



# Contents

*Preface xvii*

*List of Symbols xxiii*

## PART ONE BASICS

1

### Introduction

3

- |  |                                   |
|--|-----------------------------------|
| 1-1 The Meaning of Design              | 1-9 Factor of Safety              |
| 1-2 Mechanical Engineering Design      | 1-10*Reliability                  |
| 1-3 The Phases of Design               | 1-11 Economics                    |
| 1-4 Recognition and Identification     | 1-12 Safety and Product Liability |
| 1-5 Evaluation and Presentation        | 1-13 Units                        |
| 1-6 Design Considerations              | 1-14 Rules for Use of SI Units    |
| 1-7 Codes and Standards                | 1-15 Preferred Units              |
| 1-8 Stress and Strength Considerations |                                   |

2

### Stress

25

- |                       |                                    |
|-----------------------|------------------------------------|
| 2-1 Stress Components | 2-4 Uniformly Distributed Stresses |
| 2-2 Mohr's Circle     | 2-5 Elastic Strain                 |
| 2-3 Triaxial Stress   | 2-6 Stress-Strain Relations        |

\*Italic section numbers denote optional-reading sections.

2-7	Equilibrium	2-15	Stress Concentration
2-8	Shear and Moment	2-16	Stresses in Cylinders
2-9	Singularity Functions	2-17	Rotating Rings
2-10	Normal Stresses in Flexure	2-18	Press and Shrink Fits
2-11	Beams with Asymmetrical Sections	2-19	Temperature Effects
2-12	Shear Stresses in Beams	2-20	Curved Members in Flexure
2-13	Shear Stresses in Rectangular-Section Beams	2-21	Contact Stresses
2-14	Torsion		

3  
Deflection and Stiffness  
91

3-1	Spring Rates	3-10	Castigliano's Theorem
3-2	Tension, Compression, and Torsion	3-11	Statically Indeterminate Problems
3-3	Flexure	3-12	Deflection of Curved Members
3-4	The Area-Moment Method	3-13	Compression Members—General
3-5	Finding Deflections by Use of Singularity Functions	3-14	Long Columns with Central Loading
3-6	Finding Deflections by Numerical Integration	3-15	Intermediate Length Columns with Central Loading
3-7	Shock and Impact	3-16	Columns with Eccentric Loading
3-8	Analysis of Impact	3-17	Struts, or Short Compression Members
3-9	Strain Energy		

4  
Statistical Considerations  
145

4-1	Random Variables	4-8	Limits and Fits
4-2	The Arithmetic Mean, the Variance, and the Standard Deviation	4-9	Dimensions and Tolerancing
4-3	Data Processing	4-10	The Lognormal Distribution
4-4	Regression	4-11	The Weibull Distribution
4-5	Notation and Definitions	4-12	The Weibull Parameters
4-6	The Normal Distribution	4-13	Ranking
4-7	Propagation of Error		

PART TWO  
FAILURE PREVENTION

5  
Materials  
185

5-1	Static Strength	5-6	Temperature Effects
5-2	Plastic Deformation	5-7	Numbering Systems
5-3	Strength and Cold Work	5-8	Sand Casting
5-4	Hardness	5-9	Shell Molding
5-5	Impact Properties	5-10	Investment Casting

5-11	Powder-Metallurgy Process	5-19	Plastics
5-12	Hot Working Processes	5-20	Notch Sensitivity
5-13	Cold Working Processes	5-21	Introduction to Fracture Mechanics
5-14	The Heat Treatment of Steel	5-22	Stress State in a Crack
5-15	Alloy Steels	5-23	Fracture Toughness
5-16	Corrosion-Resistant Steels	5-24	Fracture Conditions
5-17	Casting Materials	5-25	Stress Intensity Factors
5-18	Nonferrous Metals	5-26	Stress Corrosion Cracking

6  
Steady Loading  
223

6-1	Static Strength	6-8	The Internal-Friction Theory
6-2	Stress Concentration	6-9	Failure of Ductile Materials
6-3	Failure Theories	6-10	Failure of Brittle Materials
6-4	The Maximum-Normal-Stress Theory	6-11	Stochastic Analysis—Introduction
6-5	The Maximum-Normal-Strain Theory	6-12	Factor of Safety—A Note
6-6	The Maximum-Shear-Stress Theory	6-13	Lognormal Interference
6-7	The Strain-Energy Theories	6-14	Interference—General

7  
Variable Loading  
269

7-1	Introduction	7-10	The Endurance Limit as a Random Variable
7-2	The Strain-Life Theory of Fatigue Failure	7-11	The Distributions
7-3	Stress-Life—Definitions	7-12	Fluctuating Stresses
7-4	Preliminary Observations	7-13	Fatigue Strength under Fluctuating Stresses
7-5	The Endurance Limit	7-14	Torsional Fatigue Strength under Pulsating Stresses
7-6	The Fatigue Strength	7-15	Combinations of Loading Modes
7-7	The Endurance-Limit and Fatigue-Strength Variates	7-16	Cumulative Fatigue Damage
7-8	Endurance-Limit Modifying Factors	7-17	The Fracture-Mechanics Approach
7-9	Miscellaneous-Effects Factor $k_e$	7-18	Surface Strength

PART THREE  
DESIGN OF MECHANICAL ELEMENTS

8  
The Design of Screws,  
Fasteners, and Connections  
325

8-1	Thread Standards and Definitions	8-5	Tension Connections—The Members
8-2	The Mechanics of Power Screws	8-6	Bolt Strength
8-3	Threaded Fasteners	8-7	Tension Connections—The External Load
8-4	Tension Connections—The Fastener	8-8	Torque Requirements



- 8-9 Bolt Preload—Static Loading
- 8-10 Gasketed Joints
- 8-11 Fatigue Loading
- 8-12 Stochastic Considerations
- 8-13 Bolted and Riveted Joints Loaded in Shear
- 8-14 Centroids of Bolt Groups
- 8-15 Shear of Bolts and Rivets Due to Eccentric Loading
- 8-16 Set Screws
- 8-17 Keys and Pins

9  
Welded, Brazed,  
and Bonded Joints  
383

- 9-1 Welding Symbols
- 9-2 Butt and Fillet Welds
- 9-3 Torsion in Welded Joints
- 9-4 Bending in Welded Joints
- 9-5 The Strength of Welded Joints
- 9-6 Resistance Welding
- 9-7 Bonded Joints

10  
Mechanical Springs  
413

- 10-1 Stresses in Helical Springs
- 10-2 The Curvature Effect
- 10-3 Deflection of Helical Springs
- 10-4 Extension Springs
- 10-5 Compression Springs
- 10-6 Stability
- 10-7 Spring Materials
- 10-8 Design of Helical Springs
- 10-9 Stochastic Considerations
- 10-10 Critical Frequency of Helical Springs
- 10-11 Fatigue Loading
- 10-12 Helical Torsion Springs
- 10-13 Belleville Springs
- 10-14 Miscellaneous Springs

11  
Rolling Contact Bearings  
451

- 11-1 Bearing Types
- 11-2 Bearing Life
- 11-3 Bearing Load
- 11-4 Bearing Survival
- 11-5 The Reliability Goal
- 11-6 Selection of Ball and Straight Roller Bearings
- 11-7 Selection of Tapered Roller Bearings
- 11-8 Load Cycle Analysis
- 11-9 Lubrication
- 11-10 Mounting and Enclosure

12  
Lubrication and  
Journal Bearings  
479

- 12-1 Types of Lubrication
- 12-2 Viscosity
- 12-3 Petroff's Law
- 12-4 Stable Lubrication
- 12-5 Thick-Film Lubrication
- 12-6 Hydrodynamic Theory
- 12-7 Design Considerations
- 12-8 The Relation of the Variables

- 12-9 Temperature and Viscosity Considerations
- 12-10 Clearance
- 12-11 Pressure-Fed Bearings
- 12-12 Heat Balance
- 12-13 Loads and Materials
- 12-14 Bearing Types
- 12-15 Thrust Bearings
- 12-16 Boundary-Lubricated Bearings

13  
Gearing—General  
527

- 13-1 Types of Gears
- 13-2 Nomenclature
- 13-3 Conjugate Action
- 13-4 Involute Properties\*
- 13-5 Fundamentals
- 13-6 Contact Ratio
- 13-7 Interference
- 13-8 The Forming of Gear Teeth
- 13-9 Straight Bevel Gears
- 13-10 Parallel Helical Gears
- 13-11 Worm Gears
- 13-12 Tooth Systems
- 13-13 Gear Trains
- 13-14 Force Analysis of Spur Gears
- 13-15 Bevel Gears—Force Analysis
- 13-16 Helical Gears—Force Analysis
- 13-17 Worm Gearing—Force Analysis

14  
Spur and Helical Gears  
585

- 14-1 The Lewis Formula
- 14-2 Surface Durability
- 14-3 The AGMA Stress Formulas
- 14-4 The AGMA Strength Formulas
- 14-5 Geometry Factors  $I$  and  $J$
- 14-6 The Elastic Coefficient  $C_p$
- 14-7 Dynamic Factors  $C_v$  and  $K_v$
- 14-8 Application Factors  $C_a$  and  $K_a$
- 14-9 Surface Condition Factor  $C_f$
- 14-10 Size Factors  $C_s$  and  $K_s$
- 14-11 Load Distribution Factors  $C_m$  and  $K_m$
- 14-12 Hardness-Ratio Factor  $C_H$
- 14-13 Life Factors  $C_L$  and  $K_L$
- 14-14 Reliability Factors  $C_R$  and  $K_R$

15  
Bevel and Worm Gears  
615

- 15-1 Bevel Gearing—General
- 15-2 Bevel Gear Stresses
- 15-3 Worm Gearing

16  
Clutches, Brakes, Couplings,  
and Flywheels  
627

- 16-1 Statics
- 16-2 Internal Expanding Rim Clutches and Brakes
- 16-3 External-Contracting Rim Clutches and Brakes
- 16-4 Band-Type Clutches and Brakes
- 16-5 Frictional-Contact Axial Clutches
- 16-6 Disk Brakes
- 16-7 Cone Clutches and Brakes

- 16-8 Energy Considerations
- 16-9 Temperature Rise
- 16-10 Friction Materials

- 16-11 Miscellaneous Clutches and Couplings
- 16-12 Flywheels

17

Flexible Mechanical Elements

665

- 17-1 Belts
- 17-2 Flat- and Round-Belt Drives
- 17-3 V Belts
- 17-4 Timing Belts

- 17-5 Roller Chains
- 17-6 Wire Rope
- 17-7 Flexible Shafts

18

Shafts, Axles, and Spindles

697

- 18-1 Introduction
- 18-2 Determination of Shaft Geometry
- 18-3 Static Loading—General
- 18-4 Static Loading—Bending and Torsion
- 18-5 Fatigue

- 18-6 An Example of Fatigue Analysis
- 18-7 Additional Solutions
- 18-8 Stiffness Considerations
- 18-9 Estimating Reliability—A Stochastic Task

Appendix

725

- A-1 Standard SI Prefixes
- A-2 Conversion Factors
- A-3 Optional SI Units for Stress
- A-4 Optional SI Units for Deflection
- A-5 Physical Constants of Materials
- A-6 Properties of Structural Steel Angles
- A-7 Properties of Structural Steel Channels
- A-8 Properties of Round Tubing
- A-9 Shear, Moment, and Deflection of Beams
- A-10 Cumulative Density Function of Normal Distribution
- A-11 A Selection of International Tolerance Grades—Metric Series
- A-12 Fundamental Deviations for Shafts—Metric Series
- A-13 A Selection of International Tolerance Grades—Inch Series
- A-14 Fundamental Deviations for Shafts—Inch Series
- A-15 Charts of Theoretical Stress-Concentration Factors  $K_t$

- A-16 Stress Concentration Factors  $K_t$  and  $K_{ts}$  for a Round Bar or Tube with a Transverse Round Hole
- A-17 Preferred Sizes and Renard (R Series) Numbers
- A-18 Geometric Properties
- A-19 American Standard Pipe
- A-20 Mechanical Properties of Some Hot-Rolled and Cold-Drawn Steels
- A-21 Mechanical Properties of Some Heat Treated Steels
- A-22 Results of Tensile Tests of Some Metals
- A-23 Mechanical Properties of Some Aluminum Alloys
- A-24 Typical Properties of Gray Cast Iron
- A-25 Decimal Equivalents of Wire and Sheet-Metal Gauges
- A-26 Dimensions of Square and Hex Bolts
- A-27 Dimensions of Hex Cap Screws and Heavy Hex Screws
- A-28 Dimensions of Hex Nuts