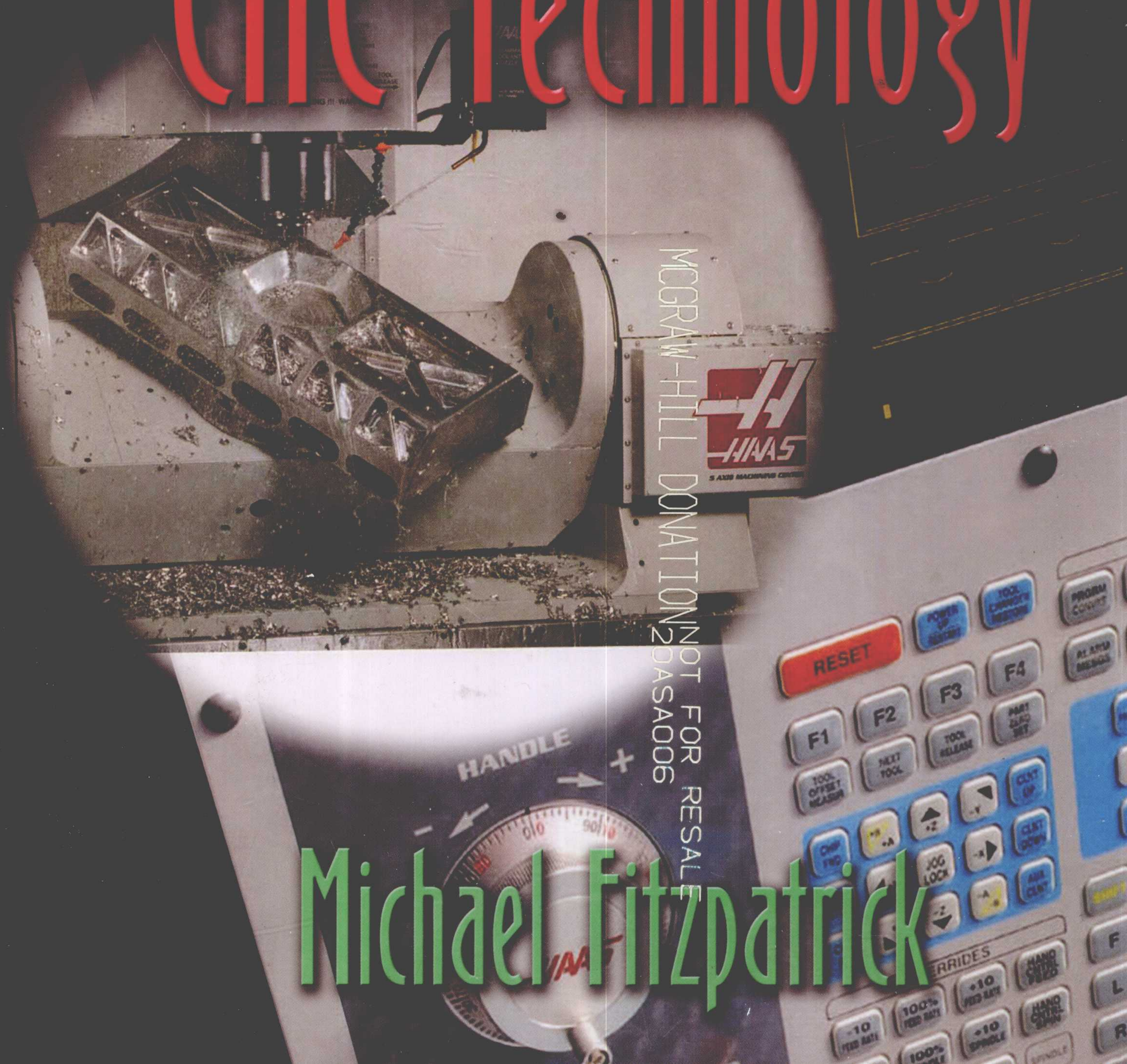
# Machining and CNC Technology

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Michael Fitzpatrick

# Machining and CNC Technology

**Michael Fitzpatrick**

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MACHINING AND CNC TECHNOLOGY

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2 3 4 5 6 7 8 9 0 VNH/VNH 0 9 8 7 6 5

ISBN 0-07-825090-0

Publisher, Career Education: *David T. Culverwell*
Publisher, Trades and Engineering Technology: *Thomas E. Casson*
Managing Developmental Editor: *Jonathan Plant*
Developmental Editor: *Patricia Forrest*
Marketing Manager: *Lynn M. Kalb*
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Cover Photography Courtesy of: *Haas Automation, Oxnard, California*
Senior Photo Research Coordinator: *John C. Leland*
Supplement Producer: *Brenda A. Ernzen*
Compositor: *The GTS Companies/York, PA Campus*
Typeface: *10/12 Stone Serif*
Printer: *Von Hoffmann Corporation*

Cover Dedication:
Haas Automation stands out in their efforts to support and invest in technical education. With several levels of involvement, Haas supports better manufacturing through full and partial partnerships with progressiveschools. Through their generosity they make it possible to upgrade machining technologies here in North America and worldwide. My fellow instructors and I salute Haas Automation and Scott Rathburn—Marketing Manager and Editor of their own publications, "CNC Machining."

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**Library of Congress Cataloging-in-Publication Data**

Fitzpatrick, Michael, 1945–
Machining and CNC technology / Michael Fitzpatrick. — 1st ed.
p. cm.
Includes index.
ISBN 0-07-825090-0 (alk. paper)
1. Machining—Handbooks, manuals, etc. 2. Machine-tools—Numerical control—Handbooks, manuals, etc. I. Title: Machining and computer numerical control technology. II. Title.

TJ1165.F54 2005
671.3'5—dc21

2001040125
CIP

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*While there were countless others along the way, these four made all the difference in my career and life. Without them I question whether this book would have been.*

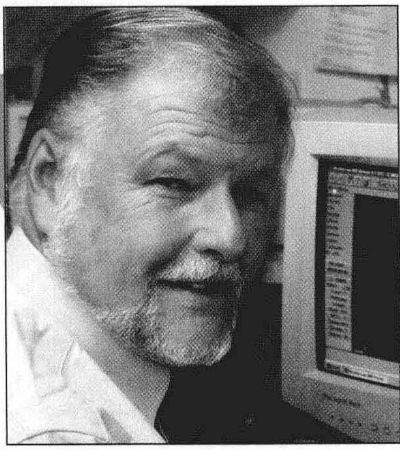
**To Linda, my wife**
*for never complaining about the time taken from us to do this, for believing, giving, and forgiving.*

**To Jan Carlson**
*for demonstrating with acts, what a caring professional should be, and especially for the encouraging space to grow.*

**To Bill Simmons**
*for trusting me with more than just your tool box, for your gentle guidance. We all miss you, Uncle Bill.*

**To Bill Coberley**
*for marketing me in the beginning and for being a life-long friend.*

# About the Author



As if it was yesterday, I remember carrying my new toolbox down the isle at Kenworth Trucks of Seattle. Scotty, the crusty drill press operator, stepped away from his machine and planted himself right in front of me. Without a welcome, he raised his bushy eyebrows, poked two fingers into my chest, and said "You see all these men here?" He waited. At eighteen, I recall only nodding, unable to speak. He went on, "Each one of us will show you everything we know if you pay attention. We'll give you lifetimes of experience, but know this, lad, it comes with an obligation. Someday you'll pass it on."

Hello, I'm Mike Fitzpatrick, your machining instructor in print. Since you've honored me by studying my book, I thought it might be a confidence builder to tell a little about why I'm qualified to pay forward to you what Scotty and countless other fine craftsmen taught me.

I began that apprenticeship on the first Monday after high school graduation, in 1964. A year or so later, I was given the life-altering opportunity to be their first employee to run the first Numerical Control machine brought to the Seattle area, other than the ones at the Boeing Aircraft Company. Nothing like the computerized machines you're about to learn, that NC machine was a turret head drill press, run by paper tapes. Not far from a music box in its technology, it was primitive compared to the machines in your training lab. Still, it was enough to hook me for life. So, with a year of applications and interviews, I transferred to Boeing where I completed my machining certificate. There I learned to run programmed machines that had basements, and ladders to get up to the cutter head!

Passing the tough final with a 100% score, I qualified to take the even tougher test to become a tool and die apprentice. I made it and finished my training in 1971. That totaled 12,000 hours of rigorous on-the-job training under a whole army of skilled people. It also came with many hours of technical classes. Since then I've either been a machinist/tool maker or taught others for my entire adult life. For the last 25 years I've taught manufacturing in technical schools, private industry, a high-school skills center, a junior high school, and in two foreign countries.

Today I can stand in front of anyone and say with pride, "I'm a journeyman tool and die maker and a master of my trade." Nearing the end of my journey, Scotty's imprint calls me to pass it forward. But don't forget, what we instructors and machinists give you comes with the same obligation.

One trait we clearly see you'll need far more than we did is adaptability. Beyond imparting skills and competencies, this book has a mission: to start its readers down the long, ever-accelerating technology path. Clearly, the machinist of the future is one who can see and adapt to a changing future. When you do pass the baton forward, the trade won't be anything like that found in this book. But I'm confident it will be passed, because machinists have a long history of adaptation.



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# Preface

Proudly we look back to see we've been right at the cutting edge of the computer revolution. We began using programmed machine tools over fifty years ago. That predates designers using computer-aided drawing or scientists doing research on giant mainframes. Although the lines I've drawn below to define eras are fuzzy, programmed machine tool evolution can be divided into three generations, based on the way they were used in industry and how they were taught in the tech schools:

## First Generation: 1940 to 1965

They began as lab experiments, then for twenty-five years slowly appeared in progressive shops. Like my tape drill at Kenworth, at first, only a few appeared within a manufacturing region. But nearing this era's end, about half of the big shops had one or more tape-driven machines. However, during this entire era, *NC was always considered a specialty*. Most machining was still completed on manually operated or automatic equipment. Programming was a labor-intense, time-consuming task. Purchasing an NC machine (tape driven with no computer) could only be justified if the shop made thousands of similar parts or if the work they wanted to produce was impossible by any other means. Since numerical control skills were a specialty, they were taught in few schools, and only *near the end of the era. NC jobs were never given to beginners.*

## Second Generation: 1965 to 1990

This era might be called the big-bang. It begins with an estimated 20/80 ratio of programmed equipment compared to manually operated, but it ends somewhere around 90/10! During the middle, PCs become affordable, and software springs forth that anyone can use. Programming becomes a desktop task. With processor chips speeding up, programmed machines becoming evermore affordable and capable, work is designed specifically for CNC manufacturing. Nearing the end of this era, *all mainstream manufacturing is done on programmed machine tools. Schools teach the subject as an advanced study* near the end of the machining course.

## Third Generation: 1990 to the Present

Programmed machine tools now represent nearly 100% of manufacturing and of greater impact to you, of new jobs. *Entry level people usually start in the shop as CNC operators*. Flexible and friendly, the machines and programming systems are so quick and easy to learn that they are now practical even for one-of-a-kind work such as mold making and die work, as well as production. *Schools integrate and teach CNC as an entry level subject—starting from the first lesson on the first day.*

This book was specifically written to serve the third generation student. To do so, subjects have been grouped into four large career partitions:

### Part 1 Introduction to Manufacturing

Manufacturing is a world of its own. Sections 1 through 8 are designed to open the door. It provides the background needed to fit into the shop, understand the rules, read and interpret the drawings, to be comfortable with extreme accuracy, and especially, to be safe.

### Part 2 Introduction to Machining

Sections, 9 though 16 teach how to cut metal the right way. These lessons assume you'll eventually perform them on CNC equipment, but probably practice first on manually operated machines because they are simple, safe places to learn setups and operations.

### Part 3 Introduction to CNC

Now we get to the text core, how to apply Parts 1 and 2 to setting up, programming, and running CNC machine tools. In Sections 17 through 24 we will learn how to professionally manage a CNC world. Because they move at lightning speeds with lots of power behind them, safety must be integrated into everything we study.

### Part 4 Advanced and Advancing Technology

The evolution isn't over—not even close! These four sections, 25 though 28, set the tone for your career after graduating. The best is yet to come so let's get started!

So, many thanks for using my book to start your manufacturing career. It's an honor to be your instructor. Here's what I can pass on about our trade.

*Mike Fitzpatrick*

# Acknowledgements

My deepest gratitude goes to these major contributors, without whom this book would not have come to be.

**Bates Technical College** *(Tacoma, Washington) Bob Storrar, Lead Instructor*
A complete program of machine instruction focused on the student's future. Bob brought his skill and knowledge as a graduate tool and die maker with 16 years industry experience and 15 years teaching at the college level to this book. Thank you for believing in this project, for your conscientious editing and encouragement, and especially for the fellowship.

**Lake Washington Technical College** *(Kirkland, Washington) Mike Clifton, Head Instructor*
A growing program of machine instruction dedicated both to career professionals and those interested in upgrading their skills. Thanks Mike, for contributing 25 years experience in advanced research and manufacturing, plus apprenticeship training, and for taking great interest in the photo manuscript.

**CNC Software, Inc. Mastercam**—*Mark Summers, President; Dan Newby, Training Director*
Thank you Mark, for believing in education and Dan, for your editing and guidance; and many thanks to your entire team for improving our trade and supporting education worldwide.

**Auburn Comprehensive High School** *(Auburn, Washington) Ron Cughan, Metal Trades Instructor*
A quality metal manufacturing program at the high school level, serving the Auburn Valley. Thanks for taking the extra time to edit this book so well, for believing in it, and being a friend!

**Milwaukee Area Technical College** *(Milwaukee, Wisconsin) Patrick Yunke & Dale Howser, lead instructors.*
Offering a nationally recognized, 2-year, tool-and-die-making diploma. MATC graduates learn die and mold making and qualify for Wisconsin's apprenticeship certificate. Thus they often serve full apprenticeships in the highly paid tooling area of manufacturing.

*Dale Howser Sr.:* 28 years journeyman tool-making experience with 15 years teaching these subjects. Dale holds degrees in tool and die making from Milwaukee Area Technical College and Voc. Ed. from Stout University. He also develops and works on educational materials for the Precision Metalforming Association and Wisconsin's Apprenticeship programs.

*Patrick Yunke:* A graduate of Wisconsin's Madison Area Technical College die making program and Stout University for Vocational Education, Patrick brings many years experience in all aspects of precision die and metal and plastic mold-making to MATC, where he has taught for 15 years. He has also been a consultant to industry for manufacturing and custom educational programs.

Many thanks to you both, for your expertise and for supplying great photos from your beautifully organized shop.

**NTMA—National Tooling and Machining Association**—*Dick Walker, President*
Many thanks for being at the root of this new book in the beginning, for investing

time and energy in it, and for the 45 drawings donated from your training materials.

**NTMA Training Centers, California—** *Max Hughes, Dean of Instruction*
Thanks Max, for the assistance with the CNC portion of this book.

**Mr. Keith Ellis—***Northwest Metalworker* Magazine
Thanks for the wonderful cartoons to emphasize safety

**Haas Automation, Inc.** *(Oxnard, California) Scott Rathburn, Marketing Manager, Sr. Editor CNC Machining*
Thanks, Scott, for your commitment to machine tool education. (See cover dedication—copyright page), and for contributing support, time, energy, and many photos to this book.

**Boeing Commercial Airplane Co.—** *Tim Wilson, Apprentice Instructor*
Thank you, Boeing Apprenticeship, for giving me the best education possible when I began my career, and Tim for your ongoing support of quality apprenticeship, for help in planning and executing this book, and for being a lifelong friend!

**Brian Mackin—McGraw-Hill Publishing**
You were the one that saw a paradigm shift in manufacturing and that a new book had to be written. For that vision, I thank you. I'm not sure this would have happened without your guidance and support.

**The Entire Career Education and Technical Team at the Higher Education Division—McGraw-Hill Publishing**
*Kay Brimeyer, Pat Forrest, Roxan Kinsey, Tom Casson, John Leland, Rick Noel, David Culverwell, Jill Peter, Michael Whitaker, and the entire Dubuque McGraw-Hill Group*
No kidding, until I crossed paths with you all, I had decided this was my last book—but I've changed my mind! This has been a totally positive experience, even through the 'hard spots.' Thanks folks. You are more than a group; you are a team composed of very likable, positive, and refreshingly real people. I hope to be working with you again.

**Pat Steele—Manuscript Copyeditor**
What often is the worst phase in book-writing became a wonderful experience. With trust in your editing, we developed one voice, then wrote this book together and became friends. Thanks Pat.

**Northwest Technical Products, Inc.—** *Vic Gallienne, President*
Serving the needs of the scientific, career, and technical educational community of the Pacific Northwest; thank you, Vic, for getting this project on the right track with Mastercam.

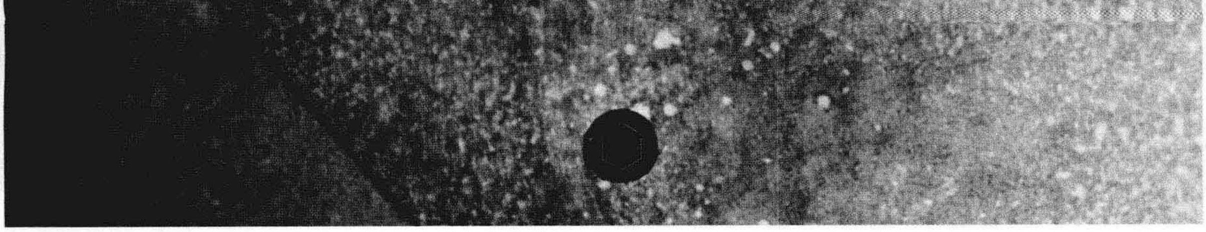
**Brown and Sharpe Corp.** *(Rhode Island) Metrology equipment*
For their commitment to education in metrology in technical schools and colleges.

**Kennametal Inc.—***Kennametal University, dedicated to finding better methods and to educate anywhere machining is taught or applied.*
Thanks for the data, advanced tooling photos, text, and charts.

**Iscar Metals—***Bill Christensen, Advanced tooling photos and text*
Advancing knowledge through research and education; thank you, Bill, for the HSM article.

**Coastal Manufacturing—***Joel Bisset, Quality Assurance Manager*
Thank you, Joel, for editing the SPC articles, and for your lifelong commitment to quality in North American manufacturing.

**Northwood Designs—MetaCut Utilities—***Bill Elliot, President/CEO, and Paul Elliot, Senior Software Engineer. Developing utility software for world manufacturing.*
Thank you for all your support and encouragement and for allowing us to



use your wonderful toolpath verification programs in this book and within Mastercam.

**Sandvik Coromat—**
Thank you for photos from *Modern Metal Cutting.*

**SME—Society of Manufacturing Engineers—**Westech Machine Tool and Productivity Exposition

**Optomec—***Text and photos of LENS® process.*
Thanks for showing us a great new technology.

In addition, I want to thank the following reviewers of the final version of the manuscript:

Richard Granlund, *Hennepin Technical College*

Thomas E. Clark, *National Institute of Technology*

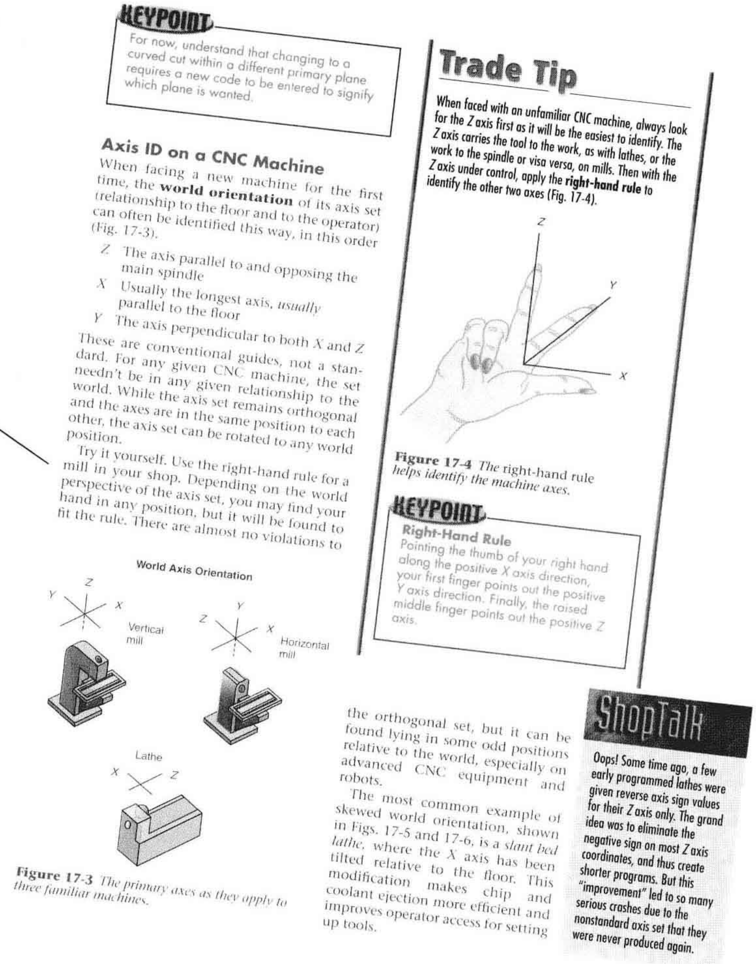
Martin Berger, *Blue Ridge Community College*

# Totally Integrates Manual and CNC Instruction!

***Machining and CNC Technology,*** provides **the most up-to-date approach** to Machine Tool technology available, with totally integrated coverage of manual and Computer Numerical Control-based equipment.

***Motivational chapter features,*** such as *Key Points, Trade Tips,* and *Shop Talk* are included to show students the practical side of the subject.

- Key Point
- Trade Tip
- Shop Talk
- Critical Thinking



**KEYPOINT**

For now, understand that changing to a curved cut within a different primary plane requires a new code to be entered to signify which plane is wanted.

**Axis ID on a CNC Machine**

When facing a new machine for the first time, the **world orientation** of its axis set (relationship to the floor and to the operator) can often be identified this way, in this order (Fig. 17-3).

*Z* The axis parallel to and opposing the main spindle

*X* Usually the longest axis, *usually* parallel to the floor

*Y* The axis perpendicular to both *X* and *Z*

These are conventional guides, not a standard. For any given CNC machine, the set needn't be in any given relationship to the world. While the axis set remains orthogonal and the axes are in the same position to each other, the axis set can be rotated to any world position.

Try it yourself. Use the right-hand rule for a mill in your shop. Depending on the world perspective of the axis set, you may find your hand in any position, but it will be found to fit the rule. There are almost no violations to the orthogonal set, but it can be found lying in some odd positions relative to the world, especially on advanced CNC equipment and robots.

The most common example of skewed world orientation, shown in Figs. 17-5 and 17-6, is a *slant bed lathe,* where the *X* axis has been tilted relative to the floor. This modification makes chip and coolant ejection more efficient and improves operator access for setting up tools.

World Axis Orientation

Vertical mill

Horizontal mill

Lathe

**Figure 17-3** *The primary axes as they apply to three familiar machines.*

**Trade Tip**

When faced with an unfamiliar CNC machine, always look for the *Z* axis first as it will be the easiest to identify. The *Z* axis carries the tool to the work, as with lathes, or the work to the spindle or visa verso, on mills. Then with the *Z* axis under control, apply the **right-hand rule** to identify the other two axes (Fig. 17-4).

**Figure 17-4** *The right-hand rule helps identify the machine axes.*

**KEYPOINT**

**Right-Hand Rule**

Pointing the thumb of your right hand along the positive *X* axis direction, your first finger points out the positive *Y* axis direction. Finally, the raised middle finger points out the positive *Z* axis.

**ShopTalk**

Oops! Some time ago, a few early programmed lathes were given reverse axis sign values for their *Z* axis only. The grand idea was to eliminate the negative sign on most *Z* axis coordinates, and thus create shorter programs. But this "improvement" led to so many serious crashes due to the nonstandard axis set that they were never produced again.

***Visual Focus*** photos and line art make concepts easier for students to understand and apply the information presented.

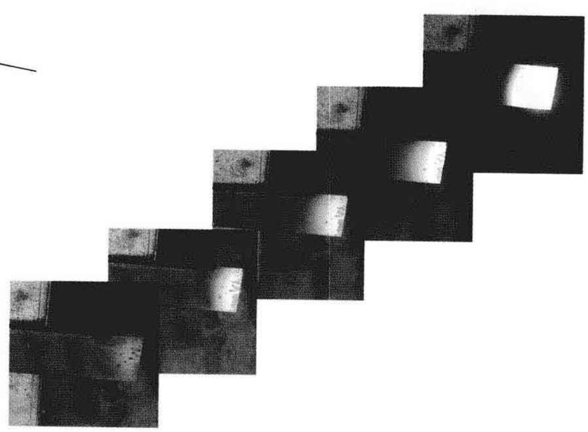


**Figure 15-15** *Learn to identify temperature by glow.*



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# Integrated Coverage of CNC Technology


UNIT 28-1

## What Does a CMM Do? How Does It Work?

**Introduction:** Without experience, most assume any computer measuring equipment does what the manual instruments and processes do, but they do it faster and more accurately. Yes, that's true in many cases (but not all), but it's only a part of the reason they improve quality and profitability. In Section 28, we're focusing on computer-coordinate machines; however, similar arguments could be presented for other computer-directed measuring equipment as well.

KEYPOINT
CMMs verify geometric requirements in ways no other process can. Proof coming up.

KEY TERMS

**Conformal axis system**
Axes are assigned to the work independent of machine axes also called a floating axis set.

**Digitizing**
Programming by hand probe motion—see teach-learn.

**Hit (CMM)**
Shop lingo for one recorded touch of a data collecting probe.

**Nontactile measurement**
Using optical methods to measure surface elements.

**Scanning CMMs**
Two types both of which collect entire surface element data. The tactile type maintains its probe in constant contact with a surface. The nontactile type collects entire surface element without touching.

**Shop hardened**
An instrument built to withstand the temperature swings and dirt of a shop environment.

**Tactile measurement**
Measuring by touching the object with a probe.

**Teach-learn (read-learn)**
Programming by recording hand probe movements and menu picks.

### Computer Inspection Advantages

#### Cures Choke Points

High-speed mills and lathes often machine parts faster than they can be measured with mics, electronic height gages, and indicators. Without a CMM, there are three options.

In the least desirable, the operator must measure the sample while the machine cranks out more questionable parts! Or, the halt button must be used until the sample part is proven right. Either way, time is lost.

The third choke point solution is to load the cutting tool drum with a touch trigger probe (information coming) and then write inspection routines into the machining program itself (Fig. 28-1). In previous sections, we've seen probes testing cutting tools to autoload offsets. But, not all feature inspection lends itself to *in-process inspection*, nor can all CNC machines perform it. There are many times when the part must still go to the stand-alone CMM.

**Figure 28-1** *In-process inspection helps check key features as they are made and keeps real-time SPC up to date.*

***New focus with fully integrated coverage of computer-related technologies*** in manufacturing, including the latest developments in CNC and CAD/CAM.

***Coverage of 21st century topics*** such as Statistical Process Control (SPC), Computer Coordinate Measuring Machines (CCMM), and the latest in cutting tool technologies.


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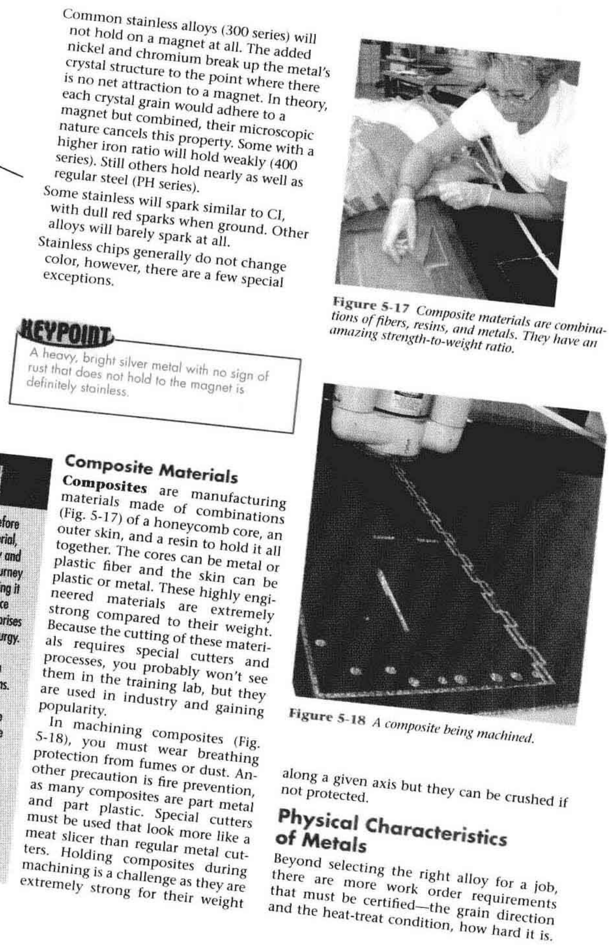
# Complete Education System

## Hands-On Training:



Common stainless alloys (300 series) will not hold on a magnet at all. The added nickel and chromium break up the metal's crystal structure to the point where there is no net attraction to a magnet. In theory, each crystal grain would adhere to a magnet but combined, their microscopic nature cancels this property. Some with a higher iron ratio will hold weakly (400 series). Still others hold nearly as well as regular steel (PH series).

Some stainless will spark similar to CI, with dull red sparks when ground. Other alloys will barely spark at all.

Stainless chips generally do not change color, however, there are a few special exceptions.

Figure 5-17 *Composite materials are combinations of fibers, resins, and metals. They have an amazing strength-to-weight ratio.*

**KEYPOINT**

A heavy, bright silver metal with no sign of rust that does not hold to the magnet is definitely stainless.

**ShopTalk**

**Look it Up or Ask** Before machining any new material, find out the machinability and hardness either from a journey level machinist or by looking it up in a machinist's reference book. There are lots of surprises within the subject of metallurgy. For example, there are two metals that actually catch on fire, given the right conditions. They are magnesium and titanium. Solid blocks of these metals are impossible to ignite but when their chips are surrounded with room oxygen and heated as during machining, they will burn! When machined some metals create carcinogenic particles that must not be breathed or exposed to bare skin!

**Composite Materials**

**Composites** are manufacturing materials made of combinations (Fig. 5-17) of a honeycomb core, an outer skin, and a resin to hold it all together. The cores can be metal or plastic fiber and the skin can be plastic or metal. These highly engineered materials are extremely strong compared to their weight. Because the cutting of these materials requires special cutters and processes, you probably won't see them in the training lab, but they are used in industry and gaining popularity.

In machining composites (Fig. 5-18), you must wear breathing protection from fumes or dust. Another precaution is fire prevention, as many composites are part metal and part plastic. Special cutters must be used that look more like a meat slicer than regular metal cutters. Holding composites during machining is a challenge as they are extremely strong for their weight along a given axis but they can be crushed if not protected.

Figure 5-18 *A composite being machined.*

**Physical Characteristics of Metals**

Beyond selecting the right alloy for a job, there are more work order requirements that must be certified—the grain direction and the heat-treat condition, how hard it is.

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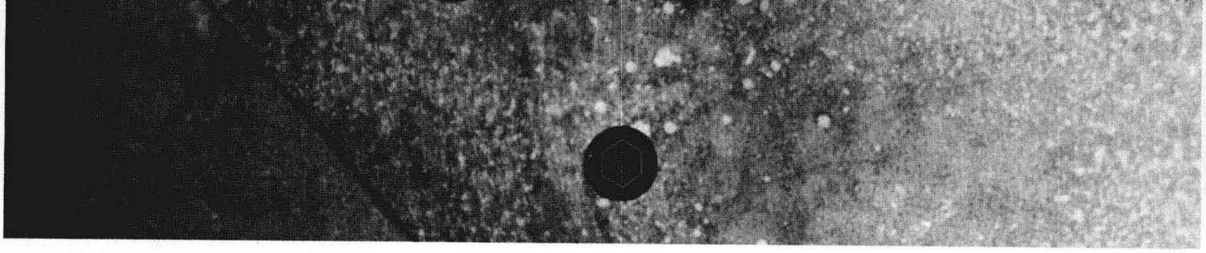
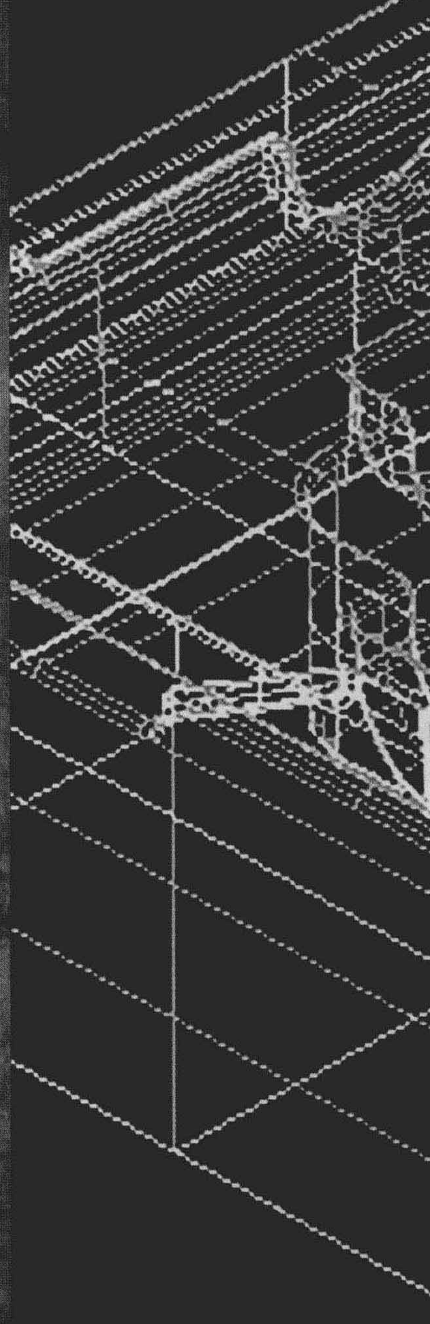


# Machining and CNC Technology

# PART 1

# Introduction to Manufacturing

This entire book is about getting a job in a machine shop. But more important, it's about keeping that job and advancing career responsibility and pay. To do so successfully, you need to know what is expected of you from the very first day. Like any workplace, there are tasks, procedures, and rules to be followed. Some are based on formal skills or rules, while some are informal and generally accepted by your fellow workers.





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