

# Contents

<b>Contributors .....</b>	<b>xi</b>
<b>Preface to the First Edition .....</b>	<b>xiii</b>
<b>Preface to the Second Edition .....</b>	<b>xv</b>
<b>1. Introduction: Standards, Codes, Regulations .....</b>	<b>1.1</b>
1.1 The Designer and the Designer's Problems .....	1.1
1.2 Decisions and Their Identification .....	1.10
1.3 Adequacy Assessment .....	1.15
1.4 Communication of Engineering Information .....	1.20
1.5 Legal Considerations in Design .....	1.34
1.6 Standards, Codes, and Governmental Regulations in Design .....	1.36
1.7 Sources of Standards, Codes, Governmental Regulations, Indexes, and Standardization Activities .....	1.40
References .....	1.43
<b>2. Statistical Considerations .....</b>	<b>2.1</b>
2.1 Introduction .....	2.2

2.2	Histographic Evidence .....	2.3
2.3	Useful Distributions .....	2.9
2.4	Random-Variable Algebra .....	2.13
2.5	Stochastic Endurance Limit by Correlation and by Test .....	2.16
2.6	Interference .....	2.19
2.7	Numbers .....	2.25
	References .....	2.27
<b>3.</b>	<b>Measurement and Inference .....</b>	<b>3.1</b>
3.1	The Measurement Problem .....	3.1
3.2	Definition of Measurement .....	3.3
3.3	Standards of Measurement .....	3.4
3.4	The Measuring System .....	3.5
3.5	Calibration .....	3.7
3.6	Design of the Measuring System .....	3.8
3.7	Selected Measuring-System Components and Examples .....	3.26
3.8	Sources of Error in Measurements .....	3.40
3.9	Analysis of Data .....	3.43
3.10	Confidence Limits .....	3.49
3.11	Propagation of Error or Uncertainty .....	3.53
	References .....	3.54
	Additional References .....	3.55
<b>4.</b>	<b>Numerical Methods .....</b>	<b>4.1</b>
4.1	Numbers .....	4.1
4.2	Functions .....	4.3
4.3	Series .....	4.6
4.4	Approximations and Error .....	4.7
4.5	Finite-Difference Approximations .....	4.16
4.6	Numerical Integration .....	4.18

4.7	Curve Fitting for Precision Points .....	4.20
4.8	Curve Fitting by Least Squares .....	4.22
4.9	Curve Fitting for Several Variables .....	4.25
4.10	Interpolation .....	4.26
4.11	Root Finding .....	4.28
4.12	Systems of Equations .....	4.34
4.13	Optimization Techniques .....	4.37
	References .....	4.38
<b>5.</b>	<b>Computational Considerations .....</b>	<b>5.1</b>
5.1	Introduction .....	5.3
5.2	An Algorithmic Approach to Design .....	5.4
5.3	Analysis Tasks .....	5.9
5.4	Mathematical Tasks .....	5.13
5.5	Statistical Tasks .....	5.21
5.6	Optimization Tasks .....	5.22
5.7	Simulation .....	5.25
	References .....	5.31
<b>6.</b>	<b>Wear .....</b>	<b>6.1</b>
6.1	General Principles in Design for Wear Resistance .....	6.1
6.2	Steps in Design for Wear Life Without Selecting Materials .....	6.4
6.3	Wear Equations .....	6.6
6.4	Steps in Selecting Materials for Wear Resistance .....	6.7
6.5	Material-Selection Procedure .....	6.14
	References .....	6.18
	Bibliography .....	6.18
<b>7.</b>	<b>Solid Materials .....</b>	<b>7.1</b>
7.1	Structure of Solids .....	7.1

7.2	Atomic Bonding Forces .....	7.2
7.3	Atomic Structures .....	7.4
7.4	Crystal Imperfections .....	7.11
7.5	Slip in Crystalline Solids .....	7.15
7.6	Mechanical Strength .....	7.17
7.7	Mechanical Properties and Tests .....	7.20
7.8	Hardness .....	7.21
7.9	The Tensile Test .....	7.25
7.10	Tensile Properties .....	7.32
7.11	Strength, Stress, and Strain Relations .....	7.36
7.12	Impact Strength .....	7.42
7.13	Creep Strength .....	7.43
7.14	Mechanical-Property Data .....	7.46
7.15	Numbering Systems .....	7.51
	References .....	7.55
<b>8.</b>	<b>The Strength of Cold-Worked and Heat-Treated Steels .....</b>	<b>8.1</b>
8.1	Introduction .....	8.2
8.2	Strength of Plastically Deformed Materials .....	8.3
8.3	Estimating Ultimate Strength after Plastic Strains .....	8.4
8.4	Estimating Yield Strength after Plastic Strains .....	8.8
8.5	Estimating Ultimate Strength of Heat-Treated Plain Carbon Steels .....	8.9
8.6	Estimating Ultimate Strength of Heat-Treated Low-Alloy Steels .....	8.11
8.7	Tempering Time and Temperature Tradeoff Relation .....	8.29
8.8	Computer Programs .....	8.29
	References .....	8.34
	Recommended Reading .....	8.34

<b>9 Usability</b>	<b>9.1</b>
9.1 Designing for Human Body Size	9.2
9.2 Designing for Human Body Posture	9.5
9.3 Designing for Reach and Mobility	9.9
9.4 Designing for Human Force and Power	9.13
9.5 Designing for Fast and Accurate Control Activation	9.17
9.6 Designing Labels and Warnings	9.23
9.7 Designing for Vision	9.24
9.8 Designing for Material Handling	9.25
9.9 Conclusion	9.28
References	9.28
Addresses	9.29
<b>10. Safety</b>	<b>10.1</b>
10.1 Why Safety?	10.1
10.2 What is Safety?	10.1
10.3 Hazard, Risk, and Danger	10.2
10.4 Designer's Obligation	10.4
10.5 Human Factors/Ergonomics	10.20
10.6 Summary	10.22
References	10.22
Recommended Reading	10.24
<b>11. Minimizing Engineering Effort</b>	<b>11.1</b>
11.1 Introduction	11.2
11.2 Reducing the Number of Experiments	11.3
11.3 Similitude	11.7
11.4 Optimality	11.9
11.5 Quadrature	11.13
11.6 Checking	11.15

References .....	11.21
<b>12. Strength under Static Circumstances .....</b>	<b>12.1</b>
12.1 Permissible Stresses and Strains .....	12.2
12.2 Theory of Static Failure .....	12.3
12.3 Stress Concentration .....	12.7
12.4 Fracture Mechanics .....	12.11
12.5 Nonferrous Metals .....	12.17
12.6 Stochastic Considerations .....	12.20
References .....	12.20
<b>13. Strength under Dynamic Conditions .....</b>	<b>13.1</b>
13.1 Testing Methods and Presentation of Results .....	13.3
13.2 SN Diagram for Sinusoidal and Random Loading .....	13.7
13.3 Fatigue-Strength Modification Factors .....	13.9
13.4 Fluctuating Stress .....	13.24
13.5 Complicated Stress-Variation Patterns .....	13.29
13.6 Strength at Critical Locations .....	13.31
13.7 Combined Loading .....	13.36
13.8 Surface Fatigue .....	13.41
References .....	13.44
Recommended Reading .....	13.45
<b>14. Fundamentals of Arc Welding .....</b>	<b>14.1</b>
14.1 Definitions and Terminology .....	14.1
14.2 Basic Welding Circuit .....	14.2
14.3 Arc Shielding .....	14.2
14.4 Nature of the Arc .....	14.4
14.5 Overcoming Current Limitations .....	14.5
14.6 Commercial Arc-Welding Processes .....	14.6
14.7 Arc-Welding Consumables .....	14.18

14.8	Design of Welded Joints .....	14.23
14.9	Codes and Specifications for Welds .....	14.39
<b>15.</b>	<b>Instabilities in Beams and Columns .....</b>	<b>15.1</b>
15.1	Euler's Formula .....	15.2
15.2	Effective Length .....	15.4
15.3	Generalization of the Problem .....	15.6
15.4	Modified Buckling Formulas .....	15.7
15.5	Stress-Limiting Criterion .....	15.8
15.6	Beam-Column Analysis .....	15.12
15.7	Approximate Method .....	15.13
15.8	Instability of Beams .....	15.14
	References .....	15.18
<b>16.</b>	<b>Curved Beams and Rings .....</b>	<b>16.1</b>
16.1	Bending in the Plane of Curvature .....	16.2
16.2	Castigliano's Theorem .....	16.2
16.3	Ring Segments with One Support .....	16.3
16.4	Rings with Simple Supports .....	16.10
16.5	Ring Segments with Fixed Ends .....	16.15
	References .....	16.22
<b>17.</b>	<b>Seals .....</b>	<b>17.1</b>
17.1	Elastomeric Seal Rings .....	17.1
17.2	Seals for Rotary Motion .....	17.4
17.3	Seals for Reciprocating Motion .....	17.9
	References .....	17.15
<b>18.</b>	<b>Flywheels .....</b>	<b>18.1</b>
18.1	Flywheel Usage .....	18.3
18.2	Sizing the Flywheel .....	18.3
18.3	Stress .....	18.13

18.4	Flywheels for Energy Storage .....	18.20
18.5	Strength and Safety .....	18.21
	References .....	18.25
<b>19.</b>	<b>Limits and Fits .....</b>	<b>19.1</b>
19.1	Introduction .....	19.2
19.2	Metric Standards .....	19.2
19.3	U.S. Standard—Inch Units .....	19.9
19.4	Interference-Fit Stresses .....	19.9
19.5	Absolute Tolerances .....	19.13
19.6	Statistical Tolerances .....	19.16
	References .....	19.18
<b>20.</b>	<b>Power Screws .....</b>	<b>20.1</b>
20.1	Introduction .....	20.2
20.2	Kinematics .....	20.3
20.3	Mechanics .....	20.6
20.4	Buckling and Deflection .....	20.8
20.5	Stresses .....	20.9
20.6	Ball Screws .....	20.10
20.7	Other Design Considerations .....	20.12
	References .....	20.13
<b>21.</b>	<b>Threaded Fasteners .....</b>	<b>21.1</b>
21.1	Screw Threads .....	21.1
21.2	Bolts .....	21.5
21.3	Screws .....	21.11
21.4	Nuts .....	21.28
21.5	Tapping Screws .....	21.35
	Reference .....	21.38



<b>22. Unthreaded Fasteners</b>	<b>22.1</b>
22.1 Rivets	22.1
22.2 Pins	22.8
22.3 Eyelets and Grommets	22.10
22.4 Retaining Rings	22.16
22.5 Keys	22.24
22.6 Washers	22.26
References	22.29
<b>23. Bolted and Riveted Joints</b>	<b>23.1</b>
23.1 Shear Loading of Joints	23.4
23.2 Eccentric Loads on Shear Joints	23.11
23.3 Tension-Loaded Joints: Preloading of Bolts	23.16
23.4 Bolt Torque Requirements	23.29
23.5 Fatigue Loading of Bolted and Riveted Joints	23.29
23.6 Programming Suggestions for Joints Loaded in Tension	23.36
References	23.38
<b>24. Springs</b>	<b>24.1</b>
24.1 Introduction	24.2
24.2 Glossary of Spring Terminology	24.2
24.3 Selection of Spring Materials	24.4
24.4 Helical Compression Springs	24.10
24.5 Helical Extension Springs	24.27
24.6 Helical Torsion Springs	24.34
24.7 Belleville Spring Washer	24.38
24.8 Special Spring Washers	24.49
24.9 Flat Springs	24.53
24.10 Constant-Force Springs	24.56
24.11 Torsion Bars	24.60

24.12 Power Springs .....	24.61
24.13 Hot-Wound Springs .....	24.64
References .....	24.67
<b>25. Lubrication .....</b>	<b>25.1</b>
25.1 Functions and Types of Lubricant .....	25.1
25.2 Selection of Lubricant Type .....	25.2
25.3 Liquid Lubricants: Principles and Requirements .....	25.3
25.4 Lubricant Viscosity .....	25.6
25.5 Boundary Lubrication .....	25.9
25.6 Deterioration Problems .....	25.12
25.7 Selecting the Oil Type .....	25.14
25.8 Lubricating Greases .....	25.17
25.9 Solid Lubricants .....	25.22
25.10 Gas Lubrication .....	25.26
25.11 Lubricant Feed Systems .....	25.26
25.12 Lubricant Storage .....	25.29
References .....	25.30
<b>26. Gaskets .....</b>	<b>26.1</b>
26.1 Definition .....	26.1
26.2 Standard Classification System for Nonmetallic Gasket Materials .....	26.1
26.3 Gasket Properties, Test Methods, and Their Significance in Gasketed Joints .....	26.2
26.4 Permeability Properties .....	26.3
26.5 Load-Bearing Properties .....	26.7
26.6 Environmental Conditions .....	26.12
26.7 Gasket Design and Selection Procedure .....	26.13
26.8 Gasket Compression and Stress-Distribution Testing .....	26.22
26.9 Installation Specifications .....	26.23

References .....	26.23
<b>27. Rolling-Contact Bearings .....</b>	<b>27.1</b>
27.1 Introduction .....	27.2
27.2 Load-Life Relation for Constant Reliability .....	27.7
27.3 Survival Relation at Steady Load .....	27.8
27.4 Relating Load, Life, and Reliability Goal .....	27.9
27.5 Combined Radial and Thrust Loadings .....	27.12
27.6 Application Factors .....	27.13
27.7 Variable Loading .....	27.13
27.8 Misalignment .....	27.16
References .....	27.17
<b>28. Journal Bearings .....</b>	<b>28.1</b>
28.1 Introduction .....	28.3
28.2 Bearing and Journal Configurations .....	28.4
28.3 Bearing Materials and Selection Criteria .....	28.7
28.4 Pressure Equation for a Lubricating Film .....	28.13
28.5 Journal Bearing Performance .....	28.16
28.6 Liquid-Lubricated Journal Bearings .....	28.20
28.7 Gas-Lubricated Journal Bearings .....	28.43
28.8 Hydrostatic Journal Bearing Design .....	28.52
References .....	28.57
<b>29. Couplings .....</b>	<b>29.1</b>
29.1 General .....	29.2
29.2 Rigid Couplings .....	29.7
29.3 Flexible Metallic Couplings .....	29.9
29.4 Flexible Elastomeric Couplings .....	29.19
29.5 Universal Joints and Rotating-Link Couplings .....	29.25
29.6 Methods of Attachment .....	29.32

References .....	29.33
Bibliography .....	29.34
<b>30. Clutches and Brakes .....</b>	<b>30.1</b>
30.1 Types, Uses, Advantages, and Characteristics .....	30.4
30.2 Torque and Energy Considerations .....	30.14
30.3 Temperature Considerations .....	30.21
30.4 Friction Materials .....	30.23
30.5 Torque and Force Analysis of Rim Clutches and Brakes .....	30.25
30.6 Band and Cone Brakes and Clutches .....	30.34
30.7 Disk Clutches and Brakes .....	30.40
30.8 Electromagnetic Types .....	30.45
30.9 Actuation Problems .....	30.48
References .....	30.50
Suggested Reading .....	30.50
<b>31. Belt Drives .....</b>	<b>31.1</b>
31.1 General .....	31.2
31.2 Flat-Belt Drive .....	31.14
31.3 V-Belt Drive .....	31.19
31.4 Synchronous-Belt Drive .....	31.25
31.5 Other Belt Drives .....	31.35
31.6 Comparison of Belt Drives .....	31.37
<b>32. Chain Drives .....</b>	<b>32.1</b>
32.1 Types, Uses, and Characteristics .....	32.2
32.2 Roller Chains: Nomenclature and Dimensions .....	32.4
32.3 Selection of Roller-Chain Drives .....	32.7
32.4 Lubrication and Wear .....	32.14
32.5 Engineering Steel Chains: Nomenclature and Dimensions .....	32.18
32.6 Selection of Offset-Sidebar-Chain Drives .....	32.20

32.7	Silent Chains: Nomenclature and Dimensions .....	32.25
32.8	Selection of Silent-Chain Drives .....	32.28
	References .....	32.32
<b>33.</b>	<b>Spur Gears .....</b>	<b>33.1</b>
33.1	Definitions .....	33.1
33.2	Tooth Dimensions and Standards .....	33.4
33.3	Force Analysis .....	33.5
33.4	Fundamental AGMA Rating Formulas .....	33.6
<b>34.</b>	<b>Bevel and Hypoid Gears .....</b>	<b>34.1</b>
34.1	Introduction .....	34.1
34.2	Terminology .....	34.1
34.3	Gear Manufacturing .....	34.7
34.4	Gear Design Considerations .....	34.10
34.5	Gear-Tooth Dimensions .....	34.19
34.6	Gear Strength .....	34.25
34.7	Design of Mountings .....	34.50
34.8	Computer-Aided Design .....	34.55
<b>35.</b>	<b>Helical Gears .....</b>	<b>35.1</b>
35.1	Introduction .....	35.1
35.2	Types .....	35.2
35.3	Advantages .....	35.2
35.4	Geometry .....	35.5
35.5	Load Rating .....	35.8
	References .....	35.57
<b>36.</b>	<b>Worm Gearing .....</b>	<b>36.1</b>
36.1	Introduction .....	36.2
36.2	Kinematics .....	36.3
36.3	Velocity and Friction .....	36.5

36.4	Force Analysis .....	36.5
36.5	Strength and Power Rating .....	36.9
36.6	Heat Dissipation .....	36.12
36.7	Design Standards .....	36.13
36.8	Double-Enveloping Gear Sets .....	36.18
	References .....	36.22
	Additional Reference .....	36.22
<b>37.</b>	<b>Shafts .....</b>	<b>37.1</b>
37.1	Introduction .....	37.2
37.2	Distortion Due to Bending .....	37.3
37.3	Distortion Due to Transverse Shear .....	37.8
37.4	Distortion Due to Torsion .....	37.13
37.5	Shaft Materials .....	37.13
37.6	Load-Induced Stresses .....	37.14
37.7	Strength .....	37.15
37.8	Critical Speeds .....	37.17
37.9	Hollow Shafts .....	37.19
	References .....	37.21
	Recommended Reading .....	37.21
<b>38.</b>	<b>Vibration and Control of Vibration .....</b>	<b>38.1</b>
38.1	Introduction .....	38.1
38.2	Single-Degree-of-Freedom Systems .....	38.1
38.3	Systems with Several Degrees of Freedom .....	38.19
38.4	Vibration Isolation .....	38.28
	References .....	38.30
<b>39.</b>	<b>A Thesaurus of Mechanisms .....</b>	<b>39.1</b>
<b>40.</b>	<b>Cam Mechanisms .....</b>	<b>40.1</b>
	Summary .....	40.1

40.1	Cam Mechanism Types, Characteristics, and Motions .....	40.1
40.2	Basic Cam Motions .....	40.6
40.3	Layout and Design; Manufacturing Considerations .....	40.17
40.4	Force and Torque Analysis .....	40.22
40.5	Contact Stress and Wear: Programming .....	40.25
	References .....	40.28
<b>41.</b>	<b>Linkages .....</b>	<b>41.1</b>
41.1	Basic Linkage Concepts .....	41.1
41.2	Mobility Criterion .....	41.4
41.3	Establishing Precision Positions .....	41.4
41.4	Plane Four-Bar Linkage .....	41.4
41.5	Plane Offset Slider-Crank Linkage .....	41.8
41.6	Kinematic Analysis of the Planar Four-Bar Linkage .....	41.8
41.7	Dimensional Synthesis of the Planar Four-Bar Linkage: Motion Generation .....	41.10
41.8	Dimensional Synthesis of the Planar Four-Bar Linkage: Crank-Angle Coordination .....	41.18
41.9	Pole-Force Method .....	41.20
41.10	Spatial Linkages .....	41.21
	References .....	41.22
<b>42.</b>	<b>Load-Cycle Analysis .....</b>	<b>42.1</b>
42.1	Introduction .....	42.1
42.2	Load-Dominated Energy Transmission System .....	42.4
42.3	Machine-Cycle Analysis .....	42.5
42.4	Load Plots .....	42.7
	References .....	42.9
<b>43.</b>	<b>Fluid Power Systems and Circuit Design .....</b>	<b>43.1</b>
43.1	Pressure Plots .....	43.2
43.2	Flow Plots .....	43.2

43.3 Power Plots ..... 43.3

43.4 Cycle Profile ..... 43.4

43.5 Circuit Design ..... 43.4

43.6 Open-Loop and Closed-Loop Circuits ..... 43.5

43.7 Constant-Flow Versus Demand-Flow Circuits–Open  
Loop ..... 43.12

43.8 Demand-Flow Circuits ..... 43.20

43.9 Hydraulic Versus Pneumatic Systems ..... 43.28

43.10 Pneumatic Circuits ..... 43.28

43.11 Effect of Fluid Characteristics on Actuator Performance ..... 43.28

43.12 Effect of Fluid Characteristics on Control-Valve  
Performance ..... 43.31

43.13 Basic Pneumatic Power Circuit ..... 43.32

43.14 Fluid Logic Systems ..... 43.38

References ..... 43.47

**44. Corrosion ..... 44.1**

44.1 Introduction ..... 44.1

44.2 Corrosion Rates ..... 44.2

44.3 Metal Attack Mechanisms ..... 44.2

44.4 Corrosion Data for Materials Selection ..... 44.28

References ..... 44.28

**45. Noise and Its Control ..... 45.1**

45.1 Introduction ..... 45.1

45.2 Noise Measurement and Analysis ..... 45.2

45.3 Noise Effects and Standards ..... 45.15

45.4 Noise Control ..... 45.18

References ..... 45.37

**46. Gear Trains ..... 46.1**

46.1 Ordinary Gear Trains ..... 46.1



46.2	Gear Type Selection .....	46.3
46.3	Planetary Gear Trains .....	46.5
46.4	Differential Trains .....	46.14
	References .....	46.16
<b>47.</b>	<b>Robots and Smart Machines .....</b>	<b>47.1</b>
47.1	Introduction .....	47.1
47.2	Design and Function .....	47.6
47.3	Structural Design .....	47.8
47.4	Actuation and Power Transmission Systems .....	47.12
47.5	Sensing Systems .....	47.17
47.6	Computer Hardware and Software Organization .....	47.21
47.7	Controller Design .....	47.26
47.8	Geometric Design .....	47.29
47.9	Tool Design .....	47.39
	References .....	47.39
<b>48.</b>	<b>Sections and Shapes–Tabular Data .....</b>	<b>48.1</b>
48.1	Centroids and Center of Gravity .....	48.1
48.2	Second Moments of Areas .....	48.11
48.3	Preferred Numbers and Sizes .....	48.14
48.4	Sizes and Tolerances of Steel Sheets and Bars .....	48.17
48.5	Wire and Sheet Metal .....	48.37
48.6	Structural Shapes .....	48.37
	References .....	48.37
<b>49.</b>	<b>Stress .....</b>	<b>49.1</b>
49.1	Definitions and Notation .....	49.1
49.2	Triaxial Stress .....	49.3
49.3	Stress-Strain Relations .....	49.4
49.4	Flexure .....	49.10

49.5	Stresses Due to Temperature .....	49.14
49.6	Contact Stresses .....	49.17
	References .....	49.22
<b>50.</b>	<b>Deflection .....</b>	<b>50.1</b>
50.1	Stiffness or Spring Rate .....	50.2
50.2	Deflection Due to Bending .....	50.3
50.3	Properties of Beams .....	50.3
50.4	Computer Analysis .....	50.3
50.5	Analysis of Frames .....	50.15
<b>Appendices</b> .....		<b>A.1</b>
	Standard Prefixes for Metric Units .....	A.1
	Greek Letters .....	A.1
	Conversion Factors <i>A</i> to Convert Input <i>X</i> to Output <i>Y</i> Using the Formula $Y = AX$ .....	A.1
	List of Symbols in General Use in Machine Design .....	A.2
<b>Index</b> .....		<b>I.1</b>