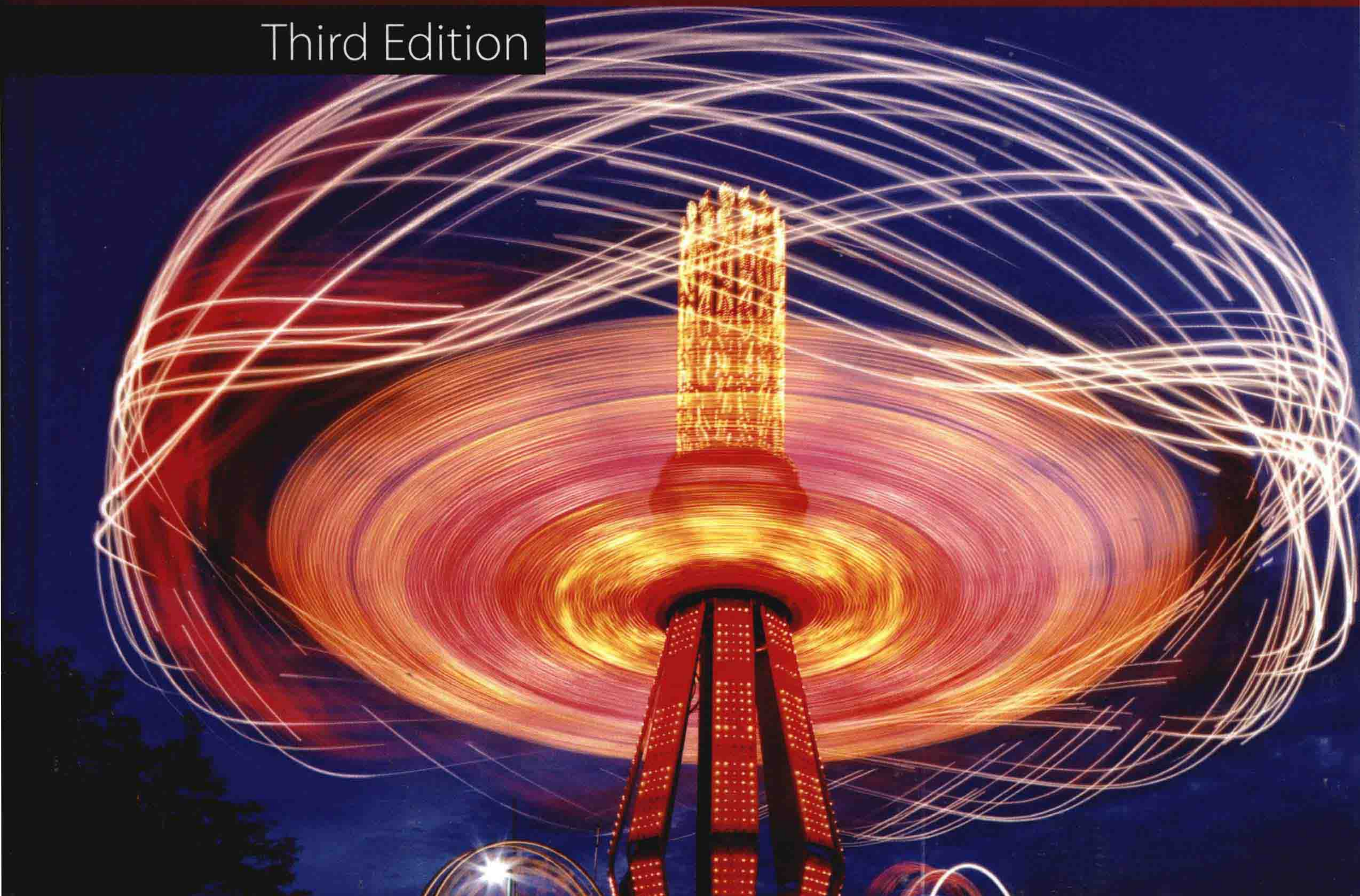
Kinematics, Dynamics, and Design of Machinery

Third Edition



Kenneth J. Waldron • Gary L. Kinzel • Sunil K. Agrawal

with website

WILEY

KINEMATICS, DYNAMICS, AND DESIGN OF MACHINERY

Third Edition

Kenneth J. Waldron
Professor Emeritus, Stanford University, USA
Professor, University of Technology, Sydney, Australia

Gary L. Kinzel
Professor Emeritus, The Ohio State University, USA

Sunil K. Agrawal
Professor, Columbia University, USA

WILEY

© 2016, John Wiley & Sons, Ltd.

Registered office
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com.

The right of the author to be identified as the author of this work has been asserted in accordance with the Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book.

Limit of Liability/Disclaimer of Warranty: While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. It is sold on the understanding that the publisher is not engaged in rendering professional services and neither the publisher nor the author shall be liable for damages arising herefrom. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

MATLAB® is a trademark of The MathWorks, Inc. and is used with permission. The MathWorks does not warrant the accuracy of the text or exercises in this book. This book's use or discussion of MATLAB® software or related products does not constitute endorsement or sponsorship by The MathWorks of a particular pedagogical approach or particular use of the MATLAB® software.

Library of Congress Cataloging-in-Publication Data is available:

ISBN: 978-1-118-93328-2

A catalogue record for this book is available from the British Library.

Set in 10/12pt TimesLTStd-Roman by Thomson Digital, Noida, India

1 2016

KINEMATICS, DYNAMICS, AND DESIGN OF MACHINERY

About the Companion Website

This book is accompanied by two companion websites: one for students and one for certified instructors.

www.wiley.com/go/waldron/kinematics

The student website includes:

- Movie files for selected linkage animations
- Sample Solidworks files illustrating the use of GCP
- MATLAB® programs
- The instructor website (password protected) includes:
  - Solutions manual
  - PowerPoint teaching slides
  - Textbook figures
  - Material in student website

此为试读，需要完整PDF请访问：www.ertongbook.com

Preface

One of the most amazing aspects of the preparation of this new edition of *Kinematics, Dynamics, and Design of Machinery* is the radical nature of the changes we found to be necessary. The first edition of this work appeared in September 1998, and it is appropriate to reflect on the changes that have occurred during the intervening eighteen years. Although this is a core subject in the mechanical engineering curriculum that has been taught in one form or another throughout the period in which it has been recognized as a technical discipline, there have been many recent changes. In 1998, most production machines were still driven by a single prime mover with their various functions mechanically coordinated. It is true that industrial robots were well established in some industries, notably the manufacture of automobiles, but they were still the exception rather than the rule in utilizing digital coordination of multiple actuators. The first edition of this work broke new ground as an undergraduate text by including chapters on robots and spatial mechanisms. Of course, this picture has totally changed with embedded controllers ubiquitous in our appliances, automobiles, and production machinery. Multiple functions are now much more likely to be coordinated digitally. We have recognized this reality by expanding the material on actuation and creating a new Chapter 17. We have, in that chapter, created an interface to courses on control, and particularly digital control.

It is even truer that the tools available to the machine designer are completely different from what was available in 1998. At that time, computer-aided engineering software was certainly well established, but modern solid modeling packages were not well developed. The constraint management capabilities built into these tools provide a very powerful new capability that renders special purpose mechanism design software—such as that we, ourselves, developed—obsolete. In recognition of this new reality, we have introduced a chapter on Geometric Constraint Programming as Chapter 2, and examples of solving mechanism design problems by this means in Chapters 3, 4, 5, and 6. In addition, Chapter 10 on cam design has been completely revised to base it on methods employing instant centers that are much simpler than the methods we used in the earlier editions. For this reason, although this text covers the same technological territory that the first edition did, it is a very different presentation that takes full advantage of new design technologies.

It is also true that the way in which the subject matter is taught has changed. In the years preceding 1998, this material most often formed the content of a separate course in the mechanical engineering curriculum. Since that time, it has become one element in an overarching discipline of mechanical systems, or *mechatronics.* As such, this material is often interleaved with material from control systems engineering and other related disciplines. To facilitate the use of our material as a component of a mechanical systems course, or in machine design courses, we have attempted to make each chapter as modular as possible. There is a box at the beginning of each chapter stating which material from elsewhere in the book is a prerequisite for successful study of that chapter. It is intended that, if the instructor so desires, he or she can place before their students only the material they intend to cover.

In addition to updating even those sections that are similar to those of Editions 1 and 2, we have added a significant number of new problems, including some open-ended design problems. Supporting material that was included on a CD with Editions 1 and 2 is now available on the companion website maintained by John Wiley & Sons: www.wiley.com/go/waldron/kinematics. It has also been updated as necessary.

We trust that this new presentation will be welcomed as an up-to-the-minute teaching tool and a useful reference for instructors and practitioners in this field. Yes, the new approaches are likely to take instructors who have taught the material for a number of years out of their comfort zone, but we believe the required extra effort to become familiar with the new techniques will prove to be very worthwhile.

In order to take advantage of the Geometric Constraint Programming (GCP) techniques, it is necessary for students to have access to parametric design software that incorporates constraint managers. We believe that tomorrow's students will increasingly be working with solid modeling packages throughout the curriculum. If this should prove not to be true, inexpensive drawing packages that have constraint managers are readily available.

We would like to express our sincere thanks to the colleagues and students who have contributed to the success of the three editions of this book. For the third edition, we especially acknowledge the help of Profs. James Schmiedeler and Edward Kinzel who co-developed the GCP procedure. Both provided assistance on writing Chapter 2 and parts of Chapter 3, and Jim in particular generously provided his tutorial notes to facilitate the development of the teaching material. We would also like to thank Dr. Matthew Detrick who rewrote the GUI-based kinematic programs for the new versions of MATLAB®. The programs for both the previous and current versions of MATLAB are included in the supplementary material for the book.

Kenneth J. Waldron
Professor Emeritus, Stanford University
Professor, University of Technology, Sydney

Gary L. Kinzel
Professor Emeritus, The Ohio State University

Sunil K. Agrawal
Professor, Columbia University

Contents

Preface xiii

1 Introduction 1

1.1 Historical Perspective, 1
1.2 Kinematics, 3
1.3 Design: Analysis and Synthesis, 4
1.4 Mechanisms, 4
1.5 Planar Linkages, 6
1.6 Visualization, 9
1.7 Constraint Analysis, 12
1.8 Constraint Analysis of Spatial Linkages, 18
1.9 Idle Degrees of Freedom, 22
1.10 Overconstrained Linkages, 24
1.11 Uses of the Mobility Criterion, 28
1.12 Inversion, 28
1.13 Reference Frames, 29
1.14 Motion Limits, 30
1.15 Continuously Rotatable Joints, 31
1.16 Coupler-Driven Linkages, 35
1.17 Motion Limits for Slider-Crank Mechanisms, 35
1.18 Interference, 38
1.19 Practical Design Considerations, 41
1.19.1 Revolute Joints, 41
1.19.2 Prismatic Joints, 42
1.19.3 Higher Pairs, 44
1.19.4 Cams versus Linkages, 44
References, 44
Problems, 45

2 Techniques in Geometric Constraint Programming 59

2.1 Introduction, 59
2.2 Geometric Constraint Programming, 60
2.3 Constraints and Program Structure, 61
2.3.1 Required Constraints, 61
2.3.2 Other Constraint Options, 62
2.3.3 Annotations, 62
2.3.4 Use of Drawing Layers, 62
2.3.5 Limitations of GCP, 63
2.4 Initial Setup for a GCP Session, 64
2.4.1 Effect of Typical Constraints, 64
2.4.2 Unintended Constraints, 66
2.4.3 Layers, Line Type, and Line Color, 66
2.5 Drawing a Basic Linkage Using GCP, 66
2.5.1 Drawing a Four-Bar Linkage Using GCP, 66
2.5.2 Including Ground Pivots and Bushings, 68
2.5.3 Drawing a Slider-Crank Linkage, 68
2.6 Troubleshooting Graphical Programs Developed Using GCP, 79

References, 80
Problems, 81
Appendix 2A Drawing Slider Lines, Pin Bushings, and Ground Pivots, 85
2A.1 Slider Lines, 85
2A.2 Pin Bushings and Ground Pivots, 87
Appendix 2B Useful Constructions When Equation Constraints Are Not Available, 88
2B.1 Constrain Two Angles to Be Integral Multiples of Another Angle, 89
2B.2 Constrain a Line to Be Half the Length of Another Line, 89
2B.3 Construction for Scaling, 90
2B.4 Construction for Square Ratio v^2/r, 91
2B.5 Construction for Function $x = yz/r$, 91

3 Planar Linkage Design 93
3.1 Introduction, 93
3.2 Two-Position Double-Rocker Design, 96
3.2.1 Graphical Solution Procedure, 97
3.2.2 Solution Using Geometric Constraint Programming, 97
3.2.3 Numerical Solution Procedure, 99
3.3 Synthesis of Crank-Rocker Linkages for Specified Rocker Amplitude, 100
3.3.1 The Rocker-Amplitude Problem: Graphical Approach, 100
3.3.2 Alternative Graphical Design Procedure Based on Specification of A*B*, 105
3.3.3 Using GCP to Design Crank-Rocker and Crank-Shaper Mechanisms, 107
3.4 Motion Generation, 114
3.4.1 Introduction, 114
3.4.2 Two Positions, 114
3.4.3 Three Positions with Selected Moving Pivots, 116
3.4.4 Synthesis of a Crank with Chosen Fixed Pivots, 117
3.4.5 Design of Slider-Cranks and Elliptic-Trammels, 118
3.4.6 Change of Branch, 118
3.4.7 Using GCP for Rigid-Body Guidance, 124
3.5 Path Synthesis, 133
3.5.1 Design of Six-Bar Linkages Using Coupler Curves, 133
3.5.2 Motion Generation for Parallel Motion Using Coupler Curves, 138
3.5.3 Cognate Linkages, 141
3.5.4 Using GCP for Path Synthesis, 144
References, 148
Problems, 150

4 Graphical Position, Velocity, and Acceleration Analysis for Mechanisms with Revolute Joints or Fixed Slides 169
4.1 Introduction, 169
4.2 Graphical Position Analysis, 170
4.3 Planar Velocity Polygons, 171
4.4 Graphical Acceleration Analysis, 173
4.5 Graphical Analysis of a Four-Bar Mechanism, 175
4.6 Graphical Analysis of a Slider-Crank Mechanism, 183
4.7 Velocity Image Theorem, 186
4.8 Acceleration Image Theorem, 189
4.9 Solution by Geometric Constraint Programming, 194
4.9.1 Introduction, 194
4.9.2 Scaling Property of Velocity Polygons, 195
4.9.3 Using GCP to Analyze Linkages That Cannot Be Analyzed by Classical Means for Velocities, 199
References, 205
Problems, 205

5 Linkages with Rolling and Sliding Contacts, and Joints on Moving Sliders 221
5.1 Introduction, 221
5.2 Reference Frames, 222
5.3 General Velocity and Acceleration Equations, 223
5.3.1 Velocity Equations, 223
5.3.2 Acceleration Equations, 225
5.3.3 Chain Rule for Positions, Velocities, and Accelerations, 226
5.4 Special Cases for the Velocity and Acceleration Equations, 228
5.4.1 Two Points Fixed in a Moving Body, 228
5.4.2 Two Points Are Instantaneously Coincident, 229
5.4.3 Two Points Are Instantaneously Coincident and in Rolling Contact, 230
5.5 Linkages with Rotating Sliding Joints, 230
5.6 Rolling Contact, 235
5.6.1 Basic Kinematic Relationships for Rolling Contact, 235
5.6.2 Modeling Rolling Contact Using a Virtual Linkage, 241
5.7 Cam Contact, 243
5.7.1 Direct Approach to the Analysis of Cam Contact, 243
5.7.2 Analysis of Cam Contact Using Equivalent Linkages, 246
5.8 General Coincident Points, 250
5.8.1 Velocity Analyses Involving General Coincident Points, 250
5.8.2 Acceleration Analyses Involving General Coincident Points, 251
5.9 Solution by Geometric Constraint Programming, 257
Problems, 263

6 Instant Centers of Velocity 279
6.1 Introduction, 279
6.2 Definition, 280
6.3 Existence Proof, 280
6.4 Location of an Instant Center from the Directions of Two Velocities, 281
6.5 Instant Center at a Revolute Joint, 282
6.6 Instant Center of a Curved Slider, 282
6.7 Instant Center of a Prismatic Joint, 282
6.8 Instant Center of a Rolling Contact Pair, 282
6.9 Instant Center of a General Cam-Pair Contact, 282
6.10 Centrodes, 283
6.11 The Kennedy-Aronhold Theorem, 285
6.12 Circle Diagram as a Strategy for Finding Instant Centers, 287
6.13 Using Instant Centers to Find Velocities: The Rotating-Radius Method, 287
6.14 Finding Instant Centers Using Geometric Constraint Programming, 295
References, 300
Problems, 300

7 Computational Analysis of Linkages 315
7.1 Introduction, 315
7.2 Position, Velocity, and Acceleration Representations, 316
7.2.1 Position Representation, 316
7.2.2 Velocity Representation, 316
7.2.3 Acceleration Representation, 317
7.2.4 Special Cases, 318
7.2.5 Mechanisms to Be Considered, 319
7.3 Analytical Closure Equations for Four-Bar Linkages, 319
7.3.1 Solution of Closure Equations for Four-Bar Linkages When Link 2 Is the Driver, 319
7.3.2 Analysis When the Coupler (Link 3) Is the Driving Link, 322

7.3.3 Velocity Equations for Four-Bar Linkages, 322
7.3.4 Acceleration Equations for Four-Bar Linkages, 323
7.4 Analytical Equations for a Rigid Body after the Kinematic Properties of Two Points Are Known, 326
7.5 Analytical Equations for Slider-Crank Mechanisms, 329
7.5.1 Solution to Position Equations When θ_2 Is Input, 330
7.5.2 Solution to Position Equations When r_1 Is Input, 332
7.5.3 Solution to Position Equations When θ_3 Is Input, 333
7.5.4 Velocity Equations for Slider-Crank Mechanism, 334
7.5.5 Acceleration Equations for Slider-Crank Mechanism, 334
7.6 Other Four-Bar Mechanisms with Revolute and Prismatic Joints, 338
7.6.1 Slider-Crank Inversion, 339
7.6.2 A RPRP Mechanism, 339
7.6.3 A RRPP Mechanism, 340
7.6.4 Elliptic-Trammel Mechanism, 340
7.6.5 Oldham Mechanism, 341
7.7 Closure or Loop Equation Approach for Compound Mechanisms, 341
7.7.1 Handling Points Not on the Vector Loops, 344
7.7.2 Solving the Position Equations, 345
7.8 Closure Equations for Mechanisms with Higher Pairs, 347
7.9 Notational Differences: Vectors and Complex Numbers, 352
Problems, 354

8 Special Mechanisms 361
8.1 Special Planar Mechanisms, 361
8.1.1 Introduction, 361
8.1.2 Straight-Line and Circle Mechanisms, 362
8.1.3 Pantographs, 368
8.2 Spherical Mechanisms, 374
8.2.1 Introduction, 374
8.2.2 Gimbals, 376
8.2.3 Universal Joints, 377
8.3 Constant-Velocity Couplings, 381
8.3.1 Geometric Requirements of Constant-Velocity Couplings, 381
8.3.2 Practical Constant-Velocity Couplings, 381
8.4 Automotive Steering and Suspension Mechanisms, 382
8.4.1 Introduction, 382
8.4.2 Steering Mechanisms, 382
8.4.3 Suspension Mechanisms, 386
8.5 Indexing Mechanisms, 387
8.5.1 Geneva Mechanisms, 387
References, 392
Problems, 392

9 Computational Analysis of Spatial Linkages 395
9.1 Spatial Mechanisms, 395
9.1.1 Introduction, 395
9.1.2 Velocity and Acceleration Relationships, 396
9.2 Robotic Mechanisms, 401
9.3 Direct Position Kinematics of Serial Chains, 403
9.3.1 Introduction, 403
9.3.2 Concatenation of Transformations, 404
9.3.3 Homogeneous Transformations, 407
9.4 Inverse Position Kinematics, 410

此为试读，需要完整PDF请访问： www.ertongbook.com

9.5 Rate Kinematics, 410
9.5.1 Introduction, 410
9.5.2 Direct Rate Kinematics, 410
9.5.3 Inverse Rate Kinematics, 414
9.6 Closed-Loop Linkages, 416
9.7 Lower-Pair Joints, 418
9.8 Motion Platforms, 421
9.8.1 Mechanisms Actuated in Parallel, 421
9.8.2 The Stewart-Gough Platform, 422
9.8.3 The 3-2-1 Platform, 423
References, 423
Problems, 423

10 Profile Cam Design 431
10.1 Introduction, 431
10.2 Cam-Follower Systems, 432
10.3 Synthesis of Motion Programs, 434
10.4 Analysis of Different Types of Follower-Displacement Functions, 436
10.4.1 Uniform Motion, 437
10.4.2 Parabolic Motion, 438
10.4.3 Harmonic Follower-Displacement Programs, 443
10.4.4 Cycloidal Follower-Displacement Programs, 444
10.4.5 General Polynomial Follower-Displacement Programs, 445
10.5 Determining the Cam Profile, 448
10.5.1 Graphical Cam Profile Layout, 450
10.5.2 Analytical Determination of Cam Profile, 460
References, 482
Problems, 482

11 Spur Gears 489
11.1 Introduction, 489
11.2 Spur Gears, 490
11.3 Condition for Constant-Velocity Ratio, 491
11.4 Involutes, 492
11.5 Gear Terminology and Standards, 494
11.5.1 Terminology, 494
11.5.2 Standards, 496
11.6 Contact Ratio, 497
11.7 Involutometry, 501
11.8 Internal Gears, 504
11.9 Gear Manufacturing, 505
11.10 Interference and Undercutting, 508
11.11 Nonstandard Gearing, 510
11.12 Cartesian Coordinates of an Involute Tooth Generated with a Rack, 514
11.12.1 Coordinate Systems, 514
11.12.2 Gear Equations, 516
References, 520
Problems, 520

12 Helical, Bevel, and Worm Gears 523
12.1 Helical Gears, 523
12.1.1 Helical Gear Terminology, 523

12.1.2 Helical Gear Manufacturing, 526
12.1.3 Minimum Tooth Number to Avoid Undercutting, 526
12.1.4 Helical Gears with Parallel Shafts, 527
12.1.5 Crossed Helical Gears, 533
12.2 Worm Gears, 536
12.2.1 Worm Gear Nomenclature, 537
12.3 Involute Bevel Gears, 540
12.3.1 Tredgold's Approximation for Bevel Gears, 541
12.3.2 Additional Nomenclature for Bevel Gears, 542
12.3.3 Crown Bevel Gears and Face Gears, 543
12.3.4 Miter Gears, 544
12.3.5 Angular Bevel Gears, 544
12.3.6 Zerol Bevel Gears, 544
12.3.7 Spiral Bevel Gears, 545
12.3.8 Hypoid Gears, 546
References, 547
Problems, 547

13 Gear Trains **549**
13.1 General Gear Trains, 549
13.2 Direction of Rotation, 549
13.3 Simple Gear Trains, 550
13.3.1 Simple Reversing Mechanism, 551
13.4 Compound Gear Trains, 552
13.4.1 Concentric Gear Trains, 555
13.5 Planetary Gear Trains, 558
13.5.1 Planetary Gear Nomenclature, 558
13.5.2 Analysis of Planetary Gear Trains Using Equations, 559
13.5.3 Analysis of Planetary Gear Trains Using Tabular Method, 567
13.6 Harmonic Drive Speed Reducers, 570
References, 572
Problems, 572

14 Static Force Analysis of Mechanisms **579**
14.1 Introduction, 579
14.2 Forces, Moments, and Couples, 580
14.3 Static Equilibrium, 581
14.4 Free-Body Diagrams, 582
14.5 Solution of Static Equilibrium Problems, 585
14.6 Transmission Angle in a Four-Bar Linkage, 587
14.7 Friction Considerations, 590
14.7.1 Friction in Cam Contact, 591
14.7.2 Friction in Slider Joints, 591
14.7.3 Friction in Revolute Joints, 593
14.8 In-Plane and Out-of-Plane Force Systems, 597
14.9 Conservation of Energy and Power, 601
14.10 Virtual Work, 605
14.11 Gear Loads, 607
14.11.1 Spur Gears, 607
14.11.2 Helical Gears, 609
14.11.3 Worm Gears, 611
14.11.4 Straight Bevel Gears, 612
Problems, 613

15 Dynamic Force Analysis of Mechanisms 623
15.1 Introduction, 623
15.2 Problems Solvable Using Particle Kinetics, 625
15.2.1 Dynamic Equilibrium of Systems of Particles, 625
15.2.2 Conservation of Energy, 630
15.2.3 Conservation of Momentum, 630
15.3 Dynamic Equilibrium of Systems of Rigid Bodies, 633
15.4 Flywheels, 639
Problems, 641

16 Static and Dynamic Balancing 645
16.1 Introduction, 645
16.2 Single-Plane (Static) Balancing, 646
16.3 Multi-Plane (Dynamic) Balancing, 649
16.4 Balancing Reciprocating Masses, 654
16.4.1 Lumped Mass Distribution, 655
16.4.2 Balancing a Slider-Crank Mechanism, 658
16.5 Expressions for Inertial Forces, 661
16.6 Balancing Multi-Cylinder Machines, 663
16.6.1 Balancing a Three-Cylinder In-Line Engine, 667
16.6.2 Balancing an Eight-Cylinder V Engine, 669
16.7 Static Balancing of Mechanisms, 671
16.7.1 Gravity Balancing of Planar Mechanisms: Examples, 672
16.7.2 Gravity-Balancing Orthosis, 675
16.8 Reactionless Mechanisms, 675
References, 676
Problems, 676

17 Integration of Computer Controlled Actuators 685
17.1 Introduction, 685
17.2 Computer Control of the Linkage Motion, 686
17.3 The Basics of Feedback Control, 687
17.4 Actuator Selection and Types, 688
17.4.1 Electric Actuation, 689
17.4.2 Hydraulic Actuation, 692
17.4.3 Pneumatic Actuation, 693
17.5 Hands-On Machine-Design Laboratory, 694
17.5.1 Examples of Class Projects, 695
References, 696
Problems, 696

Index 699

Introduction

1

Prerequisite Knowledge Needed for Chapter 1

No prior knowledge is required for this chapter. It is an advantage to have completed undergraduate courses in statics and dynamics, but is certainly not essential.

1.1 HISTORICAL PERSPECTIVE

A mechanism is a machine composed of rigid members that are joined together. Joints permit the members to interact with one another. Portions of the surfaces of the members that contact one another form the joints. The geometries of the contacting surface segments determine the properties of each joint.

Mechanisms are used for diverse purposes. Some are incorporated into items we use every day. Figure 1.1 shows a mechanism whose function is to magnify the force generated by a user squeezing the handles to a very large force exerted by the jaws. It is also designed to lock in place while generating that force, so the handles can be released while the jaws remain clamped on a work piece. This is an example of a planar mechanism because the members of the mechanism all move parallel to a single plane of motion. Many familiar mechanisms have this characteristic. Planar mechanisms are the primary focus of Chapters 3 through 7 of this book. Mechanisms whose primary function is transmitting force, like this one, are discussed in Chapter 14.

Other mechanisms are characterized by points in their members following paths that are curves in space. In Figure 1.2, the leg mechanisms allow the feet to be placed anywhere within a volume of space. Each mechanism is primarily used to generate a straight-line foot trajectory relative to the body, so that the machine can walk at a constant height with uniform speed. Notice that the critical function here is the ability to have a designated point generate a path of specified geometry (a straight line). This is known as a path generation problem. The leg mechanisms used here are called pantographs. A pantograph is a special kind of planar mechanism discussed in Section 8.1.3.

Figure 1.3 is the drive mechanism of an ornithopter, a vehicle that flies by flapping its wings like a bird. Here a spatial trajectory of the entire wing must be generated relative to the body, not just the path of a point, as was the case with Figure 1.2. The wings must flap relative to the body, but they must also rotate about the long axis of the wing at the top of the flap to allow the wing to generate lift. The wing must rotate back (feathering) at the bottom of the flap to minimize air resistance to the upstroke. This is an example of using a mechanism to generate a specified path in space of a whole body (the wing). We call this a motion-generation problem. There are many other ways in which mechanisms are used. Here the wings are flapped by two planar four-bar mechanisms that are geared

Kinematics, Dynamics, and Design of Machinery, Third Edition. Kenneth J. Waldron, Gary L. Kinzel, and Sunil K. Agrawal.
© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.
Companion website: www.wiley.com/go/waldron/kinematics.

FIGURE 1.1
A pair of vice-grip pliers. A planar mechanism that multiplies the force applied by a user to the handles to apply a much greater force at the jaws. The mechanism is also designed to be locked in the closed position.

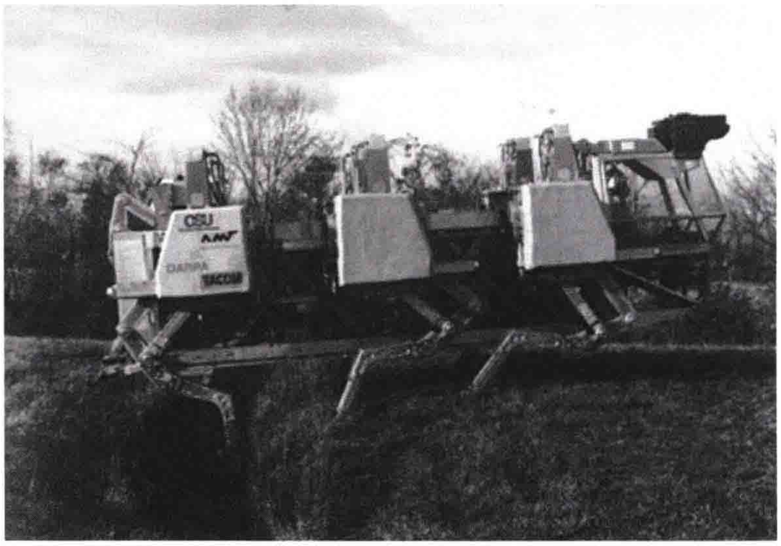


FIGURE 1.2
The Adaptive Suspension Vehicle [7]. Each leg is a planar pantograph mechanism hinged to the body about an axis parallel to the longitudinal axis of the vehicle. The feet can be placed anywhere within a volume of space, so this is, overall, a spatial mechanism. The pantograph mechanism allows the ankle joint to be moved in a straight line relative to the vehicle body by a single hydraulic cylinder.

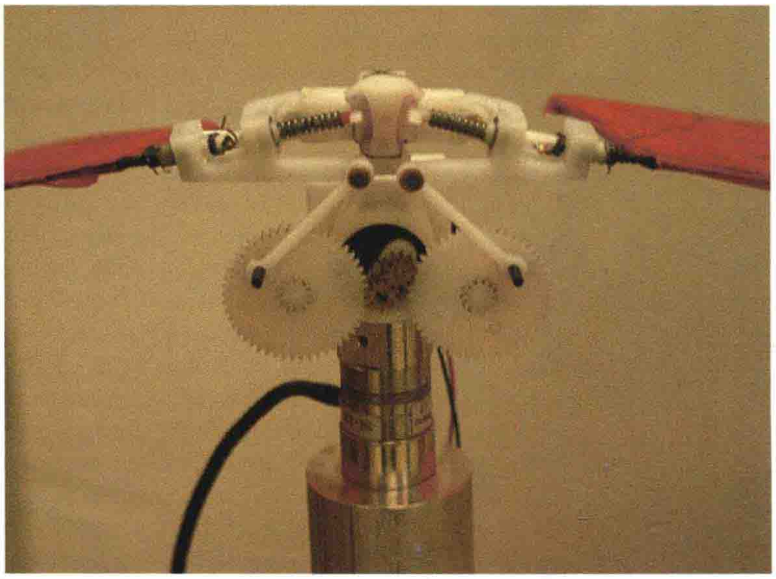


FIGURE 1.3
The drive mechanism of an ornithopter [1]. The mechanism must both flap the wings and rotate them about their long axes at the top and bottom of the flapping motion. A pair of four-bar mechanisms that are geared together accomplish the flapping motion. Cam and follower mechanisms are used to accomplish rotation of the wing at the top and bottom of the flapping motion.

together. The rotation about the wing axis is accomplished by a cam-and-follower mechanism. Cam mechanisms are discussed in Chapter 10.

Other common examples of ways in which mechanisms are used include the suspension of an automobile. A mechanism is used to maintain the wheels in a proper relationship with the body of the vehicle while allowing them to move to accommodate variations in the profile of the road. The suspension functions as a mechanical filter isolating the body of the vehicle and its occupants from bumps in the road.

此为试读，需要完整PDF请访问：www.ertongbook.com