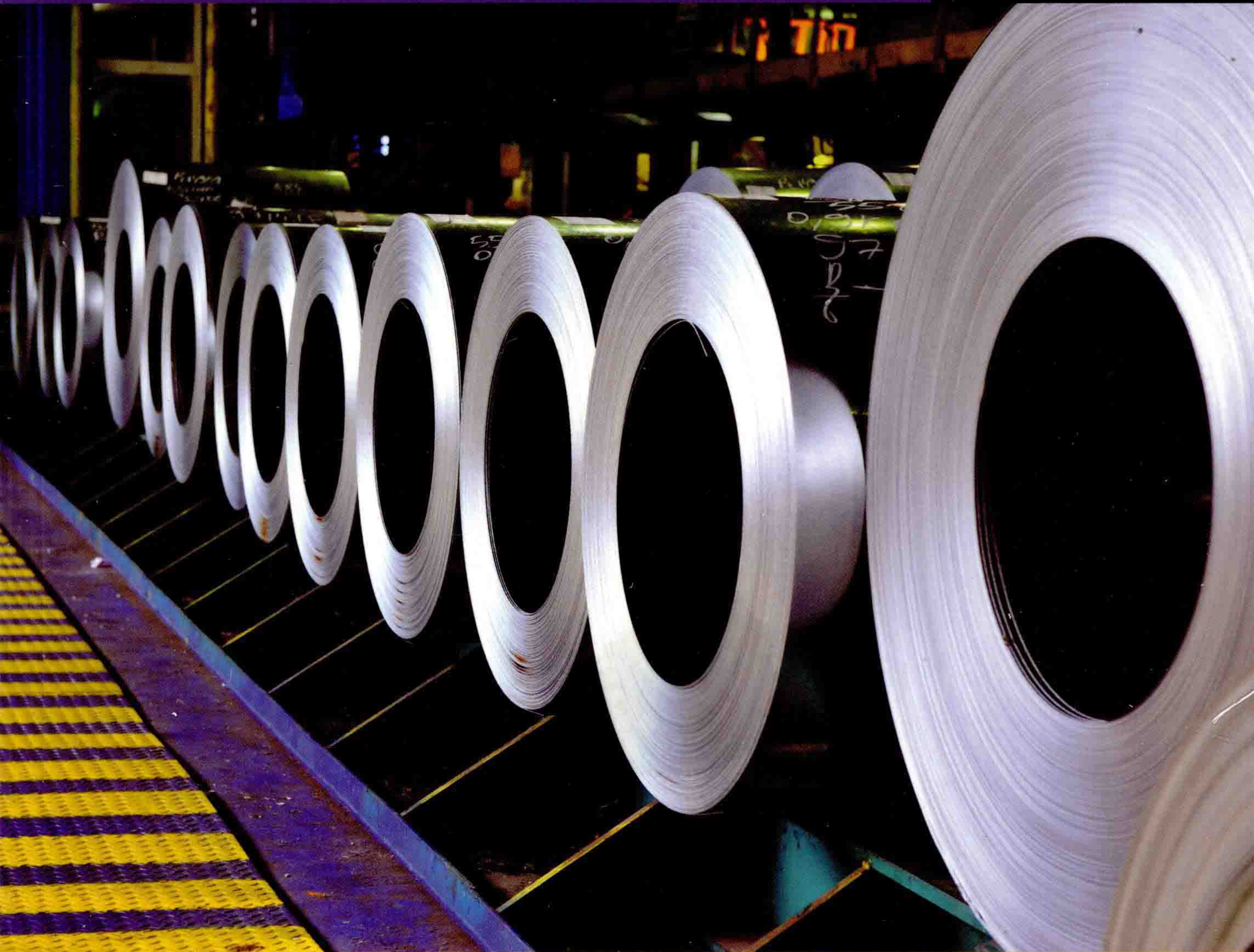
MIKELL P. GROOVER

4th EDITION



PRINCIPLES of MODERN MANUFACTURING

SI Version

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Fourth Edition

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Standard Units Used in this Book

Units for both the System International (SI, metric) and United States Customary System (USCS) are listed in equations and tables throughout this textbook. Metric units are listed as the primary units and USCS units are given in parentheses.

Prefixes for SI units:

Prefix	Symbol	Multiplier	Example units (and symbols)
nano-	n	10^{-9}	nanometer (nm)
micro-	μ	10^{-6}	micrometer, micron (μm)
milli-	m	10^{-3}	millimeter (mm)
centi-	c	10^{-2}	centimeter (cm)
kilo-	k	10^{3}	kilometer (km)
mega-	M	10^{6}	megaPascal (MPa)
giga-	G	10^{9}	gigaPascal (GPa)

Table of Equivalencies between USCS and SI units:

Variable	SI units	USCS units	Equivalencies
Length	meter (m)	inch (in)	1.0 in = 25.4 mm = 0.0254 m
		foot (ft)	1.0 ft = 12.0 in = 0.3048 m = 304.8 mm
		yard	1.0 yard = 3.0 ft = 0.9144 m = 914.4 mm
		mile	1.0 mile = 5280 ft = 1609.34 m = 1.60934 km
		micro-inch (μ-in)	1.0 μ-in = 1.0×10^{-6} in = 25.4×10^{-3} μm
Area	m^2, mm^2	in^2, ft^2	1.0 in^2 = 645.16 mm^2
			1.0 ft^2 = 144 in^2 = 92.90×10^{-3} m^2
Volume	m^3, mm^3	in^3, ft^3	1.0 in^3 = 16,387 mm^3
			1.0 ft^2 = 1728 in^3 = 2.8317×10^{-2} m^3
Mass	kilogram (kg)	pound (lb)	1.0 lb = 0.4536 kg
		ton	1.0 ton (short) = 2,000 lb = 907.2 kg
Density	kg/m^3	lb/in^3	1.0 lb/in^3 = 27.68×10^3 kg/m^3
		lb/ft^3	1.0 lb/ft^3 = 16.0184 kg/m^3
Velocity	m/min	ft/min	1.0 ft/min = 0.3048 m/min = 5.08×10^{-3} m/s
	m/s	in/min	1.0 in/min = 25.4 mm/min = 0.42333 mm/s
Acceleration	m/s^2	ft/sec^2	1.0 ft/sec = 0.3048 m/s^2
Force	Newton (N)	pound (lb)	1.0 lb = 4.4482 N
Torque	N-m	ft-lb, in-lb	1.0 ft-lb = 12.0 in-lb = 1.356 N-m
			1.0 in-lb = 0.113 N-m
Pressure	Pascal (Pa)	lb/in^2	1.0 lb/in^2 = 6895 N/m^2 = 6895 Pa
Stress	Pascal (Pa)	lb/in^2	1.0 lb/in^2 = 6.895×10^{-3} N/mm^2 = 6.895×10^{-3} MPa
Energy, work	Joule (J)	ft-lb, in-lb	1.0 ft-lb = 1.356 N-m = 1.356 J
			1.0 in-lb = 0.113 N-m = 0.113 J
Heat energy	Joule (J)	British thermal unit (Btu)	1.0 Btu = 1055 J
Power	Watt (W)	Horsepower (hp)	1.0 hp = 33,000 ft-lb/min = 745.7 J/s = 745.7 W
			1.0 ft-lb/min = 2.2597×10^{-2} J/s = 2.2597×10^{-2} W
Specific heat	J/kg-°C	Btu/lb-°F	1.0 Btu/lb-°F = 1.0 Calorie/g-°C = 4,187 J/kg-°C
Thermal conductivity	J/s-mm-°C	Btu/hr-in -°F	1.0 Btu/hr-in -°F = 2.077×10^{-2} J/s-mm-°C
Thermal expansion	(mm/mm)/°C	(in/in)/°F	1.0 (in/in)/°F = 1.8 (mm/mm)/°C
Viscosity	Pa-s	lb-sec/in^2	1.0 lb-sec/in^2 = 6895 Pa-s = 6895 N-s/m^2

Conversion between USCS and SI

To convert from USCS to SI: To convert the value of a variable from USCS units to equivalent SI units, ***multiply*** the value to be converted by the right-hand side of the corresponding equivalency statement in the Table of Equivalencies.

Example: Convert a length $L = 3.25$ in to its equivalent value in millimeters.

Solution: The corresponding equivalency statement is: 1.0 in = 25.4 mm

$$L = 3.25 \text{ in} \times (25.4 \text{ mm/in}) = \mathbf{82.55\ mm}$$

To convert from SI to USCS: To convert the value of a variable from SI units to equivalent USCS units, ***divide*** the value to be converted by the right-hand side of the corresponding equivalency statement in the Table of Equivalencies.

Example: Convert an area $A = 1000 \text{ mm}^2$ to its equivalent in square inches.

Solution: The corresponding equivalency statement is: $1.0 \text{ in}^2 = 645.16 \text{ mm}^2$

$$A = 1000 \text{ mm}^2/(645.16 \text{ mm}^2/\text{in}^2) = \mathbf{1.55\ in^2}$$

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PREFACE

Principles of Modern Manufacturing is designed for a first course or two-course sequence in manufacturing at the junior level in mechanical, industrial, and manufacturing engineering curricula. Given its coverage of engineering materials, it is also suitable for materials science and engineering courses that emphasize materials processing. Finally, it may be appropriate for technology programs related to the preceding engineering disciplines. Most of the book's content is concerned with manufacturing processes (about 65% of the text), but it also provides significant coverage of engineering materials and production systems. Materials, processes, and systems are the basic building blocks of modern manufacturing and the three broad subject areas covered in the book.

APPROACH

The author's objective in this edition and its predecessors is to provide a treatment of manufacturing that is ***modern*** and ***quantitative***. Its claim to be "modern" is based on (1) its balanced coverage of the basic engineering materials (metals, ceramics, polymers, and composite materials), (2) its inclusion of recently developed manufacturing processes in addition to the traditional processes that have been used and refined over many years, and (3) its comprehensive coverage of electronics manufacturing technologies. Competing textbooks tend to emphasize metals and their processing at the expense of the other engineering materials, whose applications and methods of processing have grown significantly in the last several decades. Also, most competing books provide minimum coverage of electronics manufacturing. Yet the commercial importance of electronics products and their associated industries have increased substantially during recent decades.

The book's claim to be more "quantitative" is based on its emphasis on manufacturing science and its greater use of mathematical models and quantitative (end-of-chapter) problems than other manufacturing textbooks. In the case of some processes, it was the first manufacturing processes book to ever provide a quantitative engineering coverage of the topic.

NEW TO THIS EDITION

This fourth edition is an updated version of the third edition. The publisher's instructions to the author were to increase content but reduce page count. As this preface is being written, it is too early to tell whether the page count is reduced, but the content has definitely been increased. Additions and changes in the fourth edition include the following:

- All text examples and end of chapter problems are now entirely in SI units (i.e. Système International d'Unités)
- The chapter count has been reduced from 45 to 39 through consolidation of several chapters.
- Selected end-of-chapter problems have been revised to make use of PC spreadsheet calculations.

- A new section on trends in manufacturing has been added in Chapter 1.
- Chapter 5 on dimensions, tolerances, and surfaces has been modified to include measuring and gauging techniques used for these part features.
- A new section on specialty steels has been added to Chapter 6 on metals.
- Sections on polymer recycling and biodegradable plastics have been added in Chapter 8 on polymers and composite materials.
- Several new casting processes are discussed in Chapter 10.
- Sections on thread cutting and gear cutting have been added in Chapter 20 on machining operations and machine tools.
- Several additional hole-making tools have been included in Chapter 21 on cutting tool technology.
- Former Chapters 26 and 27 on industrial cleaning and coating processes have been consolidated into a single chapter.
- A new section on friction-stir welding has been added to Chapter 28 on welding processes.
- Former Chapters 37 and 38 on microfabrication and nanofabrication technologies have been consolidated into a single Chapter 34.
- The three previous Chapters 39, 40, and 41 on manufacturing systems have been consolidated into two chapters: Chapter 35 titled Automation for Manufacturing Systems and Chapter 36 on Integrated Manufacturing Systems. New topics covered in these chapters include automation components and material handling technologies.
- Former Chapters 44 on Quality Control and 45 on Measurement and Inspection have been consolidated into a single chapter, Chapter 39 titled Quality Control and Inspection. New sections have been added on Total Quality Management, Six Sigma, and ISO 9000. The text on conventional measuring techniques has been moved to Chapter 5.

OTHER KEY FEATURES

Additional features of the book continued from the third edition include the following:

- A DVD showing action videos of many of the manufacturing processes is included with the book.
- A large number of end-of-chapter problems, review questions, and multiple choice questions are available to instructors to use for homework exercises and quizzes.
- Sections on ***Guide to Processing*** are included in each of the chapters on engineering materials.
- Sections on ***Product Design Considerations*** are provided in many of the manufacturing process chapters.
- ***Historical Notes*** on many of the technologies are included throughout the book.

SUPPORT MATERIAL FOR INSTRUCTORS

For instructors who adopt the book for their courses, the following support materials are available:

- A ***Solutions Manual*** (in digital format) covering all problems, review questions, and multiple-choice quizzes.
- A complete set of PowerPoint slides for all chapters.

These support materials may be found at the website www.wiley.com/go/global/groover. Evidence that the book has been adopted as the main textbook for the course must be verified. Individual questions or comments may be directed to the author personally at Mikell.Groover@Lehigh.edu.

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ABOUT THE AUTHOR

Mikell P. Groover is Professor of Industrial and Systems Engineering at Lehigh University, where he also serves as faculty member in the Manufacturing Systems Engineering Program. He received his B.A. in Arts and Science (1961), B.S. in Mechanical Engineering (1962), M.S. in Industrial Engineering (1966), and Ph.D. (1969), all from Lehigh. He is a Registered Professional Engineer in Pennsylvania. His industrial experience includes several years as a manufacturing engineer with Eastman Kodak Company. Since joining Lehigh, he has done consulting, research, and project work for a number of industrial companies.

His teaching and research areas include manufacturing processes, production systems, automation, material handling, facilities planning, and work systems. He has received a number of teaching awards at Lehigh University, as well as the ***Albert G. Holzman Outstanding Educator Award*** from the Institute of Industrial Engineers (1995) and the ***SME Education Award*** from the Society of Manufacturing Engineers (2001). His publications include over 75 technical articles and ten books (listed below). His books are used throughout the world and have been translated into French, German, Spanish, Portuguese, Russian, Japanese, Korean, and Chinese. The first edition of the current book ***Fundamentals of Modern Manufacturing*** received the ***IIE Joint Publishers Award*** (1996) and the ***M. Eugene Merchant Manufacturing Textbook Award*** from the Society of Manufacturing Engineers (1996).

Dr. Groover is a member of the Institute of Industrial Engineers, American Society of Mechanical Engineers (ASME), the Society of Manufacturing Engineers (SME), the North American Manufacturing Research Institute (NAMRI), and ASM International. He is a Fellow of IIE (1987) and SME (1996).

PREVIOUS BOOKS BY THE AUTHOR

Automation, Production Systems, and Computer-Aided Manufacturing, Prentice Hall, 1980.

CAD/CAM: Computer-Aided Design and Manufacturing, Prentice Hall, 1984 (co-authored with E. W. Zimmers, Jr.).

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CONTENTS

1 INTRODUCTION AND OVERVIEW OF MANUFACTURING

Chapter Contents

Making things has been an essential activity of human civilizations since before recorded history. Today, the term ***manufacturing*** is used for this activity. For technological and economic reasons, manufacturing is important to the welfare of the United States and most other developed and developing nations. ***Technology*** can be defined as the application of science to provide society and its members with those things that are needed or desired. Technology affects our daily lives, directly and indirectly, in many ways. Consider the list of products in Table 1.1. They represent various technologies that help society and its members to live better. What do all these products have in common? They are all manufactured. These technological wonders would not be available to society if they could not be manufactured. Manufacturing is the critical factor that makes technology possible.

Economically, manufacturing is an important means by which a nation creates material wealth. In the United States, the manufacturing industries account for about 15% of gross domestic product (GDP). A country's natural resources, such as agricultural lands, mineral deposits, and oil reserves, also create wealth. In the U.S., agriculture, mining, and similar industries account for less than 5% of GDP (agriculture alone is only about 1%). Construction and public utilities make up around 5%. The rest is service industries, which include retail, transportation, banking, communication, education, and government. The service sector accounts for more than 75% of U.S. GDP. Government alone accounts for about as much of GDP as the manufacturing sector; however, government services do not create wealth. In the modern global economy, a nation must have a strong manufacturing base (or it must have significant natural resources) if it is to provide a strong economy and a high standard of living for its people.

In this opening chapter, we consider some general topics about manufacturing. What is manufacturing? How is it organized in industry? What are the materials, processes, and systems by which it is accomplished?