

---

# Table of Contents

## ***PART I Deformations and Displacements ..... 1***

<b>Chapter 1</b>	Deformations in Mechanisms and Load Distribution over the Mated Surfaces of Parts.....	3
Reference.....		9
<b>Chapter 2</b>	Movements in Rigid Connections and Damage to the Joint Surfaces.....	11
2.1	Interference-Fit Connections (IFCs) .....	11
2.1.1	IFCs Loaded with a Torque .....	11
2.1.2	IFCs Loaded with Bending Moment .....	12
2.2	Bolted Connections (BCs).....	14
2.2.1	Forces in Tightened BC under Centrally Applied Load.....	16
2.2.2	Forces in Tightened BC under an Eccentrically Applied Load .....	18
2.3	Damage to the Mating Surfaces in the Slip Area.....	19
References .....		20
<b>Chapter 3</b>	Deformations and Stress Patterns in Machine Components .....	21
3.1	Structure and Strength of Metals .....	21
3.2	Deformations in the Elastic Range .....	24
3.3	Elastoplastic Deformation (EPD) of Parts .....	32
3.4	Surface Plastic Deformation (SPD) .....	36
References .....		39

## ***PART II Elements and Units of Machines..... 41***

<b>Chapter 4</b>	Shafts .....	43
4.1	Selecting the Basic Shaft Size .....	43
4.2	Elements of Shaft Design.....	46
4.3	Hollow Shafts .....	53
4.4	Selection of a Loading Layout for Strength Analysis.....	54
4.5	Analysis of Shaft Deformations.....	58
References .....		65
<b>Chapter 5</b>	Shaft-to-Hub Connections .....	67
5.1	General Considerations and Comparison.....	67
5.1.1	Interference-Fit Connections (IFCs) .....	67
5.1.2	Key Joints .....	69
5.1.3	Splined Joints (SJs) .....	70

5.2	Strength Calculation and Design of IFCs .....	71
5.2.1	Calculation for Total Slippage .....	71
5.2.1.1	Surface Pressure .....	72
5.2.1.2	Coefficient of Friction .....	74
5.2.2	Design of IFCs .....	77
5.3	Design and Strength Calculation of Key Joints .....	79
5.3.1	Role of IFC in the Key Joint .....	79
5.3.2	Strength of Keys .....	85
5.3.3	Strength of the Shaft Near the Keyway .....	86
5.3.4	Strength of Hub Near the Keyway .....	88
5.3.5	Round Keys .....	92
5.4	Splined Joints .....	93
5.4.1	SJs Loaded with Torque Only .....	94
5.4.2	SJs Loaded with Torque and Radial Force .....	97
5.4.3	Allowable Bearing Stresses in SJs .....	100
5.4.4	Lubrication of SJs .....	101
	References .....	102
<b>Chapter 6 Supports and Bearings .....</b>		<b>103</b>
6.1	Types and Location of Supports .....	103
6.2	Rolling Bearings (RBs) .....	108
6.2.1	Design of RBs .....	108
6.2.2	Stresses and Failures in RBs .....	111
6.2.3	Design of Supports with Rolling Bearings .....	115
6.2.4	Choice and Arrangement of Supports .....	121
6.2.5	Fits for Bearing Seats .....	123
6.2.6	Requirements for Surfaces Adjoined to RBs .....	131
6.2.7	Elastic Deformation of RBs under Load .....	133
6.2.8	RBs with Raceways on the Parts of the Mechanism .....	135
6.2.9	Lubrication of RBs .....	137
6.3	Sliding Bearings (SBs) .....	138
6.3.1	Friction of Lubricated Surfaces .....	138
6.3.2	Types of SBs .....	140
6.3.3	Materials Used in SBs .....	141
6.3.4	Design of Radial SBs .....	144
6.3.5	Design of Thrust SBs .....	149
6.3.6	Surfaces Connected with SBs: Features Required .....	151
6.3.7	Oil Supply to SBs .....	153
	References .....	158
<b>Chapter 7 Gears .....</b>		<b>159</b>
7.1	Geometry and Kinematics of Gearing .....	160
7.2	Forces in Spur Gearing and Stresses in Teeth .....	167
7.3	Kinds of Tooth Failure .....	170
7.4	Contact Strength (Pitting Resistance) of Teeth .....	174
7.5	Bending Strength (Breakage Resistance) of Gear Teeth .....	181
7.6	Unevenness of Load Distribution across the Face Width (Factor $K_w$ ) .....	187
7.7	Dynamic Load in the Gear Mesh and Factor $K_d$ .....	195
7.8	Load Distribution in Double-Helical Gears (Factor $K_{wh}$ ) .....	197
7.9	Backlash in the Gear Mesh .....	198

7.10	Lubrication of Gears.....	200
7.11	Cooling of Gears .....	208
	References .....	213
<b>Chapter 8</b>	<b>Gear Design.....</b>	<b>215</b>
8.1	Gear and Shaft: Integrate or Separate?.....	215
8.2	Spur and Helical Gears .....	217
8.3	Built-up Gear Wheels.....	224
8.4	Manufacturing Requirements and Gear Design .....	235
8.5	Bevel Gears.....	238
8.6	Design of Teeth .....	239
	References .....	240
<b>Chapter 9</b>	<b>Housings .....</b>	<b>241</b>
9.1	The Function of Housings.....	241
9.2	Materials for Housings.....	243
9.3	Design of Housings .....	248
9.3.1	Housings Split through the Axes of Shafts.....	248
9.3.1.1	Design of Mounting Feet.....	250
9.3.1.2	Design of Lifting Elements.....	251
9.3.2	Housings Split at Right Angle to the Axes of the Shafts.....	251
9.3.3	Nonsplit Housings .....	253
9.4	Deformations and Stiffness Problems.....	254
9.5	Housing Seals .....	255
9.5.1	Sealing of Rigid Connections (Static Seals).....	255
9.5.2	Sealing Movable Joints .....	262
9.5.2.1	Noncontact Seals .....	262
9.5.2.2	Contact Seals.....	264
9.5.2.3	Combined Seals.....	274
	References .....	275
<b>Chapter 10</b>	<b>Bolted Connections (BCs).....</b>	<b>277</b>
10.1	Load Distribution between the Bolts .....	278
10.1.1	Load Distribution in Bolted Joints Loaded in Shear .....	282
10.1.2	Load Distribution in Bolted Joints Loaded in Tension .....	287
10.2	Tightening of Bolts.....	292
10.2.1	Tightening Accuracy .....	292
10.2.2	Stability of Tightening .....	295
10.2.2.1	Self-Loosening of Bolts .....	295
10.2.2.2	Plastic Deformation of Fasteners and Connected Parts .....	295
10.2.3	Locking of Fasteners.....	300
10.3	Correlation between Working Load and Tightening Force of the Bolt .....	302
10.3.1	Load Normal to Joint Surface .....	302
10.3.2	Shear Load .....	305
10.3.3	Bending Load.....	311
10.4	Strength of Fasteners .....	313
10.4.1	Static Strength.....	313
10.4.2	Fatigue Strength .....	317
	References .....	319

<b>Chapter 11</b>	Connection of Units .....	321
11.1	Housing Connections.....	321
11.2	Shaft Connections.....	329
11.2.1	Alignment of Shafts.....	329
11.2.2	Rigid Couplings .....	334
11.2.3	Resilient Couplings.....	336
11.2.4	Gear Couplings .....	342
References	.....	352

## ***PART III Life Prediction of Machine Parts ..... 355***

<b>Chapter 12</b>	Strength of Metal Parts .....	357
-------------------	-------------------------------	-----

12.1	Strength of Metals .....	359
12.1.1	Strength at a Static Load .....	359
12.1.2	Fatigue Strength (Stress Method).....	363
12.1.3	Limited Fatigue Life under Irregular Loading (Stress Method).....	374
12.1.4	Fatigue Life (Strain Method).....	376
12.2	Strength of Machine Elements.....	386
12.2.1	Surface Finish .....	387
12.2.2	Dimensions of the Part .....	387
12.2.3	Stress Concentration .....	388
12.2.4	Use of Factors $K_S$ , $K_d$ , and $K_e$ .....	389
12.3	Comparative Calculations for Strength.....	390
12.4	Real Strength of Materials .....	395
References	.....	396

<b>Chapter 13</b>	Calculations for Strength.....	397
-------------------	--------------------------------	-----

13.1	Characteristics of Stresses in the Part.....	397
13.1.1	Estimation of External Loads .....	397
13.1.2	Determination of Forces Applied to the Part .....	398
13.1.3	Estimation of Stresses in the Part.....	403
13.2	Safety Factors .....	404
13.3	Errors Due to Inappropriate Use of FEM.....	405
13.3.1	Design Principles and Precision of FEM.....	405
13.3.2	Design of Model for FEM Computation.....	407
13.3.3	Interpretation of Boundary Conditions.....	409
13.3.4	Is the Computer Program Correct? .....	412
13.3.5	More about Simplified Analytical Models .....	412
13.3.6	Consideration of Deformations.....	416
13.4	Human Error .....	416
13.4.1	Arithmetic .....	416
13.4.2	Units (Dimensions).....	417
13.4.3	Is This Formula Correct?.....	418
References	.....	419

<b>Chapter 14</b>	Finale .....	421
-------------------	--------------	-----

<b>Index</b>	.....	423
--------------	-------	-----