CNC MACHINING Handbook

Building, Programming, and Implementation

ALAN OVERBY

About the Author

Alan Overby received a B.S. in Electrical Engineering from Arizona State University. He has always had a hobbyist interest in CNC technology, and has owned, programmed, and operated several CNC routers and engraving machines on a professional level within the signage industry. Mr. Overby was co-owner of Custom CNC, Inc., a company that provided new and replacement controller systems to both individuals and original equipment manufacturers.

Contents

Preface

Using CNC, whether on a professional or hobbyist level, is not only an exciting process to be involved in but is also the direction manufacturing is heading. There are a great many facets and stages involved in the end-to-end process of understanding and implementing CNC, and, although there have been several books published on specific aspects or topics (such as G-code programming, building a CNC machine, etc.), there have been no books written that guide the reader through the overall process, that is, until now. It is not the intent of this book to replace any previously written information on this topic nor to delve into any particular area. However, by the time readers finish reading this book, they will have a solid understanding of the entire CNC process from a top-down end-to-end perspective.

More specifically, this book is intended for the following audiences:

- *Academic:* This book will provide the instructor and students a very informative introduction into applied CNC, the various machines, and their uses, along with the necessary tools used in the process.
- *Business owner:* The aspect of moving a small- to medium-sized business, or even a startup company, from a manually concentric manufacturing process into the accuracy and repeatability of what CNC has to offer, can be a daunting task. This book guides business owners in the proper direction to help them understand and decide the ins and outs of automating their manufacturing process. Furthermore, also discussed will be what to look forward to when growing future CNC-based operations.
- *Hobbyist:* There are a great number of individuals interested in the understanding and technical aspects of CNC, but are not exactly sure where to begin—what is absolutely required for the application at hand from both a hardware and software perspective and what is not. There are many free and low-cost software options to choose from that are listed for the reader to appropriately determine what is needed for their particular application.

- *Readers looking for an industry guide:* This book is also intended to be used as a guide, showing the reader that there are certain industry standards within the field of CNC that should be adhered to. There are proprietary hardware and software systems for sale and this book advises the reader as to the pitfalls of using components and systems that are nonstandard. Furthermore, the reader is armed with the appropriate questions to ask the vendors when trying to determine the best approach to take.

Depending on who the reader has previously spoken with or what information they have read, this book will help to augment or clarify what is truly needed for your particular application. This information is to help arm you with the proper information rather than leaving you to rely on what a salesperson is interested in selling you. Often there are low-cost and even free software tools available. These will help you make the determination if certain hardware or software will satisfy your needs, before spending money where you may not need to.

I believe a picture is worth a thousand words. Therefore, I have made every attempt to incorporate illustrations to help the reader visualize what the part looks like and to give an example for reference. Obviously, it would be impossible to include individual pictures of each type of a component, but the main concept is conveyed to the reader with what has been included.

This book also has the following intentions:

- To simplify or demystify CNC for the reader. Where applicable, the intention is to provide the reader with an easy-to-understand, sensible, and logical order of operations.
- To list various hardware and software that I have either previously used with great success or that have been used by companies that have good reputations within the industry.
- To explain in detail the steps and operations used during CAM operations.
- To provide a listing and overview of the commands used in the G-code language.
- To list informative CNC-based Web sites, forums, and additional publications where the reader can obtain more in-depth information on topics covered here.

What I recommend you do as you are reading through this material is to use a highlighter to help you denote the specific items that you find key to understanding the CNC concepts. More importantly, you should keep a steno pad or notebook somewhere close by your computer workstation and CNC machine. Start compiling your own listing of good, known values you

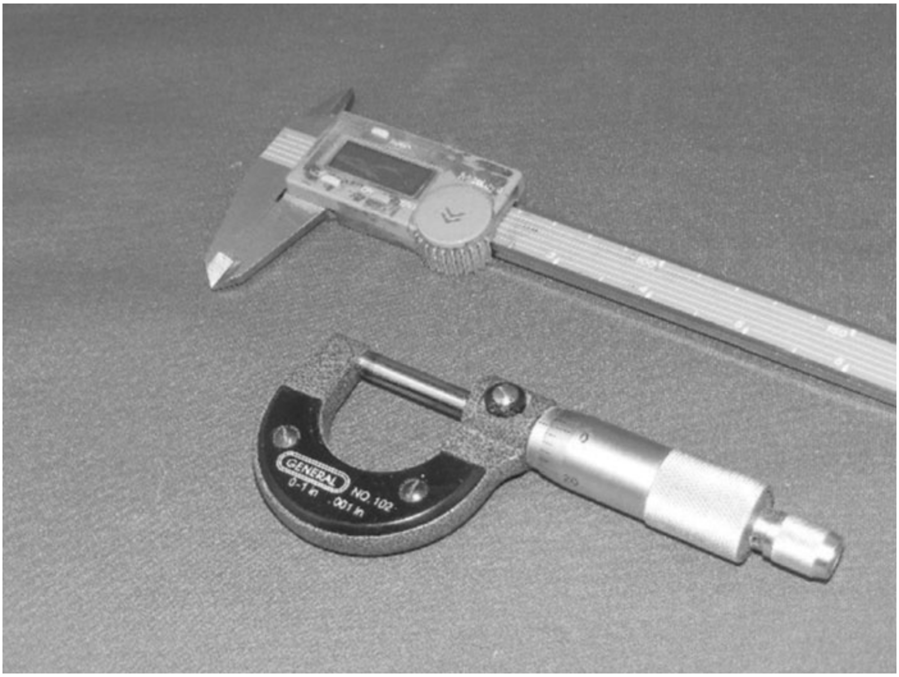


Figure P-1 Micrometer and caliper for use in testing the accuracy of both machine and cut parts.

have found for: feed rates, spindle speeds, and cut depths for certain tooling and materials, conventional or climb milling orientations for various material types you encounter, tips and tricks to help you remember various software parameters, etc. It may take you some time to find the optimum cutting parameters for a certain type of material; that is normal. If you have not written down the cutting information, you will have to reinvestigate. An additional suggestion is to make use of an accurate measuring device. Shown in Fig. P-1 are both a micrometer and a caliper. Not only will you need such devices for checking the accuracy of your final part, but they will be invaluable in the initial measurements of materials you are working with (such as thickness). In addition, they will provide accurate measurements for the replication of a given part.

I would like to state that although I will endorse several vendors and their products throughout this book, these are strictly my recommendations. I have no ownership or co-ownership in any of the companies mentioned.

There is one operation of any given CNC machine that cannot be automated, and that is for you to wear the appropriate eye safety glasses! I cannot overstress the importance of wearing protective eyewear. Any of the processes involved in a CNC operation will produce cutting swarf (i.e., dust, wood chips, metal chips, etc). Thus, proper eye protection is a must.

Also keep or install all safety guards on your machinery. Moving and rotating parts can and will pinch and hurt you—the machine will not stop when you yell ouch!

Alan Overby

CHAPTER 1

CNC Machines

This chapter describes the types of applications that are discussed throughout this text, as well as a list of the most common types of home- and shop-based CNC-controlled applications and their typical construction materials.

Common CNC Applications

This section discusses the various types of applications that can be driven or automated numerically (or numerically controlled by computer). The listing includes the most commonly used applications. Basic and general features found on most commonly used CNC machinery and other applications and their control can be extrapolated from the examples given.

Router/Engraver

Routers come in many sizes and shapes. Depending on what will be produced with a router will have a direct relationship on the proper router head, motors, reduction ratio, speed, gantry height, etc. All too often the term router is generically used to mean various things, but it boils down to a type of machine that uses a rotary process for cutting or engraving. Virtually any sized spindle motor can be used, with its horsepower and rpm capability dependent on the materials and tooling being worked with. Engraving machines can be outfitted with a 1/20 horsepower motor capable of being driven at an rpm of 40,000, whereas a system intended for cutting plywood may have a 40 horsepower spindle with a maximum rpm of 18,000. It is common to find standard woodworking router heads installed on hobby and entry-level machines. This type of motor is quite different, in many ways, by in comparison to a high-frequency spindle head controlled by a variable-frequency drive (VFD). The benefits of using a high-frequency spindle head are many. Among these are the reduced noise of operation, longer life, increased horsepower, and the ability to incorporate an automatic tool changer (ATC).

One of the major differences between these two types of units is their power ratings or the horsepower developed. To help the user understand this difference, the two types of heads are discussed next.

Router versus Spindle Head

A common question from people who are new to CNC routing concerns the difference between a router and a spindle head, as either one of these are generically referred to as a CNC router. Although they both meet the criteria as a router, there are distinct differences between the two. Here we will specifically discuss what each one of these units are and contrast the differences between them.

Router Head

The use of a standard woodworking type of router head is quite common on hobby and entry-level CNC Routers. The reason why this type of motor is used so often is because of its low cost. The type of motor used is referred to as an induction motor. Note that if you spend much time around this type of motor while it is running, you will want to wear some type of hearing protection, as they are quite loud.

These types of router units are intended for general woodworking use and are designed to be used primarily hand-held or inverted in a non-CNC router table. Basically, they are not designed nor intended for use in conjunction with a CNC device. They utilize standard sealed radial ball bearings to support both ends of the shaft and can have rather high amounts of run out. Most have the ability to select the rpm used. The router head shown in Fig. 1-1 has the ability for rpm selection ranging from 10,000 to 21,000 in increments of 2000 and 3000 rpm. They use fixed collet sizes in $^1/_4$-, $^3/_8$-, and $^1/_2$-in increments; reducer adapters are available for smaller diameter tooling (such as, $^1/_8$ in-diameter bits).

This type of router head usually will claim to having a rather high horsepower – some boasting 3.25 hp, or more. Below, we will discuss both the theoretical and actual wattage and horsepower ratings that can be achieved and conclude with a mention of how the manufacturers derive their claimed values.

Wattage is a product of voltage and current. The theoretical wattage of regular household current (in North America) is:

$$\text{Power (W)} = \text{Voltage (V)} * \text{Current (A)}$$
$$1875\ \text{W} = 125\ \text{V} * 15\ \text{A} \qquad \text{theoretical wattage}$$

From the definition that 1 hp is 746 W:

$$1875\ \text{W} * 1\ \text{hp}/746 = 2.5\ \text{hp} \qquad \text{theoretical hp}$$

This implies that, theoretically, the most usable power (rated in horsepower) that can be achieved using a standard 15-A wall outlet is 2.5 hp. Note that this value is far short of 3.25 hp.

The value of 2.5 hp is *theoretical*. A typical induction motor will have losses of more than 40 percent. Hence, you might get 60 percent usable power of

FIGURE 1-1 Common woodworking router head.

this theoretical value (which is generous). Reworking our above equation to reflect the typical losses involved yields:

$$125\ \text{V} * 15\ \text{A} * 60\% = 1125\ \text{W} \qquad \text{actual wattage}$$

or

$$1875\ \text{W}/746\ \text{W} = 1.5\ \text{hp} \qquad \text{actual hp}$$

This calculated value of 1.5 hp is less than one-half of the manufacturer's stated horsepower. The reader can be assured that this actual horsepower value is reflective of the most usable power a unit such as this can deliver.

So how did the manufacturer come to their stated value? They are using a measured value of the amperage required at the time of start up for this particular induction motor. This is known as in-rush or start-up current. This occurs for a very brief time as it is a spike in the current and is intrinsic to induction motors. The time the current spikes is so brief that it does not trip the circuit breaker in your electrical access panel. If you use the above equations, you will find that roughly 20 A of current are initially drawn (left to the reader, as an exercise). Nonetheless, in the end, it is nonusable power.

Figure 1-2 Bearing removal tool.

If you need to keep start-up costs to a minimum, going with a router head is a viable option. Obviously, depending on several factors, the bearings will often need replacement. This is easily accomplished in-house by the user by making their own simple tool, as the one shown in Fig. 1-2. This tool prevents the rotor from rotating so the unit can be disassembled and the old bearings removed with a bearing puller. These bearings are available either online or at any automotive parts store and will cost $10 to $15 for the pair.

Spindle Head

Spindle heads are physically analogous to a router head, but they work in conjunction with a spindle drive (known as a variable-frequency drive [VFD]) and are frequency controlled to vary the revolutions per minute. Spindle heads are designed and intended for heavier-duty CNC use and typically come with ceramic-style bearings, which are resilient to the higher loads being placed on them. They also yield very low amounts of shaft run out.

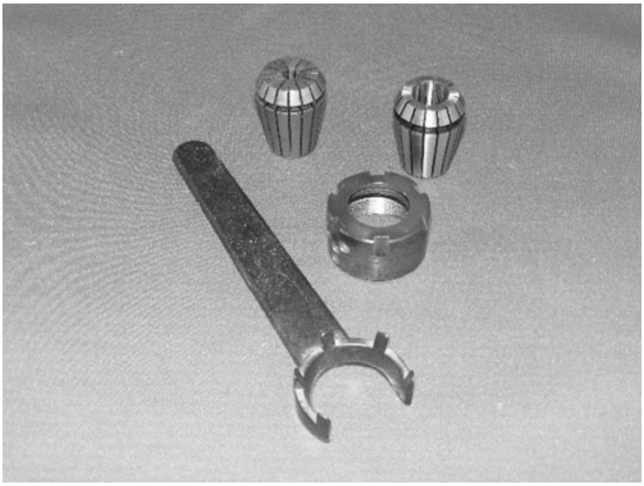
Available in a wide range of sizes, they are a constant-torque type of motor that can develop the actual rated horsepower (or kilowatts) as claimed by the manufacturer. Other than the smallest of these units, the power requirements are typically 20 to 30 A at 240 V. Typical sizing for hobby to small-shop production can range from 1.5 up to 7 hp, obviously depending upon the material type and feed rates. The 3 hp unit shown in Fig. 1-3 is made by PDS Colombo and is very popular and reliable. Spindles run very quietly and are available with various options for cooling, including a fan driven from the shaft, an electrically operated fan, and even water cooling (see Fig. 1-4).

It is the function of the variable-frequency drive to supply three-phase power output to the spindle itself. In fact, all spindles are three-phase. It is the power input to the VFD that can either be single- or three-phase. A controller hardware option is to use a spindle-speed controller card to interface

Figure 1-3
3 Horsepower spindle head.

Figure 1-4
Variable-frequency drive.

Figure 1-5 ER25 collet system.



with the VFD, allowing the user to turn the spindle on and off, run forward or backward, and to control the frequency or revolutions per minute on a granular selectable level. These controls are accessed either directly by the controller software console or via G-code commands within the cut file. The user can still manually operate the spindle via the interface located on the variable frequency drive itself if the need arises. Some type of spindle interface medium should be considered as standard or a low-cost upgrade option when shopping for a hardware controller. If you are looking to purchase a router table system or upgrade, make sure you have this ability available.

The typical collet system used for these types of devices are ER series (Fig. 1-5), where each compression collet size matches the diameter of the tooling being used. This is quite advantageous as you do not need to purchase tooling that always has common shaft diameters, as with the routers' collet system. There also are some spindles that use a drawbar type of clamping system (pneumatic or electrical), which allows the tooling to be automatically changed out. This is referred to as an automatic tool changer (or ATC). In conjunction with this adaptation on the spindle head, banks of various sized tooling are stored in a fixed location in the router table. The information for each tool, such as diameter, length of cutter, etc., and its exact Cartesian location are stored within a table in the controller software. Via the use of G code, automatic tool change-outs are possible without needing to touch off the Z each time it is accessed.

Machines that are dedicated to an engraving process make use of rather small spindles and servo motors. As the tooling is very small in diameter (generally $^1/_8$-in diameter or less) the spindles can easily achieve rpms in the 40,000 range. The photograph (Fig. 1-6) depicts an aftermarket engraving spindle that accepts $^1/_8$-in-diameter conical tooling.

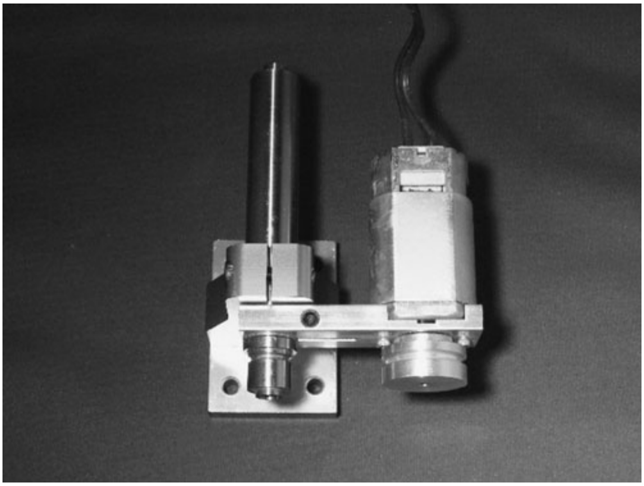


Figure 1-6
Engraving spindle.

Resolution

For machines with a smaller working envelope, it is not as important to have the ability for high-speed travel. On larger format machines, however, speed plays a critical part in the time it takes for the cutter head to travel from one end of the table to the other. What plays a key role with regard to speed (assuming same motors and drives used) is the amount of reduction being used in the transmission system. For any given generic system, there will be a specific number of steps (think of them as drive signals) that will be associated with producing a certain amount of linear travel – typically 1 in Engraving machines can have typical steps/inch value of 10,000, where a large-format table (8 or 10 ft in length) may have only 2000 steps/inch. The contrast between these two examples has a multiple of five. Hence, for the same rpm motor, the unit with 2000 steps/inch would move five times faster. However, it would have considerably less granularity of cutting ability.

For these types of machines, there will be two choices of transmissions: rack and pinion, and screw. In general, tables that have 4 ft or longer of a working envelope tend to use rack and pinion for the transmission system. When using rack and pinion, some type of reduction unit is required that fits in between the motor and the pinion gear. Without a reducer mechanism (i.e., going direct drive), the resolution of the system will be quite low and the quality of cut will greatly suffer. Short spans and, most often, the *Z* axis, a lead or ball screw provide the transmission – with lead screws being the dominant choice of the two. Screws are available in various threads/inch values and are generally selected such that a higher resolution value will be given to the *Z* axis as compared to the *X* and *Y* axes. The decision to have higher resolution on the *Z* axis is typically determined by the application (such as, 3D carving or mold making).

Hold-Down Methods

When performing rotary cutting, the rotating moving bit exerts forces on the material being worked on. To counteract these forces, there are several ways to hold the work material solidly in place. Although any of the below-mentioned hold-down methods will work, each method may not be the optimum solution in each case. It is the user's responsibility to choose and use a hold-down technique that is adequate and safe for each cutting job being performed. Attempting to hold material in place with your hands during a cutting operation is never an option.

Vacuum

Vacuum hold-down is a common method used, in particular, where full-sheet stock is the primary material being worked with. Common industries include woodworking and furniture making while working with full-sheet plywood. The signage industry also uses full sheets of plastics, composites, and thin aluminum sheeting. The vacuum pressure is generated from a unit called a regenerative blower. These blowers are rather large and noisy, and they consume a lot of power during operation. Most spoil boards are plumbed with PVC tubing to create work-area zones. Rather than always creating vacuum across the entire table surface, half- or quarter-sized sheets of material may be worked on using four or more vacuum zones.

T Track Grid Work

For users who typically work with, for example, irregular sized stock, hardwoods, and furniture pieces, great use is made of aluminum T Track, which is embedded into the surface of the spoil board. Various types of fasteners and hold-down clamps are readily available via woodworking sources that are used to securely fasten just about anything to the table. Aluminum is typically used for the track and hardware in the event the cutter bit comes in contact with a hold down.

Double-Sided Tape

Sign shops quite often make use of a sheet of melamine (or similar product) as the surface of the spoil board. Using double-sided masking tape, several rows of tape can be placed on the melamine surface, which holds down sheet stock, such as, aluminum, PVC, and acrylic. This type of tape is rather inexpensive and works as a viable solution to not having a regenerative blower for vacuum hold down.

Fat Mat

Fat Mat is a brand name of self-healing rubberized sheet of material. The material is used mainly in engraving operations where the mat securely holds small pieces of plastic or metal when being worked on. To use, simply place the engraving stock in place and firmly press it down against the mat. Removal of the material typically involves peeling the engraving stock from the mat.

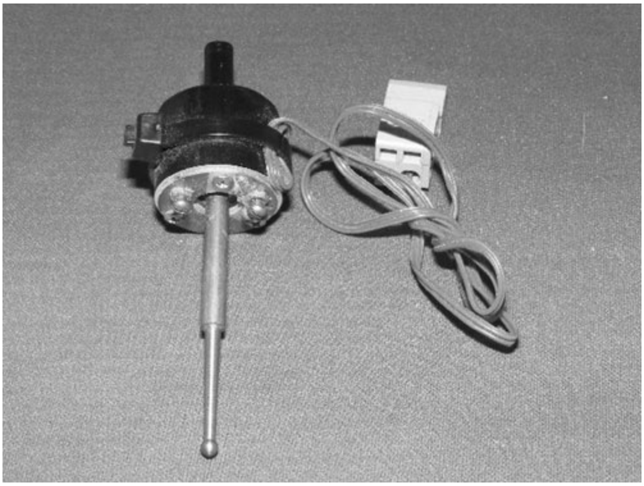


Figure 1-7 Device used in 2D probing.

Probing

Devices called probes are used many times as an application to a CNC machine. The machine is instructed to make successive passes over a user-defined area that will be scanned. The scanning process can either be mechanical or optical. The resulting output of the scan is referred to as a point cloud.

Mechanical Probing

Mechanical probes get mounted in a spindles chuck, but at no time ever does the spindle get turned on. The probe (Fig. 1-7) itself has a series of contacts that "make or break" when the probe touches the item it is scanning. The series of the contacts on and off events are concatenated together with specific reference to their *X* and *Y* locations. This file can then be replayed and used to reproduce the scanned item.

Optical Probing

There are several flatbed and optical dimensional scanners on the market. Something relatively new, however, is the advent of using a camera mounted on a CNC machine (mill, router, etc.) for very detailed optical scanning. The USB-based microscope camera takes many pictures of the scan item as the axis is moving. Once the scan completes, the software extrapolates a highly detailed mosaic image that represents the scan. This probe, was developed by Tormach and is available on their website: http://www.tormach.com/Product_CNC_Scanner.html. The software works in conjunction with Mach3 controller software.

Rotary *A* Axis

X-, *Y*-, and *Z*-based CNC machines are capable of more than just orthogonal movements. With the addition of a rotary axis (typically designated as the

A axis), horizontal column type of milling/cutting becomes possible. Note that the rotary axis is often referred to as an indexer. An indexer differs from a lathe in that the rotation is not always in one direction and not always at constant revolutions per minute. The CAD and CAM files are laid out such that the file height equals the circumference of the rotary stock. Any changes in *Y* distance of the file equate to a specific number of degrees of rotation. In essence, you end up wrapping the file around the column. The indexer size and column diameter are dictated by the gantry height, if used on a router.

There are a great number of peripheral add-on capabilities a router can have. Many of those discussed are not limited to just a router table, but are generic to CNC tables in general.

Plasma Cutters

Plasma cutters are commonly available metalworking devices that have the capability of through-cutting various types of metals in a single pass of operation. These units come in various thickness-cutting capacities and most often resemble the look and size of a small wire-feed welder. Once the plasma arc is established for the cut, compressed air is used to blow the molten metal through the cut – thus producing the cutting kerf. CNC plasma tables often resemble a CNC router. The notable exceptions in appearance are that the spoil board is replaced with a metal gridwork and the spindle head has an installed plasma torch.

Analogous to establishing a tooling touch off as in a routing or milling operation, an initial pierce height for the material is used to puncture through the metal stock. Once established, an adjunct type of controller device, referred to as a torch height controller (or THC) maintains the proper torch tip distance from the material via constantly sampling the voltage potential between the tip and material being cut. The reasoning behind needing to constantly sample the tip voltage and making subsequent adjustments is that warping of the metal occurs when it is being cut (particularly, thinner materials); not all metal sheet stock lies flat on the table surface and a constant distance between the torch tip and material must be maintained. Furthermore, many sheet metals are not flat initially, but corrugated – hence, another function of the THC is to track irregular-shaped stock.

During normal cutting operation, the motion controller hardware and software have control over both the *X* and *Y* axes for two-dimensional movements, but the THC has control of the *Z* axis for vertical adjustments. The physical interface for the THC type of device is typically via a second parallel port to the computer and controller software. Hence, a total of two db-25 connections are usually required: one for the motion controller and the second for the torch height control. Just as a controller database can store tooling information, various parameters for material type, thickness, feed rates, and plasma-cutting parameters are also typically stored in a database file for easy reference with the plasma operations.

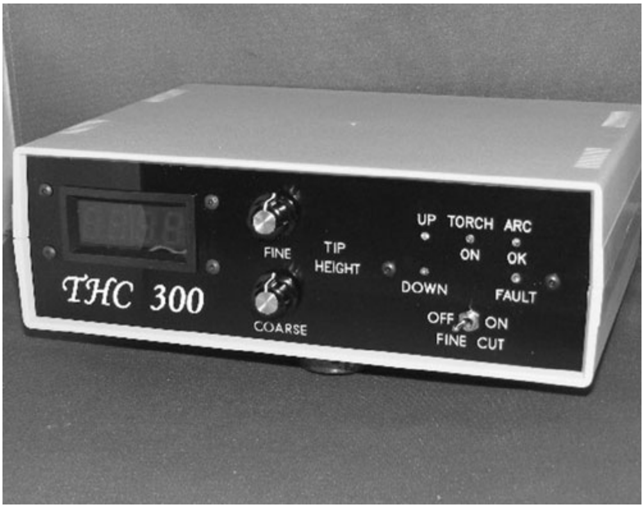


Figure 1-8 Torch height controller.

Shops often can be involved in production of materials that can make use of both a router and a plasma table. Invariably the question arises as whether to use one table for both of these types of operations. The recommendation is to avoid using one CNC table for both operations for the following reason: A CNC router table expects the spoil board table to be perfectly flat (or orthogonal) with reference to the *Z* axis. For use with plasma, there is no spoil board, but rather an open support framework for the molten metal to pass through during the torch operation. Hence, it would be rather difficult and time consuming to dismantle and reinstall a flattened spoil board each time you change out cutting operations. Simply placing a spoil board on top of the plasma grid does not ensure a flat and level surface and would need to be surfaced (i.e., fly cut) each time it is moved.

It is altogether possible to take an existing CNC router and replace its application for use of a plasma torch, which is often done. If you are building or purchasing a table for plasma use, realize that the table's mass and strength do not need to be that of a router's, since little to no force is encountered during a plasma (or laser, water jet, etc.) type of cutting operation in contrast to that of routing or milling. The advanced THC controller shown in Fig. 1-8 is the same one that is used on the plasma table, as shown in Chapter 11 on Building Your Own CNC Plasma Table, and is made by Sound Logic, Inc. (http://soundlogicus.com/). This unit is highly recommended to anyone interested in a new or retrofit for plasma cutting.

Dual *Z*

There are often times when all cutting jobs on a router will only utilize two cutting bits. In such cases, it may not make sense to purchase an ATC for a spindle, but to add a second spindle or router head. The secondary *Z* head is easily fabricated and controlled with software, as an independent axis. CAM software can also be configured for post-processor output, designating the primary *Z* axis as "*Z*" and the secondary as "*A*". During the processing of the G-code file, the CNC machine would automatically make use of the proper spindle and cutting tool. This often alleviates the need to change tooling halfway through each file.

Limit and Homing Switches

Switches are not considered an application, but rather a set of controller peripheral devices. The types of switches generally used are micro-switches (Fig. 1-9), which are mounted such as to sense the physical extremes of travel for each axis and in each direction of travel. When using the switches in a capacity of limits, they are intended as safety devices to immediately stop travel of the axis prior to a crash or the gantry running off the end of the table. When looking at the switches with regard to homing, the locations for where each switch trips is a known location. In the event your system experiences a loss of steps condition or the power to your shop goes out, the homing routine will put your machine back into a known working set of coordinates.

The extreme locations where the switches are located and will trip at are known within G code as G53 machine coordinates. The actual working envelope of your spoil board and where typically "$X = 0$ and $Y = 0$" are your G54 table coordinates. When working with switches, you must ensure you know which coordinate system you are referencing.

Micro-switches are single-pole double-throw (SPDT) devices that can be wired as normally closed (N/C) or as normally open (N/O). This topic is covered in more detail later, but make sure you have them wired as N/C devices for safety reasons.

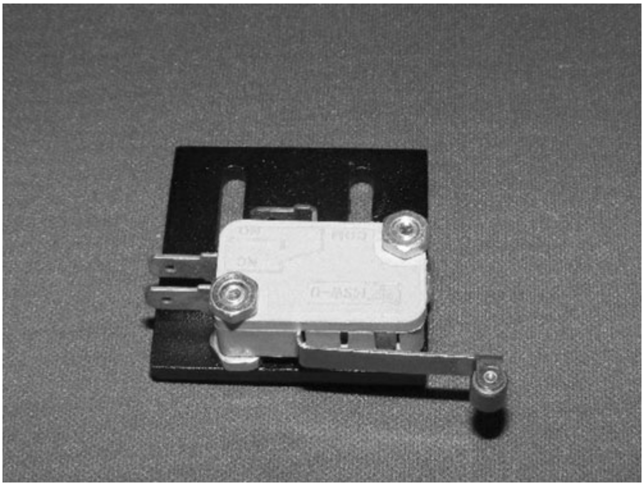


FIGURE 1-9 Micro-switch used for limits and homing.

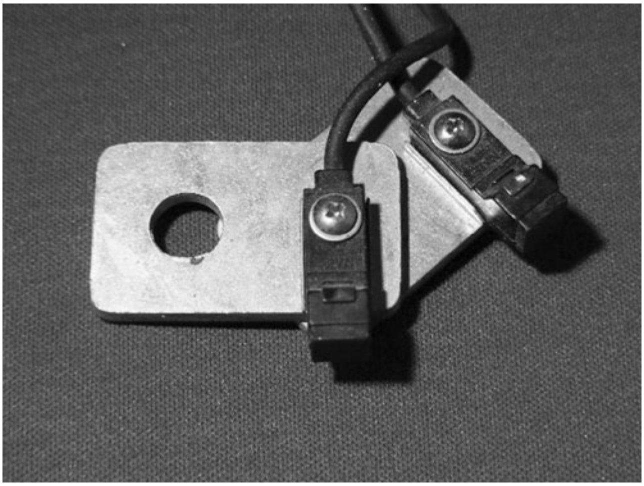


Figure 1-10 Magnetic inductive switch.

One type of switch to avoid, if possible, is the magnetic inductive type (Fig. 1-10). Although they work well as a switch, they do not work well for safety reasons, as they must be wired as N/O devices.

Mills

Mills typically have smaller footprints than most CNC machines and their primary function is working with metals. Mills generally have high transmission reduction ratios, allowing both repeatability and accuracy of 0.0001 in and greater. High-end mills can be found that can perform discrete movements as small as 0.0001 in for intricate work. (Note this is one-thousandth of one-thousandth of an inch!) As mills are intended to work in close tolerances with materials that are highly rigid, the framework of the mill is designed to compensate for high cutting stresses. Mills are exclusively manufactured from cast iron because of its higher mass and incorporate high-lead ball screws for each axis.

Accuracy versus Repeatability

Not specific to mills or metalworking, accuracy and repeatability of any CNC machine are both considered key elements in the design and/or purchasing decision. The accuracy component is a function of the anticipated performance and expectations of the application itself and the repeatability seen as a range or window encompassing it. The tightness of the window it can maintain is the accuracy of the system. The repeatability of the system is determined by its ability to return to the same location time after time. For example, your system can be commanded to move a discrete distance and its accuracy is measured to be off by a certain amount. Accuracy is how close you came to the commanded distance. However, if it is consistently off by the same amount, it has repeatability.

Lathes

Lathes primarily are intended to work with various metals, although there are CNC woodworking lathes as well. In either case, each has an *X* and *Z* Cartesian plane in which work is performed against stock that is rotated by a spindle. Note that in the case of a manually operated metal lathe, the use of back-gears determines the ratio of cutter movement with regard to spindle revolutions. With CNC control, this no longer applies, as the lead screw becomes independent of the spindle. This allows both standard and nonstandard types of threading, as well as the ability to perform wider spans of tapers on the rotating stock.

Construction Materials – Router/Plasma

The overall goal in constructing a CNC router or plasma (i.e., gantry style) machine is typically to have the heavy nonmovable stationary portions to help reduce vibration. Another goal is to have the movable parts be as lightweight as possible (yet strong and stiff enough to handle the intended loads). Thus, faster accelerations will be possible because of lower inertial mass of the movable parts.

Wood Composites

It is common for hobbyists and do-it-yourselfers to employ cheaper and easier-to-work-with materials, such as plywood, plastics, and composite materials [such as medium density fiberboard (MDF) or melamine] to construct their systems. These systems are cheap, fun, and easy to build. However, they have rather short life spans.You cannot compare their metal counterparts and typically they are not consistently accurate.

Aluminum

Another type of common material that can be used is extruded aluminum framing; see http://8020.net/ for an example of this material. There are several companies that manufacture aluminum framing materials, which are available in a wide variety of shapes and sizes. Using this type of material, one can literally build a CNC system much like an erector set. Be advised that these materials and connectors are rather expensive in comparison to an all-steel built and welded counterpart. The benefit is ease of construction for people who do not have the facilities for working with steel. The makers of this type of extruded aluminum can cut to your dimensions and have a large array of fasteners and brackets that can be used for assembly. It is especially advantageous to use the extruded aluminum framing for movable spans, such as on a plasma table or router because of its lighter mass. However, it is important to realize that the expansion and contraction of differing metals can make a difference in the way they are joined together; it is difficult to weld aluminum and steel together. Although this effect is minor, it can affect overall system accuracy as well. In most cases it is customary to bolt together sections of differing materials that cannot be welded.

Joining Materials Together

On the units that use steel and/or aluminum, the type of joining materials can be of paramount importance. For example, a system that is bolted together will, in fact, have a tendency to eventually work its way out of square over time and obviously be less rigid as compared to it being welded together. Of course, there is nothing wrong with drilling and bolting a frame or gantry together first and then following up with stick, wire feed, metal inert gas or gas metal arc welding (MIG or GMAW) and even tungsten inert gas or gas tungsten arc welding (TIG or GTAW) if you have the facilities. If you are constructing a unit from steel and do not have access to a welder, I highly recommend you first square everything up and then have someone weld it for you. There will be a notable difference in the overall rigidity. If you are purchasing a unit (as applicable) you should ask the manufacturer if the unit is a one-piece table or a bolt together. If it is a bolt-together system, either plan on welding it solid or, better yet, consider changing to another vendor that has a welded system.

It is also advisable to have a unit constructed of tubing using any type of material. One material to avoid is c-channel as it tends to be quite flexible, carries a lot of vibration, and maintains loose tolerances with regard to hot-rolled steel tubing.

Tooling

Within the machining and CNC world, the term tooling simply means the cutter you intend to use. There are a great many categories of tooling that can be used and are somewhat specific to the type of machine and material you will be working with. There are so many different types of tooling that are associated with each facet of CNC machining that it would take a separate book to cover them all. What we will do here is cover some of the basic types that are typically associated with wood and plastic routing, as well as engraving. Also bear in mind that the tools listed here are available both as SAE and metric dimensions. The picture shown here shows an array of up-cut end mill bits that range from $\frac{1}{8}$- to $\frac{1}{2}$-in diameter along with some 120- and 150-degree HerSaf v-bit cutters.

- *End mill*. You could consider the end mill (Fig. 1-11) as the workhorse bit most widely used in CNC milling operations. There are types that

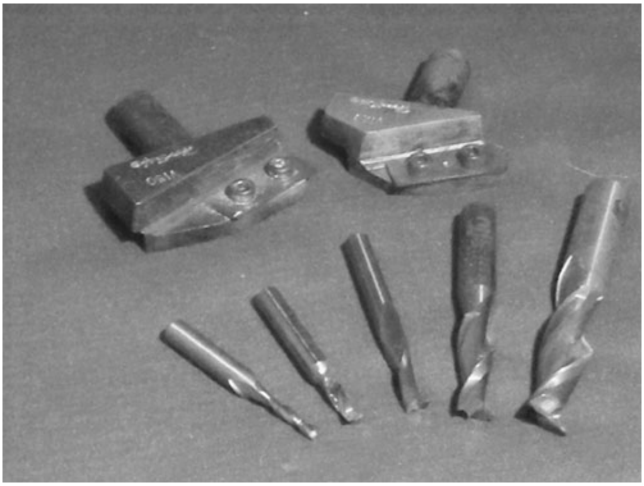


FIGURE 1-11 Various mill/router tooling.

are specific to the type of material you are working with as well (i.e., wood, composites, solid surface, plastics, and metals). End mills are used in profiling, area clearance, drilling, and inlay types of operations. Among the types of end mills you will typically use: up cut, down cut, compression (up and down cut), roughing, and finishing

- *Ball nose*. These types of bits differ from end mills in that the geometry of the end of the bit is rounded. These bits are also available in various types and are often used in areas such as decorative fluting, engraving, and in 3D finish work.
- *Engraving*. Virtually any style of bit can be used for engraving. However, when you focus your attention more on using a CNC engraving

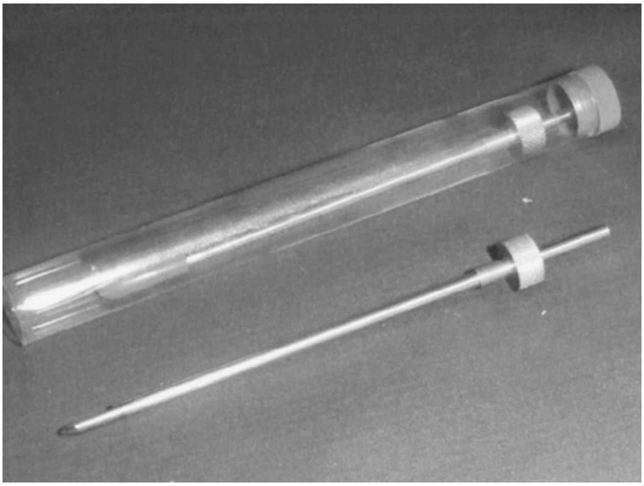


FIGURE 1-12 Conical tooling used in engraving process.

FIGURE 1-13 Set of conical tooling.

machine and working with specific engraving stock (see both http://rowmark.com/ and http://www.inoplas.com/ for just a sampling of material types), then the primary style of engraving tool is the conical bit (Fig. 1-12), although V-style bits are common in engraving operations.

The process of fine engraving uses an entirely different set of tooling. They are aptly named conical, as the tips of the cutters are shaped like a cone, and each have a specific flat spot ground on the tip. These are the long version that work with most engraving machines (this is a full set) and require specialized collets and a high-speed spindle to drive them. They are also available in $\frac{1}{4}$-in shank versions for users who have a router or spindle chuck (see photograph, Fig. 1-13). The particular vendor of these bits, Antares, has a detailed description of the anatomy and intended uses of these bits: http://www.antaresinc.net/FactCutterGeometry.html.

There are also specialized types of these cutters that are used in producing signage that complies with the American Disabilities Act (ADA). Among these are specific angled cutters for material overlay profiling, as well as dot cutters for working with Braille for the visually impaired.

Tooling Systems

For metalworking mills, there is a system that works with common metalworking tooling and is called the Tormach tooling system (TTS; Fig. 1-14). If you do much work on a mill, this tooling addition can improve both your time and accuracy. It works as a series of tool holders that quickly adapt to your existing collet system (R8 or MT3) to change out tools. Each holder fits into the collet the same distance and the protruding amount of the tool is a user-measured distance that gets stored in a file within the controller

Figure 1-14 The Tormach tooling system.

software. The result is faster tooling changes without needing to perform subsequent touch offs to zero each tool. From personal experience, this is one of the tools you wish you would have invested in long ago. The TTS is available for both manual and CNC-based mills. See the Tormach Web site http://www.tormach.com/Product_TTS2.html.