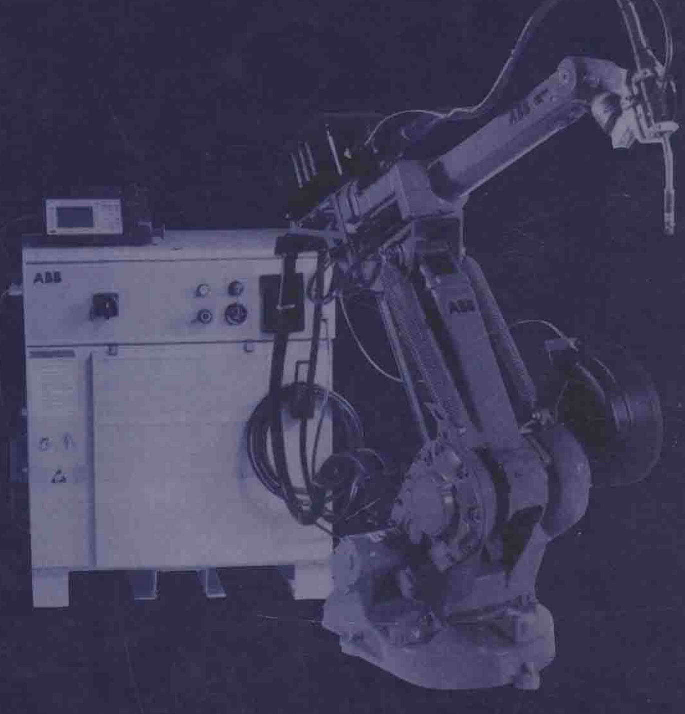
缩编国外精品教材

Kinematics and Dynamics of Machinery

机械原理

[美] Charles E. Wilson J. Peter Sadler 著
秦 伟 缩编



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缩编说明

本教材是美国新泽西技术学院(New Jersey Institute of Technology)Charles E. Wilson 教授和肯塔基大学(University of Kentucky)教授 J. Peter Sadler 合作编写的教材 Kinematics and Dynamics of Machinery(Third Edition)的缩编版。原书共 12 章,根据我国机械原理课程教学基本要求缩编为 11 章。内容为:基本概念,机构位置分析,机构速度分析,机构加速度分析,凸轮和从动件系统设计与分析,直齿轮设计与分析,斜齿轮、蜗杆蜗轮和锥齿轮设计与分析,轮系设计与分析,静力分析,动态静力分析,连杆机构综合。缩编版还附有:原书序言,作者简介,英制与国际单位制换算表,部分习题答案。

缩编版教材与原教材主要有以下不同:

- 删除了数学,理论力学,机器人等部分相关内容,保留了原教材的核心内容,减少了篇幅。缩编版贴近我国机械原理课程教学基本要求,便于学生学习和教师教学,适用于普通工科院校机械类专业机械原理课程的双语教学。
- 原教材包含有大量的例题和习题,但是为了缩减篇幅,缩编版教材只保留了部分例题和习题。
- 原书内容既有英制,又有国际单位制。为了充分保留不同类型的例题和习题,缩编版在尽可能只保留国际单位制例题、习题的前提下,也保留了个别英制单位的例题和习题,建议使用者在学习中要加以注意。
- 原书给出了大量实物照片,为了减少篇幅,缩编版只保留了部分实物照片。

缩编版保留了原教材的以下特色:

- 不少习题来自于工程实际,有助于学生工程意识与工程实践能力的培养。
- 为学生进一步学习提供了最新的、丰富的参考资料和大量的相关网站。网站资源涉及汽车传动元件,凸轮,齿轮,机器人,部分用于工程设计、计算、制造、运动仿真和试验的软件,权威的涉及机械原理学科的科技期刊等。
- 分析与设计并重,介绍了解析法和图解法。
- 既侧重基础理论,也给出实用性的设计手段。

本教材语言流畅,通俗易懂,联系实际,适应我国学生的外语水平和学习特点,是一本学习机械原理课程和进行机械原理双语教学的优秀教材。

秦　伟

2005 年 3 月

Preface

What Abilities Define an Engineer?

Part of the answer is given by the *program outcomes and assessment* criteria of the Accreditation Board for Engineering and Technology①. Engineering programs must demonstrate that their graduates have specific abilities. These include:

- an ability to apply knowledge of mathematics, science, and engineering
- an ability to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs
- an ability to identify, formulate, and solve engineering problems
- an ability to communicate effectively
- an ability to use techniques, skills, and modern engineering tools necessary for engineering practice.

Goals of the Text

A course in the kinematics and dynamics of machinery provides many opportunities to develop the abilities listed above. This text is designed to help foster development and application of those skills. One goal is to develop the ability of students to formulate and solve problems in the kinematics and dynamics of machinery. Engineering tools used to achieve this goal include motion simulation software and general-purpose mathematical software. These tools relieve the designer of repetitive tasks and provide a powerful means of communicating results through graphs and animation simulations. An equally important goal is the development of an understanding of the implications of computed results. That is, what do the results mean; how can we improve the design? Knowledge gained in previous courses is reinforced when applied to problems in the kinematics and dynamics of machinery. For example, matrix methods become meaningful when applied to equations describing velocities and accelerations in a spatial linkage. The skills learned and sharpened in studying the kinematics and dynamics of machinery are carried forward, even to unrelated courses and to engineering practice.

Scope

The coverage of this text includes mechanisms and machines, basic concepts; motion in machinery; velocity and acceleration analysis of mechanisms; design and analysis of cams, gears, and drive trains; static and dynamic force analysis; synthesis; and an introduction to robotic manipulators. Practical applications are considered throughout the text. Example

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① Accreditation Board for Engineering and Technology, *Engineering Criteria 2000*, Third Edition, December 1997.

problems and homework problems involve engineering design and provide a basis for design courses to follow. Analytical and graphical vector methods are illustrated, as well as complex number methods.

The text illustrates the use of motion simulation software, mathematics software, and user-written programs to solve problem and to present the results in plotted or tabulated form.

There are also many problems that can be solved by "hand calculations," however, using only a scientific calculator and/or simple drafting tools. The latter group may be useful as short practice problems and examination problems when laptop computers are unavailable.

What's New in the Third Edition?

The text was updated throughout. A few of the changes and additions include:

- A list of "Concepts you will learn and apply..." for each chapter.
- Chapter summaries
- Review and discussion items for each chapter
- Thorough revision of the material on cam design, including application of step and interval functions, and higher order polynomials for cam design.
- Practical design implications of results
- Gear train diagnostics based on noise and vibration frequencies
- Updates, example problems and homework using motion simulation software
- Updates example problems and homework problems using mathematics software throughout the text.
- Other updates for clarity and brevity
- Suggestions for "working smart," particularly with computers. Emphasis on computer-aided matrix solutions where appropriate
- Interpretation and assessment of results. Is it logical? Does it check? Let's compare results with another solution. What does it mean? What does the graph show?
- Practical design implications of results

Course Development

Professors who regularly teach the kinematics and dynamics of machinery will know what topics suit their students best. This note is for instructors who have not taught the course recently.

Most of the topics in this text can be covered in a three-credit-hour course given to engineering students who have completed a course in the statics and dynamics of rigid bodies. But a single course designed around the entire book would be likely to have insufficient depth. Instructors may decide to cover the parts of the text that they deem essential, and then select additional topics and solution methods according to goals set for their students. For example, either analytical vector methods or complex number methods may be used as a basis for writing computer programs to solve planar linkages. However, if analysis of spatial linkages is to follow analysis of planar linkages, then vector methods might be used for both.

For courses built around the use of motion simulation software and mathematics software, graphical methods are likely to be de-emphasized. For example, the velocity polygon might be used only to spot check a detailed analytical velocity analysis of a planar linkage. In a course concerning the kinematics and dynamics of machinery, uniformity of course content is not essential. Differences in emphasis and methods among university engineering departments may strengthen the "gene pool" of future engineers.

We have attempted to provide sufficient rigor and advanced material to challenge the student and provide a basis for further study. Student creativity may be fostered by the demands of the task, particularly if a few homework problems are expanded into open-ended design-type projects. Additional projects requiring creativity may be suggested by articles in technical publications or by an instructor's current research and consulting.

Disclaimer

The kinematics and dynamics of machinery and the design of mechanisms involve modeling of physical systems. Relationships so developed have limits of applicability. The user of this text is urged to interpret the results of calculations, rather than simply obtain problem solutions. It is the reader's responsibility to assess formulas and methods to determine their applicability to a particular situation. Although the publisher, the reviewers, and the authors have made every effort to ensure accuracy, errors invariably creep in. Suggestions and corrections are most welcome.

About the Authors

Charles E. Wilson is a Professor with the Department of Mechanical Engineering, New Jersey Institute of Technology. He received the B. S. and M. S. degrees in mechanical engineering from the Newark College of Engineering, the M. S. in engineering mechanics from New York University, and the Ph. D. degree in mechanical engineering from Brooklyn Polytechnic Institute. He is a licensed professional engineer, and has been awarded fellowships by the National Aeronautics and Space Administration, Department of Energy, and National Science Foundation.

Dr. Wilson has published papers in a number of journals and transactions. Textbooks he has authored and co-authored are widely used in the United States and Canada. English language versions are also published in Britain, Taiwan, India, and the Philippines, and translations are published in Korea and Mexico.

Dr. Wilson served as a U. S. Air Force electronics and armament officer, and as an engineer and consultant for a number of companies. He is often called on to investigate functional and design problems in vehicles, machinery, and consumer products. He has investigated and given expert testimony on auto, truck, bus, and ambulance accidents, and accidents involving elevators, hydraulic presses, welds, playground equipment, garden equipment, and truck-mounted machinery.

J. Peter Sadler is a Professor with the Department of Mechanical Engineering, University of Kentucky. He has previously held faculty positions at the State University of New York at Buffalo and the University of North Dakota. He received the B. S. M. E, M. S. M. E. , and Ph. D. degrees from Rensselaer Polytechnic Institute.

Dr. Sadler is a registered professional engineer and a member of many technical societies. He served as Editor for dynamics for the *Journal of Mechanism and Machine Theory* and Associate Editor of the *Journal of Applied Mechanics and Robotics.*

Dr. Sadler holds a U. S. patent related to predicting optimum machining coditions. His industrial projects and research include kinematics and dynamics, robotics, computer aided design, engineering optimization, and "lean" manufacturing.

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We wish to express our appreciation to all who helped with this book. Users of earlier editions and manuscript reviewers made many worthwhile suggestions based on their extensive teaching and engineering experience. Their expert analysis resulted in many changes in the text. Those sharing their expertise included: Leo Maier of Ohio Northern University, Joseph M. Mansour of Case Western Reserve University, Charles Mallory North, Jr. of Rose-Hulman Institute of Technology, G. K. Ananthasuresh of the University of Pennsylvania, Koorosh Naghshineh of Western Michigan University, Charles C. Adams of Dordt College, Noah Manring of the University of Missouri—Columbia, Melvin R. Corley of Louisiana Tech University, Dan R. Marghitu of Auburn University, Huh Jing Ying of the University of South Florida, Gary H. McDonald of the University of Tennessee at Chattanooga, Ara Arabyan of the University of Arizona, Saeed B. Nicu of California Polytechnic State University, Ferdinand Freudenstein of Columbia University, Robert Williams of Control Data Corporation, Kenneth Waldron of Ohio State University, and William Park of Pennsylvania State University. We also wish to thank our students and colleagues for their suggestions and comments and to thank the companies that provided photographs and illustrations. Thanks also to our editors and others who saw this work through to completion.

Symbols

Vectors and matrices are shown in **boldface**, scalar magnitudes in lightface.

$\mathbf{A}^{-1}$	Inverse of matrix $\mathbf{A}$
$\mathbf{A} \cdot \mathbf{B}$	Dot (scalar) product of vectors $\mathbf{A}$ and $\mathbf{B}$
$\mathbf{A} \times \mathbf{B}$	Cross (vector) product of vectors $\mathbf{A}$ and $\mathbf{B}$
a	Gear tooth addendum
$a, \mathbf{a}$	Acceleration
$a^c, \mathbf{a}^c$	Coriolis acceleration
$a^n, \mathbf{a}^n$	Normal acceleration
$a^t, \mathbf{a}^t$	Tangential acceleration
$\mathbf{bc}$	Velocity of C relative to B (velocity difference)
C	Cylinder pair; planet carrier
$\mathbf{C}$	Force couple
$\mathbf{C}_i$	Inertia couple or inertia torque
c	Center distance
CAD	Computer-aided design
D	Determinant
d	Diameter of pitch circle
d_b	Diameter of base circle
DF	Degrees of freedom
e	Instantaneous efficiency; cam-follower offset; piston offset; eccentricity
$e^{j\theta}$	Polar form of a complexnumber
$\mathbf{F}$	Force
F_a	Axial or thrust gear tooth force component
$\mathbf{F}_e$	External force
$\mathbf{F}_i$	Inertia force
$\mathbf{F}_{ij}$	Force exerted by a member i on member j
$\mathbf{F}_n$	Normal gear tooth force
F_r	Radial gear tooth force component
F_s	Shaking force
F_t	Tangential gear tooth force component
f	frequency
f_i	Joint connectivity
G	Center of mass
H	Helix pair
h	Cam follower lift
hp	Horsepower
I	Mass moment of inertia
$\mathbf{i}, \mathbf{j}, \mathbf{k}$	Cartesian unit vectors
j	Cam follower jerk; $\sqrt{-1}$, the imaginary unit used to represent quantities on the complex plane
L	Link length, sound level
L_d	Length of diagonal (of linkage polygon)
l	Lead of worm
l_i	Length of link i
$\mathbf{M}_s$	Shaking moment
m	Mass; module; slope; meters
m^n	Normal module
N	Number of gear teeth; newtons
$\mathbf{N}$	Normal force
n	Rotational speed (revolutions per minute)
n_c	Number of constraints
n_J	Number of joints
n_L	Number of links
O_1	Fixed bearing on link 1
$\mathbf{ob}$	Absolute velocity of point B
P	Prism pair; planet gear; power; diametral pitch
$\mathbf{P}$	Piston force
P^n	Normal diametral pitch
p	Transverse circular pitch, pressure
p_b	Base pitch
p^n	Normal circular pitch
p_w	Axial pitch of worm
R	Revolute pair; ring gear; length of crank
$\mathbf{R}$	Position vector
r	Radius of pitch circle
$\mathbf{r}$	Position vector; vector representing a link
$\dot{\mathbf{r}}$	Derivative of $\mathbf{r}$ with respect to time

r^*	Train value (speed ratio) for a planetary train relative to the carrier
r_a	Length of cam-follower arm; radius of addendum circle
r_b	Base circle radius; radius of back cone element
r_c	Center distance between cam and follower pivots
r_f	Radius of cam-follower roller; radius of friction circle
r_m	Mean pitch radius
r_v	Velocity ratio
$\boldsymbol{r}^u$	Unit vector
r_x	x component of vector $\boldsymbol{r}$
S	Sphere pair; sun gear
$\boldsymbol{s}, s$	Displacement
s	Seconds
s_n	Axial spacing of engine cranks and cylinders; joint offset along axis n
$\boldsymbol{T}, T$	Torque
$\boldsymbol{T}_e$	External torque
t	Time; gear tooth thickness
U	Universal joint
$\boldsymbol{v}$	Velocity
v_p	Pitch line velocity
W	Work; watts
w	Gear tooth width; weight
x, y, z	Cartesian coordinates
$\times$	Cross product
$\alpha, \boldsymbol{\alpha}$	Angular acceleration
α	Cam rotation angle; angle of approach
β	Angle of recess
Γ	Pitch angle
γ	Cam follower rotation; pitch angle; mass density
$\delta\phi, \delta x$	Virtual displacements
θ	Angular position of link; cam angle; angle of action; connecting rod angle
θ_i	Angular position of link i
θ_n	Angular spacing of engine cylinders; joint angle about axis n
λ	Lead angle of worm
μ	Coefficient of sliding friction
ρ	Radius of curvature
ρ_p	Radius of curvature of pitch curve
Σ	Angle between shafts
τ_i	Link twist of member i
Φ	Heaviside stcp function
ϕ	Transmission angle; pressure angle; transverse pressure angle; friction angle
ϕ_i	Angular position of link i
ϕ^n	Normal pressure angle
ψ	Involute angle; helix angle
ψ_n	Angular spacing of engine cranks
$\omega, \boldsymbol{\omega}$	Angular velocity

What You Will Learn and Apply in the Study of the Kinematics and Dynamics of Machinery

The following is a partial list of the knowledge and skills you will acquire or enhance. In many cases, you will be applying mathematics and scientific principles that you learned previously.

- Effective computer use and software selection
- Application of animation software to linkage design
- Application of mathematics software to mechanism design
- Computer-aided solutions to engineering problems using vector and matrix equations
- Mobility of planar and spatial linkages
- Determination of motion characteristics of linkages
- Design to avoid binding and interference
- Design and selection of mechanisms for specific applications
- Complex number methods applied to linkage design
- Analytical and graphical methods for finding linkage velocities
- Analytical and graphical methods for finding linkage accelerations

- Design and analysis of cams
- Design and analysis of spur gears
- Design and analysis of helical, worm, and bevel gears
- Arrangement of gears to produce desired input-output speed ratios
- Design of planetary speed changers
- Analysis of static forces in linkages
- Analysis of dynamic forces in linkages
- Balancing of rotors and reciprocating machines
- Synthesis of linkages to produce predetermined motion
- Critical thinking applied to mechanism design. Critical thinking involves identification of a problem, gathering of data, objective analysis, and an attempt at solving the problem by a scientific process. This skill should be honed throughout an engineer's education and practice.
- Engineering creativity. The text and problems are designed to foster creativity, but this goal depends almost entirely on the student (with encouragement from an instructor).

Contents