

Contents

Part 1 Mechanisms

Chapter 1 Introduction 3

- 1.1 Introduction to the Study of Mechanisms 3
- 1.2 Mechanisms, Machine 6
- 1.3 Motion 7
- 1.4 Cycle, Period, and Phase of Motion 9
- 1.5 Pairing Elements 9
- 1.6 Link, Chain 9
- 1.7 Inversion 10
- 1.8 Transmission of Motion 10
- PROBLEMS 13

Chapter 2 Linkages 15

- 2.1 Four-Bar Linkage 15
- 2.2 Slider-Crank Mechanism 19
- 2.3 Scotch Yoke 21
- 2.4 Quick-Return Mechanisms 22
- 2.5 Toggle Mechanism 24
- 2.6 Oldham Coupling 25
- 2.7 Straight-Line Mechanisms 25
- 2.8 Pantograph 26
- 2.9 Chamber Wheels 26
- 2.10 Hooke's Coupling 28
- 2.11 Constant Velocity Universal Joints 30
- 2.12 Intermittent Motion Mechanisms 33
- 2.13 Synthesis 38
- PROBLEMS 38

Chapter 3 Cams 45

- 3.1 Disk Cam with Radial Follower 46
- 3.2 Disk Cam with Oscillating Follower 49
- 3.3 Positive-Return Cam 51
- 3.4 Cylinder Cam 52
- 3.5 Inverse Cam 53
- 3.6 Disk Cam with Radial Flat-Faced Follower 62
- 3.7 Disk Cam with Radial Roller Follower 68
- 3.8 Disk Cam with Oscillating Roller Follower 76
- 3.9 Three-Dimensional Cams 80
- PROBLEMS 83

Chapter 4 Spur Gears 93

- 4.1 Introduction to Involute Spur Gears 93
- 4.2 Involutometry 97
- 4.3 Spur Gear Details 100
- 4.4 Characteristics of Involute Action 101
- 4.5 Interference in Involute Gears 107
- 4.6 Interchangeable Gears 109
- 4.7 Minimum Number of Teeth to Avoid Interference 14
- 4.8 Determination of Backlash 118
- 4.9 Internal (Annular) Gears 122
- 4.10 Cycloidal Gears 123
- PROBLEMS 125

Chapter 5 Nonstandard Spur Gears 129

- 5.1 Theory of Nonstandard Spur Gears 129
- 5.2 Extended Center Distance System 131
- 5.3 Long and Short Addendum System 139
- 5.4 Recess-Action Gears 141
- PROBLEMS 145

Chapter 6 Bevel, Helical, and Worm Gearing 148

- 6.1 Theory of Bevel Gears 148
- 6.2 Bevel Gear Details 153
- 6.3 Gleason Straight Bevel Gear Tooth Proportions 155
- 6.4 Angular Straight Bevel Gears 156
- 6.5 Zerol Bevel Gears 156
- 6.6 Spiral Bevel Gears 157
- 6.7 Hypoid Gears 157
- 6.8 Theory of Helical Gears 160
- 6.9 Parallel Helical Gears 165

- 6.10 Crossed Helical Gears 169
- 6.11 Worm Gearing 171
- PROBLEMS 175

Chapter 7 Gear Trains 180

- 7.1 Introduction to Gear Trains 180
- 7.2 Planetary Gear Trains 183
- 7.3 Applications of Planetary Gear Trains 193
- 7.4 Assembly of Planetary Gear Trains 196
- PROBLEMS 200

Chapter 8 Computing Mechanisms 215

- 8.1 Digital Computers 215
- 8.2 Analog Computers 215
- 8.3 Addition and Subtraction 216
- 8.4 Multiplication and Division 219
- 8.5 Integration 220
- 8.6 Trigonometric Functions 225
- 8.7 Inversion 227
- 8.8 Squares, Square Roots, and Square Roots of Products 228
- 8.9 Computing Cams and Gears 230
- 8.10 Linkage Function Generator 236
- 8.11 Accuracy 236
- 8.12 Block Diagrams 237
- PROBLEMS 240

Chapter 9 Introduction to Synthesis 244

- 9.1 Spacing of Accuracy Points 245
- 9.2 Design of Four-Bar Linkage for Instantaneous Values of Angular Velocity and Acceleration 246
- 9.3 Design of Four-Bar Linkage as a Function Generator 2
- 9.4 Graphical Design of Four-Bar Linkage as a Function Generator 260
- PROBLEMS 262

Part 2 Dynamics of Machinery

Chapter 10 Kinematics of Machinery 267

- 10.1 Introduction 267
- 10.2 Linear Motion of a Particle 269

10.3	Angular Motion	273
10.4	Relative Motion	274
10.5	Methods of Velocity and Acceleration Analysis	275
10.6	Velocity and Acceleration Analysis by Vector Mathematics	275
10.7	Graphical Determination of Velocity in Mechanisms	288
10.8	Relative Velocity of Particles in Mechanisms	288
10.9	Relative Velocity of Particles in a Common Link	289
10.10	Relative Velocity of Coincident Particles on Separate Links	293
10.11	Relative Velocity of Coincident Particles at the Point of Contact of Rolling Elements	297
10.12	Instantaneous Centers of Velocity	299
10.13	Instantaneous Center Notation	301
10.14	Kennedy's Theorem	302
10.15	Determination of Instantaneous Centers by Kennedy's Theorem	303
10.16	Determination of Velocity by Instantaneous Centers	305
10.17	Rolling Elements	308
10.18	Graphical Determination of Acceleration in Mechanisms	309
10.19	Relative Acceleration of Particles in Mechanisms	309
10.20	Relative Acceleration of Particles in a Common Link	309
10.21	Relative Acceleration of Coincident Particles on Separate Links. Coriolis Component of Acceleration	313
10.22	Relative Acceleration of Coincident Particles at the Point of Contact of Rolling Elements	321
10.23	Analytical Solution of Relative Velocity and Acceleration Equations by Unit Vectors	325
10.24	Graphical Differentiation	330
10.25	Kinematic Analysis by Complex Numbers	336
10.26	Kinematic Analysis of the Slider-Crank by Complex Numbers	339
10.27	Inversion of the Slider-Crank	343
10.28	Analysis of the Four-Bar Linkage	345
10.29	Complex Mechanisms	349
10.30	Spatial Linkages	351
	PROBLEMS	353
Chapter 11	Force Analysis of Machinery	378
11.1	Introduction	378
11.2	Centrifugal Force in Rotor Blades	379
11.3	Inertia Force. Inertia Torque	382
11.4	Force Determination	385

- 11.5 Methods of Linkage-Force Analysis 387
- 11.6 Linkage Analysis by the Method of Virtual Work 404
- 11.7 Linkage Motion Analysis from Dynamic Characteristics 408
- 11.8 Linkage Force Analysis by Complex Numbers 412
- 11.9 Engine Force Analysis 419
- 11.10 Dynamically Equivalent Masses 425
- 11.11 Application of Equivalent Masses 426
- 11.12 Engine Force Analysis Using Point Masses 427
- 11.13 Engine Block 434
- 11.14 Engine Output Torque 436
- 11.15 Flywheel Size 444
- 11.16 Forces on Gear Teeth 447
- 11.17 Cam Forces 453
- 11.18 Gyroscopic Force 456
- 11.19 Moment of Inertia Determination 461
- PROBLEMS 465

- Chapter 12 Balance of Machinery 490**
 - 12.1 Introduction 490
 - 12.2 Balance of Rotors 491
 - 12.3 Dynamic and Static Balance 497
 - 12.4 Balancing Machines 499
 - 12.5 Balance of Reciprocating Masses 500
 - 12.6 Analytical Determination of Unbalance 502
 - 12.7 Firing Order 510
 - 12.8 V Engines 510
 - 12.9 Opposed Engines 513
 - PROBLEMS 514

- Chapter 13 Vibration in Machines 523**
 - 13.1 Introduction 523
 - 13.2 Forced Vibration 524
 - 13.3 Natural Vibration 528
 - 13.4 Amplitude of Forced Vibration 530
 - 13.5 Transmissibility 533
 - 13.6 Motion Transmissibility 535
 - 13.7 Damping 535
 - 13.8 Whirl of Shafts 542
 - 13.9 Natural Frequency and Critical Speed 545
 - 13.10 Natural Frequency of a Shaft with Many Masses 545
 - 13.11 Shafts with Variable Diameter 551

13.12	Higher-Order Critical Speeds	554
13.13	Torsional Vibrations	557
13.14	Torsional Vibration of a Shaft with Two Disks	558
13.15	Torsional Vibration of a Shaft with Many Disks	563
13.16	Stepped Shafts	564
13.17	Torsional Systems with Gears	565
	PROBLEMS	567

Appendices 577

Index