时代教育·国外高校优秀教材精选

Mc Graw Hill Education

Design of Machinery

机械原理

（英文版·原书第5版）

[美] 罗伯特.诺顿（Robert L.Norton） 著

附1张DVD光盘

机械工业出版社
CHINA MACHINE PRESS

时代教育

DESIGN OF MACHINERY

机械原理（英文版·原书第5版）

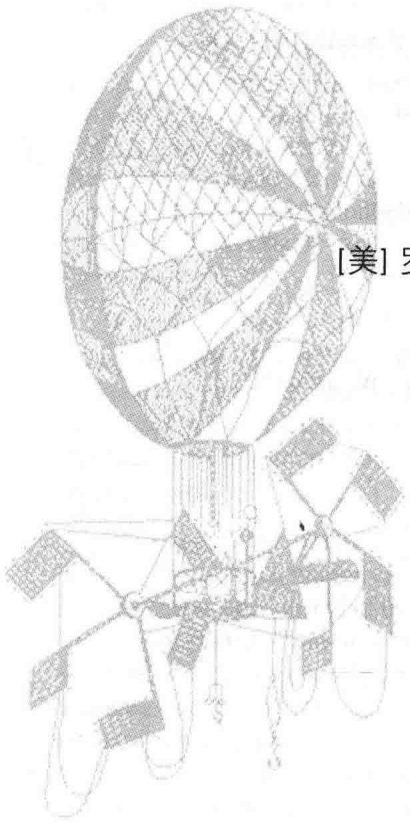
An Introduction to the Synthesis and Analysis of Mechanisms and Machines

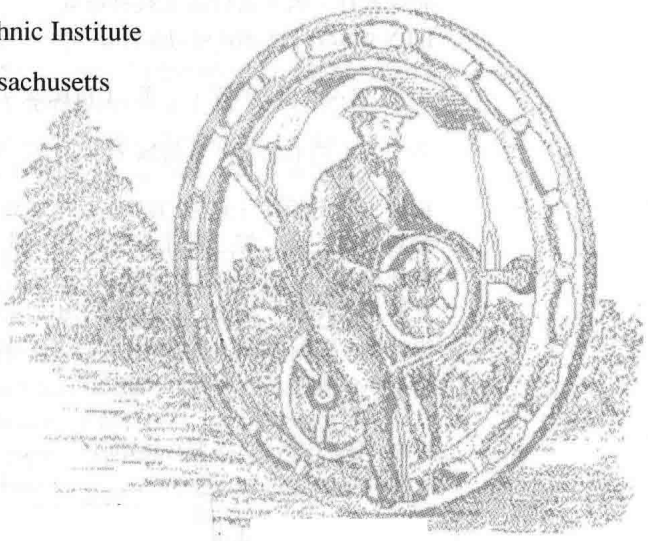
Fifth Edition

[美] 罗伯特 L.诺顿 (Robert L.Norton) 著

Worcester Polytechnic Institute

Worcester, Massachusetts





机 械 工 业 出 版 社

Robert L. Norton
Design of Machinery
ISBN 9780077421717
Copyright © 2014 by McGraw-Hill Education.
All Rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including without limitation photocopying, recording, taping, or any database, information or retrieval system, without the prior written permission of the publisher.
This authorized English reprint is jointly published by McGraw-Hill Education and China Machine Press. This edition is authorized for sale in the People's Republic of China only, excluding Hong Kong SAR, Macao SAR and Taiwan.
Copyright © 2017 by McGraw-Hill Education.
版权所有。未经出版人事先书面许可，对本出版物的任何部分不得以任何方式或途径复制或传播，包括但不限于复印、录制、录音，或者通过任何数据库、信息或可检索的系统。
本授权英文影印版由麦格劳-希尔（亚洲）教育出版公司和机械工业出版社合作出版。此版本经授权仅限在中华人民共和国境内（不包括香港特别行政区、澳门特别行政区和台湾地区）销售。
版权© 2017 由麦格劳-希尔（亚洲）教育出版公司所有。
本书封面贴有 McGraw-Hill Education 公司防伪标签，无标签者不得销售。
北京市版权局著作权合同登记号　图字 01-2016-8116。
采用本书作教材的教师可向麦格劳-希尔教育出版公司北京代表处联系索取教学课件资料。传真：010-59575582；电子邮件：instructorchina@ mheducation. com。

图书在版编目（CIP）数据

机械原理 = Design of machinery：原书第 5 版/（美）罗伯特·诺顿（Robert L. Norton）著. —北京：机械工业出版社，2017.4
时代教育·国外高校优秀教材精选
ISBN 978-7-111-56430-0

Ⅰ.①机…　Ⅱ.①罗…　Ⅲ.①机构学－高等学校－教材－英文　Ⅳ.①TH111

中国版本图书馆 CIP 数据核字（2017）第 063509 号

机械工业出版社（北京市百万庄大街 22 号　邮政编码 100037）
策划编辑：余　皞　责任编辑：余　皞
责任校对：丁昕祯　责任印制：李　飞
北京机工印刷厂印刷（三河市南杨庄国丰装订厂装订）
2017 年 4 月第 1 版第 1 次印刷
190mm×234mm·54 印张·1003 千字

标准书号：ISBN 978-7-111-56430-0
定价：158.00 元

凡购本书，如有缺页、倒页、脱页，由本社发行部调换

电话服务	网络服务
服务咨询热线：010-88379833	机工官网：www. cmpbook. com
读者购书热线：010-88379649	机工官博：weibo. com/cmp1952
	教育服务网：www. cmpedu. com
封面无防伪标均为盗版	金书网：www. golden-book. com

CONVERSION FACTORS

From U.S. Customary Units to Metric Units

1 Blob (bl)	=	175.127	Kilograms (kg)
1 Cubic inch (in^3)	=	16.387	Cubic centimeters (cc)
1 Foot (ft)	=	0.304 8	Meter (m)
1 Horsepower (hp)	=	745.699	Watts (W)
1 Inch (in)	=	0.025 4	Meter (m)
1 Mile, U.S. statute (mi)	=	1 609.344	Meters (m)
1 Pound force (lb)	=	4.448 2	Newtons (N)
	=	444 822.2	Dynes
1 Pound mass (lbm)	=	0.453 6	Kilogram (kg)
1 Pound-foot (lb-ft)	=	1.355 8	Newton-meter (N-m)
	=	1.355 8	Joules (J)
1 Pound-foot/second (lb-ft/sec)	=	1.355 8	Watts (W)
1 Pound-inch (lb-in)	=	0.112 8	Newton-meter (N-m)
	=	0.112 8	Joule (J)
1 Pound-inch/second (lb-in/sec)	=	0.112 8	Watt (W)
1 Pound/$foot^2$ (lb/ft^2)	=	47.880 3	Pascals (Pa)
1 Pound/$inch^2$ (lb/in^2), (psi)	=	6 894.757	Pascals (Pa)
1 Revolution/minute (rpm)	=	0.104 7	Radian/second (rad/sec)
1 Slug (sl)	=	14.593 9	Kilograms (kg)
1 Ton, short (2000 lbm)	=	907.184 7	Kilograms (kg)

Between U.S. Customary Units

1 Blob (bl)	=	12	Slugs (sl)
1 Blob (bl)	=	386	Pounds mass (lbm)
1 Foot (ft)	=	12	Inches (in)
1 Horsepower (hp)	=	550	Pound-feet/second (lb-ft/sec)
1 Knot	=	1.151 5	Miles/hour (mph)
1 Mile, U.S. statute (mi)	=	5 280	Feet (ft)
1 Mile/hour	=	1.4667	Feet/second (ft/sec)
1 Pound force (lb)	=	16	Ounces (oz)
1 Pound mass (lbm)	=	0.0311	Slug (sl)
1 Pound-foot (lb-ft)	=	12	Pound-inches (lb-in)
1 Pound-foot/second (lb-ft/sec)	=	0.001 818	Horsepower (hp)
1 Pound-inch (lb-in)	=	0.083 3	Pound-foot (lb-ft)
1 Pound-inch/second (lb-in/sec)	=	0.021 8	Horsepower (hp)
1 Pound/$inch^2$ (lb/in^2), (psi)	=	144	Pounds/$foot^2$ (lb/ft^2)
1 Radian/second (rad/sec)	=	9.549	Revolutions/minute (rpm)
1 Slug (sl)	=	32.174	Pounds mass (lbm)
1 Ton, short	=	2000	Pounds mass (lbm)

To Printer: Please place this page on inside of front cover - and mask out this message. Thanks.

McGraw-Hill Series in Mechanical Engineering

Alciatore	*Introduction to Mechatronics and Measurement Systems*
Anderson	*Fundamentals of Aerodynamics*
Anderson	*Introduction to Flight*
Anderson	*Modern Compressible Flow*
Beer/Johnston	*Vector Mechanics for Engineers*
Beer/Johnston	*Mechanics of Materials*
Budynas	*Advanced Strength and Applied Stress Analysis*
Budynas/Nisbett	*Shigley's Mechanical Engineering Design*
Byers/Dorf/Nelson	*Technology Ventures: From Idea to Enterprise*
Cengel/Ghajar	*Heat and Mass Transfer: Fundamentals and Applications*
Cengel	*Introduction to Thermodynamics and Heat Transfer*
Cengel/Boles	*Thermodynamics: An Engineering Approach*
Cengel/Cimbala	*Fluid Mechanics: Fundamentals and Applications*
Cengel/Turner/Cimbala	*Fundamentals of Thermal-Fluid Sciences*
Dieter/Schmidt	*Engineering Design*
Finnemore/Franzini	*Fluid Mechanics with Engineering Applications*
Heywood	*Internal Combustion Engine Fundamentals*
Holman	*Experimental Methods for Engineers*
Holman	*Heat Transfer*
Kays/Crawford/Weigand	*Convective Heat and Mass Transfer*
Norton	*Design of Machinery*
Palm	*System Dynamics*
Plesha/Gray/Costanzo	*Engineering Mechanics: Statics and Dynamics*
Reddy	*An Introduction to the Finite Element Method*
Schey	*Introduction to Manufacturing Processes*
Smith/Hashemi	*Foundations of Materials Science and Engineering*
Turns	*An Introduction to Combustion: Concepts and Applications*
Ullman	*The Mechanical Design Process*
White	*Fluid Mechanics*
White	*Viscous Fluid Flow*
Zeid	*Mastering CAD/CAM*

此为试读,需要完整PDF请访问: www.ertongbook.com

ABOUT THE AUTHOR

Robert L. Norton earned undergraduate degrees in both mechanical engineering and industrial technology at Northeastern University and an MS in engineering design at Tufts University. He is a registered professional engineer in Massachusetts. He has extensive industrial experience in engineering design and manufacturing and many years' experience teaching mechanical engineering, engineering design, computer science, and related subjects at Northeastern University, Tufts University, and Worcester Polytechnic Institute.

At Polaroid Corporation for 10 years, he designed cameras, related mechanisms, and high-speed automated machinery. He spent three years at Jet Spray Cooler Inc., designing food-handling machinery and products. For five years he helped develop artificial-heart and noninvasive assisted-circulation (counterpulsation) devices at the Tufts New England Medical Center and Boston City Hospital. Since leaving industry to join academia, he has continued as an independent consultant on engineering projects ranging from disposable medical products to high-speed production machinery. He holds 13 U.S. patents.

Norton has been on the faculty of Worcester Polytechnic Institute since 1981 and is currently the Milton Prince Higgins II Distinguished Professor in the mechanical engineering department, head of the design group in that department, and the director of the Gillette Project Center at WPI. He teaches undergraduate and graduate courses in mechanical engineering with emphasis on design, kinematics, vibrations, and dynamics of machinery.

He is the author of numerous technical papers and journal articles covering kinematics, dynamics of machinery, cam design and manufacturing, computers in education, and engineering education and of the texts *Machine Design: An Integrated Approach, 4ed* and the *Cam Design and Manufacturing Handbook, 2ed.* He is a Fellow and life member of the American Society of Mechanical Engineers and a member of the Society of Automotive Engineers. In 2007, he was chosen as *U. S. Professor of the Year* for the State of Massachusetts by the *Council for the Advancement and Support of Education (CASE)* and the *Carnegie Foundation for the Advancement of Teaching*, who jointly present the only national awards for teaching excellence given in the United States of America.

This book is dedicated to the memory of my father,

Harry J. Norton, Sr.

who sparked a young boy's interest in engineering;

to the memory of my mother,

Kathryn W. Norton

who made it all possible;

to my wife,

Nancy Norton

who provides unflagging patience and support;

and to my children,

Robert, Mary, and Thomas,

who make it all worthwhile.

PREFACE
to the Fifth Edition

How many times do you have to do this to get it right, Norton?
THE EDITORS ASKED, RE. THE FOURTH EDITION

I plead the fifth.
THE AUTHOR

The fifth edition is an evolutionary improvement over the fourth and earlier editions. See the updated *Preface to the First Edition* (overleaf) for more detailed information on the book's purpose and organization. The principal changes in this edition are:

- A new chapter (16) has been added on cam-driven and servo-driven linkages based on the author's recent consulting experience that indicates increased use of servomotors to drive mechanisms in machinery.
- Over 50 new problem assignments have been added. All of the problem figures are included as PDF files on the DVD so that students can easily print hard copies on which to work the solutions.
- Several of the author-written programs that come with the book have been completely rewritten to improve their interface and usability, and they are now compatible with the latest operating systems and computers. The programs FOURBAR, FIVEBAR, SIXBAR, and SLIDER have been combined in a new program called LINKAGES that does everything those programs collectively did and has some new features added. Program DYNACAM also has been completely rewritten and is much improved. Programs ENGINE and MATRIX are unchanged. These computer programs undergo frequent revision to add features and enhancements. Professors who adopt the book for a course may register to download the latest student versions of these programs from: http://www.designofmachinery.com/registered/professor.html.
- The Working Model program that was provided with earler editions was not a full-featured version of the program. It did not allow the user to save or print a model. The version of Working Model available with this text is a **fully capable version** but is provided only by means of a one-time download from a website and will run for one year from the time of installation. A password is provided with this text to enable its download.
- Many small improvements have been made to the discussion of a variety of topics in many chapters, based largely on user feedback, and all known errors have been corrected.

The extensive DVD content that was introduced in the Fourth Edition is included with the Fifth Edition as well. These include:

- The entire Hrones and Nelson Atlas of Coupler Curves and the Zhang Atlas of Geared Fivebar Coupler Curves are provided as PDFs on the DVD.

- Eighteen instructional videos that provide several lecture/demonstration tutorials on subjects such as position synthesis, coupler curves and cognates, the Grashof condition, etc. Others show real machinery that uses linkages, cams and gears for such tasks as spring manufacture, bottle printing, and pick-and-place mechanisms for automated assembly.
- Wang's Mechanism Simulation in a Multimedia Environment that contains over 100 Working Model (WM) files based on the book's figures and 19 Matlab® models for kinematic analysis and animation is included.
- Videos of two "virtual laboratories" that replicate labs created by the author at WPI are provided. These include demonstrations of the machines and spreadsheet files of the acceleration and force data taken during the experiments. The intent is to allow students at other schools to do these exercises as virtual laboratories.

ACKNOWLEDGMENTS The sources of photographs and other nonoriginal art used in the text are acknowledged in the captions and opposite the title page, but the author would also like to express his thanks for the cooperation of all those individuals and companies who generously made these items available. The author is indebted to, and would like to thank, a number of users who kindly notified him of errors or suggested improvements in all editions since the first. These include: Professors *Chad O'Neal* of Louisiana Tech, *Bram Demeulenaere* of Leuven University, *Eben Cobb* of WPI, *Diego Galuzzi* of University of Buenos Aires, *John R. Hall* of WPI, *Shafik Iskander* of U. Tennessee, *Richard Jakubek* of RPI, *Cheong Gill-Jeong* of Wonkwang University, Korea, *Swami Karunamoorthy* of St. Louis University, *Pierre Larochelle* of Florida Tech, *Scott Openshaw* of Iowa State, *Francis H. Raven* of Notre Dame, *Arnold E. Sikkema* of Dordt College, and *Donald A. Smith* of U. Wyoming.

Professors *M. R. Corley* of Louisiana Tech, *R. Devashier* of U. Evansville, *K. Gupta* of U. Illinois-Chicago, *M. Keefe* of U. Delaware, *J. Steffen* of Valparaiso University, *D. Walcerz* of York College, and *L. Wells* of U. Texas at Tyler provided useful suggestions or corrections. Professors *L. L. Howell* of BYU, and *G. K. Ananthasuresh* of U. Penn supplied photographs of compliant mechanisms. Professor *C. Furlong* of WPI generously supplied MEMS photos and information. Special thanks to *James Cormier* and *David Taranto* of WPI's Academic Technology Center for their help in creating the videos on the DVD. Reviewers of this edition were: Professors *J. Dave* of University of Cincinnati, *K. Fisher* of Montana State, *S. Gellin* of Buffalo State College, *D. Halsmer* of Oral Roberts University, *L. Howell* of Brigham Young University, *R. A. Lucas* of Lehigh University, *J. Mirth* of U. Wisconsin-Platteville, *C. Rubin* of Vanderbilt University, and *T. J. Thompson* of Cedarville University.

The author would like to express his appreciation to Professor *Sid Wang* of NCAT and his students for their efforts in creating the *Working Model* and *Matlab* files on the DVD. Professor *Thomas A. Cook*, Mercer University (Emeritus), provided most of the new problem sets as well as their solutions in his impressive and voluminous solutions manual and its accompanying *Mathcad*® solution files. The author is most grateful for Dr. Cook's valuable contributions.

Robert L. Norton
Mattapoisett, Mass.
August, 2010

If you find any errors or have comments or suggestions for improvement, please email the author at norton@wpi.edu. Errata as discovered, and other book information, will be posted on the author's web site at http://www.designofmachinery.com.

PREFACE

to the First Edition

When I hear, I forget
When I see, I remember
When I do, I understand
ANCIENT CHINESE PROVERB

This text is intended for the kinematics and dynamics of machinery topics which are often given as a single course, or two-course sequence, in the junior year of most mechanical engineering programs. The usual prerequisites are first courses in statics, dynamics, and calculus. Usually, the first semester, or portion, is devoted to kinematics and the second to dynamics of machinery. These courses are ideal vehicles for introducing the mechanical engineering student to the process of design, since mechanisms tend to be intuitive for the typical mechanical engineering student to visualize and create.

While this text attempts to be thorough and complete on the topics of analysis, it also emphasizes the synthesis and design aspects of the subject to a greater degree than most texts in print on these subjects. Also, it emphasizes the use of computer-aided engineering as an approach to the design and analysis of this class of problems by providing software that can enhance student understanding. While the mathematical level of this text is aimed at second- or third-year university students, it is presented *de novo* and should be understandable to the technical school student as well.

Part I of this text is suitable for a one-semester or one-term course in kinematics. Part II is suitable for a one-semester or one-term course in dynamics of machinery. Alternatively, both topic areas can be covered in one semester with less emphasis on some of the topics covered in the text.

The writing and style of presentation in the text are designed to be clear, informal, and easy to read. Many example problems and solution techniques are presented and spelled out in detail, both verbally and graphically. All the illustrations are done with computer-drawing or drafting programs. Some scanned photographic images are also included. The entire text, including equations and artwork, is printed directly from the author's computer disk by laser typesetting for maximum clarity and quality. Many suggested readings are provided in the bibliography. Short problems and, where appropriate, many longer, unstructured design project assignments are provided at the ends of chapters. These projects provide an opportunity for the students *to do and understand.*

The author's approach to these courses and this text is based on over 40 years' experience in mechanical engineering design, both in industry and as a consultant. He has taught these subjects since 1967, both in evening school to practicing engineers and in day school to younger students. His approach to the course has evolved a great deal in that time, from a traditional approach, emphasizing graphical analysis of many structured problems, through emphasis on algebraic methods as computers became available, through requiring students to write their own computer programs, to the current state described above.

The one constant throughout has been the attempt to convey the art of the design process to the students in order to prepare them to cope with *real* engineering problems in practice. Thus, the author has always promoted design within these courses. Only recently, however, has technology provided a means to more effectively accomplish this goal, in the form of the graphics microcomputer. This text attempts to be an improvement over those currently available by providing up-to-date methods and techniques for analysis and synthesis that take full advantage of the graphics microcomputer, and by emphasizing design as well as analysis. The text also provides a more complete, modern, and thorough treatment of cam design than any existing texts in print on the subject.

The author has written four interactive, student-friendly computer programs for the design and analysis of mechanisms and machines.* These programs are designed to enhance the student's understanding of the basic concepts in these courses while simultaneously allowing more comprehensive and realistic problem and project assignments to be done in the limited time available than could ever be done with manual solution techniques, whether graphical or algebraic. Unstructured, realistic design problems which have many valid solutions are assigned. Synthesis and analysis are equally emphasized. The analysis methods presented are up to date, using vector equations and matrix techniques wherever applicable. Manual graphical analysis methods are deemphasized. The graphics output from the computer programs allows the student to see the results of variation of parameters rapidly and accurately and reinforces learning.

These computer programs are distributed on DVD with this book, which also contains instructions for their use on any Windows NT/2000/XP/Vista/Windows7 capable computer. Program LINKAGES analyzes the kinematics and dynamics of fourbar, geared fivebar, sixbar, and fourbar slider linkages. It also will synthesize fourbar linkages for two and three positions. Program DYNACAM allows the design and dynamic analysis of cam-follower systems. Program ENGINE analyzes the slider-crank linkage as used in the internal combustion engine and provides a complete dynamic analysis of single- and multicylinder engine inline, V, and W configurations, allowing the mechanical dynamic design of engines to be done. Program MATRIX is a general-purpose linear equation system solver. These are student editions of professional programs that are written by the author and that he provides to companies the world over.

All these programs, except MATRIX, provide dynamic, graphical animation of the designed devices. The reader is strongly urged to make use of these programs in order to investigate the results of variation of parameters in these kinematic devices. The programs are designed to enhance and augment the text rather than be a substitute for it. The converse is also true. Many solutions to the book's examples and to the problem sets are provided on the DVD as files to be opened in these programs. Most of these solutions can be animated on the computer screen for a better demonstration of the concept than is

* One of these four programs replaces four of the original set of seven programs that came with earlier editions of the book. These were called FOURBAR, FIVEBAR, SIXBAR, and SLIDER. All four have been combined into the new program LINKAGES in the 5th edition.

此为试读,需要完整PDF请访问: www.ertongbook.com

possible on the printed page. The instructor and students are both encouraged to take advantage of the computer programs provided. Instructions for their use are in Appendix A.

The author's intention is that synthesis topics be introduced first to allow the students to work on some simple design tasks early in the term while still mastering the analysis topics. Though this is not the "traditional" approach to the teaching of this material, the author believes that it is a superior method to that of initial concentration on detailed analysis of mechanisms for which the student has no concept of origin or purpose.

Chapters 1 and 2 are introductory. Those instructors wishing to teach analysis before synthesis can leave Chapters 3 and 5 on linkage synthesis for later consumption. Chapters 4, 6, and 7 on position, velocity, and acceleration analysis are sequential and build upon each other. In fact, some of the problem sets are common among these three chapters so that students can use their position solutions to find velocities and then later use both to find the accelerations in the same linkages. Chapter 8 on cams is more extensive and complete than that of other kinematics texts and takes a design approach. Chapter 9 on gear trains is introductory. The dynamic force treatment in Part II uses matrix methods for the solution of the system simultaneous equations. Graphical force analysis is not emphasized. Chapter 10 presents an introduction to dynamic systems modeling. Chapter 11 deals with force analysis of linkages. Balancing of rotating machinery and linkages is covered in Chapter 12. Chapters 13 and 14 use the internal combustion engine as an example to pull together many dynamic concepts in a design context. Chapter 15 presents an introduction to dynamic systems modeling and uses the cam-follower system as the example. Chapters 3, 8, 11, 13, and 14 provide open-ended project problems as well as structured problem sets. The assignment and execution of unstructured project problems can greatly enhance the student's understanding of the concepts as described by the proverb in the epigraph to this preface.

ACKNOWLEDGMENTS The sources of photographs and other nonoriginal art used in the text are acknowledged in the captions and opposite the title page, but the author would also like to express his thanks for the cooperation of all those individuals and companies who generously made these items available. The author would also like to thank those who reviewed various sections of the first edition of the text and who made many useful suggestions for improvement. Mr. John Titus of the University of Minnesota reviewed Chapter 5 on analytical synthesis and Mr. Dennis Klipp of Klipp Engineering, Waterville, Maine, reviewed Chapter 8 on cam design. Professor William J. Crochetiere and Mr. Homer Eckhardt of Tufts University, Medford, MA., reviewed Chapter 15. Mr. Eckhardt and Professor Crochetiere of Tufts, and Professor Charles Warren of the University of Alabama taught from and reviewed Part I. Professor Holly K. Ault of Worcester Polytechnic Institute thoroughly reviewed the entire text while teaching from the prepublication, class-test versions of the complete book. Professor Michael Keefe of the University of Delaware provided many helpful comments. Sincere thanks also go to the large number of undergraduate students and graduate teaching assistants who caught many typos and errors in the text and in the programs while using prepublication versions. Since the book's first printing, Profs. D. Cronin, K. Gupta and P. Jensen and Mr. R. Jantz have written to point out errors or make suggestions that I have incorporated and for which I thank them. The author takes full responsibility for any errors that may remain and invites from all readers their criticisms, suggestions for improvement, and identification of errors in the text or programs, so that both can be improved in future versions. Contact norton@wpi.edu.

Robert L. Norton
Mattapoisett, Mass.
August, 1991

CONTENTS

Preface to the Fifth Edition xvii
Preface to the First Edition xix

PART I KINEMATICS OF MECHANISMS 1

Chapter 1 Introduction 3

1.0 Purpose 3
1.1 Kinematics and Kinetics 3
1.2 Mechanisms and Machines 4
1.3 A Brief History of Kinematics 5
1.4 Applications of Kinematics 6
1.5 The Design Process 7
Design, Invention, Creativity 7
Identification of Need 8
Background Research 9
Goal Statement 10
Performance Specifications 10
Ideation and Invention 10
Analysis 12
Selection 13
Detailed Design 13
Prototyping and Testing 13
Production 14
1.6 Other Approaches to Design 15
Axiomatic Design 15
1.7 Multiple Solutions 16
1.8 Human Factors Engineering 16
1.9 The Engineering Report 17
1.10 Units 17
1.11 A Design Case Study 19
Educating for Creativity in Engineering 20
1.12 What's to Come 25
1.13 Resources with This Text 25
Programs 25
Videos 25
1.14 References 26
1.15 Bibliography 27

Chapter 2 Kinematics Fundamentals 30

2.0 Introduction 30
2.1 Degrees of Freedom (DOF) or Mobility 30
2.2 Types of Motion 31
2.3 Links, Joints, and Kinematic Chains 32
2.4 Drawing Kinematic Diagrams 36
2.5 Determining Degree of Freedom or Mobility 37
Degree of Freedom (Mobility) in Planar Mechanisms 38
Degree of Freedom (Mobility) in Spatial Mechanisms 40
2.6 Mechanisms and Structures 40
2.7 Number Synthesis 42
2.8 Paradoxes 46
2.9 Isomers 47

2.10 Linkage Transformation 48
2.11 Intermittent Motion 53
2.12 Inversion 53
2.13 The Grashof Condition 55
Classification of the Fourbar Linkage 60
2.14 Linkages of More Than Four Bars 62
Geared Fivebar Linkages 62
Sixbar Linkages 63
Grashof-Type Rotatability Criteria for Higher-Order Linkages 63
2.15 Springs as Links 65
2.16 Compliant Mechanisms 65
2.17 Micro Electro-Mechanical Systems (MEMS) 67
2.18 Practical Considerations 69
Pin Joints versus Sliders and Half Joints 69
Cantilever or Straddle Mount? 71
Short Links 72
Bearing Ratio 72
Commercial Slides 73
Linkages versus Cams 73
2.19 Motors and Drivers 74
Electric Motors 74
Air and Hydraulic Motors 79
Air and Hydraulic Cylinders 79
Solenoids 80
2.20 References 80
2.21 Problems 81

Chapter 3 Graphical Linkage Synthesis 96

3.0 Introduction 96
3.1 Synthesis 96
3.2 Function, Path, and Motion Generation 98
3.3 Limiting Conditions 100
3.4 Dimensional Synthesis 102
Two-Position Synthesis 103
Three-Position Synthesis with Specified Moving Pivots 109
Three-Position Synthesis with Alternate Moving Pivots 110
Three-Position Synthesis with Specified Fixed Pivots 111
Position Synthesis for More Than Three Positions 117
3.5 Quick-Return Mechanisms 117
Fourbar Quick-Return 117
Sixbar Quick-Return 119
3.6 Coupler Curves 122
3.7 Cognates 132
Parallel Motion 136
Geared Fivebar Cognates of the Fourbar 138
3.8 Straight-Line Mechanisms 139
Designing Optimum Straight-Line Fourbar Linkages 142
3.9 Dwell Mechanisms 146
Single-Dwell Linkages 146
Double-Dwell Linkages 149
3.10 Other Useful Linkages 151
Constant Velocity Piston Motion 151
Large Angular Excursion Rocker Motion 152
Remote Center Circular Motion 153
3.11 References 155
3.12 Bibliography 156
3.13 Problems 157
3.14 Projects 170

Chapter 4 Position Analysis 174

4.0 Introduction 174
4.1 Coordinate Systems 176
4.2 Position and Displacement 176
Position 176
Coordinate Transformation 177
Displacement 177
4.3 Translation, Rotation, and Complex Motion 179
Translation 179
Rotation 179
Complex Motion 180
Theorems 181
4.4 Graphical Position Analysis of Linkages 181
4.5 Algebraic Position Analysis of Linkages 183
Vector Loop Representation of Linkages 184
Complex Numbers as Vectors 184
The Vector Loop Equation for a Fourbar Linkage 185
4.6 The Fourbar Crank-Slider Position Solution 192
4.7 The Fourbar Slider-Crank Position Solution 194
4.8 An Inverted Crank-Slider Position Solution 197
4.9 Linkages of More Than Four Bars 199
The Geared Fivebar Linkage 200
Sixbar Linkages 203
4.10 Position of Any Point on a Linkage 203
4.11 Transmission Angles 204
Extreme Values of the Transmission Angle 205
4.12 Toggle Positions 207
4.13 Circuits and Branches in Linkages 208
4.14 Newton-Raphson Solution Method 210
One-Dimensional Root-Finding (Newton's Method) 210
Multidimensional Root-Finding (Newton-Raphson Method) 212
Newton-Raphson Solution for the Fourbar Linkage 213
Equation Solvers 213
4.15 References 214
4.16 Problems 214

Chapter 5 Analytical Linkage Synthesis 228

5.0 Introduction 228
5.1 Types of Kinematic Synthesis 228
5.2 Two-Position Synthesis for Rocker Output 229
5.3 Precision Points 231
5.4 Two-Position Motion Generation by Analytical Synthesis 231
5.5 Comparison of Analytical and Graphical Two-Position Synthesis 238
5.6 Simultaneous Equation Solution 240
5.7 Three-Position Motion Generation by Analytical Synthesis 242
5.8 Comparison of Analytical and Graphical Three-Position Synthesis 247
5.9 Synthesis for a Specified Fixed Pivot Location 252
5.10 Center-Point and Circle-Point Circles 258
5.11 Four- and Five-Position Analytical Synthesis 260
5.12 Analytical Synthesis of a Path Generator with Prescribed Timing 261
5.13 Analytical Synthesis of a Fourbar Function Generator 262
5.14 Other Linkage Synthesis Methods 264
Precision Point Methods 267
Coupler Curve Equation Methods 268
Optimization Methods 268
5.15 References 271
5.16 Problems 274

Chapter 6 Velocity Analysis 285

6.0 Introduction 285
6.1 Definition of Velocity 285
6.2 Graphical Velocity Analysis 288
6.3 Instant Centers of Velocity 292
6.4 Velocity Analysis with Instant Centers 299
Angular Velocity Ratio *301*
Mechanical Advantage *303*
Using Instant Centers in Linkage Design *305*
6.5 Centrodes 307
A "Linkless" Linkage *308*
Cusps *310*
6.6 Velocity of Slip 311
6.7 Analytical Solutions for Velocity Analysis 315
The Fourbar Pin-Jointed Linkage *315*
The Fourbar Crank-Slider *318*
The Fourbar Slider-Crank *321*
The Fourbar Inverted Crank-Slider *322*
6.8 Velocity Analysis of the Geared Fivebar Linkage 324
6.9 Velocity of Any Point on a Linkage 325
6.10 References 327
6.11 Problems 327

Chapter 7 Acceleration Analysis 350

7.0 Introduction 350
7.1 Definition of Acceleration 350
7.2 Graphical Acceleration Analysis 353
7.3 Analytical Solutions for Acceleration Analysis 358
The Fourbar Pin-Jointed Linkage *358*
The Fourbar Crank-Slider *362*
The Fourbar Slider-Crank *364*
Coriolis Acceleration *366*
The Fourbar Inverted Crank-Slider *368*
7.4 Acceleration Analysis of the Geared Fivebar Linkage 371
7.5 Acceleration of Any Point on a Linkage 372
7.6 Human Tolerance of Acceleration 374
7.7 Jerk 376
7.8 Linkages of N Bars 379
7.9 Reference 379
7.10 Problems 379
7.11 Virtual Laboratory 400

Chapter 8 Cam Design 401

8.0 Introduction 401
8.1 Cam Terminology 402
Type of Follower Motion *402*
Type of Joint Closure *404*
Type of Follower *405*
Type of Cam *405*
Type of Motion Constraints *406*
Type of Motion Program *407*
8.2 ***S V A J*** Diagrams 408
8.3 Double-Dwell Cam Design—Choosing ***S V A J*** Functions 409
The Fundamental Law of Cam Design *412*
Simple Harmonic Motion (SHM) *413*
Cycloidal Displacement *414*
Combined Functions *417*

The SCCA Family of Double-Dwell Functions 421
Polynomial Functions 431
Double-Dwell Applications of Polynomials 431
8.4 Single-Dwell Cam Design—Choosing ***S V A J*** Functions 435
Single-Dwell Applications of Polynomials 437
Effect of Asymmetry on the Rise-Fall Polynomial Solution 440
8.5 Critical Path Motion (CPM) 443
Polynomials Used for Critical Path Motion 445
8.6 Sizing the Cam—Pressure Angle and Radius of Curvature 452
Pressure Angle—Translating Roller Followers 453
Choosing a Prime Circle Radius 456
Overturning Moment—Translating Flat-Faced Follower 457
Radius of Curvature—Translating Roller Follower 458
Radius of Curvature—Translating Flat-Faced Follower 462
8.7 Practical Design Considerations 467
Translating or Oscillating Follower? 467
Force- or Form-Closed? 467
Radial or Axial Cam? 468
Roller or Flat-Faced Follower? 468
To Dwell or Not to Dwell? 469
To Grind or Not to Grind? 469
To Lubricate or Not to Lubricate? 470
8.8 References 470
8.9 Problems 471
8.10 Virtual Laboratory 476
8.11 Projects 476

Chapter 9 Gear Trains 482

9.0 Introduction 482
9.1 Rolling Cylinders 483
9.2 The Fundamental Law of Gearing 484
The Involute Tooth Form 485
Pressure Angle 487
Changing Center Distance 487
Backlash 489
9.3 Gear Tooth Nomenclature 489
9.4 Interference and Undercutting 492
Unequal-Addendum Tooth Forms 492
9.5 Contact Ratio 494
9.6 Gear Types 497
Spur, Helical, and Herringbone Gears 497
Worms and Worm Gears 498
Rack and Pinion 499
Bevel and Hypoid Gears 499
Noncircular Gears 500
Belt and Chain Drives 501
9.7 Simple Gear Trains 503
9.8 Compound Gear Trains 504
Design of Compound Trains 505
Design of Reverted Compound Trains 506
An Algorithm for the Design of Compound Gear Trains 509
9.9 Epicyclic or Planetary Gear Trains 513
The Tabular Method 515
The Formula Method 519
9.10 Efficiency of Gear Trains 521
9.11 Transmissions 525
9.12 Differentials 529
9.13 References 531

此为试读，需要完整PDF请访问：www.ertongbook.com