

# MACHINE DESIGN

An Integrated  
Approach

THIRD EDITION



Robert L. Norton

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#### ABOUT THE BOOK

This textbook presents an integrated approach to the design of machine elements by uniting machine-element topics with a series of case studies that demonstrate the interrelationships between force, stress and failure analysis in real-world design. While emphasizing the design aspects of the subject, the book also presents a thorough and complete treatment of engineering mechanics topics and provides a good balance between synthesis and analysis. It is based on the author's extensive experience in the practice of machine design in industry.

The text is divided into two parts. The first part presents the fundamentals of design, materials, force, stress, strain, deflection analysis, and failure theories, including an introduction to fracture mechanics. The second part treats the design of specific elements such as springs, gears, shafts, fasteners, etc., but does so in the context of their use in integrated assemblies. The case studies provide the vehicle for this, with different elements of the same assembly being addressed in various chapters. The main emphasis is on designing for high-cycle fatigue loading of machine parts and assemblies. A new chapter in this edition presents an introduction to Finite Element Analysis in which common pitfalls of this technique's application are addressed.

The machine-design subject matter is presented in an up-to-date manner using computer-aided-design techniques. Most of the 75 examples and 26 case-study analyses are solved with equation solvers and over 250 computer files are provided on the accompanying CD-ROM that allow the book's examples, case studies, and other problems to be solved in Microsoft® Excel, MATLAB®, Mathcad®, and TK Solver™. A number of custom-written programs for kinematic, dynamic, and stress analysis are also included. The book's website, accessible via the Instructor Support tab at <http://www.prenhall.com> provides Microsoft® Powerpoint® compatible files of all the book's figures and tables. Additional supplements are available at the author's website at <http://www.designofmachinery.com>.

#### WHAT USERS SAY ABOUT THE BOOK

*This book is one of the best-written on any engineering subject that I have come across. We switched to the book because we felt that the students would get a lot out of reading the text.*

—Professor Ed Howard, Milwaukee School of Engineering

*(The) writing is clear and meaningful, (and the) text is much more accessible to students because of the practical nature of (its) case studies and problem sets.*

—Professor Douglas Walcerz, York College of Pennsylvania

*I'm doing my machine design homework now, and . . . your book is the single best text I have ever used in my educational career. It is straightforward, easy to understand and has good examples.*

—Josh, student, Colorado School of Mines

#### ABOUT THE AUTHOR

Robert L. Norton is Professor of Mechanical Engineering at Worcester Polytechnic Institute, Worcester, MA, where he teaches machine design, kinematics, and dynamics of machinery. He has over 45 years experience in the design and manufacturing of products, devices, and machines and is the inventor or co-inventor on 13 U.S. patents.

He has also written the books *Design of Machinery: An Introduction to the Synthesis and Analysis of Mechanisms and Machines* and the *Cam Design and Manufacturing Handbook*.

Professor Norton is a registered professional engineer in Massachusetts, a member of the Society of Automotive Engineers, a Fellow of the American Society of Mechanical Engineers, and recipient of the 2002 ASME Machine Design Award.

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## An Integrated Approach

**Third Edition**

*Robert L. Norton*

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without whose faith and foresight,  
this book would never have been written.

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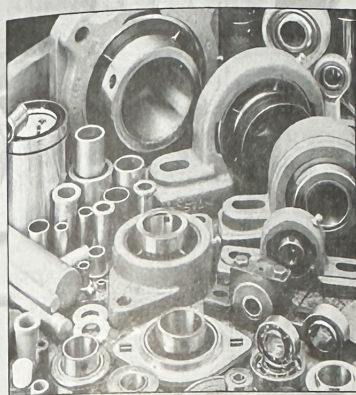
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# 10



## BEARINGS AND LUBRICATION

*The knowledge of man is as the waters,  
some descending from above,  
and some springing from beneath.*

*Francis Bacon*

### 10.0 INTRODUCTION

We use the term **bearing** here in its most general sense. Whenever two parts have relative motion, they constitute a bearing by definition, regardless of their shape or configuration. Usually, lubrication is needed in any bearing to reduce friction and remove heat. Bearings may roll or slide or do both simultaneously.

A **plain bearing** is formed by any two materials rubbing on one another, whether a sleeve around a shaft or a flat surface under a slider. In a plain bearing, one of the moving parts usually will be steel or cast iron or some other structural material in order to achieve the required strength and hardness. For example, transmission shafts, links, and pins are in this category. The parts that they move against will usually be made of a "bearing" material such as bronze, babbitt, or a nonmetallic polymer. A radial plain bearing may be split axially to assemble it to the shaft, or may be a complete circle called a **bushing**. A **thrust bearing** supports axial loads.

Alternatively, a rolling-element bearing, which has hardened steel balls or rollers captured between hardened steel raceways, may be used to provide very low friction. Plain bearings are typically custom designed for the application, while rolling-element bearings are typically selected from manufacturers' catalogs to suit the loads, speeds, and desired life of the particular application. Rolling-element bearings can support radial, thrust, or combinations of those loads depending on their design.

This chapter will discuss bearings in general, both the sliding (or plain) variety and also rolling-element bearings. Lubrication theory also will be discussed as it applies to these types of bearings. Table 10-0 shows the variables used in this chapter and notes the equations or sections in which they first occur.