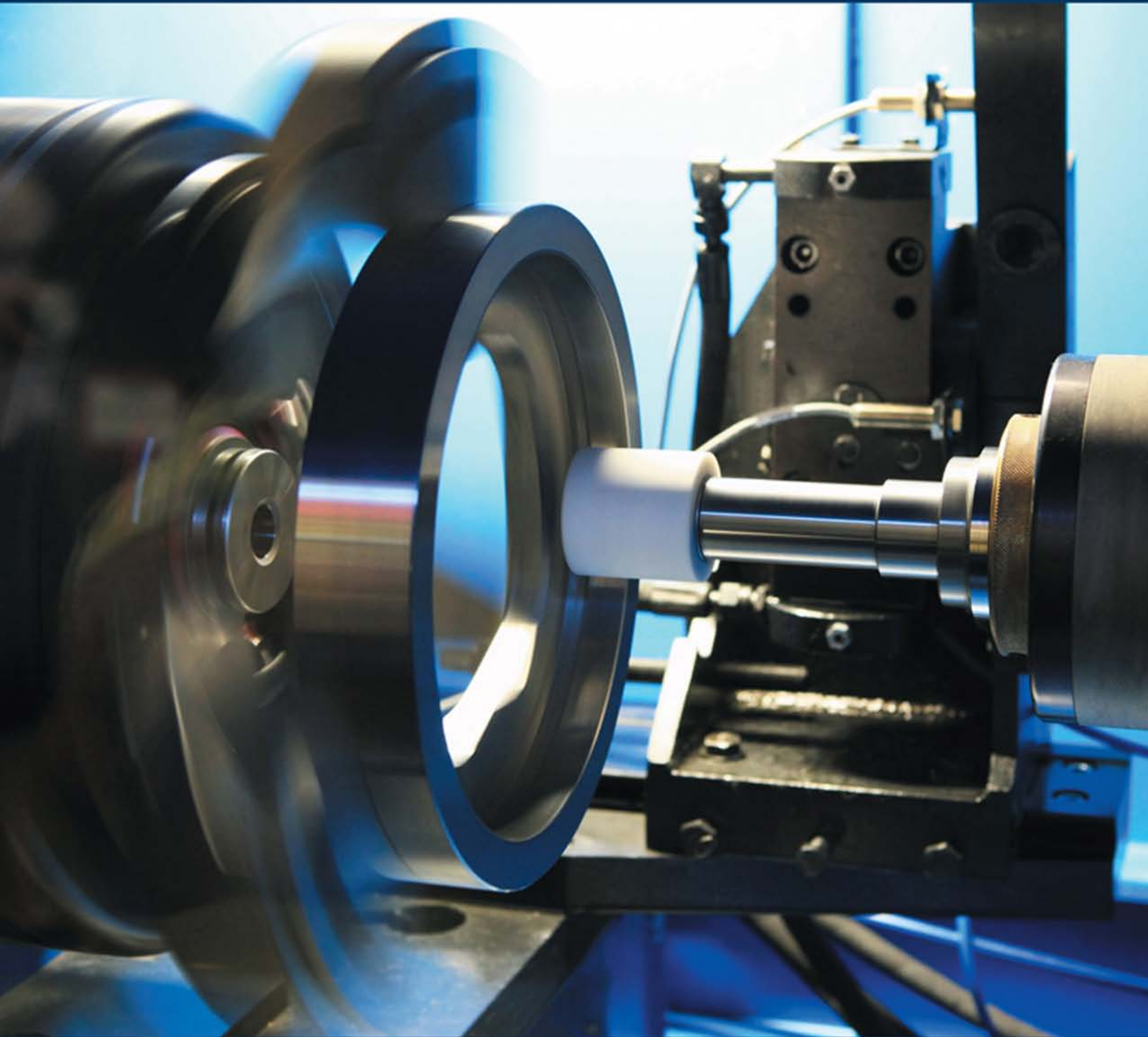
Precision Machining TECHNOLOGY

Second Edition



Peter Hoffman • Eric Hopewell • Brian Janes

Precision Machining Technology

Second Edition

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PREFACE

Precision Machining Technology introduces students, both at the secondary and postsecondary levels, to the exciting world of machine tool technology as it is practiced in the 21st century. In writing this text, the authors' main goal is to provide a deep understanding of the fundamental and intermediate machining skills needed for career success in a rapidly changing manufacturing environment. In line with this objective, the author team has taken special care to ensure that the text:

- Has a down-to-earth, practical orientation that covers what students need to know about the field of precision machining as it is practiced today
- Develops modern interpersonal skills that are demanded by the job market
- Covers current career information and trends
- Includes modern shop practices
- Contains specific instructions and examples, with images showing many step-by-step applications
- Provides in-depth knowledge as a base for strong foundational skills without becoming difficult to read or comprehend
- Includes current computer numerical control (CNC) content

This text is written for students of precision machining at the secondary and postsecondary levels who have the opportunity and desire to learn skills required by the machine tool industry and to obtain NIMS certifications. The book is written in such a way that the student needs no prior knowledge of machining to benefit.

Precision Machining Technology has been sponsored and endorsed by NIMS. The text and its supporting supplements fill the need of comprehensively covering all of the material encountered by a student during the NIMS certification process, and were written with the Machining Level I Standards in mind. The text's close adherence to NIMS's nationally recognized skills standards will be especially useful for schools and school districts that wish to comply with the funding requirements of the Carl D. Perkins Career and Technical Education Act of 2006 (Perkins IV).

How the Text Was Developed

In order to create a truly new set of teaching and learning tools, *Precision Machining Technology* was launched with no preconceived notion of how the text should be designed. A large number of instructors at NIMS-accredited programs participated in the initial development of the table of contents, which then led to the recruitment of the author team, also from NIMS-accredited programs. During the development of the project, over a dozen instructors reviewed drafts of the manuscript and provided useful feedback to the authors. Their input has played a major role in improving the final product. Last, the publisher and NIMS committed to an extra developmental step, class-testing the manuscript at multiple institutions, in order to assure the highest level of accuracy and teaching effectiveness. Reviewers and class-testers are listed in the Acknowledgments section.

To enhance the teaching and learning experience, the authors developed the text with the following objectives in mind:

- Achieve an easy-to-read writing style that assumes the student has no prior knowledge of machining and takes the student all the way through to the intermediate stage
- Include many images to clarify explanations and procedures so students can make visual connections
- Identify key and secondary terms throughout the text to guide students to important points
- Assume that students are taking or have already taken basic geometry, basic algebra, and have good proficiency in computation of fractions, decimals, and order of operations
- Allow for the companion *Workbook/Projects Manual* to provide a beneficial measure of practice to prepare the student for NIMS product creation and the knowledge examination

Organization of the Text

In designing *Precision Machining Technology*, the authors followed the typical progression through the NIMS certifications. For many of the sections, a student should have sufficient knowledge to obtain a NIMS certification at the completion of the sections.

The text is divided into eight major sections, as follows:

Section 1—Introduction to Machining

Section 2—Measurement, Materials, and Safety

Section 3—Job Planning, Benchwork, and Layout

Section 4—Drill Press

Section 5—Turning

Section 6—Milling

Section 7—Grinding

Section 8—Computer Numerical Control (CNC)

Each section of the text contains multiple “bite-sized” units, which provide the following teaching and learning aids: learning objectives, key terms, caution safety checks, chapter summary, and review questions.

Special care was taken to make each unit progress in a logical presentation of content for someone with no prior knowledge. The authors took steps to ensure that no new terminology was presented prior to a complete explanation of each term. Each unit builds on another, and many sections build on previous sections. As the text progresses, topics are explored more deeply. Previous knowledge is reinforced through new application of previous information.

What's New in This Edition

- Expanded appendix including more reference material and machining data
- New content reflecting updates to OSHA's Hazard Communication Standard
- Carbide turning insert and holder information
- Carbide milling insert and holder information
- Grinding coolant information
- Teamwork and leadership content
- Updated images

A Note for Students: How to Use This Text

Do not become overwhelmed with all of the information. The text is arranged so that you may take each piece step by step. Pause and think about key and secondary terms while reading.

Supplements for Students and Instructors

The companion *Workbook and Projects Manual* by David Lenzi and James Hillwig contains helpful review material to ensure that students have mastered key concepts in the text, and guided practice operations and projects on a wide range of machine tools that will enhance their NIMS credentialing success. All projects are keyed to NIMS Duties and Standards.

For instructors, Cengage Learning has produced an Instructor Companion Website that contains the following tools: Instructor's Guide, PowerPoint lecture slides containing selected images from the text, an image library, and correlation grids for both the text and workbook to the NIMS Machining Level 1 Standards and Cengage Learning Testing Powered by Cognero—a flexible online system that allows you to:

- author, edit, and manage test bank content from multiple Cengage Learning solutions
- create multiple test versions in an instant
- deliver tests from your LMS, your classroom, or wherever you want

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FROM THE AUTHORS

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Eric Hopewell

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Brian Janes

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Brian Janes's career in the machine trades has spanned some 20 years. His experience includes various machining positions in shops as well as in injection molding companies throughout Indiana and Kentucky. Brian has worked as a machinist for several Indy car racing teams and still holds a part-time position with both Team Leader Motor Sports in Indianapolis, Indiana, and Dave Mclerran Engineering in Los Angeles, California. He has overseen educational programs in both machine tool and industrial maintenance. His programs have won the Kentucky Technical Education Program of the Year Award, and one of his programs was the first program in Kentucky to receive NIMS accreditation. Brian has an MS degree in engineering technology.

Precision Machining Technology

SECTION 1 Introduction to Machining

- Unit 1

  Introduction to Machining

  Introduction

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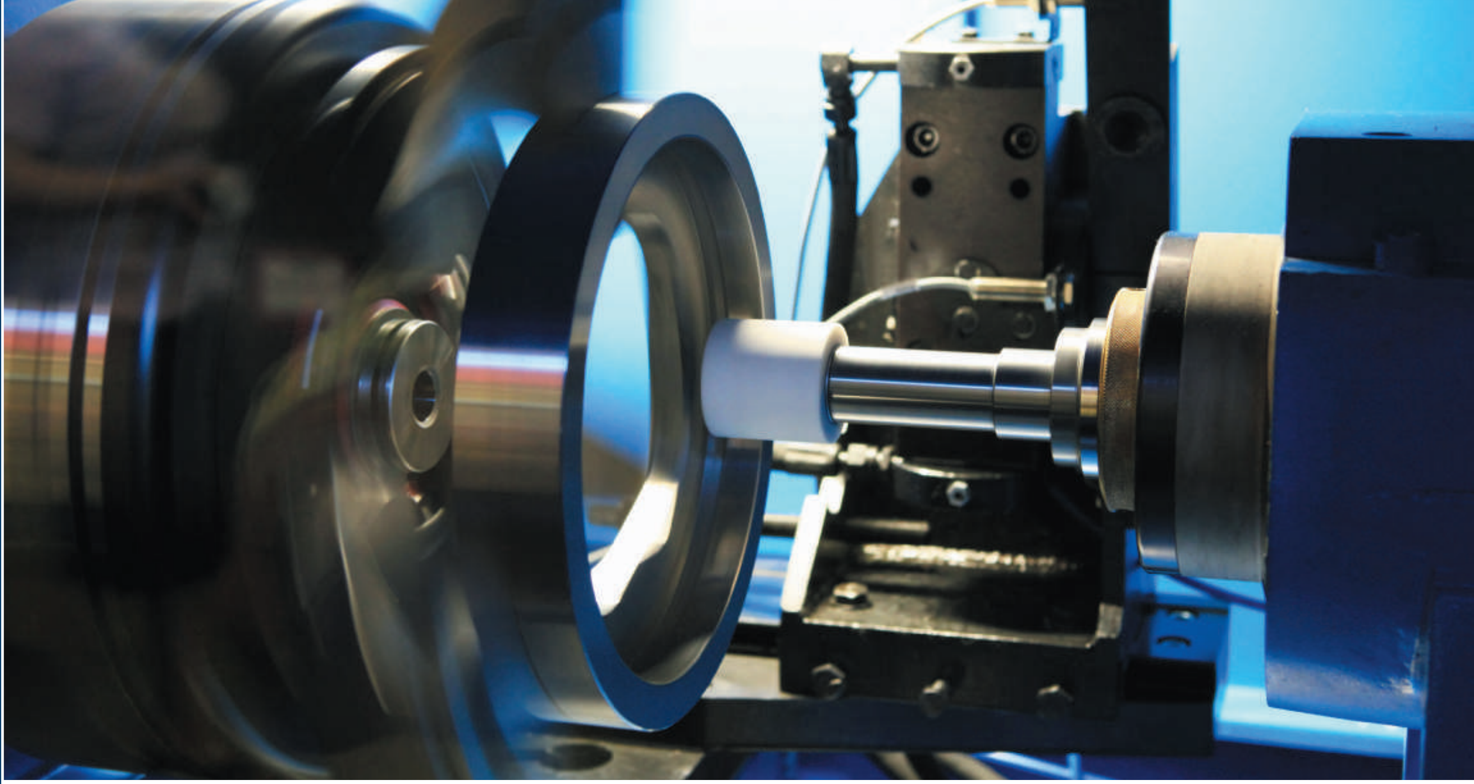


UNIT 1 Introduction to Machining

Learning Objectives

After completing this unit, the student should be able to:

- Define the term *machining*
- Define a machine tool
- Discuss the evolution of machining and machine tools
- Identify the role of machining in society
- Discuss the principles of the basic types of machining processes

Key Terms

Abrasive machining
Computer Numerical Control (CNC)
Drill press
Electrical Discharge Machining (EDM)
End product
Laser machining
Lathe
Machine tool
Machining
Manufacturing
Milling machine
Numerical Control (NC)
Sawing machine
Water jet machining

INTRODUCTION

The word *machining* probably has very little meaning to the typical person today. However, nearly all people depend on that word more than they could ever imagine. How can that be? What *is* machining and how does it influence everyday life?

The answers to these questions, and many others that will come up along the journey to discover the world of machining, involve exploring several different related topics.

First, the terms *machining* and *machine tool* need to be defined and many details of their definitions explained.

Next, a realization of how machining is connected to people's daily lives is needed. Connections will be made to a wide variety of consumable and durable goods and even services used by millions of people worldwide.

Discussion of the equipment, tools, processes, and technology used in the world of machining is necessary to begin to understand the role of machining in society. A brief history of machining and how it has progressed over time also helps to portray the importance of the machining field in the past, present, and future.

Once an overview of these topics is complete, the journey into the complex world of machining will have begun.

MACHINING DEFINED

What is *machining*?

Merriam-Webster's Dictionary defines **machining** in this way:

"to process by or as if by machine; especially: to reduce or finish by or as if by turning, shaping, planing, or milling by machine-operated tools."[1]

This definition may not give a very clear picture of machining. It is from the year 1853, and its basic meaning is still correct, but that definition does not tell the whole story of machining.

Beginning with Merriam-Webster's definition is a fine start. First, "to process by machine" means to use a machine to perform a task.

The second part of this definition, "to reduce or finish," means to change size and/or shape by cutting a piece of material. Turning, shaping, planing, and milling are cutting methods. Materials that are machined are usually metals, but other materials, including plastics and graphite, can also be machined.

[1]By permission. From Merriam-Webster's Collegiate® Dictionary, 11th Edition © 2013 by Merriam-Webster, Inc. (http://www.merriam-webster.com/).

Finally, the "machine-operated tools" used to perform the cutting are called **machine tools**.

All of these factors add to a definition of machining that is well suited for the topics discussed throughout this text:

Machining: Using machine tools to cut materials to desired sizes and shapes.

HISTORY OF MACHINING

Humans have used machine tools for centuries, beginning with very primitive forms and advancing to the high levels of technology, precision, and efficiency that exist today. The earliest machine tools were hand powered, and progressed to being powered by animals or water, then steam, and finally electricity.

Simple Machine Tools

The bow drill is the simplest and most likely the first machine tool. The cord of a bow was wrapped around a round cutting tool and, when the bow was moved back and forth, the cutting tool rotated and produced a hole. Similar to the bow drill is another hand-powered machine tool called the pump drill. It was developed around the time of the Roman Empire and was common until the 18th century. In the pump drill, a cord still rotates the round cutting tool, but motion is up and down and more easily creates rotary cutting action to produce holes. **Figure 1.1.1** shows these simple hand-powered tools.

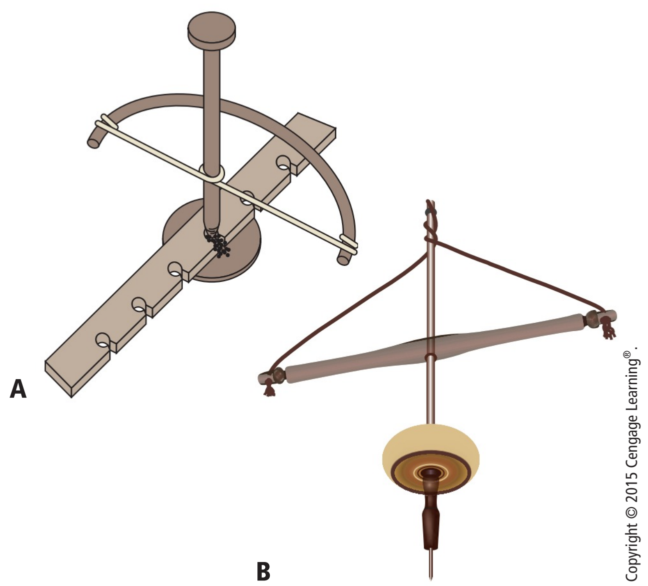


FIGURE 1.1.1 Examples of the earliest hand-powered machine tools. (A) The bow drill; and (B) the pump drill.

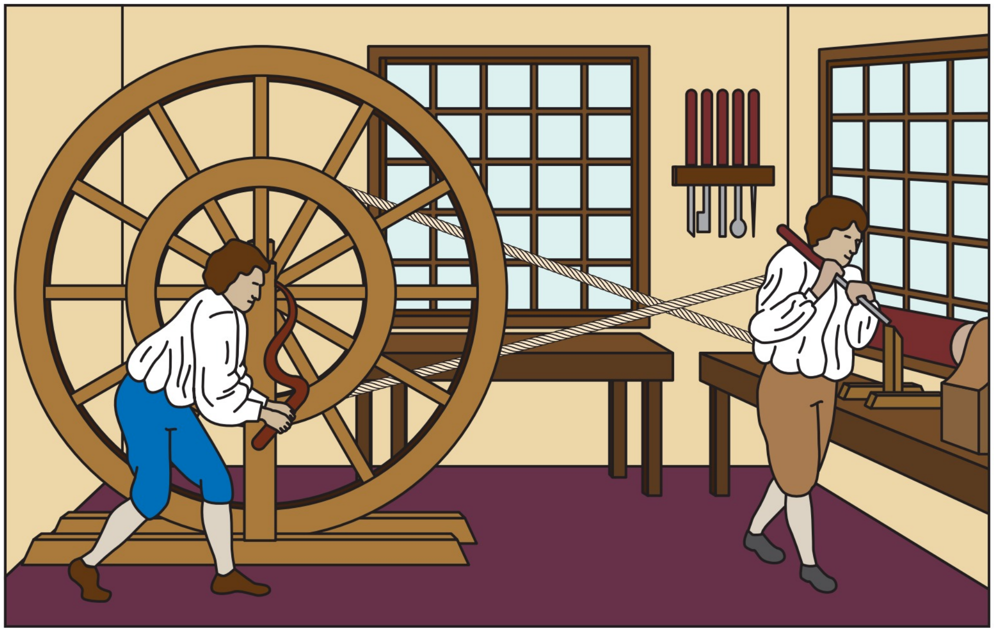


FIGURE 1.1.2 The Great Wheel lathe.

The spring pole lathe was developed in the 13th century to produce cylindrical wooden parts. One end of a rope was connected to the part being cut and the other end to a spring pole, and power was produced by use of a foot pedal. Cutting tools were then held against the rotating part to create cylindrical surfaces. Early settlers in North America used live saplings to build this type of machine tool at their home sites. Later a metal cutting version was developed.

The spring pole lathe had one drawback: its motion was not continuous. In the mid-18th century, John Smeaton developed the Great Wheel lathe that was powered by a drive cord or belt attached to a large wheel. One person spun the wheel to create power, and another performed the machining. **(See Figure 1.1.2.)**

Industrial Revolution

Machine tools began to drastically improve with the beginning of the Industrial Revolution in the late 18th century. More products were being produced from metals, and better machine tools were needed.

In England in 1775, John Wilkinson developed a water wheel–powered boring machine to machine the inside of cannons. **(See Figure 1.1.3.)** Soon the machine began to bore cylinders for Boulton and Watts's steam engines. That began the era of steam-powered machine tools.

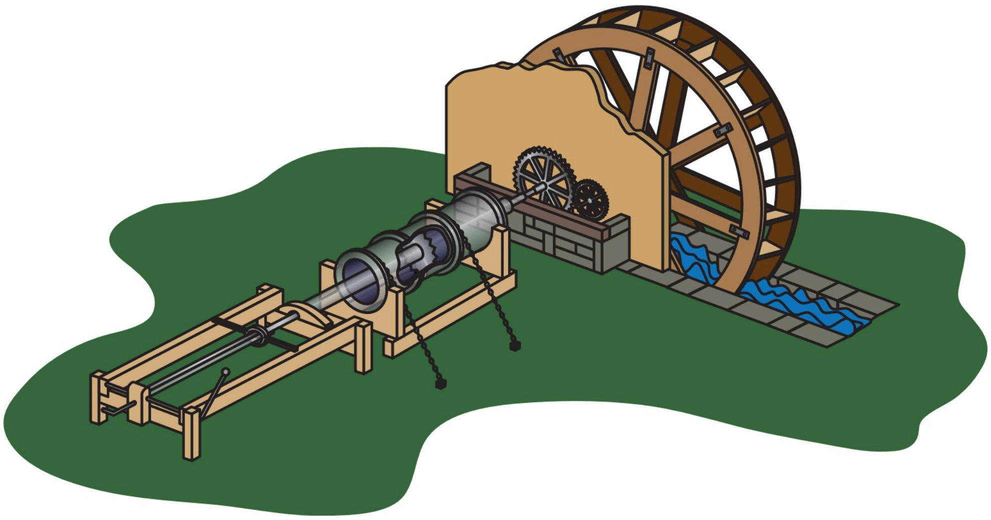


FIGURE 1.1.3 John Wilkinson's boring machine. It was first used to machine cannon bores, then cylinders for steam engines.

In 1797, Henry Maudslay developed a machine that was able to accurately cut screw threads. This revolutionized manufacturing because interchangeable threaded parts could be produced.

In 1818, Eli Whitney produced the first milling machine. This machine tool was able to produce flat surfaces more easily than by hand with filing and scraping tools. Over the next several years, several individuals made improvements on Whitney's machine and different models became available. **Figure 1.1.4** shows an early milling machine from around 1860.

The post drill produced holes by turning a crank by hand. The crank turned gears that rotated the cutting tool and advanced it into the part being drilled. It was commonly used into the early 20th century before electricity became widely available.

Throughout the 18th and 19th centuries, steam-powered machine tools were driven by a series of belts that were connected to a large centralized wheel powered by a steam engine. During the Industrial Revolution, many companies began producing machine tools as metal cutting operations became more common.

20th-Century Machining

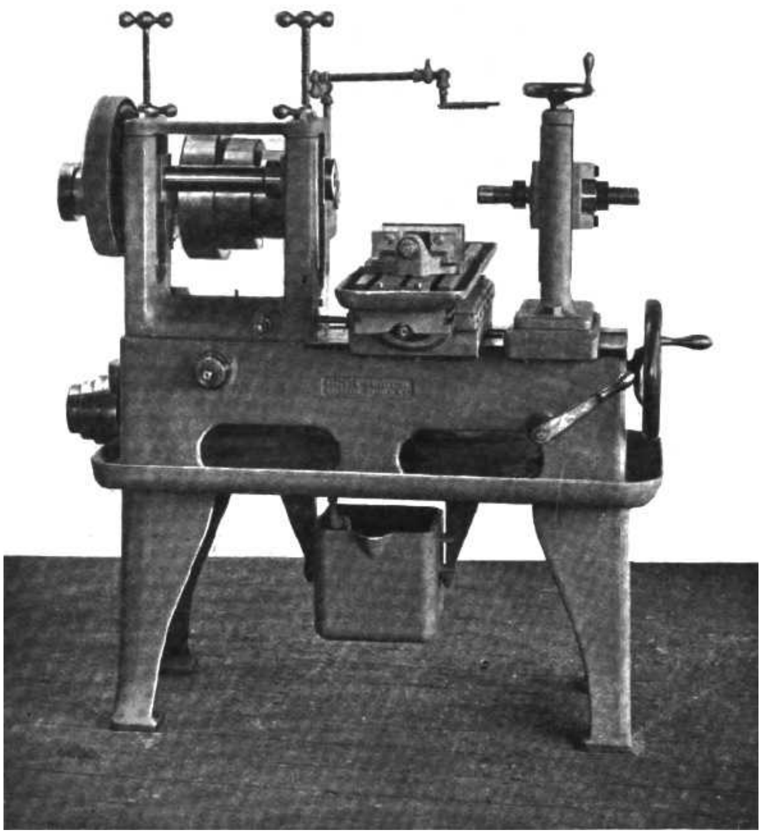
In the early part of the 20th century, electric power began to replace steam power, and machine tools continued to become more complex, more precise, and more efficient. Better machine tools were able to produce more accurate parts, which in turn produced even better machine tools, in a cycle of constant improvement.

In the early 1900s, Henry Ford's creation of the assembly line for mass production of automobiles relied heavily on machining. Parts needed to be machined efficiently to keep up with automobile assembly.

World War I and World War II both created huge growth in the machining industry in the United States as the country produced war-related materials.

Up until the 1940s, machine tool movements were controlled by levers, hand wheels, and geared transmissions. After World War II, great economic growth took place in the United States. Consumerism began, and the machining industry needed to become more efficient to support manufacturing. The invention of **numerical control (NC)** greatly improved machine tool performance. A language of machine code was developed and loaded on a punch card or tape and then fed into the machine tool to automatically guide the motions of the machine and change tools without the need of an operator.

In the 1970s, the NC punch card or tape began to be replaced with **computer numerical control (CNC)**. Instead of machine code being punched on the tape or card, code was entered through an integrated computer on



Horner, Joseph Gregory. Modern Milling Machines, C. Lockwood and Son,© 1906

FIGURE 1.1.4 An early milling machine from around 1860. Horner, Joseph Gregory. Modern milling machines.

Courtesy of Haas Automation, Inc

FIGURE 1.1.5 Today's state-of-the-art CNC machine tools can be programmed to run unattended and machine extremely complex shapes.

the machine tool. Continued advancement in computer technology and machine tool construction has resulted in machine tools that can produce intricate, complex shapes with extreme accuracy and efficiency. When properly configured, they can also perform many operations with many different types of cutting tools while running without the need of an operator. **Figure 1.1.5** shows an ultra-modern CNC machine tool in operation.

THE ROLE OF MACHINING IN SOCIETY

Nearly every person depends either directly or indirectly on machining in some way. Without machining, very few goods and services used every day would exist. How is that possible? Some exploration is needed to find the answer.

People, Manufacturing, and Machining

Many think of manufacturing in terms of big-ticket items like cars and televisions, but everyone uses manufactured items every day. **Manufacturing** simply means to produce something. Paper is a manufactured item. Plastic bags are manufactured items. So are tissues, clothing, and many foods. **End products** are final manufactured items used by consumers. The machining industry produces end products and components that are assembled as end products, and supports manufacturing for the products used by people throughout the world every day.

Machining also normally involves producing sizes and shapes to high levels of precision. Some machining operations can produce sizes with variations of 0.0001 inch or less of the desired size. This one ten-thousandth of an inch (0.0001) is approximately 1/50 of the *thickness* of an ordinary piece of paper. Why do parts need to be produced with such precision? The answer is performance and interchangeability of parts. When mating parts are assembled, high accuracy ensures proper fit and long life. Further, mating parts can be mass produced and interchangeable because they are manufactured to standard sizes, instead of needing to be custom fit to each other.

Some common connections to machining can be made fairly easily, while others require more careful investigation. It is more obvious that machining is connected to manufacturing of durable goods in a wide variety of industries, such as automotive, aerospace, and motorsports, than to the paper, computer, or food industries.

Manufacturing in the U.S.

Recent history has convinced the vast majority of people that manufacturing is a dead industry in the U.S. While it is certainly true that manufacturing has experienced some decline since the last several years of the 20th century, the U.S. is still the leading manufacturing nation of the world. The U.S. manufactures more of the world's end products (19%) with more value ($1.6 trillion in 2009) than any other country, even Japan and China. Further, half of the research and development activities conducted in the U.S. are performed by manufacturing companies, leading the way for technological advancements in many different fields.

Manufacturing also plays a major role in supporting the American workforce. U.S. Bureau of Labor and Statistics 2013 data shows that there are nearly 12 million people directly employed in manufacturing jobs in the U.S. When considering all manufacturing related jobs, that number is estimated at 17.2 million. With a total workforce of approximately 144 million, manufacturing provides employment to almost 9% of all U.S. workers. In the 2nd quarter of 2013, the average American worker in the manufacturing sector earned an hourly wage of $22.29. That equates to over $46,000 annually based on a 40-hour workweek. When benefits are included, the average manufacturing worker's hourly wage was just under $35. That equates to slightly more than $72,000 annually. These figures show

Courtesy of Penske Racing Shocks

FIGURE 1.1.6 Machined shock absorber components and an assembled shock absorber used in motorsports racing.

that manufacturing is alive and well in the U.S., and that the country is still a global leader in manufacturing.

Aerospace, Automotive, and Motorsports

Automotive and aerospace industries rely heavily on machining and machine tools. Consider cars and planes as examples. These highly complex and technologically advanced vehicles contain parts that were produced by machining operations. Engine, drive-train, and suspension components, as well as wheels, gears, and instrumentation, are just a few examples, not to mention the countless variations of nuts, bolts, and washers used for assembly. Machining operations produce all of these parts precisely. The motor-sports industry also uses many of the same types of parts as those used in the automotive and aerospace industries. **(See Figure 1.1.6.)**

Medical Fields

Other high-tech fields that are not easily seen as related to machining still depend on machining and machine tools for their existence. The medical field is one major example. Machine tools produce many medical devices that are used in today's high-tech surgical procedures. Surgical and dental tools, heart catheters; intravenous and hypodermic needles; joint replacement parts for knees, hips, and elbows; replacement discs for the spinal cord; and even artificial hearts are produced by high-tech machining operations. By manufacturing these types of components, machining operations and machine tools play key roles in medical and surgical advancements. **Figure 1.1.7** shows some machined parts used in the medical industry.

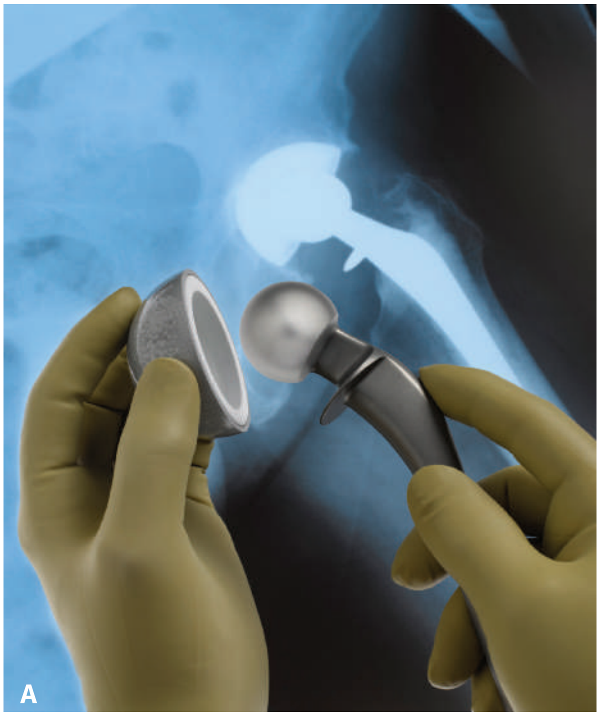


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FIGURE 1.1.7 (A) Machining produces medical products such as this hip implant and (B) surgical tool.