

VOLUME

1

MECHANISM DESIGN:
Analysis and Synthesis

ARTHUR G. ERDMAN

GEORGE N. SANDOR

PRENTICE-HALL, INC., *Englewood Cliffs, New Jersey 07632*

Mylan Exhibit - 1033

Mylan v. Sanofi

Library of Congress Cataloging in Publication Data

ERDMAN, ARTHUR G. (date)
Mechanism design.

Includes bibliographies and indexes.

1. Machinery—Design. I. Sandor, George N.

II. Title.

TJ230.E67 1984 621.8'15 83-3148

ISBN 0-13-572396-5 (v. 1)

Engin
TJ
230
E67
1984
—
1

Editorial/production supervision
and interior design: **Karen Skrable**
Manufacturing buyer: **Anthony Caruso**
Cover design: **Photo Plus Art, Celine Brandes**

© 1984 by **Arthur G. Erdman and George N. Sandor**

Volume 2 published under the title *Advanced Mechanism Design:
Analysis and Synthesis, Vol. 2.*

*All rights reserved. No part of this book
may be reproduced in any form or
by any means without permission in writing
from the publisher.*

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

ISBN 0-13-572396-5

PRENTICE-HALL INTERNATIONAL, INC., *London*
PRENTICE-HALL OF AUSTRALIA PTY. LIMITED, *Sydney*
EDITORIA PRENTICE-HALL DO BRASIL, LTDA., *Rio de Janeiro*
PRENTICE-HALL CANADA INC., *Toronto*
PRENTICE-HALL OF INDIA PRIVATE LIMITED, *New Delhi*
PRENTICE-HALL OF JAPAN, INC., *Tokyo*
PRENTICE-HALL OF SOUTHEAST ASIA PTE. LTD., *Singapore*
WHITEHALL BOOKS LIMITED, *Wellington, New Zealand*

*Art Erdman
dedicates this work
to his daughters
Kristy and Kari*



Contents

PREFACE

ix

X 1

INTRODUCTION TO KINEMATICS AND MECHANISMS

1

- 1.1 Introduction 1
- 1.2 Motion 2
- 1.3 The Four-Bar Linkage 2
- 1.4 The Science of Relative Motion 5
- 1.5 Kinematic Diagrams 5
- 1.6 Six-Bar Chains 10
- 1.7 Degrees of Freedom 16
- 1.8 Analysis versus Synthesis 24
- Problems 25

2

MECHANISM DESIGN PHILOSOPHY

49

- 2.1 Introduction 49
- 2.2 The Seven Stages of Engineering Design 51
- 2.3 How the Seven Stages Relate to This Text 56
- 2.4 The Mechanism Synthesis Process 58
- 2.5 Design Categories and Mechanism Parameters 61
- 2.6 Troubleshooting Guide: Symptoms, Causes, and Sources of Assistance 65

v

Mylan Exhibit - 1033

Mylan v. Sanofi

3

DISPLACEMENT AND VELOCITY ANALYSIS 68

- 3.1 Displacement Analysis: Useful Indices for Position Analysis of Linkages 68
- 3.2 Displacement Analysis 75
- 3.3 Concept of Relative Motion 83
- 3.4 Velocity Analysis 84
- 3.5 Instant Centers 96
- 3.6 Velocity Analysis Using Instant Centers 105
- 3.7 Mechanical Advantage 110
- 3.8 Analytical Method for Velocity and Mechanical Advantage Determination 121
- 3.9 Computer Program for the Kinematic Analysis of a Four-Bar Linkage 126
 - Appendix: Review of Complex Numbers 134
 - Problems 142
 - Exercises 174

4

ACCELERATION ANALYSIS 175

- 4.1 Introduction 175
- 4.2 Acceleration Difference 176
- 4.3 Relative Acceleration 180
- 4.4 Coriolis Acceleration 185
- 4.5 Mechanisms with Curved Slots 201
 - Problems 202

5

INTRODUCTION TO DYNAMICS OF MECHANISMS 218

- 5.1 Introduction 218
- 5.2 Inertia Forces in Linkages 223
- 5.3 Kinetostatic Analysis by Complex Numbers 232
- 5.4 The Superposition Method 233
- 5.5 Design Example: Analysis of a Variable-Speed Drive 240
- 5.6 The Matrix Method 250
- 5.7 Discussion of the Superposition and Matrix Approach to Kinetostatics 257
 - Problems 259

6

CAM DESIGN 271

- 6.1 Introduction 271
- 6.2 Cam and Follower Types 272
- 6.3 Cam Synthesis 276
- 6.4 Displacement Diagrams 278
- 6.5 Advanced Cam Profile Techniques 291

- 6.6 Graphi
- 6.7 Analyt
- 6.8 Cam S
- 6.9 Cam-M
- Proble

7

GEARS AND

- 7.1 Introduct
- 7.2 Gear T
- 7.3 Formin
- 7.4 Gear T
- 7.5 Planeta
- 7.6 The Fc
- 7.7 The Ta
- 7.8 The In
- 7.9 Tooth
- Proble

~~8~~

INTRODU
GRAPHIC

- 8.1 Introduct
- 8.2 Tasks c
- 8.3 Numbe
- 8.4 Tools c
- 8.5 Graphi
- 8.6 Graphi
- 8.7 Graphi
- 8.8 Path G
- 8.9 Graphi
- Four P
- 8.10 Functio
- 8.11 The Ov
- 8.12 Analyti
- 8.13 Comple
- 8.14 The Dy
- 8.15 Numbe
- 8.16 Three l
- Function
- 8.17 Three-l
- 8.18 Three-l

- 6.6 Graphical Cam Profile Synthesis 302
- 6.7 Analytical Cam Profile Synthesis 306
- 6.8 Cam Synthesis for Remote Follower 319
- 6.9 Cam-Modulated Linkages 322
Problems 331

7

GEARS AND GEAR TRAINS

340

- 7.1 Introduction 340
- 7.2 Gear Tooth Nomenclature 345
- 7.3 Forming of Gear Teeth 346
- 7.4 Gear Trains 350
- 7.5 Planetary Gear Trains 353
- 7.6 The Formula Method 356
- 7.7 The Tabular Method 361
- 7.8 The Instant Center Method (or Tangential Velocity Method) 364
- 7.9 Tooth Loads and Power Flow in Branching Planetary Gear Systems 369
Problems 379

8

**INTRODUCTION TO KINEMATIC SYNTHESIS:
GRAPHICAL AND LINEAR ANALYTICAL METHODS**

391

- 8.1 Introduction 391
- 8.2 Tasks of Kinematic Synthesis 394
- 8.3 Number Synthesis: The Associated Linkage Concept 406
- 8.4 Tools of Dimensional Synthesis 417
- 8.5 Graphical Synthesis—Motion Generation: Two Prescribed Positions 418
- 8.6 Graphical Synthesis—Motion Generation: Three Prescribed Positions 420
- 8.7 Graphical Synthesis for Path Generation: Three Prescribed Positions 421
- 8.8 Path Generation with Prescribed Timing: Three Prescribed Positions 423
- 8.9 Graphical Synthesis for Path Generation (without Prescribed Timing):
Four Positions 424
- 8.10 Function Generator: Three Precision Points 427
- 8.11 The Overlay Method 429
- 8.12 Analytical Synthesis Techniques 431
- 8.13 Complex-Number Modeling in Kinematic Synthesis 432
- 8.14 The Dyad or Standard Form 434
- 8.15 Number of Prescribed Position versus Number of Free Choices 436
- 8.16 Three Prescribed Positions for Motion, Path, and
Function Generation 439
- 8.17 Three-Precision-Point Synthesis Program for Four-Bar Linkages 445
- 8.18 Three-Precision-Point Synthesis: Analytical versus Graphical 452

Mylan Exhibit - 1033

Mylan v. Sanofi

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts



Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research



With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips



Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.