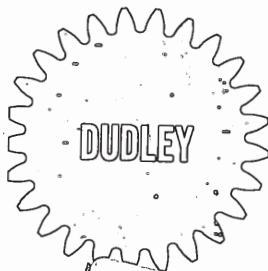


GEAR
HANDBOOK



GS
2



GEAR HANDBOOK

The Design, Manufacture
and Application of Gears

DARLE W. DUDLEY

EDITOR IN CHIEF

MCGRAW-HILL BOOK COMPANY

E7

Property of
D.B. Thomas
GE - S $\frac{1}{2}$ SE
175 Curtner Ave.
Mail Code 849
San Jose, Ca. 95125

GEAR HANDBOOK

OTHER MCGRAW-HILL HANDBOOKS OF INTEREST

AMERICAN INSTITUTE OF PHYSICS · American Institute of Physics Handbook
AMERICAN SOCIETY OF MECHANICAL ENGINEERS · ASME Handbooks:
Engineering Tables Metals Engineering—Processes
Metals Engineering—Design Metals Properties
AMERICAN SOCIETY OF TOOL AND MANUFACTURING ENGINEERS:
Die Design Handbook Manufacturing Planning and
Handbook of Fixture Design Estimating Handbook
Tool Engineers Handbook
ARCHITECTURAL RECORD · Time-Saver Standards
BEEMAN · Industrial Power Systems Handbook
BRADY · Materials Handbook
BURINGTON · Handbook of Mathematical Tables and Formulas
BURINGTON AND MAY · Handbook of Probability and Statistics with
Tables
CARRIER AIR CONDITIONING COMPANY · Handbook of Air Conditioning
System Design
CARROLL · Industrial Instrument Servicing Handbook
CONDON AND ODISHAW · Handbook of Physics
CONSIDINE · Process Instruments and Controls Handbook
CONSIDINE AND ROSS · Handbook of Applied Instrumentation
CROCKER · Piping Handbook
DAVIS · Handbook of Applied Hydraulics
EMERICK · Heating Handbook
FACTORY MUTUAL ENGINEERING DIVISION · Handbook of Industrial Loss
Prevention
FLUGGE · Handbook of Engineering Mechanics
HARRIS · Handbook of Noise Control
HARRIS AND CREDE · Shock and Vibration Handbook

HEYEL · The Foreman's Handbook
HUSKEY AND KORN · Computer Handbook
JURAN · Quality Control Handbook
KALLEN · Handbook of Instrumentation and Controls
KING AND BRATER · Handbook of Hydraulics
KNOWLTON · Standard Handbook for Electrical Engineers
KOELLE · Handbook of Astronautical Engineering
KORN AND KORN · Mathematical Handbook for Scientists and Engineers
LASSER · Business Management Handbook
LEGRAND · The New American Machinists' Handbook
MACHOL · System Engineering Handbook
MAGILL, HOLDEN, AND ACKLEY · Air Pollution Handbook
MANAS · National Plumbing Code Handbook
MANTELL · Engineering Materials Handbook
MARKS AND BAUMEISTER · Mechanical Engineers' Handbook
MAYNARD · Industrial Engineering Handbook
MAYNARD · Top Management Handbook
MORROW · Maintenance Engineering Handbook
PERRY · Chemical Engineers' Handbook
PERRY · Engineering Manual
ROSSNAGEL · Handbook of Rigging
ROTHBART · Mechanical Design and Systems Handbook
SHAND · Glass Engineering Handbook
STANIAR · Plant Engineering Handbook
STREETER · Handbook of Fluid Dynamics
TOULOUKIAN · Retrieval Guide to Thermophysical Properties Research
Literature
TRUXAL · Control Engineers' Handbook

GEAR HANDBOOK

The Design, Manufacture, and
Application of Gears

DARLE W. DUDLEY, Editor

*Manager, Advance Gear Engineering
General Electric Company
Lynn, Massachusetts*

FIRST EDITION

McGRAW-HILL BOOK COMPANY

New York Toronto London Sydney

GEAR HANDBOOK

Copyright © 1962 by McGraw-Hill, Inc. All Rights Reserved.
Printed in the United States of America. This book, or parts thereof,
may not be reproduced in any form without permission of the publishers.

Library of Congress Catalog Card Number: 61-7304

17902

6 7 8 9 10 11 12 - MAMB-7 5 4

CONTRIBUTORS

MERIWETHER L. BAXTER, Jr., Chief Research Engineer, Gleason Works, Rochester, N.Y. (*Author of Chapter 1, Basic Theory of Gear-tooth Action and Generation*)

ALBERT S. BEAM, Staff Engineer, Vinco Corporation, Detroit, Mich. (*Author of Chapter 23, Gear-inspection Devices*)

SOL BINDER, Chief, Transmission Stress, Vertol Division, Boeing Airplane Company, Morton, Pa. (*Co-author of Chapter 2, Functional Types of Gears*)

F. E. BIRTCH, Manager, Cone-Drive Division, Michigan Tool Company, Detroit, Mich. (*Contribution to Chapter 23, Gear-inspection Devices*)

FRED BOHLE, Manager of Spiroid Division of Illinois Tool Works, Chicago, Ill. (*Contribution to Chapter 5, Gear-tooth Proportions*)

BEN F. BREGI, Vice President—Manufacturing and Research, National Broach and Machine Company, Detroit, Mich. (*Author of Chapter 18, Gear Finishing by Shaving, Honing, and Lapping*)

E. G. CHARTIER, President, Tekniks Engineering Company, Elmhurst, Ill. (*Author of Chapter 17, Gears Produced by Dies*)

WELLS COLEMAN, Chief Gear Analyst, Gleason Works, Rochester, N.Y. (*Contributions to Chapter 5, Gear-tooth Proportions, and Chapter 13, Load Rating of Gears*)

WARNER T. COWELL, Chief Engineer, Gear Engineering Test Center, Gleason Works, Rochester, N.Y. (*Contribution to Chapter 12, Gear Reactions and Mountings*)

S. L. CRAWSHAW, Vice President of Philadelphia Gear Corporation. (*Contribution to Chapter 3, Gear Arrangements*)

PAUL M. DEAN, Jr., Gear Technology Engineer, General Engineering Laboratory, General Electric Company, Schenectady, N.Y. (*Author of Chapter 5, Gear-tooth Proportions, and Chapter 6, Center Distance*)

DARLE W. DUDLEY, Manager, Advance Gear Engineering, General Electric Company, Lynn, Mass. (*Author of Chapter 3, Gear Arrangements. Contribution to Chapter 5, Gear-tooth Proportions. Author of Chapter 10, Gear Materials. Contribution to Chapter 23, Gear-inspection Devices*)

THOMAS W. EDWARDS, Senior Engineer, Engineering Department, Vinco Corporation, Detroit, Mich. (*Contribution to Chapter 23, Gear-inspection Devices*)

- M. L. FALLON**, Senior Application Design Analyst, Gear Engineering Test Center, Gleason Works, Rochester, N.Y. (*Contribution to Chapter 12, Gear Reactions and Mountings*)
- WAYNE H. GLOVER**, Vice President and General Manager, Indiana Gear Works, Inc., a Division of the Buehler Corporation, Indianapolis, Ind. (*Author of Chapter 19, Grinding Spur and Helical Gears*)
- HARRY J. HART**, Sales Engineer, Gleason Works, Rochester, N.Y. (*Co-author of Chapter 20, Bevel- and Hypoid-gear Manufacturing*)
- MARTIN A. HARTMAN**, Research Specialist, Rocketdyne Division of North American Aviation, Canoga Park, Calif. (*Author of Chapter 12, Gear Reactions and Mountings*)
- RICHARD S. HILDRETH**, Chief Engineer, Michigan Tool Company, Detroit, Mich. (*Author of Chapter 22, Gear-cutting Tools*)
- CLARENCE JOHNSON**, Superintendent, Utility Manufacturing Company, North Wilbraham, Mass. (*Contribution to Chapter 17, Gears Produced by Dies*)
- STUART J. JOHNSON**, Chief Engineer, Small Tools Division, Barber-Colman Company, Rockford, Ill. (*Author of Chapter 16, Gear Cutting*)
- T. W. KHIRALLA**, Staff Engineer, Curtiss-Wright Corporation, Propeller Division, Caldwell, N.J. (*Author of Chapter 21, Worm and Wormgear Cutting and Grinding Processes*)
- CHARLES B. KING**, Associate Chief Research Engineer, Gleason Works, Rochester, N.Y. (*Contribution to Chapter 8, Calculation of Gear-tooth Profiles. Co-author of Chapter 20, Bevel- and Hypoid-gear Manufacturing*)
- LEO KINGSTON**, Chief, Transmission Design, Vertol Division, Boeing Airplane Company, Morton, Pa. (*Co-author of Chapter 2, Functional Types of Gears*)
- EDWIN R. KITCHEN**, Gear and Cutter Engineer, Farrel-Birmingham Co., Inc., Rochester, N.Y. (*Contribution to Chapter 16, Gear Cutting*)
- THEODORE F. KLEM**, Gear Engineer, Gleason Works, Rochester, N.Y., (*Contribution to Chapter 23, Gear-inspection Devices*)
- HAROLD KRON**, Chief Engineer, Philadelphia Gear Corporation. (*Contribution to Chapter 3, Gear Arrangements*)
- ROY E. LANDSTROM**, Chief Tool Designer, Michigan Tool Company, Detroit, Mich. (*Contribution to Chapter 22, Gear-cutting Tools*)
- A. J. LEMANSKI**, Supervisor of Gear Engineering, Lycoming-Avco, Stratford, Conn. (*Contribution to Chapter 17, Gears Produced by Dies*)
- GEORGE L. MCCAIN**, Gear Consultant, Birmingham, Mich. (*Author of Chapter 11, Gear Drawings*)
- GEORGE W. MICHALEC**, Head of Special Products Department, GPL Division—General Precision, Inc., Pleasantville, N.Y. (*Author of Chapter 9, Gear Tolerances*)

CONTRIBUTORS

ix

- WOODROW NELSON**, Chief Engineer, The Spiroid Division of Illinois Tool Works, Chicago, Ill. (*Contribution to Chapter 5, Gear-tooth Proportions*)
- CARL PARKER**, Assistant Chief Tool Engineer, The Fellows Gear Shaper Company, Springfield, Vt. (*Contribution to Chapter 5, Gear-tooth Proportions*)
- ROBERT T. PARSONS**, President, The Van Keuren Company, Boston, Mass. (*Author of Chapter 24, Numerical Data Tables*)
- HARRY PEDERSEN**, Chief Design Analyst, Gleason Works, Rochester, N.Y. (*Co-author of Chapter 20, Bevel- and Hypoid-gear Manufacturing*)
- FOLKE RICHARDZ**, Consulting Specialist, Gearing Products, Westinghouse Electric Corporation, Buffalo, N.Y. (*Author of Chapter 15, Lubrication of Gears*)
- GERALD L. SCOTT**, Staff Engineer, American Gear Manufacturers Association, Washington, D.C. (*Author of Chapter 4, Elements of Gears and Basic Formulas. Contribution to Chapter 5, Gear-tooth Proportions*)
- JOHN C. SEARS**, Executive Director of American Gear Manufacturers Association, Washington, D.C. (*Author of Foreword*)
- GEORGE SHIMMIN**, Sales Manager, Cone Drive Division, Michigan Tool Company, Detroit, Mich. (*Contribution to Chapter 5, Gear-tooth Proportions*)
- EUGENE E. SHIPLEY**, Project Engineer—Advance Development, General Electric Company, Lynn, Mass. (*Author of Chapter 14, Loaded Gears in Action*)
- GILMORE M. SPEAR**, Research Engineer, Gleason Works, Rochester, N.Y. (*Co-author of Chapter 20, Bevel- and Hypoid-gear Manufacturing*)
- M. F. SPOTTS**, Professor of Mechanical Engineering, Northwestern University, Evanston, Ill. (*Author of Chapter 7, Special Calculations for Spur and Helical Gears*)
- ANTONI TABAK**, Gear Metallurgist, General Electric Company, Lynn, Mass. (*Contribution to Chapter 10, Gear Materials*)
- CLARENCE UNDERWOOD**, Gear Consultant, Raytheon Company, Wayland, Mass. (*Contribution to Chapter 10, Gear Materials*)
- EDWARD C. VARNUM**, Head, Operations Research, Barber-Colman Company, Rockford, Ill. (*Author of Chapter 8, Calculation of Gear-tooth Profiles*)
- GARY L. VESEY**, Mechanical Engineer, Spiroid Division of Illinois Tool Works, Chicago, Ill. (*Contribution to Chapter 23, Gear-inspection Devices*)
- E. J. WELLAUER**, Director of Research and Development, The Falk Corporation, Milwaukee, Wis. (*Author of Chapter 13, Load Rating of Gears*)
- HAROLD WINZELER**, Vice President and General Manager, Winzeler Manufacturing Company, Chicago, Ill. (*Contribution to Chapter 17, Gears Produced by Dies*)

FOREWORD

The design and manufacture of a gear that is no better than the requirement for its successful application is an art rather than a science.

Volumes have been written and said in attempts to attain good gears. Many of them have been rather unsuccessful interpretations of what their authors opined previous authors meant or failed to say.

Thus, much of the information comes under what I call "gear folklore"—just about as obsolete as the cogwheel that sired the quality of gearing we need in modern applications.

The authors of this "Gear Handbook" are seasoned and experienced gear men. They have spent most of their careers in the study of gear phenomena, in tempering theory in the furnace of practicality and economic necessity. Several of them have received the highest honor the American Gear Manufacturers Association has to bestow on contributors to the gear art, its "Edward P. Connell" Award.

These dedicated authors set out to give the gear designer and manufacturer a true and accurate recording of the present state of the art.

They have eminently succeeded in so doing. Therefore, I personally and on behalf of AGMA enthusiastically commend this "Gear Handbook" to all who have a genuine desire and economic need to acquaint themselves with the gear art as it is now being practiced by forward-looking, down-to-earth gear designers and manufacturers.

J. C. SEARS, *Executive Director*
American Gear Manufacturers Association

PREFACE

Although a rather surprising amount of material has already been written on the subject of gears, it has been hard for the average person to quickly find the detailed gear information that he needs. A wealth of gear information has already been published in trade standards, magazine articles, manufacturers' catalogues, private company reports, and gear books. The key information to solve the design of a gear, plan tooling for a gear job, analyze a gear failure, or pick an appropriate manufacturing process may be hidden almost anywhere in current available technical literature.

The "Gear Handbook" was conceived as a means of solving this problem. In approximately one thousand pages of moderately fine print all aspects of the gear art are covered. The questions that the gear designer, the gear builder, or the gear user may have are all covered. Condensed information is given on the many types of gears that are now in use. Specific information is given on the great diversity of manufacturing processes that may be used. Considering that the field of gearing goes all the way from the little mass-produced gears for toys, clocks, instruments, and the like, up to the massive main propulsion units used for major ships or airplanes, it can be appreciated that the manufacturing techniques will vary widely.

The people who design and build gears comprise only a small fraction of the people engaged in manufacturing work. However, the people who use gears include almost everyone. It has been said quite truthfully that you can't tell the time of day without gears, you can't wash your clothes without gears, you can't drive to work without gears, and you can't make anything in your shop without gears. The user of gears is often very interested in things like the performance of gear equipment, the life expectancy of gearing, or the relative cost of different ways of making gears. Subject matter for the "Gear Handbook" has been selected with the aim of covering the whole wide field of interest in the gear art.

Chapters 1 through 4 introduce the reader to the basic theory of gearing, define the types of gear teeth, explain the many possible gear arrangements, and define the nomenclature and basic geometry of gears.

All of this is necessary background material to acquaint a person with the language and definitions peculiar to the gear trade.

Chapters 5 through 15 are the prime engineering-design chapters. These cover the elements of design, such as tooth proportions, involute calculations, choice of materials, stress calculations, load rating, tolerancing of gear dimensions, efficiency calculations, and design of lubrication systems.

Chapter 14 presents material on how to test gears and how to analyze the several possible kinds of gear failure.

Chapters 16 through 21 cover the machine tools and methods of gear manufacture. Gear cutting, gear grinding, die forming of gears, gear shaving, gear lapping, and gear honing are all covered in these chapters.

Chapter 22 covers tools to make gears, and Chapter 23 covers inspection tools. Chapter 24 presents many tables of data useful in the gear trade.

Over three dozen people were direct contributors to the project. These people were selected because of their knowledge and competence in the various aspects of gear work. The technical knowledge that this group of people was able to put together over a four-year working period represents a depth of technical knowledge in this field that is far beyond that of any one individual. From my own standpoint it has been a most rewarding experience to be associated with this project and learn from experts in all phases of gear work. In many cases, information collected for the "Gear Handbook" represents the first time this information has ever been put in public print.

I am very grateful to the many contributors for their unselfish effort in getting the required information and laboring through all the trials of putting it into handbook style. In addition, I feel particularly grateful to certain key individuals who were most helpful in providing technical guidance for the project and in making the resources of their organizations available to ferret out key items of information. My special thanks go to the officers and Headquarters staff of the American Gear Manufacturers Association, the "engineering body for the gear industry," for their assistance in checking many parts of this work. I also wish to give special thanks to Wells Coleman of the Gleason Works for his assistance in the bevel-gear field; to Mr. Gerald Brophy of International Nickel Co. for his advice on gear material developments; to Mr. Fred E. Birtch, Cone-Drive Division, Michigan Tool Co., for his assistance on double-enveloping wormgears; to Mr. S. L. Eastman, Cleveland Worm & Gear Division, Eaton Manufacturing Co., for his help on cylindrical wormgears, and to Mr. F. Bohle and Mr. W. Nelson, Spiroid Division of Illinois Tool Works, for their assistance on the Spiroid family of gears. Mr. Laurence Collins and others in the General Electric Company were very helpful in encouraging me to carry out this project and in making

PREFACE

XV

available to me extensive test and field data on spur and helical gears.

In spite of the fact that most of the gear technical material was received from contributors and others associated with this project, I must accept the responsibility for having made the final decisions that determined the technical content of this work. I believe this "Gear Handbook" will represent an important step forward in the development of knowledge in the gear field. It makes this knowledge available for the widest possible benefit of the great host of people who buy, design, build, or use geared equipment.

DARLE W. DUDLEY

Lynnfield, Mass.

CONTENTS

Contributors	vii
Foreword	xi
Preface	xiii
Chapter 1. Basic Theory of Gear-tooth Action and Generation.	1-1
<i>Principles Common to All Gears</i>	1-1
1-1. Axial Arrangement and Relative Motion	1-1
1-2. Conjugate Action of Gear-tooth Surfaces	1-2
<i>Gears with Coplanar Axes</i>	1-4
1-3. Pitch Surfaces and the Instantaneous Axis	1-4
1-4. Basic Members	1-5
<i>Gear-tooth Action in a Plane</i>	1-5
1-5. The Transverse Plane	1-5
1-6. Plane Tooth Action	1-6
1-7. Involute Tooth Profiles	1-7
<i>Spur and Helical Gears</i>	1-9
1-8. The Helical Rack	1-10
1-9. Helical Gears	1-11
1-10. Involute Helical Gears	1-12
<i>Bevel Gears</i>	1-13
1-11. Reference Planes	1-13
1-12. Tooth Action in the Sphere	1-14
1-13. Mesh in the Pitch Plane	1-15
1-14. The Normal Plane	1-16
1-15. Pitch and Angle Relationships	1-16
<i>Gears with Nonintersecting Axes.</i>	1-17
1-16. Basic Hypoid Geometry	1-17
1-17. Hypoid Surfaces of Action	1-18
1-18. Wormgears	1-19
1-19. Crossed-axis Helical Gears	1-19

<i>Gear-tooth Generation</i>	1-19
1-20. Gear Generation	1-19
1-21. Fillet Generation	1-20
Chapter 2. Functional Types of Gears	2-1
2-1. Introduction to Gear Types	2-1
<i>Parallel-axis Gears</i>	2-4
2-2. External Spur Gears	2-4
2-3. External Helical Gears	2-5
2-4. External Herringbone or Double-helical Gear	2-5
2-5. Internal Gears	2-6
<i>Intersecting-axis Gears</i>	2-7
2-6. Straight Bevel Gears	2-7
2-7. Zerol® Bevel Gears	2-8
2-8. Spiral Bevel Gears	2-9
2-9. Face Gears	2-10
2-10. Beveloid® Gearing	2-10
<i>Nonintersecting-nonparallel-axis Gears</i>	2-11
2-11. Crossed-axis Helical Gears	2-11
2-12. Wormgears	2-11
2-13. Hypoid Gears	2-12
2-14. Planoid® Gears	2-13
2-15. Spiroid® Gears	2-13
2-16. Helicon® Gears	2-13
Chapter 3. Gear Arrangements	3-1
3-1. Possibilities in Gear Arrangements	3-1
3-2. How the Arrangement May Drastically Affect Ratio, Power, Efficiency, and Gearbox Volume	3-2
3-3. Parallel-axis Arrangements, Simple Mesh	3-6
3-4. Parallel-axis Epicyclic Gearing	3-14
3-5. Right-angle-gear Arrangements	3-20
3-6. Differential Gearing	3-23
3-7. Contra-rotating Concentric-shaft Drives	3-27
3-8. Speed-changing Transmissions by Shifting	3-27
3-9. Speed-changing Transmissions by Clutches and Brakes	3-29
3-10. High-ratio Arrangements	3-34
3-11. Harmonic Drive Arrangements	3-35
Chapter 4. Elements of Gears and Basic Formulas.	4-1
<i>Nomenclature and Illustrations</i>	4-1
4-1. General Designations	4-3
4-2. Kinds of Gears	4-3

CONTENTS	xix
4-3. Pitch Surfaces	4-5
4-4. Boundary Surfaces	4-5
4-5. Principal Planes	4-7
4-6. Principal Directions	4-7
4-7. Elements of Gear Teeth	4-9
4-8. Linear and Circular Dimensions	4-12
4-9. Angular Dimensions	4-16
4-10. Numbers and Ratios	4-18
4-11. Miscellaneous Terms and Dimensions	4-20
<i>Standard Letter Symbols</i>	4-22
4-12. Manuscripts	4-22
4-13. Symbols	4-22
4-14. Subscripts	4-23
4-15. Conflicts	4-24
4-16. Typography	4-24
<i>Abbreviations for Gearing</i>	4-24
4-17. Abbreviations	4-28
<i>Gear Formulas</i>	4-28
4-18. Basic Gear Formulas	4-29
4-19. Special Gear Types	4-45
Chapter 5. Gear-tooth Proportions.	5-1
<i>Basic Requirements of Gear Teeth.</i>	5-1
5-1. Definitions of Gear-tooth Elements	5-2
5-2. Basic Considerations for Gear-tooth Design	5-4
5-3. Long- and Short-addendum-gear Design	5-16
5-4. Special Design Considerations	5-20
<i>Standard Systems of Gear-tooth Proportions.</i>	5-26
5-5. Standard System for Spur Gears	5-27
5-6. System for Helical Gears	5-41
5-7. System for Internal Gears	5-46
5-8. Standard Systems for Bevel Gears	5-48
5-9. Standard System for Worm Gears	5-64
5-10. Standard System for Face Gears	5-71
5-11. System for Spiroid and Helicon Gears	5-74
Chapter 6. Center Distance	6-1
<i>General Equations Relating to Center Distance</i>	6-2
6-1. Center-distance Equations	6-2
6-2. Standard Center Distance	6-3
6-3. Standard Pitch Diameters	6-3
6-4. Operating Pitch Diameters	6-3

6-5. Operating Pressure Angle	6-5
6-6. Operating Center Distance	6-6
6-7. Center Distance for Gears Operating on Nonparallel Non-intersecting Shafts	6-6
6-8. Center Distance for Worm Gearing	6-6
<i>Calculation of Gears to Operate on Nonstandard Center Distances</i>	6-7
6-9. Nonstandard Center Distance	6-7
<i>Elements of Center Distance</i>	6-8
6-10. Effects of Tolerances on Center Distance	6-8
6-11. Machine Elements That Require Consideration in Critical Center-distance Applications	6-12
6-12. Control of Backlash	6-14
6-13. Effects of Temperature on Center Distance	6-15
6-14. Mounting Distance	6-16
Chapter 7. Special Calculations for Spur and Helical Gears	7-1
7-1. Notation for Chapter 7	7-1
7-2. Fundamental Gear Equations	7-1
7-3. Intervals of Contact for Spur Gears	7-2
7-4. Roll Angles and Form Diameters of Spur Gears	7-4
7-5. Internal Gears	7-5
7-6. Undercutting and Interference	7-5
7-7. Center Distance and Backlash	7-7
7-8. Involute Function	7-9
7-9. Thickness of Teeth from Measurement over Rolls or Balls	7-9
7-10. Measurement over Rolls or Balls by m and μ Functions	7-15
7-11. Span Measurement by Vernier Calipers	7-16
7-12. Chordal Addendum and Chordal Thickness	7-17
7-13. Angular Relationship between Teeth and Keyway	7-18
7-14. Variation of Tooth Thickness with Cutter Setting	7-19
7-15. Thickness of Tooth at Any Diameter	7-19
7-16. Radius at Which Teeth Become Pointed	7-20
Chapter 8. Calculation of Gear-tooth Profiles	8-1
<i>Trochoids</i>	8-1
8-1. Rack Trochoid	8-2
8-2. Trochoidal Fillet	8-4
<i>Involutes</i>	8-6
8-3. Tangent and Normal Coordinates of an Involute	8-6
8-4. Polar Coordinates of Involute Curve	8-11
<i>Cutter Profile</i>	8-15
8-5. Finding Axial Cutter Profile from Known Axial Section of Work	8-15

CONTENTS	xxi
8-6. Finding Axial Cutter Profile from Transverse Section of Work	8-16
8-7. Finding Axial Cutter Profile from Known Normal Section of Work	8-18
<i>Work Profile</i>	8-18
8-8. Finding Normal Section of Work from Known Axial Section of Cutter	8-18
<i>Profiles of Bevel and Hypoid Gears</i>	8-20
8-9. Layout Procedure for Bevel Gears	8-21
8-10. Layout Procedure for Formate Hypoid Gears	8-29
Chapter 9. Gear Tolerances	9-1
<i>Terminology and Definitions Pertaining to Gear Tolerances</i>	9-1
9-1. Terms and Definitions	9-1
9-2. Symbols	9-3
<i>Introduction to Gear Tolerance</i>	9-3
9-3. Definition of Gear Tolerance	9-3
9-4. Examples of Tolerance	9-3
9-5. Gear-tolerance Magnitudes	9-4
9-6. Tolerances and Deviations	9-4
9-7. Allowances and Relation to Tolerances	9-4
9-8. Tolerances and Fabrication Cost	9-4
<i>Tolerance Effects</i>	9-5
9-9. Tolerance Effects on Function	9-5
9-10. Nonfunctional Tolerance Effects	9-5
9-11. Tolerance Effects on Fabrication	9-5
<i>Types of Tolerances</i>	9-5
9-12. Functional Gear-element Tolerances	9-8
9-13. Functional Non-gear-element Tolerances	9-8
9-14. Nonfunctional Dimension Tolerances	9-8
<i>Factors Affecting Choice of Tolerance</i>	9-8
9-15. Functional Requirements	9-9
9-16. Standardization	9-9
9-17. Methodizing	9-9
9-18. Manufacturing Needs	9-9
9-19. Ranges of Numerical Tolerances	9-9
<i>Numerical Tolerance Values</i>	9-9
9-20. Basic Gear-blank Tolerances	9-10
9-21. Fundamental Tolerances for Spur Gears	9-10
9-22. Gear-element Tolerance for Helical Gears	9-11
9-23. Fundamental Tolerances for Worms	9-11

9-24. Fundamental Tolerances for Worm Gears	9-14
9-25. Fundamental Tolerances for Bevel Gears	9-14
9-26. Tolerances for Special Gear Types	9-14
9-27. Tolerances for Quality Classes	9-14
9-28. Complete Quality Tolerances	9-20
9-29. Tolerances per Application	9-21
9-30. Tolerance per Speed of Operation	9-22
9-31. Tolerances for Various Gear Materials	9-23
9-32. Tolerances for Various Fabrication Methods	9-23
<i>Special Considerations and Tolerance Values</i>	9-24
9-33. Method of Gear-size Control and Tolerancing	9-24
9-34. Size Allowance, Tolerance, and Relation to Total Composite Error	9-25
9-35. Values of Size Allowance and Total Composite Error Size Allowance	9-27
9-36. Position Tolerance	9-28
9-37. Mounting Effects on Tolerances	9-29
9-38. Registering Surface Tolerances	9-30
9-39. Surface-finish Standards	9-31
9-40. Surface-finish Tolerances	9-32
9-41. Materials and Tolerances	9-34
9-42. Finish-coating Effects on Tolerances	9-35
9-43. Critical Geometrical Shapes and Tolerances	9-36
9-44. Deburring and Tooth-edge Round-over Tolerances	9-37
9-45. Tolerances and Noise	9-38
<i>Assembly and Installation Considerations</i>	9-39
9-46. Center-distance Tolerances	9-39
9-47. Tolerances on Mismatch of Gear Faces	9-41
9-48. Assembly Fits of Bores and Shafts	9-41
Chapter 10. Gear Materials	10-1
<i>Ferrous Gear Materials</i>	10-1
10-1. General Characteristics of Steels and Cast Irons	10-2
10-2. Heat-treatment of Steels and Cast Irons	10-3
10-3. Carbon and Alloy Steels	10-10
10-4. Localized Hardening of Steel Gears	10-15
10-5. Carburizing Gears	10-16
10-6. Nitriding Gears	10-19
10-7. Induction-hardening Gears	10-19
10-8. Shallow-hardening Gears	10-22
10-9. Gray-cast-iron Gears	10-23
10-10. Ductile Iron	10-24
<i>Nonferrous Gear Materials</i>	10-25
10-11. Gear Bronzes	10-25
10-12. Lightweight Metal Alloys for Gears	10-28

CONTENTS	xxiii
10-13. Nonmetallic Gears	10-37
Chapter 11. Gear Drawings	11-1
11-1. General Drawing Practice	11-1
11-2. Spur Gears	11-3
11-3. Helical Gears	11-7
11-4. Bevel Gears and Hypoid Gears	11-8
11-5. Wormgears	11-13
11-6. Special Gear Types	11-15
Chapter 12. Gear Reactions and Mountings	12-1
12-1. Mechanics of Gear Reactions	12-1
12-2. Basic Gear Reactions, Bearing Loads, and Mounting Types	12-4
12-3. Basic Mounting Arrangements and Recommendations	12-7
12-4. Bearing-load Calculations for Spur Gears	12-10
12-5. Bearing-load Calculations for Helicals	12-16
12-6. Mounting Practice for Bevel and Hypoid Gears	12-20
12-7. Calculation of Bevel and Hypoid Bearing Loads	12-29
12-8. Bearing-load Calculations for Worms	12-39
12-9. Bearing-load Calculations for Spiroids	12-43
12-10. Bearing-load Calculations for Other Gear Types	12-45
Chapter 13. Load Rating of Gears	13-1
<i>General Considerations for Load-rating Gears</i>	<i>13-1</i>
13-1. Limitation on Load Rating of Gears	13-1
<i>Application Data Required for Gear Rating</i>	<i>13-1</i>
13-2. Data Required Before Gears Can Be Rated	13-1
<i>Simplified Estimates for Gear Capacity</i>	<i>13-3</i>
13-3. Tabulation of Gear Capacity	13-3
13-4. Modifying Factors for Tabulated Gear Capacities	13-14
<i>Detailed Analysis of Gear Capacity</i>	<i>13-17</i>
13-5. Surface Durability of Spur, Helical, Herringbone, and Bevel Gear Teeth	13-18
13-6. Strength Rating of Spur, Helical, Herringbone, and Bevel Teeth	13-28
13-7. Power Rating of Cylindrical Wormgears	13-37
13-8. Power Rating of Double-enveloping Wormgears	13-40
<i>Scoring</i>	<i>13-44</i>
13-9. Scoring Probability	13-44
13-10. Scoring Criterion	13-44

Chapter 14. Loaded Gears in Action	14-1
<i>Efficiency of Gears</i>	14-1
14-1. Sliding Velocity	14-2
14-2. Efficiency of Coplanar Gears	14-3
14-3. Efficiency of Nonplanar Gears	14-8
14-4. Gear Trains	14-13
<i>Dynamic Loads on Gear Teeth</i>	14-30
14-5. Dynamic Loads on Spur Gears	14-30
14-6. Brief Summary of Dynamic-load Investigation	14-31
14-7. When Dynamic Loads Should Be Considered	14-33
14-8. Buckingham's Solution to the Dynamic-load Effect on Gear Teeth	14-34
14-9. Dynamic-load Effect on Gear Trains	14-38
<i>Gear Performance</i>	14-39
14-10. Factors That Affect the Performance of Gear Units	14-39
14-11. Gear Failures	14-42
14-12. Performance Testing of Gears	14-52
Chapter 15. Lubrication of Gears	15-1
15-1. Systems and Methods of Gear Lubrication	15-1
15-2. Types and Viscosity of Gear Lubricants	15-7
15-3. Gear Wear and Failures Caused by Inadequate Lubrication	15-13
15-4. Methods of Retaining Lubricants in Gearboxes	15-14
15-5. Methods of Cooling Gear Lubricant	15-16
15-6. Aircraft-gear Lubrication	15-18
15-7. Grease Lubrication of Aircraft Gears	15-20
Chapter 16. Gear Cutting	16-1
<i>Gear Milling</i>	16-1
16-1. Application of Gear Milling	16-1
16-2. Principles of Gear Milling	16-2
16-3. Milling-machine Operation	16-3
16-4. Advantages and Limitations of Gear Milling	16-4
<i>Gear Hobbing</i>	16-5
16-5. Application of Gear Hobbing	16-5
16-6. Theory of the Hobbing Process	16-6
16-7. Hobbing-machine Relationships	16-7
16-8. Hobbing-machine Operation	16-10
16-9. Advantages and Disadvantages of Hobbing	16-17
<i>Gear Shaping</i>	16-17
16-10. Application of Gear Shaping	16-17
16-11. Theory of Shaping Process	16-18

CONTENTS	XXV
16-12. Gear-shaper Operation	16-20
16-13. Advantages and Disadvantages of Shaping	16-23
<i>Shear Cutting of Gears</i>	16-23
16-14. Application of Shear-Speed Cutting	16-23
16-15. Shear-Speed Principles	16-24
16-16. Machine Operation, Shear-Speed Cutting	16-25
16-17. Advantages and Disadvantages of Shear-Speed Cutting	16-28
<i>Gear Broaching</i>	16-28
16-18. Application of Broaching	16-28
16-19. Broaching Principle	16-29
16-20. Broaching Operation	16-30
16-21. Advantages and Limitations	16-32
Chapter 17. Gears Produced by Dies	17-1
17-1. Outline of Die Processes	17-1
17-2. Gear Stamping	17-9
17-3. Cold Drawing or Extrusion	17-12
17-4. Injection Molding	17-14
17-5. Powdered-metal Sintered Gears	17-17
17-6. Die Casting	17-19
17-7. Gear Teeth and Worm Threads Formed by Rolling	17-20
Chapter 18. Gear Finishing by Shaving, Honing, and Lapping	18-1
<i>Gear Shaving</i>	18-1
18-1. Rotary Crossed-axes Shaving	18-2
18-2. Rack Shaving	18-18
18-3. Basic Design Considerations for Shaved Gears	18-19
<i>Gear Honing</i>	18-21
18-4. Gear-tooth-honing Methods and Machines	18-21
18-5. Honing Tools	18-23
18-6. Applying the Honing Process	18-23
18-7. Automating Gear-tooth-honing Processes	18-26
<i>Gear Lapping</i>	18-26
18-8. Rotary Parallel-axis Reciprocating Lapping	18-27
18-9. Rotary Crossed-axes Reciprocation Lapping	18-27
18-10. Increasing Lapping Abrasion	18-27
18-11. Lapping Compounds	18-27
18-12. Lapping Bevel, Spiral Bevel, and Hypoid Gears	18-27
18-13. Lapping Wide-face Helical Gears	18-27
Chapter 19. Grinding Spur and Helical Gears	19-1
19-1. Reasons for Gear Grinding	19-1

19-2. Form Grinding	19-2
19-3. Generating Grinding—Disk Wheel	19-7
19-4. Generating Grinding—Threaded Wheel	19-13
19-5. Control of the Grinding Process.	19-15
Chapter 20. Bevel- and Hypoid-gear Manufacturing	20-1
20-1. The Basic Process	20-1
20-2. The Basic Generator	20-2
20-3. The Basic Nongenerator	20-6
20-4. Gear-blank Requirements Prior to Tooth Processing	20-7
20-5. Bevel- and Hypoid-gear Manufacturing Procedures	20-9
20-6. Bevel-gear Workholding Equipment	20-9
<i>Straight-bevel-gear Machines</i>	<i>20-11</i>
20-7. Two-tool Generators and Roughers	20-11
20-8. Interlocking Cutter Machines	20-13
20-9. Straight Bevel Coniflex Grinder	20-16
20-10. Revacycle Machine	20-18
20-11. Straight-bevel-gear Planers	20-20
<i>Planing Generators—for Straight Bevel, Zerol Bevel, Spiral Bevel, and Hypoid Gears</i>	<i>20-22</i>
20-12. Planing Generators	20-22
<i>Face-mill-type Cutting Machines and Grinders—Spiral Bevel, Zerol Bevel, and Hypoid Gears</i>	<i>20-24</i>
20-13. Face-mill Cutters; Types and Uses	20-24
20-14. Face-mill Cutters; Specifications	20-28
20-15. General Classification of Methods	20-29
20-16. Rough Cutting	20-30
20-17. Processes for Nongenerated Gears	20-30
20-18. Processes Used for Either Generation or Nongeneration	20-33
20-19. Processes Used Only for Generation	20-33
20-20. Grinding Considerations	20-35
20-21. Machines for Nongenerated Gears	20-37
20-22. Machines for Generated Gears	20-41
<i>Spiral Bevel and Hypoid Pinion Burnishing</i>	<i>20-45</i>
20-23. Burnishing-machine Operation	20-46
20-24. Burnishing Gear	20-46
20-25. Burnishing Methods	20-47
<i>Spiral Bevel and Hypoid Gear Lapping</i>	<i>20-48</i>
20-26. Lapping-machine Cycles and Rates	20-49
20-27. Lapping-machine Types	20-50
20-28. Lapping Compounds	20-54
20-29. Lapping by Manual Positioning	20-54

CONTENTS

xxvii

Chapter 21. Worm and Wormgear Cutting and Grinding Processes	21-1
21-1. The Removal of Material	21-1
21-2. Mounting of Hob or Cutter	21-2
21-3. Mounting of the Work Arbor or Fixture	21-2
21-4. The Thread-milling Process	21-2
21-5. Thread-hobbing Process	21-8
21-6. Determination of Chip Load	21-10
21-7. Speeds and Feeds	21-11
21-8. Calculate Thread-milling Time	21-12
21-9. Calculating Hobbing Time for Worms	21-13
21-10. Thread Generating	21-13
21-11. Hobbing Wormgears	21-15
21-12. Infeed Hobbing of Wormgears	21-17
21-13. Tangential Hobbing of Wormgears	21-18
21-14. Adaptability of Tangential-feed Method	21-20
21-15. Feed for Use in Cutting Wormgears	21-22
21-16. Time Required to Cut Wormgears	21-23
21-17. Double-enveloping Worms and Wormgears	21-23
21-18. Cutting Time for Double-enveloping Gearsets	21-26
21-19. Worm-thread Grinding	21-26
Chapter 22. Gear-cutting Tools	22-1
<i>Hobs for Spur and Helical Gears</i>	22-1
22-1. General Principles of the Hob	22-1
22-2. Hob Nomenclature	22-3
22-3. Hob Classification by Threads	22-3
22-4. Classification by Tolerance	22-5
22-5. When and How to Select a Hob	22-5
22-6. Accuracy of Hobs and the Importance of Accuracy	22-7
22-7. Climb Hobbing vs. Conventional Hobbing	22-10
22-8. Hob Materials	22-15
<i>Shaper Cutters</i>	22-16
22-9. General Principles of Shaper Cutters	22-16
22-10. Field of Application	22-18
22-11. Types of Shaper Cutters	22-18
22-12. Shaper-cutter Tooth Modifications	22-22
22-13. Sharpening Shaper Cutters	22-24
22-14. Basic Shaper-cutter Calculations	22-26
<i>Gear-milling Cutters</i>	22-29
22-15. Types of Gear-milling Cutters in Common Use	22-30
22-16. Milling-cutter Design Practices	22-31
<i>Gear-shaving Cutters</i>	22-32
22-17. General Principles of Shaving Cutters	22-32

22-18. Preshave Gear	22-39
22-19. Resharpening	22-40
22-20. Shaving-tool Calculations	22-41
<i>Gear-tooth Broaches</i>	22-46
22-21. Types of Broaches	22-47
22-22. Alternate Round and Spline Broaches	22-47
22-23. Design Modifications	22-47
22-24. Spiral Involute Splines and Internal Spiral Gears	22-48
22-25. Broaches for External Gears	22-49
22-26. Design Elements	22-49
22-27. Tooling Tips	22-51
Chapter 23. Gear-inspection Devices	23-1
<i>Spur- and Helical-gear Inspection</i>	23-1
23-1. Involute-profile Measurement	23-1
23-2. Measurement of Gear-tooth Spacing	23-22
23-3. Measurement of Lead	23-32
23-4. Measurement of Eccentricity	23-35
23-5. Measurement of Tooth Thickness	23-38
23-6. Composite Gear Checking	23-41
23-7. Master Gears	23-42
23-8. Error in Action	23-45
<i>Bevel- and Hypoid-gear Inspection</i>	23-46
23-9. Testing Procedures and Equipment	23-46
23-10. Control Gears	23-58
23-11. Gear-blank Inspection	23-61
<i>Wormgear Inspection</i>	23-65
23-12. Cylindrical Wormgear Inspection	23-65
23-13. Double-enveloping Wormgear Inspection	23-67
<i>Spiroid-gear Inspection</i>	23-69
23-14. Spiroid-gear Inspection	23-69
23-15. Spiroid-pinion Inspection	23-72
23-16. Spiroid Gearsets	23-74
Chapter 24. Numerical Data Tables	24-1
24-1. Gear-measuring Tables	24-1
24-2. Trigonometric Functions	24-23
24-3. Involute Functions	24-24
24-4. Special Constants for Involute-gear Calculations	24-26
24-5. Pitch Data and Relationships	24-31
24-6. Arc and Chord Data	24-32
24-7. Hardness-testing Data	24-35

Index follows Chapter 24.

GEAR HANDBOOK

The length-to-diameter ratio of helical and spur gears can be fairly large. In most other gear types the pinion will not have face width more than about one-third the pinion pitch diameter. In spur gearing the L/D ratio may be as great as 1 while in double-helical gearing it may approach 2. Needless to say, high accuracy is needed in boring the casings and machining the teeth when a relatively large face width is used. Low-hardness gearing of about 200 BHN will exhibit some tendency to wear in and improve contact. As much as 0.001" may be worn off the high ends of the teeth to equalize the contact without too serious a result. Medium- to high-hardness gears have but slight tendency to wear in. If the contact across the face width is not good at full load, the teeth may break before any equalizing wear occurs. (See Chap. 13 for data on how to handle misalignment when load-rating gears.)

Large pinions with an L/D ratio of 1 or more will twist elastically under load an appreciable amount. It is necessary to provide helix modification to compensate for this on large gears where the material is fairly hard and the horsepower is high. (Helix modification was necessary on the gears shown in Figs. 3-4 and 3-7.)

Nested pinions tend to suffer from bowing and twisting of the long shaft between the two pinion halves. Helix compensation is often needed.

In multiple-power-path units, each power path must be able to have the teeth engage simultaneously when a slight torque is applied. In addition errors in tooth spacing and runout must be slight enough in the gears so that the flexibility of the connecting shafts can keep a uniform load on each branch. If the connections are too stiff or the teeth not precise enough, the load will shift rapidly from one power path to another as the gear revolves.

In multiple-power-path gearing, the gears will not assemble if there is a random orientation between the teeth of a gear and a pinion connected by the same shaft. Either the teeth and coupling means must be cut so that the orientation is exactly alike on each like assembly or adjustment must be provided so the proper tooth "timing" is achieved at assembly. Generally the teeth are cut at a random orientation. Then at assembly the parts are rotated until the pinion and gear by chance have their teeth in almost the right orientation. Then the final adjustment is made by some mechanical means like axial shimming (single-helix design), elongating coupling boltholes, redoweling, or using a stepped key. Incidentally, a shrewd choice on tooth numbers can make the timing problem work out much more easily.

3-4. Parallel-axis Epicyclic Gearing. A large family of gear arrangements goes under the general name of "epicyclic" gearing. Generally speaking the epicyclic train has a central "sun" gear, several "planets" meshing with the sun and spaced uniformly around the sun and an "annulus" or ring gear meshing with the planets. The sun and planets are externally toothed while the ring is internally toothed.

The name epicyclic comes from the fact that points on the planets trace out epicycloidal curves in space.

The name "planetary" gear is sometimes used interchangeably with epicyclic to denote the whole family of gears. In a more strict sense the *planetary* is one of the types of epicyclic gears.

There are a large number of possible epicyclic arrangements. These may be divided into three general groups:

1. Single epicyclic trains
2. Compound epicyclic trains
3. Coupled epicyclic trains

Single Epicyclic Trains. The simple epicyclic train consists only of the elements of sun, planet, and ring gear. This arrangement is often called a "simple" epicyclic

gear or a "simple" planetary gear to distinguish it from the more complicated arrangements.

Figure 3-13 shows schematic arrangements of the three simple epicyclic gears. These are the *planetary*, the *star*, and the *solar arrangements*. The figure shows only three planets. The number of planets will vary quite considerably in actual practice. With some ratios it has been possible to squeeze in as many as twenty planets. As few as one is sometimes used for light load applications.

The derivation of ratios for planetary units is somewhat complicated. Several references^{1,2,3,*} go into the derivation of ratios in considerable detail. Table 3-5 shows the over-all ratio for each of the three single epicyclic trains. If one of these units were driven backward, the ratio would be less than one and would simply be the reciprocal of the ratio as a speed-reducing set.

A range of ratios is shown for each kind of epicyclic gear. Note that only the solar will handle very low ratios. The ratio range of 1.7:1 to 2:1 is a range that is rather difficult to handle with simple epicyclic gearing. The star will work in this range, but it turns out to be rather awkward.

Epicyclic gears will not assemble unless the tooth numbers are properly chosen. Assuming the planets are equally spaced around the sun—which is the usual case—the equations given at the bottom of Table 3-5 must be met. The sum of the ring and sun teeth must be equally divisible by the number of planets. If there were three planets, the ring teeth plus sun teeth would have to divide evenly by three.

The tooth load at each planet is balanced between the sun-planet mesh and the planet-ring mesh. This tangential driving load may be calculated by

$$W_t = \frac{126,050 P_H}{n_s d_s \text{ No. planets}} \quad (3-2)$$

where n_s = rpm of sun

d_s = pitch diameter of sun

P_H = horsepower transmitted

It should be appreciated that Eq. (3-2) determines the theoretical load only when there is perfect sharing of load between the planets. There is quite a problem in load sharing in epicyclic gears plus the possibility of appreciable dynamic overload due to tooth errors. More will be said on this subject later in this article.

Table 3-5. Simple-epicyclic-gear Data

Kind of arrangement	Fixed member	Input member	Output member	Over-all ratio m_G	Range of ratios normally used
Planetary.....	Ring	Sun	Cage	$\frac{N_R}{N_S} + 1$	3:1-12:1
Star.....	Cage	Sun	Ring	$\frac{N_R}{N_S}$	2:1-11:1
Solar.....	Sun	Ring	Cage	$\frac{N_S}{N_R} + 1$	1.2:1-1.7:1

N_S = number of sun teeth

N_P = number of planet teeth

N_R = number of ring (annulus) teeth

To assemble,

$$N_R = N_S + 2N_P \quad (3-3)$$

$$\frac{N_R + N_S}{\text{No. planets}} \text{ must equal an integer} \quad (3-4)$$

* Superscript numbers refer to references at the end of the chapter.

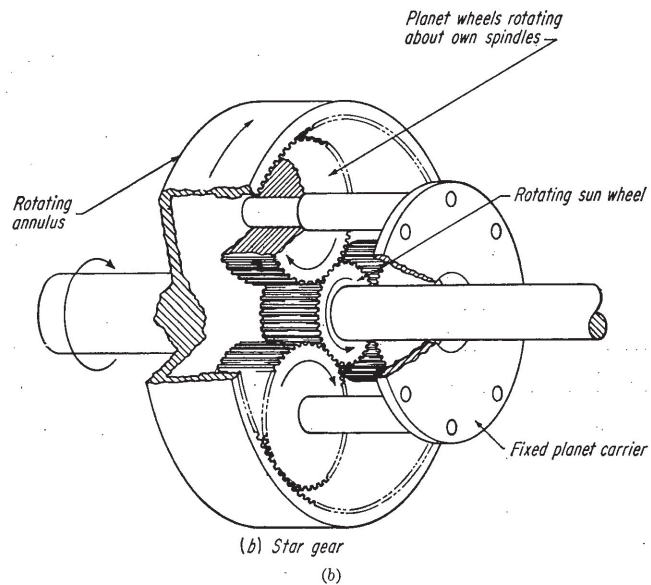
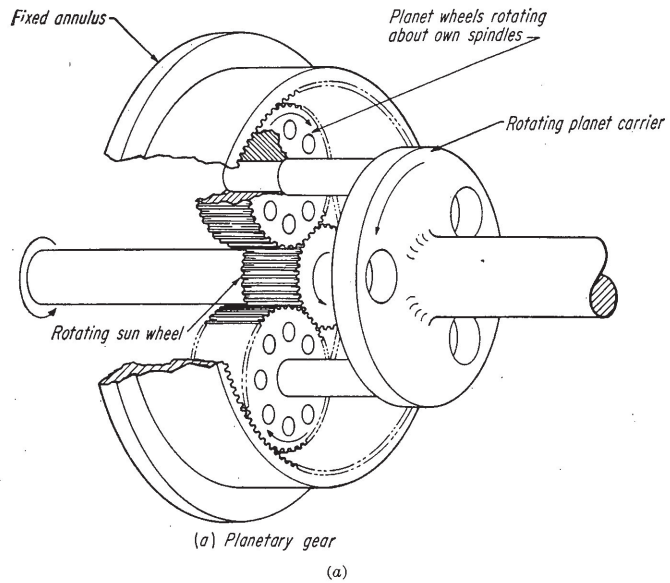


FIG. 3-13. Simple epicyclic gears. (a) Planetary

Compound Epicyclic Trains. The "compound" epicyclic train has two planet members attached together on a common shaft. Figure 3-15 shows the schematic arrangement of a compound star gear. Note the large planets (or stars) which mesh only with the sun and the small planets which mesh only with the ring gear.

Table 3-6. Compound-epicyclic-gear Data

Kind of arrangement	Fixed member	Input member	Output member	Over-all ratio m_G	Range of ratios normally used
Compound planetary.....	Ring	Sun	Cage	$\frac{N_R N_{P_1}}{N_S N_{P_2}} + 1$	6:1-25:1
Compound star.....	Cage	Sun	Ring	$\frac{N_{P_1} N_R}{N_S N_{P_2}}$	5:1-24:1
Compound solar.....	Sun	Ring	Cage	$\frac{N_S N_{P_2}}{N_R N_{P_1}} + 1$	1.05:1-2.2:1

N_S = number of sun teeth

N_{P_1} = number of first-reduction planet teeth

N_{P_2} = number of second-reduction planet teeth

N_R = number of ring teeth

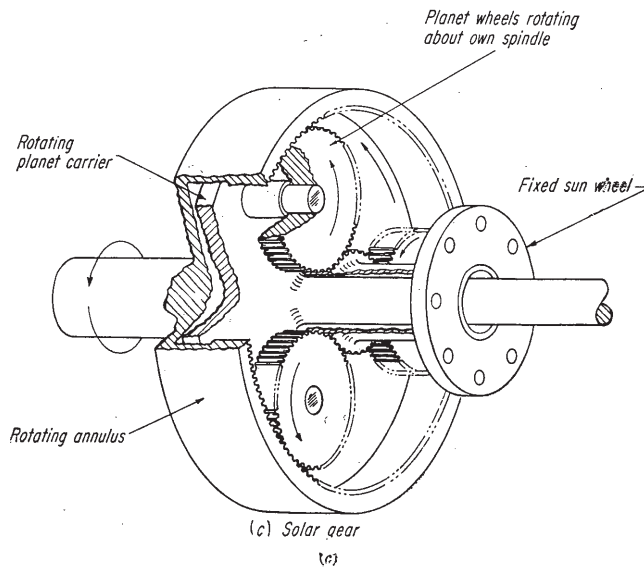
To assemble,

$$D_R = D_S + D_{P_1} + D_{P_2} \quad (3-5)$$

where D_R = ring pitch diameter

D_P = planet pitch diameter

$$\frac{N_{P_1} N_R + N_{P_2} N_S}{\text{No. planets}} \text{ must equal an integer} \quad (3-6)$$



gear. (b) Star gear. (c) Solar gear.

INDEX

- Abbreviations, recommended list, 4-28
- use, 4-24
- Abrasive wear, 15-14
- Addendum, for balanced strength, 5-37
 - for bevel gears, 5-52, 5-55, 5-63
 - for face gears, 5-72
 - for helical gears, 5-45
 - for small tooth numbers, 5-36
 - (See also Tooth proportions)
- Aircraft gear, lubrication, 15-18 to 15-21
 - quality, 9-20, 9-21
 - rating, 13-4, 13-27, 13-37
- Aircraft unit, 14-56
- AISI steels, 10-10, 10-11
- Alignment of gears, 14-41
- Allcone process, 20-34
- Aluminum bronze, 10-27, 10-28
- Aluminum gears, die-cast, 10-29, 10-30, 10-34, 10-36
 - general practice, 10-28, 10-29
- Angle of contact, 1-6
- Angular pitch, definition, 1-6
 - formula, 1-8
- Apex, definition, 1-4
- Arc and chord data, 24-33, 24-34
- Arco process, 20-34
- Arrangements, articulated gear, 3-6 to 3-10
 - automatic transmissions, 3-29, 3-31, 3-32
 - bevel gears, 3-20 to 3-24
 - contrarotating gears, 3-27
 - differential gears, 3-23 to 3-27
 - epicyclic gears, 3-14 to 3-20
 - (See also Epicyclic gears)
 - gear-shift, 3-27 to 3-30
 - high-ratio units, 3-34, 3-43
 - MD-type gear, 3-6, 3-7, 3-9
 - MDT-type gear, 3-7, 3-9, 3-10
 - nested gear, 3-7, 3-10, 3-11
 - parallel-axis, 3-6 to 3-20
 - reverse gear units, 3-22, 3-28, 3-32 to 3-34
 - right-angle gears, 3-20 to 3-23
 - Spiroid gears, 3-20, 3-22
 - worm gears, 3-20, 3-21
- Articulated gear, 3-6 to 3-10
- Assembly, bores and shafts, 9-41, 9-42
 - center distance tolerances, 9-39
 - dimensioning of center distance, 9-39 to 9-41
 - face width mismatch, 9-41
 - (See also Center distance)
- Autocollimator, 23-31, 23-32
- Automatic gaging, 18-15
- Automatic honing, 18-26
- Automatic shaving, 18-15
- Axial plane, definition, 1-4
- Axis, instantaneous, 1-4
- Backlash, for assembled gears, 7-9
 - for bevel gears, 5-63
 - check, 23-51
 - definition, 1-6
 - design considerations, 5-25, 5-26
 - for power gears, 5-37
 - for worm gears, 5-69
- Base helix angle, 1-10
- Base pitch, 1-9
- Base plane, 1-16
- Basic member, 1-5
- Bearing losses, of ball and roller bearings, 14-17 to 14-20
 - of sleeve bearings, 14-13, 14-14
 - of thrust bearings, 14-15 to 14-17
- Bearings, design recommendations, 12-8, 12-9
 - load calculations, for bevels, 12-29 to 12-35
 - for hypoids, 12-29 to 12-35
 - for Spiroid gears, 12-43 to 12-45
 - for worm gears, 12-39 to 12-42
 - reactions on, 12-4, 12-5
 - separating load chart for bevels, 12-22
 - thrust reaction chart for bevels, 12-21
- Bevel cutters, 20-12, 20-15, 20-19, 20-25, 20-26
- Bevel-gear blanks, inspection, 23-61 to 23-63
 - requirements, 20-7, 20-8
- Bevel-gear inspection, backlash, 23-51
 - blank tolerances, 23-63
 - of blanks, 23-61 to 23-63
 - machines for, 23-48, 23-49
 - procedures for, 23-46, 23-47
 - tooth thickness, 23-49, 23-51
- Bevel-gear mounting, heat-treat allowances, 23-52
 - load deflections, 23-52, 23-53
 - V and H checks, 23-53 to 23-57
- Bevel gears, assembly procedure, 12-28, 12-29
 - axial thrust chart, 12-21
 - blank design, 12-26, 12-27
 - calculation of bearing loads, 12-29 to 12-35
 - calculation procedure, 5-50 to 5-63
 - cutting (see Bevel generating)

- Bevel gears, definition, 1-2, 1-13
drawing practice, 11-8 to 11-13
efficiency, 14-6 to 14-8
equivalent pitch radii, 1-14
equivalent tooth numbers, 11-14
estimating power capacity, 13-7
face contact ratio, 8-39, 8-40
fundamental tolerances, 9-14
grinding (*see* Bevel grinding)
lapping, 18-27
layout of profile, 8-21 to 8-29
lubrication, 15-7
manufacturing procedures, 20-9
material recommendations, 20-53, 20-54
ratings for special applications, 13-27, 13-28
scoring criterion, 13-44, 13-45
separating load chart, 12-22
spiral (*see* Spiral bevel gears)
straight (*see* Straight bevel gears)
strength rating, 13-35 to 13-37
for special applications, 13-37
surface durability rating, 13-25 to 13-27
undercut, 8-39
workholding devices, 20-10
- Bevel generating, blank requirements, 20-7 to 20-9
capacities of machines, 20-41
cutting methods, 20-29, 20-30
general information, 20-1 to 20-6
planers, 20-20 to 20-24
procedures, 20-9
production rates, 20-13, 20-14, 20-21, 20-22, 20-42
straight bevel machines, 20-11 to 20-22
workholding devices, 20-10, 20-11
(*See also* Bevel nongenerator)
- Bevel grinding, capacities of machines, 20-43
general information, 20-35, 20-36, 20-37
procedures, 20-9
production rates, 20-39, 20-44, 20-45
stock allowance, 20-36
workholding devices, 20-10, 20-11
(*See also* Bevel nongenerator)
- Bevel nongenerator, correlation of machines, 20-40
general information, 20-6, 20-7
machines for, 20-37 to 20-41
processes for, 20-30 to 20-33
production rates, 20-30, 20-33, 20-38, 20-39
Revacycle machine, 20-18 to 20-20
- Bevel planers (*see* Planers)
- Beveloid-gear inspection, 23-75
- Beveloid gears, 2-9, 2-10
- Brass die castings, 10-35, 10-38
- Brinell hardness, 24-35, 24-36
- Broaches, care and use, 22-51, 22-52
design practice, 22-49 to 22-51
for external gears, 22-49
general information, 22-46 to 22-48
for spiral splines or gears, 22-48, 22-49
- Broaching, appraisal of, 16-32, 16-33
cutting speeds, 16-31, 16-32
general information, 16-28 to 16-30
procedure for, 16-30, 16-31
- Bronze, aluminum, 10-27, 10-28
gear bronzes, 10-25, 10-26
manganese, 10-26 to 10-28
phosphor, 10-26 to 10-28
silicon, 10-27, 10-28
strength, 10-26
trade standards, 10-27, 10-28
- Buckingham, Earle, 14-31, 14-32
- Buckingham dynamic-load effect, 14-34 to 14-38
- Burnishing, correlation of machines and processes, 20-47
general information, 20-47
- Calipers, 9-24, 9-25
- Capacity, estimating (*see* Rating)
- Carburizing, case depth, 10-18
case hardness, 10-18
cycles, 10-17
general practice, 10-15 to 10-18
time vs. depth, 10-16
- Case hardness, 10-18
- Cast iron, ductile, 10-24, 10-25
general properties, 10-2
gray, 10-23, 10-24
Meehanite, 10-24
- Center distance, adjustment for backlash, 7-7 to 7-9
backlash control, 6-14, 6-15
definition, 1-1, 1-6
dimensioning, 9-39 to 9-41
effect of mounting distance, 6-14, 6-15
general equations, 6-3, 6-4
nonstandard, 5-17
calculations, 6-7, 6-8
equations, 6-5, 6-6
operating, 6-5, 6-6
special cases, 6-2, 6-3
standard, 6-4, 6-5
temperature effects, 6-15, 6-16
tolerance effects, 6-8 to 6-12
- Chordal addendum, calculation, 7-17, 7-18
tables, 24-33, 24-34
- Chordal thickness, calculation, 7-17, 7-18
tables, 24-33, 24-34
- Circular pitch, definition, 1-6
- Classes of service, 13-43
- Climb hobbing, 16-16, 16-17
- Clockwork tooth profiles, 5-29
- Coefficient of friction, for ball bearings, 14-17
for cylindrical worm gear rating, 13-40
for Spiroid gears, 14-12
for spur gears, 14-5
for worm gears, 14-10
- Cold-drawing (*see* Extrusion)
- Commercial quality, 9-15
- Complementary gears, crown, 1-5
rack, 1-5
- Composite checking, 23-41
- Composite tolerances, definition, 9-25
total, 9-26, 9-27
- Computer program, for cutter profile, 8-17
for normal section, 8-19, 8-20
for rack trochoid, 8-3

- Computer program, for tangent and normal of involute, 8-11
for trochoid at fillet, 8-5, 8-6
use of, 8-1
- Cone-drive gears, sample drawing, 11-14, 11-15
(See also Worm gears)
- Coniflex cutters, 20-15
- Coniflex grinder, 20-16, 20-17
- Coniflex provisions, 20-13 to 20-17
- Conjugate action, 5-7
- Contact length, 7-2 to 7-4
- Contact normal, 1-2
- Contact patterns for bevel gears, 23-55
- Contact point, distance s from pitch point, 1-8
- Contact ratio, 7-3, 7-4
total, 1-4
- Continuity of action, 5-5
- Contrarotating gears, 3-27
- Control gears, 23-58, 23-59
- Coplanar gears, definition, 1-4
- Copper-base die castings, 10-38
- Corrosive wear, 15-14
- Crossed-axis helical gears, definition, 1-19
description, 2-11
estimated power capacity, 13-9
- Crowned teeth, drawing notes, 11-7
by shaving, 18-12, 18-13
- Curvature, relative, 1-3, 1-7
- Curve, action limit, 1-3
- Cutter profile, axial section, 8-15 to 8-18
from normal section, 8-18
from transverse section, 8-16
- Cutter setting, effect on tooth thickness, 7-7, 7-8
- Cycloidal tooth profiles, 5-28
- Deburring tolerances, 9-37, 9-38
- Delrin gears, 10-39, 10-40
- Diameter over pins (see Measurement over wires)
- Diametral pitch, definition, 1-6
recommended values, 5-34
- Die-cast materials, 10-29 to 10-39
- Die casting, design data, 17-19, 17-20
general information, 17-6
production practice, 17-20
- Die processes, casting, 17-6
cold-drawing or extrusion, 17-3, 17-4
general information, 17-1 to 17-3
injection molding, 17-4 to 17-6
rolling or forming, 17-6, 17-7
sintering powdered metals, 17-7
stamping gears, 17-3
- Differential gears, efficiency, 14-27 to 14-30
fixed differentials, 3-24 to 3-26
free differentials, 3-23, 3-24
hypoid differential, 3-24, 12-28
- Double-enveloping worms and worm gears, cutting practice, 21-23 to 21-26
- Double helical gears, 2-5, 2-6
- Drafting (see Drawings)
- Drawings, approximating involute profile, 11-1
bevel and hypoid gears, 11-8 to 11-13
gear sets, 11-5
general practice, 11-1, 11-2
helical gears, 11-7, 11-8
material specifications, 11-2, 11-3
Spiroid gears, 11-15 to 11-17
spur gear practice, 11-3 to 11-7
surface finish, 11-2
tolerances on tooth accuracy, 11-5
tooth profile, 11-5 to 11-7
worms and wormgears, 11-13 to 11-15
- Ductile iron, 10-24, 10-25
- Dudley, Darle W., internal gear practice, 5-46
 m and μ coordinates, 8-11, 8-14
total pitch variation, 23-22
where to place oil nozzle, 15-19
- Duplex spread-blade method, 20-33
- Duplex-type milling cutter, 21-7, 21-8
- Durability (see Surface durability)
- Duration of contact, 7-2 to 7-6
- Dynamic factor K_v , 13-30
- Dynamic loads, Buckingham method, 14-34 to 14-38
on gear trains, 14-38, 14-39
on spur gears, 14-30 to 14-34
when to consider, 14-33, 14-34
- Eccentricity measurement, of bevel gears, 23-59, 23-60
general information, 23-35, 23-36
by rolling with master, 23-37, 23-38
by runout over pins, 23-36, 23-37
- Edge round, recommended amounts, 5-39
- Efficiencies, nominal values for thermal rating, 13-17
- Efficiency, approximate losses, 12-7
arc of approach and recess, 5-19, 5-20
of crossed-axis helical gears, 14-10
of differential gears, 14-27 to 14-30
of double-enveloping worm gears, 13-44
general considerations, 14-1
of Helicon gears, 14-11, 14-12
of hypoid gears, 14-12
of internal gears, 14-5, 14-6
of planetary gears, 14-24 to 14-26
of Planoid gears, 14-12, 14-13
of spiral bevel gears, 14-8
of Spiriod gears, 14-10, 14-11
of spur gears, 14-3 to 14-6
of star gears, 14-26, 14-27
of straight bevel gears, 14-6, 14-7
of worm gears, 14-8 to 14-10
of Zerol bevel gears, 14-7, 14-8
- Elastic coefficient, 13-19
- Environment conditions, 14-42
- Epicyclic gears, bevel planetary, 3-21, 3-23
compound epicyclic trains, 3-17, 3-18
coupled epicyclic trains, 3-19, 3-20
efficiency, 14-24 to 14-27
planetary, 3-14 to 3-18
simple epicyclic trains, 3-14 to 3-16

- Epicyclic gears, solar, 3-15, 3-17
 star, 3-15 to 3-18
 Equivalent pitch radii, spiral bevel gears, 1-16
 Equivalent tooth numbers, spiral bevel gears, 1-16
 Error in action, 23-45, 23-46
 Euler-Savary equation, 1-7, 1-14
 Extrusion, design data, 17-12, 17-13
 general information, 17-3, 17-4
 production practice, 17-13
- Face advance, angle, 1-16
 definition, 1-12
 Face contact ratio, of bevel gears, 8-39, 8-40
 definition, 1-12
mf, 13-46
 Face-gear inspection, 23-75
 Face gears; description, 2-9, 2-10
 design, 5-71 to 5-74
 estimating power capacity, 13-8
 sample drawings, 11-18, 11-19
 Face-mill cutters, 20-24 to 20-29
 Factors of safety, general data, 13-15
 Failures of gears, general considerations, 14-42, 14-43
 by pitting, 14-47, 14-48
 by plastic flow, 14-47
 by spalling, 14-48
 by tooth breakage, 14-49 to 14-51
 by wear, 14-43 to 14-47
 Fatigue stress, 13-31
 Fellows 20° stub-tooth system, 5-28
 Ferrous gear materials, 10-1, 10-2
 (*See also* Materials)
 Field testing, 14-58
 Fillet generation, 1-20
 Fine pitch, quality classes, 9-19, 9-20
 Finish (*see* Surface finish)
 Finish coating build-up, 9-35, 9-36
 Finishing gears (*see* Grinding; Honing; Lapping; Shaving)
 Flats, theory of, 1-20
 Fly cutting wormgears, 21-20 to 21-23
 Forced-feed lubrication, 15-4 to 15-6
 Form diameter, calculation, 7-4, 7-5
 definition, 5-3
 Form grinding, estimating time, 19-3 to 19-5
 general information, 19-2, 19-3
 internal gears, 19-6
 machine capacity, 19-6, 19-7
 stock required, 19-5, 19-6
 Formate, tooth form, 5-49
 Formate gear, 20-6, 20-7, 20-31 to 20-33
 Formulas, circular pitch, 4-30
 for crossed-helical gears, 4-37
 diametral pitch, 4-30
 for double-enveloping worm gears, 4-44, 4-45
 for face gears, 4-46, 4-47
 for fine-pitch gears, 4-35
 general relationships, 4-29, 4-31
 for helical gears, 4-33, 4-36
 for internal gears, 4-33, 4-34
 for spiral bevel gears, 4-40
- Formulas, for Spiroid gears, 4-47, 4-48
 for spur gears, 4-32
 for straight bevel gears, 4-37 to 4-39
 for worm gears, 4-42, 4-43
 for Zerol bevel gears, 4-41
 Fretting corrosion, 14-51
 Friction coefficient, of spur gears, 14-5
 of worm gears, 14-10
- Gear, definition, 4-3
 Gear generation, theory of, 1-19
 Gear grinding (*see* Grinding)
 Gear hobbing (*see* Hobbing)
 Gear-milling cutters (*see* Milling cutters)
 Gear shaving (*see* Shaving)
 Gear teeth (*see* under Tooth)
 Gear types, 2-1 to 2-3
 Generating bevel gears (*see* Bevel generating)
 Generating grinding, conical wheel, 19-8 to 19-10
 disk wheel, 19-7, 19-8
 production time, 19-11 to 19-13
 saucer wheel, 19-10
 (*See also* Bevel grinding)
 Generating roll, 1-20
 Geometry factor, *J*, 13-24
J, 13-28, 13-29, 13-32, 13-34 to 13-36
 Gray cast iron, 10-23, 10-24
 Grease lubrication, 15-8, 15-20, 15-21
 Grinding, form, 19-2 to 19-7
 general information, 19-1, 19-2
 generating methods, 19-7 to 19-13
 nitral etch, 19-16, 19-17
 process control, 19-15 to 19-17
 thread, worm, 21-26 to 21-29
 threaded-wheel method, 19-13 to 19-15
 (*See also* Bevel grinding)
 Grinding wheel, 19-4
- Hand of spiral, 12-31
 Hardness, effect of carbon content, 10-1
 hardenability of steel, 10-12
 of steel and iron, 10-3
 Hardness scales, 24-35
 Hardness-testing data, 24-35, 24-36
 Harmonic drive, applications, 3-43
 arrangements, 3-35, 3-36
 coupling methods, 3-38 to 3-40
 performance, 3-40 to 3-43
 single-stage unit, 3-40
 special properties, 3-37
 wave generator, 3-38
 Heat-treatment of steels, 10-3 to 10-7
 data, 10-13
 glossary, 10-7 to 10-10
 Helical gears, bearing reactions, 12-16 to 12-20
 broaching, 16-32
 calculation procedure, 5-42, 5-44, 5-45
 definition, 1-11
 description, 2-5, 2-6
 design practice, 5-41 to 5-45
 drawing practice, 11-7, 11-8

- Helical gears, estimating power capacity, 13-3, 13-4, 13-6
 face width, 5-42
 forced-feed lubrication, 15-4 to 15-6
 generating grinding, 19-7 to 19-13
 hobbing, 16-5 to 16-17
 honing, 18-21 to 18-26
 lapping, 18-27, 18-28
 quality classes, 9-14 to 9-21
 scoring criterion, 13-44, 13-45
 shaping, 16-17 to 16-23
 shaving, 18-1 to 18-21
 splash lubrication, 15-1 to 15-5
 strength rating, 13-34, 13-35
 surface durability rating, 13-22 to 13-25
 threaded-wheel grinding, 19-13 to 19-15
 tolerances, 9-11
- Helical rack, 1-10
- Helicon gears, description, 2-13, 2-14
 design, 5-75, 5-76, 5-84 to 5-86
 efficiency, 14-11, 14-12
- Helix angle, definition, 1-11
 design, 5-42
- Helix measurement (see Lead measurement)
- Helixform cutter, 20-26
- Helixform gear, 20-6, 20-31
- Herringbone gears, description, 2-5, 2-6
 shaping, 16-19, 22-20, 22-21
- Hertz stress (allowable), 13-18, 13-27
- Hob approach distance, 16-12, 16-13
- Hob mounting, 21-2
- Hobbing, appraisal, 16-27
 climb, 22-10, 22-12, 22-13
 and conventional, 16-16, 16-17
 of double-enveloping worm gears, 21-23, 21-24
 feeds and speeds, 16-10 to 16-14
 general information, 16-5 to 16-7
 locating of hob, 16-14, 16-15
 machines, 16-7 to 16-10
 wear of hob, 16-15
 of worm threads, 21-8 to 21-10
 of wormgears, 21-15 to 21-23
- Hobs, accuracy, 22-7 to 22-12
 feeds and speeds, 22-12 to 22-14
 general principles, 22-1 to 22-5
 material, 22-15, 22-16
 nomenclature, 22-3
 selection, 22-3 to 22-5
 sharpening, 22-14, 22-15
 special features, 22-6, 22-7
 standard sizes, 22-5 to 22-7
 wear, 16-15
- Honing, automatic cycle, 18-26
 general information, 18-21 to 18-23
 machines, 18-22, 18-23, 18-25
 production rates, 18-24
 tools, 18-22, 18-23
- Hypoid gears, burnishing, 20-47 to 20-49
 calculation of bearing loads, 12-35 to 12-39
 cone distances, 1-17
 description, 2-13
 efficiency, 14-12
 estimating power capacity, 13-7
 four arrangements, 12-30
- Hypoid gears, geometry, 1-17
 lapping machines and processes, 20-49
 layout of profile, 8-29 to 8-39
 lubrication, 15-13
 manufacturing procedures, 20-9
 offset E , 1-17
 pitch plane, 1-17
 sample drawings, 11-12
 sliding velocity, 1-18
 surface of action, 1-18
- Idle bearing reaction, 12-13, 12-14
- Index tolerance, 9-28, 9-29
- Index variation, 23-23, 23-27 to 23-32
- Induction hardening, depth of case, 10-21
 frequencies required, 10-22
 general information, 10-19, 10-20
 power requirements, 10-22
- Infeed hobbing, 21-17, 21-18
- Injection molding, design data, 17-14, 17-15
 general information, 17-4 to 17-6
 production rates, 17-15
- Installation (see Assembly)
- Interchangeability, design considerations, 5-20
- Interchangeable-gear system, 3-1, 3-2
- Interchangeable gears, definition of, 1-5
- Interference, calculation, 7-5 to 7-7
 description, 1-21
- Interference point, 7-6
- Internal gears, bearing reactions, 12-12, 12-13
 broaching, 16-28 to 16-32
 calculation procedure, 5-46 to 5-48
 description, 2-6, 2-7
 design, 5-46 to 5-48
 efficiency, 14-5, 14-6
 form grinding, 19-6
 measurement over rolls, 7-12 to 7-14
 shaping, 16-17 to 16-23
 shaving, 18-13 to 18-15
- Interval of contact, 7-2 to 7-4
- Involute, approximating circle, 8-7
 coordinate equations, 8-6, 8-7
 definition, 8-6
 functions, 7-10, 7-11, 24-24, 24-25
 pointed teeth, 5-13 to 5-15
 polar coordinates, 8-11, 8-14
 rectangular coordinates, 8-14, 8-15
 study of tooth development, 5-12
 tangent and normal coordinates, 8-7 to 8-13
 zone of action, 5-10 to 5-13
- Involute charts, 11-6
- Involute checking machines (see Profile measurement)
- Involute finger-centering gate, 23-8
- Involute function, definition, 1-9
 equation, 7-9
 polar angle, 7-9
 tables, 7-10, 7-11, 24-24, 24-25
- Involute helicoid, definition, 1-12
 normal curvature, 1-12

- Involute-profile measurement (*see* Profile measurement)
 Involute roll angles, 23-3 to 23-5
 Involute setting master, 23-17
- Jominy end-quench, 10-7
 Journal failure, 14-51
- K factor, 13-3, 13-4
 Keyway, relationship to teeth, 7-18, 7-19
- Laminated plastic gears, 17-8
 Lapping, of bevel gears, 18-27
 machines and processes, 20-48, 20-49
 capacity of bevel and hypoid machines, 20-50, 20-51
 by crossed-axes method, 18-27
 general information, 18-26, 18-27
 of helical gears, 18-27, 18-28
 hypoid gear production rates, 20-49, 20-50
 reciprocating motion, 18-27
 of spur and helical gears, 18-27, 18-28
 Lapping compounds, 18-27, 20-52
 Lay of finish, 9-34
 Layout, of bevel gears, 8-21 to 8-29
 of hypoid gears, 8-29 to 8-39
 Lead measurement, by axial-pitch check, 23-34, 23-35
 by contact check, 23-35
 definitions, 23-32, 23-33
 by helix-checking machines, 23-33, 23-34
 Length of contact, 7-2
 Lewis formula, X-factor layout, 8-28, 8-29
 Lexan gears, 10-39
 Life factors, general data, 13-14
 Limit diameter, definition, 5-3
 Limits of accuracy (*see* Tolerances)
 Line of action, 7-2
 definition, 1-6
 effective, 1-6
 in sphere, 1-15
 Line of centers, 1-1
 Line of contact, definition, 1-2
 helical gears, 1-11
 Load-distribution factor, C_m , 13-20, 13-21, 13-23, 13-25, 13-26
 K_m , 13-23, 13-29
 Load rating (*see* Rating)
 Localized hardening, 10-15, 10-16
 Long addendum design, 5-16, 5-17, 5-35
 Low-friction gearing, 5-18 to 5-20
 Lubricant functions, 14-41, 14-42
 Lubricants, AGMA practice, 15-12, 15-13
 aircraft gear oils, 15-19
 aircraft greases, 15-20, 15-21
 general information, 15-7, 15-10, 15-11
 quantity required, 15-18
 recommendations for rating, 13-15, 13-16
 viscosity index, 15-11
 Lubrication, AGMA lubricants, 15-12, 15-13
 of aircraft gears, 15-18 to 15-21
 Lubrication, forced feed, 15-4 to 15-6
 of hypoid gears, 15-13
 oil coolers, 15-16 to 15-18
 oil feed trough, 15-2 to 15-4
 oil seals, 15-15, 15-16
 by rim spray, 15-7
 of Spiroid gears, 15-13
 splash system, 15-1 to 15-5
 wear failures, 15-13, 15-14
 of worm gears, 15-11, 15-13
- m and μ , definition, 24-26
 tables, 8-14, 24-27 to 24-30
 Machinability of steel and iron, 10-3
 Magnesium-base die castings, 10-32, 10-37
 Master gears, accuracy, 23-43, 23-44
 design, 23-42, 23-43
 drawing specifications, 11-4, 11-5
 size, 23-42
 Material factors, C_M , 13-46
 Materials, for bevel gears, 20-53, 20-54
 ferrous, 10-1, 10-2
 nonferrous, 10-25, 10-26
 (*See also* Steels; other specific materials)
 MD-type gear, 3-6, 3-7, 3-9
 MDT-type gear, 3-7, 3-9, 3-10
 Measurement of gears, by gear-tooth calipers, 7-17, 7-18
 by m and μ functions, 7-15, 7-16
 over rolls or balls, 7-9, 7-12 to 7-16
 by vernier calipers, 7-16, 7-17
 Measurement over wires, data, for $14\frac{1}{2}^\circ$ pinions, 24-19
 for 20° pinions, 24-18
 extra depth allowance, 24-18
 for helical gears, 24-20 to 24-22
 numerical examples, 24-2 to 24-4
 table, for $14\frac{1}{2}^\circ$ external gears, 24-9 to 24-12
 for $14\frac{1}{2}^\circ$ internal gears, 24-15, 24-16
 for 20° external gears, 24-5 to 24-8
 for 20° internal gears, 24-13, 24-14
 for 25° external gears, 24-17
 Mechanics of gear reactions (*see* Reactions)
 Mehanite, 10-24
 Mesh, region of, 5-11 to 5-13
 Meshing possibilities, 3-2
 Mil-L-7808D, 15-19
 Milling, appraisal, 16-4, 16-5
 general information, 16-1, 16-2
 machines for, 16-2, 16-3
 principles, 16-2, 16-3
 rate of cutting, 16-4
 thread, wormgear, 21-2 to 21-5, 21-12, 21-13
 Milling cutters, design practices, 22-31, 22-32
 general information, 22-29, 22-30
 standard cutter numbers, 22-30
 types used, 22-30 to 22-32
 Module, definition of, 4-26, 4-31
 Mounting distance, relation to center distance, 6-14, 6-15
 Mountings, of bevel-gear blanks, 12-26, 12-27

- Mountings, of bevel gears, 12-20 to 12-25
 of gears on shaft, 12-9
 general recommendations, 12-7, 12-8
 general types, 12-6, 12-7
 housing design, 12-10
 overhung, 12-24, 12-25
 straddle, 12-23 to 12-25
 of worm gears, 12-42, 12-43
- Nested gear unit, 3-7, 3-10, 3-11
- Niemann, G., 14-31, 14-32
- Nital etch, 19-16, 19-17
- Nitralloy (see Nitriding)
- Nitriding, case depth, 10-20
 general practice, 10-19
 materials for, 10-20
 process data, 10-20
 time vs. depth, 10-19
- Nodular iron, 10-24
- Noise, tolerance considerations, 9-38
- Nomenclature, angular dimensions, 4-16 to 4-19
 boundary surfaces, 4-5 to 4-8
 cutter calculations, 22-43
 elements of teeth, 4-9 to 4-12
 general information, 4-1, 4-3
 kinds of gears, 4-2 to 4-5
 linear and circular dimensions, 4-12 to 4-16
 metallurgy, 10-7 to 10-10
 miscellaneous terms, 4-20 to 4-22
 numbers and ratios, 4-18, 4-20
 pitch surfaces, 4-5, 4-6, 4-8
 principal directions, 4-7, 4-8
 principal planes, 4-7, 4-8
 tooth calculations, 7-1, 7-2
 (See also Symbols)
- Nonferrous gear materials, 10-25, 10-26
- Normal plane, spiral bevel gears, 1-16
- Normal section, calculation of, 8-18 to 8-20
- Number of teeth, for bevel gears, 5-51
 for face gears, 5-71, 5-72
 pinion, to avoid undercut, 5-33
 general data, 5-32
 for power gears, 5-34
 for worm gears, 5-68
- Nylon gears, material, 10-37 to 10-40
 molding practice, 17-4 to 17-6, 17-20
- Offset, definition of, 1-1
- Oil coolers, 15-16 to 15-18
- Oil feed trough, 15-2 to 15-4
- Oil finger, 15-7, 15-10
- Oil scavenging, 14-22, 14-23
- Oil systems, amount required, 15-18
 check valve arrangement, 15-6
 coolers, 15-16 to 15-18
 schematic diagram, 15-5
 summary of methods, 15-7
- Outside diameter, effective, 5-24
- Overhung mounting, 12-24, 12-25
- Overload factors, 13-19, 13-20
- Performance of gears, 14-39, 14-40
- Phenolic laminates, 10-39, 10-40
- Phosphor bronze, 10-26 to 10-28
- Pin measurement, 11-3, 11-4
- Pin size, 24-1, 24-2
- Pinion, definition, 4-3
- Pitch, definition, 1-5
 relationships, tables, 24-31 to 24-34
- Pitch angle, definition, 1-4
 kinematic, 1-2
- Pitch curves, definition, 1-5
- Pitch diameter, operating, 5-9
 standard, 5-9
- Pitch element, 1-4
- Pitch measurement, 23-22 to 23-26
- Pitch plane, definition, 1-5
- Pitch surfaces, 1-4
- Pitting, 12-47, 14-48
- Planers, production capacity, 20-21, 20-22
 for straight bevels, 20-20 to 20-24
 for Zerol, spiral, and hypoid gears, 20-22 to 20-24
- Planetary gears, arrangements, 3-14 to 3-18
 bearing reactions, 12-15, 12-16
 bevel, 3-21, 3-23
 efficiency, 14-24 to 14-26
 (See also Epicyclic gears)
- Planocentric gear, 3-34, 3-35
- Planoid gears, description, 2-13
 efficiency, 14-12, 14-13
 sample drawings, 11-17, 11-18
- Plastic flow, 14-47
- Pointed teeth, 5-13 to 5-15
 calculation, 7-20
 diameter, 5-25
- Points of contact, 1-2
- Poisson's ration, 13-19
- Powdered metal gears (see Sintered gears)
- Power, maximum gear capacity, 3-4
 (See also Rating)
- Power drives, 5-18
- Power formula, 13-29
- Power loss, 14-40
- Precision quality, 9-15
- Preshave cutting, 13-19, 19-20
- Profile contact ratio, m_p , 7-2 to 7-4
- Profile layout for bevel gears, 8-21 to 8-29
- Profile measurement, by base-diameter disk, 23-6 to 23-9
 by dividing head, 23-1, 23-2
 by master base-circle disk, 23-9 to 23-14
 by master involute cam, 23-14 to 23-17
 by pins, 23-21, 23-22
 by portable machines, 23-17 to 23-21
 by projection, 23-21
- Profile modification, design recommendations, 5-22 to 5-24
- Proportions (see Tooth proportions)
- Quality classes, AGMA classification, 9-16 to 9-20
 AGMA fine pitch, 9-19, 9-20
 aircraft gear, 9-20, 9-21
 levels of quality, 9-15
- Quantity of oil, 15-18

- Rack, definition, 1-5, 4-3
helical, 1-10
trochoid, 8-2 to 8-4
Radioactive gear test, 14-57, 14-58
Radius of curvature, profile, 1-7, 1-8
Rake angles, 22-17
Rating, application data required, 13-1 to 13-3
bevel gears, 13-25 to 13-27
strength, 13-35 to 13-37
cylindrical worm gearing, 13-37 to 13-40
effect of hardness, 13-14
estimating capacity (tables), crossed-helical gear, 13-9
cylindrical wormgear, 13-10, 13-11
double-enveloping wormgear, 13-11
high-speed helical gear, 13-6
hypoid gear, 13-7
K-factor method, 13-3, 13-4
spiral bevel gear, 13-8
large, 13-7
Spiroid gear, 13-12
spur gear, 13-5
straight and Zerol bevel gear, 13-7
straight-face gear, 13-8
general information, 13-1
helical gears, 13-22 to 13-25
strength, 13-34, 13-35
industrial bevel practice, 13-45, 13-46
life factors, 13-14
lubricants required, 13-15, 13-16
spur gears, durability, 13-21, 13-22
strength, 13-33, 13-34
thermal capacity, 13-17
Ratio, definition, 1-8
formula, 1-8
how to obtain, 3-3
Reactions, basic bearing, 12-4, 12-5
bevel gear bearings, 12-29 to 12-35
helical gears, 12-16 to 12-20
hypoid gear bearings, 12-35 to 12-39
internal gear bearings, 12-12, 12-13
mechanics of, 12-1 to 12-3
planetary gears, 12-15, 12-16
Spiroid gears, 12-43 to 12-45
spur gear bearings, 12-10 to 12-12
trains of gears, 12-13 to 12-15
worms and wormgears, 12-39 to 12-42
Reference planes, 1-16
Region of mesh, 1-6
Registering surfaces, 9-30, 9-31
Removal of material, 21-1
Revacycle cutter, 20-19
Revacycle machine, 20-18 to 20-20
Revacycle production, 20-20
Reverse gear units, 3-22, 3-28, 3-32 to 3-34
Ridging, 14-47
Rim spray, 15-7
Rockwell hardness, 24-35, 24-36
Roll angle, ϵ , calculation, 7-3 to 7-5
definition, 1-9
Roll size, 24-1, 24-2
Rolling, design data, 17-20 to 17-22
general information, 17-6, 17-7
production practice, 17-22
Root fillet, design recommendations, 5-24
finish, 9-34
Run-in of worm gears, 12-43
Scoring, criterion for, 13-44, 13-45
general information, 13-44, 13-45
industrial bevel practice, 13-45 to 13-48
Seals, face-contact, 15-15, 15-16
labyrinth type, 15-15, 15-16
radial type, 15-15, 15-16
Service factors, classes of service, 13-43
for electric motor drives, 13-13
for worm gears, 13-41
Shaft angle, definition, 1-1
Shallow-hardening, 10-22, 10-23
Shaper cutters, clearance groove, 22-21
common types, 22-19
general principles, 22-16 to 22-20
for helical gears, 22-20, 22-21
sharpening practice, 22-24 to 22-26
special calculations, 22-26 to 22-29
special features, 22-22, 22-23
Shaping, appraisal, 16-23
clearance groove required, 22-21
cutting speeds, 16-21 to 16-23
general information, 16-17 to 16-20
machines for, 16-18 to 16-20
of worm threads, 21-13 to 21-15
Shaving, angular traverse, 18-11, 18-12
automation, 18-15
axial traverse, 18-9, 18-10
contact area, 18-7 to 18-9
crossed-axes method, 18-2 to 18-8
crown method, 18-12
cutting vs. guiding action, 18-8, 18-9
diagonal, 22-35
general information, 18-1, 18-2
of internal gears, 18-13 to 18-15
multistroke angular-traverse, 18-12
preshave form, 18-19
production practice, 18-15 to 18-18
production rates, 18-17
protuberance for, 18-19, 18-20
rack method, 18-18, 18-19
right-angle traverse, 18-10
rotary crossed-axes, 18-2 to 18-18
stock allowance, 18-20, 18-21, 18-39
transverse, 22-34
undercut, 18-19
underpass, 22-35, 22-36
Shaving cutters, direction of feed, 22-37
general information, 18-4
general principles, 22-32 to 22-34
pivot point, 22-36
preshave gear, 22-39
sharpening, 22-40, 22-41
special calculations, 22-41 to 22-46
tool geometry, 22-38
Shear cutting, appraisal, 16-28
general information, 16-23 to 16-25
machines for, 16-24 to 16-27
typical production rates, 16-27
Shock loading, kinds of, 13-2
Silicon bronze, 10-27, 10-28

- Sintered gears, design data, 17-17 to 17-19
 general information, 17-7
 production rates, 17-19
- Sintered irons, 17-18, 17-19
- Size, gear, relative, 3-5
 tolerance control, 9-24 to 9-27
 (See also Rating)
- Size factor K_v , 13-36
- Sliding velocity, of bevel gears, 14-2, 14-3
 of crossed-axes helical gears, 14-3
 definition, 1-2, 1-7
 formulas, 1-8
 of hypoid gears, 14-3
 of spur gears, 14-2
 of wormgears, 14-3
- Solar gears, 3-15, 3-17
 (See also Epicyclic gears)
- Spacing measurement, definitions, 23-22, 23-23
- Spacing variation, analysis of index check, 23-31, 23-32
 analysis of pitch check, 23-27
 of bevel gears, 23-59 to 23-61
 index checking, 23-27 to 23-31
 pitch checking machines, 23-23 to 23-26
 portable spacing checker, 23-26
- Spalling, 14-48
- Span measurement, 7-16, 7-17
- Speed-increasing drives, 5-17
- Spiral angle, definition, 1-15
 of hypoid gears, 1-18
- Spiral bevel gears, burnishing, 20-47 to 20-49
 definition, 1-15
 description, 2-9
 estimating power capacity, 13-7, 13-8
 sample drawings, 11-10, 11-11
- Spiroid gear inspection, contact pattern, 23-70, 23-71
 mounting distance, 23-69, 23-70, 23-73
 pinion checks, 23-71, 23-72
 tolerances, 23-74
- Spiroid gears, arrangement, 3-20, 3-21
 calculation of bearing loads, 12-43 to 12-45
 description, 2-13, 2-14
 design, 5-74 to 5-83
 drafting practice, 11-15 to 11-17
 efficiency, 14-10, 14-11
 estimating power capacity, 13-12
 lubrication, 15-13
 proportions, 4-47, 5-78 to 5-81
- Splash lubrication, 15-1 to 15-5
- Spline failure, 14-51, 14-52
- Spur gears, bearing reactions, 12-10 to 12-12
 broaching, 16-28 to 16-33
 composite tolerances, 9-26, 9-27
 definitions, 1-2, 1-4
 description, 2-4, 2-5
 drawing practice, 11-3 to 11-7
 efficiency, 14-3 to 14-6
 estimating power capacity, 13-3 to 13-5
 form grinding, 19-1 to 19-7
 generating grinding, 19-7 to 19-13
 hobbing, 16-5 to 16-17
 housing, 18-21 to 18-26
- Spur gears, lapping, 18-27
 made by die processes, 17-1 to 17-9
 milling, 16-1 to 16-5
 quality classes, 9-14 to 9-21
 scoring criterion, 13-44, 13-45
 shaping, 16-17 to 16-23
 shaving, 18-1 to 18-21
 shear cutting, 16-23 to 16-28
 strength rating, 13-33, 13-34
 surface durability rating, 13-21, 13-22
 threaded wheel grinding, 19-13 to 19-15
 tolerances, 9-10, 9-11
 examples, 9-6, 9-7
 trochoidal fillet, 8-2 to 8-4
- Spur rack, 2-4, 2-5
- Stamping, design data, 17-9, 17-10
 general information, 17-3
 production rates, 17-11, 17-12
- Standard system, for bevel gears, 5-48 to 5-50
 for face gears, 5-71
 general considerations, 5-26, 5-27
 for helical gears, 5-41 to 5-45
 for Helicon gears, 5-74
 for internal gears, 5-46
 for Spiroid gears, 5-74
 for spur gears, 5-27, 5-28, 5-31
 for worm gears, 5-64
- Star gears, 3-15 to 3-18
 (See also Epicyclic gears)
- Steels, alloy type, 10-10 to 10-12
 carbon type, 10-10 to 10-12
 carburizing, 10-16, 10-18
 choice of, 10-12, 10-13
 composition, 10-11
 general properties, 10-2
 hardenability, 10-12
 heat-treatment, 10-3 to 10-7
 induction hardening, 10-19 to 10-22
 localized hardening, 10-15
 nitriding, 10-19
 physical properties, 10-4 to 10-7
 processing, 10-14
 shallow hardening, 10-22, 10-23
- Straddle mounting, 12-23 to 12-25
- Straight bevel gears, definition of, 1-15
 description of, 2-7, 2-8
 manufacturing practice, 20-11 to 20-22
- Strength of steel gears, 10-16
- Strength rating, allowable fatigue stress, 13-28, 13-31
 bevel gears, 13-35 to 13-37
 general formula, 13-28
 helical gears, 13-34, 13-35
 spur gears, 13-33, 13-34
- Surface of action, 1-3
- Surface durability, allowable contact stress, 13-18, 13-27
 bevel gears, 13-25 to 13-27
 cylindrical wormgears, 13-37 to 13-40
 general formula, 13-18
 helical gears, 13-22 to 13-25
 spur gears, 13-21, 13-22
- Surface finish, definition of, 9-31
 vs. dimensional tolerances, 9-32 to 9-34
 of profile, 9-34
 standard values, 9-32

- Symbols, allocation of letters, 4-22, 4-23
 Greek letters, 4-23
 special, list of, 4-25 to 4-27
 subscripts, 4-23, 4-24
 typography style, 4-24
(See also Abbreviations; Nomenclature)
- Tangent plane, 1-16
- Tangential hobbing, 21-18 to 21-22
- Teeth *(see under Tooth)*
- Temperature, effect on center distance, 6-15, 6-16
- Temperature factor, K_T , 13-31
- Tensile strength of steel, 10-4 to 10-6
- Terminology, of bevel gears, 2-8
 of internal gears, 2-7
 of spur gears, 2-5
(See also Nomenclature)
- Testing, of accessory boxes, 14-53, 14-54
 for efficiency, 14-54 to 14-57
 by four-square torque loop, 14-53
 of lubricants, 14-57, 14-58
 by power absorption, 14-53
- Thermal rating, 13-17
- Thickness of teeth *(see Tooth thickness)*
- Thread generating, 21-13 to 21-15
- Thread grinding, worms, 21-26 to 21-28
 production rates, 21-28, 21-29
(See also Grinding)
- Thread hobbing, worms, 21-8 to 21-10
 procedure, 21-10 to 21-12
 production time, 21-13
(See also Hobbing)
- Thread milling, worms, cutters used, 21-7, 21-8
 general information, 21-2, 21-3
 on hobber, 21-5 to 21-7
 procedure, 21-3 to 21-5
 production time, 21-12, 21-13
(See also Milling)
- Thread rolling *(see Rolling)*
- Threaded-wheel grinding, general principles, 19-13, 19-14
 production time, 19-14, 19-15
- Tip round, recommended amounts, 5-39
- Tolerances, AGMA quality classes, 9-14 to 9-21
 allowance vs., 9-4
 by application, 9-22
 for bevel gears, 9-14
 on center distance, 9-40
 choice of, 9-8, 9-9
 composite, 9-25 to 9-27
 critical geometric shapes, 9-36
 on deburring, 9-37, 9-38
 definition, 9-3
 effect of surface coating, 9-35, 9-36
 effects of, 9-5
 error vs. deviation, 9-4
 by fabrication method, 9-23, 9-24
 for helical gears, 9-11
 by materials, 9-23
 by rank, 9-34, 9-35
 mounting effects, 9-29, 9-30
 by pitch-line speed, 9-22
- Tolerances, position of tooth, 9-28, 9-29
 by quality classes, 9-14 to 9-21
 size control, 9-24 to 9-27
 for spur gears, 9-10, 9-11
 terminology, 9-1 to 9-3
 types, 9-5 to 9-8
 for wormgears, 9-13, 9-14
 for worms, 9-11, 9-12
(See also Quality classes)
- Tooth breakage, 14-49 to 14-51
- Tooth numbers *(see Number of teeth)*
- Tooth proportions, 24-31
 basic considerations, 5-4, 5-5
 for bevel gears, 5-50
 definition of elements, 5-2 to 5-4
 for face gears, 5-71
 for helical gears, 5-43, 5-44
 for Helicon gears, 5-84, 5-85
 for internal gears, 5-47
 low-friction drives, 5-18
 obsolete systems, 5-40
 power drives, 5-18
 speed-increasing drives, 5-17, 5-18
 for Spiroid gears, 4-47, 5-78 to 5-81
 for spur gears, 5-29 to 5-40
 standard data, 5-38
 for worm gears, 5-65 to 5-67
(See also Standard systems)
- Tooth thickness, angular, 1-6
 chordal *(see Chordal thickness)*
 circular, 1-6
 design considerations, 5-20 to 5-22
 measurement, at any diameter, 7-19, 7-20
 at any radius, 7-15
 by dimension over pins, 23-39
 with master, 23-39, 23-40
 over rolls or balls, 7-9, 7-12 to 7-16
 by span method, 23-40, 23-41
 tables of dimensions over wires, 24-8 to 24-17
 by tooth calipers, 7-17, 7-18, 23-38, 23-39, 23-49, 23-51
 by vernier calipers, 7-16, 7-17, 23-51
 for small numbers of teeth, 5-39
 thinning allowance, 9-27
 variation with cutter setting, 7-19
- Top angles, 22-17
- Top land, width, 5-25
- Toprem feature, 20-29
- Total contact ratio, definition, 1-12
- Transmissions, automatic, 3-29, 3-31, 3-32
 gear-shift, 3-27 to 3-31
 reverse gear units, 3-32 to 3-34
- Transverse plane, definition, 1-5
- Transverse shaving, 22-34
- Transverse motion in generation, 1-20
- Trigonometric functions, 24-23
- Trochoid, definition, 8-1
 fillet, 8-4 to 8-6
 of rack, 8-2 to 8-4
- Tuplin, 14-31, 14-32
- Ultraprecision quality, 9-15
- Undercut, of bevel gears, 8-39

- Undercut, contact ratio with, 7-7
 definition, 1-3
 description of, 1-21
 design table, 5-33
 general discussion, 5-15, 5-16
 in spiral bevel gears, 5-61
 in straight bevel gears, 5-60
 Undercutting, 7-5 to 7-7
 Underpass shaving, 22-35, 22-36
 Unitool method, 20-33
- V and H check, 23-54 to 23-57
 V-drive unit, 3-21, 3-22
 Velocity ratio, definition, 1-6
 Versacut process, 20-34
 Vibration of gears, 14-40, 14-41
 Viscosity, of AGMA lubricants, 15-12
 of aircraft gear oils, 15-19
 Viscosity index, 15-11
- Waviness designation, 9-34
 Wear, 14-43 to 14-47
 from inadequate lubrication, 15-13, 15-14
 Weight of gears, relative, 3-5
 Windage losses, 14-20, 14-21
 Wire size, selection, 24-1
 table, 24-2
 Workholding devices, 20-10, 20-11
 Worm gears, arrangement, 3-20, 3-21
 blank proportions, 12-43
 calculation of bearing loads, 12-39 to 12-42
 calculation procedure, 5-64 to 5-70
 cutter diameter, 5-69
 cutting, double-enveloping, 21-23 to 21-26
 cylindrical, design, 5-64 to 5-70
 definition, 1-19
 description, 2-11, 2-12
 drafting practice, 11-13 to 11-15
 efficiency, 14-8 to 14-10
- Worm gears, estimating power capacity,
 13-10, 13-11
 hobbing, 21-15 to 21-23
 general information, 21-15 to 21-17
 infeed method, 21-17, 21-18
 production time, 21-22, 21-23, 21-26
 tangential method, 21-18 to 21-22
 inspection, contact check, 23-65, 23-66
 of double-enveloping gears, 23-67, 23-68
 worm checking, 23-66, 23-67
 lead angle, 5-68
 lubrication, 15-11, 15-13
 normal pitches, 5-68
 pitch diameters, 5-70
 rating, 13-37 to 13-44
 tolerances, 9-13, 9-14
 tooth forms, 5-64
- Worms, calculation of profile, 8-18 to 8-20
 cutter for, 8-15 to 8-18
 cutting throated worm, 21-23 to 21-26
 definition, 4-3
 generating (shaping) threads, 21-13 to 21-15
 grinding threads, 21-26 to 21-29
 hobbing threads, 21-8 to 21-10
 inspection of, 23-66, 23-67
 milling threads, 21-3 to 21-7
 normal section, 8-18 to 8-20
 rolled threads, 17-20 to 17-22
 sample drawing, 11-13
 tolerances, 9-11, 9-12
- X-factor layout, 8-28, 8-29
- Zeman, J., 14-31, 14-32
 Zerol bevel gears, description, 2-8, 2-9
 lapping machines and processes, 20-48
 Zinc-base die castings, 10-33
 Zinc die castings, 10-30, 10-32, 10-33

DARLE W. DUDLEY . . .



. . . is currently Chief of Gear Technology, SOLAR, Division of International Harvester Company, and was Manager, Mechanical Transmissions, at Mechanical Technology, Inc., Latham, New York. Previously he was Manager, Advance Unit of the Gear Engineering Subsection, Medium Steam Turbine, Generator and Gear Department, General Electric Company, Lynn, Massachusetts. From 1953 to 1957 he was Section Head of the latter company's Development Section of the Gear Engineering Division where he was responsible for gear development and testing, and for the design and development of special tools and machinery for the manufacture of gears. In this capacity, he was also responsible for the design of special product gearing which included gearing for aircraft gas turbine engines, gun control, and other special military applications.

In 1958, Mr. Dudley received the Edward P. Connell award in recognition of his outstanding accomplishment in gear work. He has since been regarded as one of the outstanding gear experts in the United States and abroad.

The author of many technical articles, Darle Dudley is a Registered Professional Engineer in the state of Massachusetts, and is a member of the American Society of Mechanical Engineers and the American Gear Manufacturers' Association.

McGRAW-HILL BOOK COMPANY

1221 Avenue of the Americas

New York, N. Y. 10020

0-07-017902-6