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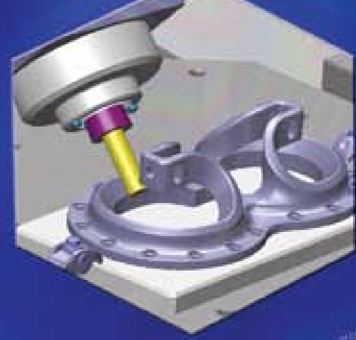

Secrets of 5-Axis Machining

Karlo Apro

Full-Color Illustrations Throughout

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by Karlo Apro

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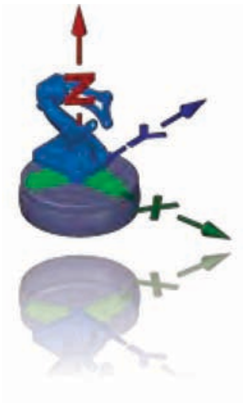
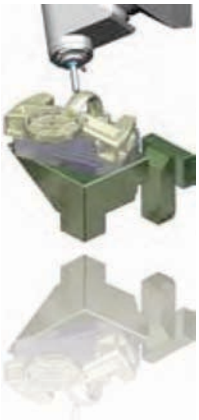




Introduction

Are you utilizing 5-axis machining? Could your shop benefit from the efficiency and power that 5-axis machining offers? The majority of people not embracing this technology lack a true understanding of 5-axis practices. There are many common misconceptions on the subject, and the intent of this book is to demystify 5-axis machining and bring it within the reach of anyone interested in using the technology to its full potential. The information presented in this book was gathered during 30 years of hands-on experience in the metal-working manufacturing industry — bridging countries, continents, and multiple languages (both human and G-code.) The author worked in Hungary, Germany, Canada, and the USA, specializing in multiaxis solutions. He spent many years setting up, programming, and repairing CNC equipment, and has used a number of different CAD/CAM systems. He has worked as a self-employed multiaxis consultant, as well as directly for CGTech (the makers of VERICUT®) and CNC Software Inc. (the makers of Mastercam®.)

The author has instructed countless multiaxis training classes over the past decade. These classes covered topics such as operating CNC equipment, programming CNC equipment, both manually and with CAD/CAM systems, and building virtual machines with different verification systems. Through the years, the author has met many professionals around the world and has come to a realization that they all have the same questions, misconceptions, and concerns, when it comes to 5-axis machining. The need for unbiased information on the subject became apparent.

Up to this point, the best way to get information on 5-axis machining was to talk to peers in the industry, in the hope that they would share what they had learned. Visiting industrial trade shows and talking to machine tool and CAD/CAM vendors are other options — except that these people all give their individual points of view and will promote their own machine or solution. Everybody claims to have the best mouse-trap, and it is left to the individual to choose the right one.

This book is not a training manual for any particular machine or CAD/CAM system. Rather, it is an overview of multiaxis machine types and the common control methods that CAD/CAM systems use to drive the machines. The book will guide you through this realm, from basic to complex concepts, and will provide information to help you choose the right tools, including the machine, work-holding method, CAD/CAM system, and machine simulation package that will best suit your specific application. The book contains numerous illustrations to help you to precisely implement these tools.

2

Know Your Machine

What do you picture when you see the words "standard 5-axis machine?" Many industry buzzwords are used when describing 5-axis machines. Some of them include: staggered guide-ways, constant dynamic control, digital AC servo motors with pre-tensioned ball-screws, permanent positioning monitoring system, maximum utilization layout, long-term accuracy, and so on. To simplify things, we will say that there are three major building blocks to these types of machines.

1 **The physical properties of the machine**
The physical properties of the machine describe the way the axes are stacked, the rigidity and flexibility of the iron, the horsepower, torque, and maximum RPM of the spindle motor, the quality and workmanship of the guides/slides, and the rotary bearings.

2 **The CNC drive system**
The drive system is the muscles or the components that make the machine slides and spindles move. The system includes the servo motors, drive system, ball screws, the way positioning is controlled and monitored, and the rapid-traverse and feed capabilities.

3 **CNC controller capabilities**
The controller is the brain of the machine. Data handling, available on-board memory size, and dynamic rotary synchronization controls, are some of the things controlled here.

The perfect combination of the above characteristics will build a fast, accurate, easy-to-program and operate, 5-axis CNC milling machine. Many manufacturers have spent many years trying to come up with the perfect combination, and as a result there are many variations and solutions.

The illustrations in Figure 2-1 show some of the variety that exists in the machines that make up the CNC manufacturing industry.

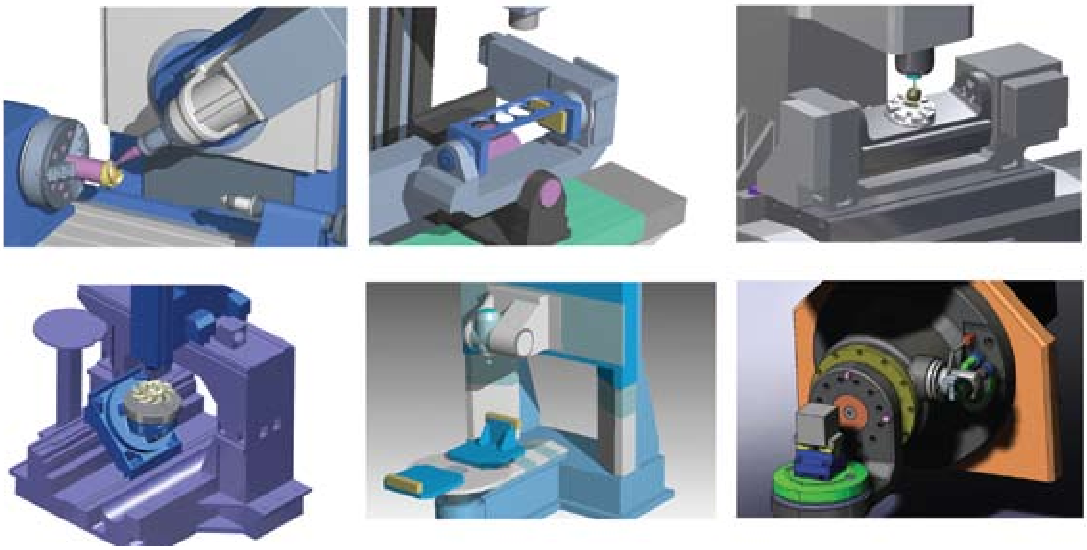


Figure 2-1 *Typical arrangements of multiaxis CNC machines.*

Multiaxis Machine Configurations

The arrangements shown in Figure 2-1 are all very popular configurations, but none of them is "standard." There is no such thing as a standard 5-axis machine. First, let's establish the definition of an axis. Any motion controlled by the NC controller, either linear or rotational is considered an axis. For instance, in the illustration in Figure 2-2, both the spindle head and the quill are capable of moving in the same direction, but are controlled by two separate commands. Movements of the head are controlled by Z and those of the quill by W.

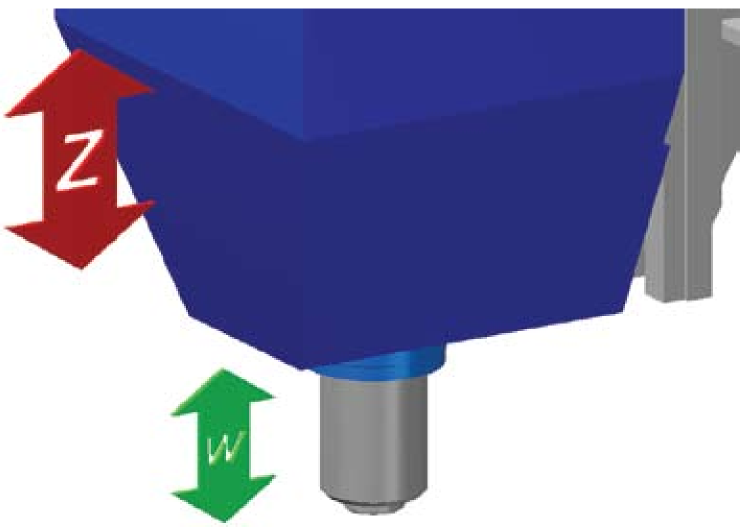
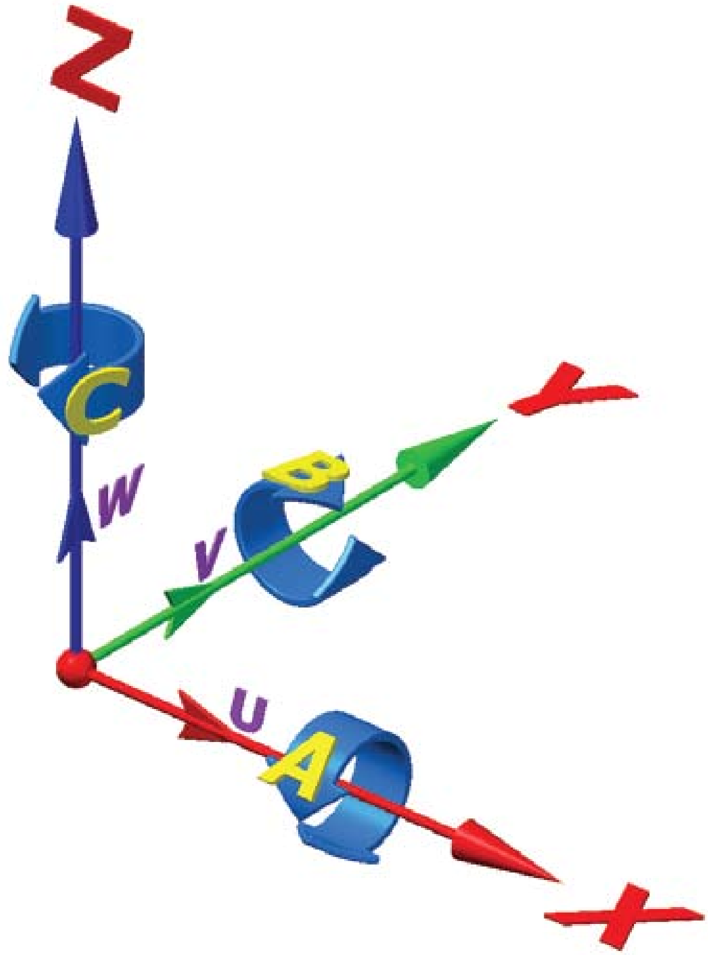


Figure 2-2 *The spindle head and the spindle quill move along parallel axes.*

The terms multiaxis and 5-axis are often used interchangeably and these terms can be confusing. The widely recognized term in the industry is 5-axis, but it is misleading because 9-axis standard possibilities exist – without adding additional sub-systems. In addition, a 4-axis machine is also considered to be a multiaxis machine. Despite the title of this book, the more accurate term multiaxis will often be used.

The following list provides the industry standard nomenclature for the basic 9-axis designations and directions.



XYZ are linear axes where Z is aligned with the spindle of the machine.

ABC are rotary axes rotating around **XYZ** respectively.

UVW are parallel linear axes along **XYZ** respectively.

3

Cutting Strategies

If drawings of the same multiaxis part were given to five different CNC programmers, chances are good that they would come up with five different methods to machine the part. This variability is a product of experience, available multiaxis equipment, available CAD/CAM systems, tooling, fixturing, material, and quantities.

What does every CNC programmer do when asked to write a program for a new part? He or she will create a mental image of the part, and based on the above factors, go through a variety of different scenarios to determine how to machine it. These decisions will include how to hold the part, and which side to start on. The programmer will then mentally go through the whole process of removing all the excess material from the starting stock in order to free the desired part from within it. Most programmers will brainstorm repeatedly and come up with multiple solutions, eliminating the weakest ones, adding new ideas, and then making the final decision. This whole process happens long before the creation of the actual toolpath. This pre-work meditation is the single most important part of the whole manufacturing process.

The process described above is the same, whether 3-axis or multiaxis work is being considered. The big difference is usually with the fixturing. Work holding is among the first decisions to be made when programming a 3-axis machine. Many multiaxis programmers will place the part data on a virtual machine. This process lets them levitate the part in the air and simulate the machine’s motions, without a fixture present, to see if all motions are possible without violating the machine’s work envelope boundaries. The part will be moved in space to achieve optimized, synchronized motions. Final fixture placement, or design, might be one of the last steps.

Of course this procedure is not always possible, but when a fixture is predetermined, additional effort will be needed to make sure there are no collisions between the fixture, tool, shank, arbor, or tool holder. Avoiding collisions is a big part of multiaxis programming. Collisions can occur not only during cutting, but also during tool changes, pallet changes, or manual retraction moves after an abrupt program stop. For example, after a power failure, the tool could be in a position where the only safe retraction move is simultaneous multiaxis motions.

5

Simultaneous Multiaxis Toolpaths

Many people think that simultaneous multiaxis is the true form of 5-axis machining, when in fact, it is not necessary for all the machine axes to move at the same time for the machine to be considered 5-axis. Even a simultaneous 2-axis, rotary cutting motion may be considered to be a multiaxis toolpath.

Simultaneous multiaxis machining is also known as **Continuous** 5-axis or **True** 5-axis machining.

The illustration in Figure 5-1 shows a 2-axis machine cutting a pattern onto a bowling ball. This machine only has a tilting B and a rotating C-axis. There is no Z axis. Instead, that motion is controlled by a software M code, which has an ON and OFF state — either lowering the tool onto the part, or lifting it to its reference position.

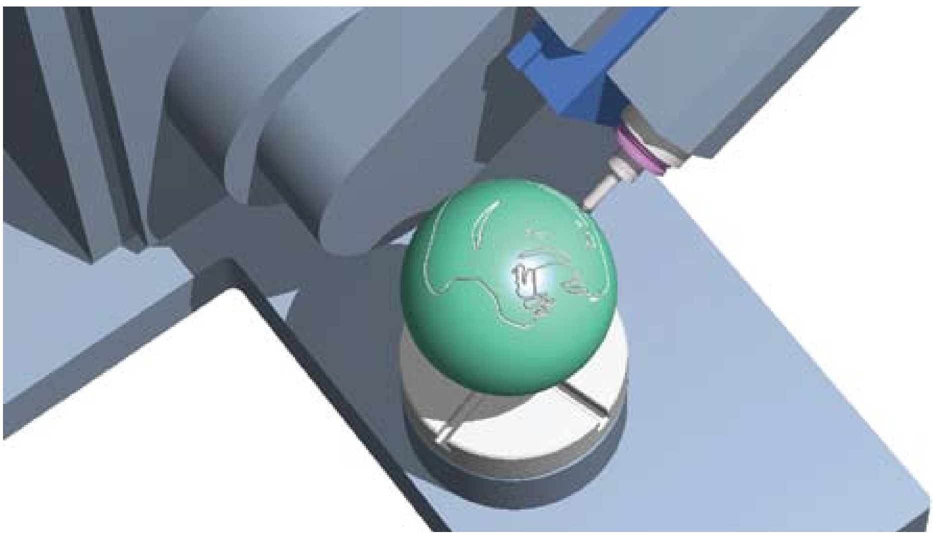


Figure 5-1 *Set-up on a 2-axis machine for engraving a bowling ball.*

The example in Figure 5-2 also shows a simple multiaxis motion — so simple that it can be programmed by hand. The program contains the following codes:

```
G01 Z2.0000 F90.

X-5.5 A2880.000 F50.

G00 Z5.
```

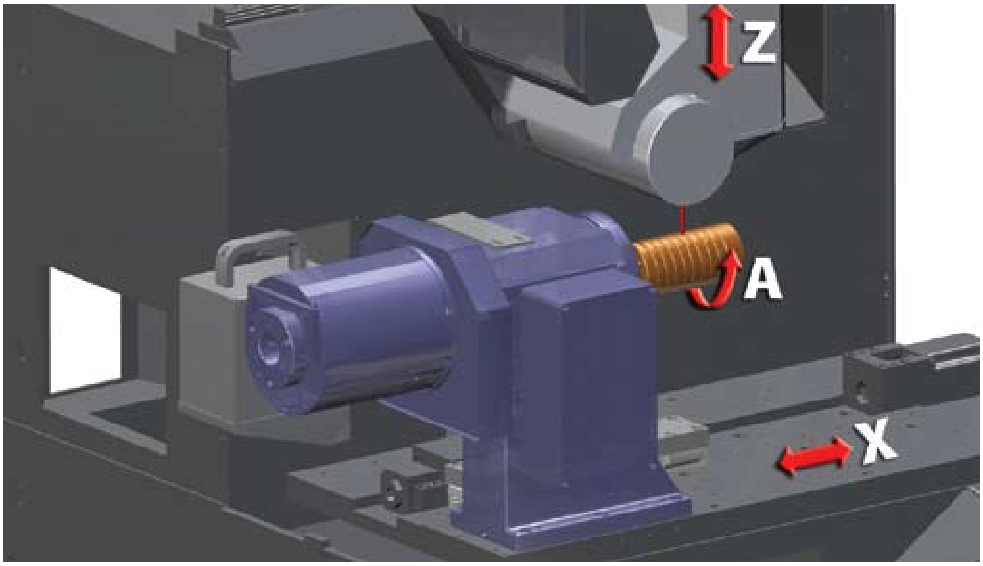


Figure 5-2 *A simple multiaxis set-up.*

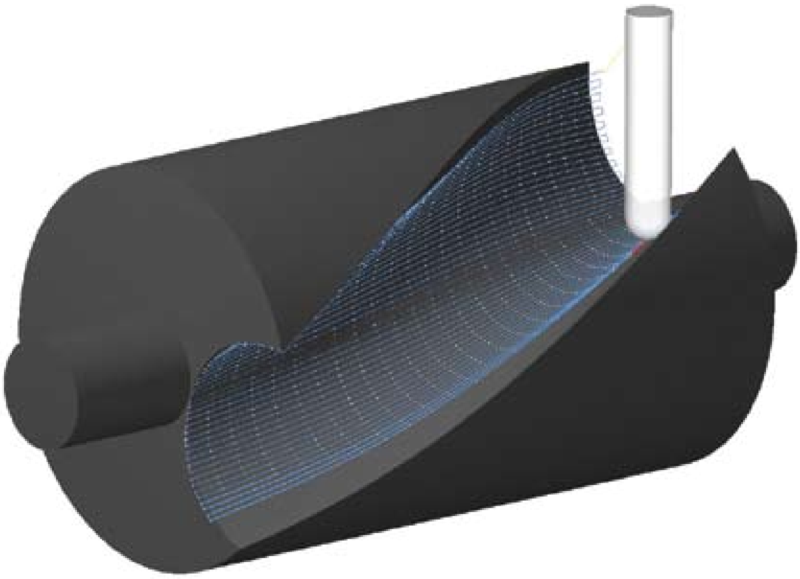


Figure 5-3 *Sketch of simultaneous cutting on a 4-axis machine -XYZA.*

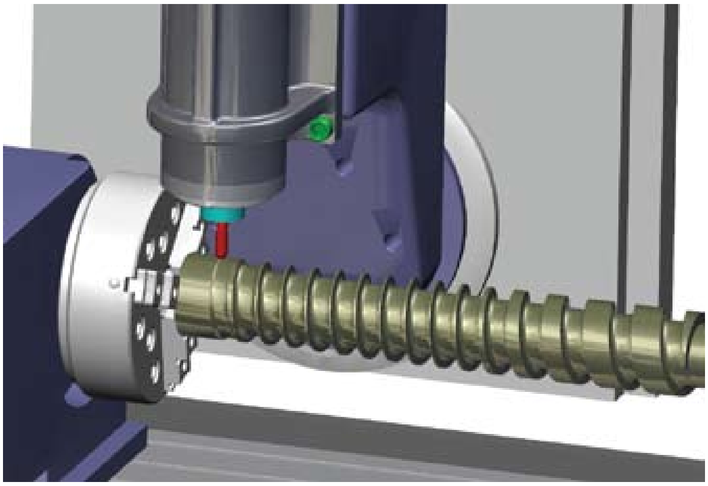


Figure 5-4 *A 4-axis machine set-up for cutting a variable-pitch thread on an auger using motions on XYZ and A axes.*

Simultaneous cutting on a 4-axis machine is shown in Figure 5-3, and a set-up for cutting a variable-pitch thread on an auger using 4-axis motions XYZ and A is shown in Figure 5-4.

Figure 5-5 illustrates a set-up on a similar machine, combining simultaneous motions, and using a flywheel to produce a knee-joint component using the 4-axis motions XYZ and C.

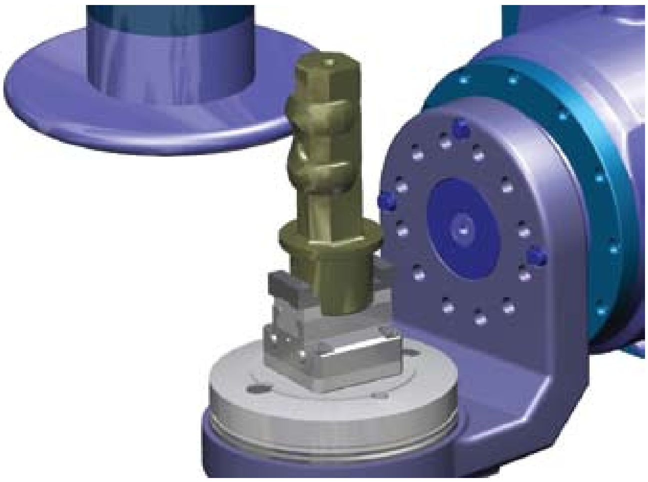


Figure 5-5 *The 4-axis simultaneous motions XYZ and C are shown cutting a knee-joint, using a fly-cutter.*

Many parts would be impossible to machine without simultaneous multiaxis motion. In the early days of multiaxis machining, many parts were designed around motion instead of as freeform CAD models.

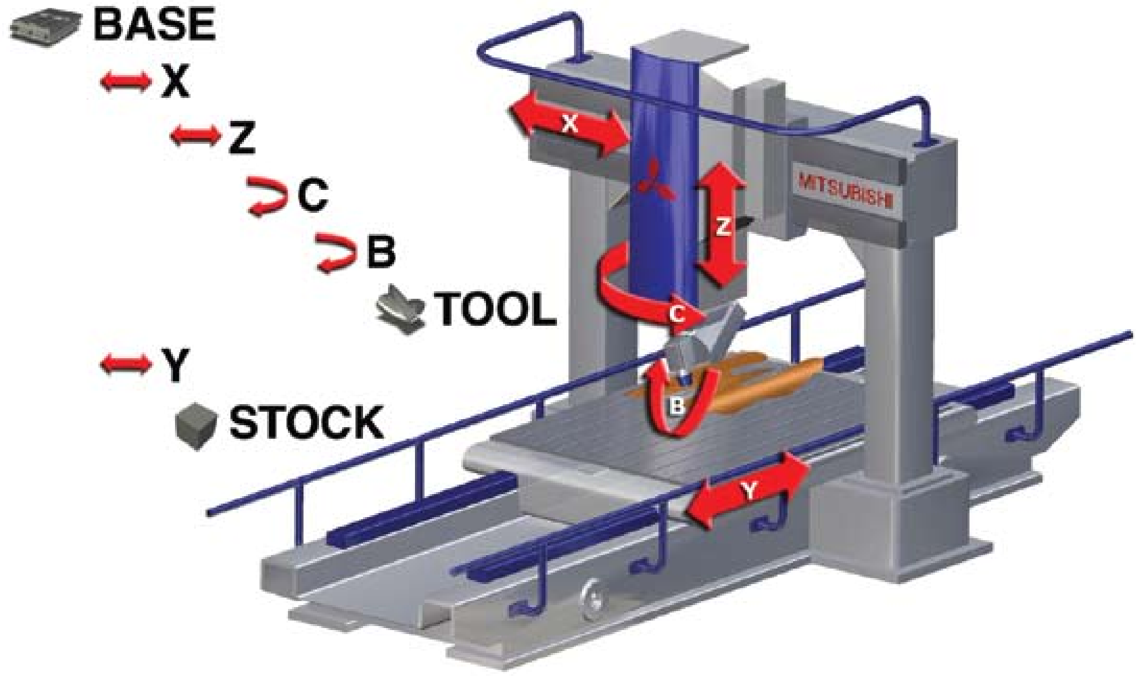


Figure 7-10 *Vertical 5-axis laser machine, with a dual rotary head.*

The vertical 5-axis machine shown in Figure 7-10 is used for laser-machining, but this kind of **Head / Head** configuration is also very popular for milling and water-jet machining.

Machine Simulation Interfaces

A GUI (Graphical User Interface), or form of text file, can be used to build virtual machines. With such a program, models, or whole component branches, can be manipulated individually. For example, the virtual machine can be used to translate, rotate, or set dependencies, translucencies, or reflectivity.

Once the virtual machine is built, all its axes can be moved individually with MDI (Manual Data Input) commands, or slider bars, to check if the correct models are assigned to the correct axes. These commands can also be used to check if the positive and negative motions are correct. Remember that all simulation software is useless if it is not emulating the movements of the real machine. The models representing the real machine must be accurate in relation to the business end of the machine. This area is near the work envelope and includes the spindle, fixturing, and rotary devices.

Once the physical model of the machine is built, the virtual controller must be configured. In a CAM system this work is done with the post processor. In Vericut, configuration is achieved with a reverse post processor. This configuration process is critical in emulating the behavior of the real machines.

Using Machine Simulation

These days, very few people program exclusively by hand. Most people use a CAD/CAM system to generate code. The part is typically either designed or imported, and then toolpaths are generated using tools from an internal or an external library. Machine simulation can be run at any time during or at the end of this process, provided the groundwork has been laid down and the machines have been built.

The process of setting up machine simulation is very similar to setting up a real machine. The part must be placed on the machine in the correct orientation and then the **Local Coordinate System** needs to be set relative to the **Machine Rotary Zero Position**. The tools then need to be loaded into the magazine and the **Tool Length Offsets** must be set correctly. This work can be time-consuming if there is no direct interface between the CAD/CAM and the simulation programs. If there is a well-configured interface, or if the simulation is an intricate part of the CAD/CAM, then setting up will take only a few seconds of processing time.

Native CAD/CAM simulation loads tools from its libraries. Vericut uses its own tool manager, or it will build a tool library automatically if it is integrated with a CAM system. Once the part, tools, and toolpaths are loaded, the simulation is ready to be run, either as single blocks, or continuously. The simulation can be slowed down or sped, and the model can be dynamically rotated. Some systems allow movements forward or backward at any time, but others don't offer this option. Some systems will show material removal with simulation, and some will permit analysis and measurement of the virtual part. Most systems will signal if there is a near-miss or collision between any configured components. They will also display an alarm if the limit switches are hit by over-travelling on any of the motion axes. Operators are able to see through models by making them invisible, which allows examination of the cutting process in ways that are not possible on a real machine.

There are many benefits to machine simulation, which allows different ideas to be tested out without pressure. Estimated program cycle times can be accessed, to help determine the best one. Crashing a machine on the computer screen is not a big concern, whereas crashing a real one is a catastrophe. But not using a multiaxis machine to its full potential is a shame. Simulation allows the best ideas from different cutting strategies, and the most efficient motion for any specific machine to be combined.

The process of setting up machine simulation is very similar to setting up a real machine. The part must be placed on the machine in the correct orientation and then the **Local Coordinate System** needs to be set relative to the **Machine Rotary Zero Position**.

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Over 30 Years of Trade Secrets Revealed!

... this great book will allow operators, NC programmers and anybody interested in multiaxis machining to learn and understand the reality of 5-axis machining. The crystal clear wording and perfect overview make this book easy to read and simple to understand for everyone, from beginner to expert.

- Yavuz Murtezaoglu, Managing Director
ModuleWorks GmbH

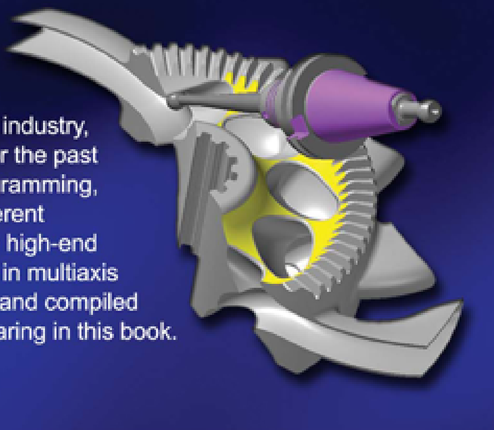
This book explains 5-axis machining in simple terms most people in the field will appreciate and quickly understand. The colorful graphics are nothing short of amazing and generously sprinkled throughout the book with incredible detail. Dozens of machining applications are illustrated and explained while taking much of the fear out of driving these complex machine tools. Anyone associated with 5-axis machine tools has much to gain by reading this book.

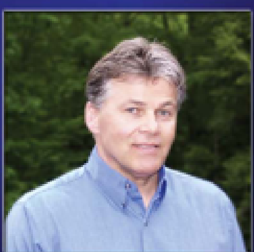
- Mark Summers, President
CNC Software, Inc.

Karlo clearly spent a lot of time transferring his many years of experience into this book. Secrets of 5-Axis Machining contains more detailed color graphics from more industries than I've ever seen in a technical book. The result is an excellent book for anyone involved in this industry. Stop reading the back cover and start reading the contents!

- Jon Prun, President
CGTech

Whether you are new to multiaxis work and feel overwhelmed, or are already using multiaxis toolpaths and need further knowledge, *Secrets of 5-Axis Machining* has been written to help you. It is an unbiased, no-nonsense, to-the-point overview of the 5-axis manufacturing industry that serves to demystify 5-axis machining and will make you better equipped to compete in the global market. It is packed with high-quality, full-color graphics that help explain the theories and principles. As a special bonus, the enclosed CD includes interactive machine simulations, videos, illustrations, and quick reference guides.





For over 30 years **Karlo Apro** has worked in the manufacturing industry, first in his native Hungary and then in Germany, Canada, and for the past 10 years in the U. S. He has spent many years setting-up, programming, running, and repairing CNC equipment and has used many different CAD/CAM systems. For the past 15 years he has specialized in high-end multiaxis applications. After over a decade of training engineers in multiaxis CNC machining, he has identified the common misconceptions and compiled the most sought-after information in the industry, which he is sharing in this book.

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