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Topic

Study and optimization of a component using a computer numerical control machine (CNC)

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Thanksgiving

In presenting this work, we would like to thank

M. Kamel IKKACHE, our promoter, for his helpfulness and for his constructive comments which were useful to us throughout our project.

We would like to thank the president and the jury members for the honor they did us by agreeing to judge our work.

Finally, all those who have, directly or indirectly, contributed to the realization of this work will find here the expression of our deep gratitude.

Dedicate

We dedicate this humble work.

To those who helped us do this modest work with their advice and encouragement:

- Our parents.
- Our supervisor Mr. IKKACHE KAMEL.
- Our brothers and sisters.
- Our teachers.
- Our dear friends.
- To everyone who helped us during our academic study.

We thank them and dedicate this work to them.

ملخص:

نظرًا للدور المهم والمفيد الذي تلعبه آلة التحكم في الصناعة، فقد ركزنا على إجراء بحث شامل لعملية صنع قطعة من الفولاذ في هذه الأطروحة. وقد قدمنا الآلة ونقشناها بشكل عام في الفصل الأول. تمت تغطية بنية الآلة والمكونات العديدة التي تشكل هيكلها في الفصل الثاني. كما تم تناول طريقة البرمجة اليدوية المستخدمة لتشغيل الآلة في الفصل الثالث. لقد قمنا أيضًا بتغطية التحليل الشامل والتطبيق الواقعي لصنع القطعة الفولاذية في الفصل الأخير . تقدم هذه الأطروحة مساهمة كبيرة في معرفة آلات التحكم العددي وتطبيقاتها وعملية صنع مكونات الفولاذ.

Résumé:

En raison du rôle important et utile de la machine de contrôle dans l'industrie, nous nous sommes concentrés sur une étude approfondie du processus de fabrication d'une pièce d'acier dans cette thèse. Nous avons présenté la machine et en avons discuté en général dans le premier chapitre. L'architecture de la machine et les différents composants qui composent sa structure ont été abordés dans le deuxième chapitre. La méthode de programmation manuelle utilisée pour faire fonctionner la machine a également été abordée dans le troisième chapitre. Nous avons également couvert l'analyse approfondie et l'application concrète de la fabrication de la pièce en acier dans le dernier chapitre. Cette thèse apporte une contribution significative à la connaissance des machines à commande numérique, de leurs applications et du processus de fabrication d'une pièce en acier.

Abstract:

Because of the control machine's significant and useful role in industry, we focused on a thorough investigation of the process of making a piece of steel in this thesis. We introduced the machine and discussed it in general in the first chapter. The machine's architecture and the several components that make up its structure were covered in the second chapter. The manual programming method used to operate the machine was also covered in the third chapter. Also we covered the thorough analysis and real-world application of making the steel piece in the last chapter. This thesis makes a significant contribution to the knowledge of numerical control machines, their applications, and the process of making a steel component.

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Abbreviations

NC: Numerical Control.

CNC: Numerical Control by Computer.

CAM: Computer-Aided Manufacturing.

CAD: Computer Aided Design.

MOCN: Machine tool numerically controlled.

ISO: International Standard Organization.

G-Code: Programming language for CNC machines.

DCN: A Digital Control Director

General Introduction

In recent years, the control of electrical machinery has undergone significant progress. These advances are mainly due to the technological revolution in industrial computing; the control of electrical machines has undergone significant progress. This has enabled the development of effective digital solutions, with the possibility of implementing more complex algorithms. Today, digital computer-controlled machines (CNCs) allow for a great deal of flexibility in industrial production. The industrial revolution that began with the creation of tools for traditional industry and others was then developed into semi-automatic machines and then automatic machines that operated with the help of computers and special programs by transferring the instructions from the command part to the operational part of the machine.

After the first generation of cable-logic digital controls, digital computer-based (CNC) or computer-by-computer controls appeared. A CNC machine is first a tool machine; it allows, according to its characteristics, various operations (drilling, sewing, rectification, cutting, milling, folding, engraving, etc.) requiring precise and repetitive gestures on various materials. The machine is equipped with one or more tools that move along axes (usually X, Y, and Z), and all of these operations are programmed in advance using software, which the machine executes.

For the proper execution of our project, we have chosen the following plant:

- The first chapter is devoted to a general study of the CNC machine.
- The second chapter is about structure and composition of CNC machinery.
- The third chapter is dedicated to manual programming methodology.
- The fourth chapter: we have raised Creation of a piece.

And we will finish our work with a conclusion and prospects for the future.

Chapter I:

General information on Computer Numerical Control machines (CNC)

I.1. Introduction:

Computer Numerical Control (CNC) is a manufacturing method that automates the control, movement, and precision of machine tools using preprogrammed computer software. It is commonly used in manufacturing for machining metal and plastic parts and can be used to control non-machine tools, such as welding, electronic assembly, and filament-winding machines. CNC machines are used in various industries, including aerospace, medicine, and electronics, where high precision is required. The process involves creating a custom computer program for each object to be manufactured, which is then executed by the CNC machine to produce the desired part with precision. CNC technology has progressed significantly over the years, from punch tape-controlled devices to more advanced machines that accept CNC programming input and produce 3D parts. CNC machines are cost-effective and bring down the cost of production due to precision manufacturing, energy efficiency, and less material waste. They are also used in industries that require high levels of precision, such as aerospace and medicine, where component failure could endanger lives.

I.2. History

In 1945, John Parsons manufactured, for the U.S. Air Force, helicopters for reproduction. To shape its dimensions, it used a method consisting of drilling several hundred holes with weak spacing in order to approach the theoretical profile. The location and depth of each hole are accurately calculated by an IBM perforated card computer. The finish of the surface is obtained by manual polishing operations. But, when the US Air Force entrusted Parsons with the creation of even more complex-shaped parts for his future supersonic aircraft, he realized that his method was too approximate and that only continuous three-dimensional machining would be able to provide satisfaction. In the spring of 1949, he entrusted the Massachusetts Institute of Technology (MIT) with the task of developing subordinates capable of piloting a machine that would receive intermittent instructions from a card reader. This machine, a prototype Cincinnati vertical pin milling machine, designed to perform simultaneous movements along three axes, was officially presented in September 1952 at the Servo Mechanisms Laboratory at MIT. Since mathematical information is the basis of the concept, it is called numerical control. It could just as well have been called a symbolic command! We still have to wait a few years for huge funding from the U.S. Air Force and the support of MIT researchers to make the first MOCN really operational.

The different stages of digital control development are as follows:

1954: Bendix acquires the Parsons patent and manufactures the first industrial CN.

1955: American manufacturer Giddins & Lewis markets the first MOCN.

1959: Appearance of the CN in Europe (foire de Hanovre).

1964: In France, the electrical telemetry company launches the CN NUM 100, designed on the basis of telestatic relays.

1968: CN adopts integrated circuits; it becomes more compact and more powerful.

1972: Mini-calculators replace cable logic.

1976: Development of the microprocessor CN.

1984: Appearance of advanced graphical functions and conversational programming mode.

1986: CN's integrates into communication networks early in the era of flexible manufacturing (CIM).

1990: Development of 32-bit micro processors. **[1]**

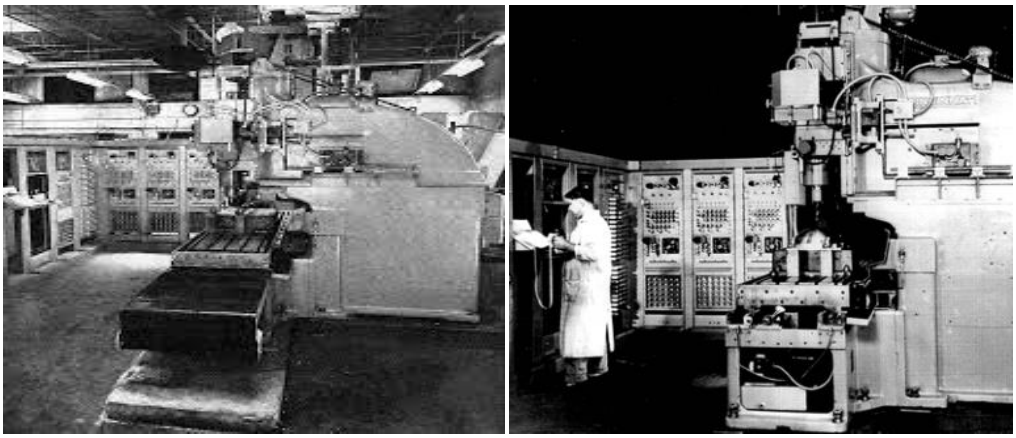


Figure I. 1: First digital-controlled machine tool. **[1]**

I.3. Definition

I.3.1. The digital command

The digital (numerical) command is a command mode in which the desired values of a commanded variable are defined according to a numerical code (the machine tool is the main area of application of the numeric command). It is a sum of automatisms in which the orders of movement or displacement, the speed of these movements, and their accuracy are given from numerical information. This information is encoded on media such as perforated tapes, magnetic cassettes, discs or simply saved in "memory" in the case of the latest generation of digital computer controls (CNC). All of this machine tool (MO) control information is developed in the form of a sequential execution program. With the response times of such commands of approximately ten microseconds, it will naturally be possible to hope to pilot the machine following more or less complex trajectories in speed and position.

I.3.2. Computer numerical control machine CNC

CNC machines manufacture parts worldwide for almost every industry. They create objects from plastics, metals, aluminum, wood, and many other hard materials. The word "CNC" means computer numerical control, but nowadays everybody calls it CNC. So, how do you define a CNC machine? All automated motion control machines have three main components: a control function, a drive/movement system, and a feedback system. CNC machining is the process of using a computer-driven tool machine to produce a piece from a solid material in a different form. CNC relies on digital instructions, generally performed on computer-assisted manufacturing (CAM) or computer-aided design (CAD) software such as SolidWorks or Master CAM. The software writes the G code that the CNC machine controller can read. The computer program on the controller interprets the design and moves the cutting tools and/or the piece over several axes to cut the desired shape of the piece. The automated cutting process is much faster and more precise than the manual movement of tools and parts that is done with levers and gears on older equipment. Modern CNC machines contain several tools and perform many types of cuts. The number of motion planes (axes) and the number and types of tools that the machine can automatically access during the machining process determine the complexity of a piece that a CNC can manufacture.

I.4. Application areas of CNC machinery

CNC (Computer Numerical Control) machines are versatile tools used across various industries and applications due to their precision, automation capabilities, and flexibility. Here are some common domains where CNC machines find extensive use:

a- Manufacturing Industries

Metalworking: CNC machines are widely used in metal fabrication processes such as milling, turning, drilling, grinding, and laser cutting for producing precise metal parts and components.

Woodworking: CNC routers are employed for carving, cutting, and shaping wood in furniture making, cabinetry, carpentry, and woodworking industries.

Plastics Fabrication: CNC machines are utilized to shape and cut plastic materials into specific designs for various applications, including automotive parts, electronic enclosures, and consumer products.

Prototyping: CNC machines enable rapid prototyping of components and products, allowing manufacturers to test and refine designs before mass production.

b- Automotive Industry

CNC machining is crucial in manufacturing automotive parts and components with high precision and consistency. It is used in producing engine components, transmission parts, chassis components, and body panels.

c- Aerospace and Defense

CNC machining is extensively used in the aerospace and defense industries for manufacturing aircraft components, missile parts, and other critical aerospace systems that demand high precision and quality standards.

d- Electronics Industry

CNC machines play a significant role in the production of electronic components such as circuit boards, connectors, housings, and enclosures with intricate designs and precise dimensions.

e- Medical Industry

CNC machining is employed in the production of medical devices, implants, surgical instruments, and prosthetics with complex geometries and tight tolerances to meet the specific requirements of healthcare applications.

f- Jewelry Making

CNC machines are used in jewelry making to produce intricate and detailed designs on various materials such as gold, silver, platinum, and gemstones with high precision and accuracy.

g- Art and Sculpture

CNC machines are utilized by artists and sculptors to create intricate sculptures, art installations, and decorative pieces from various materials like wood, metal, stone, and acrylic.

h- Educational Institutions

CNC machines are used in educational institutions, vocational schools, and training centers to teach students about computer-aided design (CAD) and manufacturing (CAM) processes, CNC programming, and machining operations.

Overall, CNC machines have become indispensable tools in modern manufacturing and fabrication processes across a wide range of industries due to their efficiency, accuracy, and versatility.

I.5. Operating principle of a CNC machine

Digital-controlled machines consist of two complementary parts (Figure I. 2).

- **The control part**
- **The operating part**

The control part consists of a calculator or computer and electronic components capable of driving the engines; this part allows for driving the operating part.

The operating part includes shift axles, tool heads, and actuators.

Orders are generated by the command through machine code or the manual action of the operator. The command will process this information and generate instructions in order to obtain the desired movements through the axle engines. Speed and position checks will then be carried out continuously by the machine. **[2]**

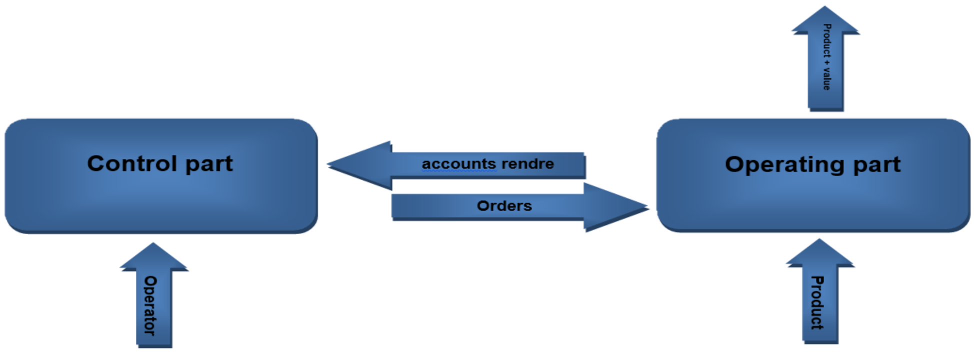


Figure I. 2: Decomposition of a digital machine. **[2]**

I.6. The different types of CNC Machines

a) CNC Lathe

CNC lathe are machine tools used to rotate cylindrical parts. They are mainly used for the manufacture of parts such as trees, axes, and mandarins.

Figure I. 3: CNC lathe machine. **[2]**

b) CNC Millers

CNC millers are used to machine parts by removing material using rotary cutting tools. They are commonly used in the machining of metal, plastic and wood parts.

Figure I. 4 : CNC millers machine. **[2]**

c) CNC Laser Cutting Machine

These machines use a laser beam to cut, engrave, or mark various materials, such as metal, wood, plastic, glass, and fabric.

Figure I. 5: CNC Laser Cutting Machine. **[2]**

d) CNC Water Jet Cutting Machine

These machines use a high-pressure water jet to cut a variety of materials, including metal, stone, glass, rubber, and plastic.

Figure I. 6: CNC Water Jet Cutting Machine. **[2]**

e) CNC 3D Printers

Although often considered different from traditional CNC machines, CNC 3D printers also use digital controls to create three-dimensional objects by adding successive layers of material.

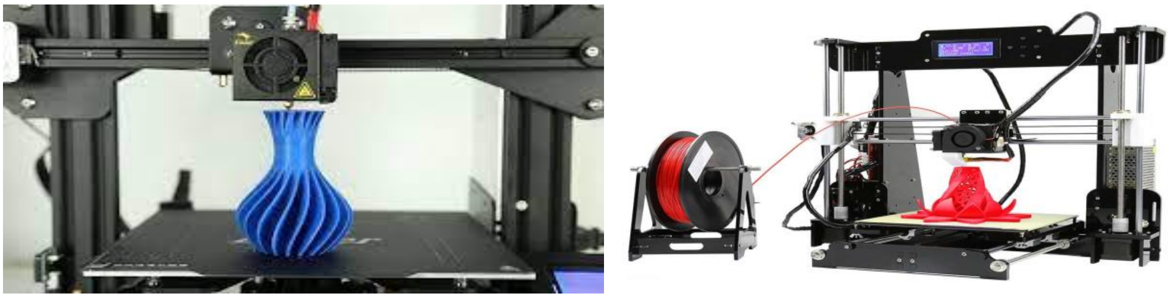


Figure I. 7: 3D CNC Printers. **[2]**

f) CNC Plasma Cutting Machine

Similar to laser cutting, plasma cutting uses a plasma jet to cut through conductive materials such as steel, aluminum, copper, etc.

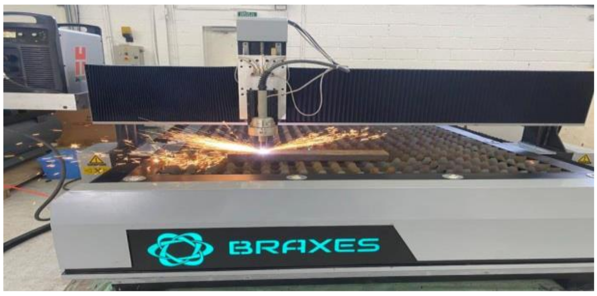


Figure I. 8: CNC Plasma Cutting Machine. **[2]**

g) (5-axis) CNC machine

It is a machine in which there are a total of five axes. Initially, it was 3 axes (X, Y, and Z). The cutting operation of any instrument was done in three directions. When two inclinations are added according to the X axis and the Y axis, which means that there are a total of 5 axes, the work is cut and carried out in the direction of 5. The 5-axis machine is used for the realization of sculptures. It offers an extreme surface finish. **[2]**

It is very precise in dimensional tolerances, capable of machining complex shapes and left surfaces, and can also cut at high speeds, which makes it capable of working in the serial parts industry.

Figure I.9: 5-axis CNC machine. **[2]**

I.7. Classification of CNC machine

Computer numerically controlled (CNC) machine tools are classified as follows:

I.7.1. Functions

According to the functions or types of machined parts, CNC machines can be classified into five types: CNC milling machines, CNC lathes, CNC drilling machines, CNC plasma cutters, and CNC grinders.

a- **CNC milling machines:** are used to create shapes, slots, holes, notches, grooves, pockets, and specialty faces and perform the machining process of manufacturing CNC milling parts. The rotary cutting tools on the mill are used to remove material from the stationary workpiece.

b- **CNC lathes:** are used to manufacture cylindrical objects and perform the process of producing CNC turning parts. A cutting tool will shape the workpiece while the material block is turning rapidly on a spindle.

c- **CNC drilling machines**: used to drill holes in the workpiece, the tool can locate the position for drilling quickly and accurately. Sophisticated drilling machines can also perform reaming, counter-boring, and tapping holes.

d- **CNC plasma cutters**: a machine carries a plasma torch, which is for cutting metals and involves cutting through electrically conductive materials by an accelerated jet of hot plasma.

e- **CNC grinders**: a machine uses a rotary wheel to abrade the material by grinding or grating it into the desired shape; it’s easier to program than milling machines and lathes.

I.7.2. Motion type

Classification by motion: CNC machines can be divided into point-to-point systems and contouring systems.

- **Point-to-point systems**: the material and tool are placed at certain fixed relative positions at which they are retained until the cutter finishes the process and retracts; this type of equipment includes drilling, boring, and tapping machines.
- **Contouring systems**: the machine tool cuts the material following a contour of a part, so it works in a continuous path. This type of equipment includes lathes, mills, and routing machines.

I.7.3. Number of Axis

When classified by the number of axes, CNC machines can generally be divided into five groups: 2-axis machines, 2.5-axis machines, 3-axis machines, 4-axis machines, and 5-axis machines.

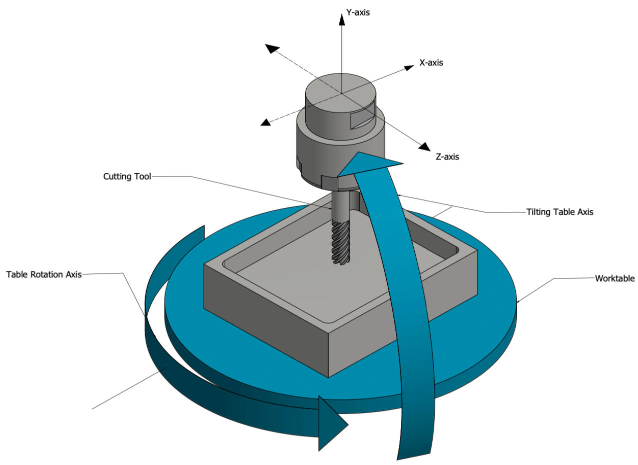


Figure I.10: Number of Axis. **[3]**

a) **2-axis CNC machines**: a machine gives access to only two axes, like the lathe machines; the tool moves in two directions, like X and Z. **[3]**

b) **2.5-axis CNC machines** are also 3-axis systems, but the movement is not three-dimensional; the X and Y axes move to the position first, and then the third axis starts to work, such as in the drilling and tapping machines. **[3]**

c) 3**-axis CNC machines:** three axes (X, Y, and Z) move simultaneously in three dimensions. It's the most widely used and versatile machine that can achieve high accuracy and precision and can be used for automatic or interactive operation, milling slots, drilling holes, and cutting sharp edges. **[3]**

d) **4-axis CNC machines:** the 3-axis machine with one more rotation on the A- or B-axis; the common example is a vertical or horizontal machine. In the case of 4-axis machining, milling is performed on the additional axis, while the operation on the X, Y, and Z is the same as in the 3-axis system, and the rotation on the A or B axis is around the X-axis. **[3]**

e) **5-axis CNC machines:** the 3-axis machine with extra rotation along two directions (Y and Z) on the A-axis and B-axis; the rotations are respectively given by the bed and spindle movement (pivot point). 5-axis machines are advanced CNC machines, and their multidimensional rotation and tool movement allow the creation of precise and intricate parts due to their improved access to undercuts and deep pockets, unparalleled finish, and speed. They are often used for high-level applications like aerospace parts, artificial bones, titanium pieces, oil and gas machine parts, military products, and more. **[3]**

I.7.4. Control loop

The classification of CNC machines according to the control loop can be divided into two types: open-loop systems and closed-loop systems.

a- An open-loop CNC machine refers to a system where communication between the controller system and the motor is one way. The process for an open-loop system is simple: CNC software creates the information with necessary step and direction signals based on the user's purpose; the computer relays this information to the controller, which then energizes the motor with no feedback. Open-loop CNC machines use stepper motors.

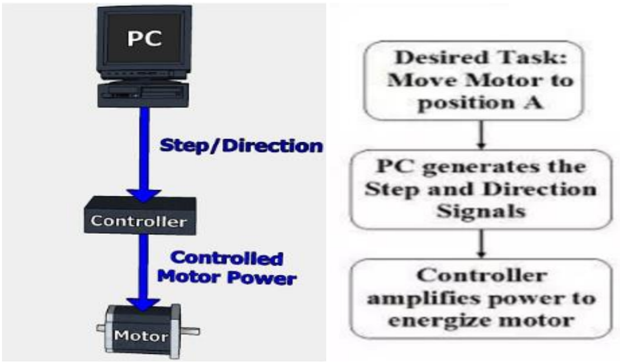


Figure I.11: Open loop system. **[4]**

b- A closed-loop CNC machine has a feedback system to monitor the output of the motors and is also able to correct errors in position, velocity, and acceleration. The feedback can be returned to the CNC controller or computer, and the former type is more common; the system with feedback fed into the signal generator or computer usually exists in high-end machines.

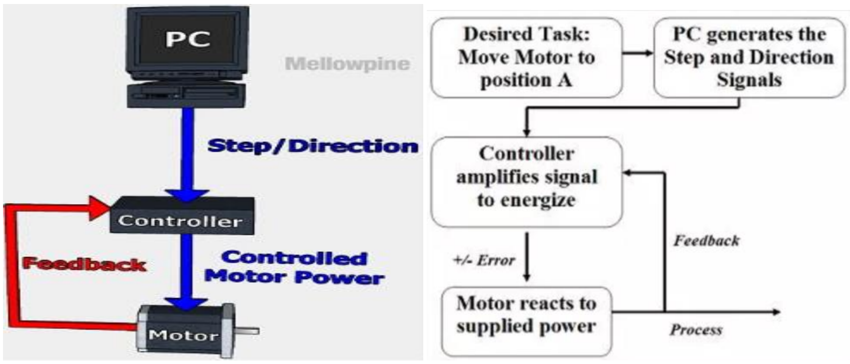


Figure I.12: Closed-loop system. **[4]**

I.8. Advantages of CNC machines

The advantages of CNC machines in comparison to conventional machining methods are numerous; these machines use higher levels of automation and reduce possible errors while increasing productivity and cost-effectiveness across the board. Here is a compilation of the main advantages of CNC machines:

1) **Productivity:** Because you can program a CNC mill or other machine to perform a complex series of actions, you can often step away while the machine gets to work. This can include out-of-hours automated machining in certain set-ups, hugely increasing your productivity and rate of output. This is particularly true for precision engineers operating several CNC centers, such as Oracle Precision.
2) **Consistency:** Because the use of a CNC almost eliminates human error, CNC machines are highly consistent and accurate in the work they produce, providing clients with uniform and faultless products. This is what makes CNC machining so crucial for areas where quality is critical, as the level of reliability and quality of the work produced is much higher.
3) **Cost-Effectiveness:** CNC machines more than make up for their initial costs with a high rate of output and a lower number of mistakes in the resulting components. Operators also require less training to operate a CNC machine and can learn how to use the machine in a virtual environment, eliminating the need for training work pieces. As these machines become more popular and widespread, their costs will continue to drop.
4) **Safety:** Any hazardous safety issues, such as a jam or other machining error, are only detrimental to the machine and not a safety issue for the operator, unlike conventional open guard machining.
5) **Versatility:** CNC machines can be reprogrammed in a short period of time to produce a completely new product, making them ideal for short or long production runs. You can change programming without it being time-consuming or too costly.

I.9. Conclusion

In this chapter, we have seen the generalities about computerized digital control machines, starting with the history and going to the definitions of digital command and CNC digital control machines. Then we mentioned the application areas of CNC machinery, then the operating principles, then the different types. Then we classified them according to different criteria before finally going into the advantages and safety measures of these machines. All of this serves as an introduction to understanding our project on making a piece using this machine.

Chapter II:

Structure and composition of CNC machinery

II.1. Introduction

CNC machines, or numerical control machines, are essential equipment in the manufacturing industry and are used to produce parts accurately and efficiently. Here is a simple note about the structure and components of CNC machines:

CNC machines are automatic devices used to manufacture industrial components with high quality and speed. It consists of several key elements that help it work effectively. The main components of a CNC machine include the automatic control unit, machine tools, operating system, suspensions, and clips where the raw materials for the equipment are placed. In this chapter, we will discuss more about this topic.

II.2. Structure of a digital controlled machine

A numerically controlled machine tool is made up of two parts:

A control part (denoted PC): the different operations constituting the machining task are managed via a DCN (direct numerical control).

An operational part (denoted PO): comprising the structure of the machine tool, the tool holder, and the part holder; the work material is the piece.

The control part allows you to control the operational part. Orders are generated and sent to the control in the form of a machine code or by manual action of the operator. The command will process this information and generate instructions in order to obtain Chapter I: General Information on Numerical Control Manufacturing. The movements desired by an electronic element capable of controlling the motors. The position of the mobiles is detected by a position sensor, and their speed is constantly measured.

II.2.1. Operational Part

The movements are controlled by engines, almost comparable to a conventional tool machine, and they include:

a- A base, often made of vibrated hydraulic concrete, ensures the machine's independence from the ground.

b- A building, a bench, whose wide slides are made of treated steel.

c- A tool support (brochure, torch, laser, water jet, etc.).

d- A room support table, mobile according to 2 or 3 axes, equipped with a screw control system and ball screw. Granite, or reconstituted granite, is used for the manufacture of tables and buildings, three-dimensional measuring machines, rectifiers, and certain towers.

e- Motors are charged with the drive of the table.

f- A measuring element or position sensor informs at all times about the position of the mobile on each axis.

g- A tachymetry dynamometer for measuring the speed of rotation.

The elements of the operational part are shown in Figure II.1.

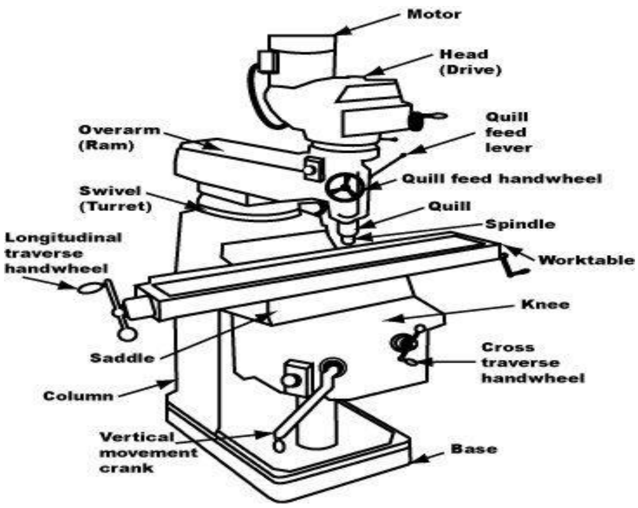
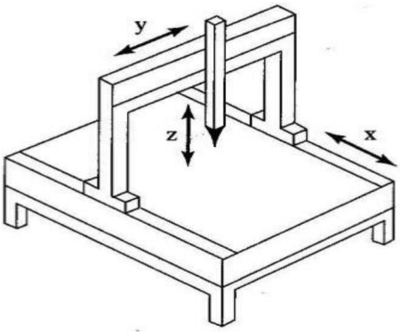


Figure II.1: The elements of the operational part. **[5]**



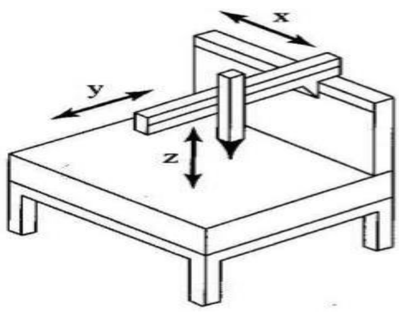


Figure II.2: movable bridge type machine. **[6]**

Figure II.3: fixed bridge type machine. **[6]**

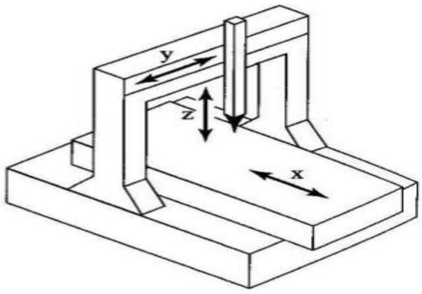


Figure II.4: cantilever type machine. **[6]**

II.2.1.1. Done tasks

The tasks carried out on the operating party site are:

1) Loading and unloading (part port part).
2) Loading and unloading (outils port outils).
3) Manual interventions are required for machining and maintenance control monitoring.

II.2.2. Command Part

It consists of a wardrobe in which

- The button for entering commands using a keyboard.
- The data reader (this drive can be an option when buying the machine)
- The display of all recorded data.
- The calculator.
- Electronic cards (axis controls, memory, etc.).
- The command part is powered by a weak current and therefore cannot power. **[3]**

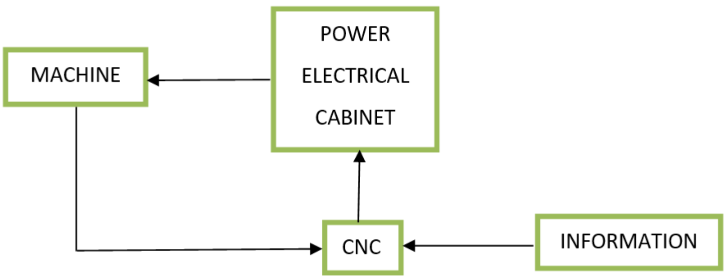


Figure II.5: Original function of a digital command. **[7]**

II.2.2.1. Digital Control Manager

A digital control director (DCN) is a control system capable of managing the machine and implementing it according to a program. This implementation is done in connection with an environment, under the direction of an operator, possibly under the dependence of a calculator; in the latter, one speaks of DNC (direct numerical control).

A “DCN” is a computer machine that has, in its operation and in its use, two fundamental aspects:

- Calculator aspect.
- Automatic appearance.

II.2.2.2. Control button

It enables dialogue between man and machine and the development of room programs using the screen keyboard system. It is also the way to modulate certain parameters, such as advance speed or pin speed. The axle control units are responsible for controlling the axles of the machine in a closed loop, under the control of the central unit.

II.3. Design and materials

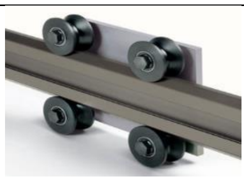
II.3.1. Guidance System

The guidance system allows for the movement of a load along a linear trajectory with high precision. There are many solutions; their common objective is to offer reduced mechanical playback, maximum efficiency, and a long service life. The common associated terms are many: rail, guide, backstage, slider, etc.

Table II.1: Types of guidance systems. **[2]**

Guidance type	Name	price	Rigidity	precision	charges
	“Hiwin” style linear guidance	**bad**	**Good**	**Good**	**Good**

	Cylindrical bearing and shaft no supported	**Good**	**bad**	**AVERAGE**	**bad**

	Open bearing and supported shaft	**AVERAGE**	**AVERAGE**	**AVERAGE**	**AVERAGE**
	With guide wheel	**Good**	**AVERAGE**	**AVERAGE**	**AVERAGE**
	Closed bearing and unsupported shaft	**Good**	**bad**	**AVERAGE**	**bad**

II.3.2. Transmission system

a) Screw Target System

The screw system allows the transformation of a rotation movement into a translation movement by combining the movements of a screw and screw (helicoidally bonding). **[2]**

Figure II.6: Screw/clutch system. **[6]**

b) Pulley-belt system

The pulley-belt system makes it possible to transmit a rotational movement; this type of mechanism is used to transmit the movement between bodies whose axes are distant. The disadvantage of the system is its limited lifespan, as well as belt slippage. **[6]**

Figure II.7: Pulley-Belt System. **[6]**

c) Chain and pinion

They are made up of a succession of family figures with unequal links arranged alternately: the interior links and the exterior links. **[2]**

Figure II.8: Chain and pinion. **[6]**

d) Ball Screw

Ball screws are mechanical linear actuators that translate rotational motion into linear motion using a ball recirculation mechanism between the screw shaft and nut. A threaded shaft provides a helical channel for the ball bearings, which act as a precision screw. **[2]**

Figure II.9: Ball screw. **[6]**

II.3.3. Movement system

II.3.3.1. Motors

One of the most common means of movement in CNC machines is a stepping motor.

a) The stepper motor

The stepper motor is a motor that rotates according to the electrical pulses received in its windings. The minimum angle of rotation between two modifications of the electrical pulses is called a step. A motor is characterized by the number of steps per revolution (i.e., for 360°). The current values are 48, 100, or 200 steps per revolution. Analysis of a theoretical motor composed of a permanent magnet (compass) and 2 windings, each made up of 2 coils, the passage of a current successively in each winding turns the magnet.

Figure II.10: Stepping motor. **[8]**

b) Types of stepper motor

Stepper motors can be classified according to:

Power supply of the windings:

- Bipolar
- unipolar

The design of its rotor, the stepper motor, is divided into three types:

- Permanent magnet motor
- Variable reluctance motor
- Hybrid engine

c) Other motors

There are several types of engines and each has its own capabilities with its own strengths and weaknesses.

Table II.2: Different types of motors.

	DC series motor	AC motor	Special purpose motors
DC Shunt Motors	Permanent magnet DC motor	Synchronous motor	stepper motor
Separately excited motors	DC compound motor	Induction motor	Brushless DC motors - Hysteresis motor - Reluctance motor - Universal motor

II.3.4. The spindle

The CNC spindle, also called spindle drive, is the central shaft of the rotating axis of machine tools, but it can also refer to the entire rotating unit with its bearings and accessories. It receives input from the CNC controller to rotate on its axis, making it an essential part of a CNC machining center. The spindle type determines the cutting speed and force, and a machine tool can have multiple spindles, with the largest being called the main spindle. There are different configurations and options available for spindles to meet different needs, such as lathe, milling, grinding, electric, low-speed, and high-speed spindles.

II.3.4.1. Types of CNC spindles

A variety of shapes and sizes are available for CNC spindles. This part will classify them based on different parameters for easy identification.

a- **Vertical Spindles:** In this type of spindle, the cutting tool is positioned vertically, with the axis of rotation perpendicular to the work table. Vertical spindles are typically used in milling and drilling machines. They are also commonly used in industrial applications such as machining centers, where the workpiece is held stationary while the cutting tool is moved along different axes.

b- Horizontal Spindles: In this type of spindle, the cutting tool is positioned horizontally, with the axis of rotation parallel to the work table. Horizontal spindles are generally used in lathes, boring machines, and grinding machines. They are also used in some milling machines and machining centers. Horizontal spindles are known for their ability to achieve high cutting speeds and precision.

Figure II.11: Vertical Spindles. **[9]**

Figure II.12: Horizontal Spindles. **[9]**

c- Collet pins: These pins secure the tool in place using a clamp. A unique instrument, such as a wrench, is used to tighten the clamp and give the user a firm grasps on the tool. Milling and router equipment frequently use collet spindles.

d- Hydraulic Chucks: The tool is clamped in place by hydraulic pressure in hydraulic chucks. These very accurate spindles are perfect for high-speed machining. They are typically found in grinding machines and turning centers.

e- Weldon Tool Holders: Weldon tool holders have a straight shank that is held in place by a screw assembly. They are commonly used in milling machines and are excellent for quickly removing material.

f- Direct Drive Spindles: In a direct drive spindle, the motor connects directly to the spindle shaft, providing more power and torque than in belt drive spindles. This configuration improves accuracy, positioning, and stability, making it a popular choice for precision CNC machining operations. Direct-drive spindles are low-maintenance and durable in the long run.

II.3.4.1. Advantages of using CNC spindles

CNC spindles offer a range of advantages over traditional machining techniques, including:

a- Precision: CNC spindles have the ability to cut and shape materials to extremely tight tolerances.

- **b- Speed:** High-speed machine spindles can operate at high speeds, enabling faster machining times and increased production efficiency.
- **c- Consistency:** CNC spindles can perform the same task repeatedly without any variation, ensuring consistent output quality.
- **d- Versatility:** CNC spindles can be used on a wide range of materials, from plastics to metals, and can perform a variety of cutting and shaping operations at high temperatures.
- **e- Automation:** CNC spindles can be fully automated, reducing the need for operator intervention and increasing productivity.
- **f- Cost-effective:** CNC spindles can save money in the long run by reducing waste, minimizing errors, and increasing production efficiency.
- **g- Flexibility:** CNC spindles can be configured in a variety of ways, including multi-axis machining and tool changers, providing greater flexibility in manufacturing processes.

II.3.5. Electrical system

II.3.5.1. Stepper motor driver

The stepper motor driver is an actuator that can transform the pulse signal into an angular displacement signal. Stepper drivers drive stepper motors to rotate at an angle called the step angle in the set direction when receiving a pulse signal. The speed of the motor is up to the pulse frequency given by the controller, and the displacement is decided by the pulse amount given by the controller. The stepper system consists of a stepper motor and a stepper driver. The performance of a stepper system depends not only on the motor but also on the stepper driver.

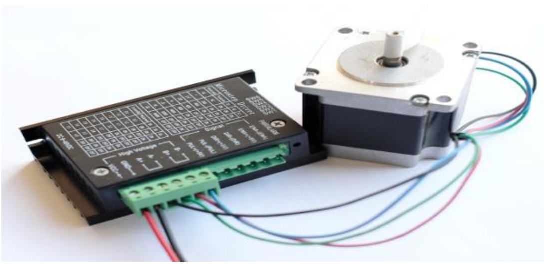


Figure II.13: Stepper motor driver. **[8]**

II.3.5.2. Power supply

For our power supply, we chose one with 24 volts and 20 amps, which is more than enough for our current setup and gives us some freedom to improve our electrical components in the future.

Figure II.14: Power supply. **[8]**

II.3.5.3. Limit switches

Limit switches are used to automatically detect the presence of an object or to monitor and indicate whether the movement limits of that object have been exceeded.

Figure II.15: Limit switches. **[8]**

II.3.5.3. Emergency button

An emergency stop button is a safety device that turns off all machines in a workshop instantly when the emergency stop button is pressed. It allows anyone to turn off a machine anywhere in a workshop to avoid an accident.

Figure II.16: Emergency button. **[8]**

II.4 Cutting tools

II.4.1. Materials of cutting tools

In order to cut through the solid workpiece, cutting tools must be made from a harder material than the workpiece material. And since CNC machining is regularly used to create parts from very hard materials, this limits the number of available cutting tool materials.

Common cutting tool materials include:

Carbon steel: Carbon steel is an affordable steel alloy containing 0.6-1.5% carbon, as well as silicon and manganese.

High-speed steel: The more expensive HSS is harder and tougher than carbon steel thanks to its blend of chromium, tungsten, and molybdenum.

Carbide: Usually sintered with another metal like titanium, carbide tools are wear-resistant and heat-resistant, providing an excellent surface finish.

Ceramic: Used to cut superalloys, cast iron, and other strong materials, ceramic tools are resistant to corrosion and heat.

II.4.2. Cutting tool coatings

The function of a cutting tool depends on its shape and material, but it can also be adjusted with a coating over the main material.

These coatings can make tools harder, increase their lifespan, or enable them to cut at faster speeds without compromising the part.

Common cutting tool coatings include:

a) **Titanium Nitride (TiN):** TiN is a general-purpose coating with a high oxidation temperature that increases the hardness of a cutting tool.
b) **Titanium carbo-nitride (TiCN):** TiCN adds surface lubricity and hardness to a cutting tool.
c) **Super-life Titanium Nitride (Al-TiN):** Al-TiN adds heat resistance to carbide cutting tools, especially when minimal coolant is employed.
d) **Diamond:** Diamond provides a high-performance coating for cutting abrasive materials.

e) **Chromium Nitride (CrN):** CrN adds corrosion resistance and hardness to cutting tools.

II.4.3. Types of cutting tools

a) End mill

The end mill is the most widely used tool for vertical CNC machining. With cutting teeth at one end and on the sides, end mills can remove large amounts of material in a short space of time.

Figure II.17: End mill. **[9]**

End mills come in many forms. Some have just a single flute, while others may have up to eight or even more. (Beyond four flutes, however, chip removal may become an issue.)

Types of end mills include:

Flat: a general purpose flat-faced tool suitable for 2D features

Ball nose: tool with a ball-shaped end that is suitable for 3D contours and curves

Bull nose: tool with a flat bottom and rounded corner suitable for fillets and roughing

b) Roughing end mill

Roughing end millA roughing end mill is a kind of end mill used for removing larger amounts of material with less precision than a standard end mill.

The tool has serrated teeth that remove large sections of material but leave a rough finish on the part. It produces small chips that are easy to clear.

Figure II.18: Roughing end mill. **[9]**

c) Face mill

Face mills consist of a solid body with interchangeable cutter inserts, usually made from carbide. They are used to make flat sections on the workpiece, often before another kind of cutter is used to make detailed features.

Since the cutting edges of face mills are found on their sides, cutting must be done horizontally.

However, face mills can be more cost-effective than other cutting tools since variations in cutting profile can be achieved by replacing the small cutter inserts rather than the entire tool.

Figure II.19: Face mill. **[9]**

d) Fly cutter

Fly cutters comprise one or two tool bits contained within a solid body. The tool bits of a fly cutter make broad, shallow cuts, producing a smooth surface finish.

It is more common to find fly cutters with one tool bit, but those with two tool bits — sometimes called “fly bars” — provides a larger swing.

Less expensive than face mills, fly cutters can nonetheless be used for similar purposes.

Figure II.20: Fly cutter. **[9]**

e) Thread mill

Thread millMany engineers prefer to make threads using taps, but threads can also be made with a CNC machine fitted with a thread mill.

Thread mills can cut internal or external threads, and they may be better than taps for penetrating very hard metals or asymmetrical parts.

Figure II.21: Thread mill. **[9]**

f) Drill bit

CNC machines can be fitted with a variety of drill bits for various cutting operations. Drill bits have one or more flutes and a conical cutting point.

Drill bits used in CNC machining include:

- Twist drill: used to make holes in the workpiece
- Canter drill: used to precisely locate a hole before drilling
- Ejector drill: used for deep hole drilling

Figure II.22: Drill bit. **[9]**

g) Reamer

Reamers are used to widen existing holes in the workpiece, providing an exact whole diameter and an excellent surface finish.

Reamers can create holes with much tighter tolerances than other cutting tools.

Figure II.23: Reamer. **[9]**

h) Hollow mill

Hollow mills are pipe-shaped cutting tools that are like inverted end mills. Their cutting edges are on the inside of the pipe shape, and they can be used to create shapes like full points and form radii.

Figure II.24: Hollow mill. **[9]**

i) Side-and-face cutter

Side-and-face cutters have teeth both on their side and around their circumference and are suitable for unbalanced cuts.

These cutting tools can be used for cutting slots and grooves with fast feed rates. Their teeth can be straight or staggered.

Figure II.25: Side-and-face cutter. **[9]**

j) Gear cutter

CNC mills are sometimes used to create metal gears for the manufacturing industry. Specific gear cutting tools can be used to make these gears.

Cutting gears sometimes requires a special kind of milling machine known as a hobbing machine.

Figure II.26: Gear cutter. **[9]**

k) Slab mill

Slab cutters or plain milling cutters are used to mill flat surfaces, usually with the target surface mounted parallel to the machine table.

These cutting tools have no side teeth and can be used for general or heavy-duty machining operations.

Figure II.27: Slab mill. **[9]**

II.5 Tool Change System

How to change the tool depends on your CNC machine. The CNC machine is divided into manual tool changes and automatic tool changes.

II.5.1. Manual change of the tool MTC

Quick and semi-automatic tool change per quarter turn of the fixing button; the machine is locked in there; no height recalibration is needed. To open the pin, press the button at the top of the pin until it locks and turn it to the left. Repeat this operation until you can remove the tool from the mandrin. For better access, you can lift the pin, but it is not recommended to remove it completely from the support. The change of tool during the execution of the program is carried out with engines on voltage. The current axis position is thus locked.

II.5.2. Automatic change of tool ATC

In machining, an automatic tool changer (ATC) is used in computerized numerical control (CNC) machine tools to improve the production and tool-carrying capacity of the machine. ATCs change tools rapidly, reducing non-productive time. They are generally used to improve the capacity of the machines to work with a number of tools. They are also used to change worn-out or broken tools. They are one more step towards complete automation.

II.6 Cutting Parameters

II.6.1. Cutting Speed

The surface speed is often referred to as the cutting speed and is abbreviated Vc. The diameter can be a spinning workpiece, such as a lathe, or a spinning cutter, such as an end mill or drill bit. The diameter is often abbreviated D and refers to the diameter of the cylinder where the speed applies, usually the periphery. The RPM (revolutions per minute) is sometimes abbreviated as N.

$$Vc = \frac{\pi * D * N}{1000}$$

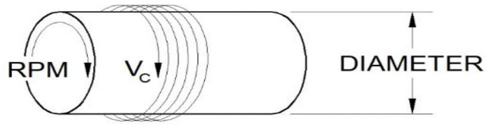


Figure II.28: Disctription of parameters. **[10]**

II.6.2. Spindle Speed

The spindle speed is obtained when the cutting speed is divided by the circumference of the work piece in revolutions per minute (R.P.M.). The speed varies depending on several factors, like the diameter of the cut or the surface area.

$$N = \frac{Vc * 1000}{D * \pi}$$

II.6.3. Feed Rate

- **Feed per Revolution (fn):** While table feed (below) is usually used to specify the feed rate of milling operations, feed per revolution is sometimes used. The distance the table moves in one revolution of the cutter without regard to the spindle speed.

Feed per revolution, table feed, or feed per tooth.

- **Table Feed (vf):** Milling feed rates for table feed are usually given in units of length per unit of time, for example, inches per minute (IPM) or millimeters per minute (mm/min).

Feed: Vf = N * fz * Z Z = number of flutes

Feed per tooth: $\mathrm{fz} = \frac{\mathrm{Vf}}{\mathrm{N*Z}}$

II.6.4. Depth of cut

There are two depths of cut: axial and radial:

- **Axial Depth of Cut (ap):** The axial depth of cut (shown as ap below) is also known as “stepdown” or ADOC.

- **Radial Depth of Cut (ae):** The radial depth of cut (shown as ae below) is also known as “stepover” or RDOC and is often specified as a percent of tool diameter.

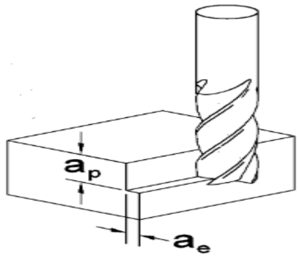


Figure II.29: Depth of Cut (ae) and (ap). **[10]**

Table II.3: Depth of cut parameters.

Symbol	Designation/definition	Metric	US Customary
a_e	Radial depth of cut	mm	inch
a_p	Axial depth of cut	mm	inch
f_z	Feed per tooth	mm	inch
f_n	Feed per revolution	mm/r	inch
n	Spindle speed	rpm	rpm
v_c	Cutting speed	m/min	ft/min
v_e	Effective cutting speed	mm/min	inch/min
v_f	Table feed	mm/min	inch/min

II.7 CNC cooling system

One of the most important parts of the machining process is the coolant. It is widely used to temper high temperatures, typically during machining, and helps in chip evacuation. CNC machining coolant serves the same purpose as coolant in other applications: to remove heat from a system. When a cutting tool contacts a workpiece, it generates heat due to friction between the workpiece and the tooling. Coolant is required to maintain proper operating temperatures and prevent overheating that leads to reduced performance, increased tool wear, and equipment failure.

Figure II.30: CNC cooling system. **[11]**

II.7.1. CNC cooling system processing type

Coolant is delivered in multiple forms, both in terms of pressure and properties. The most popular coolant forms include:

a) **Flooding Systems:** The flooding method streams massive coolant quantities onto the machine and the workpiece. It is a low-pressure method that creates lubricity and removes any chips to prevent chip recutting. The flooding system allows for easy debris management during the machining process.

b) **Misting Systems:** Another low-pressure coolant type that is adequate for scenarios where heat and chip evacuation are not the biggest concerns. This coolant system releases a fluid, usually atomized into tiny, near-invisible particles. Due to this effect, the coolant gets released in the form of mist or fog when applied to the machine surface or workpiece. It delivers more optimal lubrication and is mostly applied in high-speed usage.

c) **Air Coolant System:** This system cools down and clears away chips with no objective to lubricate. It doesn't cool as effectively as water or oil-based coolant would. Air coolant is mostly preferred over alternative types that come in direct contact with the part, especially when dealing with sensitive materials. For example with plastics, thermal shock or rapid contraction and expansion of a part can occur if a direct coolant is applied.

d) **Jetting Systems:** Jetting coolant systems deploy the coolant liquid at elevated pressures. In some ways, it is similar to the flood coolant system but delivered at a pressure higher than 1,000 psi, hence the name "jet." It's the most powerful option, but a fantastic option for chip evacuation and removal since it blasts the chip away from the component. The only downside is that the jetting system pressure can be so high that it can break miniature diameter tooling. It is often used in drilling operations for that reason.

e) **Minimum Quantity Lubricant (MQL):** Many companies go the MQL route due to its cost, performance efficiency, and exceptional environmental benefits. The appropriate coolant amount will significantly reduce your expenses and waste material. The MQL is mostly applied as an aerosol or a very fine mist to provide adequate coolant to conduct a particular operation effectively.

II.7.2. Types of coolant

Also known as a cutting fluid, it is a specific lubricant type that helps CNC machines easily cut different materials, including fiberglass, metals, high-density plastic, and so on. When technicians operate at low cutting speeds, the coolants are in charge of lubricating the process of cutting. On the other side, at high speeds of cutting, the coolant cools the workpiece.

Machining coolants are categorized into the four following categories:

a) **Synthetic fluids:** Synthetic coolants do not contain petroleum-based oil. Usually, they consist of lubricants and rust inhibitors dissolved in water. Suppliers provide synthetics as concentrates, much like soluble oils, and they are mixed with water to create the coolant.
   Synthetics are preferred for high-heat and high-velocity metalworking, such as surface grinding. Additives can have a profound effect on lubricity and, when added to some synthetics, give them better lubricating characteristics than straight oils without additives.
b) **Semi-synthetic fluids:** These types contain both synthetic (polymer) and oil. These types of fluids can contain from 5% oil to 35% oil. To put it simply, they contain the best of both worlds. The smaller percentage of oil allows for heat to be dissipated way faster than with soluble oils, improving finish and tool longevity.
c) **Soluble oils:** Soluble oils are suitable for light to heavy-duty machining operations, including ferrous and nonferrous applications. Soluble oils usually contain 40 percent or more oil and are mixed with water to create the metalworking fluid.

These fluids provide good cooling water has a high heat capacity and readily dissipates heat and lubrication capabilities that result from the blend of oil and water.

d) **Straight oils:** Water-insoluble straight oils are derived from petroleum (mineral oils), animal or vegetable origin and are used “straight,” without dilution with water.

These oils provide good lubricity and rust prevention, extended sump life and are easy to maintain. Also, they do not sour, as bacteria will normally only survive in fluids containing water.

Straight oils may be a blend of one or more of the various base oils and may also contain boundary and/or extreme-pressure additives such as sulfur, phosphorous or chlorine compounds. Straight oils reduce the forces generated as a tool cuts metal so the tool cuts cleanly to produce a smooth surface finish on the workpiece.

II.7.3. Machining without coolant

There are several negative consequences that can occur when machining without coolant, which impact both the machining process and the quality of the finished parts.

a) **Overheating**: Overheating leads to thermal expansion in the workpiece and the cutting tool, which can cause dimensional inaccuracies, part warpage, and even damage to the workpiece.

b) **Tool Wear:** High temperatures and friction from the cutting action can accelerate tool wear, so proper cooling and lubrication extend the cutting tool’s lifespan. Also, increased tool wear leads to frequent tool changes, additional downtime, increased costs, and decreased productivity.

c) **Chip Clogging:** Machining chips can accumulate around the work area and create a messy and unsafe working environment. Coolant lubricates the cutting zone and facilitates efficient chip removal. Without coolant, chips remain in the work area, which causes chip recutting and chip clogging and results in reduced productivity, excess material removal, an undesirable surface finish, or issues with features like internal threads.

d) Smearing: Friction between the tool and the workpiece in the absence of coolant can cause smearing, which causes built-up edge formation and results in rough surfaces, burrs, and other irregularities.

e) Poor Surface Finish: CNC machining without coolant can cause thermal damage to the workpiece, leaving undesirable marks and discoloration.

II.8. Conclusion

In this chapter has covered the structure and composition of CNC machines, emphasizing the critical role that each component plays in ensuring proper operation. We talked about the various components of the apparatus. Along with the design, materials, and various systems, beginning with the electrical, mechanical, guiding, and motion systems, we also talked about them. We also observed the many cutting tools and their kinds on the machine. The sorts of machine cooling systems that are now in use have been covered.

As a result, we carried out an extensive investigation and gained further knowledge regarding the design and construction of the CNC machines.

Chapter III :

Manual programming methodology

III.1. Introduction

Programming is the preparation work that consists of transposing, in the form of alphanumeric text, the machining range of the part into an ordered set of instructions understood and executed by the CNC in order to carry out its machining. This work can be done manually or with the assistance of a computer using an advanced programming language. In addition, some complex surfaces are extremely difficult, if not impossible, to program manually. This is why modern CNCs have integrated programming assistance software and fixed machining cycles. The programming method is chosen according to the skills of the programmer and the complexity of the machines to be controlled. Whatever the programming language used for the development of part programs, the only language understandable by the machine is the ISO language. Switching from a high-level language to an ISO language is possible using translation software.

III.2. Information flow concept (MOCN)

To better understand the difficulties of integrating the various modules of a complete manufacturing system, it is essential to start by exposing the information process from the initial stage of the concept of the part to be manufactured until obtaining the physical part. It is possible to uncover the origin of integration issues, allowing a more effective approach to their resolution.

A system that has every module required to take an item from its conceptual state to a real, machined model is known as an integrated manufacturing system. The system comprises various software and physical modules, denoted by rectangles in Figure III.1. Examples of these modules include the numerically controlled machine tool (CNC) and the computer-aided design (CAD) module. Figure III.1, which shows an arrow joining two modules, shows that information is transferred between the modules. Whereas an empty arrow shows a potential path the information could follow based on the capabilities of the modules connected by the arrows, a solid arrow indicates the typical direction of information flow.

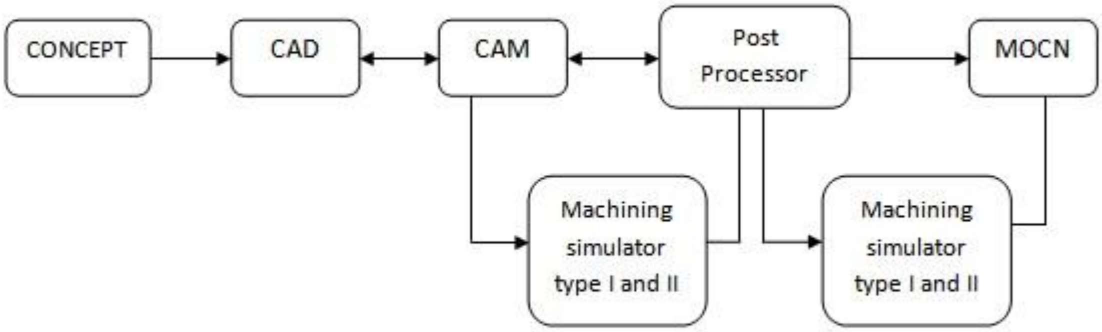


Figure III.1: Information flow concept (MOCN). **[12]**

It is observed that each module uses a proprietary or standardized format to process the information. As for the proprietary format, this results in a reduction in the overall flexibility of the system.

The part description is saved electronically in the CAD software. To then be moved to the computer-aided manufacturing (CAM) module. Then, the post-processor module translates the information to generate the data that will be transmitted to the machine tool numerically controlled (MOCN) controller. It is possible to include machining simulation steps before the post-processor module and before transfer to the MOCN. The following sections provide a detailed description of the integration challenges encountered when transferring information between each illustrated module. **[12]**

III.2.1. Computer-Aided Design (CAD)

Operation, which allows you to draw and design mechanical parts using the computer, CAD brings together software and geometric modeling techniques that make it possible to design, virtually test, and produce manufactured products. Among the CAD software we mention is SolidWorks.

III.2.1.1. CAD tools (software)

Many CAD programs are offered as open-source software:

AutoCAD – SolidWorks - CATIA - Inventor - Siemens NX - PTC Creo - Fusion 360…

III.2.2. Computer-Aided Manufacturing (CAM)

Operation that converts a CAD file into an ISO program (or ISO blocks) to transmit it to a numerically controlled machine tool (which is connected to the computer), which will manufacture the part that was designed in CAD. CAM software (such as CAMWORKS) calculates tool paths from geometric information, technical information, user instructions, and/or information from specific software. They make it possible to represent the characteristics of shapes, contours, or entities to be machined, the geometry of the stock, and the geometry of tools.

III.2.2.1. CAM tools (software)

- Camworks – SolidCAM – ArtCAM – SheetCAM - PowerMILL - Hyper MILL – Catia…

III.2.2.2. Post-Processor

A computer tool called a post-processor is used in the field of computer-aided manufacturing (CAM). A numerically controlled machine tool (NCM) is used to translate the language of a CAM (program, computer-aided manufacturing software) to the processor. So it is software that converts geometric elements such as lines, arcs, circles, tool axis direction, etc., into a code that can be understood by the controller of a CNC machine. Indeed, an FAO program generates a file that cannot be directly assimilated by the MOCN. It is necessary to translate this document in order to generate a new document usable by the MOCN. This file may be in ISO format, also called G-code, which is compatible with most machines. The post-processor plays a vital role in the field of CAM and is an integral part of machine programming. Each Cam software also has its own characteristics, which results in a difference between the post-processor of software A and that of software B for the same machine tool.

We can also say that a post-processor is software developed to manage data extracted from a source file (like APT, for example), including information, tool paths, and machining parameters, in order to adapt to a specific machine in order to save them in a program compliant with ISO standards (for example). **[12]**

III.3. CNC programming languages

a) ISO language

A program is the translation of the machining operations to be carried out on a part into a language understandable by the numerical control director of a CNC machine. **[13]**

b) The HEIDENHAIN language

The HEIDENHAIN language is a language invented by the Germans mainly to animate conversational CNC robots. **[13]**

c) The PROFORM language

The PROFORM language was invented from scratch for Charmille robots; language that has become completely absolute. **[13]**

d) The Fanuc language:

The ISO language from 1980 is the foundation of the Fanuc language. It adds new functions, making it a completely unique language. Specifications of the language are: paragraphs for the comments, Call for subprograms using M98, Virtuosity points at the end of blocks. **[13]**

e) The NUM language:

The NUM language is based on the ISO language. It adds additional functions, making it a unique language. The specificities of the language are: parentheses for comments; Calls for subprograms with G77. **[13]**

f) The SIEMEMS language:

The SIEMEMS language is based on the ISO language. It adds additional functions, which makes it a unique language. The specificities of the language are: semicolons for comments; slightly complicated cycle calls. **[13]**

III.4. digital controller language « G-code »

III.4.1. Definition

G-Code is the language used to control a CNC machine. It is indeed a programming language, which we therefore use to program the movements that the machine will perform, and the file containing the sequence of instructions is called, logically, a program. This is a simple text file that is human-readable, just like code in C, Pascal, or Basic. It consists of a number of specific "commands," telling the machine what type of movement it should perform (straight, arc, etc.), and coordinate indications on the X, Y, and Z axes (I am only considering the most classic cases of a 3-dimensional milling machine). It should be noted that G-Code is not used exclusively for CNC milling machines but also for lathes, 3D printers, and cutting lasers...

III.4.2. G-code role

A common programming language called "G-code" is used to operate digital machine tools, such as CNC (Computer Numerical Control) equipment. G code is used in the context of CNC machines to specify the cutting tool's movements and functions. The following are a few of the primary uses of G code in CNC machines:

- a- **Movement Control:** The cutting tool's movements along the CNC machine's axes are specified using G code. For instance, G00 can be used to move the tool quickly to a designated location, while G01 can be used to move the tool linearly at a predetermined speed during machining.
- b- **Speed Control:** The cutting tool's movement speeds are specified using the G code. Feed rates and quick traverse rates are defined by different G codes.
- c- **Coordinate setting:** The cutting tool's position coordinates are set using G code. For three-dimensional movements, coordinates can be described in terms of the X, Y, and Z axes; for more advanced CNC machines, additional axes can be used.
- d- **Tool Control:** The G code is used to turn on and off features related to cutting tools, such as turning on the spindle for tool rotation or turning on additional units like lubricating or cooling systems.

e- Tool change management: The CNC machine uses G codes to control tool changes, which include resetting the cutting parameters, moving the tool to a designated location for modification, and engaging tool clamps.

f- Machining Cycle Control: Using G code, predefined machining cycles, including those for tapping, drilling, and milling, can be defined.

These cycles specify the movements and cutting parameters needed for each operation.

III.4.3. Structure of a G-code program

A program is a series of instructions established in a coded language (ISO) that is broken down into a succession of blocks.

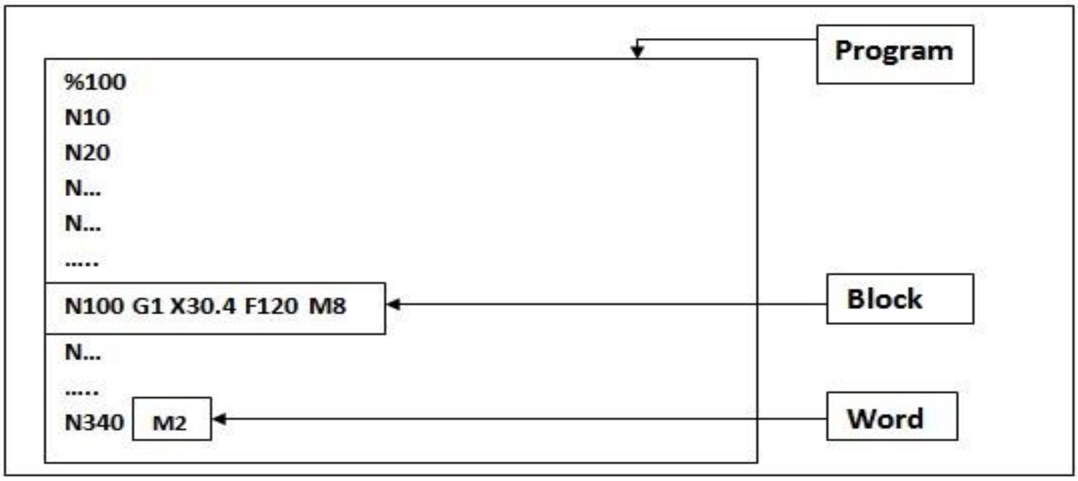


Figure III.2: Structure of a program. **[14]**

- **A block** is a line of writing composed of words that contain geometric and technological information. It is defined as follows (figure III.2):

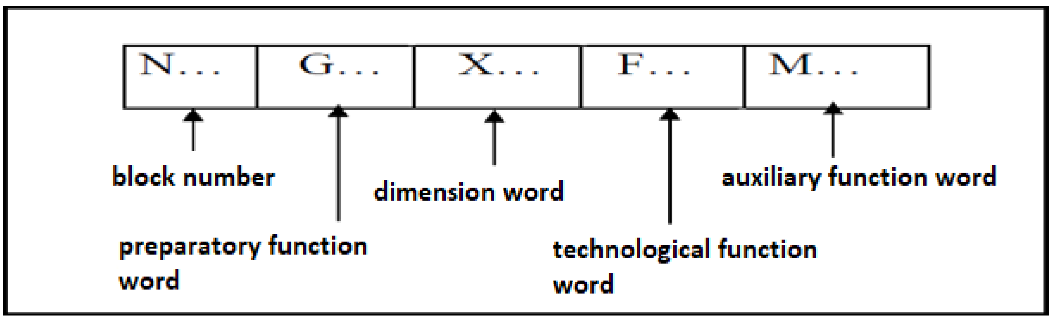


Figure III.3: Decomposition of a block. **[14]**

- **Word:** a group of characters that represent an address, followed by information-containing numbers. For instance, X 10.850
- **Address:** a machine-language letter that starts a word and indicates the overall function ordered.

  Principal address

  A comprehensive list of address codes is also included in G-code. It can be compared to the G-code lexicon, which specifies certain actions. Address codes consist of a sequence of numbers followed by a letter designation, like G. For instance, the address code X2 defines an address in X coordinates, where 2 is the value to move the machine to on the X axis.

Here is an example of the structure of an iso program:

Table III.1: Example of structure of an iso program. **[14]**

structure	example
Program number Identification	%4732 (SMI tower) (handle) (01/03/2017)
Initialization	N28 G40 G80 M5 M9
Clearance Position	N29 G0 G52 X0 Z0
Operation 1	(center operation) N30 T5 D5 M6 (center drill) N40 G0 X0 Z52 N45 G95 G97 S2500 F0.05 M3 M8 N50 G1 Z40 N60 G0 Z52
Clearance Position	N70 G0 G52 X0 Z0 M9
Operation 2	(profile finish) N240 T3 D3 M6 (finishing tool) N250 G92 S4000 N260 G1 G42 X5 Z46 N270 G1 G42 X5 Z46 N280 G96 S250 N290 G3 X34 Z22 I26 K22 N300 G1 Z18
Clearance Position	N370 G0 G52 G40 X0 Z0 M5 M9
End of Program	N710 M2

- **Structure of an operation**

Table III.2: Structure of an operation. **[14]**

Structure		**Example**
Previous operation		**(center operation)**
Position the right tool	• M6 (tool call) • T (tool number) • D (corrector number)	**N30 T5 D5 M6 (center drill)**
Approach the tool quickly	• G0 (fast movement) • X,Y,Z(end point coordinates) • M3 or M4 (direction of rotation)	**N40 G0 X0 Z52**
Adapt cutting conditions	• G96 S (Vc in m/min) Or G 97 S (N in rpm) Or G94 F (Vf in mm/min) Or G95 F (f in mm/rev)	**N45 G97 G95 S2500** **F0.05 M3 M8**
Conduct machining	• Tool path or particular cycle (machining)	**N50 G1 Z40**
Quickly release the tool	• G0 (fast movement) X,Y,Z(end point coordinates)	**N60 G0 Z52**
Next operation		**??**

- **ISO functions**

The following table groups together all the ISO functions

Table III.3: ISO functions. **[14]**

Indications	Addresses	Meaning
Start of a program	%	Start of program input parameter
Order	N	Block Number Subprogram Number
Preparatory functions	G	They predispose the machine for a precise order.
Movements along the axes	X Y Z A B C	Value of positive or negative displacement
Advance	F	feed rate expressed Speed in mm/min
Auxiliary functions	M	Special functions designating an order
Tools	T... D..	Selection of the tool and its corrector(s)
Security Plan Department	B ER	Radius of the circle in G02 G03 Reference plane in cycle
Repeat Speed	S	N or Vc following G96 or G97 placed before Repeating a sequence

III.4.4. Explanation of G-codes

III.4.4.1. Machining G-codes

G-codes are a set of programming instructions used to control CNC (Computer Numerical Control) machines, including milling, turning, and other machining processes. These codes tell the machine tool what actions to perform, such as moving the tool along a certain path, changing tools, or turning coolant on or off. Here are some common G-codes used in machining:

G00: Rapid positioning; moves the tool quickly to a specified position at the maximum feed rate.

G01: Linear interpolation; moves the tool in a straight line at a specified feed rate.

G02/G03: Circular interpolation; moves the tool in a clockwise (G02) or counterclockwise (G03) arc at a specified feed rate, creating a circular or helical path.
G04: Dwell; pauses the machine for a specified amount of time.
G17/G18/G19: Plane selection. Selects the plane in which circular interpolation will occur (XY plane for G17, ZX plane for G18, and YZ plane for G19).

G20/G21: Inch/metric mode; sets the machine to operate in either inches (G20) or millimeters (G21).

G28/G30: Return to home; Moves the tool to a predefined home position.

G40/G41/G42: Cutter radius compensation; adjusts the toolpath to compensate for the radius of the cutting tool (G41 for left compensation, G42 for right compensation, and G40 to cancel compensation).

G43/G44/G49: Tool length offset. Sets the length offset for the tool (G43 for positive offset, G44 for negative offset, and G49 for cancel offset).

G54-G59: Work coordinate system selection. Sets the work coordinate system (G54-G59 are typically user-defined coordinate systems).

G80: Cancel modal motion; cancels any modal G-codes active.

G90/G91: Absolute/incremental positioning; sets the machine to interpret coordinates as either absolute (G90) or incremental (G91).

These are just a few examples of G-codes used in CNC machining. Different machines and control systems may support additional codes or variations of these codes. Understanding and correctly programming G-codes is essential for efficiently operating CNC machines and producing accurate machined parts.

III.4.4.1.1. Linear interpolation movement (G00 and G1)

- **G00 (Fast Move):** Moves the extruder to the specified position as quickly as possible without extruding filament. Used for moving between print points.

Example: G0 X10 Y10 Z10 F1000 moves the print head to position X10, Y10, and Z10 (in mm) at a speed of 1000 mm/min.

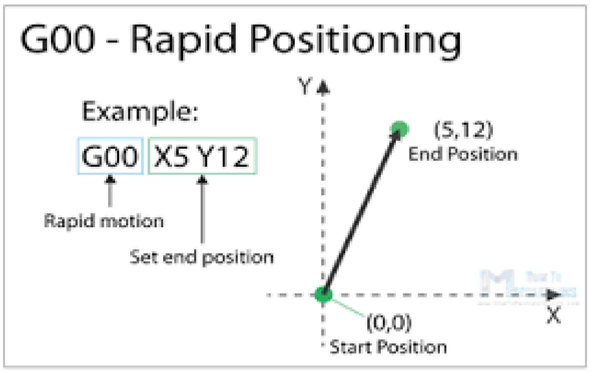


Figure III.4: Rapid positioning. **[15]**

- **G1 (Controlled Move):** Moves the extruder to a specified position while extruding filament at a controlled speed. This is used for printing layers.

Example: G1 X20 Y20 Z10 F500 E10 moves the print head to position X20, Y20, and Z10 (in mm) at a speed of 500 mm/min, extruding 10 mm of filament.

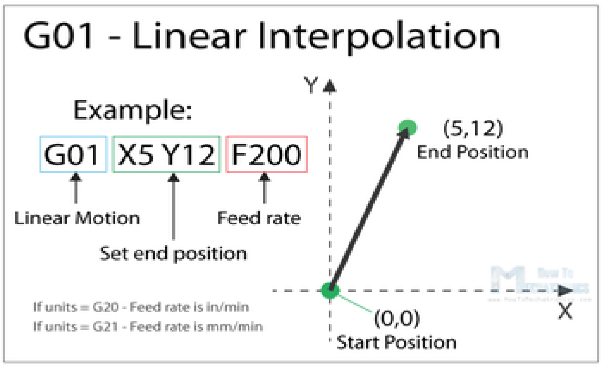


Figure III.5: Linear interpolation. **[15]**

III.4.4.1.2. Circular interpolation movement (G02 and G03)

G02 and G03 are the G codes for circular cutting movements. Circular interpolation movement has several optional address codes to define the arc or circumference. The arc or circle cut goes from the current cutter position to the geometry specified in the G02/G03 command.

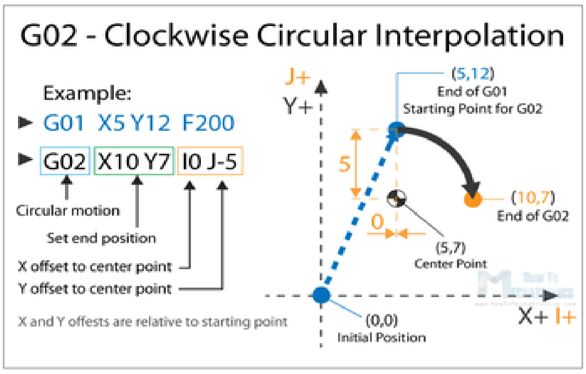


Figure III.6: Circular interpolation. **[15]**

III.4.4.1.3. Aircraft designations (G17, G18, and G19)

G17, G18, and G19 are not aircraft designations. Instead, they are G-codes used in CNC machining, as I mentioned earlier. Here's what they represent in machining:

G17: Selects the XY plane for circular interpolation. This means that when G17 is active, any circular or helical interpolation commands (such as G02 or G03) will be interpreted to move the tool in the XY plane.

G18: Selects the ZX plane for circular interpolation. In this mode, circular or helical interpolation commands will be interpreted to move the tool in the ZX plane.

G19: Selects the YZ plane for circular interpolation. Similar to G17 and G18, circular or helical interpolation commands will be interpreted to move the tool in the YZ plane when G19 is active.

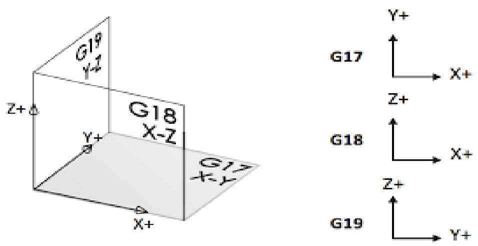


Figure III.7: G17 G18 G19 Plane selection. **[16]**

III.4.4.1.4. Table of common G preparatory functions

Table III. 4: G Code List. **[17]**

Code	Group	Description
G00	1	Rapid Move
G01	1	Linear Feed Move
G02	1	Clockwise Arc Feed Move
G03	1	Counter Clockwise Arc Feed Move
G04	0	Dwell
G09	0	Exact stop
G10	0	Fixture and Tool Offset Setting
G12	1	Clockwise Circle
G13	1	Counter Clockwise Circle
G15	11	Polar Coordinate Cancel
G16	11	Polar Coordinate
G17	2	XY Plane Select
G18	2	ZX Plane Select
G19	2	YZ Plane Select
G20	6	Inch
G21	6	Millimeter
G28	0	Zero Return
G30	0	2nd, 3rd, 4thZero Return
G31	1	Probe function
G32	1	Threading*
G40	7	Cutter Compensation Cancel
G41	7	Cutter Compensation Left
G42	7	Cutter Compensation Right
G43	8	Tool Length Offset + Enable
G44	8	Tool Length Offset - Enable
G49	8	Tool Length Offset Cancel
G50	9	Cancel Scaling
G51	9	Scale Axes
G52	0	Local Coordinate System Shift

G53	0	Machine Coordinate System
G54	12	Fixture Offset 1
G54.1	12	Additional Fixture Offsets
G55	12	Fixture Offset 2
G56	12	Fixture Offset 3
G57	12	Fixture Offset 4
G58	12	Fixture Offset 5
G59	12	Fixture Offset 6
G60	0	Unidirectional Approach
G61	13	Exact Stop Mode
G64	13	Cutting Mode (Constant Velocity)
G65	0	Macro Call
G66		Macro Modal Call
G67		Macro Modal Call Cancel
G68	15	Coordinate System Rotation
G69	15	Coordinate System Rotation Cancel
G73	16	High Speed Peck Drilling
G74	16	LH Tapping*
G76	16	Fine Boring*
G80	16	Canned Cycle Cancel
G81	16	Hole Drilling
G82	16	Spot Face
G83	16	Deep Hole Peck Drilling
G84	16	RH Tapping*
G84.2	16	RH Rigid Tapping*
G84.3	16	LH Rigid Tapping*
G85	16	Boring, Retract at Feed, Spindle On
G86	16	Boring, Retract at Rapid, Spindle Off
G87	16	Back Boring*
G88	16	Boring, Manual Retract
G89	16	Boring, Dwell, Retract at Feed, Spindle On
G90	3	Absolute Position Mode
G90.1	4	Arc Center Absolute Mode
G91	3	Incremental Position Mode
G91.1	4	Arc Center Incremental Mode
G92	0	Local Coordinate System Setting
G92.1	0	Local Coordinate System Cancel
G93	5	Inverse Time Feed
G94	5	Feed per Minute
G95	5	Feed per Revolution*

III.4.4.1.5. The auxiliary function M

M codes, or "miscellaneous codes," are used to control various auxiliary functions of the CNC machine, such as starting or stopping the spindle, turning coolant on or off, tool changes, etc.

- **Function**

M codes handle machine-specific functions and operations. They control non-motion activities, such as turning the spindle on or off, activating or deactivating coolant, and tool changes.

Table III.5: M Code List. **[17]**

Code	**Description**
M00	Mandatory Program Stop
M01	Optional Program Stop
M02	Program End
M03	Spindle Forward/Clockwise
M04	Spindle Reverse/Counterclockwise
M05	Spindle Stop
M06	Tool Change
M07	Mist Coolant On
M08	Flood Coolant On
M09	All Coolant Off
M19	Spindle Orient
M30	Program End and Rewind
M40-M45	Gear Change
M47	Repeat Program from First Line
M48	Enable Feed/Speed Overrides
M49	Disable Feed/Speed Overrides
M98	Subprogram Call
M99	Return From Subprogram / Rewind
M???	Custom Macro M Codes

[10]

III.4.4.1.5. Tools corrections

Table III.6: Tools corrections. **[17]**

Type	Meaning
G40	Canceling tool radius compensation
G41	Left tool radius compensation
G42	Right tool radius compensation
G43	Tool length compensation in + direction (milling only)
G44	Tool length compensation in direction - (milling only)
G49	Tool length override (milling only)

III.5. Classification of preparatory functions G

Functions defined by the address G and preparing the logic for a type of calculation or a specific action.

Example: G00, G01, G02, G03, G04, etc.

III.5.1. Modal G functions

A modal G function belongs to a family of G functions that are mutually revoked.

There are functions in some families of G functions that are initialized upon system startup. Until a function within the same family revokes its validity, these functions remain valid. **[11]**

- **Example**

N40 G00 X… Z…
N50 G01 Z…

Comment

- Linear interpolation at a fast speed
- Linear interpolation at a machining speed that revokes G00.

III.5.2. Non-modal G functions

A non-modal function is only valid in the block where it is programmed. **[11]**

- **Example**

N70 G09 Z…

- **Comments**

Precise stop at end of block at x=300; revocation at end of block.

III.6. Programming mode

- **ABSOLUTE programming: G90.**
- **RELATED programming: G91.**

These functions specify the machining references (Table III.7):

Table III.7: The machining references of G90 and G91. **[18]**

G90	All values are defined from the part origin (or the same origin)
G91	The reference is the previous position

In absolute G90 programming, the dimension is located in relation to the OP program origin.

G59: The called axis and the value define the offset applied to all subsequent dimensions.

A new G59 cancels and replaces the previous one.

In relative programming G91, the dimension is marked in relation to the previous position.

G59: The called axis and the value apply to the first dimension following G59.

A new G59 modifies the following rating in the same way. In absolute value, the offset will be the sum of the programmed values. G59 is modal.

The first movement programmed on each axis must be done in G90 or G52.

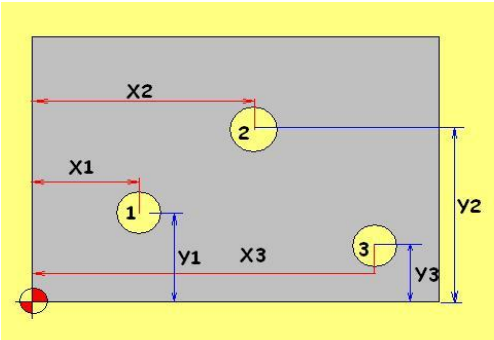
To cancel, program:

- With G90, G59 X Y Z (zero).
- With G91, return to G90, and then program G59 X Y Z (zero).

• Reminder:

Table III.8: The machining references of G90, G91 and G59. **[18]**

G59	Programmed origin offset
G90	Absolute Programming versus OP
G91	Programming Relative to the starting point of the block



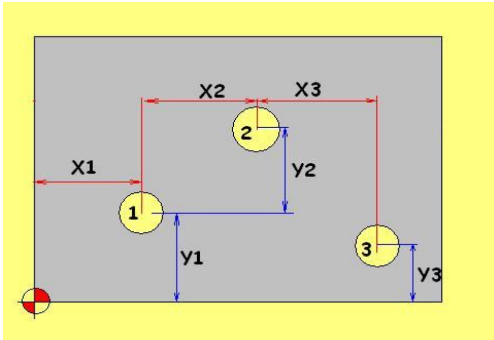


Figure III.8: ABSOLUTE programming G90. **[18]** **Figure III.9:** RELATED programming: G91. **[18]**

III.7. Conclusion:

In general, programming methodology is an important thing in the machine CNC, where the manual programming approach is defined by the direct involvement of humans in the process of producing code without the heavy dependence on automated tools or frameworks. It relies primarily on several programming languages; as we discussed in this chapter about the G code language, the use of the G-code digital control language is essential to CNC operations, and the G-code preparatory functions are used to regulate the movements of the machine tool. Selecting the programming mode is also crucial to ensuring the accuracy and efficiency of the fabrication. In this chapter, we have discussed and understood the various basics of the G code.

Chapter IV:

Creation of a piece

IV.1. Introduction:

Advanced machining instruments called CNC (Computer Numerical Control) lathes are used to remove material from a revolving workpiece to manufacture pieces. CNC lathes, which are computer-controlled, are very precise, repeatable, and efficient. For these reasons, they are very important in the automotive, aerospace, medical device, and manufacturing industries.

CNC lathes have revolutionized the manufacturing industry by offering precise, efficient, and versatile machining capabilities. The process of creating parts on a CNC lathe involves a sequence of design, programming, setup, machining, quality control, and finishing, all aimed at producing high-quality cylindrical components. Their ability to consistently produce parts with high precision and repeatability makes CNC lathes an indispensable tool in modern manufacturing.

In this chapter, we discussed how to create a piece on a lathe machine in a simplified and approximate manner.

IV.2. Turning

Turning is a machining operation that allows you to produce surfaces of revolution. The cutting movement is ensured by a rotation of the part around the axis of revolution. The forward movement is ensured by translations of the tool in a plane containing the axis of revolution.

IV.3. The machine used « EMCO Concept TURN 55 »

The Concept TURN 55 is a CNC tour with two established axes that is controlled by a PC. Its design and operation are in line with industry standards. On this tour, all of the key operations of the modern manufacturing process can be explained and replicated in accordance with reality. A sensible simplification, a clear machine conception, and an easy-to-manage approach are the keys to the training's quick success.

Figure IV.1: EMCO Concept TURN 55 with description. **[13]**

IV.3.1 Characteristics

Table IV.1: Characteristics of the Turn 55.

Work area	
Swing overbed	130 mm (5.1'')
Distance between spindle noses	335 mm (13.2'')
Max tuimg diameter	52 mm (2.1'')
Max part length	215 mm (8.5'')
Travel	
Travel in X	48 mm (1.9'')
Tlavel in Z	236 mm (9.3'')
Main spindle	
Speed range	120 - 4000 rp
Power (3 phase asynchtono us motor)	0.75 kW (1.01 hp)
Spindle diameter at front bearing	30 mm (1.2'')
Spindle bore	16 mm (0.6'')
Feed drives	
Rapid motion speed X/Z	2 m/min (78.7 ipm)
Feed force X/Z	1000 N
Positioning variation Ps (acc. VD I3441) in X/Z	8 µm (0.0003'')
Tool turret	
No . of tool station	8
Tool cross section	12 x 12 mm (0.5x0.5'')
Shan diameter forboring bars	10 mm (0.4'')
Tailstock	
Quill stroke	35 mm (1.4'')
Quill diameter	22 mm (0.9'')
Dimensions	
Height of center above fbor	320 mm (12.6'')
Dimensions Z xD xH	840 x 695 x 400(33.1x27.4x15.8'')
Total	85 kg (187 lb)

IV.3.2. The different tools

a. Tools for chariot

Whether on the left or on the right, a single working direction is possible for the realization of cylinders or outer cones. If the piece has a shoulder we obtain a work surface of envelope and a working surface of shape.

Figure IV.2: Carrying operations.

b. Tools to train

A single possible working direction perpendicular to the axis of the piece for the realization of flat outer surfaces, if the piece has a shoulder we obtain a work surface of envelope and a working surface of shape.

Figure IV.3: Dressing operations.

IV.3.3. Tool measurement

Table IV.2: Tool Features.

Execution	For steel machining	
Tail height	mm	10
Tail width	mm	10
Blade width	mm	8
Length	mm	90

IV.4. Piece measurement

To measure a piece we need first to talk about calipers.

Calipers are used to measure the dimensional characteristics of all metals. And this some ways to use calipers for measuring metal rod, sheet and plate, and how to read calipers, and explain the differences and uses of each.

a) Dial Calipers: Dial calipers are used for measuring diameters, thicknesses, and lengths of small items. To measure an object, open the dial caliper to fit around its sides, and then close down the caliper until it touches both sides. Reading the caliper scale at 7 and the round dial at 56 means that the object is 756/1000 inches in width or diameter.

Figure IV.4: Dial Calipers.

b) Digital Calipers: Digital calipers are used for measuring diameters, thicknesses, and lengths up to six inches. The readout is in inches and thousandths of an inch in decimals. The advantage of a digital readout is for accuracy and repeatability, because the operator is not required to interpret off of a scale. To use the digital calipers, turn them on, make sure it is zeroed out, and then open the calipers to fit around the object. Hold the wheel firmly to tighten both jaws of the caliper against the metal, and read out the measurement on the digital display.

Figure IV.5: Digital Calipers.

c) **Digital Micrometer:** The 0-1” digital micrometer is used to measure diameters or thicknesses up to one inch in diameter, with an accuracy of 0.0001”. To use it, open the micrometer to greater than the thickness to be measured, place the anvils on both sides of the object, and then tighten the spindle to so that the anvils touch both sides of the object. The thickness can be read from the display in thousandths of an inch.

Figure IV.6: Digital Micrometer.

d) **The vernier calipers:** The vernier calipers found in the laboratory incorporate a main scale and a sliding vernier scale which allows readings to the nearest 0.02 mm. This instrument may be used to measure outer dimensions of objects (using the main jaws), inside dimensions (using the smaller jaws at the top), and depths (using the stem).

Figure IV.7: The vernier calipers.

After talking about calipers now we can start the measure, to measure the piece we have to following the next steps:

Step 1: Make sure that the vernier Calliper is properly zeroed. To do this, loosen the locking screw and adjust the movable jaw until the zero mark on the vernier scale aligns with the zero mark on the main scale.

Step 2: Place the object to be measured between the fixed and movable jaws.

Step 3: Tighten the locking screw to secure the movable jaw in place.

Step 4: Read the measurement from the main scale and the vernier scale. The main scale will give you the overall length of the object, while the vernier scale will give you the small increments of length.

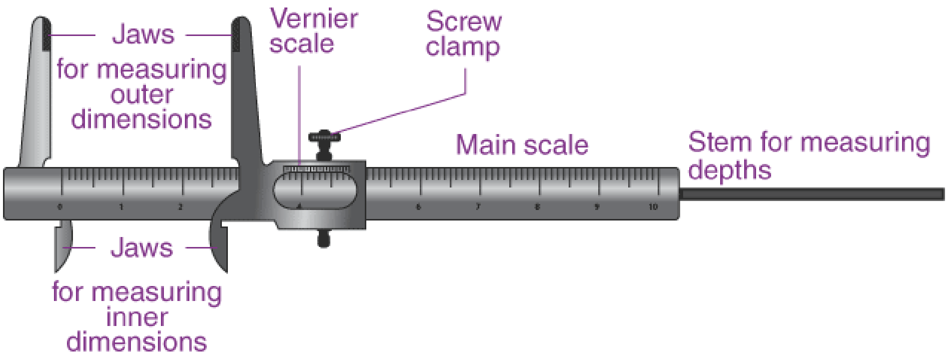


Figure IV.8: description of caliper.

This is the result of measuring the lengh (we can also use the ruler here):

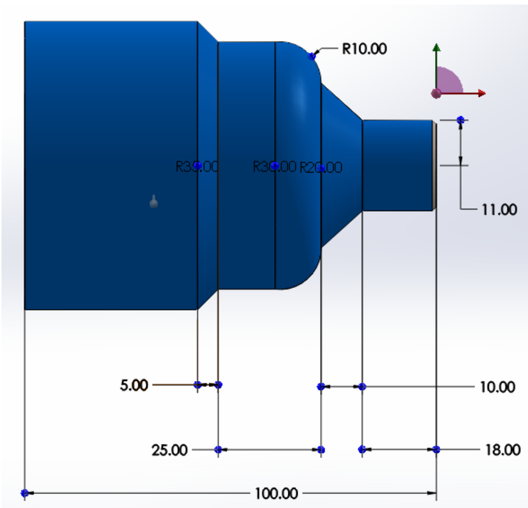


Figure IV.9: Measure of lengh.

This is the result of measuring the diamiter :

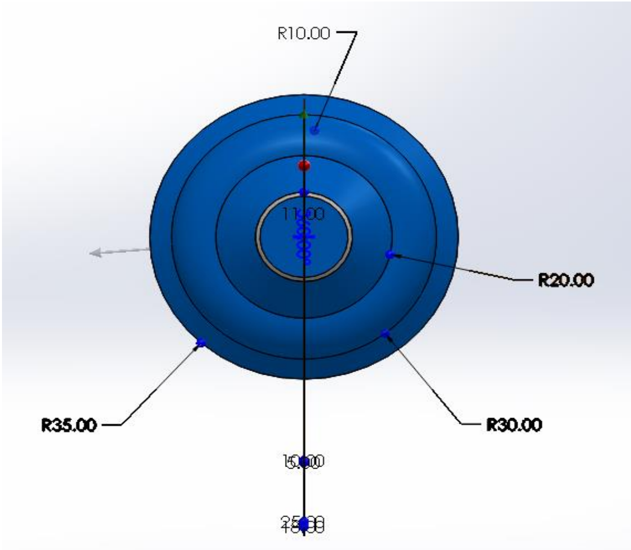


Figure IV.10: Measure of deamiter.

This is the final result:

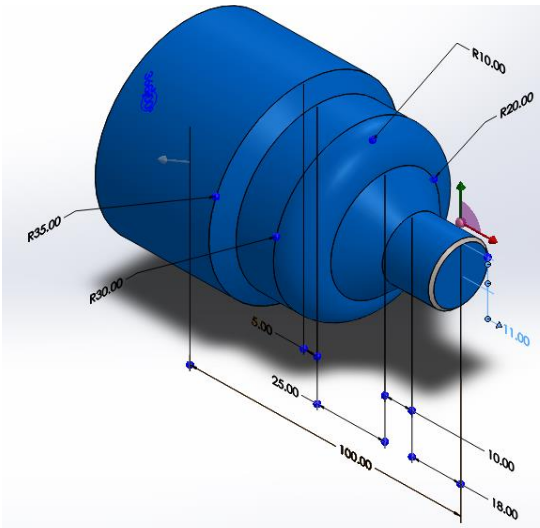


Figure IV.11: General measure.

IV.5. The material used (Alloy Steel)

IV.5.1. Definition

Alloy steel is a type of steel with alloying elements other than carbon added to improve its properties. Some of the common additions to alloy steel include: chromium, cobalt, columbium, molybdenum, manganese, nickel, titanium, tungsten, silicon, and vanadium. Alloy steels are known for their enhanced properties compared to plain-carbon steel, such as: corrosion resistance, hardness, strength, wear resistance, and toughness.

Alloy steels are used to make fabrication tooling and end products across just about all industries. The exact grade and composition of the alloy steel can be tailored to the requirements of the application.

Alloy steel is an iron-based material, which, in addition to carbon, contains one or more intentionally added elements. The alloying elements are added to the steel to improve one or more of its physical and/or mechanical properties, such as: hardness, strength, toughness, high-temperature performance, corrosion resistance, and wear resistance. These elements typically comprise 1-50 wt% of the metal's composition. There are many ways to group alloy steels. They can be grouped by their major alloying elements (e.g., stainless steels contain considerable amounts of chromium), or by the percentage of all alloying elements that the steel contains (e.g., high-alloys steel typically contains more than 8 % alloying elements, while low-alloy steel has less than 8 %).

IV.5.2. Composition of Alloy Steel

Depending on the desired properties of the material, alloy steel can contain a wide variety and variable amounts of alloying elements. Each of these elements is added to enhance some properties of the steel, such as hardness or corrosion resistance. Typical alloying elements include: boron, chromium, molybdenum, manganese, nickel, silicon, tungsten, and vanadium. Other less common elements that may be added are: aluminum, cobalt, copper, lead, tin, titanium, and zirconium.

IV.5.3. Uses of alloy steel

The application of alloy steel is very wide and depends on the type of alloy steel. Some alloy steels are used to manufacture pipes, particularly those for energy-related uses. While others are utilized in the production of corrosion-resistant containers, silverware, pots, pans, and heating components for toasters and other kitchen equipment. Alloy steels can be divided into two primary categories: low-alloy steels and high-alloy steels. The application of alloy steels is mainly determined by the category that they fall in.

Low-alloy steels are employed in a variety of industrial sectors due to their strength, machinability, and affordability. They can be found in ships, pipelines, pressure vessels, oil drilling platforms, military vehicles, and construction equipment.

High-alloy steels, on the other hand, can be expensive to produce and challenging to work with. However, they are perfect for automotive applications, chemical processing, and power generation equipment due to their high strength, toughness, and corrosion resistance.

IV.5.4. Characteristics

Table IV.3: Characteristics of alloy steel.

Element	Symbol	wt. %	Function
Aluminium	Al	0.95–1.30	Alloying element in nitriding steels
Chromium	Cr	0.5–2.0	Improves hardenability
		4–18	Corrosion resistance
Manganese	Mn	0.25–0.40	Prevents brittleness in combination with sulfur
		>1	Increases hardenability
Nickel	Ni	2–5 12–20	Increases toughness Improves corrosion resistance
Silicon	Si	0.2–0.7	Increases strength and hardenability
		2	Increases yield strength (spring steel)
		Higher %	Increases magnetic properties

IV.5.5.Properties

Table IV.4: Properties of alloy steel.

Property	Value	Value
Elasticity module	2.05e +011	N.mm-2
Poisson coefficient	0.29	S.O
Shear modulus	8+011	N.mm-
Volumic mass	7850	Kg.m-3
Pull limit	625000000	N.mm-2
Elasticity limit	530000000	N.mm-2
Thermal expansion coefficient	1.15°-055	K-1
Thermal conductivity	49.8	W. (mK)-1
Specific heat	486	J. (kg.k)-1

IV.6. Description of “Solidwork” software

Solidworks – a solid modelling computer-aided design and computer-aided engineering program is one of the best software options for mechatronics engineers.

Solidworks course is used to develop a robust and fully functioned mechatronics system from beginning to end. At the initial stage, the software is used for planning, visual ideation, modelling, prototype, and project management. The software will then help you to design and build mechanical, electrical, or software elements. Finally, you can manage things like device management, analytics, data automation, and cloud services with the help of Solidworks.

Solidworks has rapidly become a leader in mechanical computer aid design programming. Solidwork software tool lets you create, simulate, and publish while data management. This is a software program that provides the users a way to improvise the product design while they work quick and on economical basis.

- And this is description of “Solidwork” software:

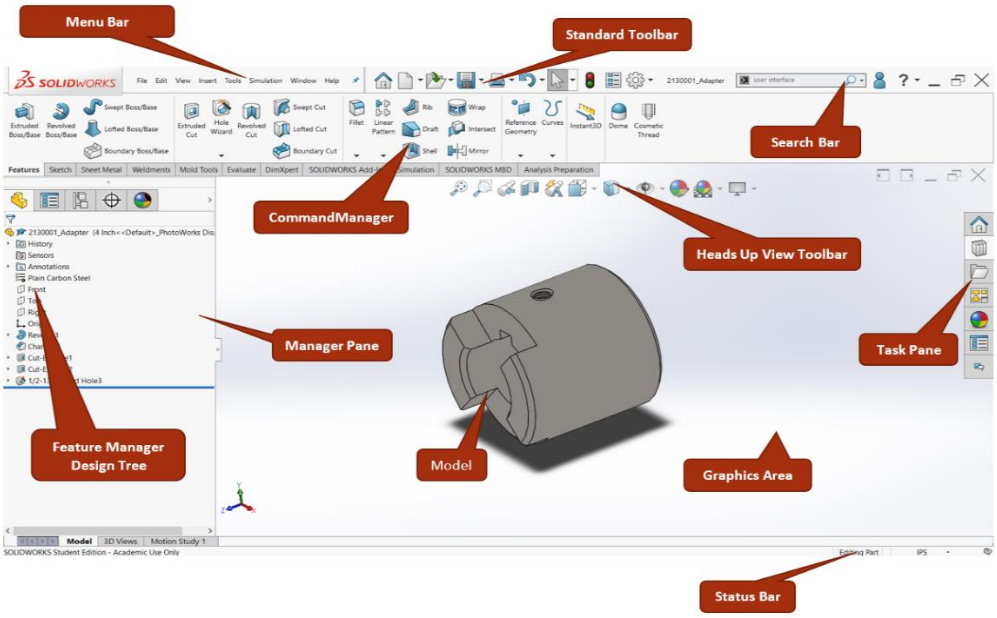


Figure IV.12: Description of “SolidWork” software. **[14]**

IV.6.1.The steps to designe the piece

After Create a new part file

- We choose the front plane and sketch the entire piece with its dimensions:

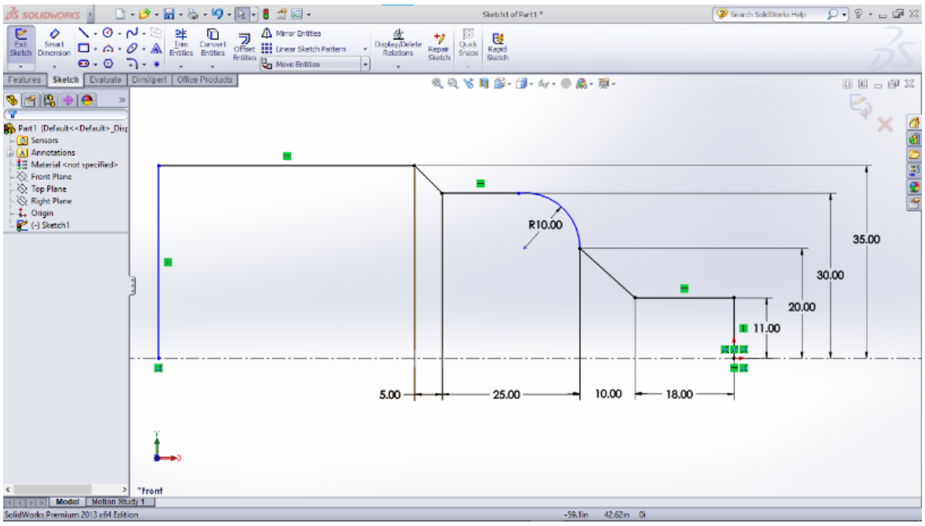


Figure IV. 13: The front plane.

- And the next step is to go to features and choose revolved boss:

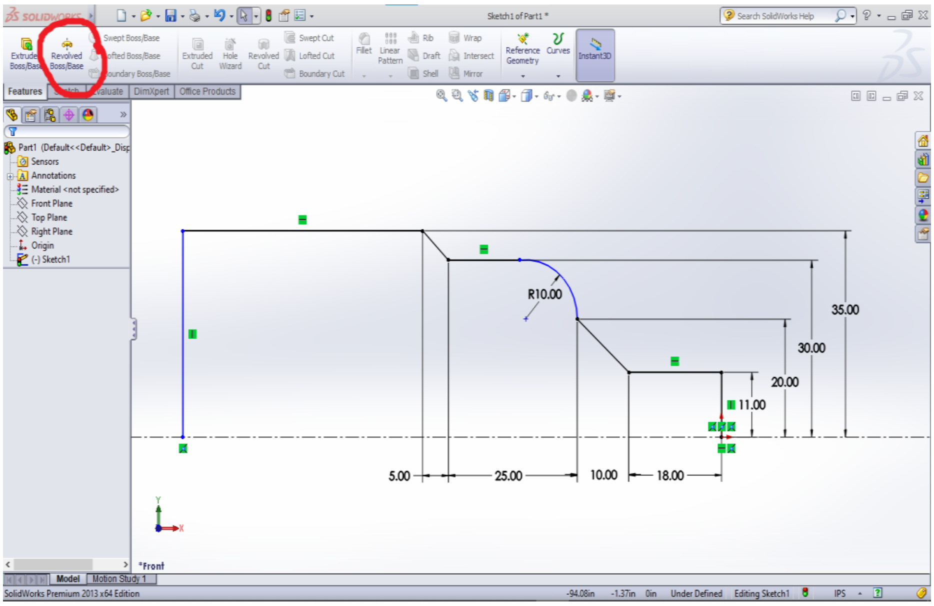


Figure IV.14: Revolved boss of the piece.

- After that we adjust the revolve:

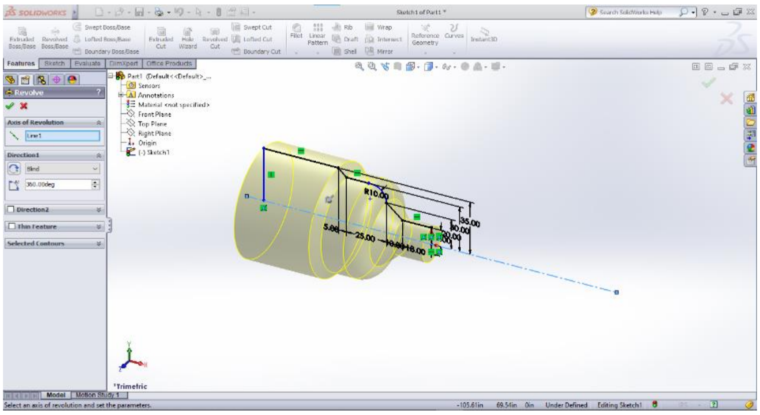


Figure IV.15: Adjust the revolve

- Than we make a chamfer 1*1:

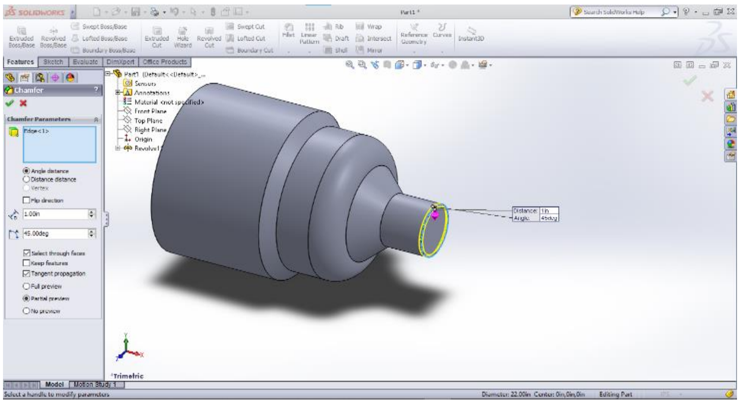


Figure IV.16: Make a chamfer.

- Last thing we choose our material (alloy steel):

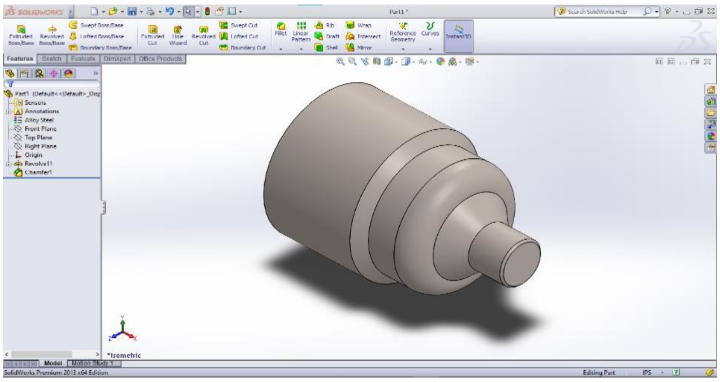


Figure IV. 17: Material (alloy steel) in our piece.

IV.7. Programming the standard code (ISO):

Table IV.5: Explanation of the program.

%500	Indicate a program start or setup code, depending on the specific CNC machine or software being used.
N10 G40 G80 G95	**N10** is a line number **G40:** Cancels cutter radius compensation. **G80:** Cancels motion mode (typically used to cancel canned cycles). **G95:** Sets feed per revolution mode. This means that the machine interprets feed rates as the distance the tool moves per spindle revolution.
N20 G0 G52 X0 Z0	**N20** is another line number **G0**: Rapid move to a specified coordinate. **G52:** Indicates that subsequent coordinates are in the machine coordinate system, rather than the work coordinate system. This is useful for setting temporary shifts or offsets. **X0 Z0**: Moves the tool to the X=0 and Z=0 coordinates. X typically represents horizontal movement, and Z represents vertical movement
N30 T1 D1 M6 N40 G97 S1000 M41 M3 M8 N50 G92 S3000	These three lines collectively prepare the CNC machine for machining operations by ensuring the correct tool is in place, setting the spindle speed, activating necessary functions, and providing flexibility for spindle speed adjustments during the machining process.
N60 G0 X72 Z100 N70 G96 S120 G95 F0.2 N80 G1 X71 Z100 N90 G1 X-2	These lines are commanding the CNC machine to move to specific positions, adjust spindle speed and feed rate, and perform cutting operations.
N100 G0 Z102 N110 G79 N190	The first line (N100 G0 Z102) moves the tool rapidly to a specific Z-coordinate, while the second line (N110 G79 N190) triggers a machine-specific function or operation, possibly referencing another part of the program (line N190). The exact meaning and effect of the G79 command would require consulting the machine's documentation or programming manual
N120 G1 X20 Z100 N130 X22 Z99 N140 Z82 N150 X40 Z72 N160 G2 X60 Z62 R10 N170 Z47 N180 X70 Z42	These lines command the CNC machine to move to specific positions in a machining operation, specifying both horizontal and vertical movements as well as circular interpolation for curved paths.

N190 G96 S120 G95 F0.2 N200 G0 X71 Z101	The first line (N190 G96 S120 G95 F0.2) sets the spindle speed and feed rate for the machining operation, while the second line (N200 G0 X71 Z101) moves the tool rapidly to a specific position. These commands are part of a CNC machining program, guiding the machine on how to execute a particular operation.
N210 G64 N180 N120 I0.2 K0.1 P1	I0.2 K0.1: These are parameters used in cutter compensation mode. I: This parameter specifies the radius offset value for the tool. In this case, it's set to 0.2 units. K: This parameter specifies the distance from the tool tip to the point where the cutter compensation takes effect. It's often referred to as the "wear" or "nose radius" compensation. Here, it's set to 0.1 units. P1: This parameter is used in cutter compensation mode to select the compensation method. P1: This typically indicates that the tool compensates for the cutter radius on the right side of the tool path. Activates cutter radius compensation mode and sets parameters for compensation, including the radius offset value, the nose radius, and the compensation method.
N220 X70 Z42 N230 Z100 N240 X20	These lines of G-code command the CNC machine to move to specific positions in a machining operation, specifying both horizontal and vertical movements.
N250 G80 G0 G52 X0 Z0	This line of G-code cancels any active canned cycle, enables a local coordinate system offset, and moves the machine rapidly to the specified position using the local coordinates X = 0 and Z = 0
N260 T2 D2 M6 N270 G0 X21 Z103 N280 G96 S160 G95 F0.1	These lines of G-code prepare the CNC machine for a machining operation by selecting the appropriate tool, setting tool offsets, performing a tool change, and setting spindle speed and feed rate for the upcoming machining tasks.
N290 G1 G42 X20 Z102 N300 G77 N120 N180	These lines of G-code instruct the CNC machine to move to specific positions while compensating for the tool's radius and cancel any active subprograms or sections of the program associated with line numbers N120 and N180.
N310 G1 X72 Z42	This line of G-code commands the CNC machine to move in a straight line to the specified coordinates, with the horizontal position set to X = 72 and the vertical position set to Z = 42.
N320 G40 G0 G52 X0 Z0 M5 M9 N330 M2	These lines of G-code prepare the CNC machine for the end of the machining process. It cancels any active cutter compensation, moves the machine to the home position, stops the spindle, turns off the coolant system, and marks the end of the program.

- **The final result**

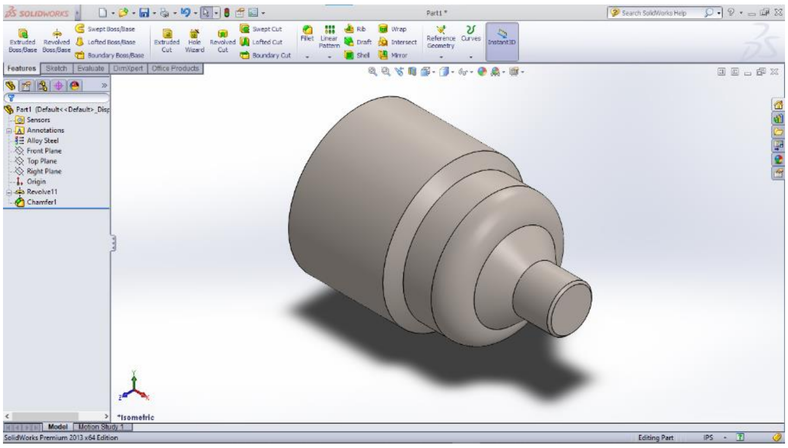


Figure IV.18: The final result of the piece.

IV.8. Conclusion:

In this experiment we saw how easy to make a piece with CNC machine that is EMCO Concept TURN 55 , with a high precision and in record time, using the alloy steel material, passing by several steps like the design by the SolidWorks and the ISO programme, also how we can measure our piece, until we get the final piece.

General conclusion

Thanks to this end of study memorandum for the master, we were able to deepen our study of the field of computer numerical control (CNC) machines and their use in the study and manufacture of a part. We covered a variety of topics, from general knowledge about CNC machines to the structure and composition of CNC machines, as well as manual programming and making a part.

In the first chapter, by analyzing the historical evolution of CNC machines, we then carried out a global study of the different bases of CNC machines and their benefits in the industry. The following chapter gave us a better understanding of the structure and composition of CNC machines. We have studied the various fundamental elements that compose them. This allowed us to know the best choices for creating a piece. Chapter three covered the manual programming methodology. The programming steps required to create a part were studied, as well as the generation of G and M codes. Good programming practices were also studied to ensure accurate results when machining the part. In the last chapter, we used the knowledge we had learned to analyze and create a part with a lathe machine. We started by designing the steps in making the piece, also from examining the machine to researching its parts and materials to understanding its programming.

To summarize, this graduation project allowed us to gain valuable scientific, cognitive and practical experience in the field of CNC machines and Manufacturing the parts.

REFERENCES

Chapter I

[1] Boualem Abderouf, Abed Soufiane “Creation and control of a CNC machine” End of study dissertation, AKLI MOHAND OULHADJ UNIVERSITY – BOUIRA, 2022/2023.

[2] ABDELLIOUA Haitem, ROULA Imad “Design and production of a numerically controlled machine tool” Master's thesis, University of Jijel - Mohammed Seddik Benyahia, 2020/2021.

[3] https://www.atelier-collectif.fr/blog/usinage-multiaxe-diffrence-entre-lusinage-cnc-3-4-et-5-axes

[4] https://www.runsom.com/blog/13-types-of-cnc-machines-and-their-categories/

Chapter II

[5] https://fr.slideshare.net/slideshow/presentation-on-different-types-of-machinespur-gear-making-single-point-cutting-tool/51758013

[6] ABDELLIOUA Haitem, ROULA Imad “Design and production of a numerically controlled machine tool” Master's thesis, University of Jijel - Mohammed Seddik Benyahia, 2020/2021.

[7] Benabderazag khalil, “CONTRIBUTION TO THE REALIZATION OF AN MOCN”. ACADEMIC MASTER, University of M’sila, 2018/2019.

[8] https://blog.technic-achat.com/aide-au-choix-dun-motoreducteur/

[9] https://prototool.com/cnc-machine-tools/

[10] http://toolnotes.com/home/machining/mills-101/cutting-parameters-for-milling/

[11] https://www.igol.com/categorie-catalogue/industrie/decoupe-emboutissage-deformation/

Chapter III

[12] YAN BOUTIN, “INTEGRATION OF ADVANCED MACHINING CYCLES FROM NUMERICALLY CONTROLLED MACHINE TOOLS TO CAM SOFTWARE”. Dissertation Presented at The School of Technology Superior, UNIVERSITY OF QUÉBEC MONTREAL- JANUARY 22, 2002.

[13] LANGAGES ET PROGRAMMATION CNC https://www.ange-softs.com/programme_cnc_usinage.php

[14] Mr.Mesbah and Mr.Zerguine, UNIVERSITY OF Tiaret, General information on CAD/CAM.

[15] https://cncmachinetoolrepair.co.uk/what-is-g-code-programming/

[16] PLANE SELECTION (G17, G18, G19)
https://tormach.com/plane-selection-g17-g18-g19

[17] https://machmotion.com/downloads/GCode/Mach4-G-and-M-Code-Reference-Manual.pdf

[18]http://cnrsm.fr/e_res_echange/04_technologie/02_USINAGE/CNCAmada/salvatore_aries/Progr/G90-91.htm

Chapter IV

[13] https://www.scribd.com/doc/90882124/Emco-Concept-TURN-55-Brochure-EN#:~:text=The%20Concept%20TURN%2055%20is,a%20variety%20of%20turning%20operations.

[14] https://openwa.pressbooks.pub/app/uploads/sites/44/2021/08/FIgure1.6-SolidWorks-user-interface.png