

الجمهورية الجزائرية الديمقراطية الشعبية  
REPUBLIQUE ALGERIENNE DEMOCRATIQUE ET POPULAIRE  
وزارة التعليم العالي والبحث العلمي  
MINISTERE DE L'ENSEIGNEMENT SUPERIEUR  
ET DE LA RECHERCHE SCIENTIFIQUE  
Université SAAD DAHLEB DE BLIDA 1  
جامعة سعد دحلب البليدة ١



FACULTE DE GENIE MECANIQUE

كلية الهندسة الميكانيكية

MEMOIRE :

Présentée en vue de l'obtention du diplôme de  
MASTER EN GENIE MECANIQUE  
ET GENIE DE LA PRODUCTIQUE

Thème

Study and design of 3 axes CNC machine

Option:

Fabrication mécanique et productique

Réalisé Par :

BOUNAB Anis

DEVANT LE JURY

(Promoteur) : Mr.KECHNIT Abd El Hakim MAA ENST

(Co-Promoteur):

Président : Mr.

Examineur : Mr.

2018-2019

## **Acknowledgement**

First of all, we would thank ALLAH ALMIGHTY, who enables us to make this project. Second, we are grateful to our supervisor KECHNIT Abd El Hakim, who allowed us to encroach upon his precious time from the very beginning of this work till the completion. His expert guidance, affectionate encouragement and critical suggestions provided us the necessary insight into the research problem and paved the way for the meaningful ending of this work in short duration. We have no hesitation to say that, without his constant supervision and valuable advices and suggestions from time to time, I could not able to complete the whole work in an efficient manner.

## **Dedication**

This work is dedicated to my beloved parents, brothers, and friends, whose affection, love, encouragement and prays of day and night make me able to get such success and honour, Along with all hard working and respected Teachers.

**Anis**

## The summary

Acknowledgement .....	2
Glossary .....	7
<b>GENERAL INTRODUCTION.....</b>	<b>8</b>
<b>Chapter I: Generality .....</b>	<b>10</b>
<b>I.1 Introduction .....</b>	<b>10</b>
<b>I.2 What does it mean “CNC” and “NC”?.....</b>	<b>10</b>
<b>I.3 The deference between CNC and NC systems.....</b>	<b>10</b>
<b>I.4 The history of developing CNC machines.....</b>	<b>12</b>
<b>I.4.1 First-generation numerical control .....</b>	<b>13</b>
<b>I.4.2 Second-generation numerical control .....</b>	<b>13</b>
<b>I.5 The types of CNC machines .....</b>	<b>13</b>
<b>I.5.1 Mills and Machining Centers.....</b>	<b>14</b>
<b>I.5.2 Lathes and Turning Centers .....</b>	<b>15</b>
<b>I.6 The main applications of CNC machines.....</b>	<b>16</b>
<b>I.7 The advantage and disadvantages of using CNC machines.....</b>	<b>17</b>
<b>I.7.1 The advantages .....</b>	<b>17</b>
<b>I.7.2 The disadvantages .....</b>	<b>17</b>
<b>I.8 Conclusion.....</b>	<b>17</b>
<b>Chapter II: Functional analysis of the CNC machine.....</b>	<b>19</b>
<b>II.1 Introduction.....</b>	<b>19</b>
<b>II.2 Definition of functional analysis.....</b>	<b>19</b>
<b>II.3 Definition of APTE method .....</b>	<b>19</b>
<b>II.3.2 Octopus Diagram.....</b>	<b>21</b>
<b>II.3.3 The octopus diagram of the CNC machine .....</b>	<b>22</b>
<b>II.4 Definition of product design specification (PDS).....</b>	<b>22</b>
<b>II.5 The Definition of the problem .....</b>	<b>23</b>
<b>II.7 The Functional description .....</b>	<b>23</b>
<b>II.7.1 Principal function: .....</b>	<b>23</b>
<b>II.7.2 Constraint function: .....</b>	<b>24</b>
<b>II.7.3 The perimeter: .....</b>	<b>24</b>
<b>II.8 The Tools and Resources.....</b>	<b>24</b>
<b>II.9 The Fabrication time limits.....</b>	<b>24</b>
<b>II.10 The definition of FAST diagram .....</b>	<b>25</b>
<b>II.1.1 The FAST diagram of the CNC machine .....</b>	<b>26</b>
<b>II.12 Conclusion .....</b>	<b>28</b>
<b>Chapter III: Design process of the CNC machine.....</b>	<b>30</b>
<b>III 1. Introduction .....</b>	<b>30</b>
<b>III.2 The study of chosen solutions for the CNC machine .....</b>	<b>30</b>
<b>III.2.1 Stepper motors .....</b>	<b>30</b>

III.2.2	Difference between DC and stepper motors.....	31
III.2.3	Applications of stepper motors .....	31
III.2.4	How stepper motors work? .....	32
III.2.4.1	The rotor .....	32
III.2.4.2	The stator .....	32
III.2.5	Advantages of stepper motors.....	32
III.2.7.1	Trapezoidal screw .....	33
III.2.7.2	Advantages of trapezoidal screw .....	33
III.2.8.1	Ball Bearings and wheels .....	33
III.2.8.2	The advantages of ball bearings .....	34
III.2.9	Wheels (roller) .....	34
III.2.10	Square steel tube .....	34
III.2.10.1	Advantages of Square steel tube.....	35
III.2.11	Arduino board .....	35
III.2.11.1	Features Arduino Interface Board .....	36
III.2.12	Safety measurements .....	36
III.2.12.1	Personal Safety Precautions.....	37
III.2.12.2	Work Area Safety.....	37
III.2.12.3	Cutter Safety.....	38
III.2.13	Power supply.....	38
III.2.14	Driver motors .....	39
III.2.14.1	Basic of stepper motors system .....	39
III.3	The design process of the CNC machine.....	40
III.3.1	Mechanical section .....	40
A)	The frame .....	40
B)	The water table.....	46
C)	The gantry and Y axis .....	46
D)	The X-axis.....	51
F)	The Z-axis .....	54
III.4	Conclusion.....	57
Chapter IV:	Electronics and Control .....	59
IV.1	Introduction: .....	59
IV.2	The electric section .....	59
IV.2.1	Stepper motor .....	59
IV 2.2	Power supply .....	61
IV.2.3	Definition of Arduino UNO .....	64
IV.2.4	Definition of TB6560 stepping motor driver V-2.0 .....	64
IV.2.4.1	Configuration the current of TB6560 stepping motor driver V-2.0.....	65
IV.2.4.2	Configuration of the micro steps of the TB6560 stepping motor driver V-2.0.....	65
IV.2.5	Emergency start and reset buttons .....	66
IV.3	Overview of Grbl Controller .....	66

<b>IV. 4 Overview of Inkscape .....</b>	<b>67</b>
<b>IV. 4.1 Highlights of Inkscape .....</b>	<b>68</b>
<b>IV.5 Using and Running the machine:.....</b>	<b>70</b>
<b>a) With Sketch part .....</b>	<b>70</b>
<b>b) With The G-code of the part .....</b>	<b>72</b>
<b>IV.6 Conclusion .....</b>	<b>74</b>
<b>General Conclusion.....</b>	<b>75</b>
<b>Bibliography .....</b>	<b>76</b>
<b>Annexes.....</b>	<b>77</b>

## List of tables

---

### List of tables

Table 1: The functional description of the CNC machine.....	22
Table 2: Square steel tube specifications.....	39
Table 3: Stepper motors specifications.....	61
Table 4: Running Current.....	65
Table 5: microsteps swtiches configuration.....	65

## List of figures

---

### List of figures

Figure 1: NC Machine using a punched tape.....	10
Figure 2: Modern CNC milling Machine.....	10
Figure 3: Tracer controlled vertical spindle contour milling machine.....	11
Figure 4: 5 axis CNC milling center machine.....	13
Figure 5: CNC lathe center machine.....	14
Figure 6: The horned beast form.....	19
Figure 7: The horned beast of the CNC machine.....	20
Figure 8: The Octopus diagram of the CNC machine.....	21
Figure 9: AND, OR decomposing in FAST diagram.....	24
Figure 10: FAST diagram of the cnc machine. ....	25&26
Figure 11: components of stepper motor. ....	29
Figure 12:Trapezoidal thread specifications.....	32
Figure 13: Ball bearing composition.....	33
Figure 14: square hollow steel.....	34
Figure 15: Arduino UNO.....	36
Figure 16: Personal safety notice.....	37
Figure 17:Cutter safety notices.....	38
Figure 18:AC\DC adapter.....	38
Figure 19: Stepper motor based system.....	39
Figure 20: simulation steps.....	41
Figure 21: E295 characteristics.....	41
Figure 22: the frame fixture.....	42
Figure 23: Applying forces on the frame.....	42
Figure 24: Mesh settings for the frame.....	43
Figure 25: Mesh of the frame.....	43
Figure 26: Mesh of the frame (gussets) .....	43
Figure 27: Von mises stress result.....	44
Figure 28: Equivalent strain result.....	44
Figure 29: Equivalent displacement result.....	45
Figure 30: The frame.....	45
Figure 31: The foot pad machine.....	45
Figure 32: The water table for plasma.....	46
Figure 33: The water table with MDF plate.....	46
Figure 34: Gantry strain result .....	47
Figure 35: Gantry displacement result .....	47
Figure 36: Gantry stress result .....	48
Figure 37: comparison of static backlashes between trapezoidale belt and GT belt.....	50
Figure 38: Omega timing belt/pulley system.....	51
Figure 39: X axis strain result .....	52
Figure 40: X axis displacement result .....	52
Figure 41: X axis stress result .....	53
Figure 42: The CNC machine after the final assembly.....	54
Figure 43 unipolar stepper basics.....	60
Figure 44: Bipolar stepper motor basics.....	60
Figure 45: Arduino UNO.....	64
Figure 46: The driver card TB6560 -V2.....	65



**List of figures**

---

Figure 27: emergency button.....66  
Figure 48 :START and STOP buttons.....66  
Figure 49: Interface of Grbl controller.....67  
Figure 50:Interface Inkscape.....68  
Figure 31: (G - Code) Transferring Cycle.....69  
Figure52: Drawing sketch.....70  
Figure 53: Sketch selection.....71  
Figure 54:Extension activation.....71  
Figure 55: Interface of Grbl.....72

## **Glossary**

AFNOR	Association Française de Normalisation
APTE	Application aux Techniques d'Entreprise in French
CAM	Computer-Assisted Manufacturing
CNC	Computer Numerical Control
CR	Constraint Requirements CR
DOF	Degree Of Freedom
EN	European Norms
FAST	Functional Analysis System Technique
FEM	Finite Element Method
FR	Functional Requirements FR
GT	Gates Tooth
NC	Numerical Control
NF	Norme Française
PDS	Product Design Specification
SADT	Structural Analysis Design Technique

### **GENERAL INTRODUCTION**

The history of industrial automation is characterized by periods of rapid change in popular methods; these periods seem closely to world economics. The use of the industrial machines specially computerized numerical control machines or simply CNC machines, which became identifiable as a unique device in the 1960s, along with computer aided design (CAD) , and computer aided manufacturing (CAM) systems, characterizes the latest trends in the automation of manufacturing process .these technologies are leading industrial automation through another transition.

Our work in this project is to study and design a prototype of a budget 3 axis CNC machine that can be used as an automatic milling machine for wood, plastic and aluminium, it also run as oxycutter, plasma cutter. We organized this project in four chapters. In the first one we covered general informations about some basics of the CNC machines and its evolution. The second is introducing functional analysis of the machine, which it explain the creation process of a product (CNC machine) starting from a simple ideas and needs and finishing with a technological solutions that can satisfied a need .The third chapter is about the design process from sketching, dimensioning and simulating using different softwares. The last chapter is talking about the electronics and wirings of the CNC machine with a simple guide for how we can run and control the machine.

# **CHAPTER I: GENERALITY**

### Chapter I: Generality

#### I.1 Introduction

Early machine tools were designed so that the operator stood in front of the machine while operating the controls. This design is no longer necessary, because in CNC machines the operator no longer controls the machine tool movements. On conventional machine tools, only about 20 percent of the time is spent removing material. With the addition of electronic controls, machining metal time has increased to 80 percent and even higher, so CNC is being used on all types of machine tools.

#### Objectives:

You will see in this chapter:

- ✓ What does it mean “CNC” and “NC” systems?
- ✓ The difference between CNC and NC systems.
- ✓ The history of developing CNC machines.
- ✓ The types of CNC machines.
- ✓ The main applications of CNC machines.
- ✓ The advantages and disadvantages of using CNC machines.

#### I.2 What does it mean “CNC” and “NC”?

Many descriptions have been used during the years, to define what Numerical Control (NC) is. The majority of all the known definitions can be summed up into a simple statement: **<<Numerical Control can be defined as an operation of machine tools by the means of specifically coded instructions to the machine control system>>**. The instructions are combinations of the letters, digits and selected symbols. All instructions are written in a logical order and a predetermined form. There is difference in the meaning of the abbreviations NC and CNC. <sup>[1]</sup>

#### I.3 The difference between CNC and NC systems

Both systems perform the same tasks, namely manipulation of data for the purpose of machining a part. In both cases, the internal design of the control system contains the logical instructions that process the data. At this point the similarity ends.

The NC system showed in figure 1 uses a fixed logical function, those are built-in and permanently wired within the control unit. These functions cannot be changed by the programmer or the machine operator. Because of the fixed wiring of the control logic, the NC control system is synonymous with the term '**hardwired**'. The system can interpret a part program, but it does not allow any changes to the program, all required changes must be made away from the control. Also, the NC system requires the use of punched tapes for input of the program information. <sup>[1]</sup>

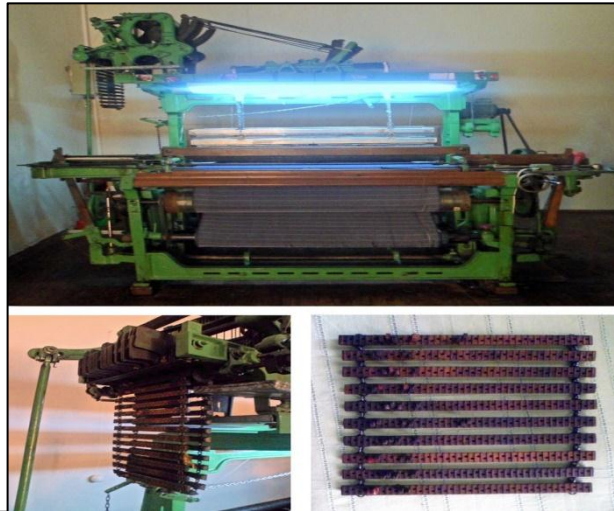


Figure 4: NC Machine using a punched tape

The modern CNC system showed in figure 2 uses an internal microprocessor. This computer contains memory registers storing a variety of routines. That means the part programmer or the machine operator can change the program on the control itself, with instantaneous results. This flexibility is the greatest advantage of the CNC systems and the key element that lead to such a wide use of that technology in modern manufacturing. The CNC programs and the logical functions are stored on special computer chips, as software instructions rather than used by the hardware connections (wires), in contrast to the NC system, the CNC system is synonymous with the term '**softwired**'. <sup>[1]</sup>



Figure 2: Modern CNC milling Machine

### Note

When describing a particular subject that relates to the numerical control technology, keep in mind that NC can also mean CNC in everyday talk, but CNC can never refer to the older.

### I.4 The history of developing CNC machines

Machines are being used due to large variety of components and discontinuous demand of products. In the conventional general purpose machines, the skilled operator is responsible for many inputs to the machine. In addition to physical work of handling the machine, he has to do a lot of information processing like reading the drawing and checking dimensions. As the degree of complexity of the component increases, tolerances become closer, and all the process is operator dependent, the mistakes on the part due to inattention and tiredness, result in production of defective components. <sup>[1]</sup>

To overcome these problems, several improvements have been made in the conventional machines by reducing the manual control elements. For small batch production, copying machines have been used (Figure3). In the copying machines, also called tracer controlled machines. A tracer scans the model and the motion of the tracer is transmitted to the cutting tool by means of servomechanism. The main disadvantage of the copying method is the time spent on producing.

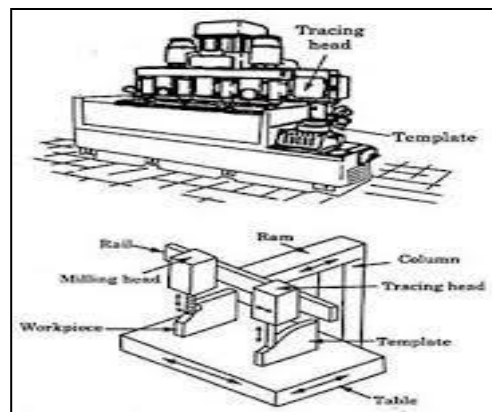


Figure 3: Tracer controlled vertical spindle contour milling machine

A more flexible system, widely used, is the automatic lathe machine. The set-up of the required dimensions of the parts is established by pairs of micro switches and stoppers. This sequence controlled machine is quite flexible but the main disadvantage is that the setting of the limit switches and stoppers for adopting the machine to produce a new product requires many working hours and highly skilled and experienced operator. Also, since the number of limit switches and stoppers is limited, the maximum number of programmed operations on a part is

also limited. These problems of automation of medium and small volume production have been overcome by numerically controlled machine tools. <sup>[1]</sup>

Numerical Control technology as it is known today emerged in the mid-20th century. Numerical control of machine tools is reported to have been first developed between 1947 and 1952 at the Massachusetts Institute of Technology, in conjunction with the Parsons Aircraft Corporation. In 1952, the U.S. Air Force, and the names of John Parsons and the Massachusetts Institute of Technology in Cambridge, MA, USA adopted these technology for military helicopter part's manufacturing. But it was not applied in production manufacturing until the early 1960's.

In the manufacturing field, and particularly in the area of metal working, Numerical Control technology has caused something of a revolution, the machine tools equipped with Numerical Control system found their special place in the machine shops. The development of CNC machines can be divided into two generations:

### **I.4.1 First-generation numerical control**

The first machines, which are frequently referred to the first generation, had been designed for manual or fixed cycle operation. These machines had NC systems added, but only for positioning the work relative to the tool. The time was considerably saved, but the operator had to select the tools, speeds and feeds. These machines were few are still in general use. They are frequently referred to as NC machines. They were also termed tape-controlled machines, because the information was stored on either punched tape or magnetic tape <sup>[2]</sup>.

### **I.4.2 Second-generation numerical control**

In the second-generation machines, a number of special mechanical design features were developed, such as recirculating ball screws and hydrodynamic slide way bearings. The use of these items enabled the machine tools to be more reliable and to have a longer useful life. With the second generation machines the information to control each operation is an input to the machine. It is not possible to edit the information at the machine; any change in the program can only be carried out at the place where the program was originated because the original second-generation machines had a very limited memory capacity.

## **I.5 The types of CNC machines**

Deferent kinds of CNC machines cover an extremely large variety. Their numbers are rapidly increased. It is impossible to identify all the applications; they would make a long list. Here are two groups of CNC machines that are largely used in metal working:



### I.5.1 Mills and Machining Centers

Standard number of axes on a milling machine is three. The X, Y and Z axes. The part set on a milling system is always stationary, mounted on a moving machine table. The cutting tool rotates, it can move up and down, but it does not physically follow the tool path. CNC mills are usually small, simple machines, without a tool or other automatic features. Their power rating is often quite low. In industry, they are used for tool room work, maintenance purposes, or small part production. They are usually designed for contouring. <sup>[1]</sup>

CNC machining centers showed in figure3 are far more popular and efficient than drills and mills, mainly for their flexibility. Then main benefit the user gets out of a CNC machining center is the ability to group several operations into a single setup. For example, drilling, boring, tapping, and contour milling can be incorporated into a single CNC program. In addition, the flexibility is enhanced by automatic tool changing and a number of other features.

CNC machining centers can be equipped with special software that controls the speeds and feeds, the life of the cutting tool, automatic in-process gauging and offset adjustment and other production enhancing and time saving devices.

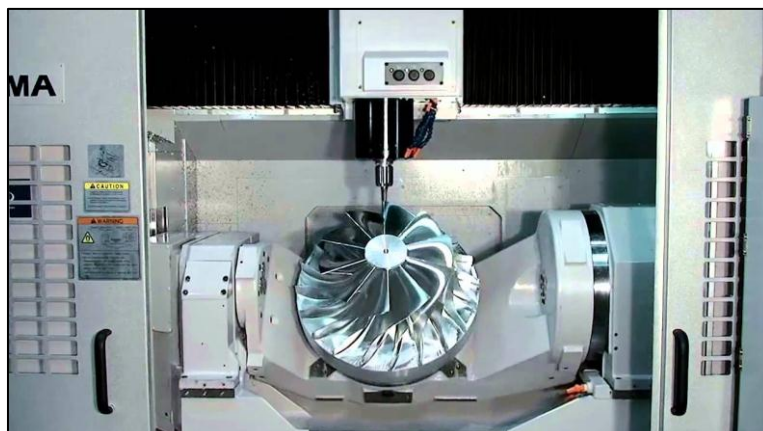


Figure 4: 5 axis CNC milling center machine

There are two basic designs of a typical CNC machining center. They are the vertical and the horizontal machining centers. The major difference between the two types is the nature of work that can be done on them efficiently. For a vertical CNC machining center, the most suitable type of work is flat parts, either mounted to the fixture on the table, or held in a vise or a chuck. The work that requires machining on two or more faces in a single setup is more desirable to be done on a CNC horizontal machining center. <sup>[1]</sup>

All machine tools from a simple milling machine up to a five axis profiler can be included in this category. They vary in size, features, Suitability for certain work. Etc... But

they do all have one common denominator - their primary axes are the X and Y axes - and for this reason, they are called the **XY machines**. In the category of the XY machines are also wire EDM machine tools, laser and water jet cutting machines, flame cutters, burners, routers, etc. Although they do not qualify as milling type machine tools. [2]

### I.5.2 Lathes and Turning Centers

A CNC lathe is usually a machine tool with two axes, the vertical X axis and the horizontal Z axis. The main feature of a lathe that distinguishes it from a mill is that the part is rotating about the machine center line. In addition, the cutting tool is normally stationary, mounted in a sliding turret. The cutting tool follows the contour of the programmed tool path. A lathe is used for machining cylindrical or conical work. Such as shafts, rings, wheels, bores, threads, etc. A lathe can also be used for internal operations such as boring as well as for grooving, threading, etc... [1]

Typical lathe work controlled by a CNC system uses machines known in industry as the CNC Turning Centers showed in figure5. CNC lathes are designed to hold several tools in special turrets. They can have a milling attachment, Index able chuck, a sub spindle, a tailstock, a steady rest and many other features not always associated with a conventional lathe design. Constant advances in machine tool technologies.

More CNC lathes appear on the markets that are designed to do a number of operations in a single setup. Basically, CNC lathes can be categorized by the type of design and by the number of axes. The two basic types are the vertical CNC lathe and the horizontal CNC lathe. Of the two, the horizontal type is by far the most common in manufacturing and machine shops. A vertical CNC lathe is somewhat less common but is irreplaceable for a large diameter work. For a CNC programmer, there are no significant differences in the programming approach between the two lathe types. [2]



Figure 5: CNC lathe center machine

The most common distinction of different CNC lathes is by the number of programmable axes. Vertical CNC lathes have two axes in almost all designs available. The much more common CNC horizontal lathes commonly designed with two programmable axes are also available with three, four or six axes for adding extra flexibility to manufacturing of more complex parts <sup>[2]</sup>.

### **I.6 The main applications of CNC machines**

The decision for using a numerically controlled machine should be for a particular application is mainly dependent on the cost and complexity of manufacture.

- A CNC machine is very expensive, but the preproduction time and set-up time can be quite low.
- The absence of skilled personnel with specialized skills needed for setting and operating manually controlled or fixed cycle machine tools, so using CNC machines with higher machine costs rather than machines with higher labour costs.
- The mass production of large quantities of components which have fairly generous machining tolerances is more economic on transfer machines than CNC machines. However, because of the accuracy obtainable with numerical control, it has been found that CNC machines can be economic to produce large quantities of components which have high quality standards such as pistons or work of up to 15 mm diameter.
- Numerical control is particularly suited for the manufacture of very small numbers of components needing a wide range of work, such as those with complex profiles or a large number of holes. It is possible that numerical control could be economic for only one component if a large number of tool or work positional changes were involved, particularly for components with close dimensional tolerances.
- CNC machines can be used very effectively for machining the cams required for the cam controlled automatics.
- The introduction of mill-turning centers which are capable of operations where there is a small amount of material removal such as the milling of flats or splines and cross drilling of components on the same machine and set up as turning has further extended the applications of CNC machines.

### **I.7 The advantage and disadvantages of using CNC machines**

#### **I.7.1 The advantages**

There are a number of reasons for the suitability of numerical control, such as:

- Faster production rates; less time spent on the positioning of tools or work.
- The CNC has high machining metal time (up to 80 percent and even higher).
- Improved cutting efficiency because speeds and feeds are controlled.
- Improved quality of work. Components are more consistently accurate, resulting in less scrap
- Less inspection, because of improved quality. It is necessary that the first component produced from a new program is checked very carefully. Once the accuracy of the component has been confirmed, it is unlikely that other components will be faulty.

#### **I.7.2 The disadvantages**

- CNC machines are more expensive than conventional machines and it is expensive to repair.
- CNC machines don't eliminate the need for expensive tools parts.
- CNC machine operator needs only basic training and skills, enough to supervise several machines. In years gone, engineers needed years of training to operate center lathes, milling machines. This means many of the old skills are been lost.
- Fewer workers are required to operate CNC machines compared to manually operated machines as a result investment in CNC machines can lead to unemployment.
- CNC machines do not totally eliminate errors. Operators can still push the wrong buttons, make incorrect alignments and fail to locate parts properly on a jig.

### **I.8 Conclusion**

The appearance of the CNC systems had changed the world of machinery, the CNC machines are now more efficient powerful, polyvalent, precise and more advantages of this machines, that's why they are more used in world production system even with its disadvantages.

**CHAPTER II:  
FUNCTIONAL  
ANALYSIS OF THE  
CNC MACHINE**

### Chapter II: Functional analysis of the CNC machine

#### II.1 Introduction

Functionality is one of the most significant hallmarks of a product. The functionality of a product can be considered as the fundamental justification for a product existence. A functional analysis which covers more than 75% of design activity for a new product and has a direct influence on design optimization, including a complete and reliable descriptor to improve product development process in various fields.

#### Objectives

You will see in this chapter:

- ✓ Definition of functional analysis.
- ✓ Definition and using the APTE method for functional analysis of the CNC machine.
- ✓ The product design specification of the CNC machine.
- ✓ Definition and creating the FAST diagram of the CNC machine.

#### II.2 Definition of functional analysis

Functional analysis is a tool to enhance creativity and innovation in design which help the designer from the very early stage of design, it's a structured approach for describing how a system might be used, it defines a functional architecture for which system products and services can be designed and Performed to a depth needed, it also Identifies and arranges lower-level functions needed to accomplish parent requirements. There are three main methods of functional analysis including APTE, FAST and IDEF0 (SADT).<sup>[5]</sup>

#### II.3 Definition of APTE method

APTE is one of the most used tools in functional analysis .it means (Application aux Techniques d'Enterprise in French: or (APplication to business TEchniques). APTE has been created by Gilbert Barbey in 1964 and it focused on the functional analysis at the early stages of design. Currently, this method is deposited by APTE Company and represents a functional analysis method and registered under NF X50150 standards to drive innovations and projects optimization. APTE is applied for various applications including product design, manufacturing process, as well as organizations<sup>[5]</sup>.

The ultimate goal of APTE is achieving to two objectives:

- To increase the product quality toward meeting the user requirements
- To reduce the cost of production.

APTE consists of six different algorithms to analysis different aspects of a product in this chapter we focused and used two from six algorithms.

### II.3.1 Horned Beast “La Bête à Cornes”

It is a diagram (see Figure 6) which is used for defining the requirements and needs of a product. To draw a horned beast, we should answer the following questions:

- ✓ Whom is the product useful for?
- ✓ What does it have an effect on?
- ✓ What is the goal?

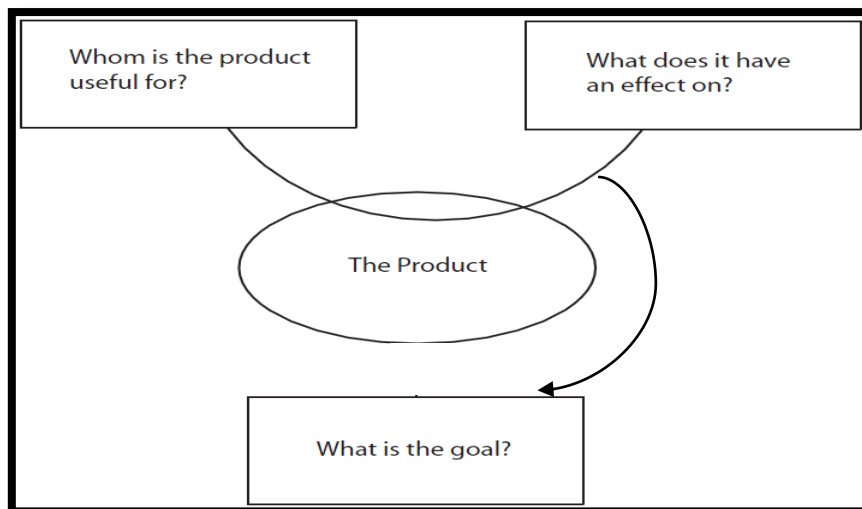


Figure 6: The horned beast form

Let's answer the questions to get the Horned Beast of our CNC machine

- ✓ Whom is the product useful for?

**The product is useful for the user**

- ✓ What does it have an effect on?

**The product has an effect on the part**

- ✓ What is the goal?

**To permit to the user to machine the part automatically**

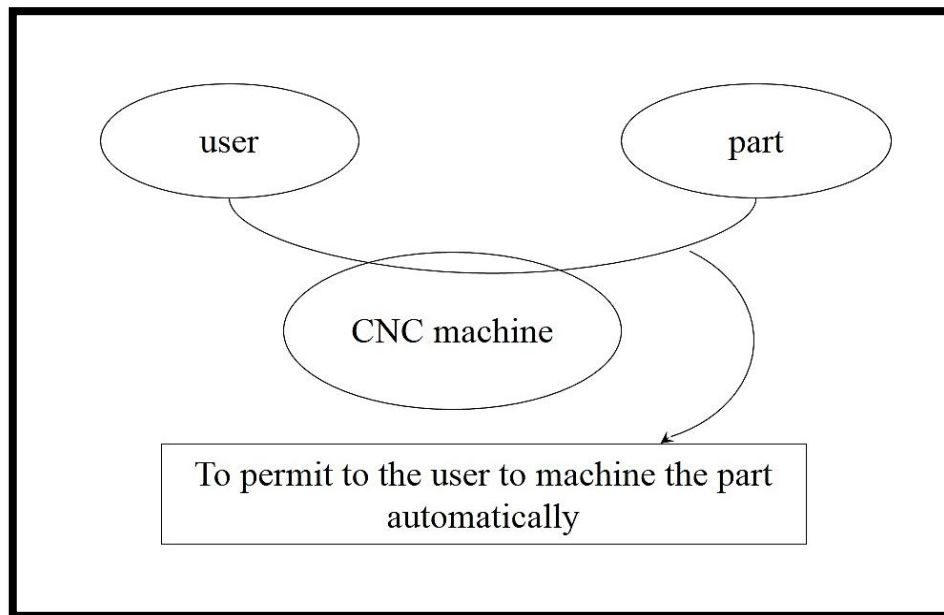


Figure 7: The horned beast of the CNC machine

After answering the questions and drawing the Horned Beast diagram (see Figure7) we can announce the requirement or the need with simple sentence

**“The CNC machine is useful for the user effecting on the part to permit to the user to machining the part automatically”**

### II.3.2 Octopus Diagram

Octopus diagram (diagramme de pieuvre in French) is applied after analysing of the costumer need where functional analysis determines the functional requirements. The first step is to investigate on the connections between the product and the external environment. According to these connections are divided into two lists <sup>[5]</sup>.

#### **Constraint Requirements (CR) (Fonction Contrainte FC):**

Refers to presents adoption or action of the product, in means of either the product has to be adopted with an element or it acts on an element.

#### **Functional Requirements (FR) (Fonction Principale FP):**

Interaction of the product with surroundings elements.



### II.3.3 The octopus diagram of the CNC machine

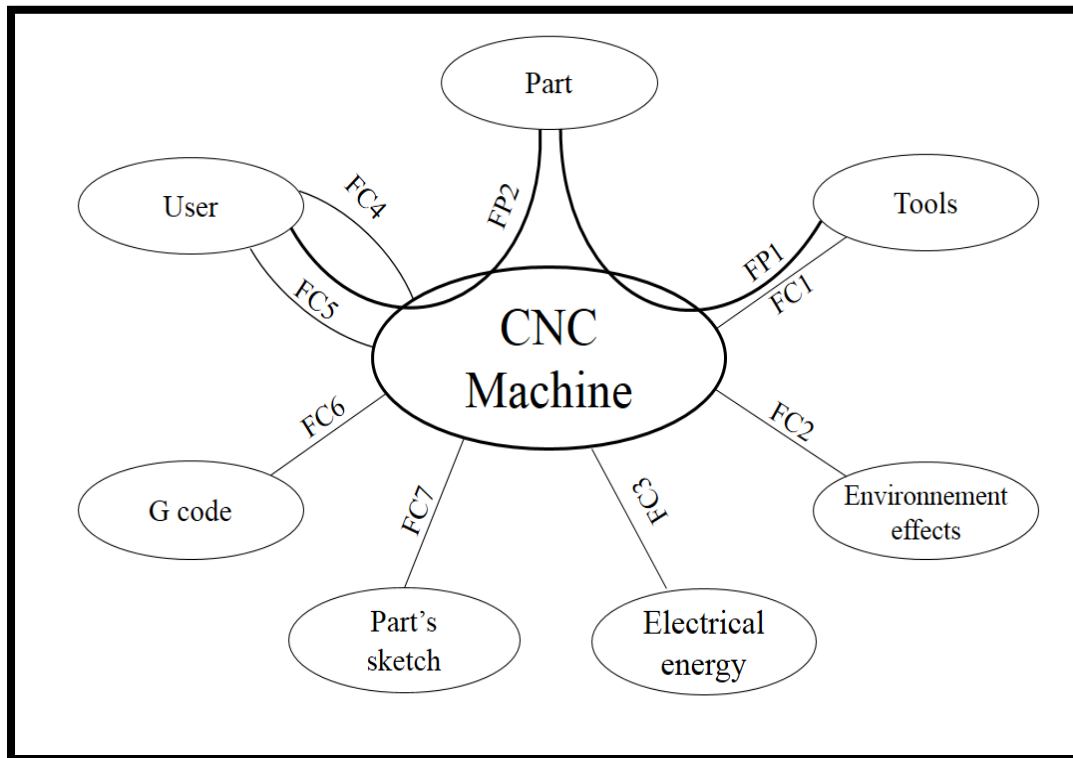


Figure 8: The Octopus diagram of the CNC machine

After defining the functions of the CNC machine with this diagram, we can now announce them:

- FP1:** to machine automatically the part using the tools.
- FP2:** to adjust the part and the machine.
- FC1:** to adapt with the machine chuck.
- FC2:** to support the environment effects (heat, dust, humidity...).
- FC3:** to supply with an electrical source.
- FC4:** to facilitate the control of the machine.
- FC5:** to respect the industrial safety measurements.
- FC6:** to use the g code file for machining the part.
- FC7:** to use the part's sketch file for machining the part.

### II.4 Definition of product design specification (PDS)

The product design specification (PDS) is a document created during the problem definition activity very early in the design process. It details the requirements that must be met in order for the product or process to be successful. Design Specifications describe how a system performs the requirements outlined in the Functional analysis. Depending on the system, this can include instructions on testing specific requirements, configuration settings,

or review of functions or code. A design specification is a detailed document providing information about the characteristics of a project.

A typical PDS includes the following information:

### II.5 The Definition of the problem

In a small workshop located in wilaya of BLIDA, this workshop is specialized in repairing Trucks and heavy vehicles. Laborers are busy to do different tasks. The most tiredness one is cutting sheet metals and parts. They work with traditional materials (hand grinder as an example) which take serious time and makes them tired out with low quality of part's surface.

### II.6 The Objective

We want to create and build a prototype of a machine that able to cut automatically the parts and sheet metal with dimensions of 0.8x0.8m. The machine will be controlled numerically equipped with software, the user will adjust the part on the machine and he will upload the part's sketch or G code program (coded instructions file) and send it with any computer to the machine. The machine uses the part's sketch or G code program to cut the parts with better quality.

### II.7 The Functional description

functions	Appreciation criteria	Levels	Flexibility
FP1	Part's thickness	Wood,plastic,glass ≤50mm Metal ≤20mm	F0 F0
FP2	Part's size	Width <800 mm Length <800mm	F1
FC1	Tool's size	Length <300mm Diameter<300mm	F1 F1
FC2	Environment's Temperature	0°C<T°<60°C	F1
FC3	Alimentation settings	Amperage ≥10 A Voltage 220v	F0
FC4	The time to prepare the machine	T<20mn	F3
FC5	Safety measurements	Safety measurements	F0
FC6	File size	S<100MB	F1
FC7	File size	S<100MB	F1

Table 3. The functional description of the CNC machine

#### II.7.1 Principal Function:

**FP1:** to machine automatically the part using the tools.

**FP2:** to adjust the part and the machine.

### II.7.2 Constraint functions:

**FC1:** to adapt with the machine chuck.

**FC2:** to support the environment effects (heat, dust, humidity...).

**FC3:** to supply with an electrical source.

**FC4:** to facilitate the control of the machine.

**FC5:** to respect the industrial safety measurements.

**FC6:** to use the g code file for machining the part.

**FC7:** to use the part's sketch file for machining the part.

### II.7.3 The perimeter:

This machine during its work will have a direct relation with

- The mechanical and electronic engineer;
- The operator of the machine;
- The maintenance and repair technician;

## II.8 The Tools and Resources

To build the CNC machine we should have some resources, our resources are the followings

- an amount of sheet metals and a stock of metal scrap;
- a welding machines;
- a conventional (lathe and drill) machines;
- Machines and tools for cutting sheet metal and tubes.
- Bearings and lead screw.
- Rectangle tubes.
- Bolts and screws.
- Electronics circuits and wirings.
- Electric motors.

## II.9 The Fabrication time limits

The time to achieve the project with all steps (study, design and build) should not pass 3 months.

**II.10 The definition of FAST diagram**

The Functional Analysis Systems Technique (FAST) was introduced by the way an engineer at Sperry Univac (Unisys) in 1960. FAST diagram constitutes an essential data set enabling to have a good knowledge of a complex product. The Association of French Normalization (AFNOR) in NF EN 12973 describes the FAST diagram as one of usual methods of functional analysis. FAST methodology is based on decomposition of each basic function of a product and their classification using a logic diagram. The logic diagram helps to find and approves alternatives for inventive new model to complete the function. This means the functions of a design are decomposed into technical functions in order to end up with technological solutions.<sup>[11]</sup>

The FAST method leans on an interrogative technique with asking three questions. The following questions complete the diagram:

- 1) HOW is (function) to be accomplished? By
- 2) WHY is it necessary to (function)? So you can
- 3) WHEN (function) occurs, what else happens?

The answers to each mentioned question are neither exclusive nor unique. They can be singular, multiple (using AND connection) or optional (using OR connection). The Functions in FAST are required to be described with a verb at the infinitive form. In order to enable an easy comprehension.

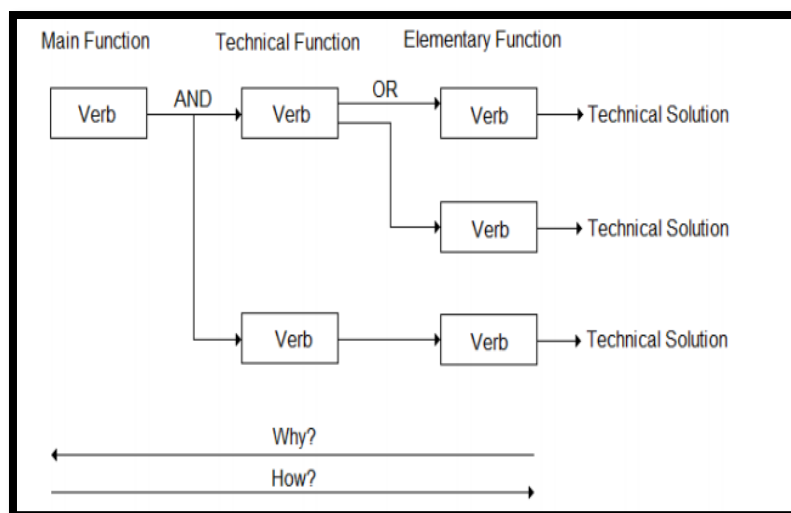
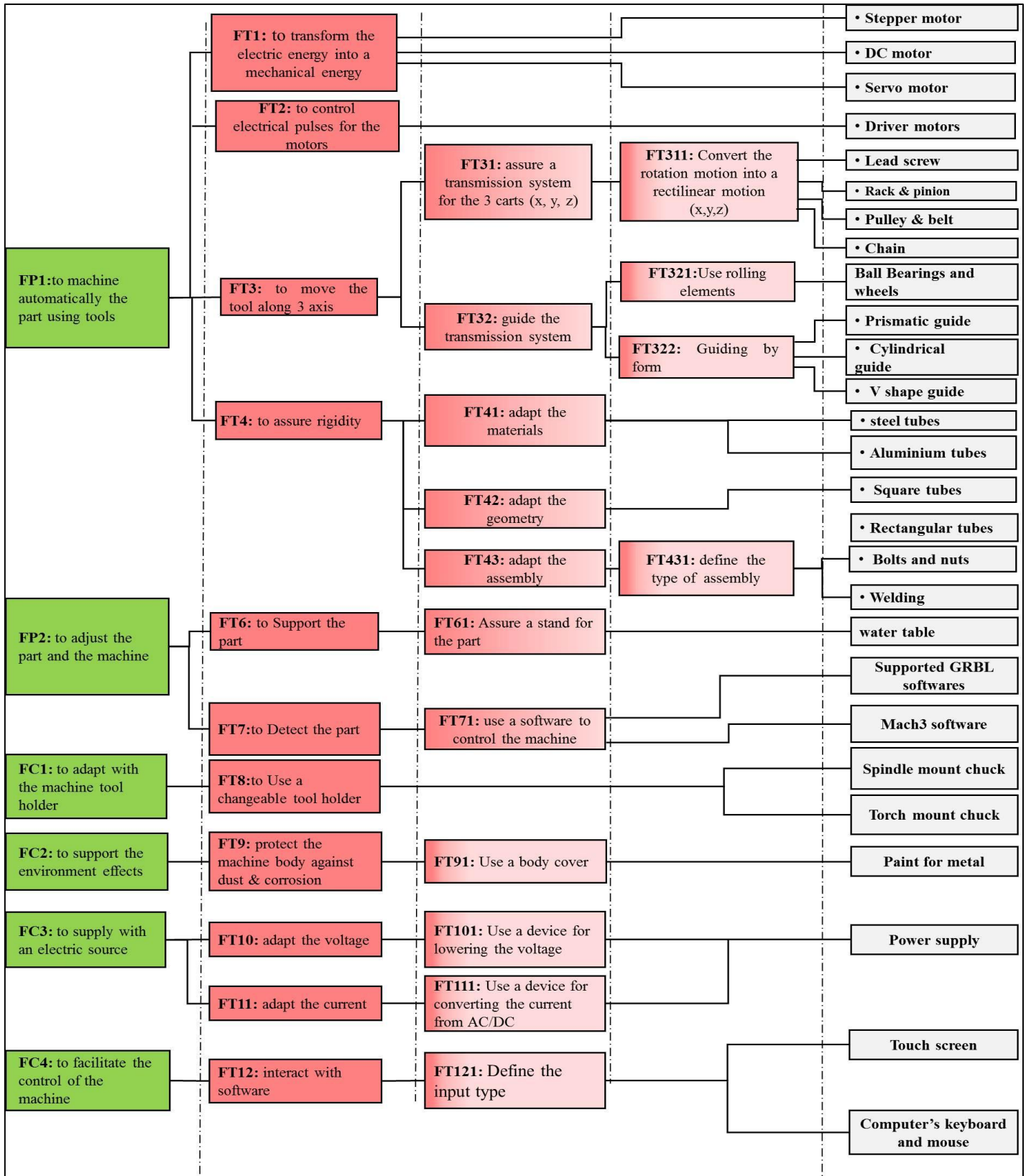


Figure 9: AND, OR decomposing in FAST diagram

II.1.1 The FAST diagram of the CNC machine

After following all the steps, we get the FAST diagram of the CNC machine



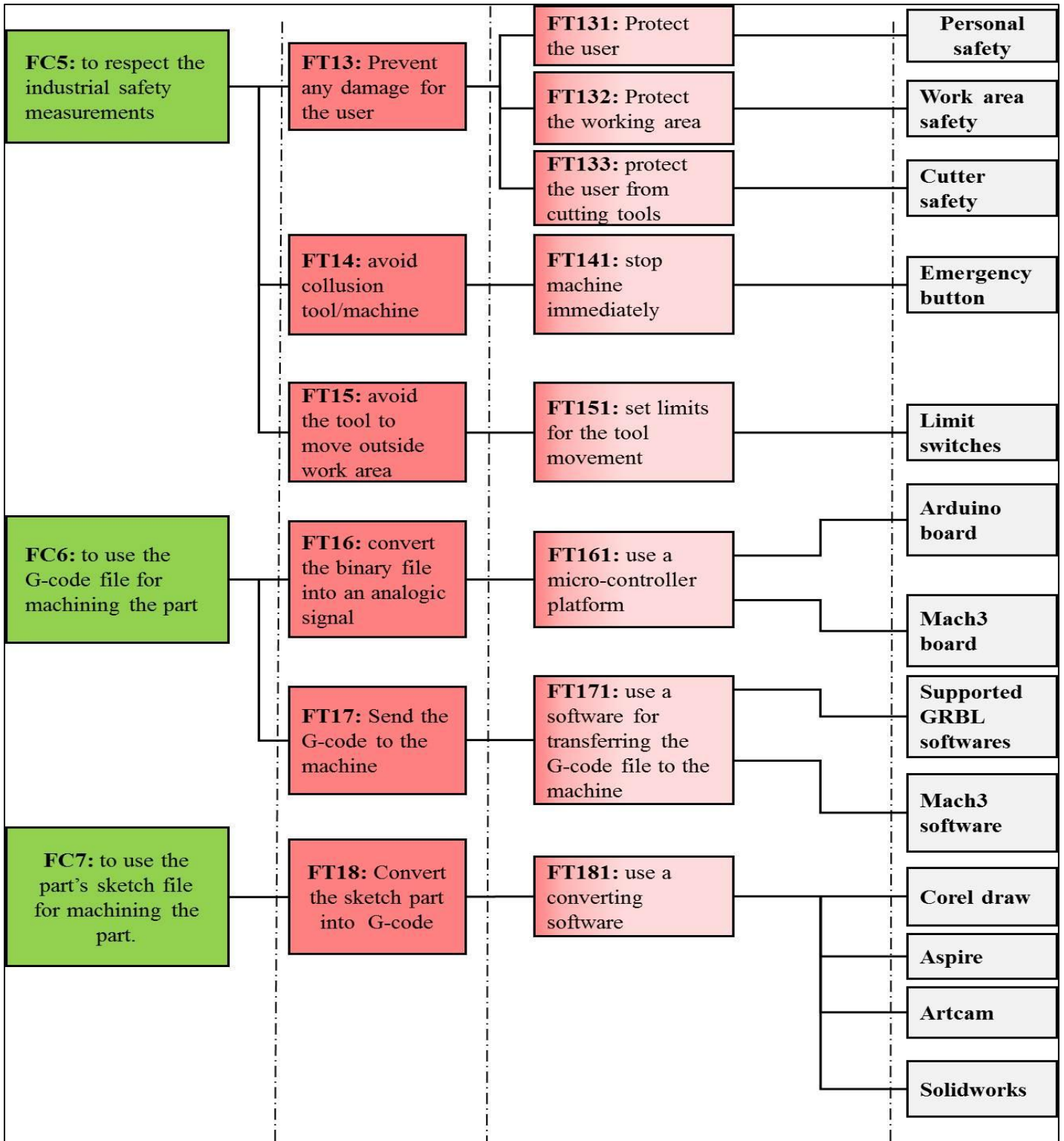


Figure 10: FAST diagram of the cnc machine.

### II.12 Conclusion

The functional analysis is an important step in every project creation, it can light up the functionality of the product and it's relation with surrounding elements, there is many tools and methods we can used in functional analysis, we used from them the APTE method. After that we can transform the functions of a product into a technological solution by following a logic decomposition which is the FAST diagram.

**CHAPTER III**  
**DESIGN PROCESS**  
**OF THE CNC**  
**MACHINE**



### Chapter III: Design process of the CNC machine

#### III 1. Introduction

Product design is the process of taking a client's requirements for a new building or changes to an existing product and translating them into an agreed design that a fabricator is then able to make. As the standard of regulations has increased, manufacturing components have become more complex, and the technical requirements of clients have become more demanding, so the design process has become more challenging.

#### Objectives

You will see in this chapter:

- ✓ The study of chosen solutions for the CNC machine.
- ✓ The design and the fabrication process of the CNC machine.

#### III.2 The study of chosen solutions for the CNC machine

After defining the service functions by using the APTE method and founding the technological solutions using the FAST diagram. We notice that there are multiple solutions. Due to too many reasons (cost of production, availability of the materials, performance, time of production) we can't take all the technological solutions, so we decided to choose the appropriate solutions for each service functions. Our most chosen solutions are the followings:

##### III.2.1 Stepper motors

A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The motor's rotation has several direct relationships to these applied input pulses. The speed of the motor shaft's rotation is directly related to the frequency of the input.

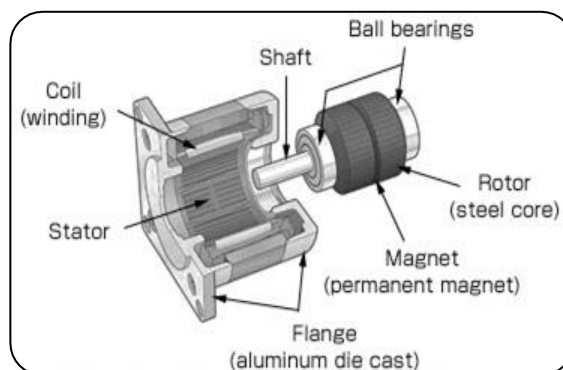


Figure 11: components of stepper motor

### III.2.2 Difference between DC and stepper motors

- They have no brushes or commutator (the parts of a DC motor that reverse the electrical current and keep the rotor the constantly turning in the same direction).
- The major difference is in what rotates. A basic DC motor, there is an outer permanent magnet or magnets that stays static, known as the stator, and an inner coil or coils of wire that rotates inside it, which is the rotor. In a brushless hub-motor, the coils of wire are static in the center and the permanent magnets spin around them on the outside.
- A stepper motor showed in figure7 is different again. This time, the permanent magnets are on the inside and rotate (making up the rotor), while the coils are on the outside and stay static (making up the stator).
- The big difference between an ordinary DC motor and a stepper motor is in the design of the stator and the rotor.
- There is one large magnet on the outside (the stator) and one large coil rotating inside it (the rotor) on DC motor, a stepper motor has an inner magnet effectively divided up into many separate sections, which look like teeth on a gear wheel. The outer coils have corresponding teeth that provide magnetic impulses, attracting, repelling, and making the teeth of the inner wheel rotate by small steps.
- The stepper motor can stay still, in a certain position, once it's rotated through a particular angle. That's important if you want a motor to power something like a robot arm, which might have to rotate a certain amount and then remain in precisely that spot while another part of the robot does something else. This feature is sometimes called holding torque simply means a stepping motor's ability to stay still.

### III.2.3 Applications of stepper motors

The Stepper motor is manufactured in various sizes ranging from mill watts to hundreds of watts. Its maximum torque value ranges up to 15 Newton Meter and the step angle ranges from 1.8 to 90 degrees. Some of the applications are given below:

- As the stepper motor are digitally controlled using an input pulse.
- They are used in numeric control of machine tools.
- Used in tape drives, floppy disc drives printers and electric watches.
- It has wide application in textile industries and integrated circuit fabrications.
- These motors also find a variety of commercial, medical and military applications and used in the production of science-fiction movies.

### III.2.4 How stepper motors work?

#### III.2.4.1 The rotor

The rotor itself is made from two discs, a little like gears, one of which is a magnetic north pole (red) and the other is a south pole (blue). When we put the two discs back to back, we get north and South Pole teeth alternating around the edge

#### III.2.4.2 The stator

Around the edge of the rotor, we have the stator example, four electromagnets that can be switched on and off individually. Generally, the electromagnets in a stepper motor work in pairs, with each opposing pair of magnets switching on together to make a north pole at the same time, followed by the magnets at right angles, which also work together. Exactly what switches on when depends on how many rotor teeth (steps) there are and how many electromagnet coils surround them: the geometry and alignment of a stepper motor has to be just right to make the rotor turn.

**Note:** stepper motor isn't really designed to keep spinning around and around: by sending as many or as few impulses to the outer electromagnets as necessary, we can make the rotor turn through a certain number of steps (precise angle). We can make it rotate the opposite way by reversing the electric current.

### III.2.5 Advantages of stepper motors

1. Stable. Can drive a wide range of frictional and inertial loads.
2. Inexpensive relative to other motion control systems.
3. Plug and play. Easy to setup and use.
4. Safe. If anything breaks, the motor stops.
5. Long life. Bearings are the only wear-out mechanism.
6. Overload safe. Motor cannot be damaged by mechanical overload.
7. The motor is simple in construction, reliable.
8. At the standstill condition, the motor has full torque.
9. They require little maintenance.
10. The stepper motor has an excellent and accurate starting, stopping and reversing response.

### III.2.7.1 Trapezoidal screw

Trapezoidal screws (figure 12) or Trapezoidal thread forms are the most common forms used for lead screws, they are used as a linkage in a machine, to translate turning motion into linear motion. They offer high strength and simplicity of manufacture. They are typically found where large loads are required, example the lead screw of a lathe. It is also called the Acme thread form. The Acme thread was developed in 1894 as a profile to power screws that has various advantages over the square thread, the Acme thread form, has angle of 29 to 30 degrees. <sup>[11]</sup>

### III.2.7.2 Advantages of trapezoidal screw

- ✓ Trapezoidal threads are manufactured on a thread milling machine with multipoint cutting tool which is an economic operation
- ✓ A trapezoidal thread has more thickness which means that the trapezoidal screw is stronger than an equivalent screw
- ✓ the trapezoidal screw has a large load carrying capacity

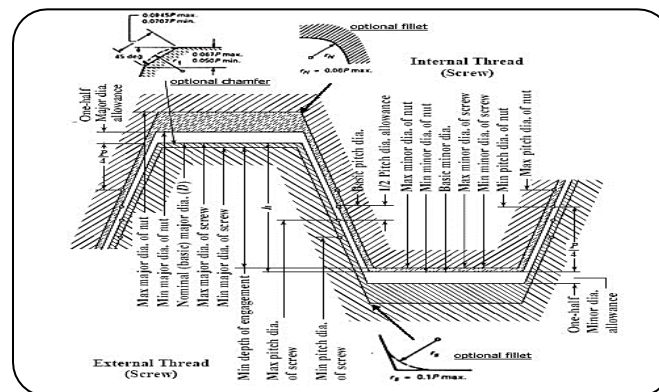


Figure 12: Trapezoidal thread specifications

### III.2.8.1 Ball Bearings and wheels

A ball bearing is a type of rolling-element bearing that uses balls to maintain the separation between the bearing races. The function of a bearing is to allow two elements to rotate with respect to one another with precision and with optimized friction by replacing a sliding by a rolling so it's made for reducing rotational friction and supporting radial and axial loads. To achieve that it uses two rings (outer and inner rings) between them the balls contained with separator, in almost applications of ball bearings, one race (ring) is stationary and the other is attached to the rotating assembly if the bearing races rotates it will cause the balls to rotate as well with lower coefficient of friction. <sup>[11]</sup>

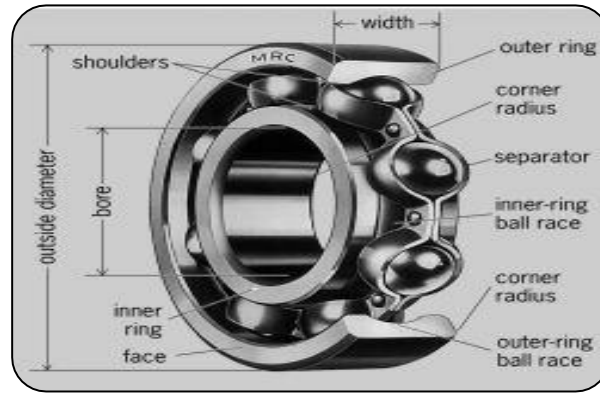


Figure 13: Ball bearing composition

### III.2.8.2 The advantages of ball bearings

- Large operating range temperature ( -40 ~ 180 degree)
- Easy bearing replacement
- Increase motor performance (less motor friction)
- Bearing is easy available in the market
- Less precaution during assembly
- Cheaper cost for replacement

### III.2.9 Wheels (roller)

In mechanical construction, a roller or wheels is a cylindrical or conical part interposed between two parts in relative movement for substituting the sliding friction by rolling friction. They have a thick outer ring, which allows them to support high radial loads while reducing bending stresses.

### III.2.10 Square steel tube

Square steel tubes are a hollow structural section which is a type of metal profile with a hollow tubular cross section. The term (HSS) is used generally in USA and the countries which follow US construction or engineering terminology. Rectangular and square HSS are also called tube steel or structural tubing. The corners of HSS are heavily rounded; they have a radius which is approximately twice the wall thickness which is uniform around the section. In the UK and countries which follow British construction or engineering terminology, the term HSS is not used, they use the three basic shapes like a reference as CHS (circular hollow sections), SHS (square hollow sections) and RHS (rectangular hollow sections). <sup>[12]</sup>



Figure 14: square hollow steel

### III.2.10.1 Advantages of Square steel tube

- Structural steel differs from other materials in its attributed compressive strength as well as tensile strength.
- Structural steel can be developed into nearly any shape, which are either bolted or welded together in construction.
- Steel is Fire resistance it's a non-combustible material.

### III.2.11 Arduino board

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards are able to read inputs - light on a sensor, a finger on a button, or a Twitter message - and turn it into an output - activating a motor, turning on an LED, publishing something online. You can tell your board what to do by sending a set of instructions to the microcontroller on the board. To do so you use the Arduino programming language (based on Wiring), and the Arduino Software (IDE), based on Processing. <sup>[6]</sup>

Over the years Arduino has been the brain of thousands of projects, from everyday objects to complex scientific instruments. A worldwide community of makers - students, hobbyists, artists, programmers, and professionals - has gathered around this open-source platform, their contributions have added up to an incredible amount of accessible knowledge that can be of great help to novices and experts alike. <sup>[6]</sup>

Arduino was born at the Ivrea Interaction Design Institute as an easy tool for fast prototyping, aimed at students without a background in electronics and programming. As soon as it reached a wider community, the Arduino board started changing to adapt to new

needs and challenges, differentiating its offer from simple 8-bit boards to products for IoT applications, wearable, 3D printing, and embedded environments. All Arduino boards are completely open-source, empowering users to build them independently and eventually adapt them to their particular needs. The software, too, is open-source, and it is growing through the contributions of users worldwide. [6]

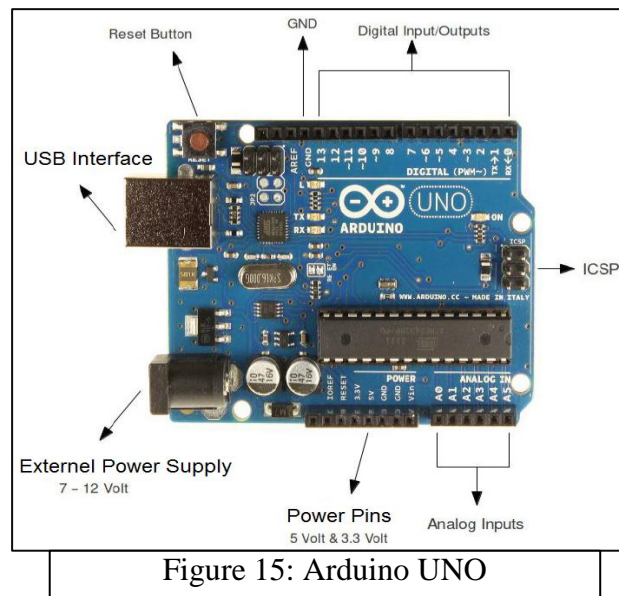


Figure 15: Arduino UNO

### III.2.11.1 Features Arduino Interface Board

1. It support 5-axis (Maximum) stepper motor driver controllers
2. It's Compatible with MACH3, Linux CNC (EMC2) etc. parallel-control CNC software.
3. USB power supply and peripherals power phase are separate to protect computer security.
4. All the signals are to-isolate which can protect your computer security.
5. input interface to define the Limit, Emergence-Stop, Cutter alignment, etc.
6. Output 0-10V analog voltage for the inverter to control the spindle speed.

### III.2.12 Safety measurements

As the user of the CNC machine routing system, each user must follow all safety procedures that are clearly outlined when operating each machine and its parts. Failure to do so may result in damage to property or personnel and could even result in death. Users should make plans for safeguarding themselves and their work areas at the point of operation as all. The CNC machines have been designed and constructed to operate under specific parameters relating to the particular application with maintaining the required level of protection.

### III.2.12.1 Personal Safety Precautions

1. Wear approved eye and hearing protection at all times when operating the routing system.
2. Restrain long hair with a cap or net when near the machines.
3. Avoid wearing neckties and scarves during machine operation.
4. Avoid wearing loose fitting clothing during machine operation.
5. Avoid wearing hanging jewelry during machine operation.
6. Wear gloves only when handling sharp or hot parts.
7. Avoid operating this machine and any other equipment if affected by alcohol, drugs, or any other substance or condition that may decrease judgment or alertness.
8. Avoid placing hands on the tabletop when the spindle is turned on.
9. Lock out the incoming power supply when any type of maintenance or other work is being performed on the machine.
10. Customers and related personnel should learn how the equipment functions and be able to respect the capabilities of the machinery.
11. Follow all safety precautions. Sudden movement, loud noises, horseplay, etc. must be avoided as such distractions may result in unsafe conditions.

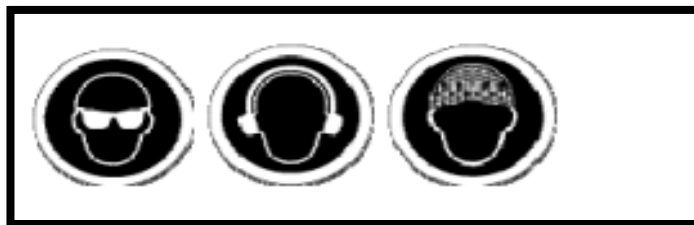


Figure 16: Personal safety notice

### III.2.12.2 Work Area Safety

- A. Fire extinguishers should always be readily accessible, and operators should always familiarize themselves with the fire prevention recommendations for each component of the CNC system.
- B. It is important to always keep the work area clean and uncluttered. Oil, debris, or water on the floor can cause unsafe conditions.
- C. Customers should be sure that all work areas are free of hazardous obstructions and that all tools and other equipment are returned to their proper storage place when not in use.
- D. Operators should never leave the machine unattended during the cutting sequence.



### III.2.12.3 Cutter Safety

Cutting tools are very sharp and should be handled accordingly. Machine operators should inspect tools before each use and discard any defective tools. Failure to properly handle tooling can result in serious injury.



Figure 17:Cutter safety notices

### III.2.13 Power supply

A power supply as showed in figure 18 is a component that supplies power to at least one electric load. Typically, it converts one type of electrical power to another, but it may also convert a different form of energy – such as solar, mechanical, or chemical - into electrical energy.

A power supply provides components with electric power. The term usually pertains to devices integrated within the component being powered. For example, computer power supplies convert AC current to DC current and are generally located at the rear of the computer case, along with at least one fan. A power supply is also known as a power supply unit, power brick or power adapter.<sup>[8]</sup>



Figure 18:AC\DC adapter

### III.2.14 Driver motors

Stepper motor driver is electronic circuit; the driver can be built with a handful of transistors. It could simply switched on and off in sequence to energize the phases and step the motor with the help of a stepper motor controller.

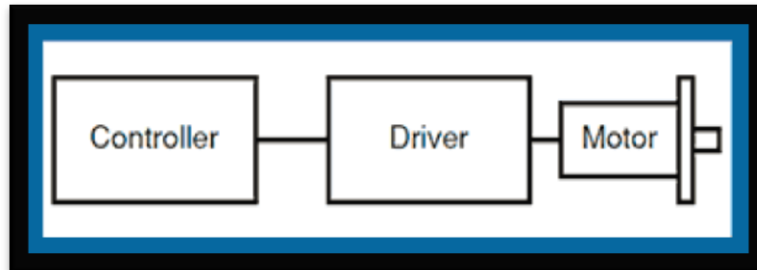


Figure 19: Stepper motor based system

#### III.2.14.1 Basic of stepper motors system

The diagram above (figure 19) shows a typical step motor based system. The stepper motor controller, step motor driver and motor must all be present in one form or another. Each component's performance will have an effect on the others.

- First is the pulse generator, also known as a stepper motor controller or indexer. The pulse generator will output command pulses that the motor will follow. By altering the frequency of the pulse train, the pulse generator can instruct the motor to accelerate, run at a speed, decelerate or stop.
- Next is the motor driver. The stepper driver's function is to control the magnitude and direction of current flow into the motor windings. The driver takes the pulses from the pulse generator and determines how and when the windings should be energized. The windings must be energized in a specific sequence to generate motion. Phase, the motor takes "steps" or small movements to keep in synchronism with the magnetic field. The degree of rotation per step depends on the style of driver used and the construction of the motor.

### **III.3 The design process of the CNC machine**

After we choose our technological solutions for the service functions of the CNC machine, we can now start an important step, it's the design process. It consists of transforming the ideas and the technological solutions to a simple model parts and mechanisms, for that we will use the C.A.D (computer aided design) software which provide a great view to the project and give a possibility to draw all mechanical parts and assemble them together, Some CAD softwares can also give a possibility for the part's simulation which allow to verify the performance of a mechanism with different conditions such as stress and loads, static forces, dynamic forces, pressure, fatigue etc... , .So there is a possibility to improve the mechanism and assure the rigidity of the model before starting the fabrication process. There are many CAD softwares exist in the market; the CAD software used in this project is SOLIDWORKS.

Our CNC machine can be divided in two major sections

#### **III.3.1 Mechanical section**

This section is composed from the mechanical elements only; it is divided into 6 parts

##### **A) The frame**

The frame (figure 30) or the chassis is from the most important part of any CNC machine, because it must carry all the other parts and support their the constraints, to build this frame we used the square steel tubes, all the specification for this tube is mentioned in the table below:

Exterior dimensions (mm)	50x50
Wall thickness (mm)	2
Mass per meter kg/m	2,93
Section area(mm <sup>2</sup> )	373.7

Table 4. Square steel tube specifications

The SHS tube will be the main element to build the frame.

The second step is to define the dimensions of the frame, to obtain an average area of 1000x800mm so the working area is about 900x600mm; all dimensions are illustrated in the frame's drawing.

After defining the design of the frame and creating an its C.A.D model, we must examine its rigidity using SOLIDWORKS Simulation. Each simulation was based on the following steps that is illustrated in the diagram below (figure 20)



Figure 20: simulation steps

First step in the process of simulation is to apply the type of material for the model we want to analysis in another way, which material this model is made of. Each material has its own properties (mechanical, chemical, physical...etc.).SOLIDWORKS library was equipped with many material list which offer a possibility to select the proper material.as we can see in our case the model is a metallic weldments structure ,the usual material for this frame is a structural steel exactly the E295.the characteristic of this material is illustrated is in figure 21 below

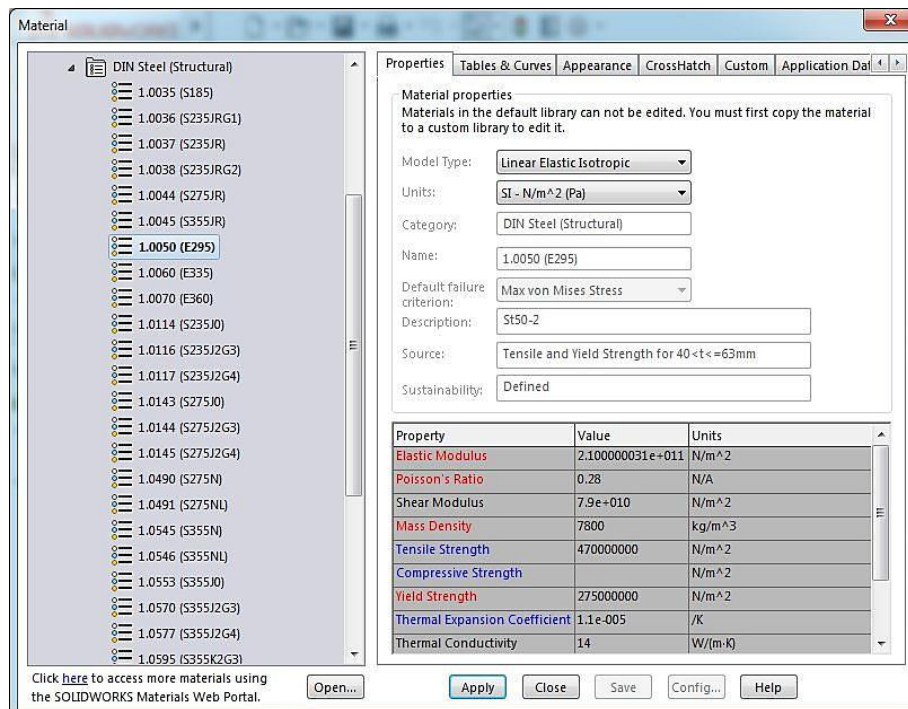


Figure 21: E295 characteristics

The second step of this process is to define fixtures, so what does it mean fixture?

To define fixture means that we should define the type of the movement that the mechanism is allowed to do in another way, we could say how many degree of freedom (DOF) which the model have .In the Cartesian space any object has 6 DOF, three of them are

## CHAPTER III: DESIGN PROCESS OF THE CNC MACHINE

translations movement ( $T_x$ ,  $T_y$ ,  $T_z$ ) and the three rotations ( $R_x, R_y, R_z$ ) each movement is correspondent with its axis of movement in orthogonal parameter ( $X, Y, Z$ ). The machine's frame is a mechanism that generally manufactured to handle or carry loads so it is not allowed to do any movement (0 DOF) or as known as a **fixed geometry**. SOLIDWORKS Simulation can easily handle it by choosing fixed geometry in fixture menu and we select the area where we want to fix the frame exactly what we can see in the figure 22 below

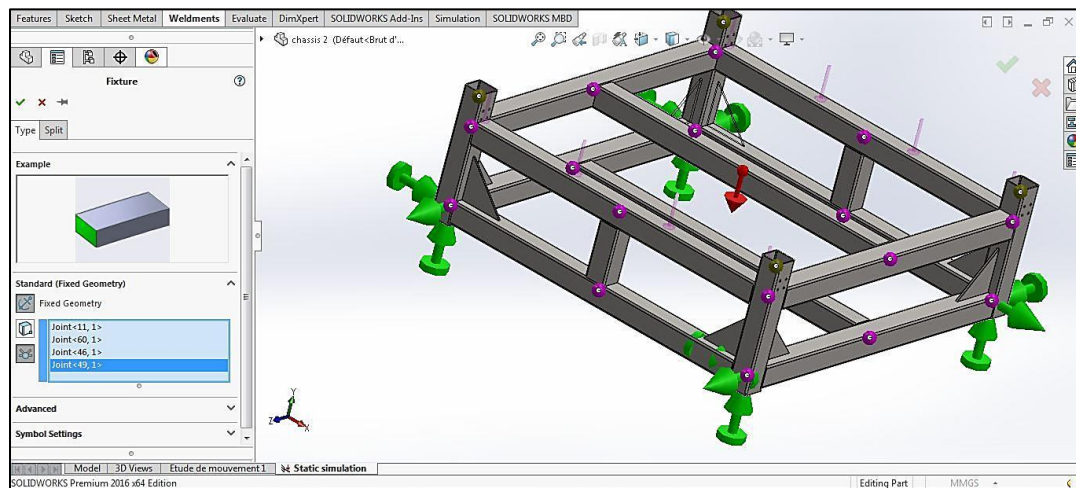


Figure 22: the frame fixture

The third step in simulation process is apply loads on the frame .there is different kind of loads (forces, pressure, temperature, gravity, torque ... etc.). The frame was examined with centered normal force on the two longitudinal tubes with value of 300 N which is equivalent of 30kg of load, gravity was also applied with  $g=9.81\text{m/s}^2$  as showed in figure 23

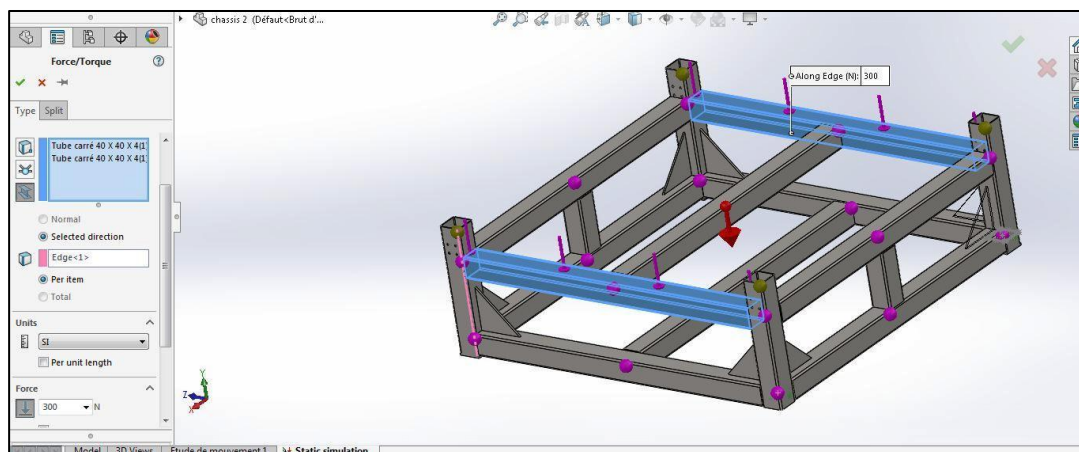


Figure 23: Applying forces on the frame

Next step is meshing the frame, The terms "mesh generation, or "grid generation," "meshing," " and "gridding," are often used interchangeably, the role of meshing is for increasing the speed or accuracy of the numerical calculations that will be performed over it.



## CHAPTER III: DESIGN PROCESS OF THE CNC MACHINE

In computer graphics rendering, and mathematics, a mesh is sometimes referred to as a tessellation. In computer graphics, tessellation is used to manage datasets of polygons presenting objects in a scene and divide them into suitable structures for rendering. Especially for real-time rendering, so data is tessellated into triangles .a finite element method (FEM) is a numerical calculation process (generally matrices calculations ) used widely in strength material calculations, for more accuracy of results in FEM it is suitable to do a meshing process before running calculations. SOLIDWORKS Simulation has been equipped with many meshing algorithms, for limit hardware resources we used the default mesh settings (see figure 24) and the result of the meshing is in the two figures 25 and 26:

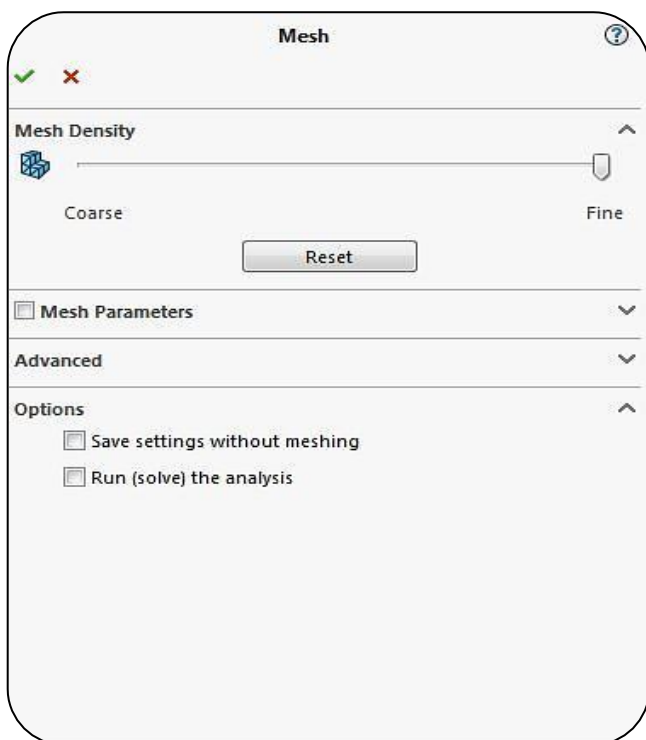


Figure 24: Mesh settings for the frame

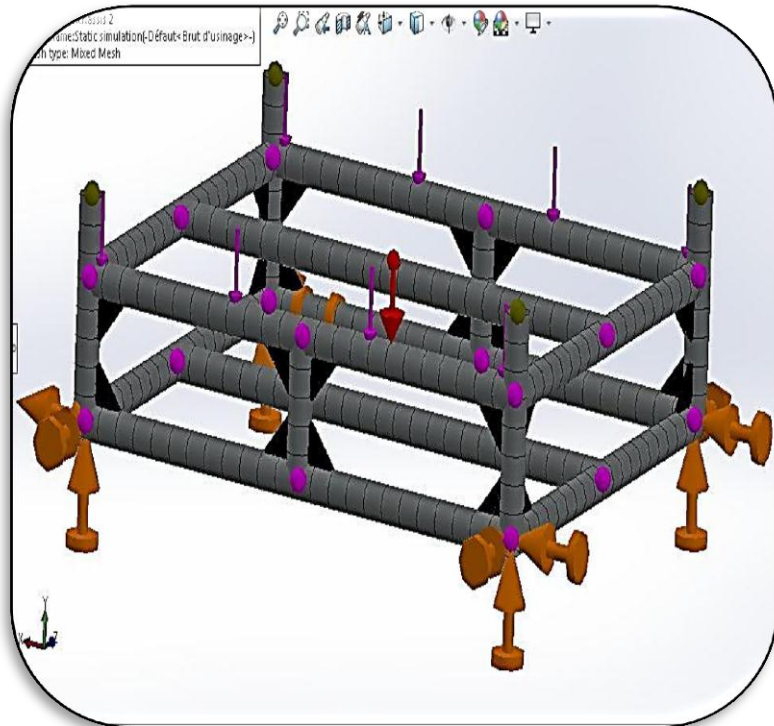


Figure 25: Mesh of the frame

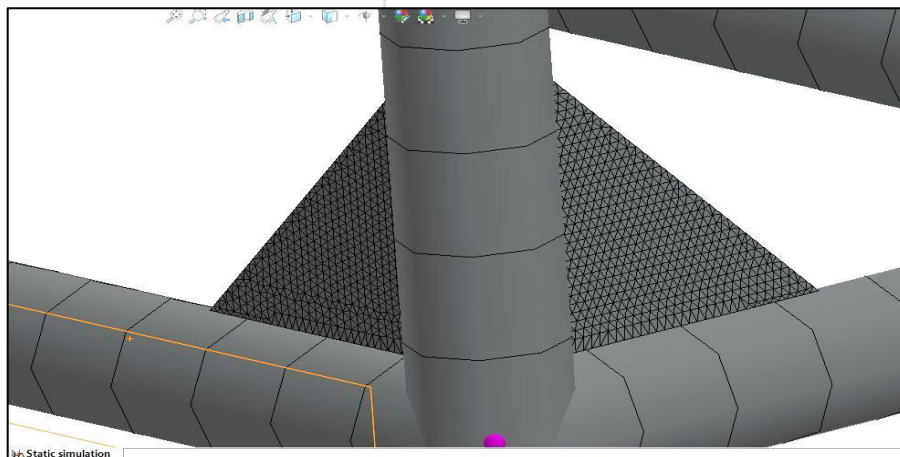


Figure 26: Mesh of the frame (gussets)

The final step in the simulation process is to run the analysis or the calculation procedure, the results of this process lead to final conformation of the frame before starting the build process, SOLIDWORKS Simulation can provide many types of solutions ,we focused on Three of them (Von mises stress – resultant displacement- equivalent strain)

As we can see in von mises stress result (figure 27) the maximum value of the von mises stress is indicated in the chart is equal to  $(p=2.745 \times 10^{-3})$  MPa) which is far less than the yield stress of the material (E295) (yield stress=275MPa),so the frame is more resistible to the applied loads. For a final check the results of equivalent strain and resultant displacement, as we can see in figure 28 and figure 29 respectively, all the body of the frame is indicated with a blue color which mean there are no deformation or a negligible displacement .all this results guaranteed the design strength of this frame.

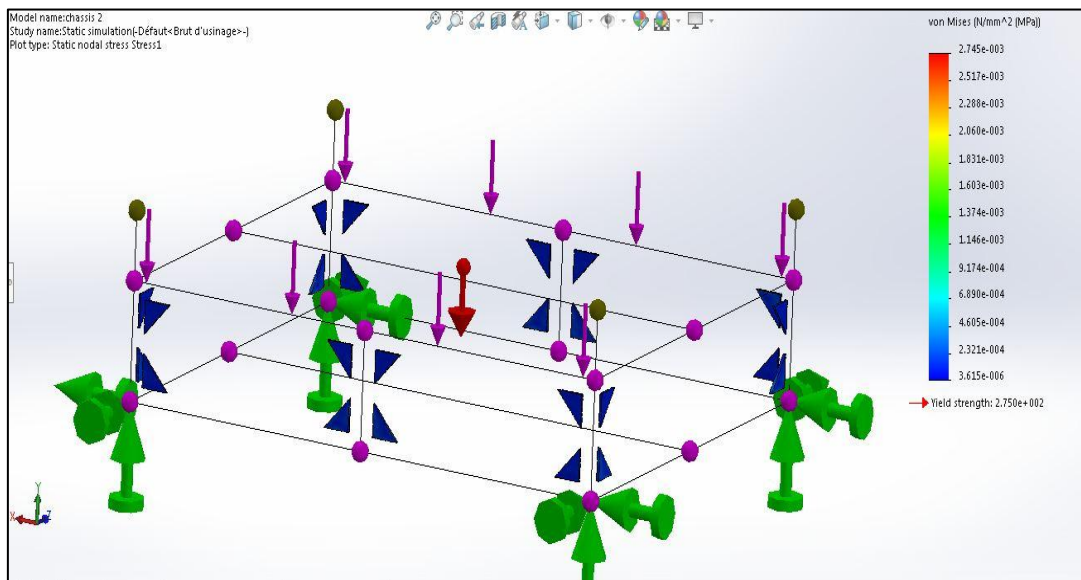


Figure 27: Von mises stress result

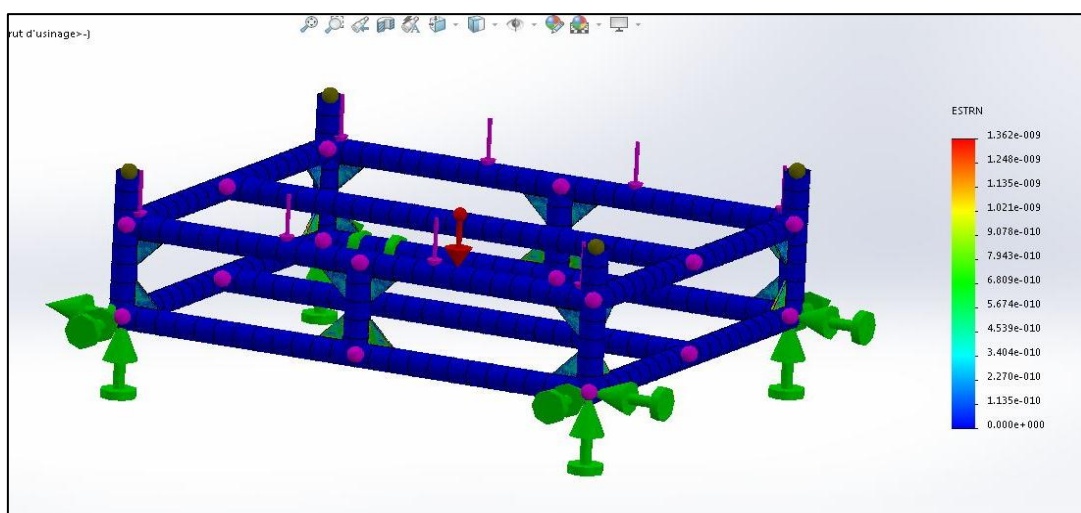


Figure 28: Equivalent strain result

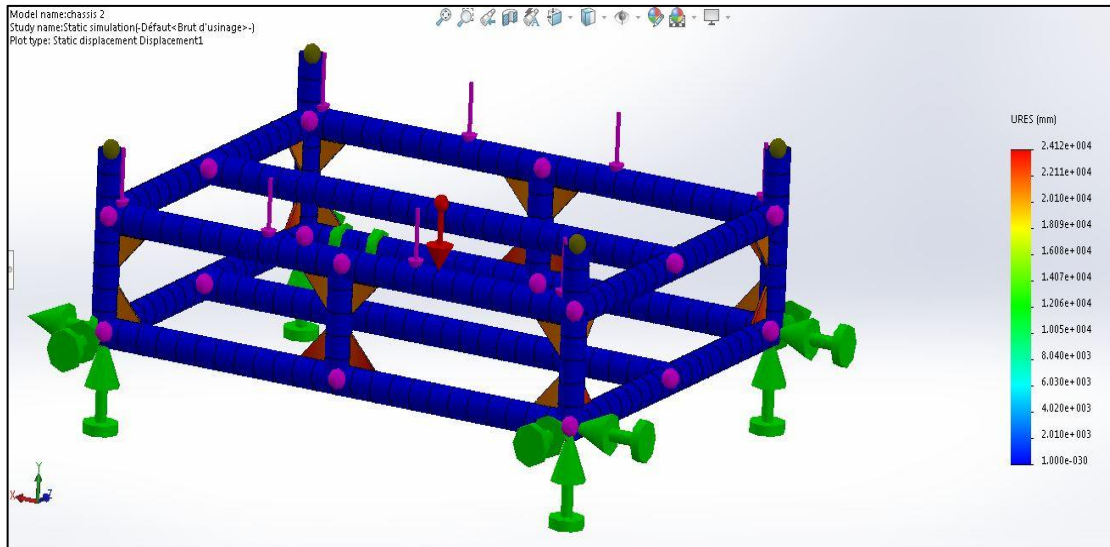


Figure 29: Equivalent displacement result

Finally, for finishing the frame a small part has been designed at the end of each leg of the frame we call it foot pad machine (figure 31). Its role is to adjust the level of the machine because when setting up the machine on floor, the machine will swing which is not suitable. This part is designed with a rectangular sheet metal (50x50x4mm) and drilled in the middle, after that we put a nut welded with sheet metal, assembled with the another part called pad which is machined and threaded on a lathe. So the level of the machine will be adjusted by just turning the pad.



Figure 31: The foot pad machine

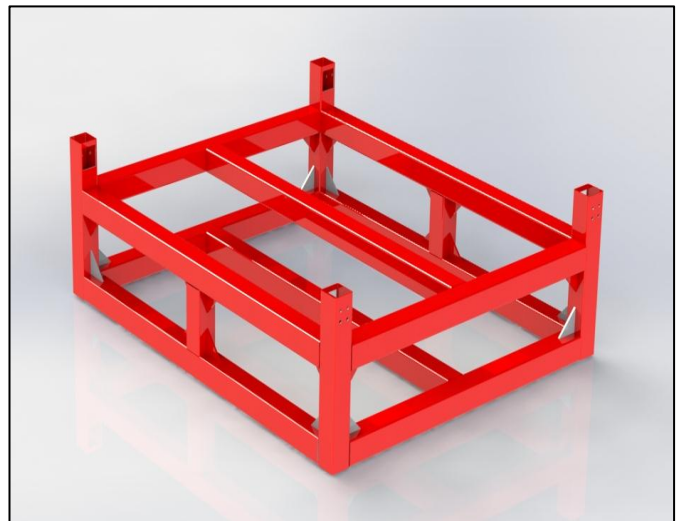


Figure 30: The frame



### B) The water table

The water table (figure 32) is the part holder of the machine, the word water refer to the design of the table, so the table will be filled with water, the role of the water is to collect and absorb the dust caused by the plasma torch, and that's the case when the machine play the role of a plasma cutter .So what a about cutting the other material such as wood? the table have been made with square steel tubes (30x30x2mm) and (50x50x5mm) steel corners , four flat slats with 3mm in depth have been used horizontal direction of the frame and 3 square steel tubes in vertical direction of the frame, they will be assembled together by the mean of slots created on the tubes as showed in figure 32,all this part are contained on steel frame made by the steel corner and welded with 3mm sheet metal work as a base of the table, so we want convert the table for cutting wood we simply assemble on top of the steel tubes by mean of bolts a MDF plate which include a T slot rails as the figure 33 shows.

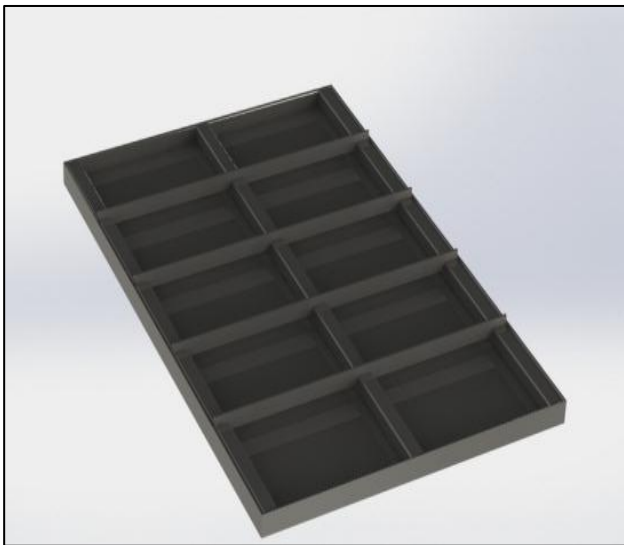


Figure 32: The water table for plasma

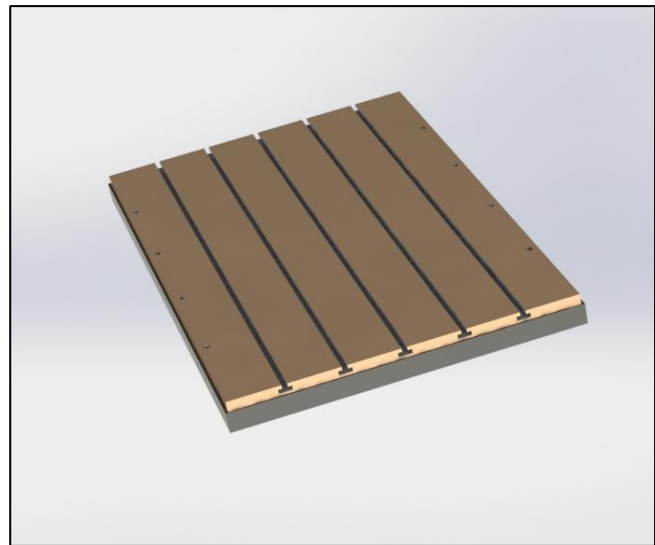


Figure 33: The water table with MDF plate

### C) The gantry and Y axis

The gantry is another chassis that carries the Y and Z axis and it moves with the length of the X axis, it consists of two V slide aluminium rail made by Openbuilds<sup>®</sup> Company .V-Slot is a high quality aluminum linear rail profile with an extremely smooth v groove shape on all 4 sides. It's precise, easy to work with and allows unlimited design control through it's modular nature. Building with V-Slot is much like working with lumber. It can be cut with a

### CHAPTER III: DESIGN PROCESS OF THE CNC MACHINE

chop saw and the rest is as simple as turning a screwdriver to make the assembly by the holes that can be threaded and they are already includes in the two sides of the rail. [4]

OpenBuilds® V-Slot is made with 6063 T-5 Aluminum Extrusion and has a Super light (1.1 kg/m), beautiful, shiny, super smooth, clear finish which allows for a smoother ride for the V Wheels.all details of the gantry and the Y system are illustrated in their drawings, the rigidity of the gantry must be verified with a simulation process using SOLIDWORKS Simulation and the result is shown in the figures 34, 35 and 36 below:

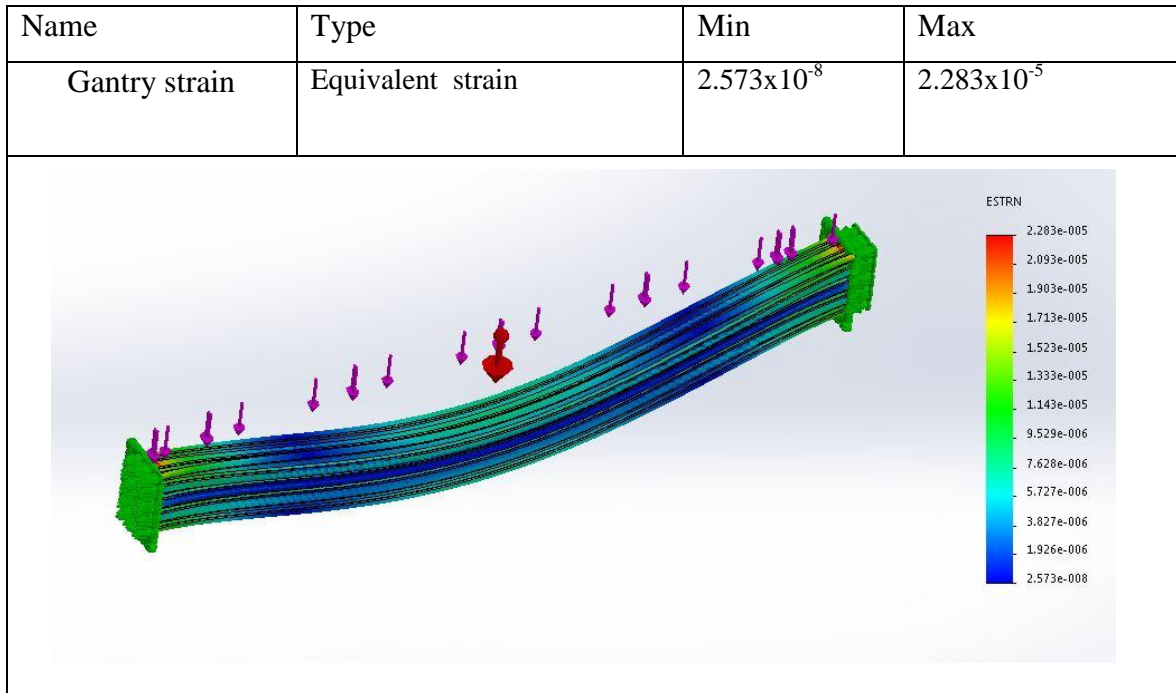


Figure 34: Gantry strain result

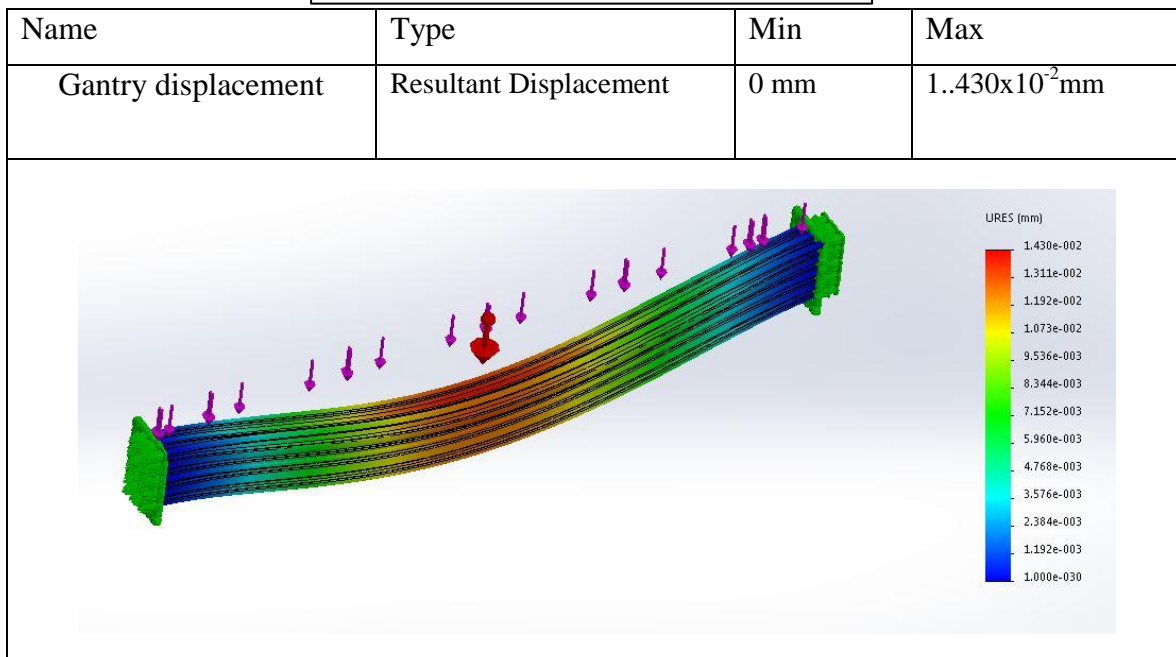


Figure 35: Gantry displacement result

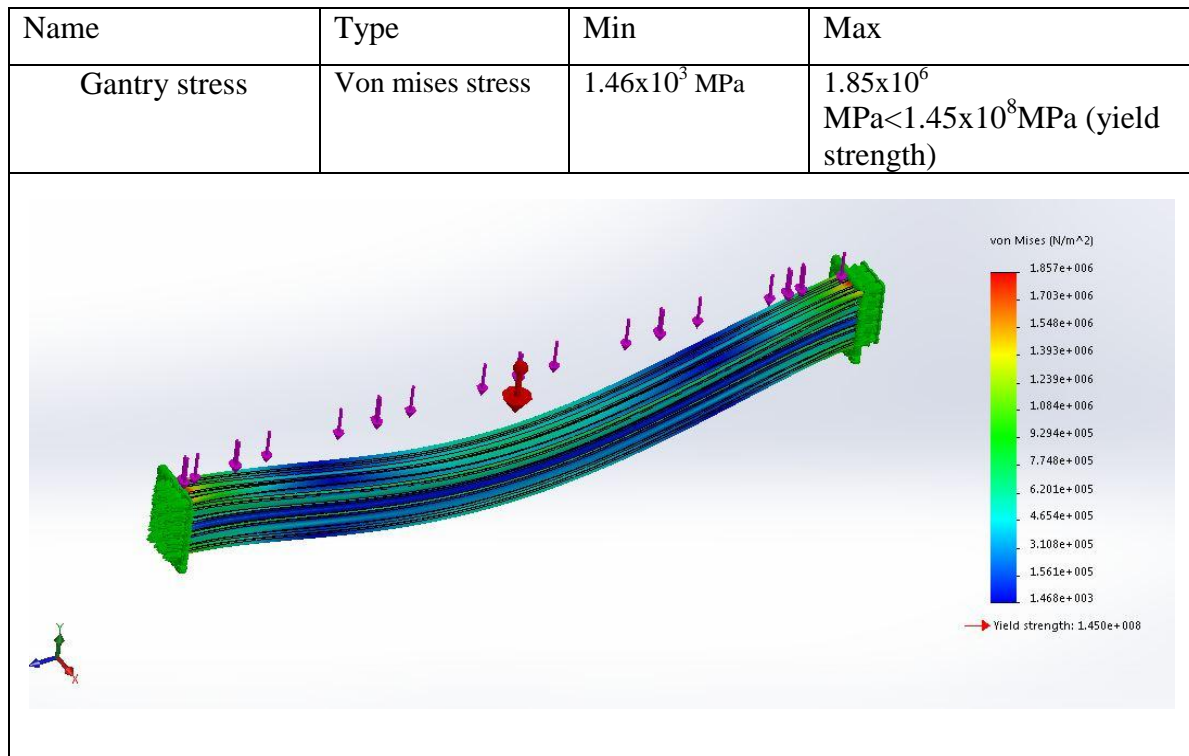


Figure 36: Gantry stress result

The gantry has been designed by two V slot aluminium rails, Then next step is the side holes, they must be threaded with M5 thread tool which help in assembly of the gantry with the motor plate of the x axis, so the machine will be consist of multi bodies as a result it will be easy to transport, assemble and to repair.

Let's focus now about the Y axis system .Each axes in this machine is composed from the transmission system and their guiding system for the Y-axes the transmission system is based on pulley belt system. A stepper motor mounted with timing pulley has been fixed on a 4mm thick plate. The CNC machine uses power transmission/timing belts, pulleys, and two idler wheels for linear motion along the Y-axes. Timing belts have teeth that prevent slippage so that the pulley and the belt always move together. They are made of rubber or other flexible polymer, reinforced with very tough tensile fibers, usually glass, running lengthwise. The tensile fibers are what give timing belts their resistance to stretching. Toothed rubber belts are manufactured as a long tube, it was extruded.

There are many different types of timing belts, suitable for different applications. For a CNC router, forces are normally low and the most important consideration is registration

(positioning accuracy). As users seek stiffer machines for more demanding materials and speeds and/or larger work areas, one of the upgrades to look at is stiffer belting. This can mean changing the basic design of the timing belt, the width, the pitch, and/or the materials. The GT belts that come with this machine are very accurate if properly tensioned and the only other belts you should consider to handle more force are either the same 2M GT2 in wider width (9mm wide) or 3M GT2 for maximum stiffness at the expense of precision (15mm wide). GT/GT2/GT3. GT stands for "Gates Tooth". GT belts have a special tooth design that allows them to have low backlash despite high torque capacity, so the positioning accuracy is an order of magnitude better than trapezoidal-tooth belts as we can see in figure 37. 2M GT2 has about 4X better positioning accuracy than 3M GT2. GT/GT2/GT3 refers to versions of

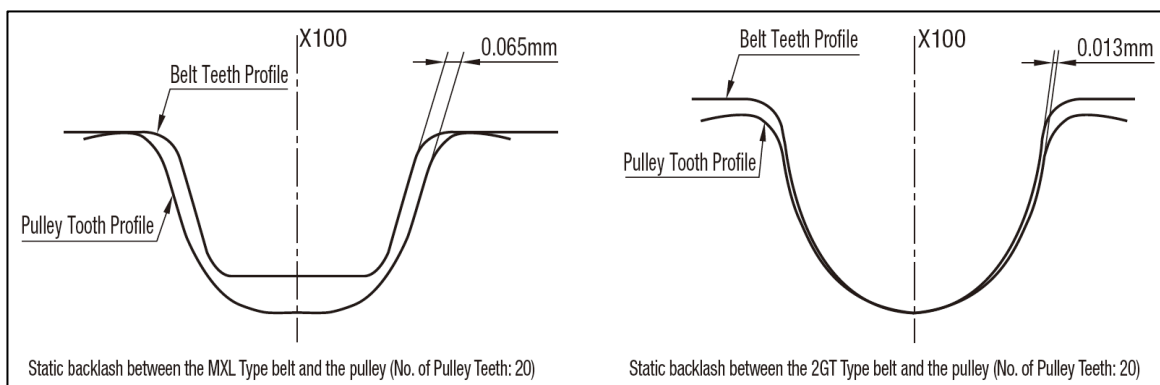


Figure 37: comparison of static backlashes between trapezoidale belt and GT belt

the same profile, which come in a variety of standard pitches. You may see 2GT/3GT/5GT used to refer to 2mm/3mm/5mm pitch original GT belting. <sup>[4]</sup>

Let's move to the guiding system, it allow the motion of the axes in a linear way or known as linear motion, their many ways to make a linear motion for our CNC machine wheels have been used. The wheels are an old method for moving heavy loads because it converts the sliding movement to a rotation movement which reduces the friction. This wheels has a V shape profile and that because it will ride on the V slide rail so it must have a coincident shape of the rail, we made them with aluminum which is solid, load carry and light material. They are machined with CNC lath machine. Inside each wheels we mounted a ball bearing. For all details check the assembly drawing of the wheels. For fixing those with the frame it will be attached with motor and gantry plates. It will be also joined together by bolts, nuts and spacers between the plates and the wheels. All Y axes system elements will be shown in an exploded drawing.



### D) The X-axis

This axes is similar to previous one, it share basically the same ideas and design, so the transmission of the X-axes is a pulley /timing belt system as the Y –axes .it consist of an open timing belt attached around the two idler pulleys and the motor pulley or simply called omega timing belt/ pulley system as showed in figure 38. When the stepper motor turns the pulley will turn with it, the timing belt and the gantry will be moved forward or backwards depending on the side of the rotation of the stepper motor and that happen by the teeth that are included in the pulley and the belt. But there is another question is how do we make the gantry moves in a linear motion? And the answer of this question is the guiding system.

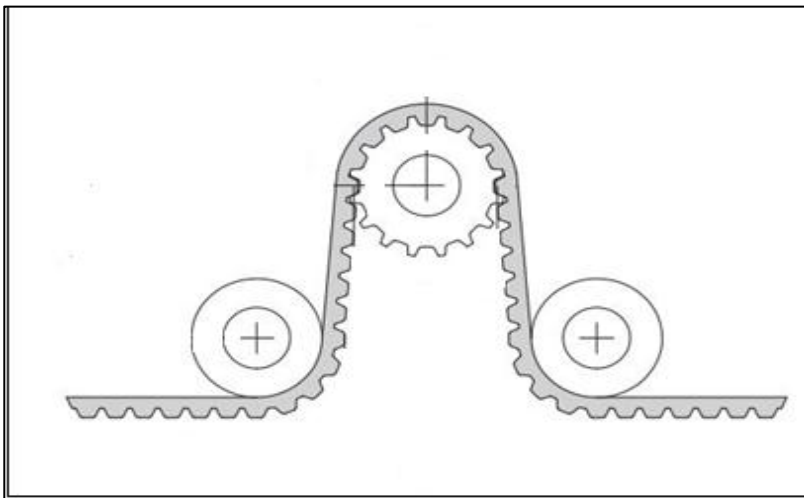


Figure 38: Omega timing belt/pulley system

The guiding system for the x axis is the same as all the axes of the machine. It's simply V shape wheels. There are 10 wheels in each longitudinal V rail of the frame. These wheels are divided in 2 sides of the tube, 6 wheels on the top of the V rail, 4 of them for guiding the transmission and the last two wheels tangent the timing belt for increasing the tension of the belt we call them the idler pulleys, 4 wheels on the bottom. The reason for such dividing is to maintain the wheels with the V rail tube and the mechanism will roll on the V slide which gives a linear motion. The result is the wheels are rolling on the aluminum rail very easily with no play.as the Y axis the V slot aluminum rail the x axis rail rigidity is also tested with simulation process using SOLIDWORKS Simulation.it was verified with a 200N normal force and the results are illustrated in figures 39, 40 and 41 bellow. All x axis system elements will be illustrated in the exploded drawing.



Name	Type	Min	Max
X axis strain	Equivalent strain	$5.810 \times 10^{-10}$	$5.433 \times 10^{-5}$

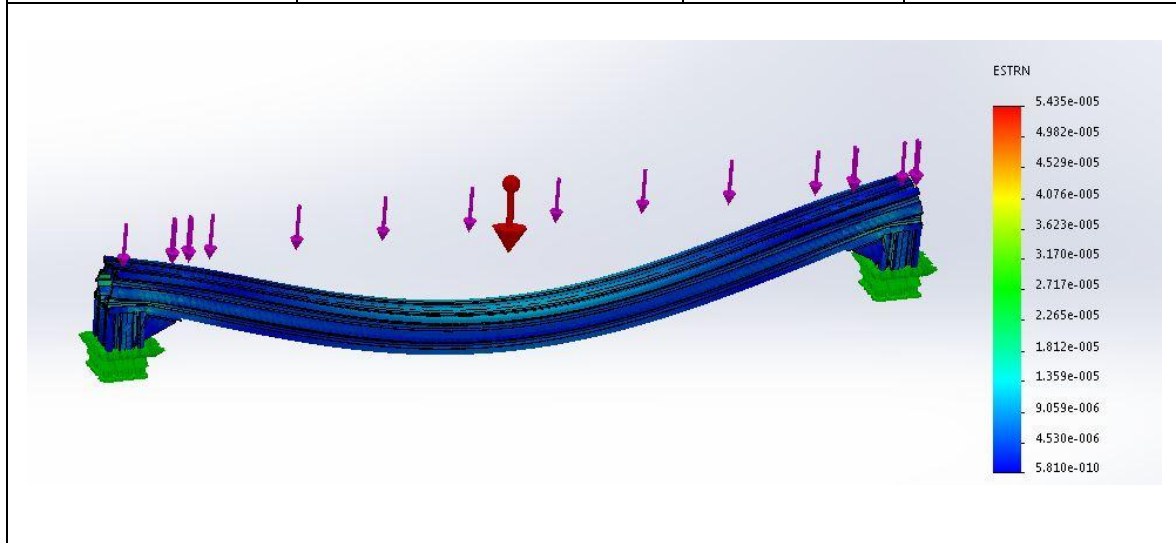


Figure 39: X axis strain result

Name	Type	Min	Max
X axis displacement	Resultant Displacement	$1.000 \times 10^{-30}$ mm	$3.435 \times 10^{-2}$ mm

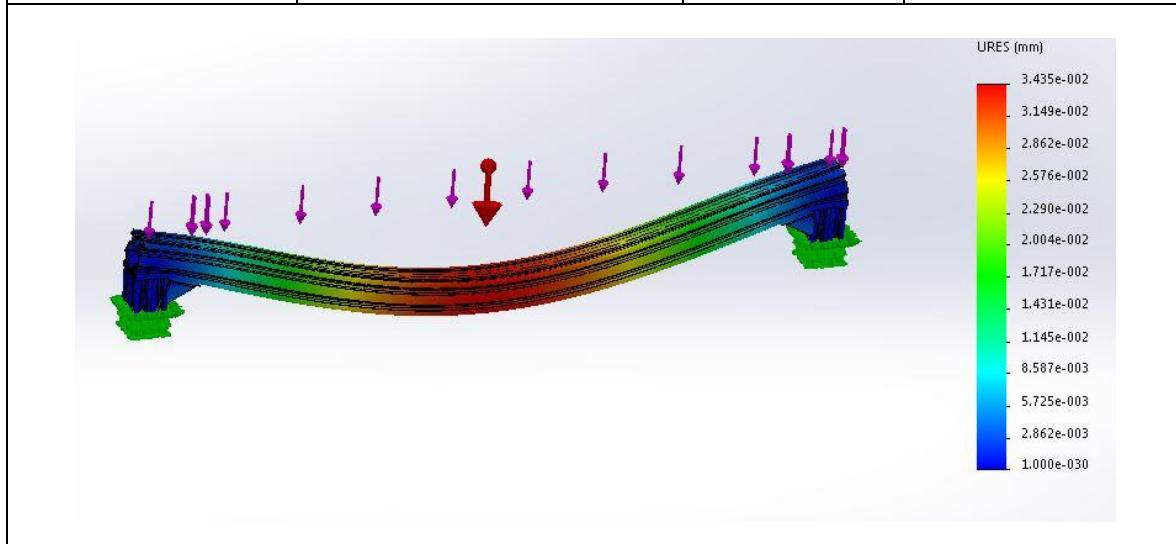


Figure 40: X axis displacement result



Name	Type	Min	Max
X axis stress	Von mises stress	$1.942 \times 10^2$ MPa	$1.594 \times 10^7$ MPa < $2.75 \times 10^8$ MPa (yield strength)

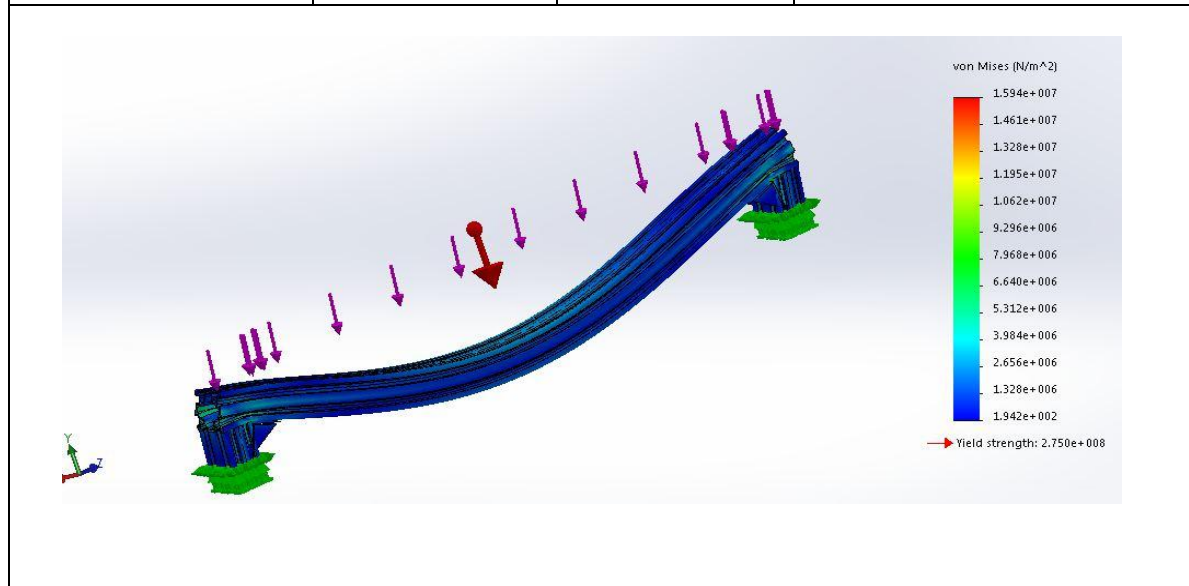


Figure 41: X axis stress result

**F) The Z-axis**

This is the last axes in this machine. it has the function to control and support the tools. This axes is also share the same design of the other axes but not all design. There is two metal plate fixed with a V slot aluminum rail in the top and bottom by 4 bolts on both sides. Each plate contain a ball bearing .The transmission system of this axes is composed with a trapezoid screws fixed with pulley and guided with the two ball bearings for a clear rotation .the stepper motor is fixed with the top plate by screws and nuts .a timing pulley is also fixed with the stepper motor shaft so when the timing belt is mount between the pulleys it form a open loop timing belt/pulley system, So when the motor turn the pulleys turns by the mean of timing belt as result the trapezoidal screw will turn and the nut of this screw which fixed with the tool holder plate and the tool will move up or down depending on direction of the rotation of the stepper motor.

The guiding system of this axes is similar to the others on the X and Y axes, it is composed of a 6 V wheels rolling six on each side rolling on V slide aluminum rail tube. After we assemble these parts together we install them on the y plates by means of bolts for easily assembly, one last part is the tool holder or also known as the tool chuck, and it has been attached with Z plate by bolts .All Z axis system will be shown in an exploded drawing.



**CHAPTER III: DESIGN PROCESS OF THE CNC MACHINE**

---

After assembling all the parts of the mechanical section starting with the frame finishing with the z axis our machine will be almost finished the assembly is illustrated in the figure below:

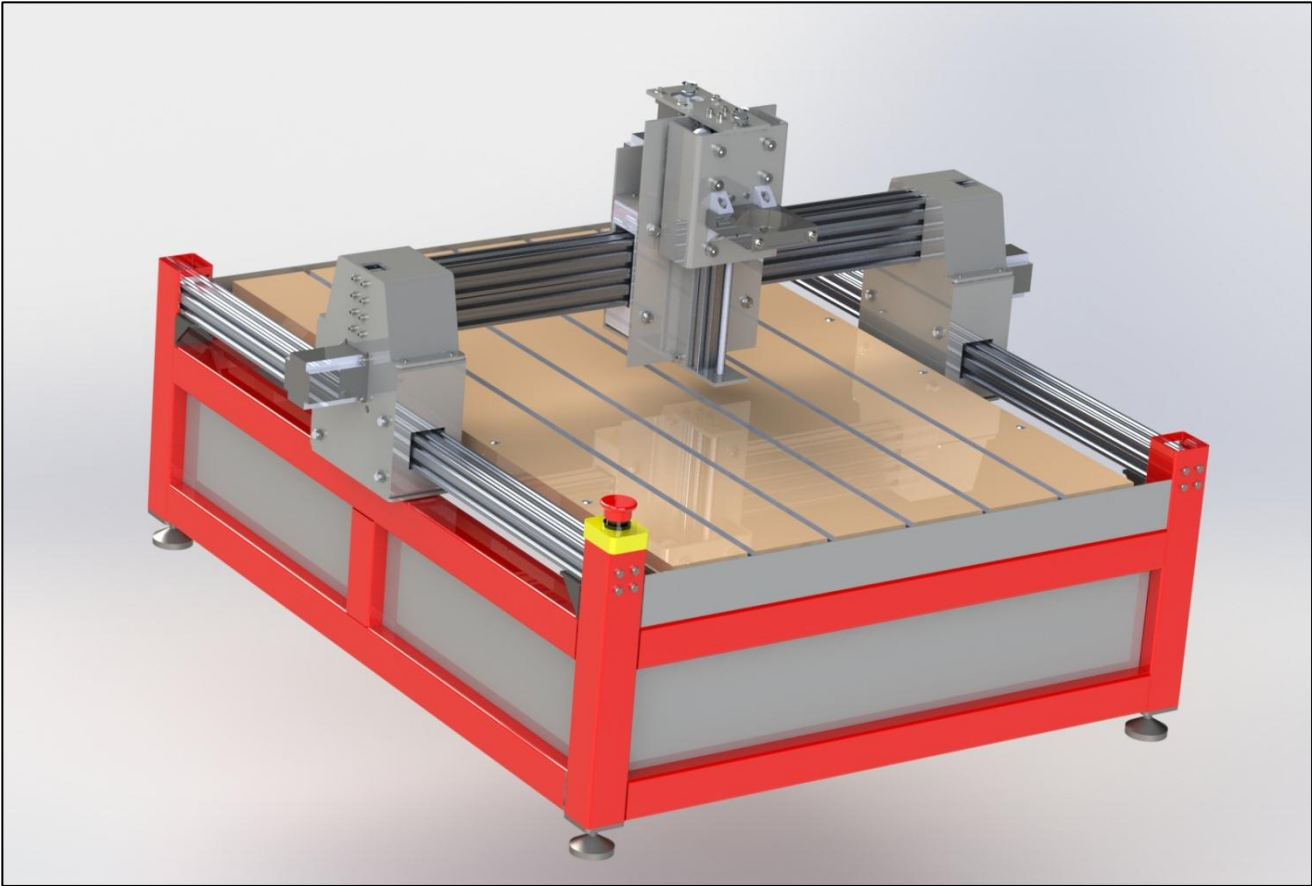


Figure 42: The CNC machine after the final assembly

### III.4 Conclusion

We have seen in this chapter a brief explanation of the creation cycle of the CNC machine starting from the choosing technological solutions step and finishing with the design process of the mechanical section of the CNC machine. For the electric section, it will be explained in the next chapter.

**CHAPTER IV:  
ELECTRONIS  
AND  
CONTROL**

### Chapter IV: Electronics and Control

#### IV.1 Introduction:

CNC (Computer Numerical Control) general term used for a system which controls the functions of a machine tool using coded instructions processed by a computer (G, M Code), it is based on an electronics boards and circuits that are relied with special softwares. The two combined form the brain the CNC machine. To manipulate our machine digitally we need a

#### Objectives

You will see in this chapter:

- ✓ The electric section of the CNC machine
- ✓ The user guide for using and controlling the CNC machine

#### IV.2 The electric section

To control a CNC machine, the user need

**Software control panel:** which is basically a personnel computer such as laptop or desktop .this panel contain the controlling software and also the CAD and CAM software.

**Electrical control panel:** this panel contain the all necessary electronic boards; those boards are responsible for transforming the binaries data to electrical signals which control the motor and the machine. This panel consists of:

- Stepper motors
- power supply
- stepper motors drivers
- arduino board
- emergency , start and reset buttons

##### IV.2.1 Stepper motor

Our CNC machine is using 4 NEMA 23 bipolar stepper motors as showed in table 2. But first let's discuss the meaning of bipolar stepper motor .generally there are two types of stepper motors the unipolar stepper motors and the bipolar stepper motors.

The unipolar stepper motor operates with one winding with a center tap per phase. Each section of the winding is switched on for each direction of the magnetic field. Each winding is made relatively simple with the commutation circuit; this is done since the arrangement has a

magnetic pole which can be reversed without switching the direction of the current. In most cases, given a phase, the common center tap for each winding is the following; three leads per phase and six leads for a regular two-phase stepper motor. You will usually see that both these phases are often joined internally; this makes the stepper motor only have five leads. Often a stepper motor controller will be used to activate the drive transistors in the proper order.

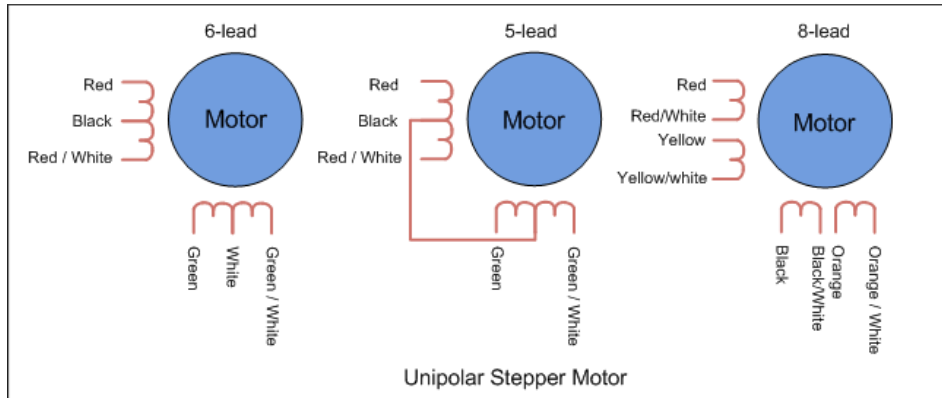


Figure 5 unipolar stepper basics

With bipolar stepper motors, there is only a single winding per phase. The driving circuit needs to be more complicated to reverse the magnetic pole; and that is possible by reversing the current in the winding. This is done with an H-bridge arrangement; however, there are several driver chips that can be purchased to make this a simpler task. Unlike the unipolar stepper motor, the bipolar stepper motor has two leads per phase, neither of which are common

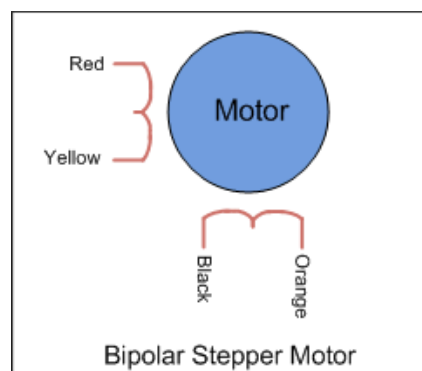


Figure 44: Bipolar stepper motor basics

Bipolar motors are generally better than unipolar motors. They have more torque and are more efficient. However, they are more complicated to drive because they need reverse current. In terms of construction, bipolar motors have multiple (at least two) independent windings. A wire comes out of each of the winding's ends, so you get two wires per winding. The absence of this third wire means that bipolar motors are slightly simpler to make.



Axis	Motors	specifications
X-axis (2 Motors)	<p>Nema23 (56x56x76mm)</p> 	<p>Step Angle 1.8°</p> <p>Step Accuracy 5 %</p> <p>Holding Torque 12.5 kg·cm</p> <p>Rated Torque 11.1 kg·cm</p> <p>Maximum Speed 600 RPM</p> <p>Maximum Motor Speed 4688 RPM</p> <p>Recommended Voltage 24 V DC</p> <p>Rated Current 2.2 A</p> <p>Voltage rating 3.2 V</p> <p>Coil Resistance 1.8 Ω</p> <p>Phase Inductance 6 mH</p> <p>Shaft Diameter 6.35mm</p> <p>Weight 916 g</p> <p>Number of Leads 4</p> <p>Wire Length 300 mm</p>
Y-axis		<p>Nema23 (56x56x41mm)</p> 
Z-axis		

Table 3: Stepper motors specifications

## IV 2.2 Power supply

As we have seen in the table above the stepper motors of our CNC machines is not identical so their power supply need to be precise. The AC/DC Adapter output voltage and current must satisfied the requirement of each motor..let's Assume this setup will be used on this CNC machine with NEMA 23 steppers. For identifying the correct voltage and current



for the stepper motors we should follow the following rules

### **Rule 1:**

For optimum speed you want a supply at **least 20 times** and **preferably 25 times** the rated voltage of the motors. A value of **15 times** the rated voltage is the bare **minimum**.

### **Rule 2:**

maximum Voltage =  $32 \times (\text{square root of the inductance})$ . Anything at this voltage may cause overheating and but it is the best voltage to run the stepper.

### **Stepper of X and Y axes calculations:**

Volts 3.2 V

Amps 2.2 A

Resistance 1.8  $\Omega$

Inductance 6mH

### **Required power supply using Rule 1:**

Minimum voltage =  $15 \times 3.2\text{vdc} = 48\text{vdc}$

Better voltage =  $20 \times 3.2\text{vdc} = 64\text{vdc}$

Best voltage =  $25 \times 3.2\text{vdc} = 80\text{vdc}$

### **Required power supply using Rule 2:**

maximum Voltage =  $32 \times (\text{square root of the inductance})$

max voltage =  $(32 \times \text{sqrt}(6)) = (32 \times 2.45) = 78.8\text{vdc}$

### **Stepper motor for Z axes calculations:**

Volts 2.4V

Amps 1.5 A

Resistance 5.7  $\Omega$

Inductance 2.5 mH

### **Required power supply using Rule 1:**

Minimum voltage =  $15 \times 2.4 = 36 \text{ vdc}$

Better  $20 \times 2.4 = 48 \text{ vdc}$

Best  $25 \times 2.4 = 60 \text{ vdc}$

### **Required power supply using Rule 2:**

maximum Voltage =  $32 \times (\text{square root of the inductance})$

$(32 \times \text{sqrt}(2.5)) = (32 \times 1.58) = 50.56\text{vdc}$

Both setups might perform similarly but the high inductance of X and Y stepper would require a much higher power supply than is normally possible. Using a power supply with a maximum of 70vdc unregulated volts pared to stepper drives rated at 80vdc max would allow

the stepper A to run at half its capacity. Stepper B is sized almost perfectly to a 48 to 60vdc power supply and would be a much better choice even at 48vdc.

Other facts I've found relating to voltage selection:

- The voltage of a stepper power supply sets the ceiling for how fast a stepper can spin. As the stepper spins it generates back EMF (voltage) as it turns. When this back EMF voltage nears the supplied voltage, the stepper ceases to produce torque. Supplying too low of a voltage also steepens the torque curve drop off as the stepper nears its limits and will cause the stepper to stall.
- Useable speed increases proportionally as we increase voltage, so if we double the power voltage it will double the speed up to the point of stepper overheating. Increasing the voltage does two things; it speeds up the motor and increases the torque at higher speeds.
- A stepper will always have torque drop off as the RPM increases but running the appropriate voltage will flatten the fall off curve. Inductance limits how fast current can flow through a stepper, so high inductance motors have a lower maximum top speed, due to reduced torque at high RPM's. Increasing voltage has the effect of forcing the current through the stepper faster.
- To get the maximum performance from a stepper, we increase the voltage to the max determined by one of the above rules. You reach a point however, where increasing voltage only adds heat, and no longer increases speed. That is the voltage greater than calculated by rule number 2 above.

**The summary:** X and Y axes Steppers would barely perform at all on the typical 48vdc power supply and would show a slower speed and similar torque compared to Z axis Stepper which is at or near it's optimum power and speed

### **Rule 3:**

Current = Amps needed per drive x Number of drives (numbers of motors) x 0.7

Current needed should be 70% of the individual amp requirement of one drive times the number of drives in your setup. Generally it is possible to run your drives from even down to 50% of the total amp requirement, but for good measure stick with 70%

### **For the X and Y axes stepper**

Current 1 =  $2.2 \times 3 \times 0.7 = 4.6a$

### **For the X axes stepper**

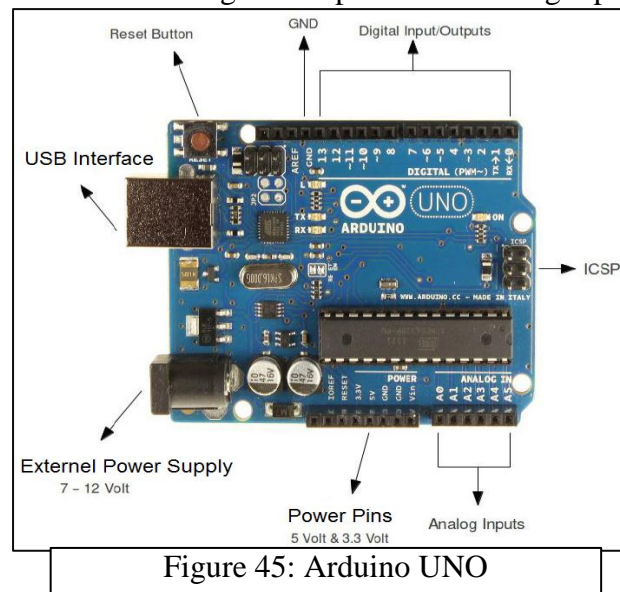
Current 2 =  $1.5 \times 1 \times 0.7 = 1.05a$

### **The total current for the stepper motors**

Current = current 1 + current 2 =  $4.6 + 1.05 = 5.65A \approx 6A$

### IV.2.3 Definition of Arduino UNO

The Arduino microcontroller is an easy to use yet powerful single board computer that has gained considerable traction in the hobby and professional market. The Arduino is open-source, which means hardware is reasonably priced and development software is free. This board features an Atmel ATmega328 microcontroller operating at 5 V with 2 Kb of RAM, 32 Kb of flash memory for storing programs and 1 Kb of EEPROM for storing parameters. The clock speed is 16 MHz, which translates to about executing about 300,000 lines of C source code per second. The board has 14 digital I/O pins and 6 analog input pins.



### IV.2.4 Definition of TB6560 stepping motor driver V-2.0

The TB6560 V-2.0 Axis Stepper Motor Driver is a microstepping driver that uses TOSHIBA TB6560 Chip, based on pure-sine current control technology. Owing to the above technology and the self-adjustment technology (self-adjust current control parameters) according to different motors, the driven motors can run with smaller noise, lower heating, smoother movement and have better performances at higher speed than most of the drives in the markets. <sup>[8]</sup>. In addition, those are some characteristics of this driver:

- Very easy to use, no instructions, all of use are marked on the board.
- With large heat sink to ensure good heat dissipation.
- Input signal high-speed optocoupler isolation, Guarantee not losing steps.
- Semi-flow mode adjustable, semi-flow current adjustable, not the general design on the market, with a variety of semi-flow model and semi-flow current setting function.
- Attenuation model adjusted for all the motors can be locked when no noise.

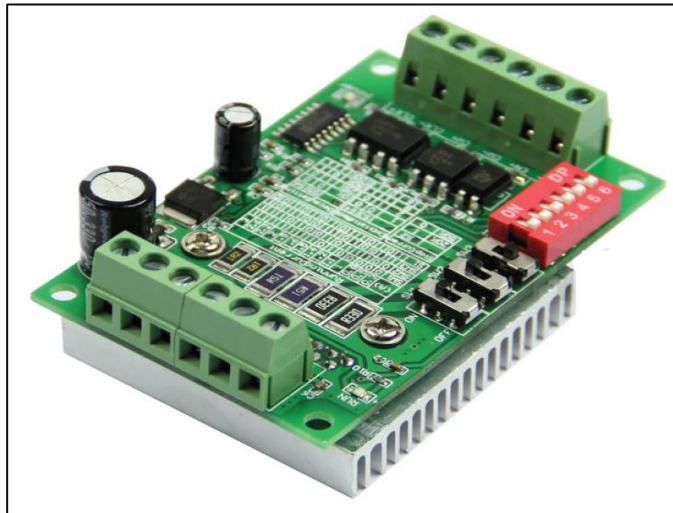


Figure 6: The driver card TB6560 -V2.0

**IV.2.4.1 Configuration the current of TB6560 stepping motor driver V-2.0**

(A)	0.3	0.5	0.8	1.0	1.1	1.2	1.4	1.5	1.6	1.9	2.0	2.2	2.6	3.0
SW1	OFF	OFF	OFF	OFF	OFF	OFF	OFF	ON	ON	ON	ON	ON	ON	ON
SW2	OFF	OFF	ON	ON	ON	OFF	ON	OFF	OFF	ON	OFF	ON	ON	ON
SW3	ON	ON	OFF	OFF	ON	OFF	ON	ON	OFF	OFF	ON	ON	OFF	ON
S1	ON	OFF	ON	OFF	ON	ON	OFF	ON	OFF	ON	OFF	ON	OFF	OFF

Table 4. Running Current

**IV.2.4.2 Configuration of the micro steps of the TB6560 stepping motor driver V-2.0**

Step	S3	S4
whole	OFF	OFF
half	ON	OFF
1/8	ON	ON
1/16	OFF	ON

Table 5. microsteps switches configuration

### IV.2.5 Emergency start and reset buttons

Emergency stop (E-Stop) buttons are an important safety component of many electrical circuits, especially those that control hazardous equipment such as gas pumps, moving machinery, saws, mills, and cutting tools, conveyor belts, and many other types of equipment. They are designed to allow an operator or bystander to stop the equipment in a hurry should anything go wrong. Emergency stop buttons are wired in series with the control circuit on a piece of equipment. Pressing the E-Stop button breaks the circuit and removes power from the holding relay that keeps the circuit energized. There are several differences between a stop , start buttons and an E-Stop button. The stop button is generally placed right next to the start button. It is the same size as the start button and if we press it the circuit is reset so that it can be restarted if desired. The E-Stop button is bigger and highly visible. It is generally located where it can be easily seen and pressed by the equipment operator or a bystander. Once pressed, the E-stop button locks into position and does not reset until manually reset by the operator. The circuit is broken and the equipment cannot be restarted until the E-stop is reset. Once the E-stop is reset, the start button can be used to bypass the normally open relay contact and energize the circuit [8].



Figure 47: emergency button



Figure 48 :START and STOP buttons

### IV.3 Overview of Grbl Controller

Grbl is an open source, embedded, high performance g-code-parser and CNC milling controller written in optimized C that will run on a straight Arduino. Else it's a high performance software for controlling the motion of machines that move, that make things, or that make things move, and will run on a straight Arduino. If the maker movement was an industry, Grbl would be the industry standard. The controller is written in highly optimized C utilizing every clever feature of the AVR-chips to achieve precise timing and asynchronous

operation. It is able to maintain more than 30 kHz of stable, jitter free control pulses <sup>[9]</sup>. Here is a list of currently supported G-code commands by Grbl:

- G0, G1 – Seek and linear motion with acceleration planning
- G2, G3 – CW and CCW arc motions with *no* acceleration planning
- G17, G18, G19 – Plane select
- G20, G21 – Inches mode enable and disable
- G53, G90, G91 – Absolute mode override, enable, and disable
- G80 – Motion mode cancel
- G92 – Coordinate offset
- G93, G94 – Inverse federate mode enables and disable
- M3, M4 – Spindle direction
- (TBD) M0, M1, M2, M30, M60 – Program pause and completed
- (TBD) G28, G30 – Go home

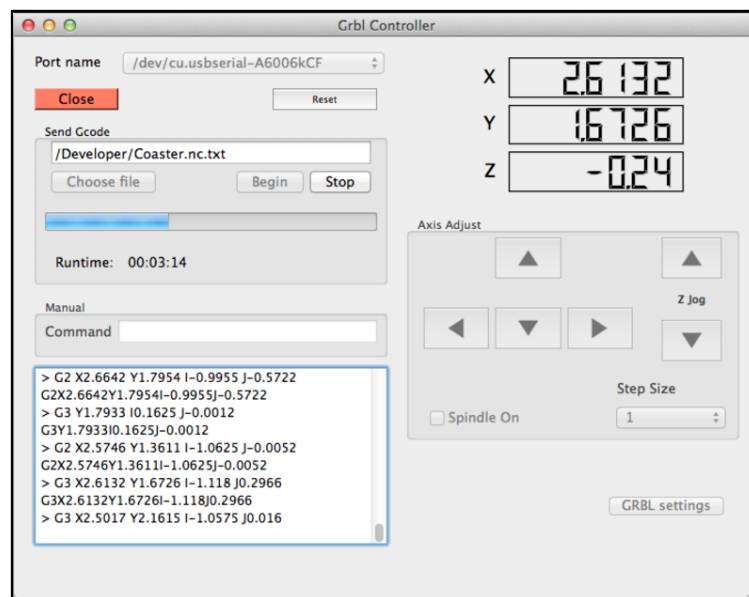


Figure 49: Interface of Grbl controller

### IV. 4 Overview of Inkscape

Inkscape is the open source community's alternative to Adobe Illustrator, the accepted industry standard tool for the production of vector-based graphics. Inkscape is a generally credible alternative for anyone whose budget can't stretch to Illustrator, although with a couple of limitations, it's also a Corel Draw, Freehand, or Xara X. What sets Inkscape apart is its use of Scalable Vector Graphics (SVG), an open XML-based W3C standard, as the native format <sup>[10]</sup>.

### IV. 4.1 Highlights of Inkscape

Inkscape has an impressive tool and feature set, including:

- Learning curve could be shallow or relatively steep depending on the user's requirements.
- 3D Boxes tool allows quick drawing and editing of boxes with perspective.
- Bezier Curves tool allows the drawing of complex shapes.
- Powerful path options to allow production of complex shapes through combining paths.
- Layer transparency effects.
- Apply Gaussian Blur to objects.

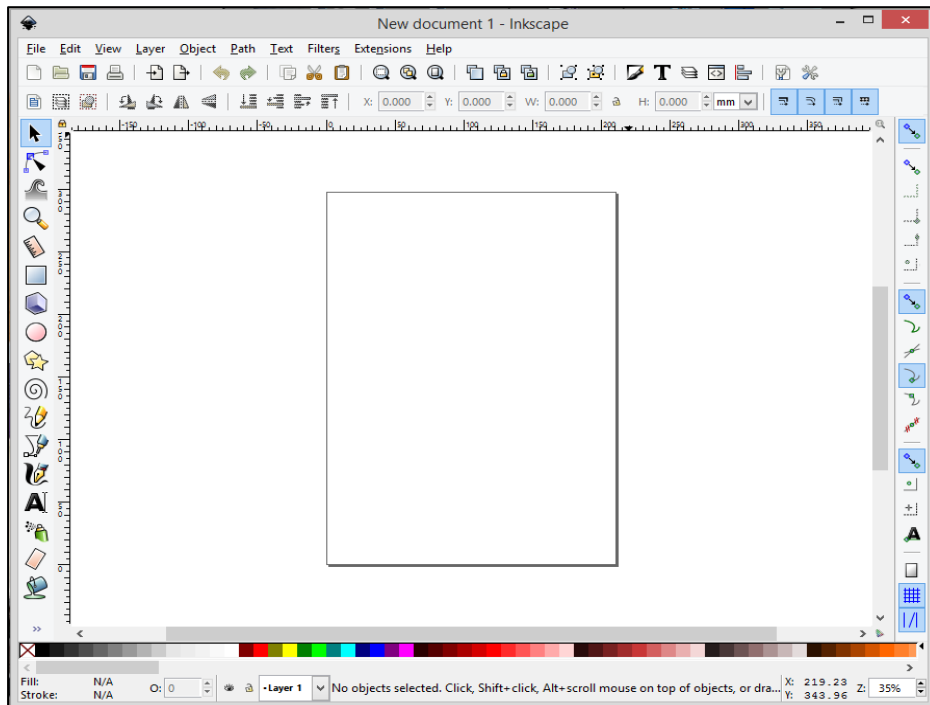
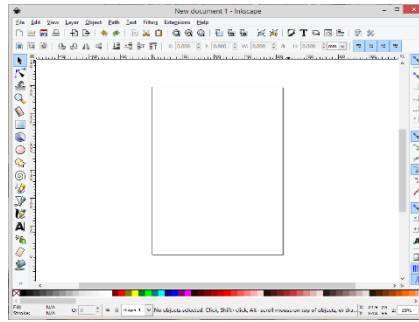
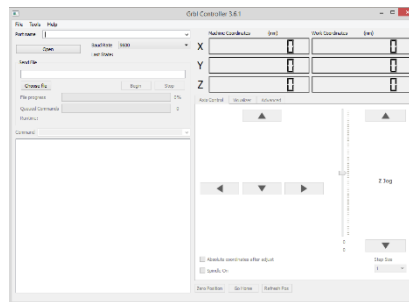


Figure 50:Interface Inkscape

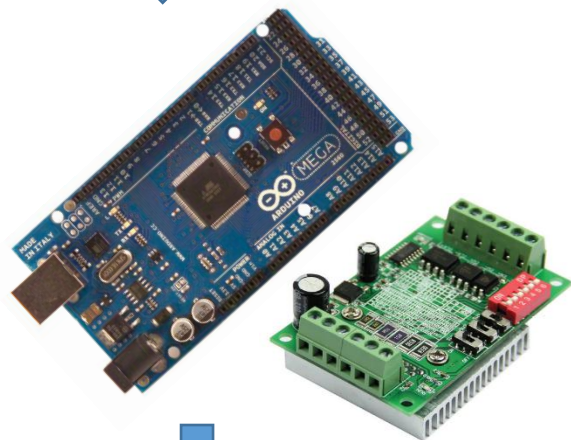
Inkscape software



GRBL controller



Arduino + Driver card



Stepper motors

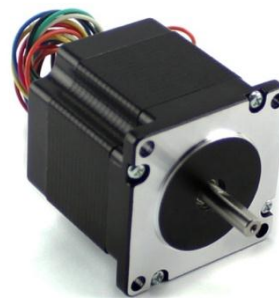


Figure 51: (G - Code) Transferring Cycle



### IV.5 Using and Running the machine:

For better working of the CNC machine the g code cycle (see figure 51) must be applied, so to do that we must follow the steps below:

- 1- Select the part which be worked on and fix it on the machine table.
- 2- Select the right tool for the right operation (Plasma tool- Laser tool . . .) and mount it on the tool holder of the machine.
- 3- Plug the power cable of the machine to the power source for turning on the machine.
- 4- Connecting the Arduino to the PC with the USB cable.

We had said that the machine is controlling by two ways:

#### a) With Sketch part

Our machine can machine or cut the parts using its sketch, to do that we must using the Inkscape software with those steps:

- 1) Have a drawing on the InkScape board.

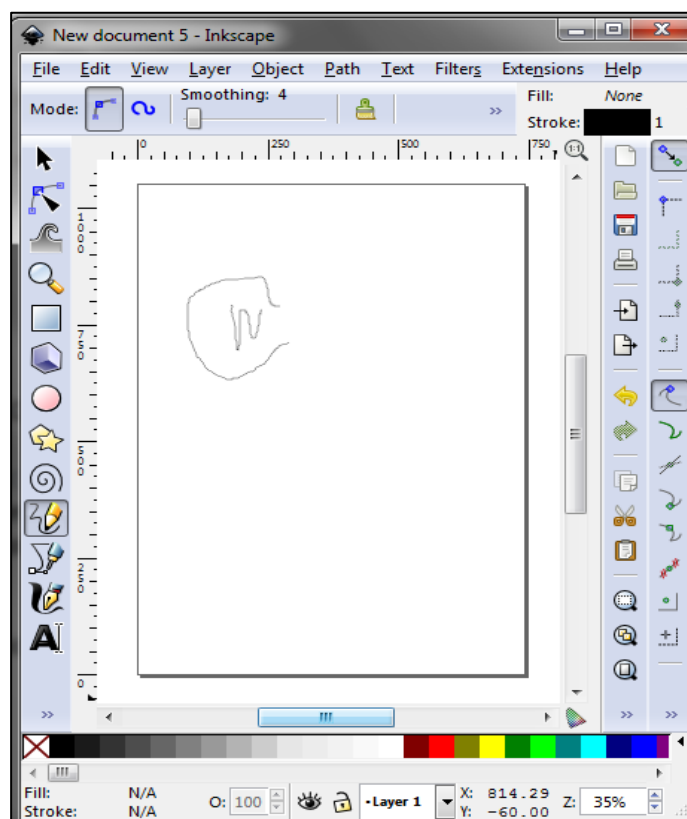


Figure 52: Drawing sketch

- 2) Select it.

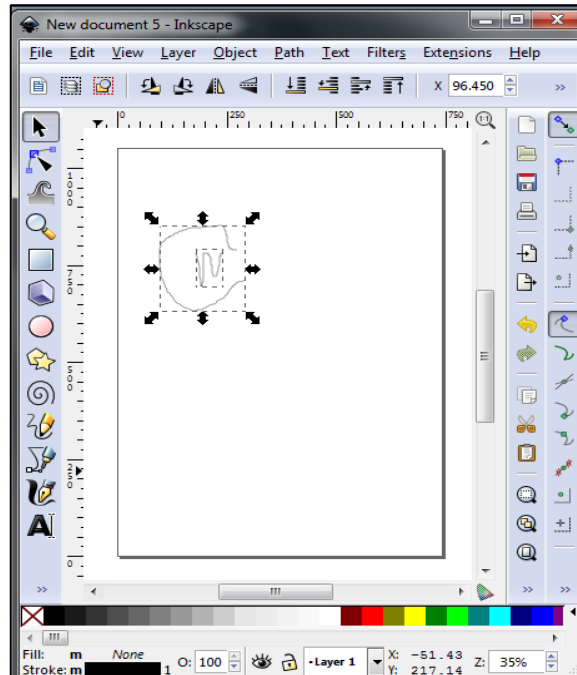


Figure 53: Sketch selection

- 3) Go to: “Extensions-Gcodetools-orientation points”.
- 4) Select “3 points Mode...” (in “orientation” tab).
- 5) Click “Apply” wait... Click “Close”.
- 6) Go to: “Extensions-Gcodetools-Tools library”.
- 7) Select “Cylinder” (in “Tools library” tab).
- 8) Click “Apply” wait...Click “Close” (you should get something like that – with big green rectangle).

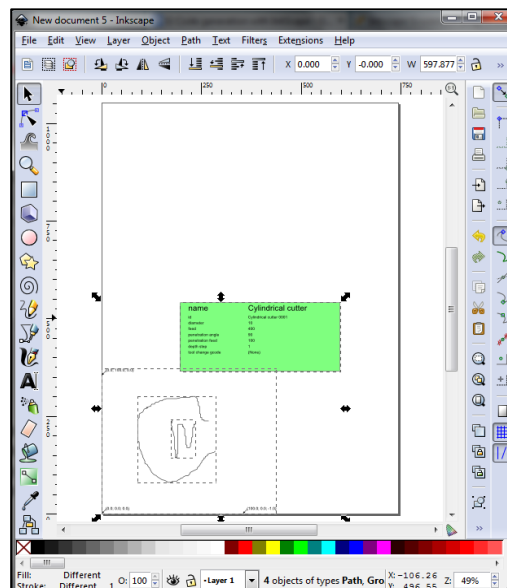


Figure 54:Extension activation

- 9) Go to: “Extensions-Gcodetools-Engraving”.

- 10) Go to “Options” tab.
- 11) Fill box “Offset along Z-axis” with the (drawing ON) position of your CNC machine
- 12) Go to “Preferences” tab.
- 13) Fill box “Z-Safe height for G00 move over blank” (drawing OFF) position of your CNC machine
- 14) Fill “File” and “Directory” for your convenience.
- 15) Go to “Engraving” tab.
- 16) Click “Apply” wait..., Click “OK” on popup window, Click “Close”.
- 17) You should have your G-Code (. ngc) file ready for use.

### b) With The G-code of the part

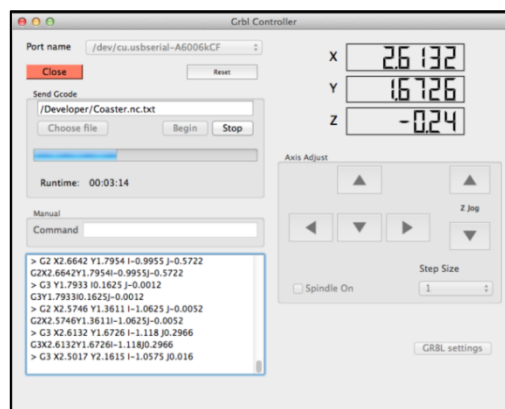


Figure 55: Interface of Grbl

**Port name:** This drop down will be populated by candidate serial ports. Only certain ports are actual serial ports connected to Grbl/Arduino. The easiest way to tell is to look at the list before you plug in your USB connector; close Grbl Controller; plug in the USB connector; open Grbl Controller and look at the list again. The item that is new is the desired COM port.

**Open – Close/Reset:** Open or close the COM port. Opening the COM port will reset Grbl and set coordinates to 0,0,0. You will see a version message from Grbl appear in the status window a few seconds after pressing this button. Closing the COM port has the effect of stopping the last operation on the Grbl. It is not a substitute for a proper emergency stop, but it is a good way to quickly stop an action.

**Choose File:** Brings up a file chooser dialog to pick your file to send to Grbl. On most systems you can choose a file while the COM port is being opened.

**Begin:** Will start sending file as soon as pressed. If Grbl Controller is still connecting with Grbl, the file will be sent immediately after all initialization is complete.

**Stop:** The file being sent will be stopped mid-stream. Currently there is no way to restart a stopped send of file.

Manual G Code/Command Enter G Code commands to execute immediately.

It has been observed that Grbl occasionally enters a state where specifying simple X1, Z30, etc. commands do not work. You must first preface with a G0 or G1. Once that is done, it should again be possible to send further commands with just the X, Y or Z command directly.

Hit the Enter key to accept the command.

The position entered will be interpreted in inches or millimeters depending on the mode specified in the options.

**Machine/Work Coordinates LCDs:** The work coordinates are the X, Y, Z coordinates that may be reset back to 0 if desired and all commands will reference the new work coordinates.

Grbl Controller displays Grbl's coordinates in the LCD displays.

**Last State:** This displays the last known Grbl operational state. This is normally going to show Idle or Run, but may contain other states.

**Axis Adjust/Jog and Step Size:** Use the buttons to move the motors by the amount relative, specified by the Step Size value.

**Absolute coordinates after adjust:** If enabled, when you enter a command in the Manual G Code entry, the values are interpreted in absolute work coordinates.

**Spindle On:** Enables or disables the spindle motor, provided you have that capability wired into your board and to an external motor controller.

**Reset Control – Soft Reset Grbl:** This sends a special reset command to Grbl which causes it to reboot and reinitialize. It does not affect machine coordinates, but it will reset work coordinates to match machine coordinates. Use Zero Position to restore work coordinates to 0.

**Reset Control – Unlock Grbl:** There are certain conditions where Grbl gets conflicting commands or otherwise enters an error state. If this happens, it will “lock” to prevent commands from causing harm to equipment.

Use this button to unlock Grbl, but only after you have ensured that the CNC machine is in proper operational condition.

**Zero Position:** Simply resets the work coordinates to 0, but is used frequently to restore operation from a new coordinate base, such as after aligning the spindle/bit over what is considered position 0,0,0 on the work piece.

**Go Home:** After running a file, this is used to move the spindle up and over the work piece back over X=0 and Y=0. The Z coordinate will be three mm higher than the highest point of Z-travel during the file send.

**Grbl Settings:** This brings up a dialog that is dynamically populated with available adjustable settings in the Grbl software. The number of settings varies with Grbl version. Any settings that are changed will be sent to Grbl and it will update its non-volatile memory.

### IV.6 Conclusion

At the end of this chapter we could say that our machine has a control flexibility, it can use both the sketch and the G-code of the part by many software and that is the benefit of using an open source software (Inkscape- Grbl controller) and an open source hardware (Arduino).

### General Conclusion

This theme, "Study and design of a CNC router machine", has shown us that the study, and design of a product is a vast project to be explored. In this brief we have played both roles, the role of the client who raises the problem and imposes its specifications and the role of the designer who takes care of the problem by seeking a solution according to the constraints demanded by the client. This study makes it possible to find the solution using the fundamentals of functional analysis to create complicated shapes with little time. The machine we have built meets the needs of the market, it works much more on metalworking. But with small modifications and changing the tools, it can be used at other workshops such as machining of wood and even can be used as a laser engraver.

In this project we used an open source hardware and software like Arduino board, GRBL library and its software for loading g-code to the machine and we used also Inkscape to transform any sketch to a g-code file. The open source community makes the project easy and cheap.

Our perspective in coming future is continuing to develop CNC machines that based on GT pulley belt system and V slot aluminum rails without leaving the open source community for both hardware electronics and the software. These abilities will guide us to prove that the cheap materials and the open source tools can lead to powerful CNC machines. We believe that price and place doesn't always refer to the performance and quality especially in machinery and we are on the road to prove it.

Finally, this project is only a starting point that motivates us to develop other systems and to increase our knowledge in our field and opens the doors for larger projects.

## Bibliography

---

### Bibliography

- <sup>[1]</sup> Steve krar; Arther Gill; Peter Smid “Computer Numerical Control –Simplified”
- <sup>[2]</sup> Peter Smid “CNC Programming Handbook “
- <sup>[3]</sup> Hazard F.Lelong B.Quinzain “ Memotech –Strucure metalique”
- <sup>[4]</sup> the official web site of Openbuilds<sup>®</sup> <https://www.openbuilds.com/>
- <sup>[5]</sup> the official web site of apte <https://www.methode-apte.com/>
- <sup>[6]</sup>The Official website of Arduino <https://www.arduino.cc/>
- <sup>[7]</sup> The website All electronics <http://www.allelectronics.com/>
- <sup>[8]</sup> The website circuit globe <http://www.circuitglobe.com/>
- <sup>[9]</sup> The Official website of Grbl Controller <https://github.com/>
- <sup>[10]</sup> The Official website of Inkscape <https://inkscape.org/>
- <sup>[11]</sup> Jean Louis FANCHON Guide des Sciences et technologies industrielles
- <sup>[12]</sup> The website Steel Tube Institute <https://steeltubeinstitute.org/>

# **Annexes**



## ملخص

يشهد القطاع الصناعي تطورا كبيرا في مجال التحكم الرقمي وقد أصبحت من ضروريات التصنيع لهذا قمنا بدراسة، تصميم وإنشاء آلة ذات تحكم رقمي بثلاث محاور لمشروع التخرج لنيل شهادة الماستر.

هذه الآلة تعتمد على العديد من الانظمة والخصائص حسب طلبات الزبون من استعمال برامج التصميم بالحاسوب وبرامج التصنيع بالحاسوب مثل SOLIDWORKS و Grbl التي تسمح بالاستعمال الحسن للآلة.

كلمات مفتاحية: التصنيع، تحكم رقمي. سي ان سي. روتر

## Abstract

The industrial sector is witnessing a great development in the field of numerical command and has become a necessary manufacturing for it. We have studied, designed and build a three-axis numerical control machine for the graduation project.

This machine depends on many systems and characteristics according to the customer's requests using the computer design programs and computer manufacturing programs such as SOLIDWORKS and Grbl which allow the good use of the machine.

Keywords: manufacturing, digital control.CNC,router

## Résumé

Le secteur industriel connaît un développement important dans le domaine de la commande numérique qui est devenue l'une des nécessités de fabrication. Pour cela, nous avons étudié la conception et la création d'une machine à commande numérique a trois axes comme projet de fin d'études pour l'obtention d'un diplôme de master.

Cette machine dépend de nombreux systèmes et caractéristiques selon les demandes des clients, en utilisant des programmes de conception informatiques et de fabrication tels que SOLIDWORKS et Grbl qui permettent de bien utiliser la machine.

Mots-clés : fabrication, commande numérique.CNC,router