

Table of Contents

1 Introduction	1
1.1 Contact and Friction Phenomena and their Applications.....	1
1.2 History of Contact Mechanics and the Physics of Friction.....	3
1.3 Structure of the Book.....	7
2 Qualitative Treatment of Contact Problems – Normal Contact without Adhesion	9
2.1 Material Properties.....	10
2.2 Simple Contact Problems	13
2.3 Estimation Method for Contacts with a Three-Dimensional, Elastic Continuum	16
Problems	20
3 Qualitative Treatment of Adhesive Contacts	25
3.1 Physical Background	26
3.2 Calculation of the Adhesive Force between Curved Surfaces	30
3.3 Qualitative Estimation of the Adhesive Force between Elastic Bodies	31
3.4 Influence of Roughness on Adhesion	33
3.5 Adhesive Tape	34
3.6 Supplementary Information about van der Waals Forces and Surface Energies	35
Problems	36
4 Capillary Forces	41
4.1 Surface Tension and Contact Angles.....	41
4.2 Hysteresis of Contact Angles.....	45
4.3 Pressure and the Radius of Curvature.....	45
4.4 Capillary Bridges	46
4.5 Capillary Force between a Rigid Plane and a Rigid Sphere	47
4.6 Liquids on Rough Surfaces.....	48
4.7 Capillary Forces and Tribology	49
Problems	50
5 Rigorous Treatment of Contact Problems – Hertzian Contact.....	55
5.1 Deformation of an Elastic Half-Space being Acted upon by Surface Forces	56
5.2 Hertzian Contact Theory.....	59
5.3 Contact between Two Elastic Bodies with Curved Surfaces	60
5.4 Contact between a Rigid Cone-Shaped Indenter and an Elastic Half-Space	63
5.5 Internal Stresses in Hertzian Contacts	64
Problems	67

6 Rigorous Treatment of Contact Problems – Adhesive Contact.....	71
6.1 JKR-Theory	72
Problems	77
7 Contact between Rough Surfaces.....	81
7.1 Model from Greenwood and Williamson	82
7.2 Plastic Deformation of Asperities.....	88
7.3 Electrical Contacts	89
7.4 Thermal Contacts.....	92
7.5 Mechanical Stiffness of Contacts.....	93
7.6 Seals.....	93
7.7 Roughness and Adhesion.....	94
Problems	95
8 Tangential Contact Problems.....	105
8.1 Deformation of an Elastic Half-Space being Acted upon by Tangential Forces	106
8.2 Deformation of an Elastic Half-Space being Acted upon by a Tangential Stress Distribution	107
8.3 Tangential Contact Problems without Slip	109
8.4 Tangential Contact Problems Accounting for Slip	110
8.5 Absence of Slip for a Rigid Cylindrical Indenter.....	114
Problems	114
9 Rolling Contact.....	119
9.1 Qualitative Discussion of the Processes in a Rolling Contact.....	120
9.2 Stress Distribution in a Stationary Rolling Contact	122
Problems	128
10 Coulomb's Law of Friction	133
10.1 Introduction.....	133
10.2 Static and Kinetic Friction	134
10.3 Angle of Friction.....	135
10.4 Dependence of the Coefficient of Friction on the Contact Time	136
10.5 Dependence of the Coefficient of Friction on the Normal Force.....	137
10.6 Dependence of the Coefficient of Friction on Sliding Speed.....	139
10.7 Dependence of the Coefficient of Friction on the Surface Roughness ..	139
10.8 Coulomb's View on the Origin of the Law of Friction.....	140
10.9 Theory of Bowden and Tabor	142
10.10 Dependence of the Coefficient of Friction on Temperature.....	145
Problems	146
11 The Prandtl-Tomlinson Model for Dry Friction.....	155
11.1 Introduction.....	155
11.2 Basic Properties of the Prandtl-Tomlinson Model.....	157

11.3 Elastic Instability	161
11.4 Superlubricity	165
11.5 Nanomachines: Concepts for Micro and Nano-Actuators	166
Problems	170
12 Frictionally Induced Vibrations.....	175
12.1 Frictional Instabilities at Decreasing Dependence of the Frictional Force on the Velocity	176
12.2 Instability in a System with Distributed Elasticity.....	178
12.3 Critical Damping and Optimal Suppression of Squeal	181
12.4 Active Suppression of Squeal	183
12.5 Strength Aspects during Squeal.....	185
12.6 Dependence of the Stability Criteria on the Stiffness of the System	186
12.7 Sprag-Slip	191
Problems	193
13 Thermal Effects in Contacts	199
13.1 Introduction	200
13.2 Flash Temperatures in Micro-Contacts.....	200
13.3 Thermo-Mechanical Instability.....	202
Problems	203
14 Lubricated Systems	207
14.1 Flow between two parallel plates.....	208
14.2 Hydrodynamic Lubrication.....	209
14.3 “Viscous Adhesion”.....	213
14.4 Rheology of Lubricants	216
14.5 Boundary Layer Lubrication.....	218
14.6 Elastohydrodynamics.....	219
14.7 Solid Lubricants.....	222
Problems	223
15 Viscoelastic Properties of Elastomers.....	231
15.1 Introduction	231
15.2 Stress-Relaxation	232
15.3 Complex, Frequency-Dependent Shear Moduli.....	234
15.4 Properties of Complex Moduli	236
15.5 Energy Dissipation in a Viscoelastic Material.....	237
15.6 Measuring Complex Moduli.....	238
15.7 Rheological Models	239
15.8 A Simple Rheological Model for Rubber (“Standard Model”).....	242
15.9 Influence of Temperature on Rheological Properties	244
15.10 Master Curves.....	245
15.11 Prony Series	246
Problems	250

16 Rubber Friction and Contact Mechanics of Rubber	255
16.1 Friction between an Elastomer and a Rigid Rough Surface.....	255
16.2 Rolling Resistance	261
16.3 Adhesive Contact with Elastomers	263
Problems	265
17 Wear	271
17.1 Introduction.....	271
17.2 Abrasive Wear	272
17.3 Adhesive Wear.....	275
17.4 Conditions for Low-Wear Friction	278
17.5 Wear as the Transportation of Material from the Friction Zone	279
17.6 Wear of Elastomers.....	280
Problems	283
18 Friction Under the Influence of Ultrasonic Vibrations	285
18.1 Influence of Ultrasonic Vibrations on Friction from a Macroscopic Point of View.....	286
18.2 Influence of Ultrasonic Vibrations on Friction from a Microscopic Point of View.....	291
18.3 Experimental Investigations of the Force of Static Friction as a Function of the Oscillation Amplitude.....	293
18.4 Experimental Investigations of Kinetic Friction as a Function of Oscillation Amplitude.....	295
Problems	297
19 Numerical Simulation Methods in Friction Physics	301
19.1 Simulation Methods for Contact and Frictional Problems: An Overview.....	302
19.1.1 Many-Body Systems	302
19.1.2 Finite Element Methods	303
19.1.3 Boundary Element Method.....	304
19.1.4 Particle Methods.....	305
19.2 Reduction of Contact Problems from Three Dimensions to One Dimension.....	306
19.3 Contact in a Macroscopic Tribological System	307
19.4 Reduction Method for a Multi-Contact Problem	311
19.5 Dimension Reduction and Viscoelastic Properties	315
19.6 Representation of Stress in the Reduction Model	316
19.7 The Calculation Procedure in the Framework of the Reduction Method.....	317
19.8 Adhesion, Lubrication, Cavitation, and Plastic Deformations in the Framework of the Reduction Method	318
Problems	318

20 Earthquakes and Friction.....	323
20.1 Introduction	324
20.2 Quantification of Earthquakes	325
20.2.1 Gutenberg-Richter Law.....	326
20.3 Laws of Friction for Rocks	327
20.4 Stability during Sliding with Rate- and State-Dependent Friction	331
20.5 Nucleation of Earthquakes and Post-Sliding	334
20.6 Foreshocks and Aftershocks	337
20.7 Continuum Mechanics of Block Media and the Structure of Faults	338
20.8 Is it Possible to Predict Earthquakes?	342
Problems	343
Appendix.....	347
Further Reading.....	351
Figure Reference	357
Index.....	359