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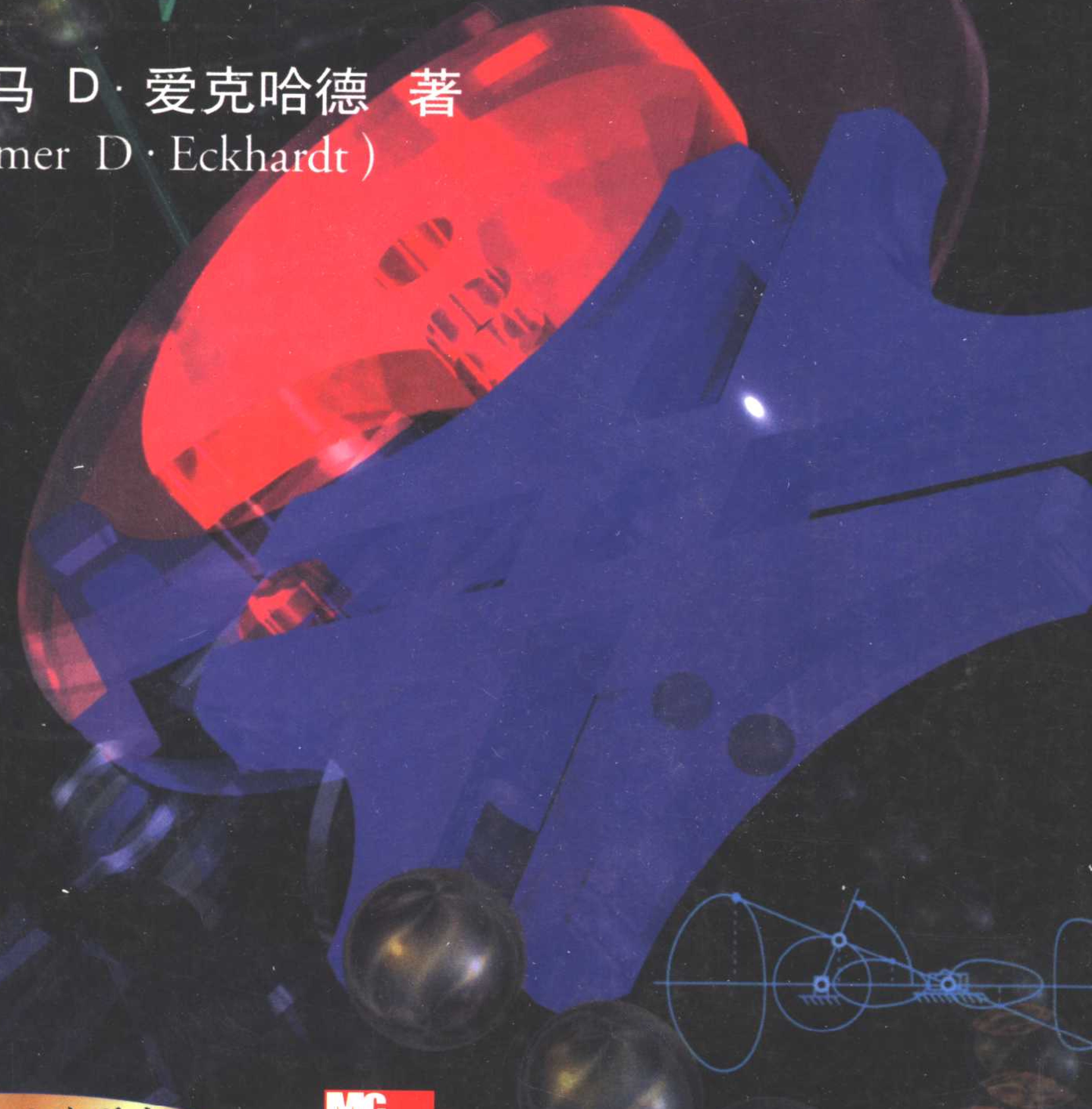
机器与机构设计（英文版）

kinematic Design of Machines and Mechanisms

（美）荷马 D·爱克哈德 著
（Homer D·Eckhardt）



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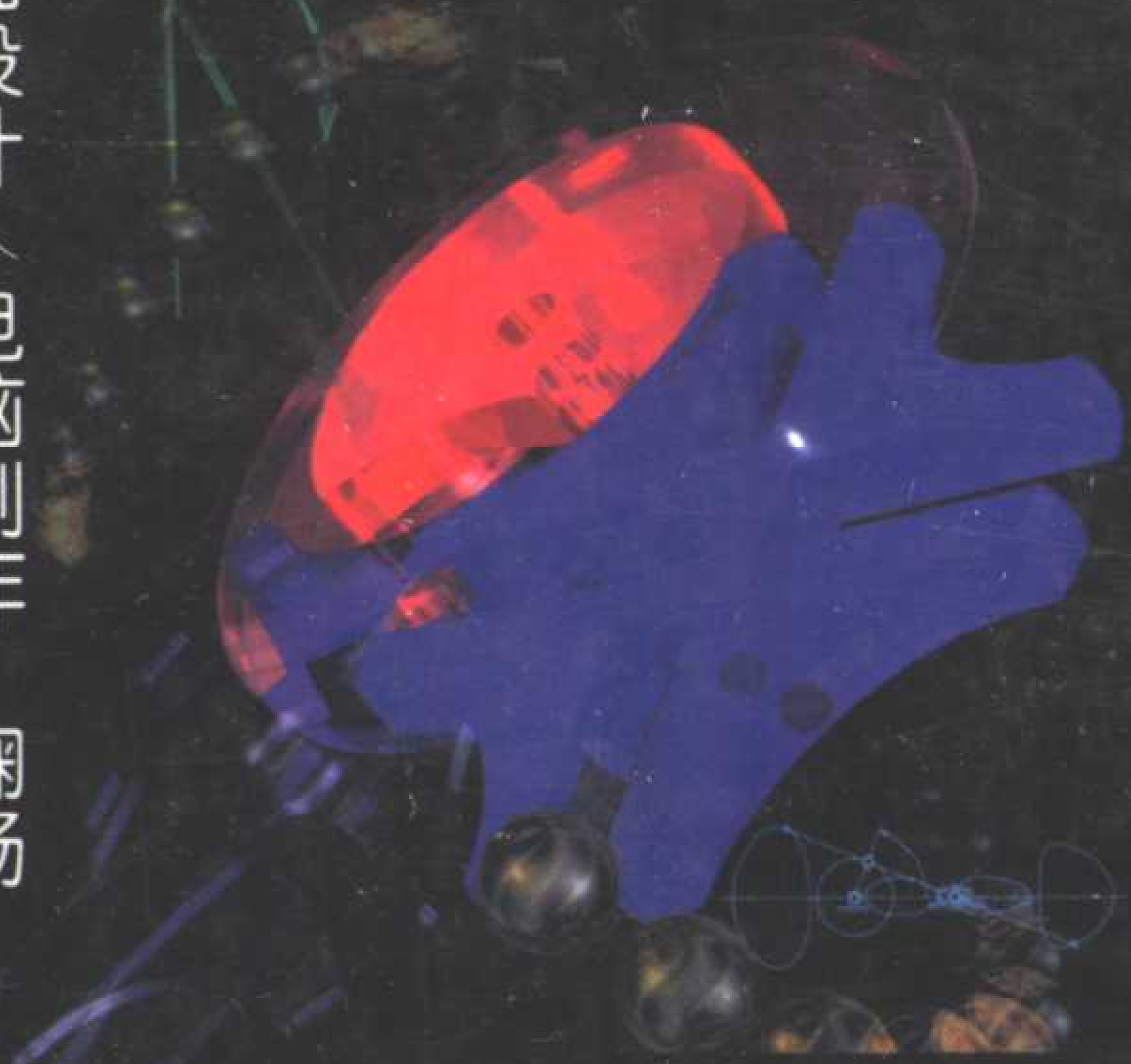

本书突出了机构的设计，以矢量分析为基础，特别是强调了利用计算机进行设计与分析。主要内容有：机器与机构运动学设计的基本概念，刚体平面运动，曲柄滑块机构，铰链四杆机构，速度匹配机构，急回机构，广义四杆机构，多环与多杆机构，机构综合的定性方法，双矢量综合与机构的计算机辅助综合，齿轮机构，齿轮与轮系，机构的力、力矩与静平衡，机构的力、力矩与动平衡。

本书可供高校工科院校使用，也可作为机械工程技术人员的参考书。

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序

由于现代科学技术的高速发展，特别是计算机技术和信息科学的高速发展，促进了经济的全球化，而经济的全球化又要求世界各国科技与教育事业有进一步的交往和协作。我国已加入 WTO，这对我国科技和教育事业的发展既是一个挑战也是一个机遇。但是我国高校还有很多方面不能适应这一现实，在教学体系、课程设置和教材等方面尚显陈旧，应本着有中国特色社会主义的教育体制和发展远景，抓紧时机，作有利的改革。荷马 D·爱克哈德所著的《机器与机构设计》一书，突出了机构的设计，以矢量分析为基础，特别是强调了利用计算机进行设计与分析。主要内容有：机器与机构运动学设计的基本概念，刚体平面运动，曲柄滑块机构，铰链四杆机构，速度匹配机构，急回机构，广义四杆机构，多环与多杆机构，机构综合的定性方法，双矢量综合与机构的计算机辅助综合，齿轮机构，齿轮与轮系，机构的力、力矩与静平衡，机构的力、力矩与动平衡。我认为这是一本值得引进和借鉴的国外优秀原版教材。该书的影印出版，有助于缩小我国在机械基础课程教学方面与国际先进水平的差距，也有助于提高我国机械类大学生的英语水平。

中国科学院院士

宋玉泉

2002 年 3 月 3 日于吉林大学

出版说明

随着我国加入WTO，国际间的竞争越来越激烈，而国际间的竞争实际上也就是人才的竞争、教育的竞争。为了加快培养具有国际竞争力的高水平技术人才，加快我国教育改革的步伐，国家教育部近来出台了一系列倡导高校开展双语教学、引进原版教材的政策。以此为契机，机械工业出版社拟于近期推出一系列国外影印版教材，其内容涉及高等学校公共基础课，以及机、电、信息领域的专业基础课和专业课。

引进国外优秀原版教材，在有条件的学校推动开展英语授课或双语教学，自然也引进了先进的教学思想和教学方法，这对提高我国自编教材的水平，加强学生的英语实际应用能力，使我国的高等教育尽快与国际接轨，必将起到积极的推动作用。

为了做好教材的引进工作，机械工业出版社特别成立了由著名专家组成的国外优秀教材审定委员会。这些专家对高校实施双语教学做了深入细致的调查研究，对引进原版教材提出许多建设性意见，并慎重地对每一本将要引进的原版教材一审再审，精选再精选，确认教材本身的质量水平，以及权威性和先进性，以期所引进的原版教材能适应我国学生的外语水平和学习特点。在引进工作中，审定委员会还结合我国高校教学课程体系的设置和要求，对原版教材的教学思想和方法的先进性、科学性进行了严格把关。同时，尽量考虑了原版教材的系统性和经济性。

这套教材出版后，我们将根据各高校的双语教学计划，举办原版教材的教师培训，及时地将其推荐给各高校选用。希望高校师生在使用教材后及时反馈意见和建议，使我们更好地为教学改革服务。

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2002年3月

Preface

The objective of this book is to provide practicing engineers and students with a practical understanding of the principles of kinematics, with an understanding of the connections between these principles and the behavior of actual machines, and with tools for the kinematic design of those machines.

The design of a machine or mechanism or any moving mechanical system always starts with a consideration of kinematics because kinematics is the study of the geometry of motion. That is, kinematics deals with (1) the functional relationships between the parts of a machine or other mechanical system, (2) how those parts are interconnected, and (3) how those parts move relative to each other. Only after choices have been made regarding those three factors can matters such as strengths, materials, fabrication techniques, and costs be seriously addressed. Failure to devote the proper attention to kinematics "up front" can, and often does, result in the design of a system with substandard or nonoptimum performance and/or with unsatisfactory reliability.

Fortunately, today, the ready availability of very powerful personal computers and the associated software allows kinematic synthesis and analysis, which were formerly laborious, to be performed quickly and cheaply. There is no longer an excuse for avoiding doing careful kinematic design up front. Because of the availability of these computer aids and the consequent incentives to apply kinematic principles in design, it is becoming *increasingly important* for the practicing engineer to have a good understanding of those kinematic principles.

Even before engineers can start to use a computer for synthesis or analysis of a machine, they must develop some initial concept of how the machine will operate. To assist engineers in generating such concepts, the first part of each of Chaps. 3 through 7 and all of Chap. 8 describe the operating capabilities of mechanisms which can be used as components of machines. Then step-by-step procedures (principally graphical) for synthesizing such mechanisms to provide the desired functions are given. If these initially synthesized configurations require further refinement, experience gained in this initial manual synthesis provides understanding and input for any further synthesis and analysis on a computer.

The graphical synthesis and analysis methods described require only the use of compass, ruler, protractor, and simple arithmetic. The CAD (computer-aided drafting or design) systems available today can also be very easily used to perform these graphical procedures and to obtain very accurate answers. Currently available spreadsheet software and equation-solving software can be used with the equations given in this book to obtain numerical values for the kinematic variables involved. Many of the equations have been left in a form in which the unknown variable has *not* been isolated on the left-hand side. When in this form:

1. the equations are closer to the derivation from the source phenomena involved and thus the significance of individual terms is more easily seen;
2. the equations are already in a form which many equation-solving software packages such as TKSolver®, MathCAD®, and others can evaluate iteratively; and
3. the equations are easily converted to a form suitable for programming into a spreadsheet by transposing the single term containing the unknown to the left-hand side and performing a simple operation such as dividing, taking a square root, taking an inverse tangent, etc. The equations can generally be evaluated in the order in which they are presented.

Very often, the answers which are provided by computerized aids are not unique and depend on details of the formulation of the problem as fed to the computer. If the computer-generated answer is not fully satisfactory to the engineer, a decision must be made as to what could and should be changed in that input formulation, how it should be changed, and what resulting change would be expected in the answer. Then new inputs must be fed to the computer and the process must be repeated, in the hope that the next answer will be more satisfactory. If the kinematic principles are not understood, this iteration process becomes one of wasteful trial and error, and valuable solutions can be missed. It is a primary aim of this book to provide help in more efficiently guiding such trial-and-error processes by providing engineers with the understanding which will allow them to visualize the connections between the relatively simple mathematics and the physical phenomena involved. Toward that aim, the later portions of each of Chaps. 3 through 7 and all of Chap. 9 describe analytical as well as graphical relationships between mechanism motion variables.

Several mathematical derivations are presented in this book. It is not necessary for readers to be familiar with, to read, or to understand these derivations in order to use the procedures and relationships presented, although derivations are usually helpful in providing understanding of the power and limitations of those procedures and relationships. The derivations are presented largely for readers who may wish to enlarge or build upon them in order to generate more elegant and/or more powerful procedures or relationships.

The only mathematics prerequisite assumed for use of the analytical portions of the book are high-school algebra, including complex numbers, high-school trigonometry, and a knowledge of differential calculus including the ability to differentiate e^x and the trigonometic functions. It is also assumed that the reader is aware that $F = ma$, and is able to add, subtract, and resolve two-dimensional vectors.

The first three chapters lay the foundations for the synthesis and analysis techniques and procedures which are presented in the remainder of the book.

Chapter 1 presents the definitions and basic concepts. Although the book deals essentially only with planar kinematics, Secs. 1.5 through 1.9 discuss three-dimensional or spatial phenomena. The remainder of the book does not depend upon the material in Secs. 1.6 through 1.9, so they could be skipped or lightly skimmed if time demands. However, because real machines are built and operated in three-dimensional space, it is important that practicing engineers have an appreciation for the phenomena covered in those sections.

Chapter 2 presents methods for analyzing the motions of rigid bodies in planar motion. The chapter covers displacements, velocities, and accelerations of isolated rigid bodies, and discusses the significant relationships between the mathematics and the physical phenomena. It provides analysis techniques which are used in subsequent chapters, where rigid bodies are connected together to form machines.

The crank-slider mechanism is a very useful mechanism, and Chap. 3 presents synthesis and analysis methods for use in its design. Because the geometry and motion of this mechanism are relatively simple and easily visualized, analysis of this mechanism is used as a basis from which the synthesis and analysis of the mechanisms in the subsequent chapters are treated as perturbations and extensions.

Chapters 4 through 7 describe the salient features and capabilities of increasingly complex mechanisms and present procedures for their synthesis. These chapters also briefly illustrate the adaptation of the previously described analysis procedures for use on these more complex mechanisms.

Chapters 8 and 9 present principles and procedures which are useful in preparation of concepts for machines which will be subjects for computer-assisted synthesis and analysis.

Chapters 10 and 11 give the principles of cam systems, gear systems, and timing-belt systems and give procedures for synthesizing such systems.

Although Chaps. 12 and 13 involve forces and inertial reactions and therefore are subjects in kinetics, the intimate involvement of geometry and thus of kinematics in the phenomena covered makes them important subjects for a kinematics text.

Chapter 12 describes the relationships between the static forces which occur in a mechanism, and presents procedures for static balancing of such mechanisms. Examples of such balancing are given. These examples involve the use of balance springs as well as the use of balance weights.

Chapter 13 extends the discussion of Chap. 12 to the relationships between the dynamic forces which occur in a mechanism, and presents procedures for dynamic balancing of mechanisms. Examples of such balancing are given.

Homer D. Eckhardt

How to Use This Book

It is intended that the step-by-step procedures presented in this book be usable without the need to refer to other portions of the text. However, to the extent that time permits, readers should become aware of the existence and nature of the background material in the remainder of this book and in other books on this subject.

Therefore, read this list and then:

1. Read the preface. (It takes only a few minutes!)
2. Read the table of contents and note the titles of sections.
3. Read the Introduction section of each chapter.
4. From the table of contents, select a section or sections of particular interest and read the introductory paragraphs of those sections. Also skim those sections for Procedures of interest (see List of Procedures also).
5. When you find a particular Procedure which is of immediate interest, read (or at least skim) the section containing that procedure, including Introduction and any Comments and suggestions.
6. Skim the index for terms which are of interest and skim the text where those terms appear. The index should be used together with the table of contents because information appears in different forms in these two places.
7. Naturally all authors want readers to read, understand, and treasure every word in their books. This particular author realizes that practicing engineers are often pressed for time. Nonetheless, although I, too, have often been pressed for time, I have found the background material in this book to be of great use over the course of many years.

Acknowledgments

I wish to express my appreciation to my many colleagues at Honeywell, Link Aviation, the Massachusetts Institute of Technology, RCA, Draper Loom, Polaroid, the Worcester Polytechnic Institute, and Tufts University for all that they have taught me over the years, and to Professor Robert Norton of the Worcester Polytechnic Institute for inspiring me to write this book. I would especially like to thank Professor Ashok Midha of the University of Missouri at Rolla and Professor Steven Kramer of the University of Toledo who kindly agreed to review the manuscript and bring any egregious errors to my attention.

I am deeply grateful to my children Gretchen, Julie, Jason, Kris, and Lili for all they have taught me about "life, death, and related subjects," and I am particularly grateful to my wife Beverly, who, in addition to teaching me so much, has shown monumental patience with my preoccupation during the preparation of this book.

Despite all the help from the above-mentioned people, I, through my own obstinate efforts, may have included some errors in this book. I apologize to readers for any such errors. I welcome readers' comments and suggestions, which may be sent to me at

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