INTRODUCTION TO CNC

Dr. C. Marcelino Rivas Santana[1], MSc. Agustín L. Almerá Baró[1], Ing. Bruno Eugenio Chirrine[1], Reynier Febles García[1]

1. Universidad de Matanzas "Camilo Cienfuegos", Vía Blanca Km.3, Matanzas, Cuba.

Abstrac

In the last years the efficiency of the manufacture process has an important role, every time the productivity increasing and the decrease of the costs are more important. Without doubt tool- machine with numerical control play an important role. In the text some aspects such as what CNC is accuracy, the origins of numerical control servos and selsyns, why CNC is used and other aspects of general interest are developed.

***Key words**: Manufacture, numerical control.*

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WHAT IS CNC?

1.1.1 Definition

Computer Numerical Control (CNC) is a process in which a set of sequenced instructions (a program) is fed into a specially designed programmable controller and then using the controller to direct the motions of a machine tool. The alphanumerical data represents the relative positions between a cutting tool and a work part, a computer is the source of the program, in other words CNC is a form of programmable automation using a computer, ignoring the word computer in the acronym CNC can be referred to as NC, actually NC existed before CNC due to the fact that before the modern day computer is newer than numerical control methods. The CNC can be compared to an Electronic Control Module (ECM) of a motor vehicle, the difference between a CNC and the ECM of a modern vehicle is that the CNC has a writable type of memory whereas the ECM type of memory is read-only once it is programmed.

CNC controllers are designed to control the movement of a cutter along the machine's axes of motion, the rotation of the spindle, the changing of cutting tools, and many miscellaneous functions such as turning the coolant on and off. In addition to producing the external geometry of a workpart, internal geometries such as pockets and recesses can be produced; holes can be drilled, reamed, bored, countersunk, and/or tapped. Machine tools that are equipped with such specialised programmable controllers are called "numerical control machines". CNC machines use electronic commutation to regulate spindle speed during machining, this permits the control to maintain the constant spindle speed during the elaboration of special surfaces with variable diameter like cones and the process of cutting off. This increases productivity, and decreases tool wear while maintaining identical surface quality of surfaces.

Whether the cutter or the workpart depends on the type of machine in question, as we know in a lathe the workpart spins and the cutter is stationery whereas in a milling machine the opposite is the case, the movement depends also on the design of the machine.

Numerical controlled machines in essence consist of four main parts;

1. The source of the workpart program

   This can be a computer or a Manual Data Input (MDI) Fig.1.1.1 (a & b) this is where the workpart program is written or edited in its word and number format. Usually there is a screen to view the end of the workpart or to see if there have been any mistakes on the program, this is true when using modern machines and CAD or CAM software.

2. The motion controller

   This is the hardware part of the CNC; its task is to transform the word and number program into electronic impulses that can cause a special kind of electric motor(s) to move the machine tool (cutter) or the stock material to the points necessary for the workpart to be obtained. The controller must have a parallel cable to be connected to a computer or an MDI. Fig.1.1.1 (c)

3. Machine (machine tool)

This can be a lathe, milling machine, grinding machine laser machine, welding machine or any type of machine with a moveable part. In modern CNC the machine tools have sensors at the tip of the cutter to feedback information about the cutting process so the controller can optimise the cutting process; this involves a primitive form of artificial intelligence and makes the CNC machine very complex and sophisticated.

An industrial robot is actually a form of an NC machine, in that its motion is controlled by a controller very similar in function to that of an NC machine (although it may be programmed differently). A robot is an articulated mechanical arm that is controlled by a special programmable controller. The motion of its mechanical arm, to which a device called an "end effector" is attached, can be used to feed a workpart into a machine, invert and reposition de workpart into the machine or remove the finished work part from the machine.

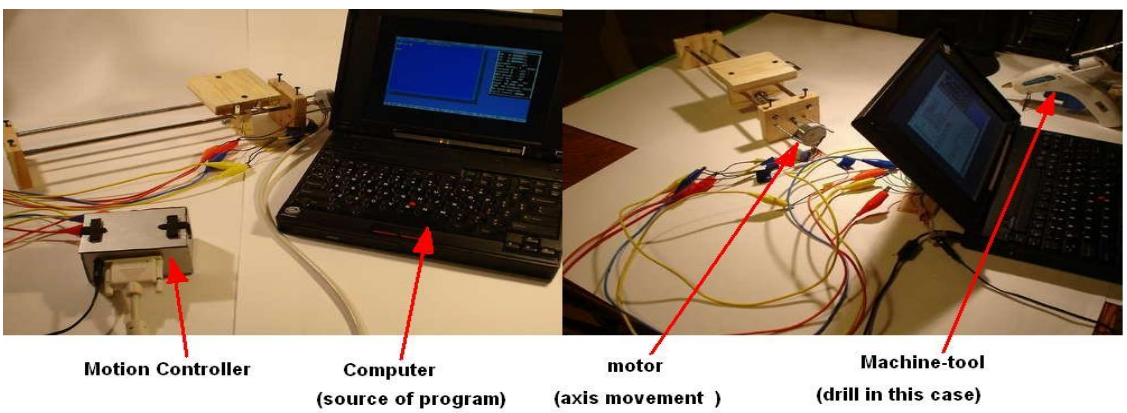

Fig.1.1.1 (a) A carpenter's CNC machine with only the basic components.

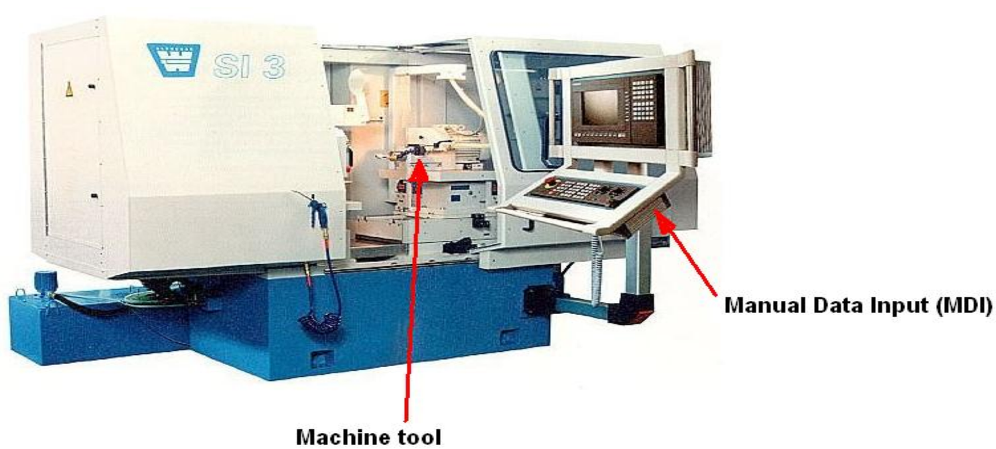

Fig.1.1.2 (b) A modern CNC machine.

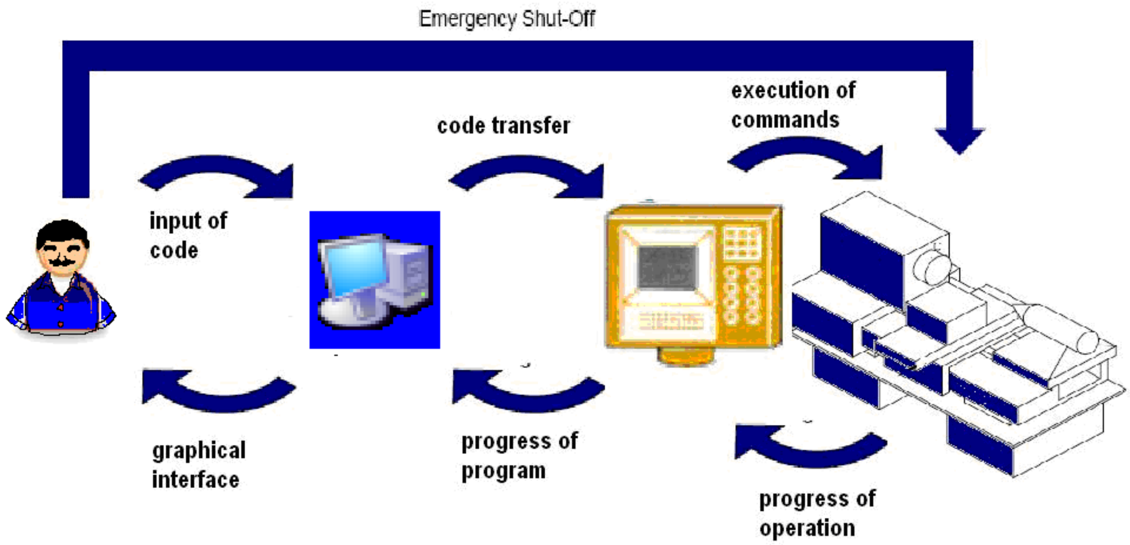

Fig.1.1.1. (c) The information flow diagram of a CNC system

In some machines the control is and the computer are integrated into a system called a Programmable Logic Controller (PLC) or Programmable Controller (PC) which is in fact an electronic unit or a small computer that controls the CNC machinery, equipment, and complete processes, and assist NC machine tools and Flexible Manufacturing Modules (FMM) and cells, they are the technological replacement for electrical relay systems.

1.1.2. CAD and CAM

Industrial robots and CNC are subsets of a greater technological family known as Computer Aided Manufacturing (CAM), Some authors claim that CAM consists primarily of NC. The is another important field in the sphere of manufacturing with the same weight as CAM, this is none other than Computer Aided Design (CAD),which refers to the generation of computer graphics that are used in engineering design and similar drawings. It is a process of constructing a geometric design of images which represent the geometric shape of a workpart (or assembly of workparts) on the screen of a computer (Figure 1.1.1 *d* and *e*), and then using the computer to drive an X-Y plotter to make the engineering drawings. In its more sophisticated forms, CAD is capable of performing stress analyses and examining other aspects of engineering design.

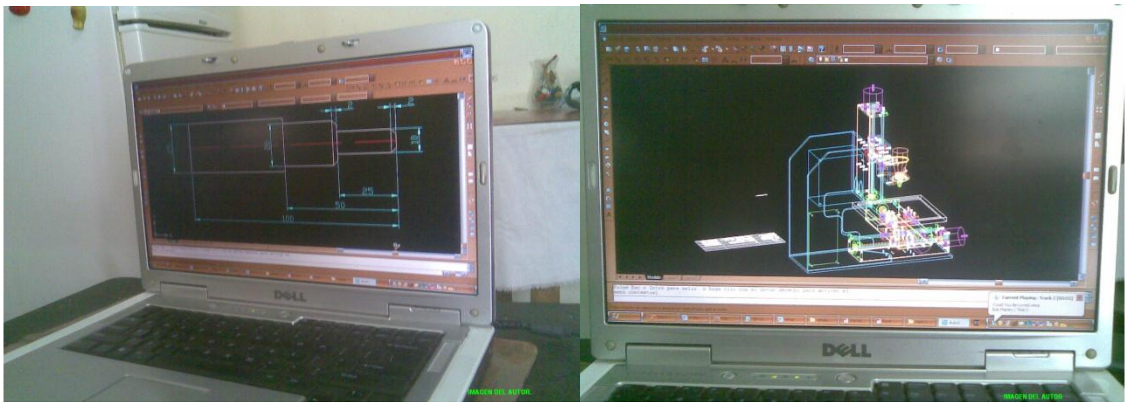

FIG.1.1.1 (d) A workpart drawing in AutoCad (e) A 3D part assembly

Advances in technology have allowed a fusion between CAD and CAM systems giving birth to the so-called CAD/CAM systems, Computer graphics is the CAD part and N/C is the CAM part of manufacturing. CAD software like AutoCAD can be used to generate a visual image of a desired workpart but cannot instruct a CAM software like WinUnisoft to directly drive a machine tool to produce the workpart, because computer software capable of making judgmental decisions about the kind and size of cutter to use, how to clamp the workpart, the cutter motion direction or depth of cut does not exist. Despite this there is some sophisticated software capable of generating tool path data and outputting an NC program, such software can output machining instructions to a NC machine tool as part of the design process if the designer has knowledge needed to specify the proper tool path and the correct machining parameters, that is a true case of CAD/CAM.

1.1.3. What makes CNC Machines More Accurate than Manual Machines?

The machine tool portion of an NC machine varies from its manually-operated counterpart in two very important respects. First, the NC machine tool is usually more rigid, since deflection must be minimised; and second, the axes are usually actuated by means of ballscrews; a hardened-and-ground leadscrew with a recirculating ball bearing nut (Fig. 1.1.3.). The thread groove on the leadscrew is ground to exactly fit the balls with zero clearance. This eliminates the backlash that results from the clearance between the screw and nut found with ordinary acme thread leadscrews used on most manual machine tools.

Fig. 1.1.3 A ballscrew connected to a stepper motor during testing.

To fully understand CNC it is vital for the reader to take a look at the history of numerical control and automation.

1.1. THE ORIGINS OF NUMERICAL CONTROL

The origins of CNC are in automation that is because Numerical control is just programmable automation. To fully understand CNC machines we must first be acquainted with the traditional mechanical concepts of machine tools, this also implies recalling one of the classical machine elements for automation, the cam. By definition a cam is a projection on a rotating part in machinery, designed to make sliding contact with another part while rotating and impart reciprocal or variable motion to it.

1.2.1 Cams

The origins of Numerical Control go back to he 1720s when the Jacquard loom was devised to control the decorative patterns woven into the cloth through the usage of cams for automation, built by the Frenchman Joseph Marie Jacquard, this power loom could base its weave (and hence the design on the fabric) upon a pattern automatically read from punched wooden cards, held together in a long row by rope (Fig.1.2.1 *a*). A more recognisable predecessor of numerical control is the player piano (Fig.1.2.1 *b*) which originated in the 1860s , it used a roll of punched paper to control the actuation of keys and notes. Tool automation used the idea as the one used in the player piano, for example special cams played machine tools the same way they played music boxes o cuckoo clocks. Thomas Blanchard built his gun-stock-copying lathes using cams in the years 1820-30, people like Christopher Miner Spencer developed the turret lathe into the screw machine in the 1870. By World War I cam automation had advanced considerably.

Fig.1.2.1 (a) Jacquard's Loom showing the threads and the punched cards

Fig.1.2.1. (b) Player Pianos like these were the first juke boxes.

Despite all this cam automation is different from numerical control in that it could not be programmed, there is direct connection between the aspired design and the machining steps needed to produce it. Cams could encode information, but obtaining information from a workpart drawing to a cam is a process that involves sculpture and/or machining or even filing, i.e. a cam needs a model of the desired workpart to guide it to generate the desired workpart. All in all only two forms of programmable automation existed in the nineteenth century; the Jacquard loom and the mechanical computers used by Charles Babbage and others.

1.2.2 Tracer control

The application of hydraulics to cam automation resulted in tracer machines that used a stylus (follower) to follow models or templates, e.g. the Keller Machine used by Pratt and Whitney that could trace templates several metres long. Another machine was the pioneer record and play machine patent of the General Motors (GM) in the 1950s, it used a storage system to record the movements of a human operator to later play them at request. Similar systems still exist today, a notable example is the “teaching lathe” which gives a new operator an active hands-on participation during a process. None of the aforementioned cases where numerically programmable, furthermore they needed a expert machinist at one point of the process, because the programming was rather physical than numerical.

Numerical control as we know it today started out before the existence of the microprocessor present in contemporary. The introduction of the turbojet engine by the U.S Air Force permitted a considerable increase in the speed of combat aircraft, which resulted in increased stresses on aircraft structural members. The structural members became more geometrically complex to withstand the increased forces and required more complex machining, this was very costly. The first successful Numerical Control machine was demonstrated by the Massachusetts Institute of Technology (MIT) in 1952. It was an adapted Cincinnati milling machine (See Fig.1.2.2*a* and *b*). It had the ability to co-ordinate the axis motions to machine a complex surface. The first "commercial" NC machines were shown at the 1955 National Machine Tool Show.

FIG.1.2.2 (a) The first NC machine, a retrofitted milling machine.

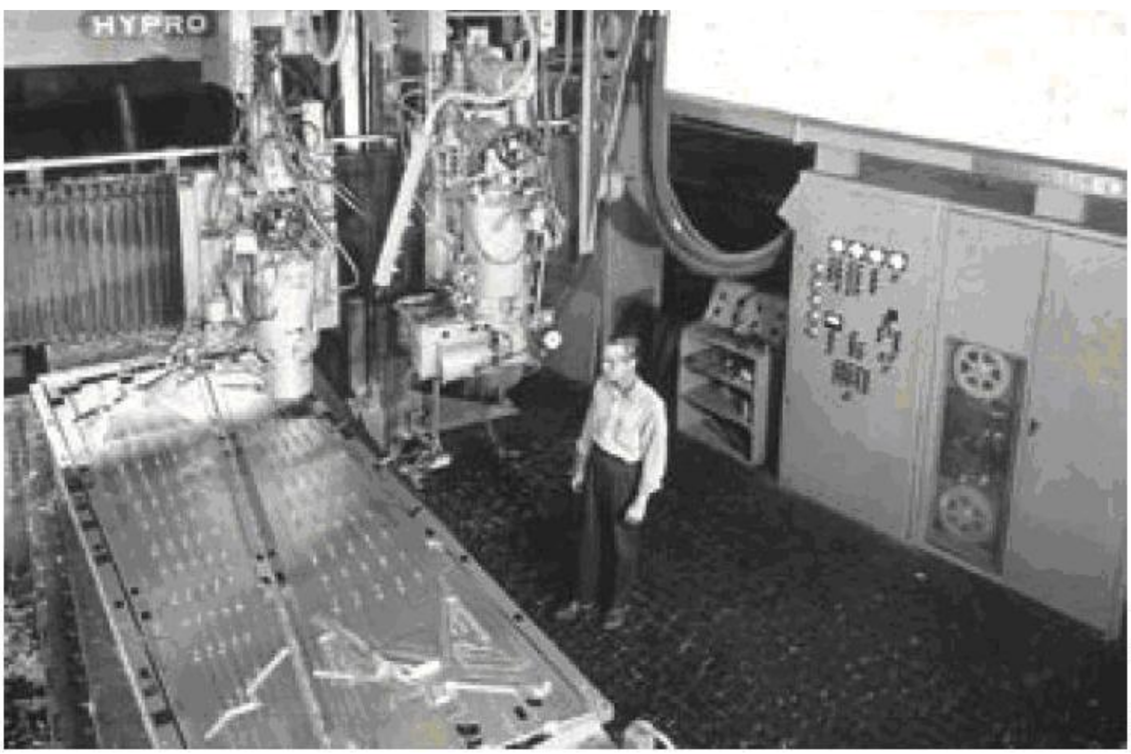

FIG.1.2.2 (b) Milling a mould for skin panels for a US airforce jet in the ‘50s

The first of NC machines used large vacuum-tube-based controllers that consumed a lot of electrical power (it had 250 vacuum tubes, 175 relays and numerous moving parts), generated a lot heat, occupied a large area of floor space, and this reduced its reliability in a production setting. the total bill presented to the Air Force was $360,000.14, $2,641,727.63 in 2005 dollars. Second generation models replaced the vacuum tubes with transistors for increased reliability, decreased power consumption, and occupied less space. Third generation models featuring integrated circuits and modular circuit design reduced costs and increased reliability even further.

1.2.3. Servos and selsyns

One barrier to complete automation was the required tolerances of the machining process, which are routinely on the order of two thousandths of a millimetre. Although connecting some sort of control to a storage device like punch cards was easy, ensuring that the controls were moved to the correct position with the required accuracy was another issue. The movement of the tool resulted in varying forces on the controls that would mean a linear input would not result in linear tool motion. The key development in this area was the introduction of the servomechanism, which produced highly accurate measurement information. Attaching two servos together produced a Selsyn, where a remote servo's motions were accurately matched by another. Using a variety of mechanical or electrical systems, the output of the selsyns could be read to ensure proper movement had occurred (in other words, forming a closed-loop control system).

The first serious suggestion that selsyns could be used for machining control was made by Ernst F. W. Alexanderson, a Swedish immigrant to the U.S. working at General Electric (GE). Alexanderson had worked on the problem of torque amplification that allowed the small output of a mechanical computer to drive very large motors, which GE used as part of a larger gun laying system for US Navy ships. Like machining, gun laying requires very high accuracy, much less than a degree, and the motion of the gun turrets was non-linear. In November 1931 Alexanderson suggested to the Industrial Engineering Department that the same systems could be used to drive the inputs of machine tools, allowing it to follow the outline of a template without the strong physical contact needed by existing tools like the Keller Machine. The concept was ahead of its time from a business development perspective, and GE did not take the matter seriously until years later, when others had pioneered the field.

As technology continued to advance, special pre-programmed circuit boards were added to perform many of the commonly used routines. The routines, called canned cycles performed cyclic operations such as drilling, boring and tapping. These first and second generation controllers had no memory. The controller had to be “fed” its instructions, one at a time, from an external source, a tape reader (Fig.1.2.3). The controller would accept a single instruction (or command), execute that command, accept the next command, execute it, accept another command, etc.

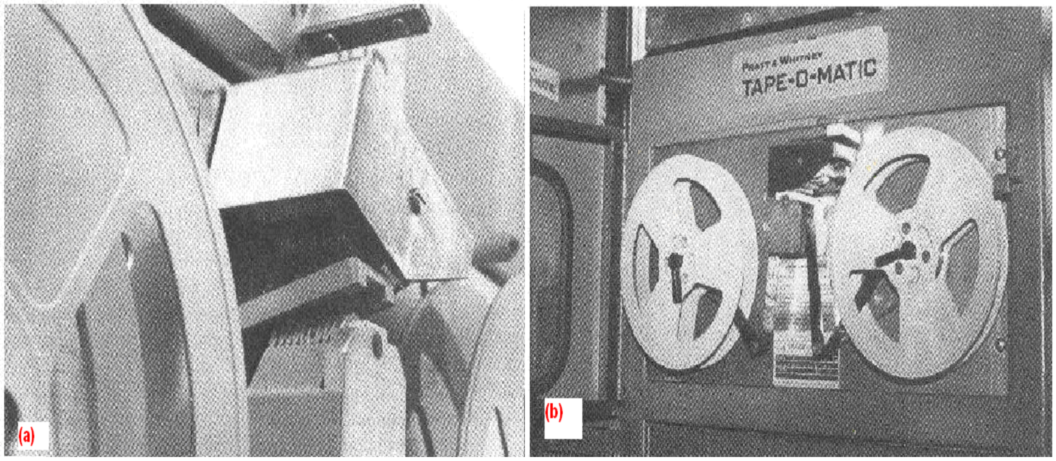

Fig.1.2.3 (a) and (b) Controllers like these used tapes to store the programs.

The commands were encoded on a paper tape. As the tape passed through the tape reader, a single block of information--the command--would be read and passed on to the controller for execution. After execution, the controller would signal the tape reader that it was ready for another command. The tape reader would then read the next block, and so on, until the entire tape was read, passed on to the controller, and executed. The last command on the tape was a code to cause the reader to rewind the tape. The first command on the tape was a code to tell the tape reader when to stop rewinding to prevent the front end of the tape from coming off the supply reel. Although NC machines like this are no longer being made, a number of these machines are still in use.

Here is a brief chronology of CNC development

1947: J. Parsons (Parsons Corporation) began experimenting for using 3-axis curvature data to control machine tool motion for the production of aircraft components.

1949: Parsons awarded a US Air Force contract to build the first NC machine.

1951: MIT was involved in the project

1952: NC achieved when MIT demonstrated that simultaneous 3-axis movements were possible using a laboratory-build controller and a Cincinnati HYDROTEL vertical spindle

1955: after refinements NC become available to industry

1.3 TODAY: COMPUTERISED NUMERICAL CONTROL (CNC)

1.3.1 The Microchip and its contributions to CNC

With the advent of the microprocessor chip, it became practicable to provide the controller with its own memory. This permitted the tape of program instructions to be read by the controller's tape reader only once and then stored in the controller's memory. Magnetic tape recorders and floppy disk drives were also being used for program recording and storage. The tape or disk could then be taken out and stored for future use. Alternatively, the controller could be connected directly to the computer (Fig.1.3.1) to receive its instructions without the use of any intermediate medium through a data cable (RS232). In addition, the controller could be fitted with its own keyboard for directly entering the program, called Manual Data Input (MDI) generally present in all turning centers (Fig.1.3.1 a), a turning centre is a large CNC lathe, its milling machine analogue is called a machining centre. Whatever the method for instructing the controller is, the controller could then execute the program by reading from its own memory.

Fig.1.3.1 A CNC milling machine with a connection to a modern laptop.

Debugging an NC program before the advent of CNC required making a new tape, trying out the new tape, finding the next error, making another tape, and so on. The process of debugging a new program could require making a dozen or more punched tapes until an error free program was achieved. Engineering changes required a new tape to be made and debugged.

(Fig.1.3.1 a) Modern turning centre, see the MDI on the right side.

The introduction of CNC, with the NC program stored in the controller's memory, made it possible to access the program directly in the controller's memory, making all the needed changes by keying in from the controller's keyboard (Fig.1.3.1 *b*). One tape (errors and all) is all it takes. When the program is finally debugged, the CNC controller can be connected to a tape punch or other recording device to output the edited program, to be saved for future use.

Presently there are three ways of introducing a program into a CNC machine, namely;

-Manual Part Programming: Manual programming of the machines

-Computer Aided Programming (CAP): Programming done by a computer

-Manual Data Input (MDI): A manual program is entered into the machine’s controller via its own keyboard

Manual Data Input

Modern Manual Data Input devices include a control panel with a screen and a keyboard; it also allows the making and feeding of data directly to the machine. It is common that in CNC machines programs can be entered through the keyboard, magnetic tapes, magnetic chips, diskettes and Computer connection to the CNC machine. The use of the keyboard with a video terminal allows the change of the workpart program; furthermore the screen gives a considerable amount of important information during workpart mechanisation. A program can be entered into the MDI block by block, this means the operator has to wait for the machine tool to carry out the command and enter the new block.

Fig.1.3.1 (b) MDI Control panel in modern CNC machines.

Fig.1.3.1 (a) Operators can introduce program data through the MDI in CNC manufacturing.

The microprocessor chip is a kind of a special-purpose computer. Hence the inclusion of the microchip to the numerical control system resulted in machines that came to be known as computerised NCs or CNCs . The canned cycle circuit boards were designed into the microprocessor chips (Fig.1.3.1 *b*) and made a little fancier by adding still more canned cycles, such as peck drilling for deep holes, rectangular and circular pocket milling, and even routines to calculate and drill bolt circle patterns. The price of computer cycles fell drastically during the 1960s with the widespread introduction of useful minicomputers. Eventually it became less expensive to handle the motor control and feedback with a computer program than it was with dedicated servo systems. Small computers were dedicated to a single mill, placing the entire process in a small box. PDP-8's and Data General Nova computers were common in these roles. The introduction of the microprocessor in the 1970s further reduced the cost of implementation, and today almost all CNC machines use some form of microprocessor to handle all operations.

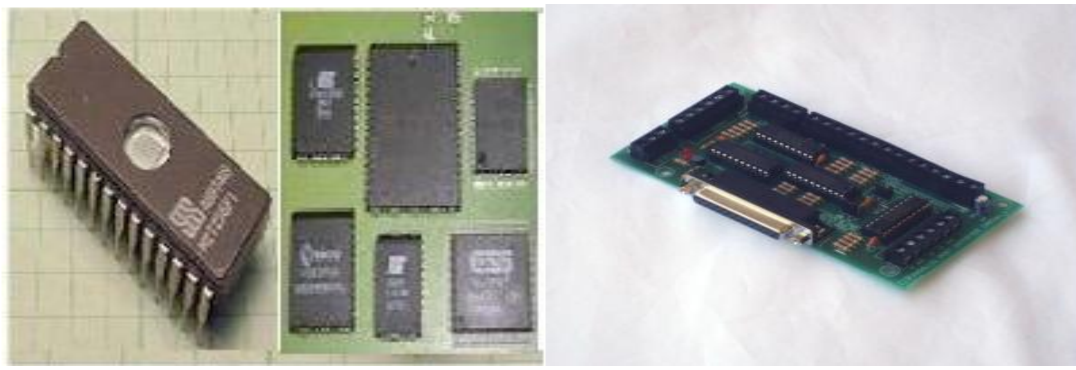

Fig.1.3.1 (b) Microchips are the principal catalysts of CNC.

1.3.2 Do It Yourself (DIY) CNC

The introduction of lower-cost CNC machines radically changed the manufacturing industry. Curves are as easy to cut as straight lines, complex 3-D structures are relatively easy to produce, and the number of machining steps that required human action has been dramatically reduced. With the increased automation of manufacturing processes with CNC machining, considerable improvements in consistency and quality have been achieved with no strain on the operator. CNC automation reduced the frequency of errors and provided CNC operators with time to perform additional tasks. CNC automation also allows for more flexibility in the way parts are held in the manufacturing process and the time required to change the machine to produce different components.

Recent developments in small scale CNC have been enabled, in large part, by the EMC project (Enhanced Machine Controller) from the National Institute of Standards and Technology (NIST), an agency of the Commerce Department of the United States government. EMC is a public domain program operating under Linux operating systems and working on PC based hardware. The availability of these PC based control systems has led to the development of DIY CNC, allowing hobbyists to build their own using open source hardware designs (Fig.1.3.2.*a*,*b* and *c*). The same basic architecture has allowed manufacturers, such as Sherline and Taig, to produce turnkey lightweight desktop milling machines for hobbyists.

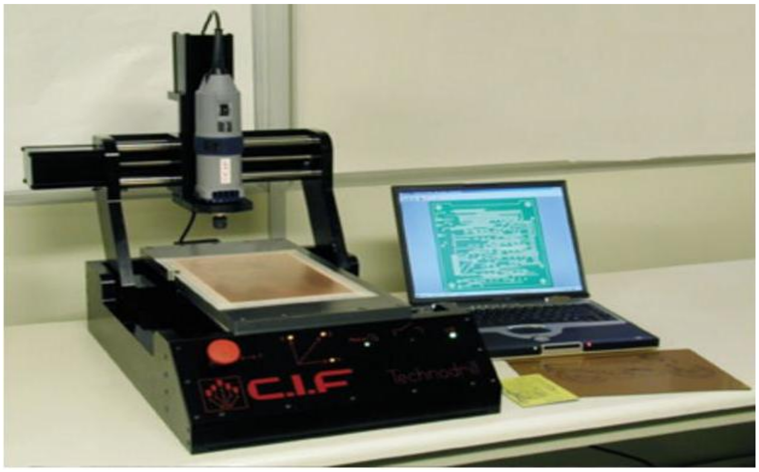

Fig.1.3.2 (a) A DIY CNC drawing machine

Fig.1.3.2.(b) A Carpenters CNC drilling machine.

Fig.1.3.2 (c) Hobbyists can buy every component needed for a home-made CNC machine.

Eventually the home-brew architecture was fully commercialised and used to create larger machinery suitable for commercial and industrial applications. This class of equipment has been referred to as Personal CNC. Parallel to the evolution of personal computers, Personal

CNC has its roots in EMC and PC based control, but has evolved to the point where it can replace larger conventional equipment in many instances. As with the Personal Computer, Personal CNC is characterised by equipment whose size, capabilities, and original sales price make it useful for individuals, and which is intended to be operated directly by an end user, often without professional training in CNC technology.

Although modern data storage techniques have moved on from punch tape in almost every other role, tapes are still relatively common in CNC systems. This is because it was often easier to add a punch tape reader to a microprocessor controller than it was to re-write large libraries of tapes into a new format. One change that was implemented fairly widely was the switch from paper to mylar tapes, which are much more mechanically robust. Floppy disks, USB flash drives and local area networking have replaced the tapes to some degree, especially in larger environments that are highly integrated. As the controller hardware evolved, the mills themselves also evolved. One change has been to enclose the entire mechanism in a large box as a safety measure, often with additional safety interlocks to ensure the operator is far enough from the working piece for safe operation. Most new CNC systems built today are completely electronically controlled.

CNC is often the cheapest alternative for obtaining high precision and safe workparts (Fig.1.3.2 *d*,*e* and *f*) with a considerably less time compared to their manual counterparts.

(Fig.1.3.2 d, e and f) With CNC, high quality products are guaranteed.

1.3.3 Direct or Distributed Numerical Control (DNC)

DNC is a common manufacturing term for networking CNC machine tools. On some CNC machine controllers, the available memory is too small to contain the machining program (for example machining complex surfaces), so in this case the program is stored in a separate computer and sent directly to the machine, one block at a time. If the computer is connected to a number of machines it can distribute programs to different machines as required Fig. 1.3.3. Usually, the manufacturer of the control provides suitable DNC software. However, if this provision is not possible, some software companies provide DNC applications that fulfil the purpose. DNC networking or DNC communication is always required when CAM programs are to run on some CNC machine control.

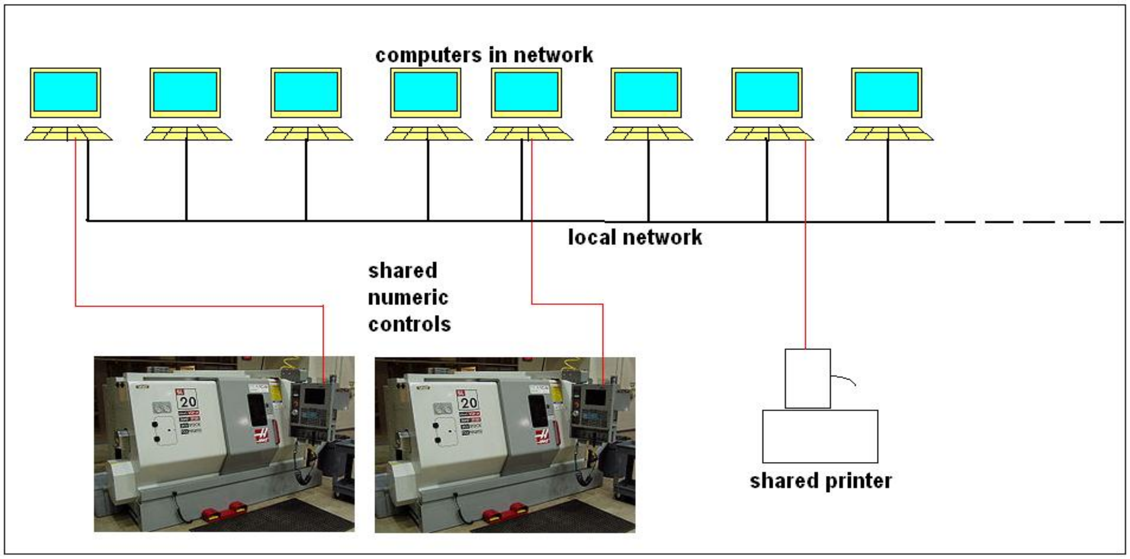

Fig.1.3.3. A group of computers can be linked to use the same CNC machines.

1.3.4. Why use CNC?

CNC machines are better than their manual counterparts due to the following advantages;

1. Flexibility

   Suppose a company produces in two weeks all the valves needed for an entire year. That means the machines would be idle for 50 weeks, which would be excessively costly. CNC solves this problem. With NC it might take three or four weeks to produce the cylinder blocks. But then the NC machine could be quickly reprogrammed to produce other types of workparts.

2. CNC machines do what manual machines cannot do

   CNC machines can produce geometrical features that would be very expensive to produce with conventional methods, with NC engineers can design tridimensional contours that were originally impossible to attain.

3. Repeatability

   A CNC machine can make 10, 100, 1000 or more workparts at exactly the same time, without deviations (except for tool wear). Although manual machine tools arranged in an automated transfer line can achieve a high degree of accuracy, they are still human controlled; their repeatability cannot compete with that of NC.

4. Reduction or elimination of storage costs

Products often need spare parts. In the past mass production required spare parts to be made and stored in warehouses for months or years before customers would need them.

Warehousing is expensive, furthermore, design changes render the stored workparts obsolete thus resulting in financial loss. It is wiser to set up a CNC workshop and produce by customer order so that instead of having a full warehouse, there is only the need to have a hard drive with part programs that could be edited, erased without resulting in loss.

5. Reduction in lead time and tool costs

Gadgets and auxiliary equipment such as slides used in manual and automatic machines are expensive, they take time to make and are very difficult to modify which results in too much expenses whenever there are changes of production. With CNC the problem is usually solved a clamp or vise. A NC can drive a cutter to a specific location, even along a contour path, special tooling is not needed to position or guide the cutter. Again, a simple vise is often all that is needed to hold the workpart. A change in design does not require modifying a lot of complex special tooling. All that is required is a quick change in the NC's program.

6. Lower operator skill requirements

NC operators do not direct the operation of the machine tool. They simply load and unload the workpart, perhaps load and unload cutting tools (although this is usually done automatically), push the button to start the operation, and push the panic button if anything goes wrong (like a tool goes dull or breaks). This does not require anywhere near the level of skill required of the journeyman machinist who directs the operation of manual machine tools. Operators are easier to find and train and command lower salaries, thereby improving the company's position in this very competitive industry.

Amongst the disadvantages of using CNC are:

- They require huge investments
- For a small CNC lathe the cost could be from 25 to 50 thousand US dollars o even up to half a million US dollars for a turning centre which means the machine has to be working always to cover the costs.
- CNC machines need skilled programmers
- Contrary to the operators, CNC programmers are highly qualified and hard to find. They also charge high salaries. That is where CAD/CAM comes in.
- High Maintenance costs
- CNC machines are very complex. Machine tools must be kept in good conditions; the control module is an electronic device that can occasionally need a switch, capacitor, transistor o an integrated circuit, which is why the maintenance personnel should have skills in both electronics and mechanics.
- CNC is not economic for small scale production

Conclusions:

In the development of the manufacture process the tool machine with numerical control has a big influence, due to the big advantages it has, it can change the kind of strength without any problem, and also it has the necessary flexibility in the present mechanic industry.

Undoubtedly, the computing development has allowed the manufacture of more effective and compact machines with a high productivity.

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