What Do You Need to Know About CNC Routers?

In this article, we will discuss the basic things to consider with CNC routers for beginners. This will include the definition of parts, tools, accessories, software, CNC programming, as well as the setup, installation, and operation of CNC routers, as well as anything pertaining to the machines themselves.

Table of Contents

Introduction

A CNC router is a machine kit, which can be controlled via a computer numerical control. CNC routers are commonly employed for all kinds of different cutting purposes and can be used on various hard materials such as wood, composites, aluminum, steel, plastics, and foams. As one of the many kinds of tool that has a computer numerically controlled (CNC) variant, CNC routers are very similar in concept to CNC milling machines.

CNC routers come in many configurations and sizes, from small home-style "desktop" CNC routers to large "gantry" CNC routers used in industrial settings, such as boat-making facilities. Despite there being many different configurations available, there are certain specific components that apply to almost all CNC routers. These will usually comprise of such parts as; a dedicated CNC controller, one or more spindle motors, multiple AC inverters, and a working surface/table.

As a general rule, CNC routers are available in 3-axis and 5-axis CNC formats.

CNC routers are usually operated via a computer, or some other, similar form of smart device, with coordinates being uploaded onto the machine controller from a separate program. CNC router owners often have two software applications – one to make designs (CAD) and another to translate those designs into a set of instructions that can be functionally read by the machine (CAM).

Just as with CNC milling machines, CNC routers can be controlled directly using manual programming. However, the CAD/CAM system lends itself to wider possibilities for contouring, which is defined as creating a fine finish on an uneven or largely irregular surface. This speeds up the programming process and, in some cases, helps to create programs whose manual programming would be commercially impractical, if not altogether impossible.

CNC routers can be very useful when carrying out identical, repetitive jobs. This is because they typically produce consistent and high-quality work, which improves factory productivity. In fact, using a CNC router can reduce waste, frequency of errors, and thus the amount of time a finished product can take to find its way to market.

CNC routers tend to lend extra flexibility to most manufacturing processes. They can be used in the production of many different items, such as door carvings, interior and exterior decorations, wood panels, sign boards, and wooden frames and moldings. In addition, they can be used on musical instruments, furniture, several forms of appliance, and so on.

Another useful aspect of the CNC router is that it makes the thermo-formation of most plastics much easier, by automating – and thus streamlining – the trimming process. CNC routers ensure that parts produced in industrial settings are easily and accurately replicable, which helps to keep factory output at optimal efficiency.

Introduction to Numerical Controls

Numerical control technology, as it is known today, emerged in the mid-20th century. It can be traced all the way back to 1952, the U.S Air Force, a certain fellow named John Parsons, and the esteemed Massachusetts Institute of Technology (MIT) in MA, USA. However, CNC tech was not actually applied to large-scale production and general manufacturing until the early 1960s. In fact, the real boom came around the year of 1972, and again decade later, with the introduction of affordable microcomputers. If you wish to learn more on this fascinating subject, the history and development of CNC technology has been well documented in many publications and documentaries available online.

In the manufacturing field, and particularly in the area of metal working, Numerical Control technology is practically considered a revolutionary concept. Even in the years before computers became a standard fixture for every company, and in most homes, machine tools equipped with Numerical Control systems had already found their way into the public domain. Through the modern evolution of microelectronics (and ceaseless computer development), Numerical Controls have been significantly impacted. This, in turn, has brought many noticeable changes to the manufacturing sector in general, and the metalworking industry in particular.

What is “Numerical Control”?

In various publications and articles, many different descriptions have been employed over the years, in order to truly define what Numerical Controls are, and how they can be used. Nevertheless, many of these definitions share the same idea and basic concept, just using different wording – so do not be put off or confused if you see what appear to be disparate descriptions online.

The vast majority of the known interpretations on Numerical Controls and their usage can be summed up into this single, relatively simple statement:

Numerical Controls are defined as; the operation of machine or smart tools by means of a specifically encoded set of instructions, which can be input to the machine control system itself.

These instructions can be combinations of the letters of alphabet, digits and selected symbols (a decimal point or the percent sign, for example), or anything else that can be used as code. All instructions will generally be written in a logical order and using a pre-established and predetermined form. Careful and diligent sequencing of instructions is absolutely necessary for producing parts accurately in an industrial setting, and is usually referred to as an NC program, CNC program, or a part program. One of the advantages of such a program is that it can be stored for a future use and used repeatedly to achieve identical machining results at any time.

What are the advantages of using numerical control?

What are the main advantages of numerical controls?

It is important to know which areas of machining can benefit from numerical controls and in which areas it is better to use more conventional methods. It is absurd to think that a two horsepower CNC mill could possibly manage a job that is usually done on a manual mill that is twenty times as powerful. Equally unreasonable are high expectations of improvement to cutting speeds and feed rates on a conventional machine that does not typically achieve those rates. In most cases where machining and tooling conditions are more-or-less the same, cutting times should only vary sparingly.

Some of the major areas where the CNC users can and should expect to see obvious improvement are as follows:

1. Setup time reduction.
2. Lead time reduction.
3. Accuracy and repeatability.
4. Contouring of complex shapes.
5. Simplified tooling and workholding.
6. Consistent cutting time.
7. General productivity increase.

Each of these areas offers only a small window for potential improvement. Individual users will experience different levels of tangible improvement, depending on which products are actually manufactured on-site, the CNC machine(s) used, and the setup methods employed. Even factors such as the complexity of fixtures, quality of cutting tools, management philosophy, and engineering design, as well as experience level of the workforce, and individual attitudes come into play, along with many other key aspects.

Setup time reduction

In certain situations, the setup time for a CNC machine can be reduced, and in some cases really quite dramatically. It is important to realize that setup is (at least generally speaking) a largely manual operation, and greatly dependent on the performance of the CNC operator, and general practices at the associated machine shop. Setup time is unproductive, but highly necessary as it is considered as part of the overhead costs of doing business. To keep the setup time to a minimum should be one of the primary considerations of any machine shop supervisor, programmer, or operator.

Because of the design of CNC machines, setup times are not usually a major problem. Modular fixturing, standard tooling, fixed locators, automatic tool changing, and other advanced features make the setup time more efficient than any comparable setup of a conventional machine. Thus, with a decent knowledge of modern manufacturing, productivity can be increased significantly – often in more ways than one.

The number of parts machined during each setup can also prove extremely important in order to properly assess the cost of setup, with one of the key factors being the amount of time it takes. If a great number of parts are machined in one setup, the setup cost per part can be very insignificant. A very similar level of reduction can be achieved by grouping several different operations into a single setup. Even if the setup time takes marginally longer in these cases, it can easily be justified when compared to the time required to setup most conventional machines.

Lead time reduction

Once a part program is written, proven, and approved, it is ready to be used again in the future, even at relatively short notice. Despite the fact that lead time for the first run usually takes noticeably longer, that quickly begins to tail off for any subsequent runs, before eventually reaching close to nothing. Even if there is an engineering change that severely compromises part design, requiring the program to be modified, it can usually be done quite quickly, which in turn reduces lead time.

Long lead time, which is required to design and manufacture several special fixtures for conventional machines, can often be reduced by preparing a part program and the use of simplified fixturing.

Accuracy and repeatability

The high degrees of accuracy and repeatability achieved by modern CNC machines have been the largest benefits achieved for many users. Whether part programs are stored on a disk, in a computer’s memory banks, or even on a tape (the original method), they always remain the same. Any program can be changed at will, but once approved, no further changes are usually required again, nor any other form of input of any kind. Most programs can be reused as many times as needed, without losing a single bit of the precious data they contain. Though it is true that programs have to account for such interchangeable factors as tool wear and operating temperatures, and they have to be stored safely, but generally very little interference from the CNC programmer or operator will be required. The high accuracy of CNC machines and their reliability allows high quality parts to be produced consistently time after time.

Contouring of complex shapes

CNC lathes and machining centers are capable of contouring (which is creating a fine finish on an irregular surface) in a whole different variety of shapes. Many CNC users acquired their machines to be able to handle advanced movements and create complex parts in such a way. Good examples are CNC applications used in both the aircraft and automotive industries. They use some of the same forms of computerized programming, which is virtually mandatory for the creation of any three-dimensional tool paths.
Complex shapes, such as molds for example, can be manufactured without additional time and resource needing to be expended into making a model that needs to be traced. Mirrored parts can be triggered at literally the switch of a button, as can templates, wooden models, and other pattern making tools of variable design.

Simplified tooling and work holding

Many standard, or even homemade, tools that sit cluttering up the benches and drawers surrounding a conventional machine can be eliminated by using standard tooling. This even applies to those that are specially designed for numerical control applications. Multi-step tools such as pilot drills, step drills, combination tools, counter borers, and many others can be replaced with several individual standardized CNC tools. These tools are often cheaper and easier to replace than special and nonstandard versions, making them both specific to the job at hand – while maintaining cost effectivity.

This is important, in part because cost-cutting measures have forced many tool suppliers to keep a low or even a nonexistent supply of replacement parts, which in turn can hinder productivity. Standard, off-the shelf tooling can usually be obtained faster than nonstandard tooling.

Fixturing, and workholding, for CNC machines both have essentially only one major purpose – to hold a workpiece rigidly, locked in the same position so that all parts within a batch can be replicated accurately. Fixtures designed for CNC work do not normally require jigs, pilot holes, or any other form of hole-locating aid.

Cutting time and productivity increase

The cutting time on a CNC machine is most commonly known as the cycle time, and is almost always consistent, with associated timescales generally not fluctuating either way. Unlike conventional machining, where the operators skill, experience, and levels of personal fatigue are subject to change, CNC machining is controlled via a computer. The small amount of manual work required is largely restricted to the setup, including the loading and unloading of any attachable or customizable parts.

For large batch runs, the high cost of the unproductive time is spread among many parts, making it less significant. The main benefit of this consistent cutting time is most evident during repetitive jobs, where the production scheduling and work allocation for individual machine tools can be allocated very accurately.

The main reason companies often purchase CNC machines is to reduce the associated cost of a project – and it is a serious investment. Having a competitive edge is always on the mind of every plant manager and numerical control technology offers excellent means to achieve a significant improvement in multiple areas. By increasing manufacturing productivity and the overall quality of the machined parts, managers can often expect to achieve a large boost to overall efficiency.

Just like any other form of expensive and potentially dangerous manufacturing tool, CNC machines must be used wisely and carefully. As more and more companies use this type of technology, just purchasing and using a CNC machine does not offer the extra edge anymore, leading to experimentation when it comes to workload. Thus, the companies that get ahead are the ones that know how to use the technology both efficiently and competitively in the modern global economy.

To achieve a sharp increase in overall productivity, it is essential that users understand the fundamental principles upon which CNC technology is based. These take many different forms; from understanding electronic circuitry, to complex ladder diagrams, to computer logic, and metrology, as well as machine design, principles, and practices, just to name a few. As follows, each of these practices have to be studied and mastered by the person in charge of the operation.

In this handbook, the emphasis is on the topics that relate directly to CNC programming and understanding the most common CNC machine tools. This includes the machining centers themselves, as well as lathes used (sometimes also called turning centers). The amount of consideration that goes into part quality should be of utmost importance to any programmer or machine tool operator. This is why approach is heavily referenced in this handbook, as well as numerous other examples found online.

The differences: NC and CNC technology

If we adhere strictly to the terminology, there is a slight difference in the meaning of the abbreviations NC and CNC. The NC stands for an input which uses Numerical Control technology, whereby the abbreviation CNC stands for the newer Computerized Numerical Control technology — a modern spin-off of its older relative. However, in modern times, CNC is the preferred abbreviation. To further clarify the proper usage of each term, please conduct additional research of the major differences between NC and CNC systems online.

Both systems perform similar tasks, namely manipulation of data for the purpose of machining parts and pieces for industrial use. In both cases, the internal design of the control system contains logical instructions that process data. However, it is at this point that the similarities end.

An NC system (as opposed to a CNC system) uses fixed logical functions, meaning those that are built-in and permanently wired within the existing control unit. These are functions that cannot be changed by the programmer, by the machine operator, or any other individual using the device. Because of the unchangeable nature of writing Numerical Control code, NC control systems can interpret part programs easily and quickly. However, they do not allow for any changes to be made on-site or while being operated, as these changes must be made away from a separate device (typically in an office environment, and using a computer). Also, NC systems require the compulsory use of punched tapes for input of program information – in a process not entirely dissimilar from the punch card technology that developed for weaving looms in the 1800s.

A modern CNC system, unlike older NC systems, rely entirely on internal microprocessors (i.e. computers) for program information input. These computers contain memory registers that store a variety of different routines, each capable of manipulating logical function and allowing for the administration of controls. This essentially means that a part programmer, or any other machine operator, can easily change the program that runs the controls on-site, producing near instantaneous results. This inherent flexibility is the greatest advantage of CNC systems and probably the key element that has contributed to such a wide use of the technology in modern manufacturing terms. CNC programs, and the logical functions used to operate them, are stored on special computer chips, which contain software instructions. In contrast to NC systems, CNC system is generally synonymous with the term “softwired,” as they use software inputs rather than hardware connections (such as wires) to control their function.

When attempting to convey information on a particular subject that relates to numerical control technology, it is customary to use either the term NC or CNC. Bear in mind that NC can also mean CNC in general terms, but CNC can never refer to the older technology, as CNC is a form of NC – but NC is not a form of CNC. The letter “C” stands for computerized, and it is not applicable to the hardwired system. Almost all control systems manufactured today are of the CNC design, barring a few examples usually made for the purpose of demonstration. Abbreviations such as C&C, or CandC, are not correct and reflect poorly on the user, as it becomes easily apparent that the speaker/writer is unaware of the conventional terminology – and therefore probably unfamiliar with CNC technology.

The must knows: CNC terminology

Absolute zero

This refers to the position of all the axes (which, in this case, refers to the plural form of “axis”) when they are located at the point where the sensors can physically detect them. An absolute zero position is normally arrived after a home command is executed by the user, which is mentioned below.

Axis

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

Ball screw

A ball screw is a mechanical device used for translating rotational motion into linear motion. It essentially consists of a ball bearing nut which imparts a circular motion onto a precision threaded screw, allowing it to turn quickly and efficiently, with the ball essentially acting as a conventional nut.

CAD

Computer-aided design (CAD) is the use of a wide range of computer-based tools, used to assist engineers, architects, and other design professionals in their design projects and 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 manufacturing or prototyping process of product components.

CNC

The abbreviation CNC stands for computer numerical control and refers specifically to a computer "controller" that reads the G-code instructions used to drive several different forms of machine tool.

Controller

A control system is a device or series of devices that are used to manage, command, direct, or regulate the behavior of other devices and systems.

Daylight

This is the distance between the lowest point/part of the tool and the machine table or working surface, creating a registerable gap. 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

Feed cutting speed refers to the amount of distance a cutting tool can cover across the surface of the part it is operating on, in a set amount of time. In literal terms, it means the velocity required by the tool during a single revolution of the spindle, which is mentioned below.

Fixture offset

Fixture offset refers to a data coordinate or value that the user specifies and then applies to the path of a tool they are operating. This enables them to efficiently shift the toolpath, without the need for any form of recalculation, allowing the machine to be used in a new position.

G-code

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

Home

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

Linear and circular interpolation

Linear and circular interpolation refers to the method of constructing new data points from a discrete set of pre-existing data points. In other words, this represents the way a CNC program can calculate a cutting path in a full circle, despite only knowing the center point and the radius.

Machine home

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

Nesting

Nesting refers to the process of efficiently manufacturing parts from sheets of inorganic material, or in some cases even organic materials such as wood. By using complex algorithms, nesting software helps determine how to lay out parts in such a way as to maximize the use of any available stock.

Offset

Offset quite simply refers to the optimal distance required between the drill mechanism/cutting apparatus and the working surface or table for proper functionality. This is calculated using the centerline measurement provided by the CAM software.

Piggyback tools

Piggyback tools are air activated tools mounted alongside the main spindle.

Post processor

Any software that provides some final processing to data, such as formatting it for display, printing or machining is considered to be a post processor.

Program zero

Program zero is the reference point 0, 0 specified in the program. In most cases it is different than the machine zero to allow programmers to easily differentiate between the two.

Rack and pinion

A rack and pinion are 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. This is what the "router" part of a CNC router actually refers to, as it is the motor that rotates the cutting apparatus – usually at extremely high speeds. As such, the spindle is without doubt one of the most crucial and core elements of a CNC router.

Spoilboard

Also known as the sacrificial board, a spoilboard refers to the material used as a base for any material being cut. It is usually made of many different materials, of which MDF and particleboard are perhaps the most common.

Tool loading

This refers to the pressure exerted onto a tool while cutting through material.

Tool speed

Sometimes called spindle speed, tool speed is the rotational frequency of the spindle on the machine, measured in revolutions per minute (RPM).

Tooling

Tooling, surprisingly enough, is often the least understood aspect of CNC equipment. Given the fact that it is the single element that will most effect the quality of cut and the cutting speed, operators should spend more time exploring this subject. Tooling refers to the different cutting devices that can be used for a CNC router, which usually come in three different forms of material; high speed steel (mentioned below), carbide, and diamond.

High speed steel (HSS) tooling

HSS is the sharpest of the three materials used in CNC router tooling, and also the least expensive. However, it wears out the fastest too, and should only be used for the drilling or cutting of non-abrasive materials. Thus, HSS tools often require frequent changes and sharpening and, for that reason, they are usually used in cases where the operator will need to cut a custom profile in-house for a special job or request.

Carbide tooling

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 its crystalline structure varies greatly between the various different manufacturers of these kinds of tools. As a result, these tools react differently to variable heat, vibration, impact, and cut loads.

Generally, low-cost generic carbide tools will wear and chip more rapidly than higher priced name brands, as you might expect.

In order to initially create the tool, silicon carbide crystals are embedded in a cobalt binder and slowly heated up. When the tool is fully heated, the cobalt binder loses its ability to hold on to the carbide crystals and it becomes dull and lifeless. Simultaneously, the hollow space left by the missing carbide fills up with contaminants from the material being cut, which amplifies the overall dulling process.

Diamond tooling

This category of tooling is expensive, but it has come down in price in the last couple of years. Diamond has a remarkable resistance to abrasive material, making it ideal for cutting all sorts of substances, such as high-pressure laminates or MDF board. Some claim that it will outlast carbide, with up to 100 times the lifespan. However, diamond tipped tools are brittle, and prone to chip or crack if hit with an embedded nail or hard knot. Some manufacturers use diamond tools for rough cutting abrasive materials, before switching to carbide or HSS tooling for the finishing process.

Tool geometry

Shank

The shank is the part of the instrument secured in place by the tool holder. The shank will generally bear no evidence of machining, as it must be kept free of contamination, oxidation, and scratching.

Cut diameter

This is the diameter or the width of fissure that the tool will produce when cutting.

Length of cut

This is the effective cutting depth of the tool, indicating how deep the tool can cut into any given material.

Flutes

The number of flutes on a cutter is important for determining its chip load, as it is the part of the tool that extracts the material using a spiral, or corkscrew-like motion.

Tool profile

There are many different profiles of tools that can be used for a CNC router. The main ones to consider are as follows; up cut and down cut spirals, compression spirals, rougher/finisher, low helix, and straight cut tools. All of these come in a combination of one to four flutes (which are explored in greater detail in the above section).

Up cut spirals tend to cause chips to fly upward out of the cut, which can prove useful when doing a blind cut or when drilling straight down. The geometry of such a tool does, however, induce and upward lifting motion – and tends to tear out the top edge of the material being cut.

As follows, down cut spiral tools will often push chips of loose material downward into the cut. In certain situations, this improves how securely a part can be held in place, but is prone to cause clogging, and even overheating in some extreme cases. This tool will also tend to tear out the bottom edge of any material being cut, unless said material is extremely robust.

Both the up cut and down cut spiral tools come with roughing, a chip breaker and/or what is known as a finishing edge.

Compression spirals are a combination of up cut and down cut flutes.

Compression tools push the chips of loose material away from the edges being cut, and towards its center. They are commonly employed when cutting double sided laminates or when torn out edges become a costly or repeated problem.

Low helix (or high helix) spiral bits are used when cutting softer materials such as plastic and foam, and also as an aide to productivity when welding and chip evacuation are critical.

Chip load

The most important factor for increasing CNC router tool life is to dissipate the heat that is absorbed via its surface, or from its internal components. The fastest way to achieve this is by cutting more material, rather than by going slower. Chips extract more heat away from the tool than dust particulate does as, in addition, rubbing the tool against a material tends to cause friction, which can quickly translate into heat.

Another factor to consider when trying to improve tool life is how to efficiently keep the tool, the collet, and the tool holder clean; free of dust/dirt deposits or corrosion. This reduces any imbalances or other imperfections caused by badly stored and exposed tools.

In basic terms, the quantity of any given material removed by each tooth of the tool being used to cut it, is quite simply called the Chip Load. The formula for calculating chip load is as follows:

Chip load = Feed rate divided by RPM divided by the number of flutes in operation.

When the chip load is increased, tool life is thereby increased as well, while simultaneously decreasing its cycle time. Furthermore, a broad range of different chip loads can achieve a finish with an edge of remarkable quality. This is why it is best to refer to your tool manufacturers chip load chart, in order to find the best number for you to use. Most recommended chip loads will range between 0.003" and 0.03" or 0.07 mm to 0.7 mm depending on your preferred metric.

Who are the personnel needed for CNC?

Computers and machine tools have no inherent or natural intelligence; they cannot think, they cannot even evaluate their station in a rational way. Only people possessed of a certain set of skills and knowledge can do that, despite the advances in the AI sector in recent years. In the field of numerical control, these skills are usually in the hands of two key people – one involved with the programming, the other doing the machining. Their respective numbers and duties typically depend on which company employs them, based on; product preference, company size, and even which products they manufacture. However, each position is quite distinct from the other, though many companies combine two functions into one, often called a CNC programmer/operator.

CNC Programmer

The CNC programmer is usually the person on-site who has the largest amount of experience working in a CNC machine shop. This person will often be responsible for the success of all numerical control technology used throughout the plant. Equally this person can be held responsible for problems related to any CNC operations, so the position can come with a great burden of duty placed upon it.

The specific tasks required of a CNC programmer may vary, as they are also responsible for a variety of different activities that relate directly to the effective usage of CNC machines. In fact, this person will often be held accountable for the production and quality of all CNC operations, whether the outcome is positive or negative.

Many CNC programmers are experienced machinists, who have had a practical, hands-on experience as machine tool operators long before entering the realm of CNC machine operation. They often know how to read technical drawings to a professional standard, which allows them to comprehend the engineering intent behind the design and execute the necessary path efficiently. This practical experience is the foundation of such an operator's ability to machine parts in an industrial environment, or even an office environment, if necessary.

A good CNC programmer must be able to visualize all tool motions and recognize all the potential limiting factors that may be involved during a project. The programmer must also be able to collect, analyze, process, and logically integrate all relevant data into a single, cohesive program. In simple terms, a CNC programmer must be able to decide upon the best manufacturing methodology in almost all regards and respects, at least where it pertains to the use of CNC technology.

In addition to machining skills, a CNC programmer is required to have an understanding of all mathematical principles. These will include such fundamental basics as the application of equations, solutions of arcs and angles, and a knowledge other geometrical and algebraic solutions. Equally important is the understanding of trigonometry as, especially with computerized programming, an underlying knowledge of more manual programming methods can be absolutely essential to thoroughly comprehend computer output, and the control of this output.

The last, but equally important, quality of a truly professional CNC programmer is their ability to listen to other people, and communicate directly – the engineers, the CNC operators, and especially the managers. A good CNC programmer must be flexible in order to offer a high level of programming quality to a project, so good time management and listing skills are also invaluable.

CNC Machine Operator

The position of CNC machine tool operator is essentially complementary to a CNC programmer. In some cases, a single person will actually fill both positions and act as both programmer and operator, as is the case in many small shops and businesses. This is in part because the majority of duties performed by a conventional machine operator have now been transferred to the CNC side of each operation, which gives the CNC operator many unique responsibilities.

In typical cases, a CNC operator is responsible for the tool and machine setup, the changing of parts, and often even for some in-process and on-site inspection. Many companies expect quality control to be performed at the machine - and the operator of any machine tool, manual, or computerized, is generally held responsible for the quality of the work done on their machine. One of the most important responsibilities for a CNC machine operator is to report findings on each program to the programmer and help to propose possible solutions where possible.

Even with the best knowledge, skills, attitudes, and intentions, a "final" program can always be improved and worked upon to ensure optimal efficiency. As the CNC operator is generally the one who is the closest to the actual machining, they know precisely what such improvements might entail, and how to execute them seamlessly.

What accessories are needed for CNC?

Label printing

This is the option that is rapidly becoming the most popular within the industry, especially since CNC machines are becoming more integrated into most standard, accepted business models. The controller can be connected to the sales or scheduling software, and any labels for parts are printed once they are machined, to allow for rapid and efficient identification. In fact, some vendors use labels to identify left over material for easy retrieval in the future, should this become necessary.

Optical readers

Otherwise known as bar code wands, optical readers can be integrated with a controller, so that its programs can be easily recalled by scanning a barcode on the work schedule. This option saves valuable time by automating the program loading process.

Probes

These measuring devices come in a variety of forms, and therefore perform many different integral functions. Some probes merely measure a surface’s height to ensure proper alignment for height sensitive applications. Other probes can automatically scan the surface of a three-dimensional object for later reproduction, should this be needed for whatever reason.

Tool length sensor

A tool length sensor acts like a probe, except that it measures daylight, or the distance between the end of the cutter and the surface of the workspace. The tool length sensor enters the value (or number) generated into the control's tool parameters. This little addition will save the operator from the lengthy process that is required of them each time they change a tool.

Laser projectors

These devices were first seen in the furniture industry in the form of CNC leather cutters. A laser projector mounted above a CNC worktable will project an image of the part about to be cut, allowing for greater magnification, and thus engendering a deeper understanding of the task at hand. This greatly simplifies the positioning of a material upon the table or surface which it is placed, in order to avoid defects, and other common issues.

Vinyl cutter

Vinyl knife attachments are often used by the sign industry, as this is a cutter that can be attached to the main spindle. Alternatively, vinyl attachments can be fixed onto the side of a cutter using a free-turning knife – whose pressure can be adjusted via a dial. 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 frequently used with a wood CNC router in order to cut aluminum or some other non-ferrous metal. These attachments blast a jet of cold air (or a mist of cutting fluid) near the cutting tool, to help ensure that it remains cool while working.

Engraver

Generally speaking, engravers are mounted to the main spindle of a CNC router and consist of a floating head holding a small diameter engraving knife – one that can turn between 20,000 and 40,000 RPM. A floating head ensures the engraving depth will be constant even if the thickness of the material changes while being worked. This option is most often found in the sign making industry again, though trophy makers, luthiers, and millwork shop's still use it for marquetry, as well.

Rotating axis

A rotating axis, set along its X or Y axis, can essentially turn almost any router into a CNC lathe. Some of these rotating axes are simply a form of rotating spindle, while still others are "index-able," which means they can be used for carving much more intricate parts.

Floating cutter head

Floating cutter heads are used to keep a cutter at some pre-specified height and separate from the top surface of a material being cut. This is important when some form of cutting is required on the top surface of a part, and one that might not present an even surface of any kind. Imagine cutting a V-shaped groove on the top of a dining room table, for example, and then apply this to an industrial setting.

Plasma cutter

Plasma cutters are an extension that can be used by some machines, lending a user the ability to cut sheet metal parts into pieces of varying thicknesses.

Aggregate tools

Aggregate tools can be used for many different operations, and one's that a straight cutter cannot easily provide, or in some cases perform at all.

Conventional and CNC Machining explained

What makes CNC machining superior to other, more conventional methods? And is it even superior at all? Where are the main benefits? If the CNC and the conventional machining processes are compared, a common general approach to machining a part will emerge:

1. Obtain and study the preview designs, if applicable.
2. Select the most suitable machining method for the task at hand.
3. Decide on an appropriate method of workholding, which is a general term used to describe the act of holding a part in a fixed or immobile position for the purpose of fabrication.
4. Select the cutting tools best suited for the selected area of work.
5. Establish speeds, feeds, work times, and security measures.
6. Begin machining the part using the CNC router.

This basic approach is actually best suited for both types of machining, NC and CNC. The major difference is in the way how various data are input, as we examined earlier. A feed rate of 10 inches per minute (10 in/min) is the same in manual or CNC applications, but the method of applying that feed speed is not. The same can be said about the coolant employed during the machining process – as it can easily be activated by turning a knob, pushing a switch, or programming a special code. All these actions will result in a coolant rushing out of a nozzle, but one requires human intervention on-site, while the other does not.

In both kinds of machining, a certain amount of knowledge on the part of the user is absolutely essential, to prevent possible mishaps. After all, metal working (particularly metal cutting) is not only a particular skill, but it is also, an art form applied to a great number of different walks of life. So is the application of Computerized Numerical Control. Like any skill or art or profession, mastering it to the last detail is necessary to be successful. It takes more than just technical knowledge to be a CNC machinist or CNC programmer. Work experience, intuition and what is sometimes called a “gut-feel” are all but essential when entering into a workspace as competitive, and potentially dangerous, as machine cutting.

For conventional machine use, a machine operator will set up the machine and move each cutting tool (using one or even both hands) to produce the part required. The design of a manual machine tool offers many features that help the process of machining part-levers, handles, gears and dials, to name just a few examples.

The same body motions are repeated by the operator for every part in each order, and to an almost meticulous standard. However, the word “same” in this context really means “similar” rather than literally “identical.” Humans are not capable of replicating results exactly the same at all times – which is why this is a job left to machines, whose skillsets are perfectly suited to complete such a task.

People cannot work at the same performance level all the time, without the need of rest, nourishment, and exercise. All of us have some good and some bad moments. The results of these moments, when summarized and applied to industrial machining, can be difficult to predict at best, if not downright disastrous.

There will always be some differences and inconsistencies within each batch of parts, no matter which method you use; the parts will not always be exactly the same.

Maintaining dimensional tolerances and surface finish quality are the most essential aspects of conventional machining, and can therefore represent the biggest challenge.

The machining under CNC does away with the majority of the inherent inconsistencies of machine cutting, drilling, and shaping. It does not require the same physical involvement as NC machining, and therefore does not present the same level of associated risk.

Controlled machining does not involve the need for any levers, or dials, or handles – at least not in the same sense as conventional machining does. Once the part program has been approved, and applied, it can be used any number of times over, always returning consistent (if perhaps not 100% perfect) results.

That does not mean there are no limiting factors to using a CNC router. The cutting tools do eventually wear out, depending on the level of usage, and quality of the original parts. In addition, the blank material used in one batch is rarely identical to the material blank in another batch, so setups may vary, etc. These factors are to be considered and compensated for, wherever necessary, as doing so properly can ensure maximum and optimal efficiency.

The emergence of numerical control technology does not spell the instant, or even long term, demise of all manual machines. There are even times when traditional machining methods are more preferable to a computerized method. For example, a simple one-time job may be performed more efficiently on a manual machine than its CNC counterpart, as they generally require less time and resource to set up. Certain types of machining jobs can benefit from manual or semiautomatic machining, rather than numerically controlled machining. Which is good, as CNC machine tools are not meant to replace every manual machine, only to supplement them in cases where it is clearly sorely needed.

In many instances, the decision on whether certain work will be done on a CNC machine or not is based on the number of required parts and very little else. Although the volume of parts machined in a batch is always an important criteria, it should never be the sole factor.

Consideration should also be given to the complexity of different parts, their tolerances, the required quality of surface finish, etc. In many cases, a single complex part will benefit from CNC machining, where perhaps fifty relatively simple parts would not.

Keep in mind that numerical controls cannot machine any single part by themselves. Numerical controls are simply a method of input that enables machine tools to be used in a productive, accurate, and consistent way.

Types of CNC machine tools

Different kinds of CNC machines cover an extremely large variety. There is a high number of different CNC machine tools, and as such they vary wildly in their design.

With CNC machine numbers rapidly increasing, as the technology development advances, it is almost impossible to identify all the different, associated applications; as that would make for a long list. Here is a brief summary of just some of the groups CNC machines belong to:

1. Mills and machining centers.
2. Lathes and turning centers.
3. Drilling machines.
4. Boring mills and profilers.
5. EDM machines.
6. Punch presses and shears.
7. Flame cutting machines.
8. Routers.
9. Water jet and laser profilers.
10. Cylindrical grinders.
11. Welding machines.
12. Benders, winding and spinning machines, etc.

CNC machining centers and lathes form the majority of installations found in industrial use, with these two groups sharing the market between each other just about equally. Some industries may give a higher need for one group of machines, depending on their needs. Depending on their needs, some industries have historically had an elevated requirement for such technology, as you might expect, and have therefore invested heavily in the CNC machine sector.

It is important to remember that there are many different kinds of lathes and just as many different kinds of machining centers. However, the programming processes required for a vertical machine are inherently similar to those for a horizontal machine, or even a simple CNC mill. Even between different machine groups, there is a large number of general applications used, so the programming process is generally more-or-less the same. For example, a contour milled with an end mill has a lot in common with a contour cut with a wire.

Mills and machining centers

In standard terms, there are usually three different axes located on a milling machine – the X, Y, and Z axes. The stock part set on most milling systems is an Al-cutting tool which rotates, and can even move up and down (or in and out), but does not specifically follow the tool path.

CNC mills – sometimes called CNC milling machines – are usually small, simple machines, without an automatic tool changer or other automated features, and their power-rating is often relatively low. In industrial use, they are commonly employed for tool-room work, maintenance purposes, or the production of small parts – despite being designed for contouring, unlike CNC drills.

CNC machining centers are far more popular and efficient than drills and/or mills, mainly due to their superior flexibility. The main benefit a user gets out of a CNC machining center is the ability to integrate several diverse and disparate operations into a single setup. For example, drilling, boring, counter boring, tapping, spot facing, and contour milling can be incorporated into a single CNC program, if managed correctly.

In addition, flexibility can be further enhanced through the use of pallets, allowing for automatic tool changing, and minimizing idle time. This can have a number of other benefits as well, including allowing a user to; index different sides of the part, use a rotary movement of additional axes, and a number of other useful features besides. CNC machining centers can be equipped with special software that controls the feed speeds, the life of the cutting tool, automatic in-process gauging and offset adjustment, as well as other production enhancing/time saving devices.

There are two basic designs for a standard CNC machining center, which are vertical and the horizontal machining centers. As you might expect, the major difference between these two types of machine is the nature of work for which they are best suited. For a vertical CNC machining center, the most suitable type of operation would generally be working on flat parts, either mounted to a fixture on a table/working surface or held in a vise (or a chuck).

For work that requires machining on two or more sides during a single setup, it is generally preferential to be finish the job using a CNC horizontal machining center. A good example of this would be pump housing, and other machining work that requires the construction of three dimensional, particularly cubic shapes. Some multi-face machining for smaller parts can also be done on a CNC vertical machining center, which usually come equipped with a rotary table.

The programming process is much the same for both horizontal and vertical machining centers, but an additional axis (usually a B axis) is added to the horizontal design. This axis will usually be either a simple positioning axis (indexing axis) for the table/working surface used, or a fully-rotational axis, which allows for multiple simultaneous contouring.

This handbook focuses on CNC vertical machining center applications, with a special section dealing specifically with horizontal setup and machining. Many of the same programming methods can also be applied to small CNC mills (including drilling and/or tapping machines), but in practice a programmer is often rather limited by the different restrictions this can impose.

Lathes and turning centers

A CNC lathe is usually a machine tool with two axes, the vertical X axis and the horizontal Z axis. The main future of the lathe that distinguishes it from a mill is the part that rotates directly around the machine center's central line. In addition, the cutting tool is normally stationary, and mounted on a sliding turret, while the cutting tool follows the contour of the pre-programmed tool path. For a CNC lathe with a milling attachment (which is sometimes called a live tooling lathe) the milling tool has its own motor – and rotates while the spindle is stationary.

In modern design, lathes can easily be horizontal or vertical. The horizontal type is far more common than the vertical type, but both designs exist just in case they are needed for a specific task, to cut down on possible set-up time. For example, a typical, horizontal group can be designed with a flat bed or a slant bed, as a bar-type, chucker-type, or universal-type. Added to these combinations are many other different accessories, which makes a CNC lathe an extremely flexible and multi-purpose machine tool. Typically, accessories such as a tailstock, steady rests (or follow-up rests), part catchers, pullout-fingers, and even a third axis milling attachments are popular additions for standard CNC lathes.

CNC lathes can be very versatile – so versatile, in fact, that they are often referred to as CNC turning centers. All text and program examples in this handbook use the more traditional term CNC lathe, which is why this is mentioned here; to try and prevent any possible confusion.

How to offset and justify the cost of CNC machine operations?

The cost of a CNC machining, including the very cost of the machines themselves, might make most manufacturers balk slightly. However, it is important to remember that the financial benefits of owning a CNC router will most likely offset its high cost in very little time at all, especially if used correctly.

The first cost to take into consideration is the price of the machine. Some vendors offer bundled deals that include installation, software training, and shipping charges. Nevertheless, in most cases, everything is sold separately to allow for personal customization of the CNC router, permitting it to be set up for specific use.

Light duty

Even low-end CNC router machines cost from $2,000 to $10,000. They are usually DIY-kits made of bent sheet metal and use stepper motors, intended to be flat packed and then later assembled on-site. In some cases, in fact most cases, they will even come with a training video and/or an instruction manual as a part of the package.

As mentioned above, these machines are usually intended for do-it-yourself assembly, for the sign-making industry, and other very light duty operations. CNC routers will also usually come with power adapters for conventional plunge routers, and accessories such as a spindle and workholding vacuum are also optional. These machines can easily be successfully integrated into an industrial environment specializing in high production, or even used for a more dedicated process (such as serving as part of a manufacturing cell). As an example, certain CNC machines can be programmed to drill hardware holes on drawer fronts before assembly, a procedure for which they were not actually intended, at least originally.

Medium duty

Mid-range CNC machines will generally cost between $10,000 and $100,000. These machines are built of heavier gauge steel and/or aluminum, and other more durable materials. They sometimes function through stepper motors and other mechanical servos, and use rack and pinion drives, or belt drives to enhance their work speed. Generally speaking, they will have a separate controller and offer a good range of optional features, which include different quality-of-life functions such as automatic tool changers and vacuum plenum tables. Mid-range CNC machines are meant for heavier duty use in the sign-making industry (signage), and for light panel processing applications.

Such machines can present themselves as a good option for start-ups with limited resources or restricted manpower. They can perform most operations required for cabinet making, and other three-dimensional designs, though not with the same degree of sophistication or with the same efficiency as their more expensive counterparts.

Industrial strength

High-end routers cost upward of $100,000. This can include a whole range of machines, some with up to 5 axes, suited for a broad range of applications. These machines will typically be built out of heavy gauge welded steel, and come fully loaded with automatic tool changing features, vacuum tables, and other high-end accessories included – depending on the model and variety. High-end CNC machines are usually installed by the manufacturer, and some form of training is often included.

Shipping

CNC router transportation can carry with it considerable and heavy cost. With routers weighing anywhere from a few hundred pounds to several tons, freight costs can range from $200 to $5,000 or more, depending on location your location. Please remember that, unless the machine was manufactured in a location not far from your very own, there may be hidden costs or penalties incurred during the transportation process – particularly between Asia and Europe.

Additional costs may also be incurred just to get the machine inside once it is delivered, and it is always a good idea to use professional riggers to deal with this kind of operation. All of these must be taken into account when budgeting, otherwise the overall price may overshoot what would otherwise be expected.

Installation and training

CNC vendors typically charge from $300 to $1,000 per day for an installation. Such a process can take anywhere from a half day to a full week to install and test the router, depending on the size of the router and the location in which it is being installed. This cost could be included in the price of buying the machine too. Additionally, as mentioned above, some vendors will provide free training on how to use the hardware and software, usually on-site. If this is not the case, however, this training could cost upwards of $300 to $1,000 per day for the same service, so make sure that you conduct due diligence when budgeting.

Safety related to CNC work

On the wall of many companies is a safety poster with a simple, yet powerful message:

The first rule of safety is to follow all safety rules.

The heading of this section does not indicate whether such safety protocols are oriented more for the programming or the machining level. The reason for is that such safety orientation is totally independent of position or employment type. It stands alone as its own institution, and as such helps to governs behavior of everybody working on a machine shop-related project. At first glance, it may appear that safety is something related specifically to machining and machine operation, and perhaps (to a slightly lesser degree) the setup as well. While that is definitely partially true, it hardly presents a complete picture of how such a project should be set-up correctly.

Safety is the most important element for programming, setup, machining, tooling, fixturing, inspection, chipping, and any other operation that presents itself in daily machine shop operation and work. Safety can never be overemphasized.

Companies talk about safety, conduct safety meetings, display slogans and posters. They make speeches, hire experts, and call upon any other resource available to them to ensure strict workplace regulations are adhered to, and on a regular basis. This, sometimes confusing, mass of information/instructions is presented to all of us for with such frequency for some very good and understandable reasons. Quite a few are formed in the advent of past tragic occurrences, to prevent such an incident from occurring again. In fact, many laws, rules, and regulations have been written as a result of inquests and inquiries into serious accidents in the workplace.

To all outward appearances it may seem that, for CNC work, safety concerns are generally a secondary issue, and of little importance or consequence to all but a few who work with such machines. This is largely because there is a lot of automation; part programs that run over and over again, tooling that has been used in the past, a simple setup, etc. All this can lead to complacency and the false assumption that safety is taken care of, and this wayward point of view can have serious and dire consequences.

Safety is, in many cases, given to be an all-encompassing subject, but a few points that relate to CNC work are important, and not be overlooked. In fact, every machinist (machine operator) should know the hazards of mechanical and electrical devices, and the inherent complications that can arise from working with such devices.

The first step towards creating a safe workplace is to ensure you have a clean work area, where no chips of discarded material, oil spills, and other debris have been allowed to accumulate. Taking care of personal safety is equally important. Loose clothing, jewelry, ties, scarves, unprotected long hair, improperly placed gloves (and similar infractions) are dangerous in any machining environment. Protection of eyes, ears, hands, and feet is strongly recommended at all times.

While a machine is in operation, protective devices should be in place and no moving parts should be exposed in such a way that they might accidentally cause physical harm. Special care should be taken around rotating spindles and automatic tool changers, too. Other devices that could potentially pose a hazard are pallet changers, chip conveyors, high voltage areas, hoists, and other tools immediately associated with CNC machine operation. Disconnecting or otherwise disengaging any interlocks and/or other safety features is extremely dangerous - and therefore also illegal, without appropriate skills and authorization.

Even in programming, observation of safety rules is also important. A tool motion can be programmed in many ways, and ones that can have real-world consequence when scheduled incorrectly. Speeds and feeds have to be realistic, not just mathematically "correct," as well – another important aspect to note. Depth of cut, width of cut, the tool characteristics; all have a profound effect on overall safety and are therefore not to be taken lightly.

Please remember that, despite the overall length of this document, all the ideas contained herein are but a very short summary, and a reminder that safety should always be taken seriously.