Tooling

Tooling, surprisingly enough, is often the least understood aspect of CNC equipment. Given that it is the one element that will most affect the quality of cut and the cutting speed, operators should spend more time exploring this subject.

Cutting tools usually come in three different materials; high speed steel, carbide and diamond.

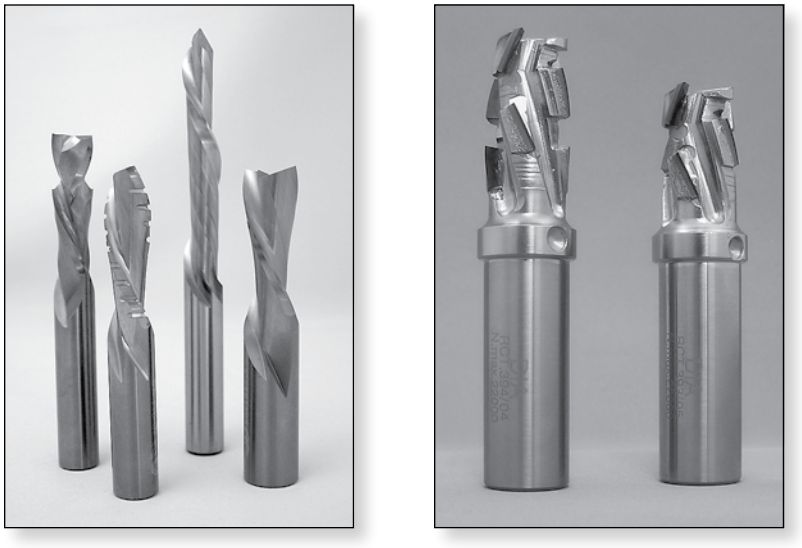
High speed steel (HSS)

HSS is the sharpest of the three materials and the least expensive, however, it wears the fastest and should only be used on non-abrasive materials. It requires frequent changes and sharpening and for that reason it is used mostly in cases where the operator will need to cut a custom profile in-house for a special job.

Solid carbide

Carbide tools come in different forms: carbide tipped, carbide inserts and solid carbide tools. Bear in mind that not all carbide is the same as the crystalline structure varies greatly between makers of these tools. As a result, these tools react differently to heat, vibration, impact and cut loads. Generally, low cost generic carbide tools will wear and chip more rapidly than higher priced name brands.

Silicon carbide crystals are embedded in a cobalt binder to form the tool. When the tool is heated, the cobalt binder loses its ability to hold on to the carbide crystals and it becomes dull. At the same time the hollow space left by the missing carbide fills up with contaminants from the material being cut, amplifying the dulling process.



Solid carbide (left) and diamond (right) tooling

Photos courtesy of ROYCE//AYR Cutting Tools

Diamond tooling

This category of tooling has come down in price in the last couple of years. Its remarkable abrasion resistance makes it ideal for cutting materials such as high pressure laminates or MDF. Some claim that it will outlast carbide by up to 100 times. Diamond tipped tools are prone to chip or crack if they hit an embedded nail or a hard knot. Some manufacturers use diamond tools for rough cutting abrasive materials and then switch to carbide or insert tooling for the finishing work.

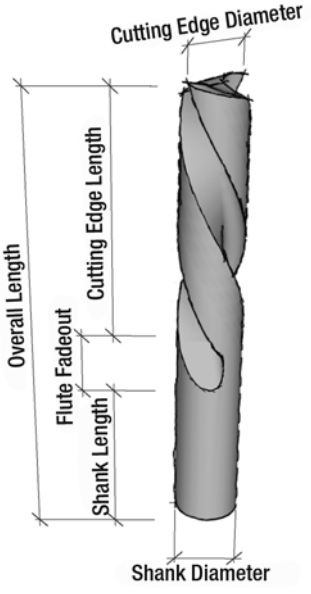
Tool geometry

Shank
The shank is the part of the tool that is held by the tool holder. It is the part of the tool that has no evidence of machining. The shank must be kept free of contamination, oxidation and scratching.

Cut diameter
This is the diameter or the width of the cut that the tool will produce.

Length of cut
This is the effective cutting depth of the tool or how deep the tool can cut into the material.

Flutes
This is the part of the tool that augers out the cut material. The number of flutes on a cutter is important in determining the chip load.



Tool geometry

Tool profile

There are many profiles of tools in this category. The main ones to consider are upcut and downcut spirals, compression spirals, rougher, finisher, low helix and straight cut tools. All of these come in a combination of one to four flutes.

The upcut spiral will cause the chips to fly upward out of the cut. This is good when doing a blind cut or when drilling straight down. This geometry of tool however promotes lifting and tends to tear out the top edge of the material being cut.

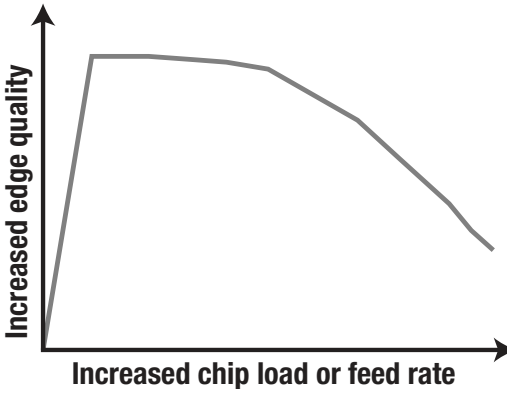
Downcut spiral tools will push the chips downward into the cut which tends to improve part holding but can cause clogging and overheating in certain situations. This tool will also tend to tear out the bottom edge of the material being cut.

Both the upcut and downcut spiral tools come with a roughing, chip breaker or a finishing edge.

Compression spirals are a combination of upcut and downcut flutes. Compression tools push the chips away from the edges towards the center of the material and are used when cutting double sided laminates or when tear out of the edges is a problem.

Low helix or high helix spiral bits are used when cutting softer materials such as plastic and foam, when welding and chip evacuation are critical.

Chip load



The most important factor for increasing tool life is to dissipate the heat that is absorbed by the tool. The fastest way to do this is by cutting more material rather than by going slower. Chips extract more heat away from the tool than dust does. As well, rubbing the tool against the material will cause friction which translates into heat.

Another factor to consider in the quest to increase tool life is to keep the tool, the collet and the tool holder clean, free of deposits or corrosion thus reducing vibrations caused by unbalanced tools.

The thickness of material being removed by each tooth of the tool is called the Chip Load.

The formula for calculating chip load is as follows:

Chip Load = Feed Rate / RPM / # Flutes

When the chip load is increased, tool life is increased, while decreasing the cycle time. Furthermore, a broad range of chip loads will achieve a good edge finish. It is best to refer to the tool manufacturer's chip load chart to find the best number to use. Recommended chip loads usually range between 0.003" and 0.03" or 0.07 mm to 0.7 mm.

Cutting Parameters

Having an intimate knowledge of the characteristics and limitations of a machine will have a huge impact on the quality of the parts that can be produced on it.

When programming a part to be cut, bored, shaped, etc, having a good handle on the cutting parameters will be crucial to the quality of the end result. Sometimes these parameters will change as a result of extensive trial and error. Here are a few of the main ones:

Feed speed

This is by far the most fundamental to consider and often the most misused. In theory, the fastest feed speed possible that will produce an acceptable cut finish should be programmed. There are many factors that affect this parameter, such as RPM, material density, machine rigidity, tool geometry and many more.

The best starting point for calculating feed speed is to refer to the tooling manufacturer's chip load chart. Keep the tools running as fast as possible without compromising edge quality and without breaking the tool. Remember that running a tool too slowly in a cut can also lead to breakage because of the excessive heating that occurs.

Always remember to cut as fast as possible while still maintaining an acceptable edge quality. This will increase tool life and increase the machine's output.

Climb and conventional cutting

Conventional cutting or chip cutting is the term used when the tool rotates against the direction of the material being fed. Climb cutting refers to the material being fed in the same direction as the rotation of the cutter. When using a hand-held router it is quite dangerous to climb cut because the router or the part would be pulled away from the operator which can result in serious injury. In the case of a CNC router however, the spindle and the material are held rigidly in place and both directions of cut are possible.

A climb cut can be very useful when cutting material that has a tendency to splinter but it also tends to create more fuzz in fibrous material. Again, some experimenting will be necessary to determine the best parameter to choose in specific situations.

Rough cutting and finish cutting

In some situations, it is a good idea to do one pass with a rough mill to quickly remove most material without consideration for edge quality and then come back in with a finish cutter to smooth off the edges. Remember that depending on the cutting tool being used, the same finish can probably be achieved in one pass instead of two.

On less rigid machines or when cutting hard material, it might be a good idea to use a two pass combination to offset the accuracy issues that might result from flexing on the axes.

Ramping and offset

These parameters are used at the start and at the end of a cut. Dwelling and plunge entry can create burn marks causing quality issues. As well, when using a non-plunging tool, a long ramp can alleviate some of the pressure and excess heat that would be produced on the end of the tool.

Tab and skin

Tab and skin parameters are used when trying to cut small parts that are hard to hold down. The tabs or the skin left on the bottom of the piece can then be cut in a second pass or by other means.

Work Holding

In order to machine a part on a CNC router the part must be held securely in place. This seems obvious, however, this is the one area that often causes major headaches.

Another term used for part holding is fixturing. The hold-down system has a significant impact on part accuracy, quality of finish and on feed speeds and tooling life.

Keep in mind that holding the part securely is important and there is no one system that will properly hold all parts.

There are two fundamentally different types of parts that must be held in place. The first is a flat part or a sheet of material and the second is a three-dimensional object. The fixturing systems for each are similar, however, the three-dimensional part normally requires somewhat more complex arrangements.

Some materials require higher cutting forces than others and these materials will require a more rigid hold-down system. Some materials will vibrate or chatter when cut.

Manual

The most cost effective way to hold down parts to a table is to screw, nail or to bolt the part to the work table. Other good methods of manually holding parts down are to glue the part down with regular or thermo fusible glue or with double sided tape. In the case where a prototype or a single piece will be cut, it might not be cost effective to build a holding fixture.

For short production runs or for fixturing prototypes, another useful method is to use a toggle clamp. These come in many different configurations and sizes are easy to adjust and to setup on a jig.

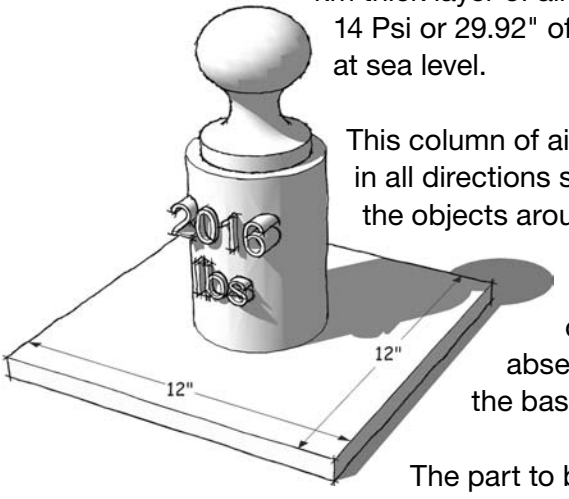
One must be careful not to crash the tool or the spindle into the clamp when using this kind of device. It is always a good idea to test the program in a dry run at low speeds before putting such a fixture into production.

Toggle clamp

Photo courtesy of DE-STA-CO

Vacuum

The most common system for holding down parts on the CNC router is conventional vacuum. Vacuum is simply the absence of air. The 45 km thick layer of air surrounding the Earth weighs about 14 Psi or 29.92" of mercury (Hg) or 100 kilopascals (kPa) at sea level.



This column of air pushes down equally on everything in all directions so that no resultant force is felt on the objects around us. When the air is removed from one side of an object, the air on the other side now pushes against the object with a force proportional to the absence of air on the opposite side. This is the basis of vacuum hold-down.

The part to be machined is sealed against the tabletop or a fixture and then the air inside the seal is removed using a vacuum pump. The air on the outside then pushes the part against the fixture.

The vacuum pressure is not the only thing holding the part against the table. Since lateral pressure is exerted by the cutter when it is machining the part, the coefficient of friction between the part and the fixture plays an important part as well.

A perfect vacuum is not possible with current technology, no matter which kind of vacuum pump is used.

Capacity

The capacity for vacuum pumps is specified in a couple of different ways, depending on the type of vacuum pump and the manufacturer. It is important to know the ACFM rating of the pump. It expresses the “actual cubic feet per minute” inlet capacity at a specific vacuum level. Capacities expressed in CFM or SCFM (standard cubic feet per minute) can be very misleading because one has to take into consideration the volumetric efficiency of the pump at a specific vacuum level. Rotary vane pumps are generally rated in CFM of free air displacement, which is the theoretical displacement at 0" Hg vacuum.

The requirements in vacuum flow or the capacity of the pump will be different whether vacuum cups, clamps or high flow universal vacuum tables are being used.

A vacuum hold-down where the part rests on rubber seals may allow the part to move or wiggle slightly on the soft seals. This can easily result in excessive tooling marks, chatter and a poor quality edge. It is also possible that under the pressure of cutting, the part may move slightly resulting in a loss of accuracy.

Conventional vacuum fixturing

This method is mostly used in 5-axis production when trimming moulded parts. Since these parts are almost never flat, special vacuum fixtures are made using plaster to conform to the part and a rubber seal is used around the vacuum ports.

Pod and rail

This vacuum cup type of hold-down is a widespread method of holding parts on a CNC machine. This is well indicated when one part at a time needs to be machined.

There are many different configurations of pods for different applications and as it takes time to adjust the pods to different configurations and part sizes, this can be an inefficient way to work. Pod systems are not the universal solution that some manufacturers advertise.

Combination pod/flat table

On lower-priced or older systems, a combination of pods on a flat table using conventional vacuum is often found.

Rotary vane vacuum pumps are relatively inexpensive as they are small and are not required to pull a great volume of air. This system works well when there is a good seal with the part.

High flow vacuum

This method is often associated with nested based systems. A sacrificial board otherwise known as a spoilboard made of MDF or particleboard sits atop a vacuum plenum on the worktable. Flow is

so high through the MDF that a low-pressure area is created on the surface. A flat part that is laid on this table will be held in place in this low-pressure area without the need for fixtures or seals.

The amount of force generated on the part is much less than with conventional vacuum. The best systems today generate a force between 4 and 6 pounds per square inch. This means that a 12"x12" piece of melamine will be held to the surface with a force of 576 to 864 pounds. This is more that enough to do the job in most cases.

Remember to take into consideration the permeability of the material that is being worked when purchasing a vacuum pump. Low density fiberboard is very porous and will let a good quantity of air seep right through the material while Plexiglas is completely impermeable and once a good seal is achieved, it takes very little work to maintain it.

Roller hold-down

Other methods of material holding have surfaced in response to specific industry needs. Roller hold-down systems are often seen in upholstery shops. This method is used to hold rough and often warped plywood that could not otherwise be held in place by a high flow vacuum.

Roller hold-down fitted with an automatic sheet loader

Photo courtesy of Thermwood Corporation

Some advantages of this method include achieving faster accelerations and that more than one sheet

at a time can be held down. The outcome is a lower quality edge but this is not often an issue with upholstered furniture. Also, small parts will be difficult to cut if they are not pressed by the two rollers at all times.

Vacuum Pumps

Machine vendors will present a variety of choices regarding the type of vacuum pumps that they offer. These vary widely in specification and in price range.

The main features to look for when specifying a pump for a particular application are:

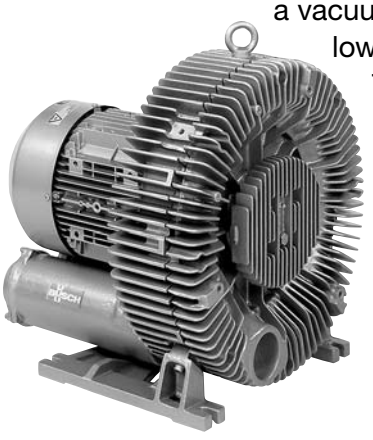
- vacuum level (in Hg or kPa)
- vacuum flow (CFM or m^3/min)
- operation noise level (db)
- price ($).

The best pump for any particular application will be a compromise arrived at after a thorough analysis of cost and performance of the different components available at the time.

All vacuum pump manufacturers publish performance curves. As part hold-down efficiency will be a very important factor in the success of any CNC application, proper selection is vital.

Regenerative vacuum blowers

These are the lowest in cost and consist of a motor connected to an impeller. As the impeller pushes air through the exhaust, it creates a vacuum. These types of pumps typically generate low vacuum pressure but a great volume of air. They are noisy, operating at approximately 90 decibels. These pumps are best suited for holding less dense material such as foam and fabric.



Vacuum blower

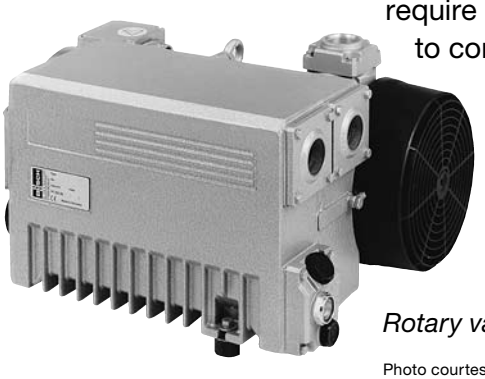
Photo courtesy of Busch Vacuum Technics Inc.

Dry running rotary vane vacuum pumps

Widely used in the woodworking industry they use self-lubricating phenolic vanes that rub against the pump housing as they turn. They run moderately quietly at approximately 80 decibels. Although they require more maintenance and are less efficient than their oil recirculating cousins, they are inexpensive. They are best used to hold down non-porous materials when a good seal is achievable, such as with suction cups.

Oil recirculating rotary vane vacuum pumps

These pumps reach a very high vacuum although at relatively low volumes. Because the vanes slide continuously on an oil film they offer a practically wear free operation. On the other hand, they require an oil separator which is prone to contamination and the oil filters have to be replaced often. These pumps are widely used in the woodworking industry in veneer presses and in some clamping operations.



Rotary vane pump

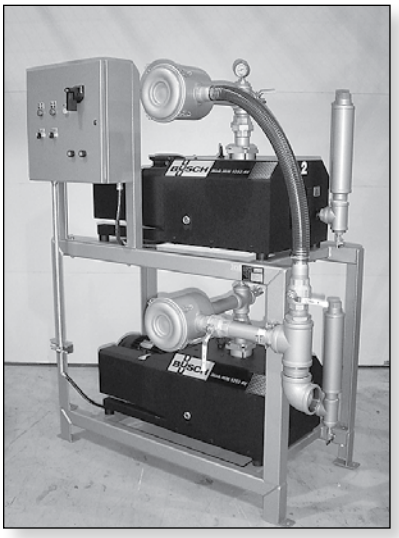
Photo courtesy of Busch Vacuum Technics Inc.

Positive displacement rotary blowers

These types of pumps use either one rotor or two rotors that turn in opposite directions to one another compressing the air as it is exhausted. These blowers are very noisy, approximately 100 decibels and should be kept in a separate enclosed area. These blowers are used mainly in material handling applications as they are not suited for clamping purposes.

Rotary claw vacuum pumps

Also called Roots pumps, these dry running pumps are relatively new and rapidly gaining acceptance in the woodworking industry. Since no parts are in contact with each other or with the housing, these pumps require less maintenance than other models. They are relatively noisy and generate an average level of vacuum but a very good displacement of volume. As such they are very well suited in all kinds of high volume applications.



Two rotary claw pumps mounted in parallel

Photo courtesy of Busch Vacuum Technics Inc.

Rotary screw vacuum pumps

These are the most costly and the noisiest of the lot. As well, they need the most maintenance with regular oil changes and upkeep to sensitive electronic controls. On the other hand, they achieve the best vacuum/flow ratio of all the different pump types.

Liquid sealed pumps

These are also called liquid ring pumps because oil or water is used as a seal between the vanes and the pump housing. As no parts are in contact with each other, they achieve very high vacuum levels while producing very little noise, approximately 70 decibels. They need regular maintenance as their efficiency is greatly reduced

when the water or oil temperature increases. These units are fairly expensive and should be used where high vacuum pressure and moderate volumes of air are needed.

Material Handling

Manual material handling is often the norm in furniture and cabinet shops. This oversight is often at the expense of the manufacturer since the time spent loading and unloading machines often makes up most of the wasted time in a day.

Often, CNC owners will try to trim seconds off a program or even try to run parts at much faster speeds. This will result in marginal savings in time and most often result in poor cut quality. Often they overlook parts and machine idleness and unnecessary material handling in their time analysis.

Most of the efficiencies that can be gained at a CNC work station are in handling material. Whether talking about the methods used to handle material or the strategies used to deal with material handling, large quantities of inventory or work in progress can usually be found all around the shop. Ensuring that raw material gets to the shipping door as a finished product in the best possible time will always have the greatest impact on a manufacturer's bottom line.

Scissor lifts

A simple scissor lift at the end of the worktable is often enough when mostly the same material is being processed all day. When more than one material is used, manufacturers often pre-stage lifts with the right combination of material so the operator can slide the right sheet onto the worktable. Care must always be taken when dragging sheets across each other as this can ruin the surface of the sheet below.

Vacuum lifts

Vacuum lift with tilt option

Photo courtesy of Anver Corp.

Vacuum lifts are a little more expensive than a scissor lift but are also more versatile. They can pick up sheets from different piles around the CNC and give the added ability of removing larger parts from the work table once the machining is done. They are usually mounted on a crane bolted to the floor or wall. Some use high flow vacuum for both the holding and the lifting, while others use an electric winch for lifting and an Air-Vac on a suction cup for holding.

Automated material handling

Automated material handling equipment is mostly found in very large production plants. Automation can vary from a mechanized conveyor system to robotic arms doing most of the loading and unloading of the work.

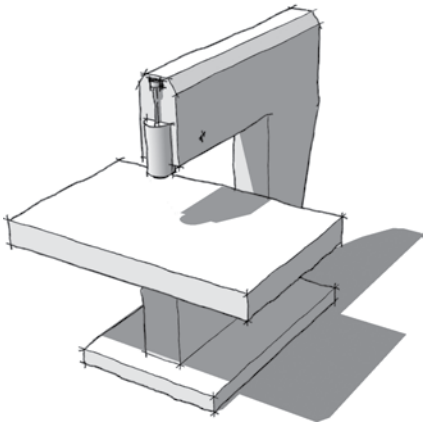
Router Configurations

- X-Y Tables
- Cantilevered
- Moving Table
- Moving Gantry
- Pendulum
- 5-Axis
- Industrial Robot
- Other Categories of CNC Equipment

X-Y Tables

This is a machine style that is seldom used anymore. They can usually be found on smaller machines or in special applications such as for chair legs or for making templates.

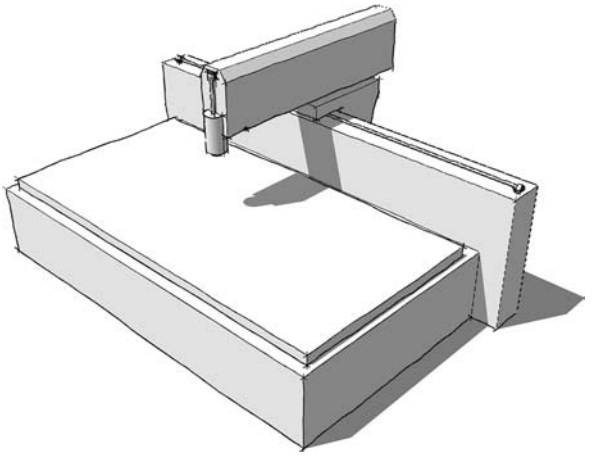
In this configuration, a table that moves both right to left and front to back is mounted under a spindle that moves up and down. The first of these machines was actually a pin router with an X-Y table mounted to it.



X-Y tables have evolved from pin routers

It is quite easy to get a very rigid machine in this manner. However, from a practical standpoint it is limited to rather small table sizes. The spindle must be attached to the machine base by an upright column. The distance from the column to the spindle defines the maximum table width and this distance cannot be too large without making the overall machine structure impractical.

Cantilevered



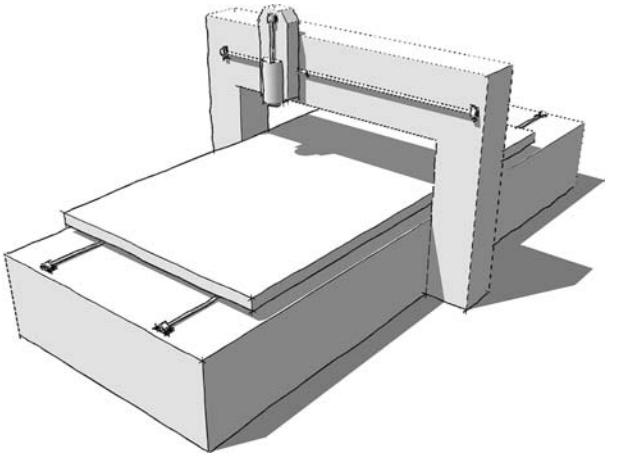
Cantilevered Arm Router

These are usually referred to in the industry as point-to-point machines although only very old machines actually qualify as such anymore.

This configuration has one major advantage. It is easy to load and unload. The table is suspended in front of the operator and all of the operating mechanism is located behind the table. Every part of the table can be easily reached.

Since the arm structure is suspended from only one side, developing a structure that remains rigid becomes quite difficult.

Moving Table



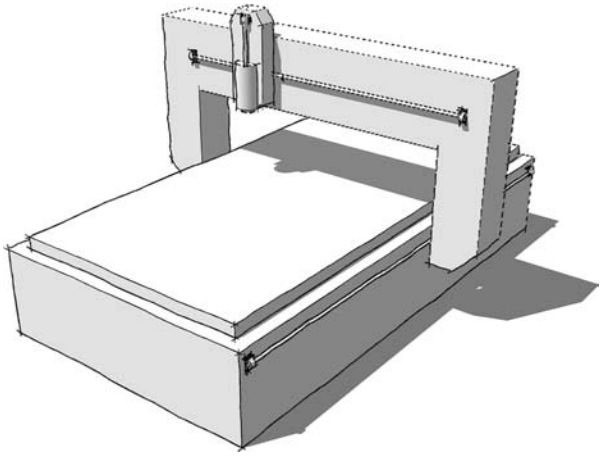
Moving Table Router

The moving table and the moving gantry designs are the most common in industry today.

The moving table machine is more popular than the moving gantry machine, not because it is inherently more stable but because of a control system limitation. A moving table machine has a single lead screw moving the head back and forth on the gantry and a single screw moving the table front to back.

Moving Gantry

A moving gantry machine has the gantry mounted to a rail located on either side of the table. One lead screw moves the head back and forth on the gantry, but two lead screws are required to move the gantry. As a result, the moving gantry machine requires one extra servo motor and drive making it more expensive. Each screw must also have its own independent compensation table which makes it more demanding on the controller.



Moving Gantry Router

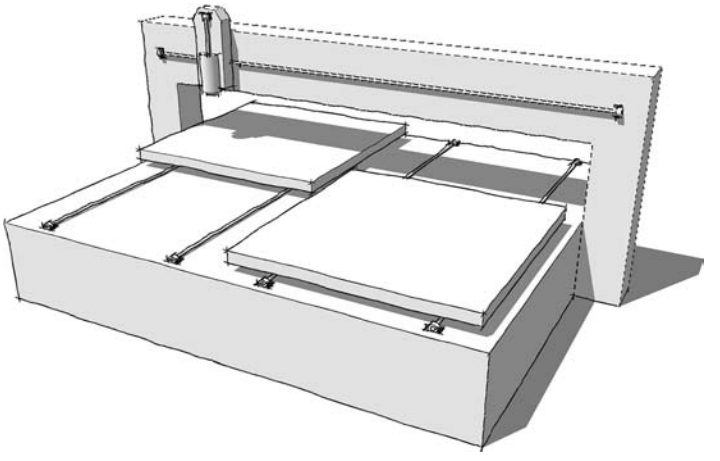
The biggest practical difference between the moving gantry and the moving table construction is that for equal table size, the moving gantry design requires about half the floor space.

A moving gantry machine can generally carry heavier parts than a moving table machine.

This is mostly true when working with stone or metals. When the fixture and work piece weighs thousands of pounds, this can become a problem. In these circumstances it is better to place the fixture and work piece on a fixed table braced to the floor and move the gantry over the work.

Pendulum

Pendulum, or dual table routers are usually seen in high volume applications where maximizing cutting time is key. One table works at a time allowing for setup and parts removal from the other table. In certain cases, both tables can work in tandem allowing for the machining of larger parts.



Pendulum or Double Table Router

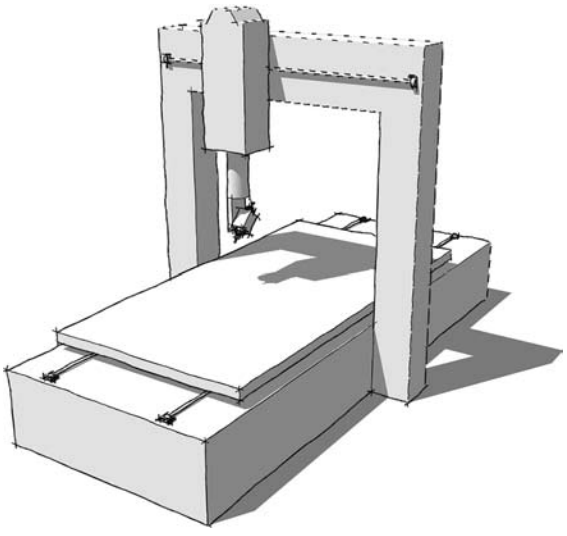
These machines were popular in the early days of CNC routers since price was not an issue. They fell out of favour when manufacturers started making lower cost machines, but are coming back in style now that maximum efficiency is of the essence.

These machines are often seen in a multiple spindle configuration.

5-Axis

5-axis machines were first used in the aerospace industry and used to cost millions of dollars. They soon became sought after by other industries because of their potential for machining large three-dimensional objects.

Both moving table and moving gantry 5-axis CNC designs are commercially available. The vast majority of machines are of the fixed gantry, moving table design.



5-Axis CNC Router

There are several major differences between the 3-axis CNC routers and the 5-axis machines. The biggest difference is that 5-axis machines are generally designed to work on large three-dimensional parts where the 3-axis machines are intended to process primarily flat parts. The gantry, whether it is fixed or moving, must be taller and the z-axis, will have much more stroke than the 3-axis machines, sometimes up to 60 inches (1500 mm) or more.

This greater height does offer larger part processing capability but at a significant cost. As the gantry gets taller and the z-axis gets longer, both accuracy and stability are diminished. This situation can be improved by reducing the acceleration and deceleration of the various axes that affect the gantry, although this will significantly slow the machine down. For this reason alone it is best to try to keep the z-axis and gantry height as low as possible for every application.

Industrial Robot

Industrial robots, once relegated to material handling applications have come a long way. Because of better software applications and their widespread use in many industries, their price is significantly lower.

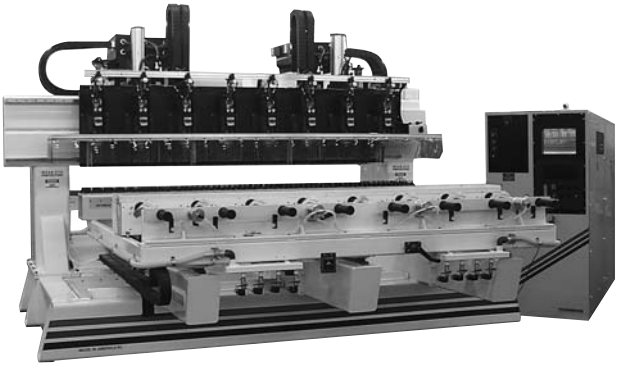
They are well suited to replace 5-axis CNC routers in trimming operations on large parts such as boats and hot-tubs. They can

6-Axis robot fitted with a router spindle

also be very useful in finishing applications as a robot can be made to sand the part, apply the finish and then move it along to the next operation.

These machines cost about $50,000 for the basic machine, plus tooling and integration costs. New applications are being worked on by independent companies as each one is likely to be customized to the customer's particular needs. Expect to see more of these machines in the wood industry in the near future.

Other Categories of CNC Equipment



8-head CNC carving machine

Photo courtesy of Thermwood Corporation

Aside from the omnipresent CNC router, ther are many other applications that use CNC technology. Amongst these are CNC edgebanders, CNC lathes, CNC bandsaws, CNC sanders etc. All these machines use computer controlled motion hence the label CNC.

Software

- **CAD**
- **CAM**
- **Parametric Design**
- **Nesting Software**
- **Post Processors**
- **G-Code**

Software is at the heart of any NC machine. Even the most advanced piece of machinery cannot perform to its full potential without the proper software to make it happen. It is also the area that will require the highest skill set on the path toward CNC success.

There are many levels of software needed to run a CNC router: from the technical drawings to the sales requirements and scheduling, to the actual NC code that makes the axes move. All have a specific role to play in the overall solution.

A new concept is evolving in automated manufacturing circles. It is called “Human Machine Interface” or HMI. This is the means by which the operator (the user) interacts with a particular machine (the system). This concept aims to improve the interactions of the operator with the machine. An example of this is when the operator can visualize the machining operation on the screen and they can change or adjust cutting parameters on the fly in the middle of the operation.

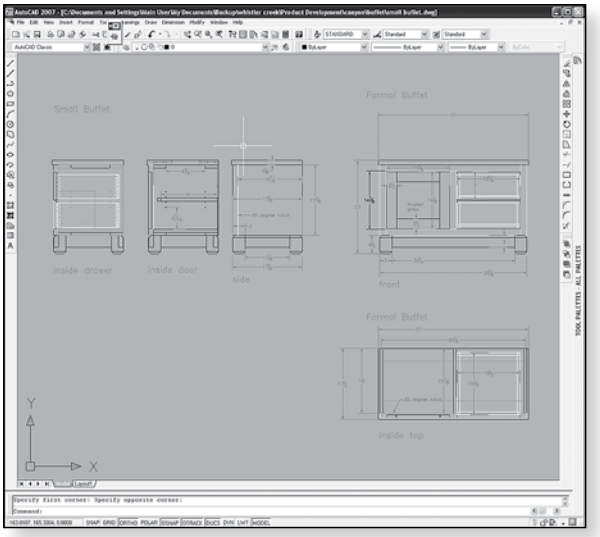
Great progress has been seen in the past decade, and even greater advances can be expected in the years to come. Software and CNC technology are proving to be a fundamental tool in the continued survival of the North American wood products industry.

CAD

The acronym for Computer Aided Design (CAD) originally meant Computer Aided Drafting because of its use as a replacement for traditional drafting.

CAD is used to design, develop and optimize products which include goods used by end consumers or intermediate goods used in other products.

CAD enables designers to lay out and develop work on screen, print it and save it for future editing, saving time on their drawings.



2D CAD program showing line drawing

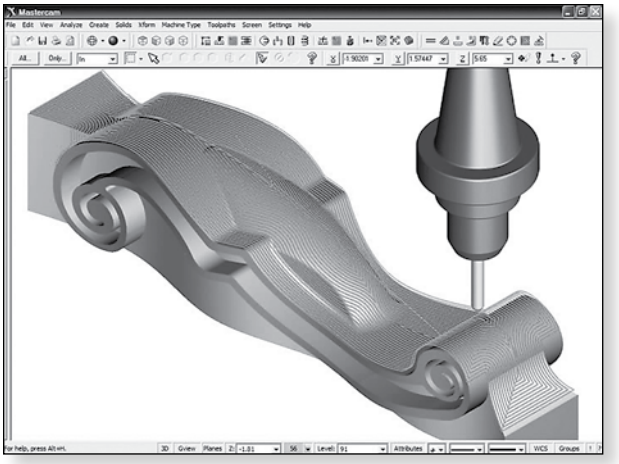
Many different CAD software packages exist, some drawing in 2D, some in 3D, some cater to architects, some to engineers and some are made for the layman. Some are very complex and require a long learning curve, while others are unsophisticated and very intuitive to use. Still others are made with specific products in mind such as kitchen cabinets or doors and windows.

Care must be taken in choosing CAD software so that it corresponds well to needs. It's very easy to waste a lot of time on unnecessary functions in day to day operations. An example of this is if parts are drawn in 3D when only shop drawings are needed. On the other hand, the 3D drawings can be very useful in product marketing.

CAM

Computer Aided Manufacturing (CAM) takes the CAD drawings and helps translate them into manufactured parts by adding tool sequences, machining parameters, cutting speeds, etc.

CAM refers to a wide range of computer-based software tools that assist engineers, tool and die makers and CNC machinists in the manufacture or prototyping of product components.



CAM software simulating machining of complex 3D part

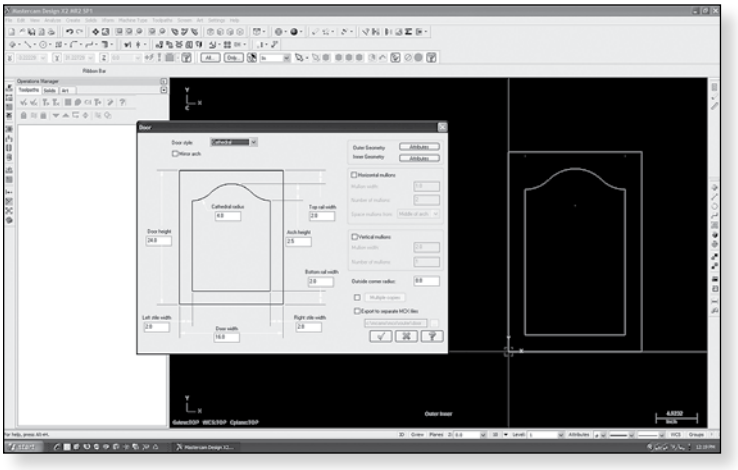
Photo courtesy of CNC Software - Mastercam

Traditionally, CAM has been exclusively considered as an NC programming tool. Although this is most often the case, CAM functions have expanded to integrate more fully with different engineering functions.

The days of programming parts in cryptic G-code on a small monochromatic display at the control are long gone and today's CAM software can offer much more versatility and efficiency.

Parametric Design

Parametric design software has often been associated with very specialized industries but it is becoming more and more widespread.



Parametric software automates the design process

Photo courtesy of CNC Software - Mastercam

An example of this is its use in CNC work centers dedicated to making window frames. In this application, the operator inputs the style and required size of the window and the machine calculates all the parameters needed to produce the parts. The same is true for other types of components, including

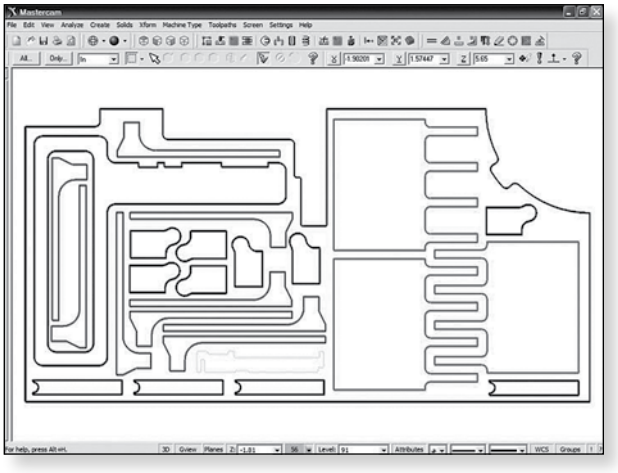
drawer boxes, kitchen cabinet doors and cardboard boxes to name a few.

This software is often associated with a dedicated machine and will not work for producing out of the ordinary parts, however they are most often very productive and outperform some of the more universal programs.

Nesting Software

Nesting or optimizing refers to the process of efficiently manufacturing parts from sheet goods to minimize waste.

Although most nesting is done through the CAM software, there still exist stand alone nesting programs. Some will import part descriptions from other CAD or CAM software and others will also permit the user to import cut sizes directly from sales or spreadsheet software.



Nested parts maximize the use of available material

Photo courtesy of CNC Software - Mastercam

Nesting uses various powerful and intelligent nesting algorithms that rotate and translate part geometries into the most efficient use of the panel surface.

There are two major nesting models. Rectangular or block nesting bounds the shape by a rectangular border and moves the rectangle around the panel. True shape or geometric nesting takes into

consideration the real shape of the part, including holes and protrusions, to find the best arrangement for maximizing raw material usage.

Post Processors

A post processor is a program that translates the centreline data it receives from the CAM software into the NC code that the machine will use to machine the part.

There must be a post processor for each CAM software program and for each CNC machine. Even similar machines of the same make and model require subtle tool shift data that is unique to each machine.

G-Code

G-Code is the language that the CNC understands in order to move its axes and perform operations. Also known as RS-274D, it is the standard for numerically controlled machines and was developed by the Electronic Industry Association in the early 1960's.

G-Code was developed and first used with the original punched paper tape. The basic unit of the program is called a 'block', which is seen in printed form as a 'line' of text. Each block can contain one or more 'words', which consist of a letter, describing a setting to be made, or a function to be performed, followed by a numeric field, supplying a value to that function. Various words can be combined to specify multi-axis moves, or perform special functions.

Descriptors preceded by the percent sign (%) or bound by parentheses are text or comments that are ignored by the machine. Their sole purpose is to add comments and clarity to the code.

G-Code can be entered manually using a text editor but these days it is usually produced by a post processor directly from the CAM software.

```
% TOOL CHANGE T309 1/2 in fin/dwn/cut POCKET iOP: 3
M5  (PRE-TOOLCHANGE STOP)
S18000  (SPINDLE SPEED)
T309 M3
G00 X-.475 Y-33.215 (RAPID X Y)
G00 Z.5
M31    (CHECK UP 2 SPEED)
G00 Z.1
G01 Z-.5 F75.
G01 X-.51 Y-30.14 F380.
G01 X-.475 Y-30.34
G01 Y-33.215
G01 X-.21 Y-33.54
G01 X-.74
G01 Y-29.9389
G03 X-.8162 Y-29.7551 I-.26 J0.
G02 X-.7949 Y-29.7338 I.0106 J.0106
G03 X-.6111 Y-29.81 I.1838 J.1838
G01 X-.21
G01 Y-33.54
G00 Z.5
G00 X-.983 Y-31.9989
```

Sample block of G-code

Accessories

Label printing

This is an option that is becoming more and more popular in the industry especially since CNC machines are becoming more integrated into the whole business formula. The controller can be connected to the sales or scheduling software and part labels are printed once the part is machined. Some vendors use labels to identify left over material for easy retrieval in the future.

Optical readers

Otherwise known as bar code wands, they can be integrated into the controller so that a program can be called by scanning a barcode on the work schedule. This option saves valuable time by automating the program loading process.

Bar code reader facilitates program automation

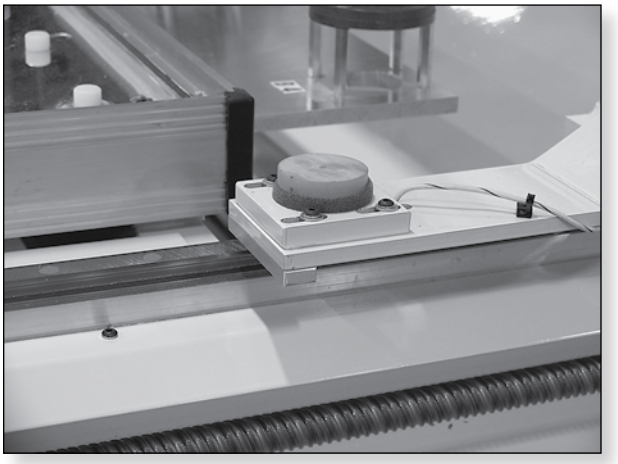
Photo courtesy of Thermwood Corporation

Probes

These measuring devices come in a variety of forms and perform many different functions. Some probes merely measure the surface height to ensure proper alignment in height sensitive applications. Other probes can automatically scan the surface of a three-dimensional object for later reproduction.

Tool length sensor

A tool length sensor acts like a probe that measures the daylight or the distance between the end of the cutter and the surface of the workspace and enters this number in the control's tool parameters. This little addition will save the operator from the lengthy process required each time he changes a tool.



A tool length sensor quickly measures tool daylight

Photo courtesy of Thermwood Corporation

Laser projectors

These devices were first seen in the furniture industry in CNC leather cutters. A laser projector mounted above the CNC work table projects an image of the part about to be cut. This greatly simplifies positioning the blank on the table to avoid defects and other issues.

Vinyl cutter

A vinyl knife attachment is often seen in the sign industry. This is a cutter that can be attached to the main spindle or on the side with a free turning knife whose pressure can be adjusted by a knob. This attachment permits the user to turn his CNC router into a plotter to make vinyl masks for sandblasting or vinyl letters and logos for trucks and signs.

Coolant dispenser

Cool air guns or cutting fluid misters are used with a wood router to cut aluminium or other non-ferrous metals. These attachments blast a jet of cold air or a mist of cutting fluid near the cutting tool to ensure that it remains cool while working.

Engraver

Engravers are mounted to the main spindle and consist of a floating head holding a small diameter engraving knife that turns between 20,000 and 40,000 RPM. The floating head ensures that the engraving depth will be constant even if the material thickness changes. This option if most often found in the sign making industry although trophy makers, luthiers and millwork shops use it for marquetry.

Rotating axis

A rotating axis set along the x or the y axis can turn the router into a CNC lathe. Some of these rotating axes are simply a rotating spindle while others are indexable which means they can be used for carving intricate parts.

Turn a CNC router into a lathe with a rotating axis

Photo courtesy of Thermwood Corporation

Floating cutter head

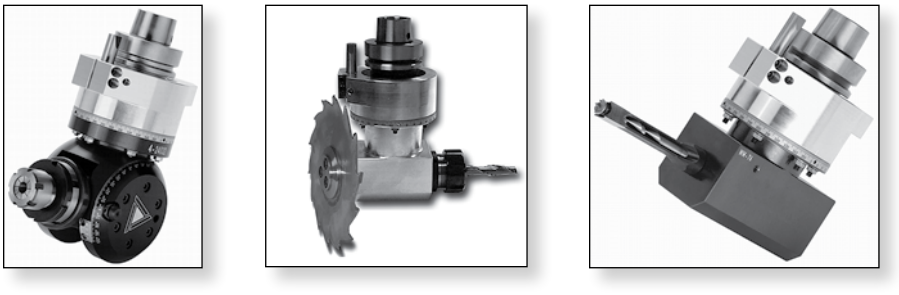
Floating cutter heads will keep the cutter at a specific height from the top surface of the material being cut. This is important when cutting features onto the top surface of a part that might not present an even surface. An example of this is cutting a v-groove on the top of a dining room table.

Plasma cutter

Plasma cutters are an add-on to some machines and allow the user to cut sheet metal parts of varying thicknesses.

Aggregate tools

Aggregate tools can be used for many operations that a straight cutter cannot perform.



Aggregate tools can perform functions that straight cutters cannot

Photo courtesy of Benz Inc.

Justifying the Cost of CNC

The cost of a CNC machine might make most manufacturers nervous but the benefits of owning a CNC router will most likely justify the cost in very little time.

The first cost to take into consideration is the machine cost. Some vendors offer bundled deals that include installation, software training and shipping charges. But in most cases, everything is sold separately to allow for customization of the CNC router.

Light duty

Low-end machines cost from $10,000 to $30,000. They are usually bolt-it yourself kits made of bent sheet metal and use stepper motors. They come with a training video and an instruction manual. These machines are meant for do-it-yourself use, for the signage industry and other very light duty operations. They will usually come with an adapter for a conventional plunge router. Accessories such as a spindle and vacuum work holding are options.

A process dedicated CNC can be a valuable component of a manufacturing cell

Photo courtesy of ShopBot Tools Inc.

These machines can be very successfully integrated into a high production environment as a dedicated process or as part of a manufacturing cell. For instance, one of these CNC's can be programmed to drill hardware holes on drawer fronts before assembly.

Medium duty

Mid-range CNC machines will cost between $30,000 and $120,000. These machines are built of heavier gauge steel or aluminium. They might use stepper motors and sometimes servos; and use rack and pinion drives or belt drives. They will have a separate controller and offer a good range of options such as automatic tool changers and vacuum plenum tables. These machines are meant for heavier duty use in the signage industry and for light panel processing applications.

These are a good option for start-ups with limited resources or manpower. They can perform most operations needed in cabinet making although not with the same degree of sophistication or with the same efficiency.

Industrial strength

High-end routers cost upward of $120,000. This includes a whole range of machines with 3 to 5 axes suited for a broad range of applications. These machines will be built out of heavy gauge welded steel and come fully loaded with automatic tool changer, vacuum table and other accessories depending on the application. These machines are usually installed by the manufacturer and training is often included.

A broad range of machines fit this category

Photo courtesy of Thermwood Corporation

Shipping

Transporting a CNC router carries a considerable cost. With routers weighing anywhere from a few hundred pounds to several tons, freight costs can range from $350 to $3,000 or more, depending on location. Remember that unless the machine was built nearby, the hidden cost of moving it from Europe or Asia to the dealer's showroom is likely included. Additional costs may also be incurred just to get the machine inside once it is delivered as it is always a good idea to use professional riggers to deal with this kind of operation.

Installation and training

CNC vendors typically charge from $500 to $1,000 per day for installation costs. It can take anywhere from a half day to a full week to install and test the router; this cost could be included in the price of buying the machine. Some vendors will provide free training on how to use the hardware and software, usually on-site, while others will charge $500 to $1,000 per day for this service.

The Formula

In the book "Furniture Manufacturing in the New Millennium" by K.J. Susnjara, the author describes how he would justify the cost of buying a CNC machine for a woodworking operation. The formula that he puts forward can be used to compare present processing costs with future costs using a CNC machine.

Processing Cost = Machine Cost + Labour & Overhead + Tooling Cost + Handling Cost

Using this formula and also referring to many websites and magazine articles, it can be concluded that any company of 2 or more workers cutting 15 to 80 sheets a week and selling around $300,000 per year or more should seriously consider purchasing a CNC router.

An example

While it is always hard to justify this kind of capital cost using proven arguments and quantifiable facts, consider the following:

A machine that is fully loaded with a vacuum table, pump, attached computer terminal, automatic tool changer, and additional accessories can cost upwards of $200,000. A lease over 60 months on a $200,000 machine with 10% down and a buy back option of 10% will cost approximately $3,500 per month. All told, that is roughly the same amount of money as a $20 per hour worker.

The Future

- **The New Factory**
- **New Techniques**
- **New Materials**

The New Factory

Wood products' manufacturing, like any other discipline, is in a state of constant evolution. While there is certainly a great deal of turmoil in the industry in North America today, it would be foolish to predict its demise. Those companies that make good use of available technologies such as CNC will have a better chance of survival.

For the last fifty years and maybe more, the industry has remained the same. The methods and the tools in use today have been refined and modernized over time but the industry is essentially the same as it was after the Second World War.

The wood manufacturing industry is steeped in tradition and the old formulas simply don't compute anymore. Competition is no longer in a local marketplace with just one or two shops that make similar products.

The economy and markets are now worldwide. Factories half-way around the world can ship their wares to our client's stores. They benefit from very cheap labour and heavily subsidised raw materials. Even when one factors in shipping costs, their product is less expensive than anything similar that can be made in North America.

Another factor to consider is that the consumer's tastes and habits are evolving very rapidly. They have access to a world of choice through the internet and they can research anything from wood species to styles in an instant. Consumers today are configuring and customizing their purchases online and they expect to receive their orders in very short order.

Can the same stale products of yesteryear continue to be delivered with a long turnaround time of 6 to 8 weeks or more?

The North American secondary wood manufacturing company of the future may look somewhat like this:

It will be a modern manufacturing plant with the latest automated equipment.

This company will be lean. No inventories and the production flow will be fine-tuned so that once an order is started, it doesn't stop until it's in the customers hands, along with the invoice. The production cycle will be measured in days, not weeks.

The product offering will be fully customizable. New product introductions will utilize the principles of mass customization. The manufacturer will stay away from commodity products and his offering will be much differentiated and most likely cater to a niche high-end market.

The manufacturer will sell directly to the end customer and will take advantage of a complete online presence.

New Techniques

As CNC technology becomes more sophisticated, so do the techniques. Three-dimensional machining is becoming commonplace. Combined with portable laser scanning technology and powerful CAM software, intricately detailed carvings and turnings are not only possible but easy to do.

Other simpler procedures are making the life of the modern manufacturer much easier than that of his ancestors. Blind dado joinery, nested dovetail drawer boxes and countless other techniques are making the integration of mass customization into today's factories possible.

High end carvings made to order using CNC technology

Photo courtesy of Art for Everyday Inc.

All these innovations are blurring the line between specializations as well. Indeed, a kitchen cabinet manufacturer today can make children's furniture and office furniture as well as kitchen cabinets and closet organizers.

New Materials

There is an amazing array of new materials available to manufacturers today. The days of knotty pine and red oak as the only two choices are long gone. Lightweight panels, reconstituted veneers, sustainable and low VOC particleboard are only a few of the items that are readily available today. One can buy metal laminates and reconstituted stone that can be cut with a CNC router. The combinations are limitless and are bound only by the limits of the imagination.

Conclusion

To quote a well respected CNC manufacturer:

"CNC machine engineering is a highly complex science. It involves physics, electronics, pneumatics, mathematics and a bunch of other disciplines. There is no scientifically proven best way to design a CNC machine. Every decision, every component is a compromise. In no area of machine design can you gain something without giving up something else."

Remember this when looking to purchase a machine.

Scalloped solid wood cabinet

Photo courtesy of Pacific Woodworking

The only really accurate way to judge a machine is to judge the results.

- How well does the machine actually perform its tasks?
- How good is the quality of the machining it produces?
- How easy is it to use?
- How well does it hold up in production?
- How reliable is it?
- How long will it last?
- How easy is it to upgrade or change?
- What does it cost?
- How much can you rely on the vendor for after sales service?

While it is true that much of the North American wood products manufacturing capacity has now moved to developing countries, the new market opportunities that are now open have never been more plentiful. Find a niche and make it happen.

CNC technology should help a business become more successful and improve the bottom line. The one common fact that has been experienced by countless manufacturers of wood products around the world is that a taste of CNC technology will change a business forever.

Terminology

Absolute zero
This refers to the position of all the axes when they are located at the point where the sensors can physically detect them. An absolute zero position is normally arrived at after a home command is performed.

Axis
A fixed reference line about which an object translates or rotates.

Ball screw
A ball screw is a mechanical device for translating rotational motion to linear motion. It consists of a re-circulating ball bearing nut that races in a precision threaded screw.

CAD
Computer-aided design (CAD) is the use of a wide range of computer-based tools that assist engineers, architects and other design professionals in their design activities.

CAM
Computer-aided manufacturing (CAM) is the use of a wide range of computer-based software tools that assist engineers and CNC machinists in the manufacture or prototyping of product components.

CNC
The abbreviation CNC stands for computer numerical control, and refers specifically to a computer "controller" that reads G-code instructions and drives the machine tool.

Controller
A control system is a device or set of devices that manage, command, direct or regulate the behaviour of other devices or systems.

Daylight
This is the distance between the lowest part of the tool and the machine table surface. Maximum daylight refers to the distance from the table to the highest point that a tool can reach.

Drill banks
Otherwise known as multi-drills, these are sets of drills usually spaced in 32 mm increments.

Feed speed
Or cutting speed is the speed difference between the cutting tool and the surface of the part it is operating on.

Fixture offset
This is a value that represents the reference zero of a given fixture. It corresponds to the distance in all axes between the absolute zero and the fixture zero.

G-code
G-code is a common name for the programming language that controls NC and CNC machine tools.

Home
This is the programmed reference point also known as 0,0,0 represented either as the absolute machine zero or a fixture offset zero.

Linear and circular interpolation
Is a method of constructing new data points from a discrete set of known data points. In other words, this is the way the program will calculate the cutting path of a full circle while knowing only the center point and the radius.

Machine home
This is the default position of all the axes on the machine. When executing a homing command, all the drives move toward their default positions until they reach a switch or a sensor that tells them to stop.

Nesting
Refers to the process of efficiently manufacturing parts from sheets. Using complex algorithms, nesting software determines how to lay out the parts in such a way as to maximize the use of available stock.

Offset
Refers to the distance away from the centerline measurement that comes from the CAM software.

Piggyback tools
This is the term used to refer to air activated tools that are mounted beside the main spindle.

Post processor
Software that provides some final processing to data, such as formatting it for display, printing or machining.

Program zero
This is the reference point 0,0 specified in the program. In most cases it is different than the machine zero.

Rack and pinion
A rack and pinion is a pair of gears which convert rotational motion into linear motion.

Spindle
A spindle is a high frequency motor fitted with a tool holding apparatus.

Spoilboard
Also known as the sacrificial board, it is the material used as a base for the material being cut. It can be made of many different materials, of which MDF and particleboard are most common.

Tool loading
This refers to the pressure exerted onto a tool while it is cutting through material.

Tool speed
Also called the spindle speed, this is the rotational frequency of the spindle of the machine, measured in revolutions per minute (RPM).

Tool diameter offset
This is the measured diameter of the tool. It will be used to determine the distance between the centerline of the edge of the part and the edge of the tool.

Tool length offset
This is the measurement that gives the machine the real distance between the end of the tool and the material to be cut.

Wear compensation offset
In certain cases when the diameter of the tool is bound to change while machining a part, parameters for compensation are given.

Acknowledgement

In making this book

I would like to thank the many people that helped make this book a reality. They provided me with invaluable information and acted as a sounding board in its development.

Special thanks go to:

- Roland Baumeister, FPInnovations
- Scott Burton, ROYCE//AYR Cutting Tools Inc.
- Michael Chimienti, Proficom Financing
- Sheena Fritsvold, NEMI Products
- Kirk Holland, Pacific Woodworking
- Frank Horvath, FS Tool Corporation
- Ken Jennison, FDM Magazine
- Robert Laforest, Busch Vacuum Technics Inc. (Canada)
- Andrew Legault, CNC Automation
- David Lowey, In-House Solutions Inc.
- Dave Minella, ShopBot Tools, Inc.
- Cully Murphy, ANVER Corp.
- Art Raymond, A.G. Raymond & Company Inc.
- Paul Roza, Benz Incorporated
- Sandy Stewart, Stewart & Associates Graphic Design
- Matt Sumner, In-House Solutions Inc.
- Jason Susnjara, Thermwood Corporation
- Gene Veening, ROYCE//AYR Cutting Tools Inc.
- Robert Weaver, SCM Group
- Norine Young, FPInnovations

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"Upholstery Manufacturing Best Practices: Frame Design & Production" by Eric Hill published by Nester Software Technologies.

"Machine Evaluation Tips and Flexible Manufacturing Cells", presented by Craig Sexton of SCM Canada.

"Cours 7 : Machines à Commande Numérique" and "Cours 8 : Applications novatrices des machines à commande numérique Choix et operation" presented by Torsten Lihra of Forintek Canada Corp., Quebec and Rado Gazo of Purdue University, West Lafayette, Indiana and Robert Beauregard of Université Laval, Quebec.

"Introduction aux machines à commande numérique (Théorie complémentaire aux Notes de cours)" by Benoit St-Pierre, Université Laval.

"Techno Book of CAD/CAM/CNC 3rd Edition" by Techno, Inc. CNC Router Systems, 2101 Jericho Turnpike, New Hyde Park.

"Vacuum Technology in the Woodworking Industry" by Uli Merkle, Dr.-Ing for K. Busch GmbH.

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Alain Albert is an Industry Advisor to the wood manufacturing sector for FPInnovations – Forintek Division.

Alain started his career studying architecture at the University of Waterloo in Ontario when he developed a passion for furniture. Alain went on to start his own industrial design company where he helped countless furniture manufacturers in Quebec with their new product developments.

As an industrial designer, Alain earned many prestigious design awards and his work was published in countless design magazines. He was accepted as a Chartered Professional Member of ACID (Association of Canadian Industrial Designers), ADIQ the Quebec chapter and BCID the British Columbia Industrial Design Association.

Alain started his own furniture manufacturing plant in Montreal in 1995 and purchased his first CNC machine. After he sold his company in 1999, Alain moved on to work as a designer and a production manager for many furniture related manufacturers across the country where he was exposed to many brands and models of CNC machines.

Cover photo courtesy of Thermwood Corporation

Printed on recycled paper.
Contains a minimum of 10% post-consumer fibre.

$19.95 CAN

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