Richard G.
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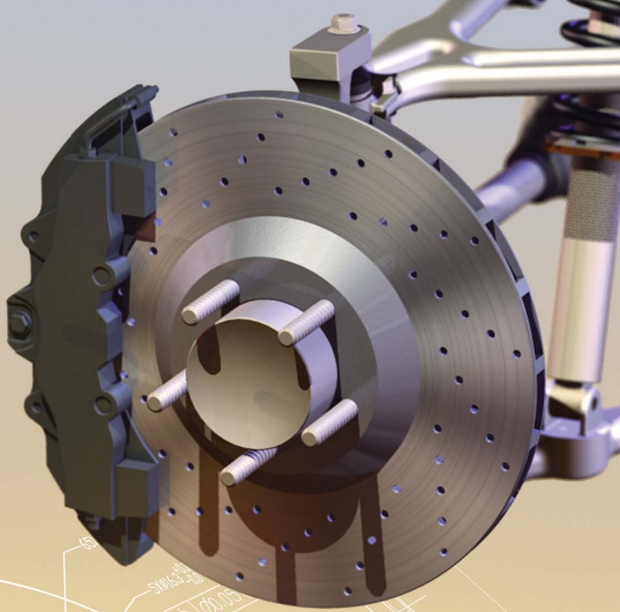
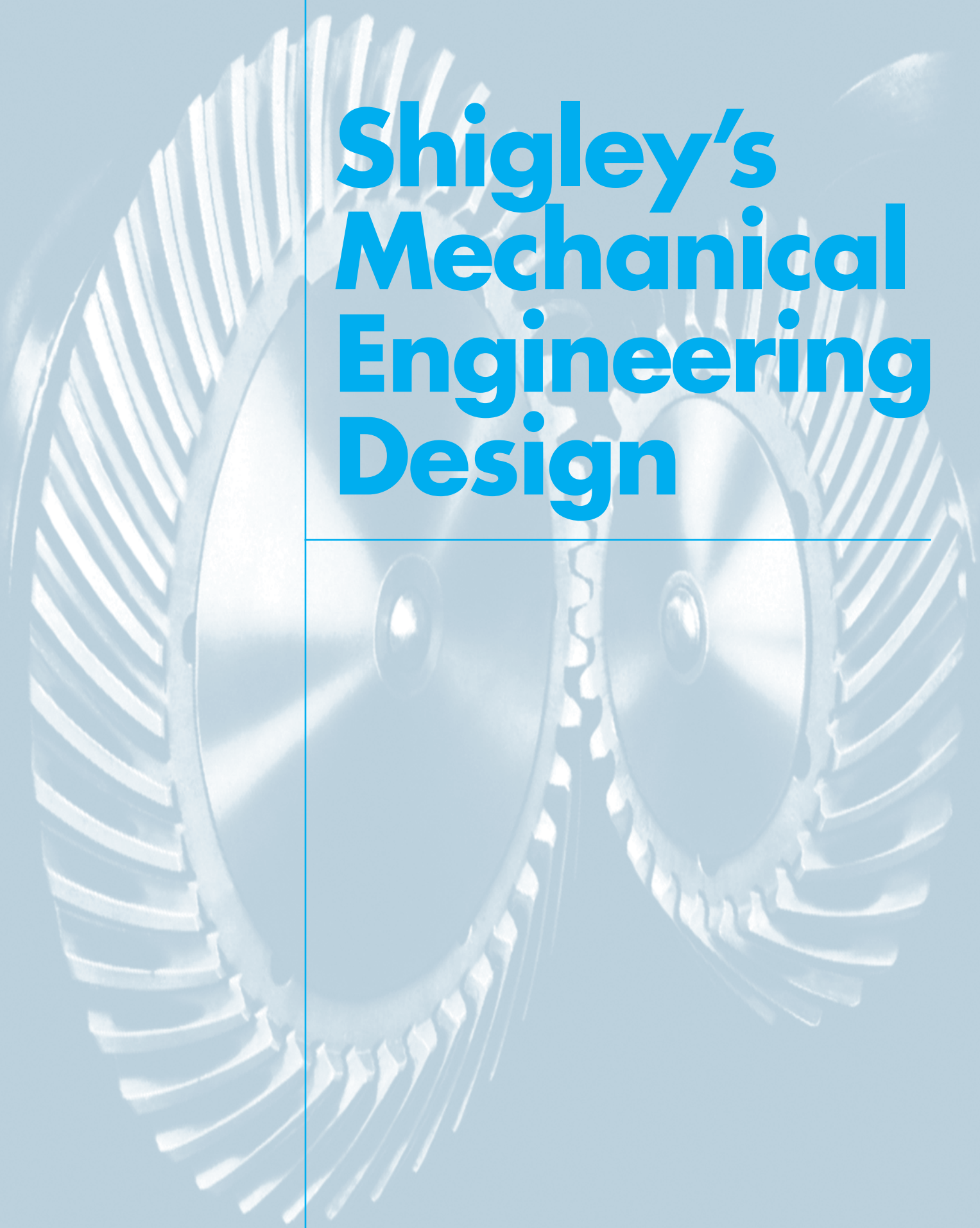


Tenth Edition

Shigley's

Mechanical Engineering Design



Shigley's Mechanical Engineering Design

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Shigley's Mechanical Engineering Design

Tenth Edition

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Mc Graw Hill Education

SHIGLEY'S MECHANICAL ENGINEERING DESIGN, TENTH EDITION

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 0 RJC/RJC 1 0 9 8 7 6 5 4

ISBN 978-0-07-339820-4
MHID 0-07-339820-9

Senior Vice President, Products & Markets: *Kurt L. Strand*
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Production Supervisor: *Jennifer Pickel*
Cover Designer: *Studio Montage, St. Louis, MO*
Cover Image: *Adam Nisbett*
Compositor: *Aptara®, Inc.*
Typeface: *10/12 Times LT Std*
Printer: *R. R. Donnelley*

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Library of Congress Cataloging-in-Publication Data

Budynas, Richard G. (Richard Gordon)
Shigley's mechanical engineering design.—Tenth edition / Richard G. Budynas, professor emeritus, Kate Gleason College of Engineering, Rochester Institute of Technology, J. Keith Nisbett, associate professor of mechanical engineering, Missouri University of Science and Technology.
pages cm—(Mcgraw-Hill series in mechanical engineering)
Includes index.
ISBN-13: 978-0-07-339820-4 (alk. paper)
ISBN-10: 0-07-339820-9 (alk. paper)
1. Machine design. I. Nisbett, J. Keith. II. Shigley, Joseph Edward. Mechanical engineering design. III. Title.
TJ230.S5 2014
621.8′15—dc23

2013035900

www.mhhe.com

Dedication

To my wife, Joanne, my family, and my late brother, Bill, who advised me to enter the field of mechanical engineering. In many respects, Bill had considerable insight, skill, and inventiveness.

Richard G. Budynas

To my wife, Kim, for her unwavering support.

J. Keith Nisbett

Dedication to Joseph Edward Shigley

Joseph Edward Shigley (1909–1994) is undoubtedly one of the most well-known and respected contributors in machine design education. He authored or coauthored eight books, including *Theory of Machines and Mechanisms* (with John J. Uicker, Jr.), and *Applied Mechanics of Materials*. He was coeditor-in-chief of the well-known *Standard Handbook of Machine Design*. He began *Machine Design* as sole author in 1956, and it evolved into *Mechanical Engineering Design*, setting the model for such textbooks. He contributed to the first five editions of this text, along with coauthors Larry Mitchell and Charles Mischke. Uncounted numbers of students across the world got their first taste of machine design with Shigley's textbook, which has literally become a classic. Nearly every mechanical engineer for the past half century has referenced terminology, equations, or procedures as being from "Shigley." McGraw-Hill is honored to have worked with Professor Shigley for more than 40 years, and as a tribute to his lasting contribution to this textbook, its title officially reflects what many have already come to call it—*Shigley's Mechanical Engineering Design*.

Having received a bachelor's degree in Electrical and Mechanical Engineering from Purdue University and a master of science in Engineering Mechanics from the University of Michigan, Professor Shigley pursued an academic career at Clemson College from 1936 through 1954. This led to his position as professor and head of Mechanical Design and Drawing at Clemson College. He joined the faculty of the Department of Mechanical Engineering of the University of Michigan in 1956, where he remained for 22 years until his retirement in 1978.

Professor Shigley was granted the rank of Fellow of the American Society of Mechanical Engineers in 1968. He received the ASME Mechanisms Committee Award in 1974, the Worcester Reed Warner Medal for outstanding contribution to the permanent literature of engineering in 1977, and the ASME Machine Design Award in 1985.

Joseph Edward Shigley indeed made a difference. His legacy shall continue.

About the Authors

Richard G. Budynas is Professor Emeritus of the Kate Gleason College of Engineering at Rochester Institute of Technology. He has more than 50 years experience in teaching and practicing mechanical engineering design. He is the author of a McGraw-Hill textbook, *Advanced Strength and Applied Stress Analysis,* Second Edition; and coauthor of a McGraw-Hill reference book, *Roark's Formulas for Stress and Strain,* Eighth Edition. He was awarded the BME of Union College, MSME of the University of Rochester, and the PhD of the University of Massachusetts. He is a licensed Professional Engineer in the state of New York.

J. Keith Nisbett is an Associate Professor and Associate Chair of Mechanical Engineering at the Missouri University of Science and Technology. He has more than 30 years of experience with using and teaching from this classic textbook. As demonstrated by a steady stream of teaching awards, including the Governor's Award for Teaching Excellence, he is devoted to finding ways of communicating concepts to the students. He was awarded the BS, MS, and PhD of the University of Texas at Arlington.

Brief Contents

Contents

Preface

Objectives

This text is intended for students beginning the study of mechanical engineering design. The focus is on blending fundamental development of concepts with practical specification of components. Students of this text should find that it inherently directs them into familiarity with both the basis for decisions and the standards of industrial components. For this reason, as students transition to practicing engineers, they will find that this text is indispensable as a reference text. The objectives of the text are to:

- Cover the basics of machine design, including the design process, engineering mechanics and materials, failure prevention under static and variable loading, and characteristics of the principal types of mechanical elements.
- Offer a practical approach to the subject through a wide range of real-world applications and examples.
- Encourage readers to link design and analysis.
- Encourage readers to link fundamental concepts with practical component specification.

New to This Edition

Enhancements and modifications to the tenth edition are described in the following summaries:

- A new Chap. 20, *Geometric Dimensioning and Tolerancing,* has been added to introduce an important topic in machine design. Most of the major manufacturing companies utilize geometric dimensioning and tolerancing (GD&T) as a standardized means of accurately representing machine parts and assemblies for the purposes of design, manufacture, and quality control. Unfortunately, many mechanical engineers do not have sufficient exposure to the notation and concepts of GD&T to interpret the drawings.

  During the time when GD&T was becoming most prevalent in manufacturing, many engineering schools were phasing out comprehensive drafting courses in favor of computerized CAD instruction. This was followed by another transition to 3D solid modeling, where the part was drawn with ideal dimensions. Unfortunately, this ability to draw a perfect part in three dimensions is all too often accompanied by a neglect of focus on how to accurately and uniquely represent the part for manufacture and inspection.

  A full understanding of GD&T is usually obtained through an intensive course or training program. Some mechanical engineers will benefit from such a rigorous training. *All* mechanical engineers, however, should be familiar with the basic concepts and notation. The purpose of the coverage of GD&T in this new chapter is to provide this foundational exposure that is essential for all machine designers.

  It is always a challenge to find time to include additional material in a course. To facilitate this, the chapter is arranged and presented at a level appropriate for students

to learn in an independent study format. The problems at the end of the chapter are more like quiz questions, and are focused on checking comprehension of the most fundamental concepts. Instructors are encouraged to consider using this chapter as a reading assignment, coupled with even a minimal lecture or online discussion. Of course, there is ample material for expanded presentation and discussion as well.

- Chapter 1, *Introduction to Mechanical Engineering Design,* has been expanded to provide more insight into design practices. Further discussion of the development of the *design factor* is presented, as well as the statistical relationships between *reliability* and the *probability of failure,* and reliability and the design factor. Statistical considerations are provided here rather than in a chapter at the end of the text as in past editions. The section on Dimensions and Tolerances has been expanded to emphasize the designer's role in specifying dimensions and tolerances as a critical part of machine design.
- The chapter of the previous edition, *Statistical Considerations,* has been eliminated. However, the material of that chapter pertinent to this edition has been integrated within the sections that utilize statistics. The stand-alone section on stochastic methods in Chap. 6, *Fatigue Failure Resulting from Variable Loading,* has also been eliminated. This is based on user input and the authors' convictions that the excessive amount of development and data provided in that section was far too involved for the simple class of problems that could be solved. For instructors who still want access to this material, it is available on McGraw-Hill's Online Learning Center at www.mhhe.com/shigley.
- In Chap. 11, *Rolling-Contact Bearings,* the Weibull probability distribution is defined and related to bearing life.
- In conjunction with the Connect Engineering resource, the end-of-chapter problems have been freshly examined to ensure they are clearly stated with less room for vague interpretations. Approximately 50 percent of the problems are targeted for Connect implementation. With the problem parameterization available in this Web-based platform, students can be assigned basic problems with minimal duplication from student to student and semester to semester. For a good balance, this edition maintains many end-of-chapter problems that are open-ended and suitable for exploration and design.

Connect Engineering

The tenth edition continues to feature McGraw-Hill Connect Engineering, a Web-based assignment and assessment platform that allows instructors to deliver assignments, quizzes, and tests easily online. Students can practice important skills at their own pace and on their own schedule.

McGraw-Hill LearnSmart®

McGraw-Hill LearnSmart is an adaptive learning system designed to help students learn faster, study more efficiently, and retain more knowledge for greater success. Through a series of adaptive questions, Learnsmart pinpoints concepts the student does not understand and maps out a personalized study plan for success. It also lets instructors see exactly what students have accomplished, and it features a built-in assessment tool for graded assignments. Ask your McGraw-Hill Representative for more information, and visit www.mhlearnsmart.com for a demonstration.

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Powered by the intelligent and adaptive LearnSmart engine, SmartBook is the first and only continuously adaptive reading experience available today. Distinguishing what students know from what they don't, and honing in on concepts they are most likely to forget, SmartBook personalizes content for each student. Reading is no longer a passive and linear experience but an engaging and dynamic one, where students are more likely to master and retain important concepts, coming to class better prepared. SmartBook includes powerful reports that identify specific topics and learning objectives students need to study. These valuable reports also provide instructors insight into how students are progressing through textbook content and are useful for identifying class trends, focusing precious class time, providing personalized feedback to students, and tailoring assessment.

How does SmartBook work? Each SmartBook contains four components: Preview, Read, Practice, and Recharge. Starting with an initial preview of each chapter and key learning objectives, students read the material and are guided to topics for which they need the most practice based on their responses to a continuously adapting diagnostic. Read and practice continue until SmartBook directs students to recharge important material they are most likely to forget to ensure concept mastery and retention.

Electronic Textbooks

This text is available as an eBook at www.CourseSmart.com. At CourseSmart your students can take advantage of significant savings off the cost of a print textbook, reduce their impact on the environment, and gain access to powerful web tools for learning. CourseSmart eBooks can be viewed online or downloaded to a computer.

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Additional media offerings available at www.mhhe.com/shigley include:

Student Supplements

- *Fundamentals of Engineering (FE) exam questions for machine design.* Interactive problems and solutions serve as effective, self-testing problems as well as excellent preparation for the FE exam.

Instructor Supplements (under password protection)

- *Solutions manual.* The instructor's manual contains solutions to most end-of-chapter nondesign problems.
- *PowerPoint® slides.* Slides outlining the content of the text are provided in PowerPoint format for instructors to use as a starting point for developing lecture presentation materials. The slides include all figures, tables, and equations from the text.
- *C.O.S.M.O.S.* A complete online solutions manual organization system that allows instructors to create custom homework, quizzes, and tests using end-of-chapter problems from the text.

Acknowledgments

The authors would like to acknowledge those who have contributed to this text for over 50 years and nine editions. We are especially grateful to those who provided input to this tenth edition:

Expanded Connect Implementation

Peter J. Schuster, *California Polytechnic State University*

Drawings for GD&T Chapter

Glenn Traner, *Tech Manufacturing, LLC*

CAD Model Used in Cover Design

Jedrzej Galecki, *University of the West of England*

Reviewers

Kenneth Huebner, *Arizona State*
Gloria Starns, *Iowa State*
Tim Lee, *McGill University*
Robert Rizza, *MSOE*
Richard Patton, *Mississippi State University*
Stephen Boedo, *Rochester Institute of Technology*
Om Agrawal, *Southern Illinois University*
Arun Srinivasa, *Texas A&M*
Jason Carey, *University of Alberta*
Patrick Smolinski, *University of Pittsburgh*
Dennis Hong, *Virginia Tech*

List of Symbols

This is a list of common symbols used in machine design and in this book. Specialized use in a subject-matter area often attracts fore and post subscripts and superscripts. To make the table brief enough to be useful, the symbol kernels are listed. See Table 14–1, pp. 727–728 for spur and helical gearing symbols, and Table 15–1, pp. 781–782 for bevel-gear symbols.

A	Area, coefficient
a	Distance
B	Coefficient
Bhn	Brinell hardness
b	Distance, Weibull shape parameter, range number, width
C	Basic load rating, bolted-joint constant, center distance, coefficient of variation, column end condition, correction factor, specific heat capacity, spring index
c	Distance, viscous damping, velocity coefficient
COV	Coefficient of variation
D	Diameter, helix diameter
d	Diameter, distance
E	Modulus of elasticity, energy, error
e	Distance, eccentricity, efficiency, Naperian logarithmic base
F	Force, fundamental dimension force
f	Coefficient of friction, frequency, function
fom	Figure of merit
G	Torsional modulus of elasticity
g	Acceleration due to gravity, function
H	Heat, power
H_B	Brinell hardness
HRC	Rockwell C-scale hardness
h	Distance, film thickness
$\hbar_{CR}$	Combined overall coefficient of convection and radiation heat transfer
I	Integral, linear impulse, mass moment of inertia, second moment of area
i	Index
i	Unit vector in x-direction
J	Mechanical equivalent of heat, polar second moment of area, geometry factor
j	Unit vector in the y-direction
K	Service factor, stress-concentration factor, stress-augmentation factor, torque coefficient
k	Marin endurance limit modifying factor, spring rate
k	Unit vector in the z-direction
L	Length, life, fundamental dimension length