CHAPTER 3

GROWTH OF CNC MACHINES IN INDIA

CNC stands for Computer Numerical Control and has been around since the early 1970's. Prior to this, it was called NC, for Numerical Control. (In the early 1970's computers were introduced to these controls, hence the name change) While people in most walks of life have never heard of this term, CNC has touched almost every form of manufacturing process in one way or another. If you'll be working in manufacturing, it's likely that you'll be dealing with CNC on a regular basis.

3.1 BEFORE CNC

While there are exceptions to this statement, CNC machines typically replace (or work in conjunction with) some existing manufacturing process/es. Take one of the simplest manufacturing processes, drilling holes, for example. A drill press can of course be used to machine holes. (It's likely that almost everyone has seen some form of drill press, even if you don't work in manufacturing.) A person can place a drill in the drill chuck that is secured in the spindle of the drill press. They can then (manually) select the desired speed for rotation (commonly by switching belt pulleys), and activate the spindle. Then they manually pull on the quill lever to drive the drill into the workpiece being machined.
As you can easily see, there is a lot of manual intervention required to use a drill press to drill holes. A person is required to do something almost every step along the way. While this manual intervention may be acceptable for manufacturing companies if but a small number of holes or workpieces must be machined, as quantities grow, so does the likelihood for fatigue due to the tediousness of the operation. And do note that we've used one of the simplest machining operations (drilling) for our example. There are more complicated machining operations that would require a much higher skill level (and increase the potential for mistakes resulting in scrap workpieces) of the person running the conventional machine tool.

### 3.2 MACHINING CENTER

By comparison, the CNC equivalent for a drill press (possibly a CNC machining center or CNC drilling & tapping center) can be programmed to perform this operation in a much more automatic fashion. Everything that the drill press operator was doing manually will now be done by the CNC machine, including: placing the drill in the spindle, activating the spindle, positioning the workpiece under the drill, machining the hole, and turning off the spindle.

### 3.3 HOW CNC WORKS

As you might already have guessed, everything that an operator would be required to do with conventional machine tools is programmable with CNC machines. Once the machine is setup and running, a CNC machine is quite simple to keep running. In fact CNC operators tend to get quite bored during lengthy production runs because there is so little to do. With some CNC machines, even the workpiece loading process has been automated. (We don't mean to over-simplify here. CNC operators are commonly required to do other things related to the CNC operation like measuring workpieces and
making adjustments to keep the CNC machine running good workpieces.) Let's look at some of the specific programmable functions.

### 3.3.1 Motion Control

All CNC machine types share this commonality: They all have two or more programmable directions of motion called axes. An axis of motion can be linear (along a straight line) or rotary (along a circular path). One of the first specifications that implies a CNC machine's complexity is how many axes it has. Generally speaking, the more axes, the more complex the machine. The axes of any CNC machine are required for the purpose of causing the motions needed for the manufacturing process. In the drilling example, these (3) axes would position the tool over the hole to be machined (in two axes) and machine the hole (with the third axis). Axes are named with letters. Common linear axis names are X, Y, and Z. Common rotary axis names are A, B, and C.

### 3.3.2 Programmable Accessories

A CNC machine wouldn't be very helpful if all it could only move the workpiece in two or more axes. Almost all CNC machines are programmable in several other ways. The specific CNC machine type has a lot to do with its appropriate programmable accessories. Again, any required function will be programmable on full-blown CNC machine tools. Here are some examples for one machine type.
3.3.3 Automatic Tool Changer

Most machining centers can hold many tools in a tool magazine. When required, the required tool can be automatically placed in the spindle for machining.

3.3.4 Spindle Speed and Activation

The spindle speed (in revolutions per minute) can be easily specified and the spindle can be turned on in a forward or reverse direction. It can also, of course, be turned off.

3.3.5 Coolant

Many machining operations require coolant for lubrication and cooling purposes. Coolant can be turned on and off from within the machine cycle.

3.3.6 The CNC Program

Think of giving any series of step-by-step instructions. A CNC program is nothing more than another kind of instruction set. It's written in sentence-like format and the control will execute it in sequential order, step by step. A special series of CNC words are used to communicate what the machine is intended to do. CNC words begin with letter addresses (like F for feedrate, S for spindle speed, and X, Y & Z for axis motion). When placed together in a logical method, a group of CNC words make up a command that resemble a sentence. For any given CNC machine type, there will only be about 40-50 words used on a regular basis. So if you compare learning to
write CNC programs to learning a foreign language having only 50 words, it shouldn't seem overly difficult to learn CNC programming.

### 3.3.7 The CNC Control

The CNC control will interpret a CNC program and activate the series of commands in sequential order. As it reads the program, the CNC control will activate the appropriate machine functions, cause axis motion, and in general, follow the instructions given in the program. Along with interpreting the CNC program, the CNC control has several other purposes. All current model CNC controls allow programs to be modified (edited) if mistakes are found. The CNC control allows special verification functions (like dry run) to confirm the correctness of the CNC program. The CNC control allows certain important operator inputs to be specified separate from the program, like tool length values. In general, the CNC control allows all functions of the machine to be manipulated.

### 3.4 CAM SYSTEM

For simple applications (like drilling holes), the CNC program can be developed manually. That is, a programmer will sit down to write the program armed only with pencil, paper, and calculator. Again, for simple applications, this may be the very best way to develop CNC programs. As applications get more complicated, and especially when new programs are required on a regular basis, writing programs manually becomes much more difficult. To simplify the programming process, a computer aided manufacturing (CAM) system can be used. A CAM system is a software program that runs on a computer (commonly a PC) that helps the CNC programmer with the programming process. Generally speaking, a CAM system will take the tediousness and drudgery out of programming.
In many companies the CAM system will work with the computer aided design (CAD) drawing developed by the company's design engineering department. This eliminates the need for redefining the workpiece configuration to the CAM system. The CNC programmer will simply specify the machining operations to be performed and the CAM system will create the CNC program (much like the manual programmer would have written) automatically.

3.5 DNC SYSTEM

Once the program is developed (either manually or with a CAM system), it must be loaded into the CNC control. Though the setup person could type the program right into the control, this would be like using the CNC machine as a very expensive typewriter. If the CNC program is developed with the help of a CAM system, then it is already in the form of a text file. If the program is written manually, it can be typed into any computer using a common word processor (though most companies use a special CNC text editor for this purpose). Either way, the program is in the form of a text file that can be transferred right into the CNC machine. A distributive numerical control (DNC) system is used for this purpose.

A DNC system is nothing more than a computer that is networked with one or more CNC machines. Until only recently, rather crude serial communications protocol (RS-232c) had to be used for transferring programs. Newer controls have more current communications capabilities and can be networked in more conventional ways (Ethernet, etc.). Regardless of methods, the CNC program must of course be loaded into the CNC machine before it can be run.
3.6 TYPES OF CNC MACHINES

As stated, CNC has touched almost every facet of manufacturing. Many machining processes have been improved and enhanced through the use of CNC. Let's look at some of the specific fields and place the emphasis on the manufacturing processes enhanced by CNC machine usage.

3.6.1 In the Metal Removal Industry

Machining processes that have traditionally been done on conventional machine tools that are possible (and in some cases improved) with CNC machining centers include all kinds of milling (face milling, contour milling, slot milling, etc.), drilling, tapping, reaming, boring, and counter boring.

In similar fashion, all kinds of turning operations like facing, boring, turning, grooving, knurling, and threading are done on CNC turning centers. There are all kinds of special "off-shoots" of these two machine types including CNC milling machines, CNC drill and tap centers, and CNC lathes. Grinding operations of all kinds like outside diameter (OD) grinding and internal diameter (ID) grinding are also being done on CNC grinders. CNC has even opened up a new technology when it comes to grinding. Contour grinding (grinding a contour in a similar fashion to turning), which was previously infeasible due to technology constraints is now possible (almost commonplace) with CNC grinders.

3.6.2 In the Metal Fabrication Industry

In manufacturing terms, fabrication commonly refers to operations that are performed on relatively thin plates. Think of a metal filing cabinet. All of the primary components are made of steel sheets. These sheets are
sheared to size, holes are punched in appropriate places, and the sheets are bent (formed) to their final shapes. Again, operations commonly described as fabrication operations include shearing, flame or plasma cutting, punching, laser cutting, forming, and welding. Truly, CNC is heavily involved in almost every facet of fabrication. CNC back gages are commonly used with shearing machines to control the length of the plate being sheared. CNC lasers and CNC plasma cutters are also used to bring plates to their final shapes. CNC turret punch presses can hold a variety of punch-and-die combinations and punch holes in all shapes and sizes through plates. CNC press brakes are used to bend the plates into their final shapes.

3.6.3 In the Electrical Discharge Machining Industry

Electrical discharge machining (EDM) is the process of removing metal through the use of electrical sparks which burn away the metal. CNC EDM comes in two forms, vertical EDM and Wire EDM. Vertical EDM requires the use of an electrode (commonly machined on a CNC machining center) that is of the shape of the cavity to be machined into the workpiece. Picture the shape of a plastic bottle that must be machined into a mold. Wire EDM is commonly used to make punch and die combinations for dies sets used in the fabrication industry. EDM is one of the lesser known CNC operations because it is so closely related to making tooling used with other manufacturing processes.

3.6.4 In the Woodworking Industry

As in the metal removal industry, CNC machines are heavily used in woodworking shops. Operations include routing (similar to milling) and drilling. Many woodworking machining centers are available that can hold several tools and perform several operations on the workpiece being machined.
3.6.5 Other Types of CNC Machines

Many forms of lettering and engraving systems use CNC technology. Waterjet machining uses a high pressure water jet stream to cut through plates of material. CNC is even used in the manufacturing of many electrical components. For example, there are CNC coil winders, and CNC terminal location and soldering machines.

The high modularity of modern modular systems and the selling point's need and aptitude of a strongly customized design cause a big criticality in the productive sector. This mainly happens due to the complex personalization of each single panel and due to necessity of reducing factory costs, mistakes, and caring out orders times. The modern and versatile CNC machines on the market, with their superb management software, provide an accurate solution of these problems. However CNC machines must be correctly supplied with real time part-programs, exhaustive and much optimized. Modern CNC Machines are able to link the graphic configurators technical peculiarities with the internal and external production departments, feeding correctly and in real time the more sophisticated production's lines.

3.7 ORIGIN AND GROWTH OF MACHINE TOOL

A machine tool is a machine for shaping or machining metal or other rigid materials, usually by cutting, boring, grinding, shearing or other forms of deformation. Machine tools employ some sort of tool that does the cutting or shaping. All machine tools have some means of constraining the work piece and provide a guided movement of the parts of the machine. Thus the relative movement between the work piece and the cutting tool (which is called the tool path) is controlled or constrained by the machine to at least some extent, rather than being entirely "offhand" or "freehand".
The precise definition of the term *machine tool* varies among users, as detailed in the "Nomenclature and key concepts" section. It is safe to say that all machine tools are "machines that help people to make things", although not all factory machines are machine tools.

Today machine tools are typically powered other than by human muscle (e.g., electrically, hydraulically, or via line shaft), used to make manufactured parts (components) in various ways that include cutting or certain other kinds of deformation.

With their inherent precision, machine tools enabled the economical production of interchangeable parts.

### 3.7.1 Nomenclature and Key Concepts, Interrelated

Many historians of technology consider that true machine tools were born when the tool path first became guided by the machine itself in some way, at least to some extent, so that direct, freehand human guidance of the tool path (with hands, feet, or mouth) was no longer the only guidance used in the cutting or forming process. In this view of the definition, the term, arising at a time when all tools up till then had been hand tools, simply provided a label for "tools that were machines instead of hand tools". Early lathes, those prior to the late medieval period, and modern woodworking lathes and potter's wheels may or may not fall under this definition, depending on how one views the headstock spindle itself; but the earliest historical records of a lathe with direct mechanical control of the cutting tool's path are of a screw-cutting lathe dating to about 1483. This lathe "produced screw threads out of wood and employed a true compound slide rest".

The mechanical tool path guidance grew out of any of various root concepts:
• First is the spindle concept itself, which constraints work piece or tool movement to rotation around a fixed axis. This ancient concept predates machine tools per se; the earliest lathes and potter's wheels incorporated it for the work piece, but the movement of the tool itself on these machines was entirely freehand.

• The machine slide, which has many forms, such as dovetail ways, box ways, or cylindrical column ways. Machine slides constrain tool or work piece movement linearly. If a stop is added, the length of the line can also be accurately controlled. (Machine slides are essentially a subset of linear bearings, although the language used to classify these various machine elements includes connotative boundaries; some users in some contexts would contradistinguish elements in ways that others might not.)

• Tracing, which involves following the contours of a model or template and transferring the resulting motion to the tool path.

• Cam operation, which is related in principle to tracing but can be a step or two removed from the traced element's matching the reproduced element's final shape. For example, several cams, no one of which directly matches the desired output shape, can actuate a complex tool path by creating component vectors that add up to a net tool path.

Abstractly programmable tool path guidance began with mechanical solutions, such as in musical box cams and Jacquard looms. The convergence of programmable mechanical control with machine tool tool path control was delayed many decades, in part because the programmable
control methods of musical boxes and looms lacked the rigidity for machine tool tool paths. Later, electromechanical solutions (such as servos) and soon electronic solutions (including computers) were added, leading to numerical control and computer numerical control.

When considering the difference between freehand tool paths and machine-constrained tool paths, the concepts of accuracy and precision, efficiency, and productivity become important in understanding why the machine-constrained option adds value. After all, humans are generally quite talented in their freehand movements; the drawings, paintings, and sculptures of artists such as Michelangelo or Leonardo da Vinci, and of countless other talented people, show that human freehand tool path has great potential. The value that machine tools added to these human talents is in the areas of rigidity (constraining the tool path despite thousands of newtons (pounds) of force fighting against the constraint), accuracy and precision, efficiency, and productivity. With a machine tool, tool paths that no human muscle could constrain can be constrained; and tool paths that are technically possible with freehand methods, but would require tremendous time and skill to execute, can instead be executed quickly and easily, even by people with little freehand talent (because the machine takes care of it). The latter aspect of machine tools is often referred to by historians of technology as "building the skill into the tool", in contrast to the tool path-constraining skill being in the person who wields the tool. As an example, it is physically possible to make interchangeable screws, bolts, and nuts entirely with freehand tool paths. But it is economically practical to make them only with machine tools.

In the 1930s, the U.S. National Bureau of Economic Research (NBER) referenced the definition of a machine tool as "any machine operating by other than hand power which employs a tool to work on metal".
The narrowest colloquial sense of the term reserves it only for machines that perform metal cutting—in other words, the many kinds of [conventional] machining and grinding. These processes are a type of deformation that produces swarf. However, economists use a slightly broader sense that also includes metal deformation of other types that squeeze the metal into shape without cutting off swarf, such as rolling, stamping with dies, shearing, swaging, riveting, and others. Thus presses are usually included in the economic definition of machine tools. For example, this is the breadth of definition used by Max Holland in his history of Burgmaster and Houdaille, which is also a history of the machine tool industry in general from the 1940s through the 1980s; he was reflecting the sense of the term used by Houdaille itself and other firms in the industry. Many reports on machine tool export and import and similar economic topics use this broader definition.

The colloquial sense implying (conventional) metal cutting is also growing obsolete because of changing technology over the decades. The many more recently developed processes labeled "machining", such as electrical discharge machining, electrochemical machining, electron beam machining, photochemical machining, and ultrasonic machining, or even plasma cutting and water jet cutting, are often performed by machines that could most logically be called machine tools. In addition, some of the newly developed additive manufacturing processes, which are not about cutting away material but rather about adding it, are done by machines that are likely to end up labeled, in some cases, as machine tools.

The natural language use of the terms varies, with subtle connotative boundaries. Many speakers resist using the term "machine tool" to refer to woodworking machinery (joiners, table saws, routing stations, and so on), but it is difficult to maintain any true logical dividing line, and
therefore many speakers are fine with a broad definition. It is common to hear machinists refer to their machine tools simply as "machines". Usually the mass noun "machinery" encompasses them, but sometimes it is used to imply only those machines that are being excluded from the definition of "machine tool". This is why the machines in a food-processing plant, such as conveyors, mixers, vessels, dividers, and so on, may be labeled "machinery", while the machines in the factory's tool and die department are instead called "machine tools" in contradistinction. As for the 1930s NBER definition quoted above, one could argue that its specificity to metal is obsolete, as it is quite common today for particular lathes, milling machines, and machining centers (definitely machine tools) to work exclusively on plastic cutting jobs throughout their whole working lifespan. Thus the NBER definition above could be expanded to say "which employs a tool to work on metal or other materials of high hardness". And its specificity to "operating by other than hand power" is also problematic, as machine tools can be powered by people if appropriately set up, such as with a treadle (for a lathe) or a hand lever (for a shaper). Hand-powered shapers are clearly "the 'same thing' as shapers with electric motors except smaller", and it is trivial to power a micro lathe with a hand-cranked belt pulley instead of an electric motor. Thus one can question whether power source is truly a key distinguishing concept; but for economics purposes, the NBER's definition made sense, because most of the commercial value of the existence of machine tools comes about via those that are powered by electricity, hydraulics, and so on. Such are the vagaries of natural language and controlled vocabulary, both of which have their places in the business world.

3.7.2 Earlier History

Machine tools filled a need created by textile machinery during the Industrial Revolution in England in the middle to late 1700s. Until that
time machinery was made mostly from wood, often including gearing and shafts. The increase in mechanization required more metal parts, which were usually made of cast iron or wrought iron. Cast iron could be cast in moulds for larger parts, such as engine cylinders and gears, but was difficult to work with a file and could not be hammered. Red hot wrought iron could be hammered into shapes. Room temperature wrought iron was worked with a file and chisel and could be made into gears and other complex parts; however, hand working lacked precision and was a slow and expensive process.

Table 3.1 Growth of CNC machines

<table>
<thead>
<tr>
<th>Year</th>
<th>Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1949</td>
<td>US Air Force asks MIT to develop a &quot;numerically controlled&quot; machine.</td>
</tr>
<tr>
<td>1952</td>
<td>Prototype NC machine demonstrated (punched tape input)</td>
</tr>
<tr>
<td>1980</td>
<td>CNC machines (computer used to link directly to controller)</td>
</tr>
<tr>
<td>1990</td>
<td>DNC: external computer “drip feeds” control programmer to machine tool controller</td>
</tr>
</tbody>
</table>

Source: Compiled from various news briefs

James Watt was unable to have an accurately bored cylinder for his first steam engine, trying for several years until John Wilkinson invented a suitable boring machine in 1774, boring Boulton & Watt's first commercial engine in 1776.

The advance in the accuracy of machine tools can be traced to Henry Maudslay and refined by Joseph Whitworth. That Maudslay had established the manufacture and use of master plane gages in his shop (Maudslay & Field) located on Westminster Road south of the Thames River in London about 1809, was attested to by James Nasmyth who was employed
by Maudslay in 1829 and Nasmyth documented their use in his autobiography.

The process by which the master plane gages were produced dates back to antiquity but was refined to an unprecedented degree in the Maudslay shop. The process begins with three plates each given an identification (ex., 1,2 and 3). The first step is to rub plates 1 and 2 together with a marking medium (called bluing today) revealing the high spots which would be removed by hand scraping with a steel scraper, until no irregularities were visible. This would not produce absolutely true plane surfaces but a "ball and socket" fit, as this mechanical fit, like two perfect planes, can slide over each other and reveal no high spots. Next, plate number 3 would be compared and scraped to conform to plate number 1. In this manner plates number 2 and 3 would be identical. Next plate’s number 2 and 3 would be checked against each other to determine what condition existed, either both plates were "balls" or "sockets". These would then be scraped until no high spots existed and then compared to plate number 1. After repeating this process, comparing and scraping the three plates together, they would automatically generate exact true plane surfaces accurate to within millionths of an inch.

The traditional method of producing the surface gages used an abrasive powder rubbed between the plates to remove the high spots, but it was Whitworth who contributed the refinement of replacing the grinding with hand scraping. Sometime after 1825 Whitworth went to work for Maudslay and it was there that Whitworth perfected the hand scraping of master surface plane gages. In his paper presented to the British Association for the Advancement of Science at Glasgow in 1840, Whitworth pointed out the inherent inaccuracy of grinding due to no control and thus unequal distribution of the abrasive material between the plates which would produce uneven removal of material from the plates.
With the creation of master plane gages of such high accuracy, all critical components of machine tools (i.e., guiding surfaces such as machine ways) could then be compared against them and scraped to the desired accuracy.

The first commercial NC machines were built in the 1950's, and ran from punched tape. While the concept immediately proved it could save costs, it was so different that it was very slow to catch on with manufacturers. In order to promote more rapid adoption, the US Army bought 120 NC machines and loaned them to various manufacturers so they could become more familiar with the idea. By the end of the 50's, NC was starting to catch on, though there were still a number of issues. For example, g-code, the nearly universal language of CNC we have today, did not exist. Each manufacturer was pushing its own language for defining part programs (the programs the machine tools would execute to create a part).

Figure 3.1 1959 CNC Machine

Milwaukee-Matic-II was first machine with a tool changer...
3.7.3 Marketing of First Machine Tools

The first machine tools offered for sale (i.e., commercially available) were constructed by Matthew Murray in England around 1800. Others, such as Henry Maudslay, James Nasmyth, and Joseph Whitworth, soon followed the path of expanding their entrepreneurship from manufactured end products and millwright work into the realm of building machine tools for sale.

Important early machine tools included the slide rest lathe, screw-cutting lathe, turret lathe, milling machine, pattern tracing lathe (shaper) and metal planer, which were all in use before 1840. With these machine tools the decades old objective of producing interchangeable parts was finally realized. An important early example of something now taken for granted was the standardization of screw fasteners such as nuts and bolts. Before about the beginning of the 19th century, these were used in pairs, and even screws of the same machine were generally not interchangeable. Methods were developed to cut screw thread to a greater precision than that of the feed screw in the lathe being used. This led to the bar length standards of the 19th and early 20th centuries.

Forerunners of machine tools included bow drills and potter's wheels, which had existed in ancient Egypt prior to 2500 BC, and lathes, known to have existed in multiple regions of Europe since at least 1000 to 500 BC. But it was not until the later Middle Ages and the Age of Enlightenment that the modern concept of a machine tool—a class of machines used as tools in the making of metal parts, and incorporating machine-guided toolpath—began to evolve. Clock makers of the Middle Ages and renaissance men such as Leonardo da Vinci helped expand humans' technological milieu toward the preconditions for industrial machine tools. During the 18th and 19th centuries, and even in many cases in the 20th, the builders of machine tools tended to be the same people who would then use
them to produce the end products (manufactured goods). However, from these roots also evolved an industry of machine tool builders as we define them today, meaning people who specialize in building machine tools for sale to others.

The demand for machine tools has been driven by various manufacturing industries over the centuries. The human desire for firearms (from small arms through artillery) was the earliest, and it has lasted as a top driver through the present. Lathes and boring machines for boring cannon barrels led the way. The next major impetus of machine tool development was the building of textile machinery during the Industrial Revolution in England. Historians of machine tools often focus on a handful of major industries that most spurred machine tool development. In order of historical emergence, they have been firearms (small arms and artillery); clocks; textile machinery; steam engines (stationary, marine, rail, and otherwise; the story of how Watt's need for an accurate cylinder spurred Boulton's boring machine is discussed by Roe (1916); sewing machines; bicycles; automobiles; and aircraft. Others could be included in this list as well, but they tend to be connected with the root causes already listed. For example, rolling-element bearings are an industry of themselves, but this industry's main drivers of development were the vehicles already listed—trains, bicycles, automobiles, and aircraft; and other industries, such as tractors, farm implements, and tanks, borrowed heavily from those same parent industries.

The production of machine tools is concentrated in about 10 countries worldwide: China, Japan, Germany, Italy, South Korea, Taiwan, Switzerland, USA, Austria, Spain and a few others. Machine tool innovation continues in several public and private research centers worldwide.
3.7.4 Drive Power Sources

Machine tools can be powered from a variety of sources. Human and animal power were used in the past, as was water power; however, following the development of high pressure steam engines in the mid 19th century, factories increasingly used steam power. Factories also used hydraulic and pneumatic power. Many small workshops continued to use water, human and animal power until electrification after 1900.

Today most machine tools are powered by electricity; however, hydraulic and pneumatic power are sometimes used, but this is uncommon.

3.7.5 Automatic Control

Machine tools can be operated manually, or under automatic control. Early machines used flywheels to stabilize their motion and had complex systems of gears and levers to control the machine and the piece being worked on. Soon after World War II, the Numerical Control (NC) machine was developed. NC machines used a series of numbers punched on paper tape or punched cards to control their motion. In the 1960s, computers were added to give even more flexibility to the process. Such machines became known as computerized numerical control (CNC) machines. NC and CNC machines could precisely repeat sequences over and over, and could produce much more complex pieces than even the most skilled tool operators.

Before long, the machines could automatically change the specific cutting and shaping tools that were being used. For example, a drill machine might contain a magazine with a variety of drill bits for producing holes of various sizes. Previously, either machine operators would usually have to manually change the bit or move the work piece to another station to perform
these different operations. The next logical step was to combine several different machine tools together, all under computer control. These are known as machining centers, and have dramatically changed the way parts are made.

From the simplest to the most complex, most machine tools are capable of at least partial self-replication, and produce machine parts as their primary function.

Table 3.2 Top 10 CNC Machines manufacturers in India

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Name of the Companies</th>
<th>Official Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Yamazaki Mazak</td>
<td>India Office – 115, Pune Nagar Road, Sanaswadi, Pune</td>
</tr>
<tr>
<td>4</td>
<td>Toyoda</td>
<td>Corporate Office –Plot No. 550-E, 2nd floor Pace City-II, Sector-37, Gurgaon</td>
</tr>
<tr>
<td>No.</td>
<td>Company</td>
<td>Location</td>
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<tr>
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<td>--------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>7</td>
<td>Okuma</td>
<td>Corporate Office – 701-C, Poonam Chambers, Dr. Annie Besant.Road, Worli.Mumbai</td>
</tr>
<tr>
<td>8</td>
<td>Yasda</td>
<td>Corporate Office – 701-C, Poonam Chambers, Dr. Annie Besant.Road, Worli.Mumbai</td>
</tr>
<tr>
<td>9</td>
<td>Makino</td>
<td>India Office – Export Promotion Industrial Park, Whitefield Road, Bangalore</td>
</tr>
<tr>
<td>10</td>
<td>Hitachi</td>
<td>Corporate Office – Jasola Vihar New Delhi, Delhi</td>
</tr>
</tbody>
</table>

Source: Compiled from official websites of respective companies
3.8 DIRECT DRIVE MECHANISM IN CNC MACHINES

Direct drive mechanism is another form of innovation. The following are the various advantages of direct mechanism in CNC Machines

**Increased efficiency:** The power is not wasted in friction (from the belt, chain, etc., and especially, gearboxes.)

**Reduced noise:** Being a simpler device, a direct-drive mechanism has fewer parts which could vibrate, and the overall noise emission of the system is usually lower.

**Longer lifetime:** Having fewer moving parts also means having fewer parts prone to failure. Failures in other systems are usually produced by aging of the component (such as a stretched belt), or stress.

**Faster and precise positioning:** High torque and low inertia allows faster positioning times on permanent magnet synchronous servo drives. Feedback sensor directly on rotary part allows precise angular position sensing.

**Drive stiffness:** Mechanical backlash, hysteresis and elasticity is removed avoiding use of gearbox or ball screw mechanisms.

Like advantages, it also has several Disadvantages. The following are the disadvantages of direct drive mechanism. The main disadvantage of the system is that it needs a special motor. Usually motors are built to achieve maximum torque at high rotational speeds, usually 1500 or 3000rpm. While this is useful for many applications (such as an electric fan), other mechanisms need a relatively high torque at very low speeds, such as a phonograph turntable, which needs a constant (and very precise) 33⅓ rpm or 45 rpm.
The slow motor also needs to be physically larger than its faster counterpart. For example, in a belt-coupled turntable, the motor diameter is about 1 inch (2.5 cm). On a direct-drive turntable, the motor is about 4" (10 cm). Also, direct-drive mechanisms need a more precise control mechanism. High speed motors with speed reduction have relatively high inertia, which helps smooth the output motion. Most motors exhibit positional torque ripple known as cogging torque. In high speed motors, this effect is usually negligible, as the frequency at which it occurs is too high to significantly affect system performance; direct drive units will suffer more from this phenomenon, unless additional inertia is added (i.e. by a flywheel) or the system uses feedback to actively counter the effect.

3.9 CNC MACHINING BUSINESS

When a person is starting a business with CNC machines, there are many opportunities available. The person has to search for various opportunities available. The following are the various suggestions.

Starting a new business can be a challenging endeavor, especially if the entrepreneur is entering a crowded market with large, well-established competitors already in place. Small CNC machines shops face hurdles similar to those of other small businesses, and, like their non-industrial counterparts, have the same potential for securing contracts and growing within the industry despite these obstacles. Here are some tips and suggestions that may help in establishing or expanding your small CNC shop:

3.9.1 Develop Partnerships

For many start-up machine shop owners, the early days can be an uncertain time in which numerous concerns, such as volume expectations, client lists, or even floor plans, have yet to be resolved. In these
circumstances, existing friendships and business connections can be valuable assets. Whether having friends steer clients in your direction, enter into partnerships, or simply provide advice on business practices, relying on your current connections can give you a useful leg-up.

3.9.2 Target Your Segment of the Marketplace

It is generally a good practice to focus on the specific types of purchasers that will buy your products at the best volume rate. For example, if your shop specializes in producing gear shafts with a diameter under five inches, try to establish relationships with companies that purchase this product at a rate favorable to your production cycle and turnover. Targeting your market niche will help you make the best use of your specialty. A good example of a company who targets a niche market is Fanuc Spares. They focus only on this specific manufacturer and specialize only in replacement parts. This proved to be a very successful model for what may seem like a limited market. Another marketing method is leveraging, emerging technologies such as the internet and social networking can help leverage your shops visibility in both search engines and online helping reach people near and far.

3.9.3 Don’t Rush to Expand

Purchasing machines that are not yet cost-efficient or enlarging facilities without the staff needed to maintain them can slowdown revenue growth and actually hinder long-term expansion. In many cases, it may be better to concentrate on making steady gains rather than giant leaps forward, as even a small shop with fewer than a dozen machines or employees can still meet or exceed the national productivity average.
3.9.4  **Diversify According to Demand**

While it’s usually a bad idea to take on a job outside the capabilities of your shop, new projects that seem within reach and will provide a cost-efficient result can be a helpful way to diversify your operations. If, for example, a lathing shop has the training and funds to undertake a profitable milling or plastic fabrication contract, then the resulting diversity can help provide sustainable growth even during periods when one sector of the market is on a downswing.

3.9.5  **Remain Open to New Technology**

Even though a new technical innovation can be costly in terms of additional training and initial set-up, recently-developed equipment may have a positive long-term effect by simplifying production methods or providing the means to accomplish tasks that were once considered impractical. New technology can sometimes help a business remain competitive, especially if the innovation gains widespread notice.

3.9.6  **React to Your Competition**

Being aware of your main competitors is a valuable practice under most circumstances, particularly in times of economic volatility. For example, market fluctuations can cause a slowdown in commercial manufacturing, while leaving military production relatively unchanged (and vice-versa). In this case, competitors from one side of the spectrum may bring their operating standards to the other, forcing companies to accelerate their production rates or lower prices in order to maintain market share.
3.9.7 Be Flexible in Multi-Stage Processes

Companies that combine both internal fabrication and machining operations can often save time or money by acquiring equipment that incorporates secondary work into its primary function. For example, using a cutting laser can often reduce the need for post-fabrication finishing, such as smoothing or evening edges.

3.9.8 Integrate Your Operations

While vertical or horizontal integration is beyond the reach of many small CNC businesses, it may still be helpful to bring as much of the manufacturing process in-house as you can. Streamlining measures, such as organizing a production schedule around a machine shop’s in-house capabilities or prioritizing jobs based on your own production center rather than an external supplier’s availability, can help smooth workflow and ultimately improve output.

3.9.9 Initiate Scalable Growth

In many cases, successful business growth is not dependent on the size of the products being manufactured, but on the depth of the fabricating process. It can be beneficial to evaluate the services or products you provide to your customers, and see if you can expand the reach of those services. For example, if you are producing steel tubing for your purchasers, see if you can also provide them with the fasteners used to join these components together. Securing more expansive contracts from within existing relationships can be a secure and scalable method of growth.
3.9.10 Step-by-Step Value Addition

CNC machining is essentially a multi-staged process in which there is the potential for value-added work at each stage. Consequently, a shop’s potential for expanding its business largely depends on how many of those value-added steps it is able to perform. A small business seeking to expand can evaluate its manufacturing strengths and take advantage of any opportunity to insert itself into a value-added production stage. This approach, coupled with gradual service integration and streamlining, can be a valuable way to expand your small CNC business.

3.10 CNC OPERATOR/MACHINIST JOB PURPOSE

CNC Machine operator is doing many jobs. Though they are called as operator, they are expected to be well versed in all inter related tasks of CNC machines. The following are the summary of various work carried out by CNC machine operators. Produces machined parts by programming, setting up, and operating a computer numerical control (CNC) machine; maintaining quality and safety standards; keeping records; maintaining equipment and supplies.

3.10.1 CNC Operator Job Duties

Plans machining by studying work orders, blueprints, engineering plans, materials, specifications, orthographic drawings, reference planes, locations of surfaces, and machining parameters; interpreting geometric dimensions and tolerances (GD&T). Plans stock inventory by checking stock to determine amount available; anticipating needed stock; placing and expediting orders for stock; verifying receipt of stock.
Programs mills and lathes by entering instructions, including zero and reference points; setting tool registers, offsets, compensation, and conditional switches; calculating requirements, including basic math, geometry, and trigonometry; proving part programs. Sets-up mills and lathes by installing and adjusting three- and four-jaw chucks, tools, attachments, collets, bushings, cams, gears, stops, and stock pushers; indicating vices; trimming heads.

Loads feed mechanism by lifting stock into position. Verifies settings by measuring positions, first-run part, and sample work pieces; adhering to international standards. Maintains specifications by observing drilling, grooving, and cutting, including turning, facing, knurling and thread chasing operations; taking measurements; detecting malfunctions; troubleshooting processes; adjusting and reprogramming controls; sharpening and replacing worn tools; adhering to quality assurance procedures and processes. Maintains safe operations by adhering to safety procedures and regulations.

Maintains equipment by completing preventive maintenance requirements; following manufacturer's instructions; troubleshooting malfunctions; calling for repairs. Maintains continuity among work shifts by documenting and communicating actions, irregularities, and continuing needs. Documents actions by completing production and quality logs. Updates job knowledge by participating in educational opportunities; reading technical publications. Accomplishes organization goals by accepting ownership for accomplishing new and different requests; exploring opportunities to add value to job accomplishments.
3.10.2 **Skills/Qualifications of CNC Machine Operators**

The following are the skills required or expected from the CNC machine operators.

- Conceptual Skills
- Process Improvement
- Verbal Communication
- Functional and Technical Skills
- Controls and Instrumentation, Supply Management
- Tooling, Coordination
- Inventory Control
- Attention to Detail
- Judgment

3.11 **TOOLS USED BY CNC MACHINES**

Computer Numerical Control (CNC) machine tools are computer controlled pieces of equipment with a number of material forming applications. Each machine follows certain protocols designated by its CNC software.

![Figure 3.2 Drills](image)
3.11.1 Drills

CNC machine drills follow specific instructions in the manufacturing of a part. A software platform can control the position of the cut, as well as the depth of the hole being drilled. Computer control is used when the work piece requires repeated drilling or tapping cycles. Certain parameters, such as depth, feed rate, retraction and cancellation of the cycle control the drilling sequence.

![Figure 3.3 Lathes](image)

3.11.2 Lathes

A lathe is a machine that spins a part in place while a cutting blade removes excess material to prepare it for deformation. Lathes can be used for cutting, sanding, drilling, knurling, or deforming. Cutting fluid may be used to remove the swarf (debris), and to serve as a lubricant or coolant during the cutting process. CNC lathes are often used in the production of camshafts and crankshafts.

![Figure 3.4 Electrical Discharge Machining Machine (EDM)](image)
3.11.3 Electrical Discharge Machining Machines (EDMs)

Electrical discharge machining is a technique for making minute, complex cuts or contours in hardened materials that would otherwise be difficult to shape. EDM is only effective on electrical conductors, and is used mainly on ferrous alloys. EDM machines fire a series of rapid electrical bursts from an electrode to melt or vaporize material. The remaining debris is flushed away with dielectric fluid.

![Milling Machines](image)

**Figure 3.5 Milling Machines**

3.11.4 Milling Machines

Milling machines are used to make complex shapes out of metals and other solids. A work piece is fixed to a moveable table that guides the material around a stationary rotating cutter, or, inversely, a moving cutter operates across a stationary table. Some of them also feature a spindle that can be moved along its Z-axis, thus offering a more adjustable cutting method. Milling machines are commonly used for planning, drilling, rebating, routing, and slot cutting. In addition, machines equipped with the Z-axis spindle can be used to create advanced three dimensional objects, such as relief
sculptures. Milling machines can also be used for die-sinking and engraving projects.

3.11.5 Plasma Cutting Machines

CNC plasma cutters use a plasma torch to cut material under the direction of a software program. A computerized torch head slices a work piece along the axes of a CNC table, often preparing welding seams for the manufacture of multi-part components. Plasma cutting can usually handle thick material, and the process is frequently used in the production of ducts and vents.

Figure 3.6 Plasma Cutting Machines

Figure 3.7 Water Jet Cutting Machines
3.11.6 Water Jet Cutter Machines

Water jet cutting simulates erosion by using a stream of high-pressure water (sometimes in combination with an abrasive, such as grit or aluminum oxide) to cut through material. The process reduces the risk of heat-damaging the work piece, and though it can be applied to a wide range of materials, some substances are impervious to it. As in other CNC systems, the table or the jet mechanism are under computer control.

![Figure 3.8 Laser Cutting Machines](image)

3.11.7 Laser Cutting Machines

Laser cutters use a high-powered laser to shape work pieces. Since the excess material usually melts, vaporizes, or is blown away from the cut, the process can yield clean, high quality finishes. CNC lasers can provide improved accuracy due to the precision of computer controlled cutting.

3.11.8 Oxy-Fuel Cutting Machines

Oxy-fuel cutters use a torch to heat ferrous metals to their kindling point and apply a pressurized stream of pure oxygen to cause a chemical
reaction in which slag is channelled away from the cut. These cutters are powered with gases, such as acetylene, and a CNC program guides both the torch and the oxygen release rate.

3.12 THE PROGRAMMING AND PROCESSES OF CNC MACHINING

Many CNC machines employ a numerical control programming language that uses preparatory codes, or “G-Codes,” to coordinate the tool and initiate its work orders. Three dimensional models generated in computer aided design (CAD) programs are converted into CNC code through computer aided manufacturing (CAM) software before work can begin. There are roughly four stages in the CNC manufacturing process: roughing, semi-finishing, finishing, and contour milling. Here is a brief outline of each step:

Roughing begins with the introduction of the raw stock, or billet, which is cut into the approximate shape of the final product.

- Semi-Finishing employs raster passes, constant step-over passes, waterline passes, or pencil milling techniques to hone the material closer to its final shape.

- Finishing initiates a faster spindle rotation speed and a decreased material feed rate. This step produces applies a finer finish to the piece.

- Contour Milling is usually used on hardware with five or more axes. During contouring, the work piece is rotated to allow a cutting tool to finish the part with higher dimensional accuracy. Contour milled components can have greatly improved surface finish.
As CNC software and computer hardware becomes more cost-efficient, it may be useful for manufacturers to consider including computer-controlled tools in their shops. The relative precision, uniformity of products, and standardization of methods that CNC tools provide can make them a valuable addition to a range machining projects.

3.13 INDIAN MACHINE TOOL INDUSTRY

India stands 13th in production and 6th in the consumption of machine tools in the world as per the latest survey. The country is set to become a key player in the global machine tools industry and is likely to see substantial high-end machine tool manufacturing. Industry experts say that the phenomenon is linked to the spurt in manufacturing, for which the machine tools sector serves as the mother industry. Since, the manufacturing capacity is stagnating and the growth rate for the machine tools industry falling in developed economies, shifting machine tool capacity to low-cost high skill geographies like India, has become imperative.

The Indian Machine tool Industry has around 1000 units in the production of machine tools, accessories/attachments, subsystems and parts. Of these, around 20 in the large scale sector account for 70 percent of the turnover and the rest are in the SME sector of the industry. Approximately, 75 per cent of the Indian machine tool producers are ISO certified. While the large organized players cater to India’s heavy and medium industries, the small-scale sector meets the demand of ancillary and other units. Many machine tool manufacturers have also obtained CE Marking certification, in keeping with the requirements of the European markets.
3.13.1  **World Machine Tool Scenario in 2012**

Dollar-volume production of machine tools around the world during 2012 dipped by 1%. Output by the 28 principal producing countries was $93.2-billion.

That represents a decline from 2011’s $94.3-billion, following previous increases of 35% and 25%. So the hole caused by the deep worldwide recession in 2009 has been filled. Most major producers had relatively small percentage changes in their output. Among the larger gainers were Germany with a 10% increase; the United States with a 7% improvement; Austria, +15%; and the Czech Republic, which increased one-quarter over 2011. Other countries declined in production, including Brazil, Belgium, and the United Kingdom.

China saw a slight dip in output in 2012 but remains by far the largest maker of machine tools. Japan ranks second, with no change in production from the year before, and it is followed by Germany. The output from those top three account for 64% of 2012’s total world shipments measured in this survey. The United States, still seventh in output, shipped almost $5-billion. It continues to be a large importer of factory equipment with a whopping 30% gain in 2012, and so total consumption of machine tools increased 19% to $8.7-billion.

The largest-consuming country in the world continues to be China, which installed $38.5-billion worth of machine tools, more than one-third of it in imports. On a per-capita basis, consumers Switzerland, South Korea, and Taiwan top the list.

Results of the World Machine Tool Output and Consumption survey 2013 conducted by Gardner Publication is ready and they have shared
the results of the survey with all the respondents. Based on the survey report India’s position in the world during 2012 is 13th in Consumption, & 4th in Imports. Figures regarding Production, Import, Export & Consumption are attached. Brief analysis of the data compiled by them is as follows:

### 3.13.2 Production of Machine Tools

Global Machine Tool estimated production amounted to USD 93.2 Billion during 2012 a slight decline of 1% from revised USD 94.2 Billion during 2011. India Production now occupies 13th position in the world compared to 12th during 2011. Top five countries are China(30%), Japan (20%), Germany (15%), Korea (6%), & Italy (6%). Top 3 countries accounts for 64% of the global output.

#### Table 3.3 Global Machinetool Production

<table>
<thead>
<tr>
<th>Country</th>
<th>2012</th>
<th>2011</th>
<th>Change in US Dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td>China, peoples Republic</td>
<td>28,270.00</td>
<td>27,540.00</td>
<td>-3%</td>
</tr>
<tr>
<td>Japan</td>
<td>18,326.60</td>
<td>18,252.90</td>
<td>0%</td>
</tr>
<tr>
<td>Germany</td>
<td>13,373.70</td>
<td>13,622.90</td>
<td>2%</td>
</tr>
<tr>
<td>Korea, Republic of</td>
<td>5,754.00</td>
<td>5,705.00</td>
<td>-1%</td>
</tr>
<tr>
<td>Italy</td>
<td>5,912.60</td>
<td>5,667.70</td>
<td>-4%</td>
</tr>
<tr>
<td>Taiwan</td>
<td>5,160.00</td>
<td>5,430.00</td>
<td>5%</td>
</tr>
<tr>
<td>United States</td>
<td>4,676.70</td>
<td>4,983.20</td>
<td>7%</td>
</tr>
<tr>
<td>Switzerland</td>
<td>3,607.00</td>
<td>3,199.30</td>
<td>-11%</td>
</tr>
<tr>
<td>Spain</td>
<td>1,072.60</td>
<td>1,060.30</td>
<td>-1%</td>
</tr>
<tr>
<td>Austria</td>
<td>971.1</td>
<td>1,032.00</td>
<td>6%</td>
</tr>
<tr>
<td>France</td>
<td>855.6</td>
<td>805.8</td>
<td>-6%</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>646</td>
<td>728.4</td>
<td>13%</td>
</tr>
</tbody>
</table>
Table 3.3 (Continued)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>13 India</td>
<td>720.7</td>
<td>880</td>
<td>-18%</td>
</tr>
<tr>
<td>14 Canada</td>
<td>639.3</td>
<td>693</td>
<td>8%</td>
</tr>
<tr>
<td>15 United Kingdom</td>
<td>731.5</td>
<td>649.8</td>
<td>-11%</td>
</tr>
<tr>
<td>16 Turkey</td>
<td>659.4</td>
<td>649</td>
<td>-2%</td>
</tr>
<tr>
<td>17 Brazil</td>
<td>891.3</td>
<td>643.2</td>
<td>-28%</td>
</tr>
<tr>
<td>18 Netherlands</td>
<td>407.6</td>
<td>402.3</td>
<td>-1%</td>
</tr>
<tr>
<td>19 Belgium</td>
<td>357.5</td>
<td>296.9</td>
<td>-17%</td>
</tr>
<tr>
<td>20 Russia</td>
<td>263</td>
<td>263</td>
<td>0%</td>
</tr>
<tr>
<td>21 Sweden</td>
<td>218.4</td>
<td>201.8</td>
<td>-8%</td>
</tr>
<tr>
<td>22 Finland</td>
<td>196.2</td>
<td>185.1</td>
<td>-6%</td>
</tr>
<tr>
<td>23 Australia</td>
<td>150</td>
<td>155</td>
<td>3%</td>
</tr>
<tr>
<td>24 Mexico</td>
<td>122.4</td>
<td>122.4</td>
<td>0%</td>
</tr>
<tr>
<td>25 Denmark</td>
<td>76.5</td>
<td>70</td>
<td>-8%</td>
</tr>
<tr>
<td>26 Portugal</td>
<td>50.1</td>
<td>46.3</td>
<td>-8%</td>
</tr>
<tr>
<td>27 Romania</td>
<td>42.5</td>
<td>42.5</td>
<td>0%</td>
</tr>
<tr>
<td>28 Argentina</td>
<td>32.4</td>
<td>36.4</td>
<td>12%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>94,344.00</strong></td>
<td><strong>93,204.90</strong></td>
<td><strong>-1%</strong></td>
</tr>
</tbody>
</table>

Source: Gardner Publications, Inc., 2013

Consumption of Machine Tools

Global consumption of machine tools amounted USD 85.4 Billion during 2012 had decreased by 3% from USD 87.6 Billion during 2011. China which occupies top position accounts for 41% of the world’s consumption. Top 5 consuming countries are China (41%), Japan (8%), Germany (7%), USA (9%) & Korea (5%) India with about 3% global share occupies 6 compared to 7th position during 2011.
Table 3.4 Global Machinetechnology Consumption

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 China, Peoples Republic</td>
<td>39,090.00</td>
<td>38,510.00</td>
<td>-1%</td>
</tr>
<tr>
<td>2 United States</td>
<td>7,321.30</td>
<td>8,722.50</td>
<td>19%</td>
</tr>
<tr>
<td>3 Japan</td>
<td>7,417.70</td>
<td>7,462.80</td>
<td>1%</td>
</tr>
<tr>
<td>4 Germany</td>
<td>6,901.80</td>
<td>6,400.20</td>
<td>-7%</td>
</tr>
<tr>
<td>5 Korea, Rep. of</td>
<td>5,244.00</td>
<td>4,646.00</td>
<td>-11%</td>
</tr>
<tr>
<td>6 India</td>
<td>2,286.10</td>
<td>2,556.40</td>
<td>-11%</td>
</tr>
<tr>
<td>7 Italy</td>
<td>2,762.90</td>
<td>2,172.00</td>
<td>-21%</td>
</tr>
<tr>
<td>8 Brazil</td>
<td>2,385.70</td>
<td>1,867.20</td>
<td>-22%</td>
</tr>
<tr>
<td>9 Taiwan</td>
<td>1,989.00</td>
<td>1,844.00</td>
<td>-7%</td>
</tr>
<tr>
<td>10 Mexico</td>
<td>1,360.90</td>
<td>1,360.90</td>
<td>0%</td>
</tr>
<tr>
<td>11 Turkey</td>
<td>1,341.10</td>
<td>1,344.30</td>
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</tr>
<tr>
<td>12 Russia</td>
<td>1,317.00</td>
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<td>0%</td>
</tr>
<tr>
<td>13 Canada</td>
<td>1,143.60</td>
<td>1,255.60</td>
<td>10%</td>
</tr>
<tr>
<td>14 France</td>
<td>1,309.10</td>
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<td>-15%</td>
</tr>
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<td>15 Switzerland</td>
<td>1,274.50</td>
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<td>-19%</td>
</tr>
<tr>
<td>16 United Kingdom</td>
<td>745.8</td>
<td>816.2</td>
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<tr>
<td>17 Austria</td>
<td>620.5</td>
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<td>403.3</td>
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<tr>
<td>22 Argentina</td>
<td>210.1</td>
<td>261.3</td>
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<tr>
<td>23 Belgium</td>
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<td>246.8</td>
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</tr>
<tr>
<td>24 Romania</td>
<td>243</td>
<td>243</td>
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</tr>
<tr>
<td>25 Australia</td>
<td>213</td>
<td>210</td>
<td>-1%</td>
</tr>
<tr>
<td>26 Finland</td>
<td>150.3</td>
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<td>-7%</td>
</tr>
<tr>
<td>27 Portugal</td>
<td>118.3</td>
<td>137.5</td>
<td>16%</td>
</tr>
<tr>
<td>28 Denmark</td>
<td>43.1</td>
<td>39.8</td>
<td>-8%</td>
</tr>
<tr>
<td>Total</td>
<td>87,600.90</td>
<td>85,449.80</td>
<td>-3%</td>
</tr>
</tbody>
</table>

Source: Gardner Publications, Inc., 2013
Table 3.5 India’s Status in the World Market

<table>
<thead>
<tr>
<th>India's Position Globally during 2012</th>
<th>Value in US$ Million</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>721</td>
<td>13</td>
</tr>
<tr>
<td>Consumption</td>
<td>2286</td>
<td>7</td>
</tr>
</tbody>
</table>

Source: Primary Data

Table 3.6 Machine Tool Segmentation

<table>
<thead>
<tr>
<th></th>
<th>CNC</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forming</td>
<td>Rs. 376 Cr</td>
<td>Rs. 189 Cr</td>
</tr>
<tr>
<td>Cutting</td>
<td>Rs. 2811 Cr</td>
<td>Rs. 509 Cr</td>
</tr>
</tbody>
</table>

Source: Indian Machines Tool Association Annual Report, 2013

Table 3.7 Growth of Indian Machine Tool Industry

<table>
<thead>
<tr>
<th></th>
<th>2011-12</th>
<th>2012-13</th>
<th>Growth Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>4299</td>
<td>3885</td>
<td>-10%</td>
</tr>
<tr>
<td>Exports</td>
<td>180</td>
<td>214</td>
<td>19%</td>
</tr>
<tr>
<td>Imports</td>
<td>7645</td>
<td>7598</td>
<td>-1%</td>
</tr>
<tr>
<td>Consumption</td>
<td>11764</td>
<td>11265</td>
<td>-4%</td>
</tr>
</tbody>
</table>

Source: Indian Machines Tool Association Annual Report, 2013

The Indian machine tools sector offers several opportunities for investment. Given the current gap between demand and supply, there is a clear need for adding capacities in this sector. The industry is moving towards increasingly sophisticated CNC machines, driven by demand from key user segments, such as, automobiles and consumer durables. Machine tool manufacturers need to develop capabilities to cater to this demand and investments in this area could yield long term benefits.
3.13.3 CNC Market in India

Since many players involved in the business of CNC machine manufacturing and also in marketing, the volume of business also increases day by day. The following table shows the split-up of machine types already in usage in Indian industries.

**Table 3.8 Type of Machines Used**

<table>
<thead>
<tr>
<th>Machine Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mills</td>
<td>50</td>
</tr>
<tr>
<td>Lathes</td>
<td>20</td>
</tr>
<tr>
<td>Routers</td>
<td>12</td>
</tr>
<tr>
<td>3D Printers</td>
<td>5</td>
</tr>
<tr>
<td>Plasma Tables</td>
<td>4</td>
</tr>
<tr>
<td>Lasers</td>
<td>3</td>
</tr>
<tr>
<td>EDM</td>
<td>2</td>
</tr>
<tr>
<td>Waterjet</td>
<td>2</td>
</tr>
<tr>
<td>Press Brakes</td>
<td>1</td>
</tr>
<tr>
<td>Others</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: Primary Data

**Figure 3.9 Status of Type of Machines**
Mills, Lathes, and CNC Routers were the most common machine types. The category of “Machines for cutting sheet material” consisting of Plasma Tables, Lasers, and Waterjets would be close to CNC Routers if considered together. The most common machines in the “Other” category were press brakes, waterjets, CNC’d Knee Mills, and Tormach mills, which makes good sense to me.

Even in the face of growing demand, India's manufacturing sector continues to be over dependent on import of machine tools, including CNC (computer numerical control) and non-CNC machines, lathes, forgings and dyes, as the Indian machine tools industry is able to meet around 33 percent of the total consumption due to capacity constraints and lack of investments.

According to the association's data, of the Rs.11,818 crore sales revenue generated last fiscal (2010-11) from consumption, imports accounted for Rs.7,722 crore while domestic production contributed Rs.4,096 crore. In contrast, sales revenue in fiscal 2009-10 was Rs.8,845 crore, with imports accounting for Rs.5,647 crore and domestic production for Rs.3,198 crore.

In terms of orders booked, demand for CNC machines in fiscal 2010-11 was in value of Rs.3,775 crore and for non-CNC machines Rs.1,203 crore as against Rs.3,039 crore and Rs.1,151 crore, respectively, in fiscal 2009-10.

Though India ranks seventh in machine tools consumption globally in value terms ($1.74 billion) as against China at $27 billion, Germany $5 billion and Japan $4.5 billion, the country ranks 13th in terms of production in value terms at $500 million and 27th in exports, with China, Germany and Japan dominating the top three positions.
Almost all current CNC controls use a word address format for programming. (The only exceptions to this are certain conversational controls.) By word address format, we mean that the CNC program is made up of sentence-like commands. Each command is made up of CNC words, each of which has a letter address and a numerical value. The letter address (X, Y, Z, etc.) tells the control the kind of word and the numerical value tells the control the value of the word. Used like words and sentences in the English language, words in a CNC command tell the CNC machine what it is we wish to do at the present time.

One very good analogy to what happens in a CNC program is found in any set of step-by-step instructions. Say, for example, you have some visitors coming in from out of town to visit your company. You need to write down instructions to get from the local airport to your company. To do so, you must first be able to visualize the path from the airport to your company. You will then, in sequential order, write down one instruction at a time. The person following your instructions will perform the first step and then go on to the next until he or she reaches your facility.

In similar manner, a manual CNC programmer must be able to visualize the machining operations that are to be performed during the execution of the program. Then, in step-by-step order, the programmer will give a set of commands that makes the machine behave accordingly. Though slightly off the subject at hand, we wish to make a strong point about visualization. Just as the person developing travel directions must be able to visualize the path taken, so must the CNC programmer be able to visualize the movements the CNC machine will be making before a program can be successfully developed. Without this visualization ability, the programmer will not be able to develop the movements in the program correctly. This is
one reason why machinists make the best CNC programmers. An experienced machinist should be able to easily visualize any machining operation taking place.

Just as each concise travel instruction will be made up of one sentence, so will each instruction given within a CNC program be made up of one command. Just as the travel instruction sentence is made up of words (in English), so is the CNC command made up of CNC words (in CNC language).

The person following your set of travel instructions will execute them explicitly. If you make a mistake with your set of instructions, the person will get lost on the way to your company. In similar fashion, the CNC machine will execute a CNC program explicitly. If there is a mistake in the program, the CNC machine will not behave correctly. At right is a short example program that drills two holes in a workpiece on a CNC machining center. Keep in mind that we are not stressing the actual commands in this program (though the messages in parentheses should make it relatively clear as to what is happening in each command). Instead, we are stressing the structure of a CNC program and the fact that it will be executed sequentially.

While the words and commands in this program probably do not make much sense to you (yet), remember that we are stressing the sequential order by which the CNC program will be executed. The control will first read, interpret and execute the very first command in the program. Only then will it go on to the next command. Read, interpret, execute. Then on to the next command. The control will continue to execute the program in order for the balance of the program. Again, notice the similarity to giving any set of step-by-step instructions.
3.14.1 Other Notes about Program Makeup

As stated, programs are made up of commands and commands are made up of words. Each word has a letter address and a numerical value. The letter address tells the control the word type. CNC control manufacturers do vary with regard to how they determine word names (letter addresses) and their meanings. The beginning CNC programmer must reference the control manufacturer's programming manual to determine the word names and meanings. Here is a brief list of some of the word types and their common letter address specifications.

O - Program number (Used for program identification)
N - Sequence number (Used for line identification)
G - Preparatory function (See below)
X - X-axis designation
Y - Y-axis designation
Z - Z-axis designation
R - Radius designation
F - Feedrate designation
S - Spindle speed designation
H - Tool length offset designation
D - Tool radius offset designation
T - Tool Designation
M - Miscellaneous function

As you can see, many of the letter addresses are chosen in a logical manner (T for tool, S for spindle, F for feed rate, etc.). A few require memorizing. There are two letter addresses (G and M) which allow special functions to be designated. The preparatory function (G) specifies is
commonly used to set modes. We already introduced absolute mode, which is
specified by G90 and incremental mode, specified by G91. These are but two
of the preparatory functions used. You must reference your control
manufacturer's manual to find the list of functions for your machine.

Like preparatory functions, miscellaneous functions (M words)
allow a variety of special functions. Miscellaneous functions are typically
used as programmable switches (like spindle on/off, coolant on/off, and so
on). They are also used to allow programming of many other programmable
functions of the CNC machine tool. To a beginner, all of this may seem like
CNC programming requires a great deal of memorization. But rest assured
that there are only about 30-40 different words used with CNC programming.
If you can think of learning CNC manual programming as like learning a
foreign language that has only 40 words, it shouldn't seem too difficult.

3.14.2 Decimal Point Programming

Certain letter addresses (CNC words) allow the specification of real
numbers (numbers that require portions of a whole number). Examples
include X-axis designator (X), Y-axis designator (Y), and radius designator
(R). Almost all current model CNC controls allow a decimal point to be used
within the specification of each letter address. For example, X3.0625 can be
used to specify a position along the X axis.

On the other hand, some letter addresses are used to specify integer
numbers. Examples include the spindle speed designator (S), the tool station
designator (T), sequence numbers (N), preparatory functions (G), and
miscellaneous functions (M). For these word types, most controls do not
allow a decimal point to be used. The beginning programmer must reference
the CNC control manufacturer's programming manual to find out which
words allow the use of a decimal point.
All but the very simplest CNC machines have programmable functions other than just axis motion. With today's full blown CNC equipment, almost everything about the machine is programmable. CNC machining centers, for example, allow the spindle speed and direction, coolant, tool changing, and many other functions of the machine to be programmed. In similar fashion, CNC turning centers allow spindle speed and direction, coolant, turret index, and tailstock to be programmed. And all forms of CNC equipment will have their own set of programmable functions. Additionally, certain accessories like probing systems, tool length measuring systems, pallet changers, and adaptive control systems may also be available and will require programming considerations.

The list of programmable functions will vary dramatically from one machine to the next, and the user must learn these programmable functions for each CNC machine to be used. In key concept number two, we will take a closer look at what is typically programmable on different forms of CNC machine tools.