubrication 586
- 11-12** Mounting and Enclosure 587
- Problems** 591
- 12 Lubrication and Journal Bearings** 597
- 12-1** Types of Lubrication 598
- 12-2** Viscosity 599
- 12-3** Petroff's Equation 601
- 12-4** Stable Lubrication 603
- 12-5** Thick-Film Lubrication 604
- 12-6** Hydrodynamic Theory 605
- 12-7** Design Considerations 609
- 12-8** The Relations of the Variables 611
- 12-9** Steady-State Conditions in Self-Contained Bearings 625
- 12-10** Clearance 628
- 12-11** Pressure-Fed Bearings 630
- 12-12** Loads and Materials 636
- 12-13** Bearing Types 638
- 12-14** Thrust Bearings 639
- 12-15** Boundary-Lubricated Bearings 640
- Problems** 649
- 13 Gears—General** 653
- 13-1** Types of Gear 654
- 13-2** Nomenclature 655
- 13-3** Conjugate Action 657
- 13-4** Involute Properties 658
- 13-5** Fundamentals 658
- 13-6** Contact Ratio 664
- 13-7** Interference 665
- 13-8** The Forming of Gear Teeth 667
- 13-9** Straight Bevel Gears 670
- 13-10** Parallel Helical Gears 671
- 13-11** Worm Gears 675
- 13-12** Tooth Systems 676
- 13-13** Gear Trains 678
- 13-14** Force Analysis—Spur Gearing 685
- 13-15** Force Analysis—Bevel Gearing 689
- 13-16** Force Analysis—Helical Gearing 692
- 13-17** Force Analysis—Worm Gearing 694
- Problems** 700
- 14 Spur and Helical Gears** 713
- 14-1** The Lewis Bending Equation 714
- 14-2** Surface Durability 723
- 14-3** AGMA Stress Equations 725
- 14-4** AGMA Strength Equations 727
- 14-5** Geometry Factors I and J (Z_I and Z_J) 731
- 14-6** The Elastic Coefficient C_p (Z_E) 736
- 14-7** Dynamic Factor K_v 736
- 14-8** Overload Factor K_o 738
- 14-9** Surface Condition Factor C_f (Z_R) 738
- 14-10** Size Factor K_s 739
- 14-11** Load-Distribution Factor K_m (K_H) 739
- 14-12** Hardness-Ratio Factor C_H 741
- 14-13** Stress Cycle Life Factors Y_N and Z_N 742
- 14-14** Reliability Factor K_R (Y_Z) 743
- 14-15** Temperature Factor K_T (Y_θ) 744
- 14-16** Rim-Thickness Factor K_B 744
- 14-17** Safety Factors S_F and S_H 745
- 14-18** Analysis 745
- 14-19** Design of a Gear Mesh 755
- Problems** 760
- 15 Bevel and Worm Gears** 765
- 15-1** Bevel Gearing—General 766
- 15-2** Bevel-Gear Stresses and Strengths 768
- 15-3** AGMA Equation Factors 771
- 15-4** Straight-Bevel Gear Analysis 783
- 15-5** Design of a Straight-Bevel Gear Mesh 786
- 15-6** Worm Gearing—AGMA Equation 789
- 15-7** Worm-Gear Analysis 793
- 15-8** Designing a Worm-Gear Mesh 797
- 15-9** Buckingham Wear Load 800
- Problems** 801
- 16 Clutches, Brakes, Couplings, and Flywheels** 805
- 16-1** Static Analysis of Clutches and Brakes 807
- 16-2** Internal Expanding Rim Clutches and Brakes 812

- 16-3** External Contracting Rim Clutches and Brakes 820
- 16-4** Band-Type Clutches and Brakes 824
- 16-5** Frictional-Contact Axial Clutches 825
- 16-6** Disk Brakes 829
- 16-7** Cone Clutches and Brakes 833
- 16-8** Energy Considerations 836
- 16-9** Temperature Rise 837
- 16-10** Friction Materials 841
- 16-11** Miscellaneous Clutches and Couplings 844
- 16-12** Flywheels 846
- Problems** 851

- 17 Flexible Mechanical Elements** 859

- 17-1** Belts 860
- 17-2** Flat- and Round-Belt Drives 863
- 17-3** V Belts 878
- 17-4** Timing Belts 886
- 17-5** Roller Chain 887
- 17-6** Wire Rope 896
- 17-7** Flexible Shafts 904
- Problems** 905

- 18 Power Transmission Case Study** 913

- 18-1** Design Sequence for Power Transmission 915
- 18-2** Power and Torque Requirements 916
- 18-3** Gear Specification 916
- 18-4** Shaft Layout 923
- 18-5** Force Analysis 925
- 18-6** Shaft Material Selection 925
- 18-7** Shaft Design for Stress 926
- 18-8** Shaft Design for Deflection 926
- 18-9** Bearing Selection 927
- 18-10** Key and Retaining Ring Selection 928
- 18-11** Final Analysis 931
- Problems** 931

Part 4 Analysis Tools 932

- 19 Finite-Element Analysis** 933

- 19-1** The Finite-Element Method 935
- 19-2** Element Geometries 937
- 19-3** The Finite-Element Solution Process 939
- 19-4** Mesh Generation 942
- 19-5** Load Application 944
- 19-6** Boundary Conditions 945
- 19-7** Modeling Techniques 946
- 19-8** Thermal Stresses 949
- 19-9** Critical Buckling Load 949
- 19-10** Vibration Analysis 951
- 19-11** Summary 952
- Problems** 954

20 Statistical Considerations

957

- 20-1** Random Variables 958
- 20-2** Arithmetic Mean, Variance, and Standard Deviation 960
- 20-3** Probability Distributions 965
- 20-4** Propagation of Error 972
- 20-5** Linear Regression 974
- Problems** 977

Appendices

- A Useful Tables** 983
- B Answers to Selected Problems** 1035

Index 1040