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HIGHER SCHOOL IN APPLIED SCIENCES
–T L E M C E N–

وِزَارَة التَعليم العَالِي وَالبَحث العِلمِي
اَلمَدرَسَة العُليَا فِي العُلُوم التَطبِيقِيَة
–تِلِمسَان–

Graduation Thesis

For the attainment of the Engineer's degree

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speciality : Automatic Control

Presented by : KORICHI Mohamed Yasser
LAZREG Abdellah

Title

Manufacturing of a computer numerical control (CNC) cutting machine.

Publicly defended, on 07/01/2024, before the jury composed of :

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بسم الله الرحمن الرحيم

Dedications

I dedicate this modest work to my entire family in particular to my dear father and mother and to all those who helped me

Yasser

I express my deepest gratitude to my parents for their unwavering support throughout our school years, and to my sisters and extended family.

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Abdellah

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الملخص

تلعب ماكينات التحكم الرقمي بالكمبيوتر (CNC) دوراً محورياً في عمليات التصنيع في مختلف القطاعات في المشهد الصناعي سريع التطور اليوم. تستكشف هذه الأطروحة الجوانب الأساسية لماكينات التحكم الرقمي الحاسوبي، بما في ذلك تاريخها وتعريفها ومبادئ عملها وهيكلها وتصنيفها وتطبيقاتها ومزاياها واعتبارات تصميمها. ومن خلال الخوض في هذه الجوانب، تهدف هذه الأطروحة إلى توفير فهم شامل لتكنولوجيا التحكم الرقمي باستخدام الحاسوب وآثارها في التصنيع الحديث.

كلمات مفتاحية : التحكم الآلي باستخدام الحاسب الآلي، القطع بالليزر، المغزل، التفريز باستخدام الحاسب الآلي، GRBL، وحدة التحكم باستخدام الحاسب الآلي، MOCN، 3 محاور ,CNC، نقش.

Abstract

In today's rapidly evolving industrial landscape, Computer Numerical Control (CNC) machines play a pivotal role in manufacturing processes across various sectors. This thesis explores the fundamental aspects of CNC machines, including their history, definition, working principles, structure, classification, applications, advantages, and design considerations. By delving into these aspects, this thesis aims to provide a comprehensive understanding of CNC technology and its implications in modern manufacturing.

Key words: CNC, laser cutting, spindle, CNC milling, GRBL, CNC controller, MOCN, 3-axis CNC, engraving.

Résumé

Les machines à commande numérique par ordinateur (CNC) jouent un rôle essentiel dans les processus de fabrication de toutes les industries dans le paysage industriel actuel qui évolue rapidement. Cette thèse explore les aspects fondamentaux des machines à commande numérique, notamment leur histoire, leur définition, leurs principes de fonctionnement, leur structure, leur classification, leurs applications, leurs caractéristiques et leur conception. En approfondissant ces aspects, cette thèse vise à fournir une compréhension complète de la technologie CNC et de ses implications pour la fabrication moderne.

Mots-clés : CNC, découpe laser, broche, fraisage CNC, GRBL, contrôleur CNC, MOCN, CNC 3 axes, gravure.

Contents

List of Figures

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List of Acronyms

LASER Light Amplification by Stimulated Emission of Radiation

NC Numerical Control

CNC Computer Numerical Control

LSI LARGE SALE INTEGRATED

MIT Massachusetts Institute of Technology

MOCN Machines Outils a Commande Numerique in franch

CAD Computer Aided Design

CAM Computer Aided Manufacturing

EDM Electrical Discharge Machining

OL OPEN LOOP

CL Close Loop

Dacro:R&DR&D Dacro:R&DResearch and Development

ASF INSURES AND Financial Services

SEO Search Engine Optimization

SME Small and Medium-sized Enterprises

UGS universal G-code Sender

PCB Printed Circuit Board

EIA electrical industry association

EDA Electronic Design Automation

NO Normally Open

NC Normmaly closed

SPDT single pole doble throw

3D 3 dimensions

GENERAL INTRODUCTION

In the dynamic and ever-evolving realm of modern industry, the significance of Computer Numerical Control (CNC) machines cannot be overstated. These machines have fundamentally transformed the landscape of manufacturing, offering unprecedented levels of precision, efficiency, and automation. From the production of intricate aerospace components to the fabrication of precision medical devices, CNC machines have become indispensable tools across a wide array of industries.

The primary objective of this thesis is to provide a comprehensive exploration of CNC machines, spanning their historical origins, operational mechanisms, structural components, classification systems, diverse applications, inherent advantages, and crucial design considerations. By delving deeply into these fundamental aspects, this thesis seeks to offer a holistic understanding of CNC technology and its profound impact on contemporary manufacturing practices. The evolution of CNC machines can be traced back to the mid-20th century, with the emergence of early numerical control (NC) systems. These primitive systems relied on punched cards or tapes to control the movements of machine tools. However, it was not until the advent of computers in the 1970s that CNC machines truly came into their own, ushering in a new era of digital control and automation. A typical CNC machine comprises several key components, including the control panel, machine bed, spindle, cutting tool, and worktable.

Selecting the appropriate CNC machine involves a critical decision between a laser CNC machine and a mechanical CNC machine (machine-outil à commande numérique, MOCN), considering factors such as the machine's structure and frame, guiding systems, and motors and actuators. Equally significant is the electronic design, encompassing the controllers and drivers responsible for the machine's precise movements and operations. This thesis endeavors to thoroughly analyze these choices and elucidate the inherent advantages of each, particularly in defense applications.

- Chapter One: Historically, CNC machines evolved from early numerical control (NC) systems to sophisticated computer-controlled machines. These machines operate based on programmed instructions that dictate precise movements and actions, resulting in highly accurate and repeatable operations.
- Chapter Two:CNC machines are classified based on function, number of axes, motion systems, and operating modes. They find applications in diverse industries, including aerospace, automotive, electronics, defense, and healthcare, for various machining tasks.
- Chapter Three: Mechanical and electronic designs are crucial aspects of CNC machines, requiring robust structures, precise guiding systems, and efficient motors and actuators. Integration of laser or spindle systems, along with proper programming and calibration, is essential for optimal CNC machine performance.
- chapter four:The Business Model Canvas (BMC) chapter in this thesis presents a comprehensive overview of the strategic framework for a CNC machine manufacturing business. It outlines key components such as the value proposition, customer segments,

channels, and revenue streams. By utilizing the BMC, the company can effectively articulate its business model and strategize for sustainable growth in the competitive CNC machine market.

Overall, this thesis aims to deepen understanding of CNC technology and its significance in modern manufacturing, inspiring further research and innovation in the field.

Chapter 1

Generality on CNC machines

Introduction

Numerically controlled machines, which are typical mechatronic products, comprise machine tools which and a numerical control system, which is an electrical component.
This chapter discusses the history, constituent units, functions and future directions of NC systems, i.e. the intelligence of NC machines. In this chapter, the history, constituent units, functions and future directions of numerical control systems, i.e. the intelligence of numerical control machines, will be discussed. By studying this chapter, you will gain an overall understanding and fundamental knowledge of NC systems.fundamental knowledge of numerical control systems.

1.1 Historic

Numerical control is the system that enables machine tools to machine parts of various shapes with speed and precision. In NC (Numerical control), the servomotor is used to control the machine tool according to a user's operation and a servomotor drive mechanism to activate the servomotor. In other words, NC is a control device that machines a target part by activating the servomotor according to commands. NC combined with computer technology is known as computerised NC or CNC (Computer Numerical Control). A CNC machine made up of vacuum tubes, transistors, circuits, logic elements such as LSI (large-scale integrated) circuits is called a "hardwired CNC" and performs the functions of the CNC by connecting the elements using electrical wiring. Instead of elements and circuits, NC functions are implemented by software in the CNC. The move from wired NC to CNC was driven by advances in the capacity and availability of microprocessors and memory.

In 1947, the year the numerical control was born. It all started when John C. Parsons of the Parsons Corporation, Traverse City, Michigan, a manufacturer of helicopter rotor blades, couldn't make his models fast enough. So he invented a way of coupling computers with a template moth. Parsons used the cards to run his Ron fist number system.

1949 was the year of a new "urgent need". The US Air Materiel Command realised that the parts for its aircraft and missiles were becoming increasingly complex. In addition, as designs were constantly being improved, design changes were often difficult to make, As designs were constantly being improved, design changes were often being made. Were made. So, in search of faster production methods, an Air Force design contract was awarded to Parsons Corporation. Parsons Corporation was awarded an Air Force design contract.MIT (Massachusetts Institute of Technology) was the subcontractor.[7]

In 1951, MIT took over all the work and, in 1952, the prototype of today's NC machine, a modified Cincinnati Hydrotel milling machine, was successfully demonstrated. The term NC was born at MIT.[11]

Initially, CNC technology was applied to lathes, milling machines, etc. that could perform a single type of machining operation. Later, attempts were made to process a variety of parts that might require several different types of machining operation, and to perform them all at once. This led to the development of CNC machining centres capable of performing multiple operations. Initially, CNC machining centres were designed for prismatic machining of components, combining operations such as milling, drilling, boring and tapping. Gradually, machines designed for the manufacture of cylindrical parts, known as turning centres, were developed. [1]

1.2 Definition of NC (numerical control)

NC (Numerical control) is currently imposing its technology on the world of machining. It is designed to control the operation of machine tools based on a program, without operator intervention during execution, and has therefore become capable of producing in quantity and quality.

The system comprises a set of automated mechanisms where movement commands, displacement speeds, and precision parameters are controlled using digital information. This information is encoded on various media such as punched tapes, magnetic cassettes, or diskettes, or stored in memory within the latest generation of CNCs with integrated computers. Figure 1.15 illustrates the A0 diagram of the CNC machine, depicting the overall function of the system in adding value to the work material.

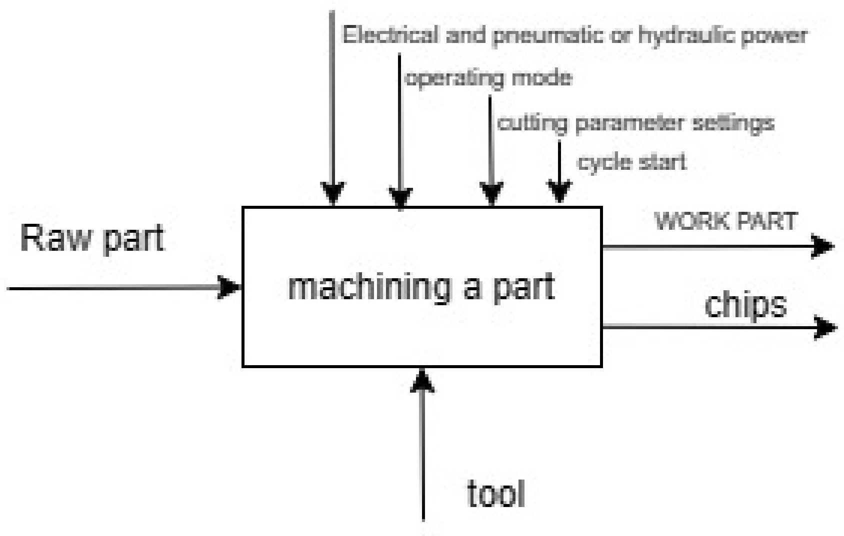

Figure 1.1 *A0 diagram of CNC machine.*

1.3 How a CNC machine works?

CNC (numerically controlled) machines operate based on codes programmed by predefined software. These codes provide precise instructions for movements across one or more axes and for the necessary tool changes to transform 2D designs into 3D products. These machines significantly enhance production and quality, especially when machining multiple parts identically with the same tool. The figure 1.2 you sent is a block diagram of a CNC. It depicts the fundamental parts and their interactions.

The CNC machine system is comprised of three main components: an electronic system, a mechanical system, and a software system.

The electronic system facilitates the precise activation of motors, receives commands from the software, and communicates them to the mechanical system. It generates control signals for the motors responsible for guiding the tool's movement and includes the power supply, control board, and stepper motor drivers. **The mechanical system**, dedicated to

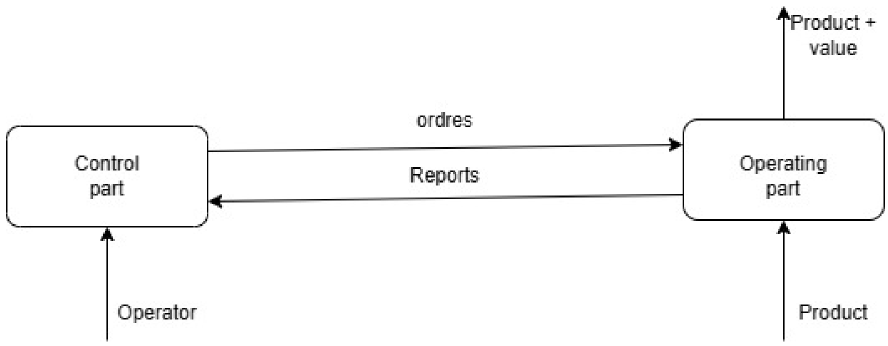

Figure 1.2 *Decomposition of a CNC machine.*

three-axis movement, consists of linear rails connected by bearings for stability. Motors on each axis respond to signals from the electronic system. Each motor is connected to a motion transmission system that converts motor rotation into translational motion. Managing motor rotation involves controlling movement on each axis and directly regulating motor speed to control axis movement speed. Limit switches are integrated into each axis to prevent exceeding operational ranges, and an emergency stop button is frequently included.

The software system involves using CAD (computer-aided design) software to design the part to be machined. This design is then processed by CAM (computer-aided manufacturing) software to translate it into a line of code (computer program). This code must be compatible with the software that operates the machine.

1.4 CNC machine Structure

The control parts work together to interpret the programming instructions and precisely control the motion and operation of the machine's cutting tools and workpiece. The operation parts are the physical components that actually perform the machining work.

- **control part**
  - A display screen for viewing inputs.
  - The data reader.
  - The calculator.
  - The electronic cards and memories.
  - The keyboard for entering commands.
- **Operating part**
  - A base, ensuring the machine's independence from the ground.

– A frame with wide guides made of treated steel.
– A tool support.
– A table supporting moving parts with 2 or 3 axes.
– A Motors to drive the stepper motor table.
– A position sensor measuring element resilient at all times to the position of the moving parts on each axis.

1.5 CNC machines Classification

There are a number of different types of CNC machine on the market today, distinguished by their operating mode, cutting tool, materials and the number of axes they can machine simultaneously. The aim of this article is to give advice on the different types of CNC machine available according to the different classifications, and to explain how to choose the CNC machine best suited to your needs.

1.5.1 Types of CNC machine by function

CNC machines can be categorised in a number of ways, one of which is based on their design and function. In this section, based on this classification we find :

- **CNC Router:** A CNC router, similar to a CNC milling machine, is used for machining softer materials and may have slightly lower precision. Components of a typical CNC router include a mechanical base, power supply, spindle, stepper drivers, stepper motors, and controllers. shown in figure 1.3 Compared to traditional machining methods, CNC routers offer advantages such as higher productivity, greater precision, and reduced material wastage, enabling faster production of products.

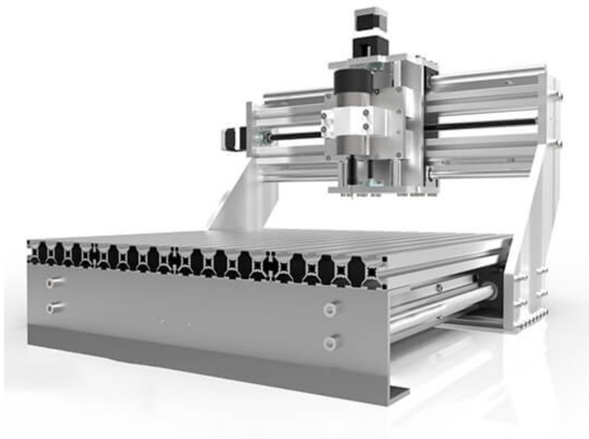

Figure 1.3 *cnc router.*

- **CNC plasma cutting machine:** A CNC plasma cutter figure 1.4 delivers precise, accurate cuts through the use of an electric discharge arc, much like a plasma torch. This arc ionizes the air and melts the material at the contact point, ensuring accuracy. However, the plasma cutting process is limited to electrically conductive materials, including commonly used materials such as aluminum, stainless steel, steel, brass, and copper.

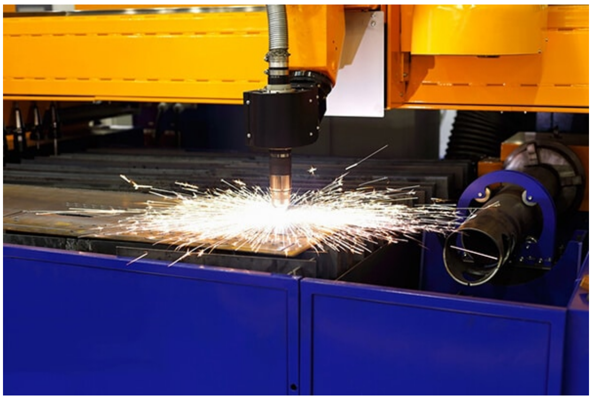

Figure 1.4 *CNC plasma cutting machine.*

- **CNC laser cutting:** CNC laser cutters, akin to CNC plasma cutters, excel at cutting tough materials. However, CNC laser cutters utilize a highly concentrated laser beam, contrasting with plasma cutters that employ ionized gases. Because of the smaller contact point and thermal propagation of lasers, CNC laser cutters typically provide superior precision and surface finish compared to CNC plasma cutters. Nevertheless, CNC laser cutters are generally more costly than CNC plasma cutters with similar capabilities in terms of precision and cutting depth.

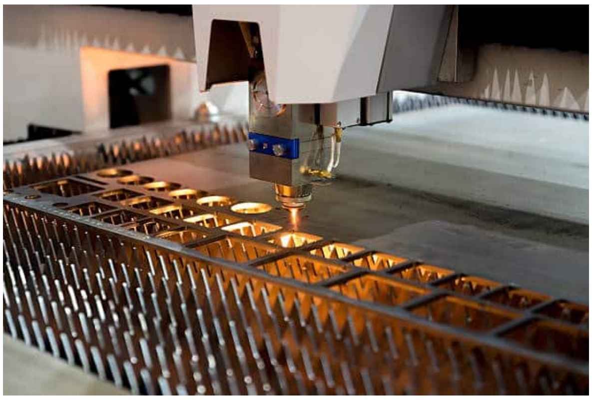

Figure 1.5 *CNC laser.*

- **electric discharge machine:** as figure 1.6 shows CNC electric discharge machines (EDMs) , also commonly called CNC spark erosion machines, use electrical sparks to form and shape materials. The EDM process is alternatively referred to as wire burning, sinking, spark machining, or spark erosion.

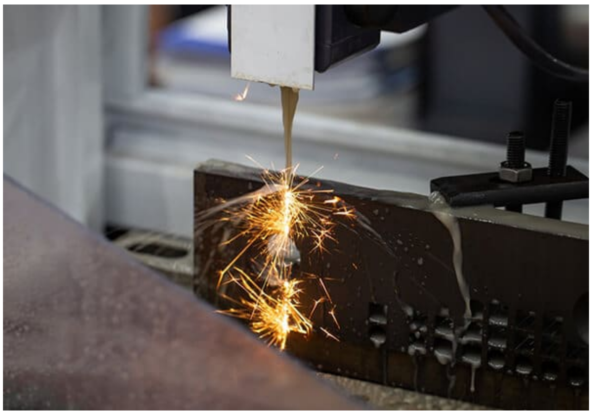

Figure 1.6 *Electric discharge machine.*

- **Water jet cutting machine:**example in figure 1.7 CNC waterjet cutters,true to their name, employ high-pressure water jets, sometimes supplemented with abrasive materials, to efficiently cut diverse materials. These cutters are proficient in handling both 2D and 3D cuts and are particularly skilled at cutting thick materials.

Figure 1.7 *Watterjet cnc machine.*

- **CNC pick and place robot**: Pick-and-place robots have gained significant traction in the manufacturing industry because they are specifically designed for repetitive tasks. These CNC machines require no manual handling of parts as we can see on the figure 1.8, minimizing human intervention and reducing associated risks. A pick-and-place robot typically includes motors or actuators that guide its robotic arm's movements and a manipulator that holds the part securely. The choice of manipulator depends on the part's nature: a collet is perfect for rigid, heavy parts like car frames, while a suction cup is more appropriate for delicate items like glass panels.

Figure 1.8 *Pick and place robot.*

- **3D printer:** A CNC machine, commonly referred to as a 3D printer, is utilized to produce three-dimensional parts by layering materials according to a digital design or model as shown in figure 1.9. To prepare the 3D design, an operator employs CAD software, which is subsequently sliced into 2D layers by CAM software to generate the necessary commands for controlling the printing process.

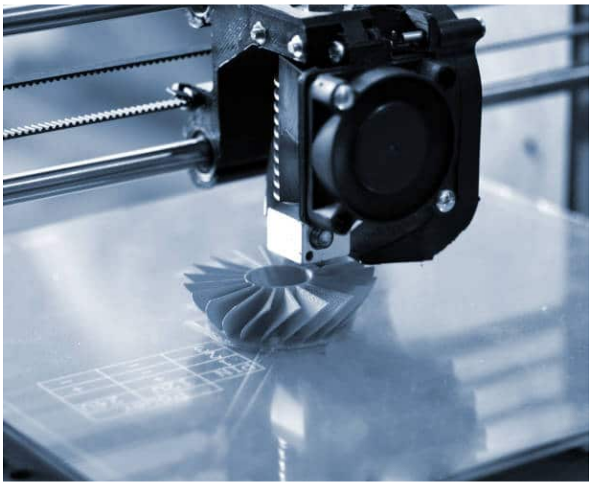

Figure 1.9 *3D printer.*

1.5.2 Types of CNC machine by number of axes

Having identified the type of CNC machine, further classification is based on the number of axes used. Multi-axis machining is a specialised form of CNC machining that involves the use of multiple axes of movement to achieve complex geometric shapes and precise tolerances.

For example, a CNC milling machine can be categorised into 3-axis, 4-axis or 5-axis variants, each offering different capabilities and pricing. Here are some of the most common types of CNC machines:

- **2-axis CNC machine:** These machines are most often employed for simple tasks, including creating straight cuts or drilling holes in boards. They are usually appropriate for machining a single surface of a workpiece without the necessity for repositioning. On 2-axis CNC machines, the workpiece remains stationary during the machining process..

- **3-axis CNC machine:** These machines are capable of machining all six surfaces of a square or rectangular block of material, but the block must be repositioned. However, the part itself remains stationary during the machining process on 3-axis CNC machines.

- **4-axis CNC machine:** Known as the A axis, this extra axis enables the cutting tool to execute rotational movements along the X axis. The workpiece can similarly be moved along this axis. Such machines are particularly advantageous for making cut-outs and executing cutting operations along arcs.

- **5-axis CNC machine:** These machines are acclaimed for their capability to simultaneously work on five surfaces of a part without requiring repositioning, making them highly efficient for manufacturing complex and precise parts. This is particularly advantageous in the production of medical and aerospace equipment.

- **7-axis CNC machine:** These machines are widely used in the military, aerospace, and medical industries because they can produce highly complex parts. The 7-axis configuration's additional motion axes enable sophisticated machining operations and complex part designs.

- **9-axis CNC machine:** This configuration allows a 9-axis machine to create parts with both internal and external features. These machines are perfect for producing dental implants, surgical tools, and complex aerospace equipment. The capability to perform milling and turning operations within a single setup provides enhanced versatility and efficiency in manufacturing processes.

- **12-axis CNC machine:** By integrating two cutting heads and using all six possible axes, these machines offer a significant increase in precision. They have the potential to double production speeds, and even achieve higher levels of productivity. However, it's important to note that the use of 12-axis CNC machines is generally reserved for specialized, demanding applications where precision and efficiency are paramount. For most standard applications, the complexity and cost of these machines can outweigh the benefits.

1.5.2.1 The different types of 3-axis CNC machines

There are two main types of traditional 3-axis CNC machine traditional 3-axis machines. We have type 1 machines where the worktable moves in the Y axis and the gantry is fixed in this axis. as shown in figure 1.10 **Advantages:**

- Movement along the Y axis can be achieved with fewer stepper motors, given that the table is lighter than the gantry.

- Utilizing a stepper motor for Y-axis movement is more economical.

Disadvantages:

- Considering the table dimensions, the machine needs to be larger in the Y direction than the work surface.

- This design results in a heavier machine.

Figure 1.10 *CNC machine type 1.*

There are also Type 2 machines, where the gantry moves along the Y axis while the worktable remains fixed. In our case, we opted for a Type 2 machine to fulfill our requirements for a lightweight, portable, and compact solution. example figure 1.11 **Advantages:**

- The machine's size can be minimized due to the closer ratio between the work surface and the frame.

- Since there is no need to accommodate table dimensions, the machine will be lighter.

Disadvantages:

- To handle the gantry's weight, Y-axis movement needs either two stepper motors or a larger motor coupled with a belt system.

- As a result, the machine will be pricier.

Figure 1.11 *CNC Machine type 2.*

1.5.3 Types of CNC machines based on motion systems

The basic principle of a CNC machine is to move the cutting tool and the workpiece relative to each other. The cutter is constantly readjusted and oriented towards its intended position. Several methods are used to reposition the tools, leading to the emergence of three distinct types of CNC machine:[7]

- **Point-to-point positioning system**
  The most basic type of computerized digital control system is a PTP (Point to point) CNC Controller.In this control system, the cutting tool is directed to a predetermined point, at which time the machining process begins around that specific cutting point.

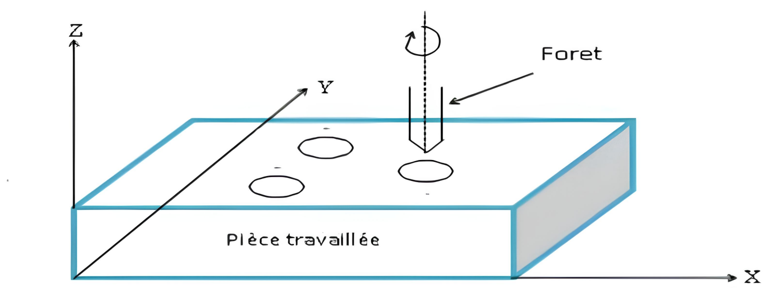

Figure 1.12 *Point-to-point positioning system.*

- **Linear positioning system**
  A linear positioning control system allows simultaneous repositioning of the cutting tool and machining of the workpiece. However, the movement is limited to being parallel to a single axis at a given moment. The repositioning and machining processes are performed at a controlled speed.

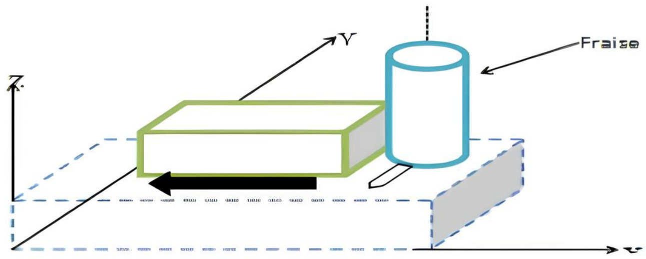

Figure 1.13 *Linear positioning system.*

- **CNC contouring system**
  The CNC Contouring Path system, also known as the continuous path CNC system, is the most expensive of the three positioning control systems, with the ability to create very complex pieces. This system can perform both a PTP positioning and a linear positioning. In addition, they can simultaneously control the positioning of the'cutting tool on several axes.

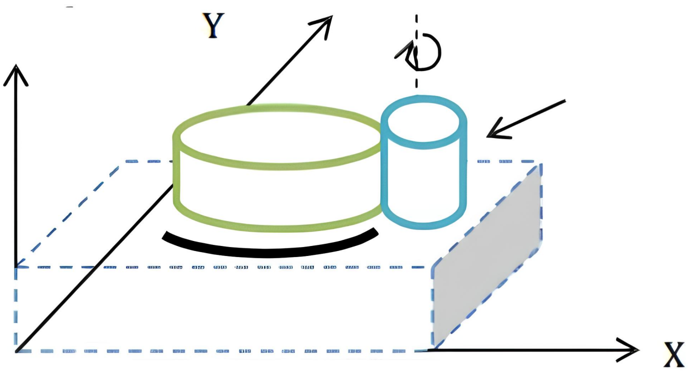

Figure 1.14 *CNC contouring system.*

1.5.4 CNC Machine Types by Operating Mode

Based on the servo system, there are different types of CNC machine systems.

- **OL (Open-loop) control system:**
  In an OL (open-loop) control system, the absence of detection or feedback devices is notable. The drive circuit amplifies the power, and the instruction signal from the CNC device propagates in a single direction to control the stepper motor responsible for moving the machine table.
  This system has the advantage of being economical, due to its relatively low cost. However, its disadvantages lie in its mediocre stability and precision, which may compromise the quality of the work performed.

- **Semi-closed-loop control system :**
  In a semi-closed-loop control system, the actual displacement of the worktable is determined by an angular displacement sensing device placed directly at the end of the servomotor or ball-screw shaft.
  This detection device compares the calculated value with the initial value of the worktable displacement command and adjusts the disparity accordingly. Although this control system is moderately priced, it offers high accuracy and stability.

- **CL(Closed-loop) control system :**
  In a CL (closed-loop) control system, a linear displacement sensing device is used, usually mounted on the moving parts or machine tool bed. The CNC comparator receives the actual displacement detected and compares it with the value of the programmed instruction.
  Maintaining the stability of a CNC machine with CL control can be difficult, but this type of system offers considerable accuracy.

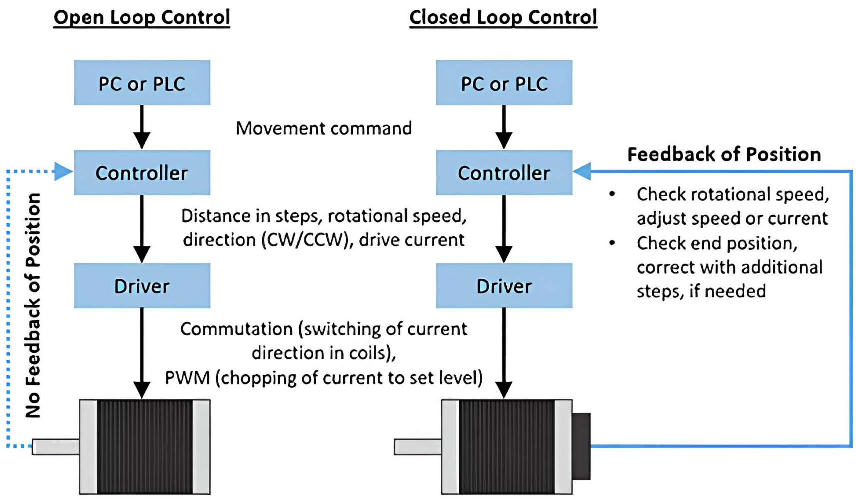

Figure 1.15 *OL control systems (left) , CL control systems (right) ..*

1.6 CNC machines Applications

CNC machining, a versatile and economical manufacturing process, is compatible with a wide range of materials. It benefits a wide range of industries and applications, whether used directly, indirectly or in combination with other processes. The unique advantages of CNC make it ideal for a multitude of industries, suitable for the manufacture of diverse parts and products, thanks to the ability of CNC machines to work on almost any type of material. Some fields of application for CNC machines.

1.6.1 Aerospace industry sector

The aerospace industry has long used CNC machining. The manufacture of metal components for aircraft demands a high level of precision, crucial for safety-critical applications. What's more, the variety of technical metals compatible with CNC offers aerospace engineers a wide range of options to meet the specific requirements of their designs.

1.6.2 Automotive industry

The automotive industry frequently uses CNC milling machines for prototyping and production. Extruded metal can be machined to create cylinder blocks, gearboxes, valves, axles and various other components. In parallel, CNC machines are employed to transform plastics into items such as dashboard panels and fuel gauges.

1.6.3 Electronics

CNC machining is also essential in the prototyping and manufacture of consumer electronics, encompassing devices such as laptops, smartphones, and various other appliances. A case in point is the chassis of an Apple MacBook, made from CNC machining of extruded aluminum, followed by an anodizing process to achieve the desired finish.

1.6.4 Defense sector

The military sector frequently uses CNC machining to prototype robust, reliable parts. The aim of this process is to ensure that parts can withstand wear and tear with minimum maintenance.

1.6.5 Health sector

CNC machining is applied to a variety of medically-safe materials, offering a process suited to the manufacture of unique, customized parts. It has many applications in the medical industry, where the tight tolerances ensured by CNC machining are crucial to guaranteeing the high performance of machined medical components.

1.7 Key Advantages of CNC Machines

In the world of modern manufacturing, Computer Numerical Control (CNC) machines have revolutionized the production process. Their ability to operate with minimal human intervention, adapt to different tasks swiftly, and enhance safety standards has made them indispensable in various industries. This section delves into the primary benefits of CNC machines, highlighting their automaticity, flexibility, and safety features.

1.7.1 Automaticity

One major advantage of a CNC is the high degree of automation it provides to machines. This reduces or eliminates the need for operator intervention during part production. Many CNC machines can operate without assistance throughout the machining cycle, enabling the operator to handle other tasks away from the workstation. This capability offers numerous key benefits, including:

- Greatly reduced operator fatigue.
- Reduced occurrence of human errors.
- Consistent and predictable machining times for parts within the same series.

1.7.2 Flexibility

Program-controlled NC machines can machine different parts simply by loading a new program. Once verified and executed for the initial series, this program can be easily recalled for repeated production. NC machines also feature extremely short changeover times, making them perfect for just-in-time production demands. The extensive flexibility of NC machines offers numerous advantages:

- Quick and easy part program changeover

- Shortened manufacturing time
- Reduction in tooling needs and elimination of jigs
- Fewer special tools and form tools required
- Reduced setup and adjustment times for workstations (most settings, especially tool settings, are made outside the machine)
- Swift processing of machining modifications (it's simpler to alter a program line than to adjust a tool or special jig)
- More efficient and reliable definition of optimum machining conditions
- Fewer parts stored due to the machine's versatility
- Decreased waiting time between different machining centers in a workshop
- Space-saving in the workshop
- Ability to produce complex parts with simultaneous movements on multiple axes
- Automatic control of tools and part dimensions, with NC accounting for any necessary corrections

1.7.3 Safety

CNC has greatly contributed to improving machine safety:

- It accurately understands the working envelope for tool operation (including the ability to memorize maximum strokes of moving parts).
- It permits graphic simulation of new programs outside of the machining process, allowing for the verification and detection of potential collision risks.
- By consistently monitoring the ongoing machining, it can halt the process and notify the operator if an incident occurs.
- Manufacturers provide advanced protection devices (e.g., against splashing chips or coolant) that are not typically needed on a conventional machine.[6]

1.7.4 Industrial impact

The use of numerical control is not limited to machine tools working by removing material with cutting tools. It is present on laser beam cutting installations, in electroerosion whether in routing or wire cutting, in punching or folding of sheet products, for the installation of components, during assembly operations. It is also used to control plotting tables, three-dimensional measuring machines and robots. It increases the efficiency of manufacturing operations while reducing costs, it also allows a single facility to produce a variety of product and increase production. [3]

Conclusion

In conclusion, this chapter provides a comprehensive overview of Computer Numerical Control (CNC) technology and its diverse applications in various industries. It intricately explains the operation, structure, classification, and applications of CNC machines, emphasizing the significance of this technology in sectors such as aerospace, automotive, electronics, defense, and healthcare.
CNC machines facilitate increased production and quality by executing programmed codes that control movements across multiple axes.
Furthermore, the various classifications of CNC machines based on their function, number of axes, motion systems, and operating modes offer a broad range of capabilities to meet diverse needs.
In essence, CNC technology plays a crucial role in prototyping and manufacturing precise and complex parts, radically transforming industrial production processes.
The next chapter will delve into the intricate process of designing a CNC machine, detailing the critical stages and technical specifications involved, and exploring common solutions for mechanical and electrical components as well as material selection challenges.

Chapter 2

CNC Design

Introduction

Designing a CNC (Computer Numerical Control) machine is a complex and rigorous process that requires an in-depth analysis of requirements and technical specifications. The aim of this chapter is to detail the various crucial stages in the design of a CNC machine, highlighting the most common solutions for the mechanical and electrical parts and also the main challenges in choosing the materials.

2.1 Analysis of Requirements and Specifications

The first step in designing a CNC machine is to analyze specific needs and technical specifications. This includes determining the types of materials to be worked (metal, wood, plastic), the precision and tolerances required, and the machine's dimensions and capacity. These criteria are essential for defining the machine's technical characteristics and guiding subsequent design choices.

2.1.1 Types of Materials to be Worked

The nature of the materials that the CNC machine will process greatly influences the mechanical and electronic design. For example, metalworking requires a more robust structure and more powerful motors compared to woodworking or plastics.

2.1.2 Precision and Tolerance Requirements

Precision and tolerance are crucial factors in the design of a CNC machine. They determine the quality of the machined parts and are influenced by the guidance systems, motors, and controllers used.

2.1.3 Machine Dimensions and Capacity

Machine dimensions and capacity must be adapted to the workpieces to be machined. This includes the size of the work surface and the maximum travels of the axes (X, Y, Z).

2.1.4 Choice of CNC Type: Laser or Mechanical

Choosing the type of CNC is a key step, as each type has its own advantages and disadvantages. Laser CNCs are renowned for their precision and ability to cut thin materials with complex contours, while mechanical CNCs are more versatile and can work with thicker, harder materials.

Mechanical Design

Mechanical design includes the machine structure and frame, guide systems (rails, ball screws, belts), motors and actuators (stepper motors, servomotors), and the design of motion axes (X, Y, Z). These elements must be carefully selected to meet precision and capacity specifications.

Electronic Design

The electronic part of the design includes controllers and drivers, command systems, and the interface with CNC control software. Electronic choices directly influence the machine's precision, speed, and ease of use. Control systems and software such as LaserGRBL, Mach3, and GRBL firmware play a crucial role in overall machine operation.

2.1.5 Common Challenges and Solutions

The design of a CNC machine presents several challenges, particularly in terms of precision, robustness, and component compatibility. Common solutions include using rigid structures to minimize vibration, integrating feedback systems to improve accuracy, and selecting high-quality electronic components to ensure machine reliability.

This chapter aims to provide an overview of the various stages and considerations involved in the design of a CNC machine, guiding through the technical and strategic choices to create an efficient machine tailored to specific needs.

2.2 Choice of machine type: laser vs spindle

To choose between a laser CNC machine and a CNC machine with a spindle, it's important to understand the fundamental differences between the two types of machine, their advantages and disadvantages, and their specific applications. Here's a detailed comparison to help you make an informed choice

2.2.1 Advantages and disadvantages of laser CNC

Laser cutters use focused, high-energy laser beams to cut sheets of steel, wood, plastic and other materials into two-dimensional parts for manufacturing and hobby applications. The term "laser" means "light amplification by stimulated emission of radiation" and describes the physical science behind laser light production. This technology is widely adopted and well suited to the mass production of precise two-dimensional parts.

Laser cutting is a versatile and efficient manufacturing process with numerous advantages, as well as some drawbacks. Here are the main advantages and disadvantages of laser cutting:

- **Laser cutting : advantages**
  - **High Precision** Laser cutting is renowned for its high precision, enabling the creation of complex designs and cuts with minimal margin for error. This precision ensures that the final product meets the required specifications and maintains a high level of quality.
  - **Speed** Laser cutting boasts significant speed advantages over traditional cutting methods, especially for intricate cuts. This rapidity is particularly advantageous for large production runs and for cutting thick materials.
  - **Non-contact cutting** The non-contact nature of laser cutting minimizes the risk of deformation, warping and damage to parts, guaranteeing higher-quality products.

- **Automation** Laser cutting machines are highly automated, requiring minimal human intervention. This level of automation reduces labor costs and improves overall efficiency.
- **Flexibility** Laser cutting requires no tooling or tool changes, facilitating rapid reprogramming and efficient production cycles.
- **Consistency** Laser cutting delivers consistent results with high precision and repeatability, making it ideal for mass production.

- **Laser cutting : drawbacks**
  - **High up-front costs** Laser cutting machines generally entail higher costs than other cutting tools, representing a significant initial investment for manufacturers.
  - **Expertise required** Laser cutting requires skilled and experienced operators to ensure correct use and maintenance of the machine, which can lead to higher overall costs.
  - **High energy consumption** Depending on the material being cut, laser cutting machines can consume a substantial amount of energy, posing a challenge for manufacturers with limited energy resources.
  - **Toxic fumes** The cutting process can generate toxic fumes, particularly when certain materials are involved, requiring adequate ventilation and safety measures.
  - **Restrictions on material thickness** Laser cutting machines have limits on the thickness of the materials they can cut, which may not be suitable for all manufacturing applications.
  - **Limited material compatibility** While laser cutting can be applied to a wide range of materials, it is not necessarily suitable for all materials or thicknesses, potentially limiting its versatility.

2.2.2 Advantages and disadvantages of MOCN (machine-outil à commande numérique)

A numerically controlled machine tool, often referred to as a machining center, is equipped with a programmable automatic cycle. The CNC manager, also known as the "computer", controls the machine's moving parts using digital speed and position setpoints. Instructions for controlling the machine and shaping the part are entered either directly from the keyboard, or via independent media such as punched or magnetic tapes.

CNC (Computer Numerical Control) milling offers many advantages that make it a preferred machining method in modern manufacturing. However, it also has certain disadvantages that need to be taken into account in specific manufacturing scenarios. Here are some of the main advantages and disadvantages of CNC milling.

- **CNC machine: advantages**
  - **Precision and surface quality** CNC machines excel at creating components with extremely precise surfaces and exceptionally fine surface finishes. This capability is essential for maintaining the quality and reliability of parts manufactured in sectors such as aerospace, defense, automotive and medical.
  - **Flexibility** CNC machines have the ability to manufacture parts to precise dimensional tolerances and exceptionally fine surface finishes, enabling them to meet specific requirements in a variety of industrial sectors.

  - **Speed** CNC machines operate at a faster pace than traditional machining methods, which is particularly advantageous for mass production and the manufacture of complex parts.
  - **Automation** CNC machines feature high levels of automation, reducing labor costs and improving production efficiency.
  - **Quality** CNC machines guarantee the high quality of the parts produced, an essential factor in meeting the rigorous demands of industries such as aerospace, defense, automotive and medical.

- **CNC machine disadvantages**
  - **High cost** CNC machines are generally more expensive than traditional machining methods, which can be a problem for companies with limited budgets.
  - **Expertise required** The operation and maintenance of CNC machines requires skilled operators, which can increase costs and production times.
  - **Material limitations** CNC machines have constraints regarding the materials and part sizes they can handle, which may limit their applicability in certain scenarios.
  - **Failure risks** CNC machines can be subject to technical failures, which can lead to production interruptions and additional repair costs.
  - **Quality control** Ensuring the quality of parts produced by CNC machines requires strict quality control measures, which can increase production costs and lead times.

Overall, laser cutting and CNC machines offer numerous advantages, such as high precision, speed, versatility, and automation. However, both technologies also have significant drawbacks, including high initial costs, the need for skilled operators, and limitations regarding material thickness and compatibility. Manufacturers must carefully consider these factors when deciding whether to invest in these technologies.

2.2.3 Typical applications for each type

CNC (Computer Numerical Control) machines find extensive application across diverse industries owing to their precision, efficiency, and capability to automate intricate processes. Notably, within the spectrum of CNC machines, laser cutting machines and spindle machines (also known as CNC milling machines) emerge as distinctive tools with specialized applications and unparalleled advantages, Some of its key applications include

- **The main industries in which laser cutting machines are used**
  - **In the cookware industry:** traditional processing methods often run into difficulties such as low labor efficiency, excessive mold consumption and high operating costs. Laser cutting machines offer a solution thanks to their fast cutting speed and exceptional precision, improving processing efficiency while facilitating the creation of customized and personalized products. This solution addresses the long-standing problems faced by cookware manufacturers, earning them recognition and approval.
  - **Advertising industry:** In the advertising sector, laser cutting is used to manufacture panels, illuminated signs and other advertising elements with precise cuts and high-quality finishes.

  - **In the fitness equipment industry:** the wide variety of fitness equipment poses significant challenges for processing. Traditional methods struggle with the complexity and inefficiency arising from multiple specifications and shapes. Laser cutting offers a highly flexible solution, allowing for customized processing of various pipes and plates. The resulting products are smooth and free of burrs, eliminating the need for secondary treatment. This not only enhances the quality of the finished products but also significantly improves efficiency compared to traditional processing methods.
  - **As sheet metal processing technology advances rapidly:** traditional sheet metal cutting equipment struggles to meet the evolving process and cutting shape demands. Laser cutting, with its high flexibility and rapid cutting speed, has emerged as a superior alternative, gradually replacing traditional methods. Its widespread adoption in the sheet metal processing industry reflects an inevitable trend driven by its numerous advantages.
  - **In the shipbuilding industry:** laser-cut marine steel plates offer several advantages. They exhibit excellent cut seam quality, ensuring a smooth and vertical cut surface with no suspended slag. Additionally, they feature a thin oxide layer and a smooth surface, eliminating the need for secondary treatment and enabling direct welding. Laser-cut plates also experience low thermal distortion and curved cutting, allowing for high precision and reduced man-hours. These characteristics facilitate unobstructed cutting of high-strength ship plates, making laser cutting a preferred choice in shipbuilding.

- **The main industries in which CNC machines are used**
  - **In the aerospace industry:** CNC milling plays an essential role in the manufacture of complex components for aircraft, satellites and spacecraft. It facilitates the production of lightweight, high-strength parts essential to aerospace applications, including turbine blades, engine components, structural elements and landing gear.
  - **In the automotive industry:** CNC milling is indispensable for producing critical components such as engine blocks, cylinder heads, and transmission parts. This technology empowers automakers to attain unparalleled precision and consistency in their products.
  - **In the medical sector:** CNC milling plays a vital role in manufacturing various critical components such as medical implants, surgical instruments, prostheses, and other medical devices. The capability to fabricate customized and patient-specific parts is especially advantageous in this field.
  - **Electronics field:** CNC milling is used to manufacture printed circuit boards (PCBs), which are essential components of electronic devices. It enables precise routing, drilling and milling of printed circuit boards, guaranteeing exact electrical connections.
  - **Mold making:** CNC milling is widely used in the creation of molds for plastic injection molding, die casting and other molding processes. The ability to produce complex and precise molds leads to high-quality finished products.

  CNC machines and laser cutting machines are essential in various industrial sectors for their precision and efficiency. CNC machines are used to produce complex parts, while laser cutting machines offer flexibility and speed, enhancing product quality and customization.

In conclusion, we compare laser and CNC machines in terms of advantages, disadvantages and typical applications. Laser CNCs stand out for their precision, speed and ability to process a wide variety of materials, although they involve high initial costs and require specialized expertise. In contrast, mechanical CNCs offer robustness and versatility, but can be limited by their speed and ability to process certain materials. The specific applications of each type of CNC, from aerospace to moldmaking, illustrate the importance of choosing the right technology for your production needs. The choice between laser and mechanical CNC must therefore be guided by specific project requirements and available resources.

2.3 Mechanical Design

The mechanical design of a CNC machine is of crucial importance for many reasons. A solid, well thought-out mechanical design can greatly improve the machine's performance, precision, durability and safety. Here are some key points that underline the importance of mechanical design in a CNC machine

2.3.1 Machine structure and frame

The structure and frame of a CNC (Computer Numerical Control) machine are key to its operation and precision.The structure of the CNC machine is generally composed of several parts:
Main Frame: The primary structure that supports both the machine and the worktable.
Rotation Frame: The component that enables the spindle to rotate.
Movement Frame: The section that facilitates the machine's linear and circular movements.
Bed : The base of the machine, often made of cast iron, which supports all the other parts.
Tool holder: The tool holder holds the cutting tool in position. It usually comprises a lens that focuses the laser beam and a nozzle that sends an assisting gas into the cutting zone.
Worktable: The workplace is placed on the worktable surface.
Figure 2.1 shows the three projections of the assembled CNC machine overview. The different components of the machine can be distinguished In the table 2.1 bellow.[12]

Table 2.1 *CNC machine main components.*

Article N°	Description	Quantity
1	Z-axe	2
2	guide wheel	20
3	STEPPER MOTOR SUPPORT	5
4	NON-RETURN BLOCK NUT FOR METRIC SCREW	5
5	ball bearing	10
6	LOCKING COLLAR	10
7	C-BEAM PORTAL PLATE	5
8	y-axe	2
9	Motor coupling	5
10	stepper	5
11	table	1
12	frame	1
13	y-axe	1
14	power supply	2
15	fluid adjustment screw	5

2.3.2 Guiding systems

Linear guidance systems play a crucial role in facilitating precise and seamless movements within CNC machines. Below, we present an outline of the primary systems employed for

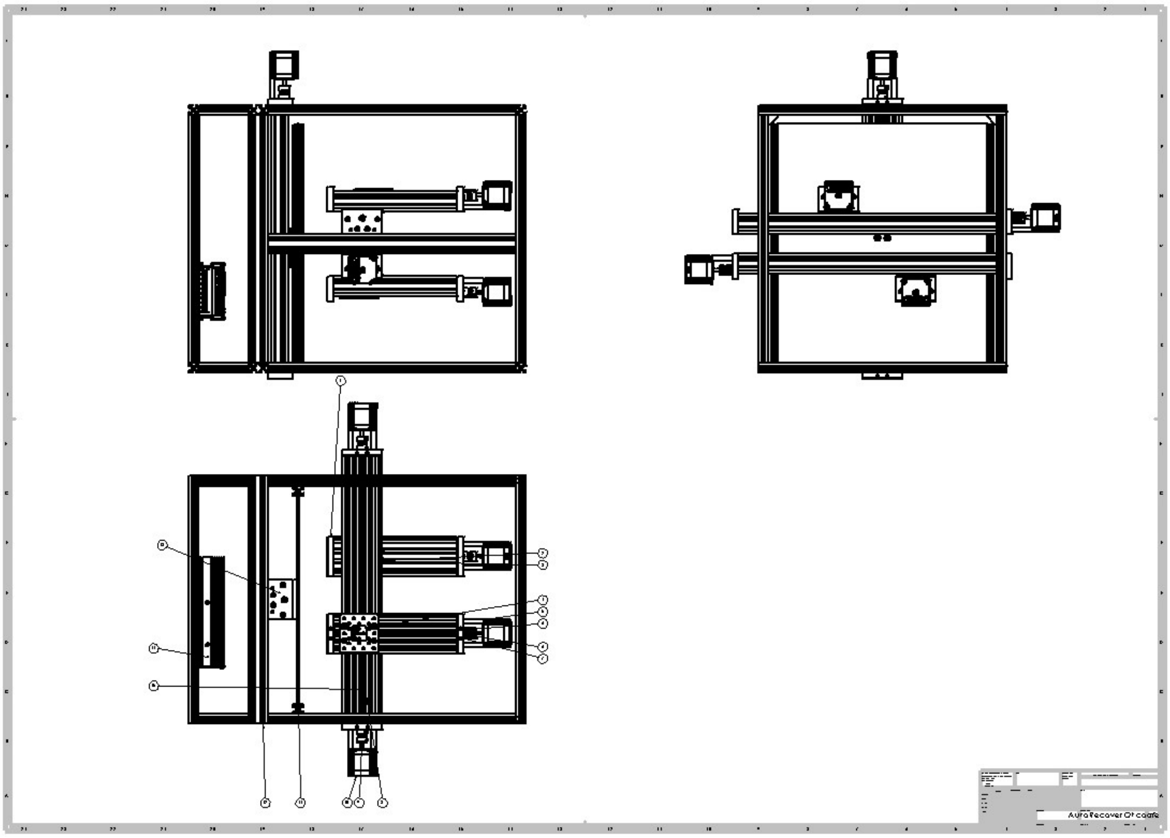

Figure 2.1 *The three projections of the assembled CNC machine overview.*

this purpose:

1. **Rail-mounted guidance systems:** are extensively utilized, employing profiled, heat-treated steel rails and runners equipped with either ball or roller bearings. This configuration as shown in the figure 2.2 allows for highly accurate linear motion while minimizing friction. Variants tailored to specific load and space constraints are readily available.[4]

2. **Ball screws:** are pivotal in transforming rotary motion into linear motion, propelled by a motor to achieve exceptionally precise movements. Their suitability shines in applications demanding top-tier positioning accuracy, notably in machine tools. the following figure 2.3 example of the system that is usually used in CNC machines. [4]

Figure 2.3 *Ball screws:.*

3. **Timing belts:** are a simple, economical way of generating linear motion, powered

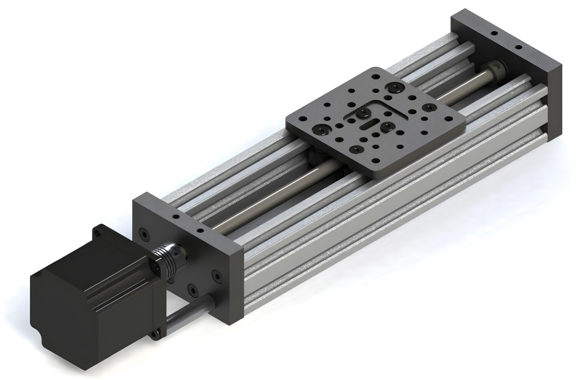

Figure 2.2 *Rail-mounted guidance systems.*

by a motor to achieve high speeds and accelerations.the figure 2.4 shows how Timing belts are often combined with rail guides to create compact, high-performance linear modules. [2]

Figure 2.4 *Timing belts:.*

Guidance systems play a crucial role in CNC machines, influencing precision, rigidity and overall performance. The following table 2.2, which summarizes the advantages and disadvantages of different guidance systems, can be a valuable tool for designers and users of CNC machines.

In short, guide rails offer high rigidity and precision, ballscrews very high positioning accuracy, while belts provide high dynamic performance at low cost. The choice of guiding system depends on the specific requirements of the application in terms of precision, speed, load and cost.

Table 2.2 *Guidance systems advantages and disadvantages.*

System	Advantages	disadvantages
Rail-mounted	Delivering high rigidity and precision, they ensure accurate linear movements effectively guiding the machine's X, Y, and Z axes.	Can be expensive, especially for applications requiring high-quality guides.
Ball screws	Transforms rotary motion into linear motion with high precision. Suitable for applications requiring high positioning accuracy.	May be limited in length to maintain high rotational speeds.
Timing belts	Offers a simple, cost-effective solution for generating linear motion. Enables high speeds and accelerations to be achieved at low cost.	May present problems of bending and stretching, affecting the precision and repeatability of movements.

2.3.3 Motors and actuators

Motors and actuators play a crucial role in the design and performance of CNC machines. They determine the precision, speed, force and reliability of machine movements. Here's an analysis of the different types of motor and their importance in CNC machine design, focusing on stepper motors, servomotors and brushless motors.

stepper motors

The principle of the stepper motor has been known for a long time, but its development began in 1960 with the advent of digital electronics. A stepper motor is a rotating machine whose rotor moves by a specific angle (α), known as a "step," each time the control circuit sends a current pulse to one or more coils. This eliminates the need for a feedback chain to verify that the output matches the commands, as long as certain operating limits are respected. [10]

Stepper Motor Types There are three categories of motors:

- **Variable reluctance motors**
  Variable reluctance motors operate on a different principle compared to permanent magnet motors. While they also have a stator, it is made of non-magnetic mild steel and is not smooth, featuring several teeth. Figure 2.5 illustrates this type of motor. In this example, the stator is composed of 8 studs with windings, forming 4 phases A,B,C and D. The rotor, in contrast, has only 6 teeth.[13] [10]

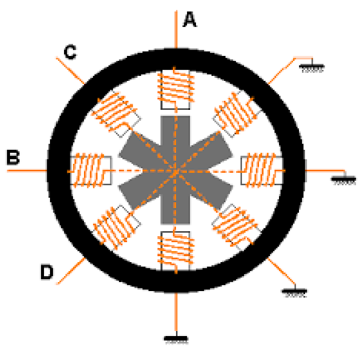

Figure 2.5 *Variable reluctance motor.*

The operating principle of these motors is straightforward: they consist of a soft iron bar and several coils. When a coil is energized, it becomes an electromagnet, causing the iron bar to align itself with the magnetic field. The sequence of energizing the phases goes as follows: phase 1, then phase 2, followed by phase 3, and finally phase 4. To change the motor's direction, simply alter the order in which the coils are energized. In practice, the ferrite has several teeth (in our example, 6). When phase 2 is energized, the motor rotates by 15° (i.e., 60° - 45° = 15°), then phase 3 is energized, and so on. The motor thus rotates 15° with each phase activation. It requires 24 pulses to complete one full revolution, making it a motor with 24 steps per revolution. This is illustrated in the following figure 2.6 [8]

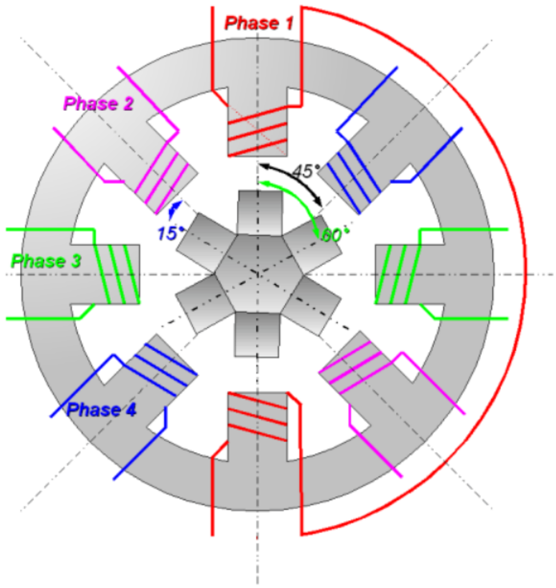

Figure 2.6 *Variable reluctance motor operating principle.*

In this case, the control modes can include:

– Single-step mode, with one phase powered at a time.
– Dual-step mode, with two phases powered simultaneously.
– Half-step mode.

The control sequences for these modes are presented in the table 2.3:

Table 2.3 *Control sequences for different modes..*

Full step mode and (One phase On)	**Full step mode and (Two On phases at the same time.)**	**Half-step mode**
Ph1 ON Ph2 ON Ph3 ON Ph4 ON	Ph1 and Ph3 ON Ph2 and Ph3 ON Ph2 and Ph4 ON Ph1 and Ph4 ON	Ph1 and Ph3 ON Ph3 ON Ph2 and Ph4 ON Ph4 ON Ph1 and Ph4 ON

- **The permanent magnet motor:** Permanent magnet motors resemble variable reluctance motors, with the distinction that their rotor features two poles, NORTH and SOUTH. Thanks to the permanent magnets, the rotor stays locked in its last position once the power supply stops providing pulses. An easy analogy to understand this system is to imagine placing a compass between two magnets. Depending on which coil is activated and the direction of the current, the magnet will align itself with the magnetic field. [9]

1. **Bipolar permanent magnet motor** The control current is bidirectional, and the advancement of a step is achieved through a specific switching sequence of the stator windings.as in the figure 2.7

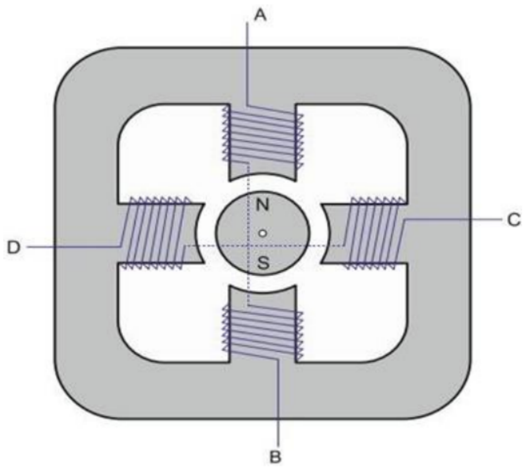

Figure 2.7 *Bipolar permanent magnet motor.*

Full-step operation: as shown in the figure 2.8 In this operating mode, the coils are energized sequentially in one direction and then in the opposite direction. The permanent magnet aligns itself with the magnetic field generated by these coils and rotates to one of its four stable positions.[9]

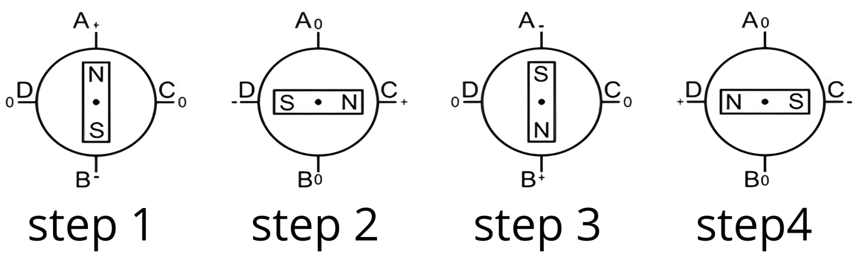

Figure 2.8 *Full-step operation.*

Maximum torque operation: In this operating mode, as energizing a pair of phases simultaneously, and thus transitioning from one phase to the next, enhances the magnetic flux intensity generated by the stator and consequently increases the motor torque.as demonstrate the figure 2.9 Each coil is energized in one of four positions, depending on the direction of current flow through the coil.[9]

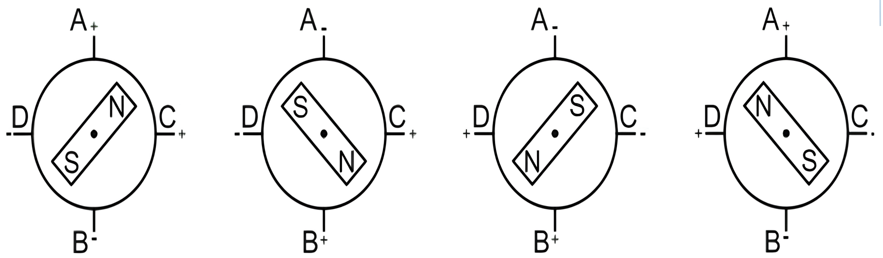

Figure 2.9 *Maximum torque operation.*

Half-step operation: The third mode combines the characteristics of the two previous modes by energizing one phase, then two, and then one again. This increases the number of stable positions and consequently the number of steps per revolution. This mode is commonly referred to as "half-step." The figure 2.10 illustrates the operation of this mode.[9]

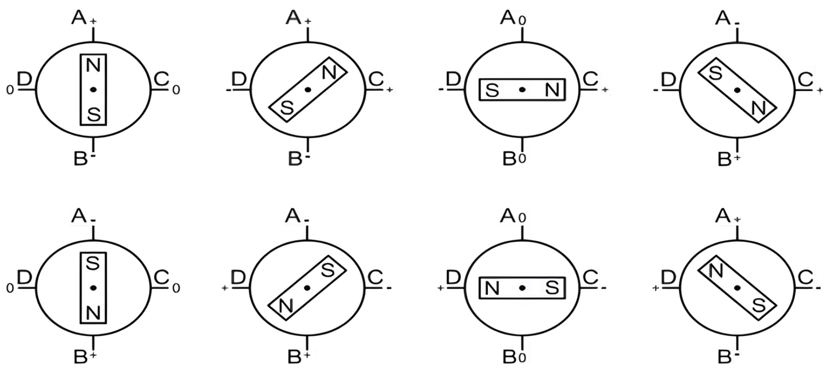

Figure 2.10 *Half-step operation.*

2. **Single-pole permanent magnet motor:** The windings of a unipolar motor are always energized in the same direction by a single voltage, hence the name "unipolar." This is illustrated in the following figure 2.11

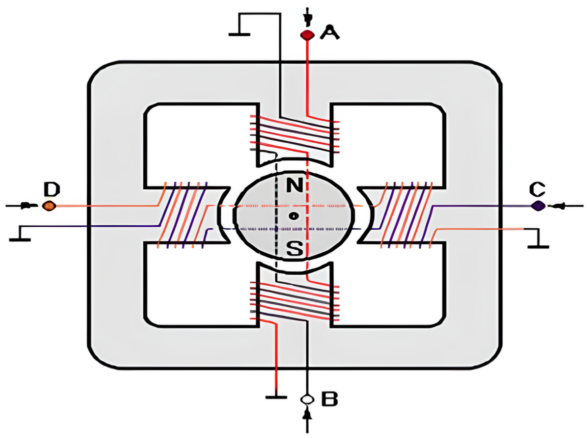

Figure 2.11 *Single-pole permanent magnet motor.*

Single-pole stepper motor operation: The rotation of a stepper motor is conventionally divided into four stages. However, in reality, the motor comprises a series of alternating poles. A standard stepper motor model completes one full revolution in 48 steps, with each step corresponding to an angular movement of 7.5° (calculated as 360° divided by 48).

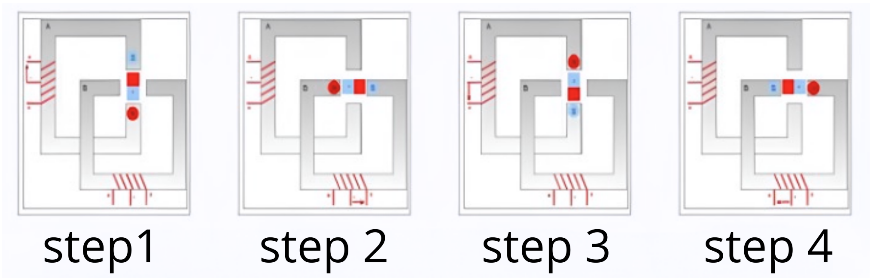

Figure 2.12 *Single-pole stepper motor operation.*

- **Hybrid motor** By combining as shown in figure 2.13 the structures of the two previously mentioned motors—placing the permanent magnets of the permanent-magnet motor within a ferromagnetic circuit—a new type of motor known as a hybrid motor is created. In this configuration, a reluctance torque is generated by the variation in permeance associated with each magnet and coil. [5]

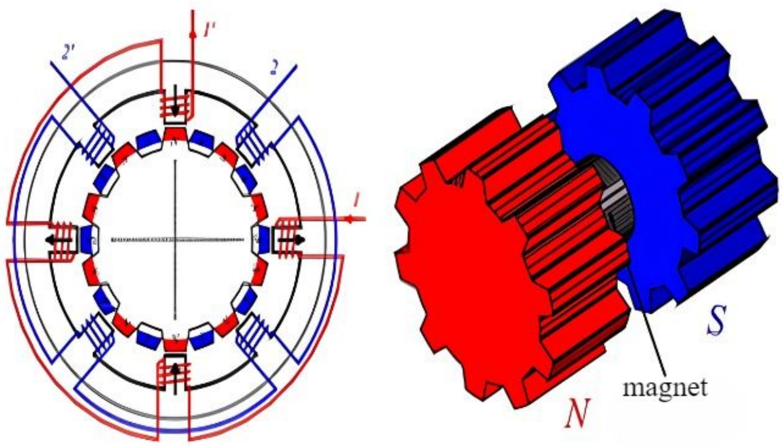

Figure 2.13 *Hybrid motor.*

Advantages of Stepper Motors:

- **Low Cost**: Stepper motors are generally more affordable than other types of motors, making them a cost-effective option for many projects and applications.
- **Rugged**: These motors are durable and can withstand harsh conditions, contributing to their longevity and reliability.
- **Simple Construction**: The design of stepper motors is straightforward, leading to ease of manufacturing and maintenance.
- **Low Maintenance**: Due to their simple construction and lack of brushes, stepper motors require less maintenance compared to other motor types.

- **Less Risk of Stalling or Slipping**: Stepper motors have a high holding torque and can maintain their position firmly, reducing the risk of stalling or slipping.
- **Works in Any Environment**: Stepper motors can function effectively in a variety of environments, including those with high temperatures or exposure to dust and moisture.

The disadvantages of stepper motors include:

- **Low torque capacity compared to DC motors:** Stepper motors typically have lower torque output for a given size compared to DC motors. This limits their use in applications requiring high torque.
- **Limited speed:** Stepper motors have a maximum speed at which they can operate effectively. This speed is typically lower than that of DC motors, which can be a limitation in high-speed applications.
- **Synchronization issues during overload:** Stepper motors can lose synchronization with the control signals if they are overloaded. This can result in missed steps and positioning errors.
- **Vibrations and noise during high-speed operation:** Stepper motors can produce vibrations and noise, especially at high speeds. This can be a disadvantage in applications where noise and vibrations need to be minimized.

servomotor

Servomotors represent specialized electromechanical components engineered to deliver precise degrees of rotation. Integrating a position sensing mechanism, a servo motor can be categorized as a DC, AC, or brushless DC motor. Often referred to as control motors, they play a pivotal role in regulating mechanical systems. Employed within a closed-loop servo system (illustrated in Figure 2.14), servomotors receive a reference input, which is then managed by the servo amplifier to dictate motor speed. Typically, a feedback device, such as an encoder or resolver, is affixed to the machinery, converting mechanical motion into electrical signals to provide feedback. This feedback is relayed to the error detector, comparing actual performance with the reference input. Any detected error is promptly transmitted to the amplifier for corrective action. In many servo setups, both velocity and position are meticulously monitored. Servomotors excel in delivering precise speed, torque, and directional control.

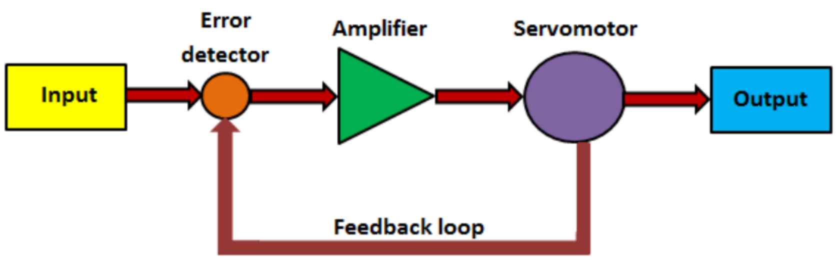

Figure 2.14 *Servo system block diagram.*

1. **DC servomotors** DC servomotors are characterized by their rapid response to error signals, often resulting in swift acceleration of the load. These servomotors are typically composed of four distinct components:

   - **The DC Motor**: Serving as the primary power source, the DC motor converts electrical energy into mechanical motion.

- **The Gear**: Gearing mechanisms are commonly used to adjust the motor's output speed and torque to match the application's requirements.
- **The Position Sensing Device**: This component, such as an encoder or resolver, monitors the motor shaft's position and provides feedback to the control system.
- **The Control Circuit**: Responsible for interpreting feedback from the position sensing device, the control circuit generates the necessary signals to adjust the motor's speed and position accurately.

2. **AC servomotors** In this type of motor, the magnetic force is generated by a permanent magnet and current which further produce the torque. It has no brushes so there is little noise/vibration. This motor provides high precision control with the help of high resolution encoder. The stator is composed of a core and a winding. The rotor part comprises of shaft, rotor core and a permanent magnet.

Advantages of Servo Motors

- Provides high intermittent torque, high torque to inertia ratio, and high speeds
- Work well for velocity control
- Available in all sizes
- Quiet in operation
- Smoother rotation at lower speeds

Disadvantages of Servo Motors

- More expensive than stepper motors
- Require tuning of control loop parameters
- Not suitable for hazardous environments or in vacuum
- Excessive current can result in partial demagnetization of DC type servo motor

Brushless DC motor

A brushless DC motor is constructed with a rotor containing permanent magnets and a stator with windings. The rotor can feature ceramic permanent magnets, and instead of brushes and a commutator, the windings are connected to the stator. Control electronics replace the commutator and brushes, powering the stator sequentially. In this setup, the conductor remains fixed while the magnet moves (refer to Figure 2.15). The current supplied to the stator is determined by the rotor's position and is switched in sequence using transistors. Hall-effect sensors detect the rotor's position, ensuring continuous rotation.

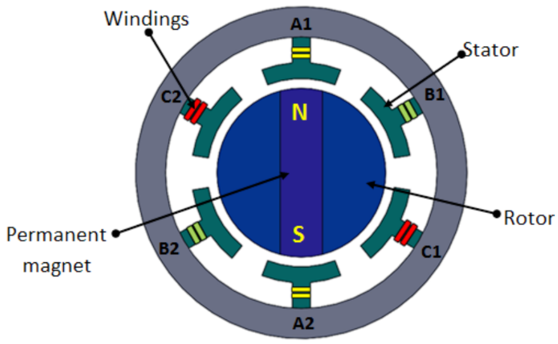

Figure 2.15 *Brushless DC motor.*

Advantages of the Brushless DC Motor

- More precise thanks to computer control
- More efficient
- No sparks thanks to brushless design
- Less electrical noise
- No brush wear
- The electromagnets are located on the stator, making them easy to cool
- The motor can operate at speeds in excess of 10,000 rpm, under load and at no load
- Quick response and acceleration thanks to low rotor inertia

Disadvantages of the Brushless DC Motor

- Higher initial cost
- Complex due to the presence of a computer controller
- Requires additional wiring to supply the electronic commutation circuit

2.4 Electronic Design

The importance of electronic design in a CNC machine cannot be underestimated. The controller, motor drivers and limit switches are essential components that determine the machine's performance, precision and safety. Here's a detailed analysis of the importance of these elements

2.4.1 Controllers and drivers

In the realm of CNC machine design, selecting the appropriate controllers, drivers, and control systems is paramount to achieving optimal performance and precision. This section provides an in-depth examination of various controllers and drivers, including Arduino CNC, NVUM V2 3-axis, RYC GRBL V3, and motor drivers. Additionally, it explores key control systems such as Marlin, GRBL firmware, Mach 3, and LaserGRBL, highlighting their unique features and applications in CNC machining. Understanding these components is essential for building and operating efficient CNC machines that meet specific technical requirements and project goals.

Arduino CNC Overview

Arduino CNC is a widely embraced DIY project that utilizes an Arduino board as the core controller for a CNC machine. The Arduino board interfaces with various components, such as stepper motor drivers, stepper motors, and a CNC shield, to manage the machine's movements. Here are some essential points about the Arduino CNC:

- **Arduino Board**: The central component of the CNC machine, responsible for reading and executing G-code commands to control machine motion.

- **CNC Shield**: A specialized board that connects to the Arduino and provides interfaces for stepper motor drivers and other components. It simplifies the configuration and control of the CNC machine.

- **Stepper Motor Drivers**: Devices used to control the stepper motors that move the machine axes. These are typically connected to the CNC shield and managed by the Arduino board.

- **Stepper Motors**: Motors used to move the machine axes. Commonly, Nema17 motors are employed, which are widely used in 3D printers and desktop CNC machines.

- **GRBL**: An open-source G-code interpreter installed on the Arduino board. It reads and executes G-code commands to control the CNC machine.

- **Marlin**: is an open-source firmware for controlling 3D printers and CNC machines, running on Arduino-compatible boards. It's highly configurable, interpreting G-code for precise motion control and managing functions like temperature and bed leveling.

Assembly

The assembly process involves mounting the CNC shield on the Arduino board, connecting the stepper motor drivers, and configuring the jumpers for microstepping. the following figure 2.25 gives the connection and Various sheild connectors

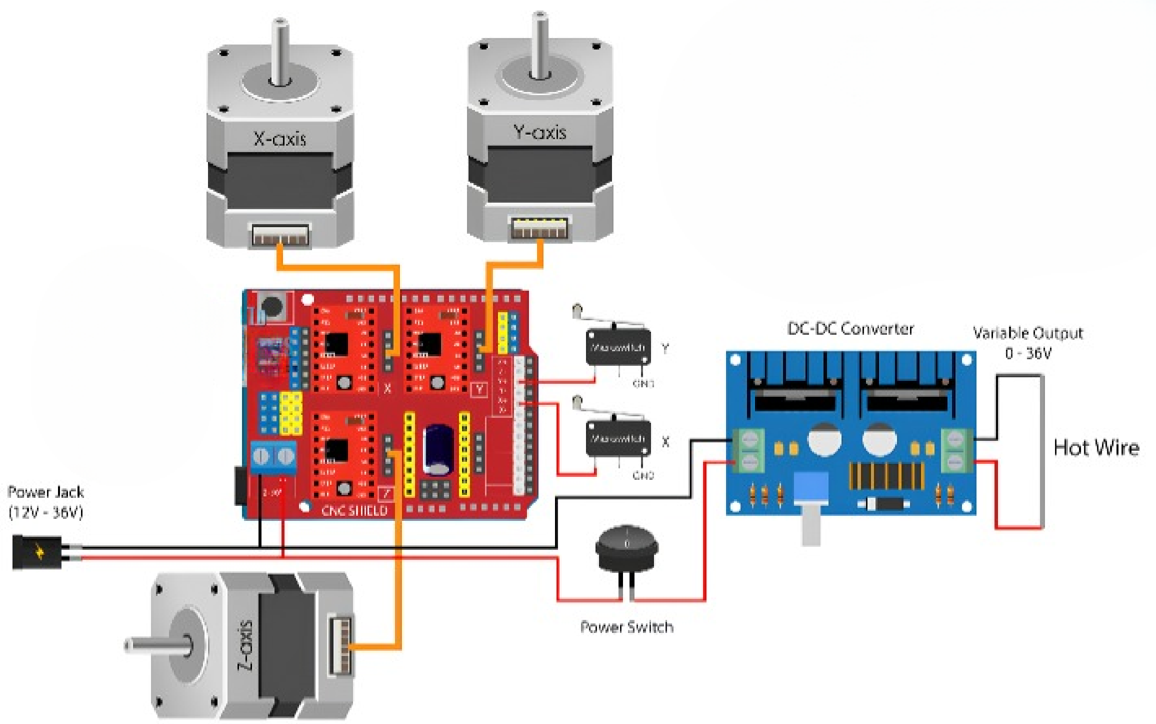

Figure 2.16 *Connection and Various shield connectors.*

NVUM V2 3-axis

The NVUM V2 3-axis is a USB CNC motion control board designed for use with Mach3 software. It supports the standard MPG and communicates with the computer via a USB port. Compatible with various stepper motor drivers, it's ideal for DIY CNC projects.

NVUM V2 Features and Specifications

- **Application:** Designed for use with Mach3 software, supporting motion control on 3/4/5/6 axes.
- **Stepper Motor Driver:** Compatible with various stepper motor drivers.
- **Communication:** Utilizes a USB port for communication.
- **Power Supply:** Operates from a 12V power supply.
- **Spindle Motor Interface:** Supports a DC spindle motor of up to 400W.
- **Fan Interface and TTL Signal Output:** Features a fan interface and a TTL signal output for controlling the laser module with a TTL module.
- **Laser Interface:** Compatible with 12V laser heads.
- **GRBL Support:** Supports GRBL control.
- **Mach3 Integration:** Specifically designed for use with Mach3 software.

Assembly

As the Figure 2.17 show,the connection of the controller includes power supply interface, USB connection interface, MPG interface, Stepper/Servo control output interface, spindle control output interface, Estop and limited switch and tool setting input interface and so on. Now we descript them in the table 2.4.

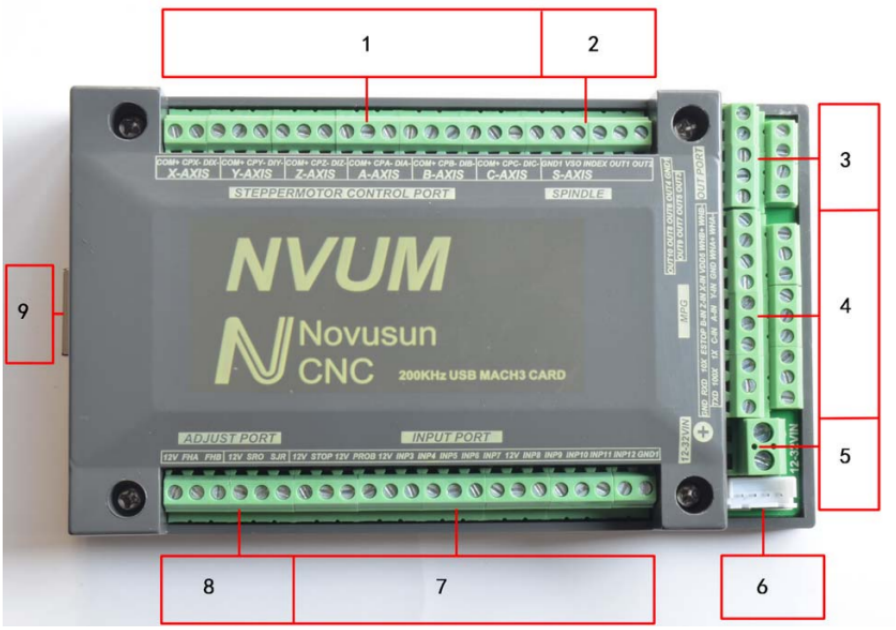

Figure 2.17 *Product wiring section and interface summary.*

Table 2.4 *NVUM V2 Interface Description.*

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Mark	Description
1	Stepper driver connection
2	Spindle control output and inverter connection
3	OUTX connect with external relay method
4	Connection between Differential MPG and NVUM
5	Main power supply input Interface
6	Communication external interface
7	Estop limited Tool setting input interface
8	Parameter adjust interface
9	USB Port

RYC-GRBL-V3

The RYC-GRBL-V3 is a 3-axis GRBL controller board designed for hobby engravers or toy laser engravers. It requires an external stepper motor driver and is suitable for users building long-stroke engraving machines. The board supports GRBL control and can be used with other software that supports GRBL code.

Features and Specifications

- **Application:** The board is designed for DIY engraving machines or laser engraving machines for toys.
- **Stepper Motor Driver:** The board requires an external stepper motor driver for direction and pulse signal control.

- **Communication:** The board uses USB (USB-CH340) for communication.
- **Power Supply:** The card operates from a 12V power supply.
- **Spindle Motor Interface:** The board supports a DC spindle motor of up to 400 W.
- **Fan Interface and TTL Signal Output:** The board features a fan interface and a TTL signal output interface for controlling the laser module with a TTL module.
- **Laser Interface:** The board is compatible with 12V laser heads.
- **GRBL Support:** The board supports GRBL control.
- **Mach3 Compatibility:** The board also supports Mach3 software.

assembly

the Figure 2.18 show,the connection of the controller and the description of all the component.

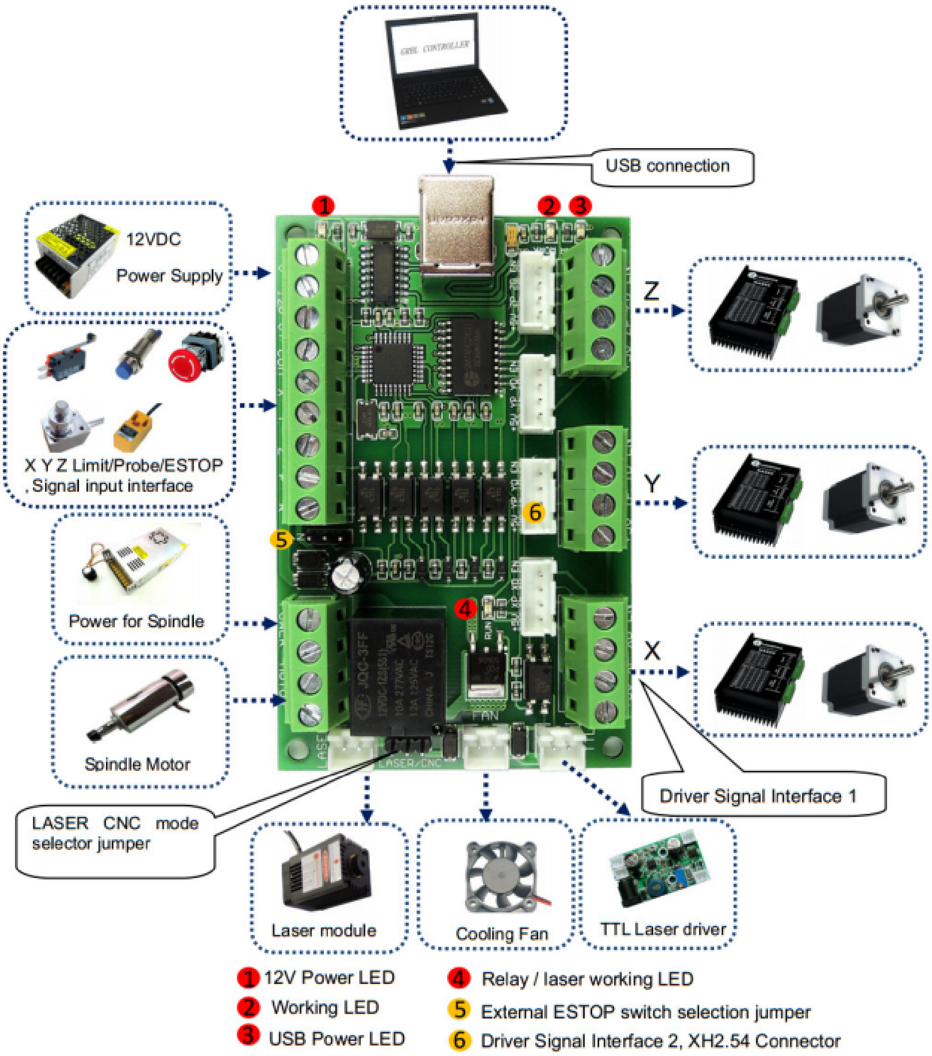

Figure 2.18 *connection and Various controller connectors.*

drivers motors

TB6600 4-axis The TB6600 4-axis stepper motor driver board utilizes Toshiba's TB6600 chip for precise control of up to four bipolar stepper motors, each capable of handling a maximum current of 4.5 A per axis. Operating within a voltage range of +14 V to +40 V, it offers flexibility in power supply options. Additionally, the board includes two alarm inputs, a reset input, and a mode selection input, along with six stepper motor control signal outputs for comprehensive control and compatibility. this devise is suitable for a variety of small and medium sized automation equipment's and its connected to the controller as it is shown in the figure 2.19

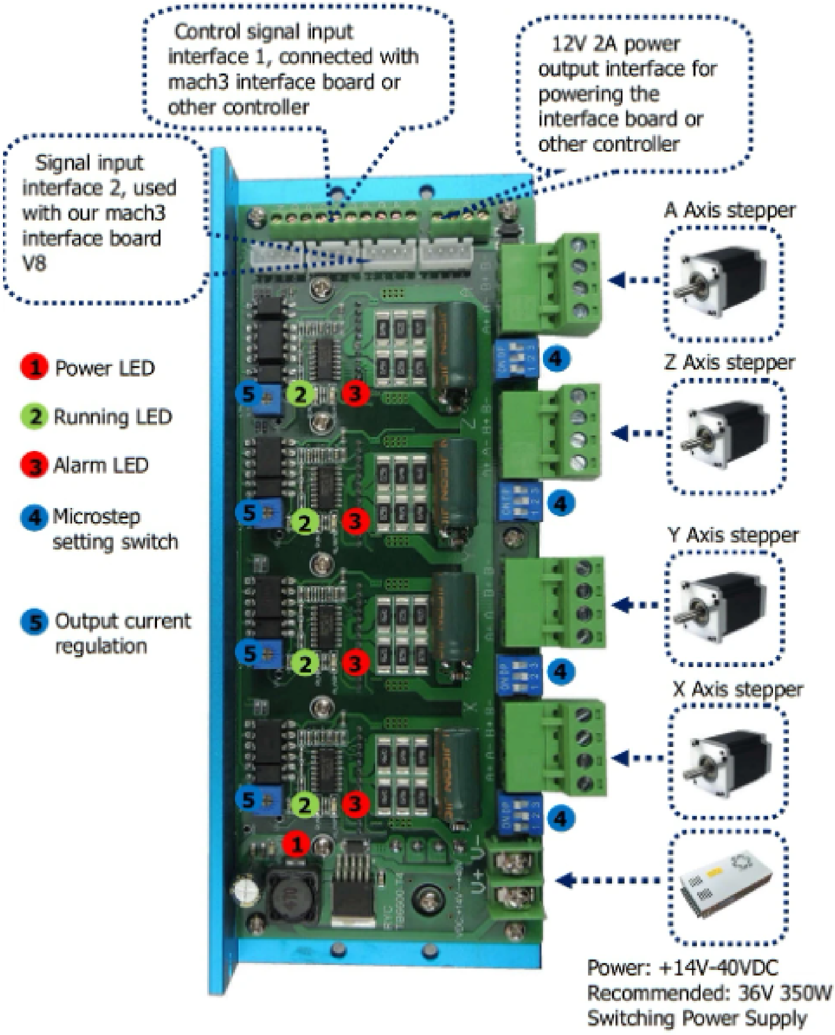

Figure 2.19 *TB6600 4-axis stepper motor driver connection.*

Stepstick A4988 This micro-stepping motor controller offers the advantage of adjustable current control through a potentiometer. It provides protection features and supports five different step resolutions Full step, half step, quarter step, eighth step and sixteenth step. and the specifications of the A4988 stepper motor driver are known, so it is connected as indicated in the figure 2.20. [10]

- **Minimum Operating Voltage:** 8 V
- **Maximum Operating Voltage:** 35 V

- **Current per Phase (Continuous):** 1.2 A
- **Maximum Current per Phase:** 2.3 A
- **Control Logic:**
  - **Minimum Voltage:** 3 V
  - **Maximum Voltage:** 5.5 V

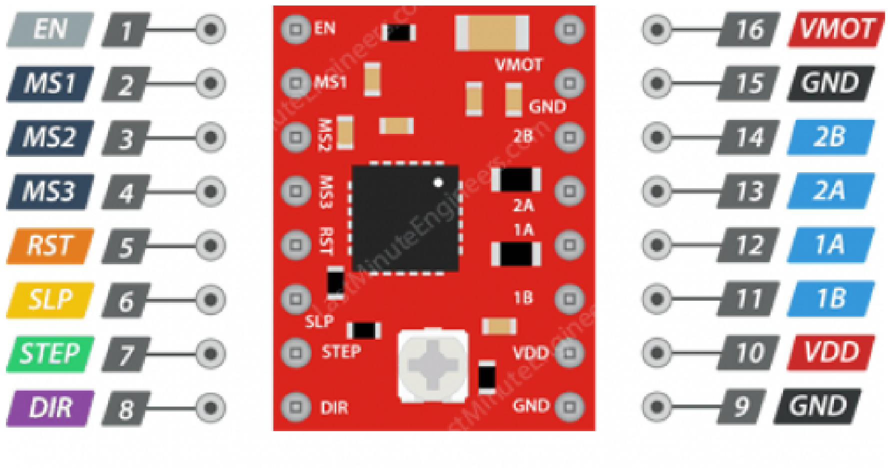

Figure 2.20 *A4988 connection.*

2.4.2 Control systems

marlin firmware

Marlin is open-source firmware originally developed for the RepRap family of 3D printers, and became a standalone project on August 12, 2011. Licensed under GPLv3, it is free for all applications. While initially designed for 3D printers, Marlin is also capable of driving CNC machines and laser engravers, making it a versatile choice for various digital fabrication tools.

Built around the lightweight Arduino framework, Marlin runs on a range of microcontrollers, from classic 8-bit Atmel AVR boards to the latest 32-bit ARM boards from companies like BigTreeTech and Makerbase. This flexibility allows Marlin to support numerous board and machine configurations, making it configurable, customizable, extensible, and cost-effective for both hobbyists and vendors. A minimal version of Marlin can be under 64 KB, with features activated as needed to support additional components. This adaptability and broad hardware compatibility make Marlin a robust solution for CNC machines.

Marlin Firmware Overview Marlin goes beyond 3D printing! This open-source firmware can be the brains behind your 3D printer, CNC machine, or even a laser engraver.

Control with Choice

- Works with various machines: 3D printers, CNCs, and laser engravers.
- Compatible with many microcontrollers: from simple 8-bit Atmel AVRs to powerful 32-bit ARM boards.

Tailor-made for Your Needs

- Highly configurable: Marlin adapts to different hardware and machine setups.

– Customizable parameters: fine-tune motor control, emergency stops, sensors, and more.

Precise Movement, Exceptional Results

– Motion control: achieve accurate and flexible control of axes and motors.

– Advanced algorithms: improve print quality and machine performance with jerk and acceleration control.

Perfecting the Print Bed

– Leveling options: choose from manual, automatic (probe-based), or mesh bed leveling.

– Calibration routines: ensure precise positioning and movement.

Multi-extruder Mastery

– Supports multiple extruders, including mixing extruders.

– Advanced temperature control: manage heating heads and beds with precision.

Safety First

– Thermal runaway protection: prevents overheating for safer operation.

– Shutdown detection and error management: avoids breakdowns and damage.

User-friendly Interface

– Works with LCD displays, touchscreens, and other user interfaces.

– Menu-driven interface: configure and control Marlin with ease.

Connectivity Options

– Supports various connections: USB, SD card, and Wi-Fi.

– Integrates with OctoPrint and other remote control solutions.

G-code Expertise

– Fully supports G-code, the standard language for CNC and 3D printing.

– Customize G-code commands for even greater functionality.

GRBL firmware

GRBL is open-source firmware designed for Arduino microcontrollers to operate CNC machines. It converts G-code commands, which dictate CNC machine movements and operations, into signals that control the stepper motors, spindle, and other components. GRBL is popular in DIY CNC projects and small-scale commercial CNC machines because of its simplicity, reliability, and efficiency.

Marlin Firmware Overview

– **G-code Guru**: GRBL flawlessly interprets standard G-code, allowing you to create intricate machining projects.

– **Movement Maestro**: Get precise control over your machine's movements with smooth and accurate stepper motor control.

- **Real-time Control Freak**: Need to make adjustments on the fly? GRBL allows real-time command input and overrides for dynamic control during operation.

- **Customization King**: Tailor your machine's performance by adjusting step size, acceleration, speed, and even spindle control.

- **Lightweight Champion**: Designed for efficiency, GRBL requires minimal resources and runs well on the Arduino Uno's limited memory and processing power.

- **Easy Setup**: Compatible with various user interfaces and control software, GRBL offers a straightforward setup process.

- **Safety First**: Includes features like limit switches to prevent over-travel and safety interlocks to manage unexpected situations.

- **G-code Guru**: GRBL flawlessly interprets standard G-code, allowing you to create intricate machining projects.

- **Movement Maestro**: Get precise control over your machine's movements with smooth and accurate stepper motor control.

- **Real-time Control Freak**: Need to make adjustments on the fly? GRBL allows real-time command input and overrides for dynamic control during operation.

- **Customization King**: Tailor your machine's performance by adjusting step size, acceleration, speed, and even spindle control.

Mach3 Software

Mach3 software serves as a widely used control system for CNC (Computer Numerical Control) machines like mills, routers, lathes, and plasma cutters. It transforms a standard PC into a comprehensive 6-axis CNC controller, offering users control over all aspects of their machine, from axis movements to spindle speed and tool changes, through a computer interface.the figure 3.12 represent the software interface.

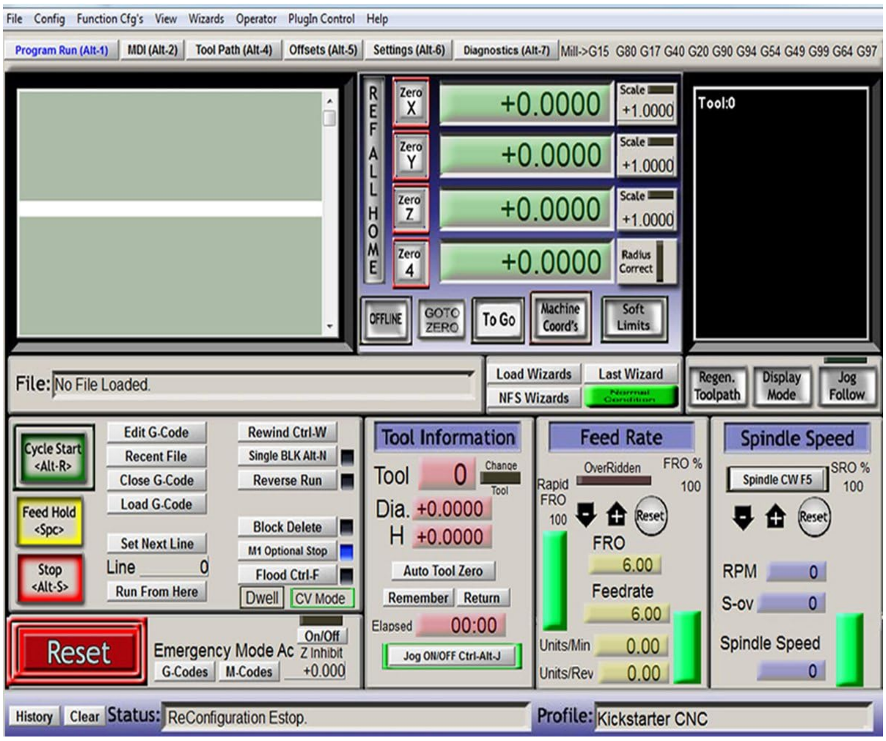

Figure 2.21 *Mach3 software interface.*

2.4.2.1 Software interfacing

Mach3 Software Overview

Compatibility

- Mach3 is compatible with a broad spectrum of CNC machines, making it adaptable to various industries and applications.
- It can be employed with both new CNC machines and retrofitted ones.

User Interface

- Featuring a user-friendly interface, Mach3 enables users to effortlessly program and manage their CNC machines.
- The interface includes functionalities like toolpath display, virtual tool simulation, and customizable toolbars.

G-code Support

- Mach3 supports G-code programming, the standard language for CNC machine control.
- It interprets intricate G-code programs to execute precise machining operations.

Axis Control

- Users can manage multiple axes of movement, encompassing linear and rotary axes.
- It provides features such as jog control, homing, and backlash compensation to ensure precise tool positioning.

Spindle Control

- Mach3 facilitates control over spindle speed and direction, enabling a wide array of machining operations.

- It offers features like tool speed override and spindle synchronization.

Tool Management

- Mach3 incorporates features for tool management, including tool length offsets, tool wear compensation, and automatic tool changes.

- Users can efficiently set up and maintain tool libraries for different machining tasks.

Simulation and Visualization

- The software includes tools for simulating toolpaths and visualizing machining operations.

- Users can preview tool movements and validate machining programs before executing them on the actual machine.

Customization and Expansion

- Highly customizable, Mach3 allows users to configure the software to meet their specific requirements.

- It supports plugins and add-ons for expanding functionality, such as additional axis control or advanced toolpath generation.

Reliability and Support

- Renowned for its reliability and stability, Mach3 is a trusted choice among CNC machine operators.

- It benefits from a large community of users and developers who offer assistance, tutorials, and updates.

LaserGRBL software

LaserGRBL is a free, open-source software package specially designed for laser engravers and cutters using GRBL-based control boards. It is primarily developed for Windows, making it easily accessible to users who depend on the Windows operating system. LaserGRBL is designed to work seamlessly with GRBL-based laser machines, offering real-time control of laser power and feed rate.

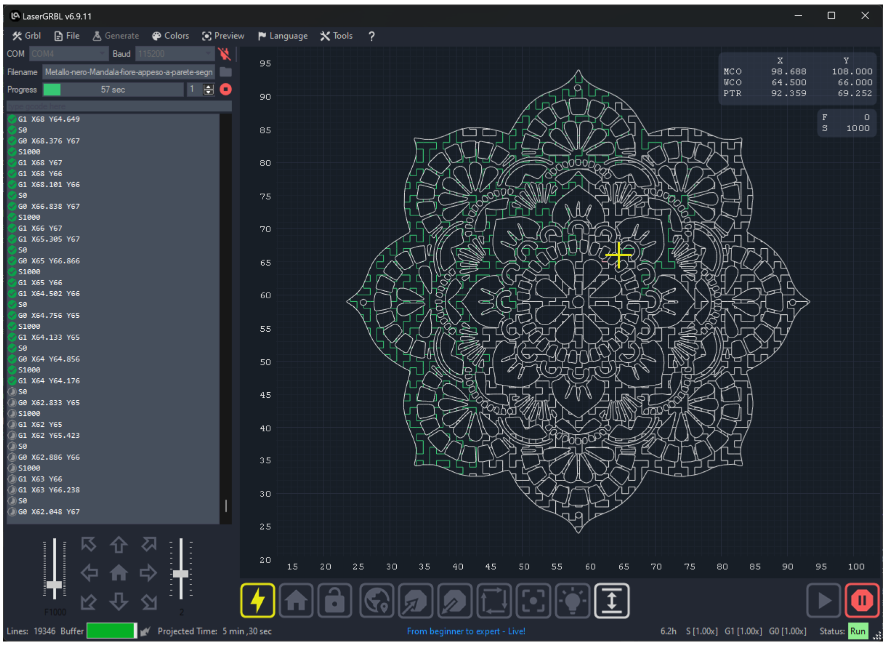

Figure 2.22 *laserGRBL interface.*

LaserGRBL overview

- **GRBL-centric compatibility:** LaserGRBL is designed to work seamlessly with GRBL-based laser machines, ensuring compatibility and efficient operation.
- **Simple, intuitive interface:** LaserGRBL features a clean, minimalist user interface that focuses on essential functionality, making it user-friendly and easy to use.
- **Image engraving support:** LaserGRBL offers integrated raster image processing capabilities, enabling users to engrave images directly onto materials. It supports various image formats and offers grayscale conversion and rasterization options.
- **Open-Source Community:** As open-source software, LaserGRBL benefits from a community-driven development approach, enabling users to contribute to the project, report issues or request features for continuous improvement.
- **Cost-effective solution:** LaserGRBL is a cost-effective option for laser engraving and cutting technicians using GRBL-based machines, offering efficiency and affordability.
- **Resource-efficient:** LaserGRBL is less resource-intensive than more feature-rich solutions, making it suitable for older or less powerful computers.

2.4.3 Safety system

limit switch

A limit switch is an electro-mechanical device triggered by physical force or machine movement. It detects the presence or absence of an object, monitors machine positions, and controls machinery by turning it on or off. Limit switches are crucial for precise control and safety in various industrial applications. They consist of an actuator mechanically linked to a set of contacts. When an object engages the actuator, the contacts are operated to either make or break an electrical connection. The actuator type—plunger, roller, rod, or whisker—varies with the limit switch.

Contact Configuration

- **Normally Open (NO)**: Contacts are open in the off state and close upon activation of the switch.
- **Normally Closed (NC)**: Contacts remain closed in the resting state and open when the switch is actuated.
- **Changeover or Single-Pole, Double-Throw (SPDT)**: Has a common terminal and two other contacts, allowing the switch to alternate between opening and closing the circuit.

in the figure 2.23 bellow we find the configuration of the limit switch

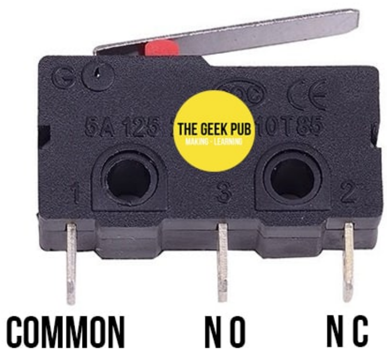

Figure 2.23 *Limit switch.*

emergency stop button

An emergency stop button is a self-holding switch that remains activated until manually released by the operator, allowing the machine to restart safely. This button is designed to be highly visible and easily accessible, characterized by a red mushroom-shaped head and a yellow bottom or housing. Typically, the button is red with a yellow housing, base, or bezel to ensure it stands out. There are also models that illuminate for better visibility in low-light conditions. **Emergency Stop Button Operation**

1. **Direct Operating Mechanism:** The emergency stop button utilizes a direct operating mechanism, with the electrical contacts in the normally closed (NC) position. Pressing the button interrupts the electrical circuit, causing the machine to stop.
2. **Unlocking Mechanism:** The knob can be unlocked by pulling, turning, or using a key, but only under strict authorized operation to ensure the safety of both people and equipment.

Figure 2.24 *Emergency stop button.*

Emergency stop buttons and limit switches are a crucial component in ensuring the safety of both operators and machinery. Understanding the different types and configurations of emergency stop buttons and limit switches is essential for selecting the appropriate device for a specific application.

Relay Shield: Definition, Types, and Applications

A Relay Shield is an Arduino-compatible module designed to control high-voltage devices with low-voltage signals. It simplifies the control of devices like motors, lights, and other appliances via the digital I/O pins of an Arduino board. The Relay Shield has four high-quality relays example in figure 2.25, each with a NO (Normally Open) and NC (Normally Closed) interface, ensuring precise switching control of high-voltage devices.

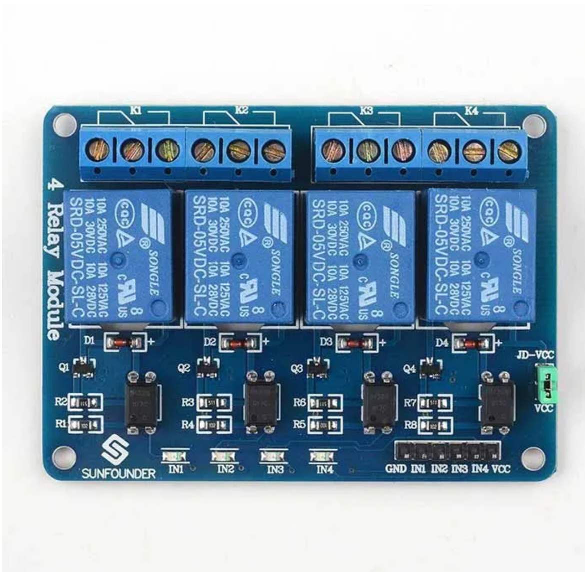

Figure 2.25 *4 channal 5V relay shield module.*

Types of Relay Shields

1. Relay Shield V1.0:
    - Push buttons for manual control.
    - Working voltage: +7V to +12V.
    - Requires an external power supply.
    - Maximum switching current: 2A.
2. Relay Shield V1.1:
    - Selectors for manual control.
    - Working voltage: +5V.
    - Requires an external power supply.
    - Maximum switching current: 8A.
3. Relay Shield V2.0:
    - Four high-quality relays with NO/NC interfaces.
    - Dynamic LED indicators for each relay.
    - Standardized shield form factor.
    - Compatible with Arduino boards.
    - Maximum switching current: 8A.

How Relay Shields Work

1. **Electromagnetic Principle:** Relays utilize the electromagnetic principle to switch high-voltage devices. When a low-voltage signal is applied to the coil, a magnetic field is created, attracting the contacts and enabling the high-voltage device to be turned on or off.
2. **Control Circuit:** The control circuit energizes the relay coil, which creates the magnetic field necessary for switching the high-voltage device. This circuit can range from a simple switch to a complex electronic system.

conclusion

Designing a computer numerically controlled (CNC) machine is a process that requires careful consideration of many aspects and technical requirements. By analyzing material types, precision, tolerances, dimensions and capacity, we can establish a solid basis for informed design decisions. The choice between a laser CNC and a mechanical CNC is essential, each offering unique advantages tailored to different applications.

Mechanical and electronic design is a crucial step that needs to be carefully planned and executed to ensure that the CNC machine meets the desired performance criteria. By selecting the right components and integrating advanced control systems and software, we can improve the machine's precision, speed and ease of use.

The challenges encountered in CNC machine design, such as achieving high precision, structural robustness and component compatibility, are met by common solutions such as the use of rigid structures, feedback systems and high-quality electronic components. These solutions contribute to machine reliability and efficiency.

This chapter outlines the main stages and considerations in the design of a CNC machine, providing a comprehensive guide to navigating the technical and strategic choices involved. By following these guidelines, we can create a CNC machine that is not only efficient, but also tailored to specific needs, guaranteeing optimum performance and reliability in a variety of machining applications.
in thee following chapter we will detail the steps involved in building and assembling our CNC machine, explaining the technical choices and manufacturing methods used, as well as the test and adjustment procedures.

Chapter 3

CNC Machine Design and Assembly

Introduction

The design of a CNC (Computer Numerical Control) machine is a complex process requiring careful planning, rigorous selection of materials and components, and careful integration of mechanical and electronic systems. It is also essential to plan tests and adjustments to ensure the machine's accuracy and reliability. In this chapter, we will detail the steps involved in building and assembling our CNC machine, explaining the technical choices and manufacturing methods used, as well as the test and adjustment procedures. Our aim is to provide an in-depth understanding of the processes involved, from the manufacture of the frame to the integration of the laser and spindle systems, as well as the programming and calibration required to ensure optimal operation.

3.1 Frame and Mechanical Component Manufacturing

Manufacturing the frame and mechanical components of a CNC machine is a crucial step in determining the machine's stability, precision and durability. Well thought-out mechanical design and quality manufacturing are essential for a high-performance machine. Here's a detailed guide to the importance and key considerations of manufacturing the frame and mechanical components of a CNC machine.

3.1.1 Choice of frame materials

The frame of a CNC machine is akin to the skeleton in the human body; it offers structure and support, shaping the machine's overall functionality and efficiency. Next, we will examine the top materials for a CNC machine, highlighting their pros and cons in Table 3.1 and we can see some examples int the figure 3.1

MDF (Medium Density Fiberboard)

MDF is an engineered wood product made from wood fibers combined under heat and pressure. It is appreciated for its affordability and ease of use, particularly for joinery projects. However, while it offers a smooth surface ideal for finishes, it lacks the durability of metals and can be sensitive to moisture and warping.

Aluminum

Aluminum is a lightweight yet robust metal known for its corrosion resistance and malleability. Its good strength-to-weight ratio makes it an excellent choice for CNC frames. Although more expensive than wood-based materials, its resistance to rust and the possibility of anodizing enhance its durability and longevity.

Steel

Steel, an alloy composed mainly of iron and carbon, is renowned for its high tensile strength. Its extreme durability and ability to withstand heavy loads make it ideal for the most intensive CNC operations. While it offers unrivaled rigidity, it is heavier than aluminum and requires protection against rust.

Figure 3.1 *Different CNC machines made from various materials: wood, aluminum, and steel.*

pros and cons of every material

Table 3.1 *Comparison of Materials for CNC Machines.*

Material	Pros	Cons
MDF	• Affordable and widely available.Easy to work with using standard woodworking tools. • Provides a smooth surface ideal for painting or sealing.	• Less durable compared to metals. • Can warp over time, especially in humid conditions. • Susceptible to moisture damage if not sealed properly.
Aluminium	• Lightweight yet strong, offering a good strength-to-weight ratio. • Resistant to rust and corrosion. Can be anodized for enhanced durability and aesthetics.	• More expensive than wood-based materials. • Requires specialized tools for cutting and drilling.
Steel	• Exceptionally durable and capable of bearing heavy loads. • Offers outstanding rigidity, minimizing vibration. • Available in various grades, allowing for customization to meet specific requirements.	• Heavier than aluminum, making transport more difficult. • Susceptible to rust if not treated or painted.

Ultimately,The choice of frame material for a CNC machine depends on factors like cost, durability, and project requirements. MDF is affordable but less durable, aluminum offers a good balance of strength and weight, and steel is heavy but exceptionally durable. Consider these factors to select the most suitable material for your CNC project, ensuring optimal performance and longevity.

3.1.2 Reasons for choosing these materials

The materials used for construction were chosen on the basis of price, weight and mechanical properties. For the X, Y and Z axis supports and the frame, we used a 3003 aluminum alloy to save weight and for its good mechanical properties.

3.1.3 Manufacturing techniques

3.1.3.1 Fastening system

Screws and nuts

Screw mounting is a highly practical method for securely attaching components together, maintaining structural integrity, functionality, simplicity, and ease of assembly and disassembly. It involves a threaded rod and a corresponding nut, offering versatility in fastening elements of various materials. This method is particularly useful for connecting components made of materials like aluminum and steel, which cannot be welded together.

Semi-elastic coupling

For rotary contact between drive shafts and trapezoidal screws, semi-elastic couplings have been have been used. These can be used to correct minor misalignments (typically machining faults). alignment faults (typically machining defects). These couplings are generally made up of two rigid parts rigid parts fixed to the shafts and a slightly slightly adaptable part that compensates for misalignment.[3]

3.1.3.2 3D printing

In the construction of CNC machine, we leveraged the capabilities of 3D printing to create custom parts that enhanced the overall performance and precision of the machine. One such example is the stepper motor support and laser support , which were designed and printed using a 3D printer. This innovative approach allowed us to create complex geometries and internal structures that would be difficult or impossible to achieve through traditional manufacturing methods.

3.1.3.3 Cutting

In the construction of our CNC machine, we utilized cutting tools to fabricate critical components that provide the structural foundation for those tool's operation. Two such examples are the frame and table, which were precision-cut using cutting machines.

The integration of cutting machines in our CNC machine construction process highlights the importance of precision cutting in the fabrication of critical components. By combining the strengths of cutting machines with other manufacturing techniques, such as 3D printing, we were able to create a machine that is both precise and robust. [11]

3.2 Installation of guidance systems and actuators

3.2.1 Mounting C-beam rails

The assembly of C-beam rails in CNC machine construction closely resembles that of standard linear rails as shows the figure 3.2 , yet it includes specific nuances unique to C-beam rails. To assemble C-beam rails, begin by ensuring they are clean and in good condition. Attach the C-shaped extrusions, typically composed of two parts, to the machine structure using bolts and T-nuts designed for T-slots on the extrusions. Install the carts supporting movement along the rails, ensuring they glide smoothly. If C-rails are used to guide motor movement, mount motor support plates onto the profiles using appropriate hardware. Proper alignment of the rails is crucial for precise movement; verify alignment and parallelism of the profiles.

Finally, conduct a thorough test of the machine's movement to detect and correct any issues like excessive play or friction, ensuring smooth operation.[1]

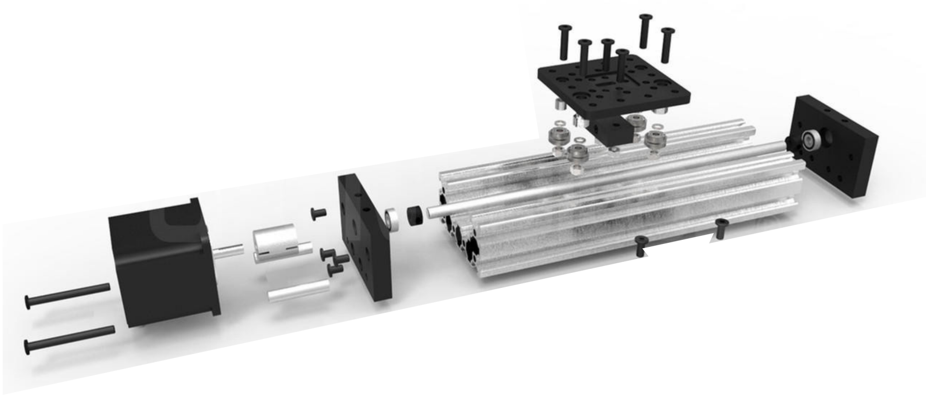

Figure 3.2 *C-beam rails.*

3.2.2 Motor and rod mounting

Couplings are used to connect the motor shaft to the screw shaft or threaded rod, while motor brackets securely fasten the motor to the machine frame. For this project, we used a flexible aluminum coupler sized 5 mm to 8 mm for the NEMA 17 motor and 8 mm to 8 mm for the NEMA 23 motor figure 3.3 . We also designed and 3D printed the necessary brackets to ensure a precise fit figure 3.4.

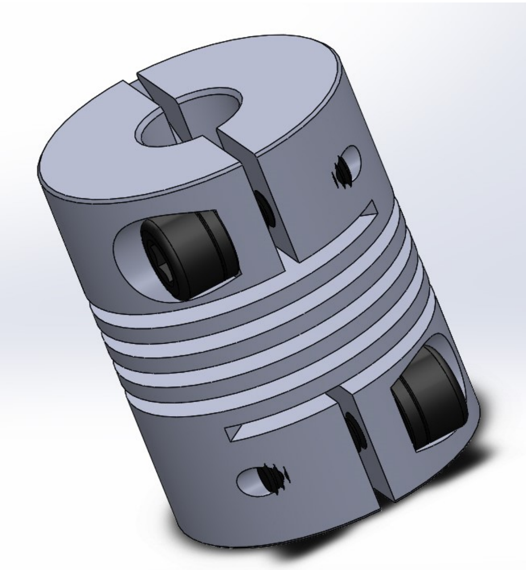

Figure 3.3 *Flexible aluminum coupler.*

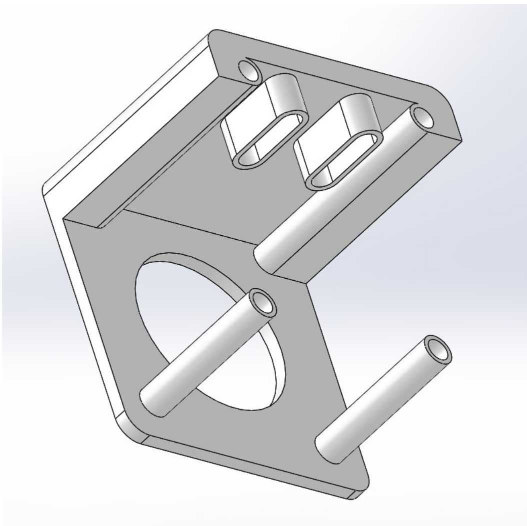

Figure 3.4 *Motor bracket.*

3.3 Laser systems integration

the beam is directed towards the laser head from the deflecting mirror at the top of the head. This mirror, like the others, is adjustable by means of pointing screws, to ensure the best possible focus. pointing screws, to ensure the best possible focus. The aim is to concentrate the laser beam at a very high density. The aim is to concentrate the laser beam at a very high density, thanks to the lens, which directs it at a single angle. lens, which directs it at a single point on the material to be cut. to be cut. In short, the principle of the laser is to concentrate a large quantity of energy, in the form of light, on a very small surface. on a very small surface.

3.3.1 Laser types

When implementing a laser marking system, it's vital to consider the different types of lasers on the market, such as CO2, fiber, and diode. Here's a thorough explanation of the attributes and benefits of each laser type:[4]

CO2 lasers:

Commonly used to cut, engrave and mark a wide range of materials, including wood, acrylic and certain metals, CO2 lasers operate at a wavelength of 10.6 micrometers. This makes them particularly effective on non-metallic materials. Although initially less expensive than fiber lasers, they have higher operating costs and require more maintenance due to the complexity of their beam emission systems.

Fiber Lasers:

Known for their high efficiency and rapid operation, fiber lasers operate at a wavelength of 1.06 micrometers, making them suitable for metal cutting and engraving. Despite a higher initial cost, fiber lasers feature lower operational expenses and demand less maintenance. They also boast a longer lifespan and enhanced power efficiency compared to CO2 lasers.

Diode Lasers:

Often used for lower power tasks like engraving and marking, diode lasers are the most economical type of laser and have an extended lifespan. Despite their affordability, they are less powerful compared to CO2 and fiber lasers, typically handling lighter materials like plastics and thin woods.The table 3.2 shows a comparison between the three laser types mentioned earlier

Table 3.2 *Comparison of Different Types of Lasers.*

Material	**Power**	**Applicable Materials**	**Application Areas**
CO2 Laser	The power of CO2 lasers is generally between 25 and 100 W.	Metallic materials include non-ferrous metals, such as thin aluminum plates. Non-metallic materials include wood, paper, acrylic, leather, fabrics, and wallpapers.	Used for cutting non-metallic materials and food processing, such as cheese and chestnuts.
Diode Laser	Diode lasers have lower power ratings than fiber and CO2 lasers, generally in the order of a few watts.	Used for marking and cutting applications on thin materials, such as plastics and paper.	Electronics, automotive, and medical sectors for marking and cutting applications.
Fiber Laser	Fiber lasers are very powerful, can reach power levels of several kilowatts.	Metallic materials include ferrous and non-ferrous metals, as well as composite materials. Non-metallic materials include glass, wood, and plastics.	Automotive, aerospace, electronics, and semiconductor industries to manufacture high-precision components and products.

3.3.2 Laser source installation

Our CNC machine was equipped with the ZBAITU laser module, providing an optical output power of 10W. The module features a laser emitter that connects to a driver, which then interfaces with the controller (see figure 2.18) using the TTL and POWER ports, as shown in the figure 3.5 below.

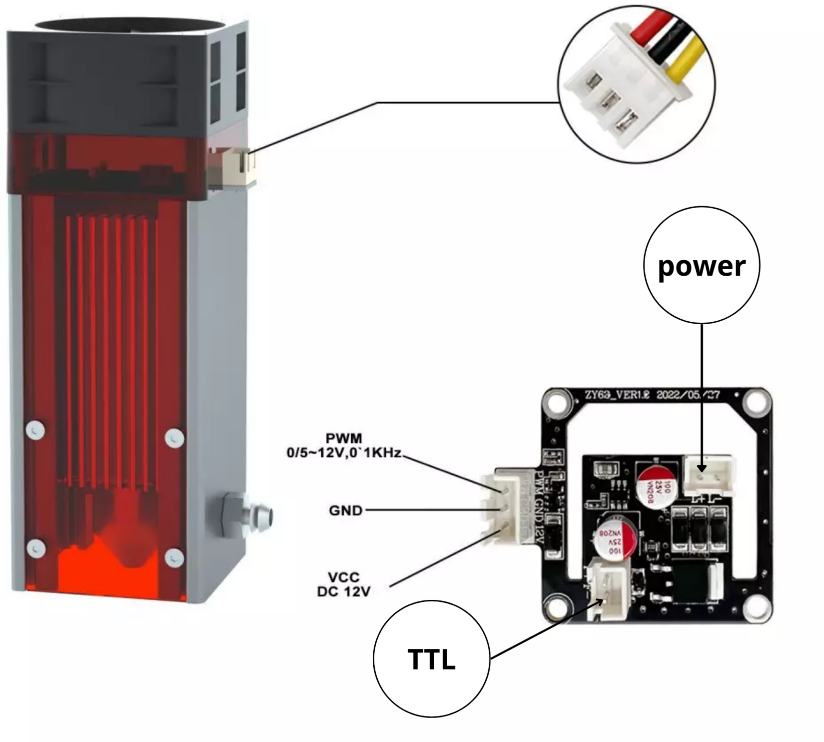

Figure 3.5 *ZBAITU laser module.*

3.3.3 Optical Alignment

Optical alignment is crucial for the performance of any laser system. It involves aligning the laser beam with the optical components to ensure the beam is focused correctly on the target material to complete the job perfectly and its resumed in the following table.

Table 3.3 *Cutting reference table.*

material	**cutting speed (mm/min)**	**pass**	**cutting height(mm)**
2* 2 mm plywood	600	1	5
	1800	3	5
2* 3mm plywood	450	1	4*4.5
	1200	3	
2* 5mm plywood	240	1	
	500	3	
2* 8mm plywood	120	1	2*3.5
	360	3	
2* 10mm pine board	90	1	3*2.5
	270	3	
15mm pine board	180	4	
20mm pine board	180	10	0.5
3* 3mm MDF board	180	1	3*4.5
	360	2	
	450	3	
3* 5mm MDF board	120	2	3*2.5
	200	3	
	360	4	
6mm black acrylic	70	1	4.5
6mm black acrylic	180	18	2.5

3.4 Mechanical system integration (spindle)

3.4.1 Assembly and technical specifications.

for the spindle control we used WS55-220 BLDC(brushless direct current motor) motor controller, this controller can be used to control the speed and direction of a Brushless Motor. It can start, stop, and reverse its rotation. Suitable for motors with and without sensors. A BLDC motor controller detects the position of the rotor either by using sensors (for example, a Hall-effect sensor) or senselessly. The sensors measure the rotor's position and send out this data. The controller receives the information and enables the transistors to switch the current and energize the required winding of the stator at the right time.

The driver uses advanced technology and provides high speed, high torque, low noise, low vibration, over current protection, overload protection, phase line short protection, alarm output, speed signal output, positive negative rotation control etc.

This controller is designed to be used in Small Equipment, Electric Power Tools, Exhaust Fan, Jade Grinding Machine, Vibrating Motor, CNC Spindles, etc. There are two modes of speed regulation used is ThroughExternal potentiometer: Speed is controlled through the potentiometer.

in the table 3.4 and figure 3.6 we find the Electrical Specifications also connection mode for adjust speed with Potentiometers that helped us in the cnc machine assembly

Table 3.4 *Electrical Specifications.*

Parameter	Definition
Rated Voltage	20-50 VDC
Rated Current	10A
Limited Current	12A
Maximum Speed	20000 RPM
Speed Control	Regulation resistance
Alarm Output	Al signal 5V output
Forward or Reverse Rotation	It can change the direction of rotation of the motor to stir the side switch F/R Positive inversion
Startup and Shutdown	1. Stir the side switch EN 2. Turn on or turn off the external switch
Speed Adjust	Twist external potentiometer or the side potentiometer
Locked Rotor Protection	The motor will shut down when locked and restart after power is opened again
Power Light	Green LED
Operation Condition Light	Red LED

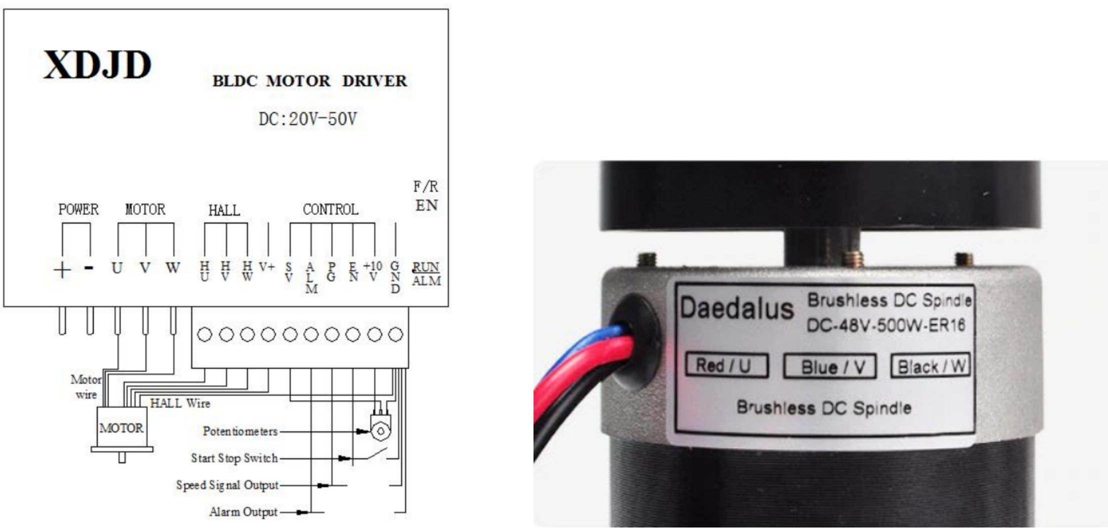

Figure 3.6 *Connection mode for adjust speed with Potentiometers.*

3.5 Programing and Calibration

Files in 2D formats, such as DXF or DWG, or 3D formats, like STEP or SAT, can be analyzed to understand a design's construction. Using this data, a flat shape is produced by adjusting the cut size to accommodate necessary curvature tolerances or other factors impacting the final product. Software packages can determine the optimal component configuration for a specific sheet size.

Common sheet sizes include 2 meters by 1 meter, 2.5 meters by 1.25 meters, and 1.5 meters by 3.0 meters. Additionally, leftovers from completed projects are a valuable resource. CNC nesting is used to automate this process. By nesting numerous parts within a single sheet of metal or across multiple sheets of different sizes, software such as Radan® can maximize productivity. It is advantageous to group similar items on the same sheet to optimize material usage.

Compared to programming a punching machine, CAM for laser cutting is often simpler. However, there are many details to consider. The laser cutting process involves several steps, including labeling (to prevent parts from spilling out of the nest), cutting (to optimize scrap size and shape), and cutting scraps (to break them into small pieces that will fall through the gaps in the laser cutting bed).

3.5.1 Control Systems and Software

3.5.1.1 Computer-aided design (CAD) software

CAD is a set of computer tools and programs designed to help engineers design and develop a product.CAD systems help engineers to design and develop a product. A CAD system makes it possible to represent and study the functioning of an object without having manufactured it, i.e. virtually. virtual. A large number of CAD programs are available, for example :

- SolidWorks.
- proteus
- freeCAD
- QCAD
- EasyEDA

As we had become familiar with PROTEUS and SOLIDWORKS during our training, we decided to use it.We decided to use it.

SOLIDWORKS: Created in 1993 by the eponymous American software publisher, SolidWorks was acquired on June 24, 1997 by Dassault Systèmes.

SolidWorks is a powerful, easy-to-use CAD (Computer Aided Design) and easy interface figure3.7 software package for dedicated to 3D design and modeling. It is widely used in industry for the manufacture of manufacturing of various mechanical, hydraulic and electrical parts, as well as the assembly and the design of machines and devices from A to Z.

SOLIDWORKS is a 3D modeler using parametric design. It generates 3 types of files relating to three basic concepts: part, assembly and drawing. These files are interrelated. Any modification at any level is reflected in all the files concerned.

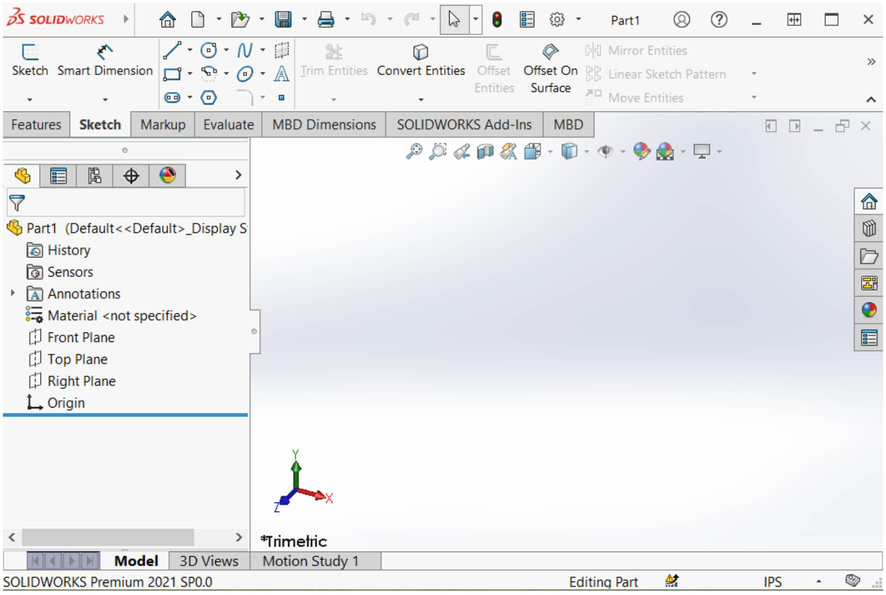

Figure 3.7 *SOLIDWORKS interface.*

PROTEUS: Proteus is a software tool used for electronic design automation (EDA). It is primarily used for schematic capture, simulation, and PCB (printed circuit board) design.Proteus is developed by Labcenter Electronics and is widely used by engineers, students, and hobbyists for designing and testing electronic circuits due to his easy and simple interface figure 3.8. It offers a comprehensive set of features for circuit design and simulation, Allows users to draw electronic circuits using various components, Provides a virtual environment to simulate and test the behavior of circuits, Enables users to design printed circuit boards based on their schematics and finally Supports simulation of microcontroller-based circuits, allowing users to develop and test embedded systems.

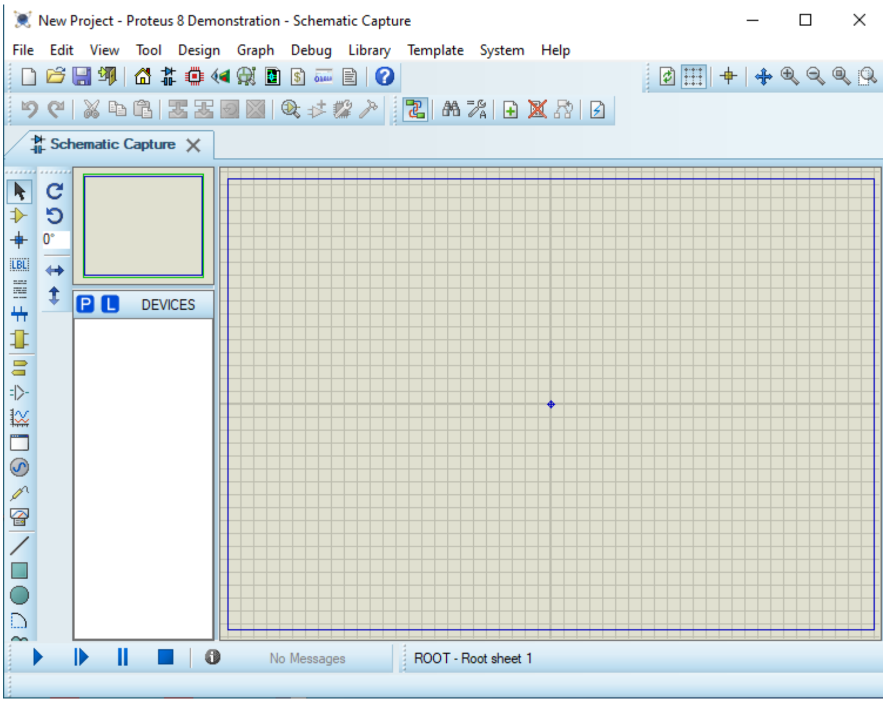

Figure 3.8 *Proteus software interface.*

3.5.1.2 Software integration with the CNC machine

Programming is the preliminary process of converting the machining program of a part from alphanumeric text into a sequence of instructions that the CNC machine can interpret and execute. This task can be performed manually or using a computer with a high-level programming language.
All machining operations in a program require certain identical functions, which are defined in G-code. G-code, established in the 1960s by the Electronics Industry Association (EIA) and documented as RS-274D, is commonly referred to as Code-G because the majority of commands start with the letter G.
While G-code is designed to be a universal standard, each machine manufacturer has its own version depending on the capabilities of the machine. **G-Code program** The objective of any G-Code program is to produce parts with maximum safety and efficiency. To achieve this, G-Code blocks are typically sequenced in a specific order, as shown below:

1. Start the CNC program.
2. Load the required tool.
3. Activate the spindle.
4. Turn on the coolant.
5. Position over the workpiece.
6. Commence the machining process.
7. Stop the coolant.
8. Deactivate the spindle.
9. Move away from the workpiece to a safe location.
10. End the CNC program.

3.5.1.3 User interfaces

CNC machines are known as CNC machines and can be used with recommended CNC programming software. CNC software is primarily responsible for creating the instructions and program code that a CNC machine or milling machine uses to accomplish a task. Most CNC software eliminates human intervention while making the entire process completely automated, precise, consistent and efficient. Actually, there are different CNC machine software in the market, but the question remains which software to choose ? **Best Free CNC Machine Software**

- **LinuxCNC:** LinuxCNC is software that runs on Linux, on most standard PCs, that can interpret G-code and run a CNC machine. It was originally developed on a milling machine, but support was added for lathes and many other types of machines. It can be used with mills, lathes, plasma cutters, routers, robots, and so on.

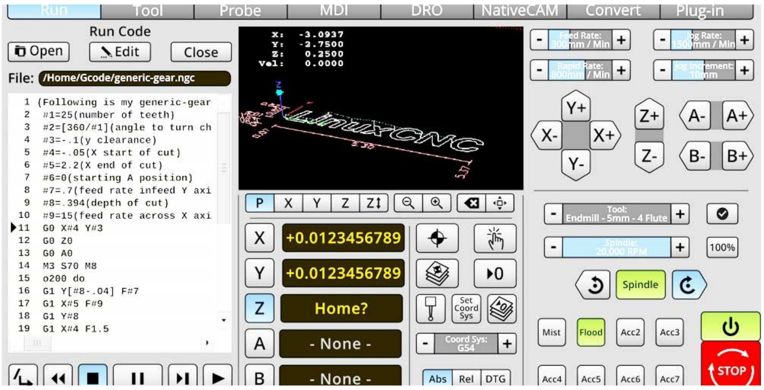

Figure 3.9 *LinuxCNC interface.*

- **GRBL:** GRBL is one of the free CNC software that shows its compatibility with the best CNC machines. For example, the software is fully compatible with Vevor CNC 2418 3 axis and Sainsmart Genmitsu 3018 Pro. GRBL is a simple software, but it is reliable and gives quality results. Typically, GRBL is Arduino-based software and is compatible with most Arduino boards; However, Arduino Mega is not one of them. At the same time, the software is easy to configure and use, which helps the CNC machine enhance its impressive acceleration and deceleration control.

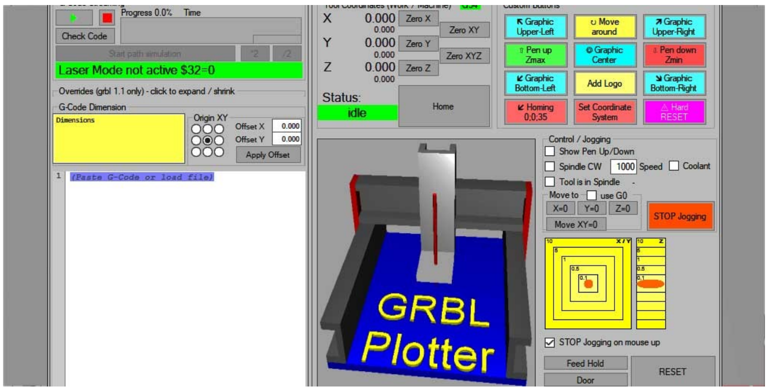

Figure 3.10 *GRBLCNC interface.*

- **Universal G-code Sender (UGS):** is also one of the free software available in the market. Although it is free, this CNC programming software has almost all the advanced features needed to accomplish advanced tasks, in addition to being easy to use. Likewise, being user-friendly and easy to use, this software has become the priority of most beginners.

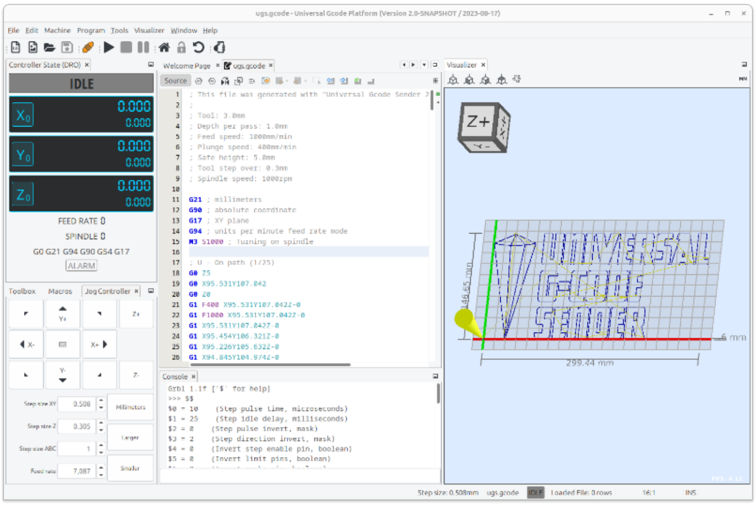

Figure 3.11 *UGS interface.*

- **Mach3:** Mach3 is a commonly used CNC control software that provides a range of features for CNC machines. These include multi-axis control, support for G-code (a standard programming language for CNC machines), and customizable user interfaces. This makes it suitable for various machining operations and user preferences.

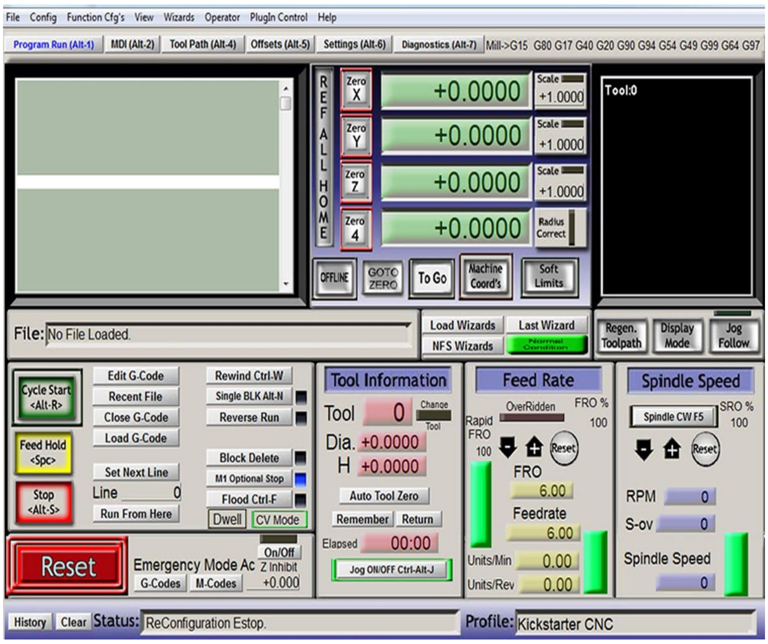

Figure 3.12 *Mach3 interface.*

3.6 Assemblage

Whether for machining or 3D printing, mastering the movement of a tool in three dimensions has become essential. This involves proficiency in managing the three spatial axes (X, Y, Z), requiring expertise in electronics, mechanics, and IT. In this part, we will detail the solutions we adopted to meet our specifications, addressing the design of each system part comprehensively.

The frame

: The frame consists of several 20x20 V-grooved rails and four 20x40 base rails, all interconnected. like shown in figure 3.13

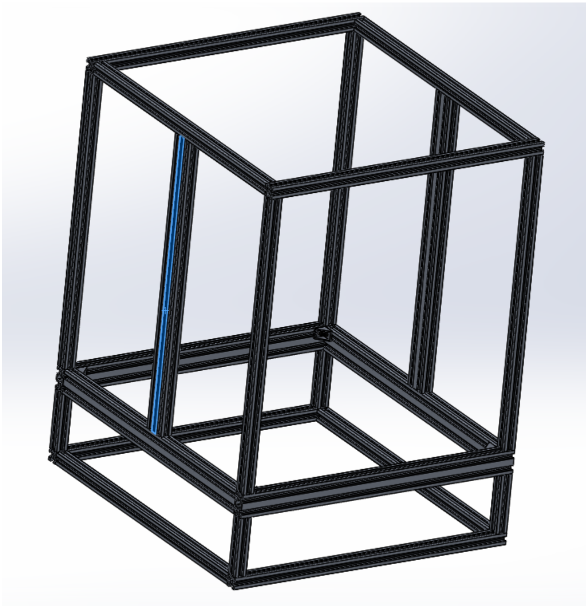

Figure 3.13 *Frame assemble.*

X-axis assembly:

For the X-axis, a C-beam is attached to the frame with an angle bracket and a T-nut figure 3.14. To ensure accurate alignment, a spirit level is used to adjust the axle correctly.

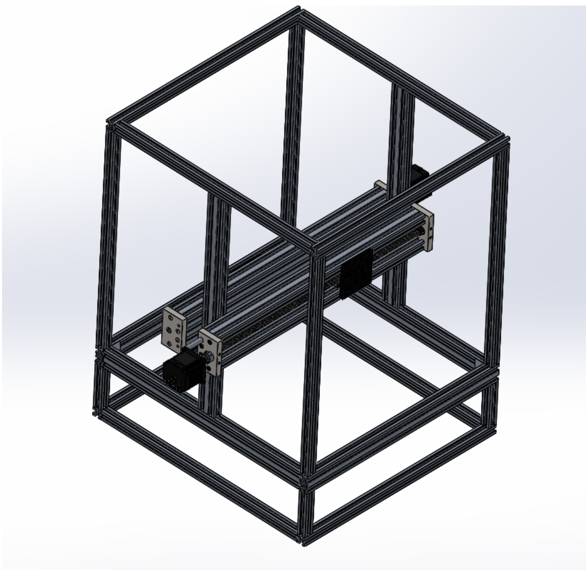

Figure 3.14 *X axes Assembly.*

Y-axis assembly:

The X-axis is made up of a C-beam attached to the base by means of an ANGLE BRACKET and a T-nut.see figure 3.15
In figure 3.16 the table is fastened to the C-PLATFORM on top of the axe with 5mm screws, and a 20x20 V-slots rails has been attached to the side to ensure the table's level adjustment.

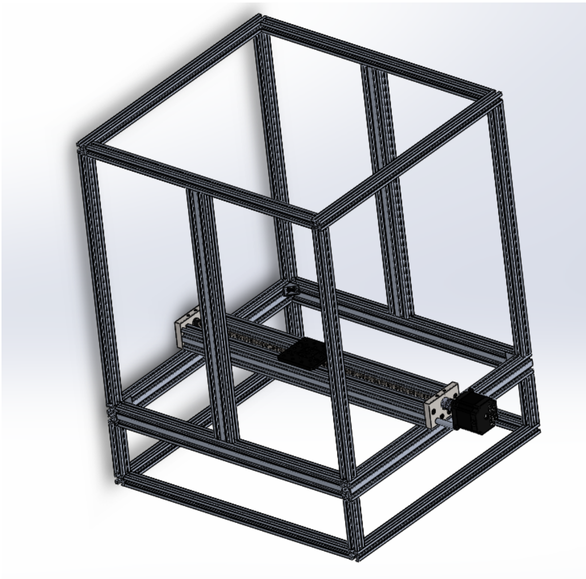

Figure 3.15 *Y-axis assembly.*

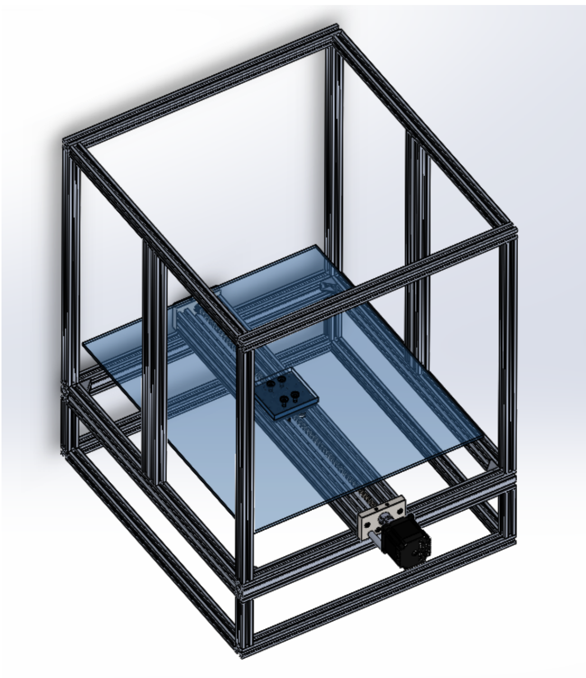

Figure 3.16 *Table assembly .*

Z-axis assembly:

These axes are different between the axis made for the laser in figure 3.18 which has been 3D printed for the laser head and the axis used for the spindle which is made by C-beam figure 3.17 due to the difference in forces applied to these axes between the spindle and the laser and both are connected to the X axis using the C-BEAM GANTRY PLATE the final assemble can be seen in figure 3.19.

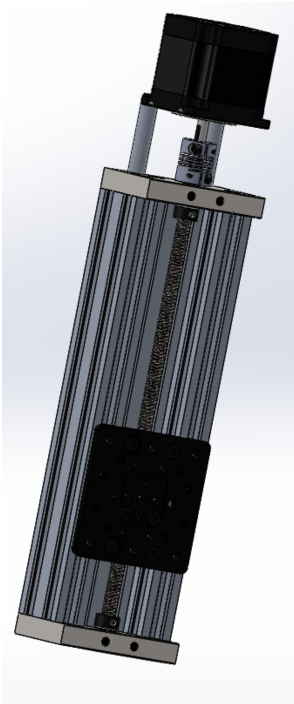

Figure 3.17 *Spindle Z-axe.*

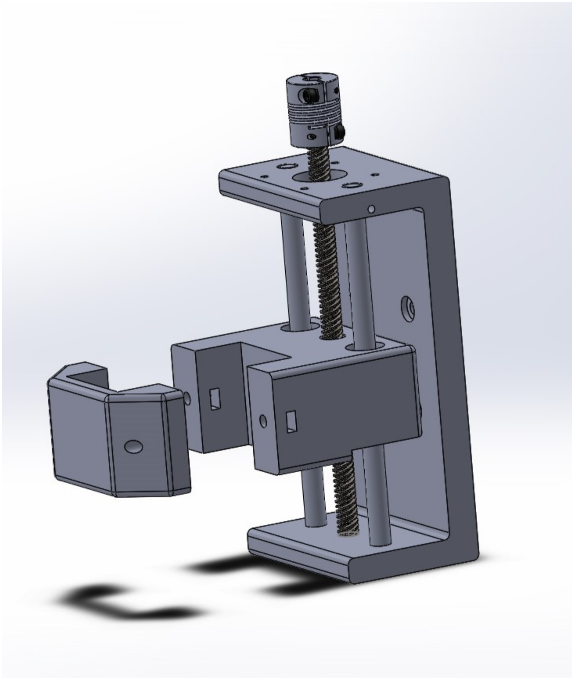

Figure 3.18 *Laser Z-axe.*

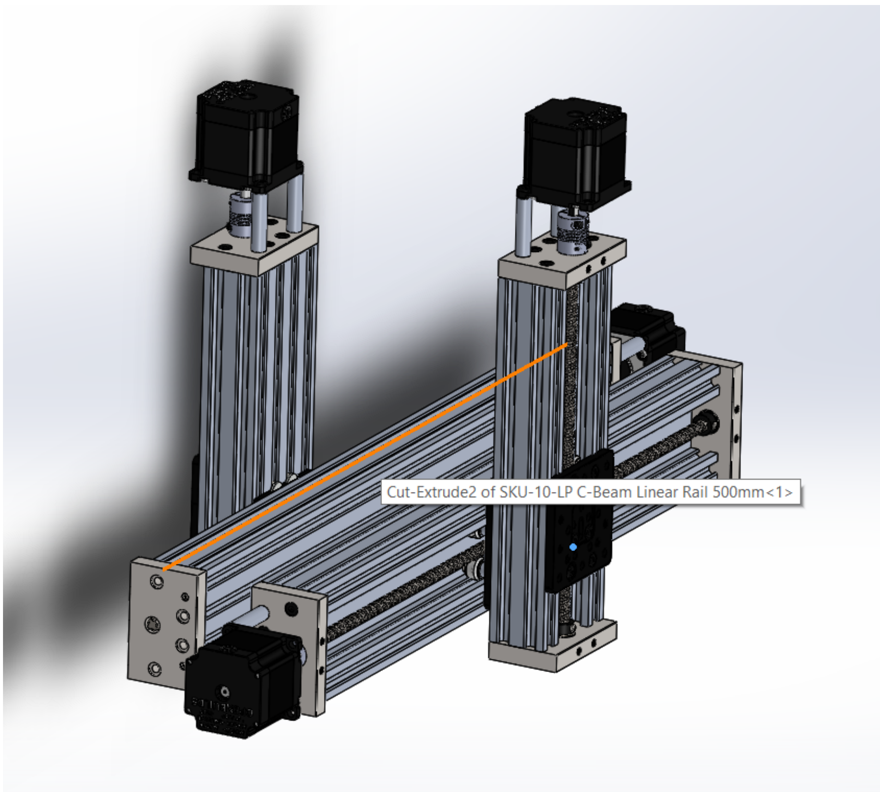

Figure 3.19 *Z-axis assembly.*

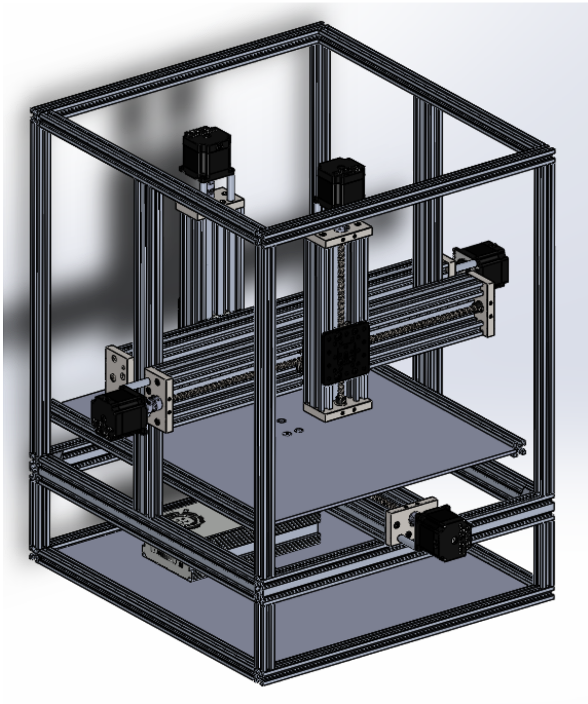

Figure 3.20 *Complete assembly of the three axes with the base.*

The final assembly of machine

Having listed the various parts of the CNC machine, we'll now assemble them to form a complete CNC machine, as shown in the figure 3.20 below.

Electrical assembly

For the assembly of the electrical and control system we have placed a sliding drawer to hold all the necessary equipment such as power supplies, controller and drivers The drawer is equipped with a M/F CIRCULAR CONNECTOR to separate the inside from the outside in case of maintenance needs shown in figure **??** th drawer contain :

- 12V power supply
- 48v power supply
- CNC controller
- Diver motor
- Spindle motor driver
- stepper motor connectors
- limit switch connector
- on/off switchs
- potentionmettre
- power supply input
- USB port

To facilitate the switch operation between the laser module and the spindle, a relay was implemented. This relay receives signals from both the X and Z axes and directs them to either the laser or spindle axis, based on the operator's input received through a switch located at the back of the machine.

CNC machine realization

Despite all these difficulties, we were determined to build our CNC machine. To do this, we followed the steps and information listed above, and the result can be seen in the following figure 3.21.

Figure 3.21 *The full assembly of the CNC machine.*

3.7 Function tests

To evaluate our machine's performance, we used GRBL laser software to engrave and cut both simple shapes and a few complex parts. This allowed us to assess the quality of the engraving and cutting capabilities of the laser component. The results are shown in the following figures 3.22.

Figure 3.22 *Results of testing the cnc laser machine .*

As evidenced by the results, the precision and detail achieved are remarkable. Both complex images with intricate details and simpler designs were reproduced with exceptional accuracy and clarity. This demonstrates the machine's capability to handle a wide range of engraving and cutting tasks with a high degree of precision.

for the spindle part we used Proteus to draw a PCB example and UGS software The results are shown in the following figures 3.23 .

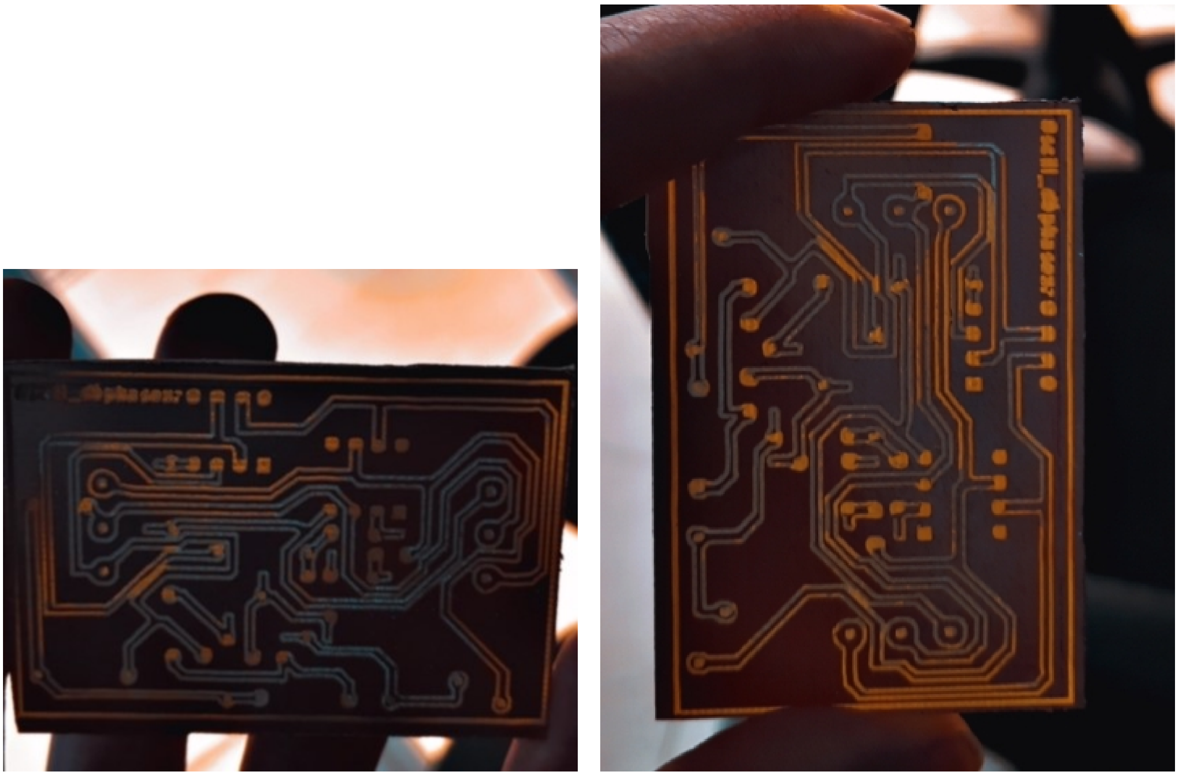

Figure 3.23 *Results of testing the cnc spindle .*

As evidenced by the results, the precision and detail achieved are remarkable. Both circuit engraving and drilling were reproduced with exceptional accuracy and clarity. This demonstrates the machine's capability to handle a wide range of engraving and drilling tasks with a high degree of precision.

conclusion

Designing and assembling a CNC machine is a demanding task, requiring mastery of the principles of mechanics, electronics and programming. Through this project, we demonstrated the importance of material selection, precision guidance systems and actuators, as well as the integration of electronic and laser components. We also integrated cooling and thermal management systems to ensure stable operation over long periods. Test runs confirmed the accuracy and efficiency of our machine, underlining the importance of rigorous calibration and programming. This report provides a detailed guide to the design of a CNC machine, offering valuable information for engineers and hobbyists with a passion for computer-aided manufacturing.

Annex Business Model Canvas

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our city or municipality of activity	TLEMCN

A.1 Problems and solutions

The Algerian industrial sector faces numerous challenges, including the lack of companies that construct CNC machines, the scarcity of multi-tool machines, and the absence of high-quality and precision products. These issues hinder the country's ability to produce complex parts and products efficiently and effectively. The CNC machine manufacturing industry is crucial for addressing these problems, as it provides the necessary tools and technologies for producing high-quality and precision parts.

A.2 TechFab BMC

At TechFab, our primary mission is the design, manufacture, and marketing of advanced CNC laser and spindle cutting machines. In the subsequent sections, we will systematically explore each component of the Business Model Canvas (BMC) in detail.

A.2.1 Value proposition

Technological innovation: The company must constantly innovate to offer its customers cutting-edge solutions. This includes developing new functionalities, improving machine performance, and integrating emerging technologies such as the Internet of Things (IoT) and artificial intelligence (AI). For example, the integration of IoT sensors enables real-time monitoring and predictive maintenance, reducing downtime and extending machine life. Using AI to optimize cutting processes improves precision and efficiency, offering a significant competitive advantage.

- **Machine design and production:** The company's expertise in the design and production of CNC machines is a major asset. By mastering every stage of the manufacturing process, from initial design to final assembly, the company guarantees high standards of quality and performance. Particular attention to ergonomic design, the use of durable materials and the optimization of manufacturing processes contribute to the reliability and longevity of our machines.

- **Customization:** The ability to tailor solutions to specific customer needs is another major added value. Customers in the CNC industry often have unique requirements based on their specific applications, be it industrial component manufacturing, prototype production or artistic creation. By offering CNC machines tailored to customers' precise specifications, the company demonstrates its flexibility and commitment to providing tailor-made solutions. This includes modifications in machine size, laser power, control software, and other technical features.

- **Operational efficiency:** CNC laser cutting machines are often used for applications requiring high precision and repeatability. By supplying reliable, high-performance machines, the company enables its customers to reduce waste, increase productivity and minimize production costs. A well-designed CNC machine can perform complex cut-outs with great precision, reducing the need for manual rework and material waste. Simplified maintenance and an intuitive user interface also contribute to maximizing uptime and minimizing downtime.

- **Sustainability:** Today, environmental concerns and increasingly stringent regulations are driving companies to adopt more sustainable practices. A CNC machine manufacturing company can differentiate itself by focusing on the energy efficiency of its machines, the use of recyclable materials and the reduction of carbon emissions. For example, by designing machines with energy recovery systems and eco-friendly components, the company can not only meet customers' environmental expectations, but also contribute to reducing the industry's overall carbon footprint.

- **Training and technical support:** CNC laser-cutting machines can be complex to operate, and customers appreciate the ongoing support and training offered by the manufacturer. By providing educational resources, detailed guides, and training sessions, the company helps customers maximize the use of their machines and overcome technical challenges. Responsive, competent technical support is crucial to resolving problems quickly and minimizing production downtime. A customer-centric approach reinforces trust and builds lasting relationships.

- **Cost optimization:** CNC laser cutting machines represent a considerable investment for companies, and offering flexible financing options, extended warranties, and after-sales service contracts can make this investment more affordable. For example, leasing solutions or staggered payment plans enable small and medium-sized businesses to acquire cutting-edge technology without compromising their cash flow. Comprehensive warranties and regular maintenance services increase customers' peace of mind and reinforce their confidence in the durability of their investment.

- **Human Machine Interface (HMI):** The integration of an intuitive, user-friendly human-machine interface is essential to enhance the user experience and maximize operational efficiency. A well-designed HMI facilitates programming, control and monitoring of CNC machines, even for less experienced users. This reduces human error, increases productivity and enables users to take full advantage of advanced machine capabilities.

- **Machine versatility (multi-tool machine):** The versatility of CNC machines, capable of supporting different tools and applications, is a key value proposition. By developing multi-tool machines, the company enables its customers to perform various operations (cutting, engraving, drilling, etc.) with a single machine, thus reducing equipment costs and increasing production flexibility. This versatility is particularly beneficial for manufacturing plants that have to handle varied and changing orders.

By offering these values, the company seeks to set itself apart from the competition and meet the specific needs of its customers, providing them with advanced, reliable and easy-to-use technological solutions for their CNC laser cutting requirements.

A.2.2 Customer segments

The customer segments of a CNC laser cutting machine manufacturing company are diverse, encompassing many specific industries and applications. Identifying and understanding these segments is essential to customizing the offering and maximizing customer satisfaction.

- **Manufacturing:** Manufacturing companies use CNC laser cutting machines to produce precise, high-quality components. This segment includes the automotive, aerospace, electronics and industrial equipment sectors. The needs of these customers include precision, repeatability and the ability to produce complex parts to exacting tolerances. Machine durability and reliability are also essential to minimize downtime and optimize production costs.

- **Rapid prototyping :** Companies and prototyping shops use CNC laser cutting machines to create functional prototypes quickly and efficiently. This segment appreciates the flexibility and speed of CNC machines, enabling them to test and refine their designs before mass production. Customers in this segment appreciate the precision and ability to work with a variety of materials to create true-to-life prototypes.

- **Furniture and decoration industry:** Furniture manufacturers and interior designers use CNC laser cutting machines to create unique pieces and complex patterns. The specific needs of this segment include the ability to work with a variety of materials such as wood, metal and acrylic, as well as the ability to make precise, customized decorative cuts. Flexibility and large-scale production capacity are also important to meet the demands of this market.

- **Arts and Crafts:** Artists and craftsmen use CNC laser cutting machines to create works of art, jewelry and other handcrafted objects of a precision and complexity impossible to achieve manually. This segment particularly appreciates the customization and design freedom offered by CNC machines. Ease of use and compatibility with artistic design software are also crucial aspects for these customers.

- **Medical industry:** Medical device manufacturers use CNC laser cutting machines to produce high-precision medical components and surgical instruments. The requirements of this segment include extremely tight tolerances, biocompatible materials and rigorous traceability. CNC machines must meet high quality and safety standards to be used in the manufacture of medical products.

- **The education sector:** Educational establishments, including universities and technical schools, use CNC laser cutting machines in their engineering, design and manufacturing training programs. This segment appreciates machines that are easy to use, safe and robust, with integrated educational functions. CNC machines enable students to gain valuable hands-on experience and familiarize themselves with modern manufacturing technologies.

- **Research centers:** Research and development centers use CNC laser cutting machines to explore new technologies, materials and applications. The specific needs of this segment include highly precise and flexible machines, capable of adapting to experimental projects and unique requirements. Close collaboration with these centers can also lead to the co-development of innovations and technological improvements.

- **SMEs and start-ups:** Small and medium-sized enterprises (SMEs) and start-ups are a growing customer segment for CNC laser cutting machines. These companies are looking for affordable, flexible and easy-to-use solutions to start up or improve their production. They need attractive financing options, solid training and technical support, and versatile machines capable of adapting to a wide variety of applications.

- **Medical industry:** The medical industry uses CNC laser cutting machines to manufacture medical devices, surgical instruments and other high-precision equipment. The requirements of this segment include rigorous quality standards, the ability to cut biocompatible materials and extreme precision. Compliance with health and safety regulations is also crucial.

By identifying and targeting these specific customer segments, the company can tailor its products and services to meet the unique needs of each customer, thus increasing its chances of market success.

A.2.3 Customer relations

Customer relations play an essential role in the success of a CNC laser cutting machine manufacturing company. Effective management of these relationships can improve customer satisfaction, strengthen loyalty and promote long-term growth.

- **Personalized customer support:** Providing personalized customer support is essential to meet the specific needs of each customer. This includes technical assistance, rapid problem resolution and advice on optimizing machine use. Customers appreciate responsive, competent assistance to help them overcome technical challenges and maximize the productivity of their machines.

- **Training and education:** We offer training programs and educational resources to help customers use their CNC machines safely and efficiently. These include training workshops, webinars, detailed user manuals and tutorial videos. Good training not only improves the user experience, but also reduces errors and downtime.

- **Proactive maintenance and after-sales service:** Offering proactive maintenance and reliable after-sales service is essential to ensure machine durability and performance. Regular maintenance contracts, rapid repair services and availability of spare parts minimize downtime and extend machine life. Customers particularly appreciate proactive maintenance, which prevents breakdowns before they occur.

- **Transparent communication:** Maintaining transparent communication with customers builds trust and loyalty. Keeping customers informed of product updates, new features and technological improvements helps to stay at the forefront of innovation. Customer feedback must be taken into account to continually improve products and services.

- **Loyalty and reward programs:** Implementing loyalty and reward programs can encourage customers to remain loyal and recommend the company to others. Discounts for repeat purchases, special offers for regular customers and rewards for referrals can strengthen long-term relationships.

- **Personalized support:** Providing personalized support based on customers' specific needs is an effective strategy for strengthening relationships. This can include technical consultations, personalized recommendations and solutions tailored to each customer's unique challenges. A dedicated account manager can serve as the main point of contact, ensuring smooth communication and a thorough understanding of the customer's needs.

By adopting a customer-centric approach and investing in strong, lasting relationships, the company can build customer loyalty, enhance its reputation and increase its market share in the CNC laser cutting machine industry.

A.2.4 Channels

The channels through which a CNC laser manufacturer reaches its customers are critical to the effective distribution of its products and services. A well-designed multi-channel strategy optimises customer reach and engagement.

- **Direct sales:** Direct sales through an internal sales force allows the company to maintain close contact with its customers. Sales representatives can provide product demonstrations, personalised advice and support services. This approach is particularly effective for industrial customers with specific, complex needs.

- **Website and e-commerce:** A well-designed website with an online store allows customers to search for product information, place orders and request quotes online. E-commerce offers convenience and accessibility, allowing customers to browse the company's offerings anytime, anywhere.
- **Distributors and resellers:** Working with local distributors and resellers extends the company's geographical reach. These partners can provide local support, product demonstrations and customer service, facilitating access to remote or hard-to-reach markets.
- **Trade shows and events:** Attending trade shows and industry events allows the company to showcase its products to a targeted audience. These events provide opportunities for networking, live demonstrations and valuable feedback. They also increase brand awareness and provide an opportunity to meet potential customers.
- **Digital marketing:** Digital marketing campaigns, including search engine optimisation (SEO), online advertising, social network marketing and email marketing, are essential for attracting new customers and retaining existing ones. A strong digital presence helps to increase business visibility and generate qualified leads.
- **Strategic partnerships:** Partnerships with other complementary businesses, such as CAD/CAM software suppliers, engineering consultants and technical training centers, help create combined offerings that better meet customer needs. These partnerships broaden the company's ecosystem and increase overall value for customers.
- **Sales representatives:** Sales representatives play a key role in customer relations, including direct sales and personalized support. They can offer product demonstrations, on-site consultations and personalized follow-up to ensure that customers get the most out of their CNC machines.

By using these channels strategically, the company can effectively reach potential customers, promote its products and increase sales of CNC laser cutting machines.

A.2.5 Key Partners

Key partners are essential to the success of a CNC laser cutting company. They play an important role in the value chain, from component supply to distribution and support.

- **Component suppliers:** Suppliers of high quality components such as lasers, motors, controllers and guidance systems are essential to the manufacture of CNC machines. Maintaining close relationships with these suppliers ensures the availability, quality and continuous innovation of key components
- **Material suppliers:** Suppliers of materials such as aluminum, steel, plastics and composites play a crucial role in the manufacture of CNC machines. Strong partnerships with these suppliers guarantee access to the high-quality, competitively-priced materials needed to produce durable, high-performance machines..
- **Training centres and educational institutions:** Partnerships with training centres and educational institutions enable us to offer training and certification programmes for CNC machine users. These partnerships enhance user skills, increase customer satisfaction and create a well-trained customer base.
- **Distributors and resellers:** Distributors and resellers play a key role in extending the company's geographical reach. They provide local support, product demonstrations and after-sales services, facilitating access to distant markets. These partners also allow you to benefit from their local market knowledge and customer networks.

- **Banks and financial institutions:** Banks and other financial institutions play a key role in financing the company and its customers. They can offer lines of credit, commercial loans and financing options for customers wishing to purchase CNC machines. In addition, partnerships with banks can facilitate international transactions and financial risk management.

- **Insurers and financial services (ASF):** Insurers offer coverage for risks associated with the manufacture, transport and use of CNC machines. They offer insurance policies to protect the company against losses due to accidents, breakdowns and natural disasters. In addition, financial services can include leasing and financing solutions for customers, making CNC machines more affordable.

- **Academic institutions and research centers:** Collaboration with universities and research centers provides access to technological innovations and new talent. These partnerships can lead to joint R&D projects, the creation of new technologies and continuous product improvement. Research centers can also provide solutions to specific technical challenges facing the company.

- **Marketing and advertising companies:** Marketing and advertising agencies help promote CNC machines, increase brand visibility and attract new customers. They provide content creation, advertising campaign management, public relations and branding services, contributing to the company's growth in the marketplace.

By establishing strategic partnerships with these different players, a CNC laser-cutting machine manufacturer can strengthen its value chain, improve the quality of its products and services, and increase its competitiveness on the global market.

A.2.6 Key Activities

The key activities for a CNC laser cutting machine manufacturing company encompass various essential operations that ensure the smooth functioning and success of the business. These primary activities including

- **Research and Development (R&D):** Continuous innovation and the development of new technologies are crucial to remain competitive in the market. This includes improving machine performance, developing new features, and integrating the latest technological advancements.

- **Machine Manufacturing with High Standards:** Producing high-quality CNC laser cutting machines requires rigorous manufacturing processes and adherence to the strictest industry standards. This includes using high-quality materials, precision assembly, and stringent quality control checks.

- **Sales and Distribution Channel Management:** Effective sales and distribution channel management are crucial to reach potential customers and maximize revenue. This includes managing relationships with distributors, direct sales, pricing strategy, and logistics.

- **Customer Training:** Providing comprehensive training programs for customers to effectively operate the CNC machines. This includes online training sessions, hands-on workshops, and detailed user manuals.

- **Marketing and Promotion:** Developing and executing marketing strategies to promote products and services. This includes online advertising, trade shows, industry events, and public relations campaigns.

- **Technical Support and After-Sales Service:** Providing responsive and knowledgeable technical support to assist customers in resolving issues and maintaining their machines in good working order. This includes maintenance services, repairs, and software updates.
- **Supply Chain Management:** Ensuring efficient supply chain management to guarantee the availability of components and materials necessary for machine manufacturing. This includes managing supplier relationships, inventory planning, and logistics.
- **Software Development:** Creating and maintaining the software required for CNC machine operation, including control software, user interfaces, and computer-aided design (CAD) tools.
- **Customer Service and Relationship Management:** Maintaining strong customer relationships by providing excellent customer service, gathering feedback, and ensuring customer satisfaction with their purchases.

By carrying out these key activities efficiently, the company can guarantee the production of high-quality CNC machines, meet customer needs and maintain a competitive market position.

A.2.7 Key Resources

Key resources are the essential assets required for the operation and success of a CNC laser cutting machine manufacturing company. These primary resources include:

- **Human Resources:** This includes engineers, operators, marketing specialists, and managers. A skilled and motivated workforce is crucial for innovation, production, marketing, and overall business management.
- **Production Facilities:** Modern and well-equipped production facilities are necessary for the manufacturing of high-quality CNC machines. This includes workshops, production lines, R&D laboratories, and storage spaces.
- **Production Equipment:** The company must have advanced production machinery and equipment to manufacture the CNC machines. This includes precision equipment for machining, assembly, testing, and quality control.
- **Supplier Network:** Having a reliable network of suppliers for components and materials is crucial to ensure production continuity and the quality of the final products. This includes suppliers of lasers, motors, guidance systems, and other critical components.
- **Intellectual Property:** Patents, trademarks, and copyrights protect the company's technological innovations and branding, providing a competitive advantage in the market.
- **Financial Capital:** Adequate access to financial capital is essential to fund operations, R&D, expansions, and marketing strategies. This includes initial investments, working capital, and financing for growth.
- **Technology and Software:** CAD/CAM software, CNC control systems, production management tools, and CRM (Customer Relationship Management) platforms are key resources for product development, manufacturing, and business management.
- **IT Infrastructure:** Robust and secure IT systems are necessary to manage the company's operations, including production processes, customer data, inventories, and internal communications.

- **Distribution Network:** A well-established distribution network, including logistics partners, distributors, and dealers, is crucial to reach customers and ensure product availability in target markets.
- **Brand and Reputation:** A strong brand and a good market reputation increase customer trust and facilitate sales. This includes the perception of product quality, customer service, and the company's innovation.
- **Strategic Partnerships:** Collaborations with other companies, academic institutions, and research centers are essential for continuous innovation and product improvement.

By effectively combining these key resources, the company can efficiently develop, produce, market, and distribute CNC laser cutting machines, while meeting the diverse needs of its customers and maintaining a competitive position in the market.

A.2.8 Cost structure

The the cost structure of Techlab for a CNC machine fabrication manufacturer include:

- **Fixed Costs**
  - **Rent or mortgage:** The cost of the physical space where the business operates, whether it's a factory or a smaller workshop, is a substantial fixed expense.
  - **Salaries and wages:** The cost of employing staff, including engineers, machinists, administrative personnel, and sales teams, forms a significant portion of fixed costs.
  - **Utilities:** The cost of electricity, water, gas, and other essential services required to keep the operations running smoothly.
  - **Insurance**: The cost of various insurance policies, including liability, property, and health insurance for the business and its employees, ensures risk management.
  - **Equipment and machinery:** The cost of purchasing advanced CNC machines, 3D printers, and other necessary equipment, along with their maintenance, is a critical investment.
  - **Marketing and advertising:** The cost of promoting the business and its products or services through various channels, such as online advertising, trade shows, and industry publications.
  - **Maintenance and repair:** Regular maintenance and occasional repairs of equipment and machinery are essential to avoid downtime and ensure optimal performance.
- **Variable Costs**
  - **Raw material cost:** The cost of aluminum, steel, electronics, and other materials used for machining varies depending on market prices and order volumes.
  - **Machining cost:** Costs associated with programming CNC machines, creating fixtures, and the actual cutting process, including tool wear and consumables.
  - **Post-processing cost:** Expenses related to surface finishing, assembly, quality control, and other post-processing requirements to meet customer specifications.
  - **Overhead cost:** Includes facility expenses, utilities, administrative costs, and other miscellaneous expenses that can fluctuate with production levels.
  - Profit margin: Added to the total cost to cover the supplier's profit and ensure the business remains financially viable.

A.2.9 Revenue Streams

The revenue streams for a CNC machine fabrication manufacturer include:

- **Sales Revenue**
  - **Product sales:** The revenue generated from selling CNC machines and related accessories to various customers, including businesses and hobbyists.
  - **Service sales:** The revenue generated from providing services such as machine customization, maintenance, and repair.
  - **Subscription revenue:** The revenue generated from subscription-based services like software updates, remote support, and maintenance plans.
- **Other Revenue Streams**
  - **Advertising revenue:** The revenue generated from advertising on the business's platforms, including website banners and industry magazine ads.
  - **Data analytics revenue:** The revenue generated from selling data analytics services related to machine performance and production efficiency.
  - **Data analytics revenue:** The revenue generated from selling data analytics services related to machine performance and production efficiency.
  - **Licensing revenue:** The revenue generated from licensing the business's intellectual property, such as patented technologies or proprietary software, to other manufacturers or users.

A.3 Financial analysis

A.3.1 Optimistic case

Table A.1 *Sales increase.*

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total Sales	**41,500,000**	**48,000,000**	**53,100,000**	**59,250,000**	**66,450,000**
CNC Spindle					
Price	350,000	350,000	350,000	350,000	350,000
Quantity	50	60	66	75	87
Total Sales	**17,500,000**	**21,000,000**	**23,100,000**	**26,250,000**	**30,450,000**
CNC Laser					
Price	300,000	300,000	300,000	300,000	300,000
Quantity	80	90	100	110	120
Total Sales	**24,000,000**	**27,000,000**	**30,000,000**	**33,000,000**	**36,000,000**

Table A.2 *Consumption Increase.*

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Consumption	**34,348,380**	**39,662,040**	**43,887,580**	**48,929,210**	**54,786,930**
CNC Spindle					
Cost	272,030	272,030	272,030	272,030	272,030
Quantity	32	36	40	46	58
Consumption	**13,601,500**	**16,321,800**	**17,953,280**	**20,402,250**	**23,666,610**
CNC Laser					
Cost	259,336	259,336	259,336	259,336	259,336
Quantity	48	54	60	69	82
Consumption	**20,746,880**	**23,340,240**	**25,933,600**	**28,526,960**	**31,120,320**

Table A.3 *Income statement table.*

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Sales	41,500,000	48,000,000	53,100,000	95,250,000	66,450,000
Consumption	-34,348,380	-39,662,040	-43,887,580	-48,929,210	-54,786,930
Gross Margin	**7,151,620**	**8,337,960**	**9,212,420**	**10,320,790**	**11,663,070**
Rental Expenses	-240,000	-240,000	-240,000	-240,000	-240,000
Energy, Water	-72,000	-73,440	-74,909	-76,407	-77,935
Telecommunications	-172,200	-175,644	-179,157	-182,740	-186,395
Subscriptions	-24,000	-24,480	-24,970	-25,469	-25,978
Marketing	-240,000	-252,000	-264,600	-277,830	-291,722
Other Charges	-140,000	-144,200	-148,526	-152,982	-157,751
Staff	-3,402	-3,402,000	-3,402,000	-3,402,000	-3,402,000
Gross Operating Income	**2,861,420**	**4,026,196**	**4,878,259**	**5,963,362**	**7,281,469**
Amortization Grants	-28,500	-28,500	-28,500	-28,500	-28,500
Profit Before Tax	**2,832,920**	**3,997,696**	**4,849,759**	**5,934,862**	**7,252,969**
Income Tax	0	0	0	0	0
Net Income	**2,832,920**	**3,997,696**	**4,849,759**	**5,934,862**	**7,252,969**

- **Sustained growth:** The company is showing sustained growth in sales and gross margin, which is a positive sign of performance.
- **Cost control:** Gross margin and EBITDA show that the company is successfully controlling its costs, but there is a slight decrease in EBITDA towards the end of the period, which may require further analysis.
- **Net profitability:** Net profit, although increasing, remains relatively low, indicating that there may be opportunities to improve tax efficiency, reduce financial charges, or optimize other non-operating costs.

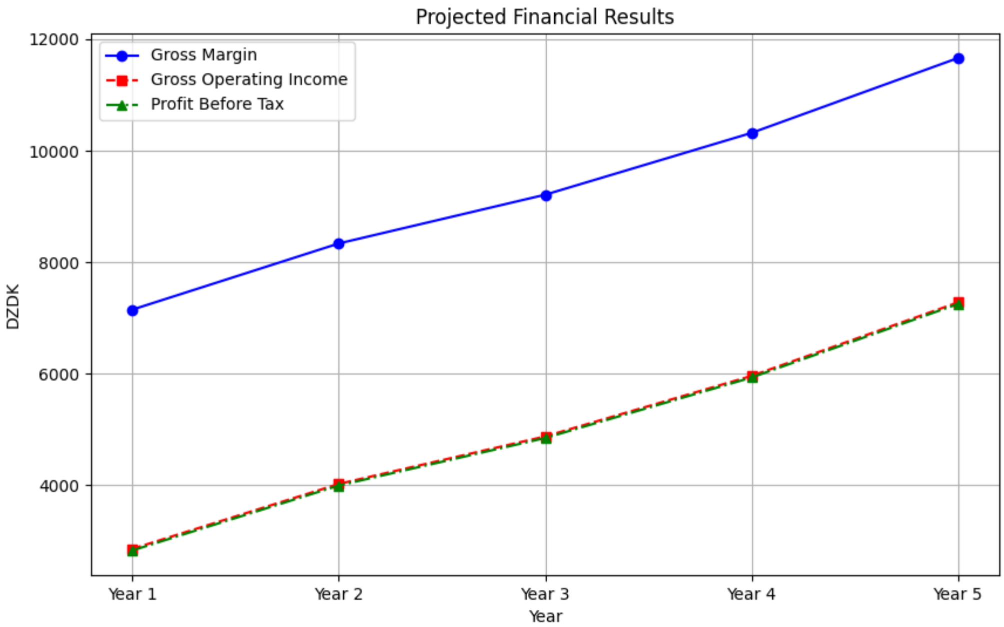

Figure A.1 *Enter Caption.*

All in all, the financial projection shows a growing company with a solid financial performance, but one which could benefit from a finer management of its costs and expenses to further improve its net profitability.

conclusion: The company achieved a positive financial performance between Year 1 and Year 2, with growth in all its key indicators. Sales growth is particularly strong, showing that the company has been able to win new customers and expand its business. Gross margin growth is also encouraging, as it shows that the company is able to generate higher profits on sales.

EBITDA is also up, showing that the company is able to generate higher cash flow. Net income is also up, showing that the company is more profitable and able to create more value for its shareholders.

A.3.2 Pessimistic case

Table A.4 *Sales increase.*

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total Sales	**25,600,000**	**28,800,000**	**32,000,000**	**36,800,000**	**44,900,000**
CNC Spindle					
Price	350,000	350,000	350,000	350,000	350,000
Quantity	32	36	40	46	58
Total Sales	**11,200,000**	**12,600,000**	**14,000,000**	**16,100,000**	**20,300,000**
CNC Laser					
Price	300,000	300,000	300,000	300,000	300,000
Quantity	48	54	60	69	82
Total Sales	**14,400,000**	**16,200,000**	**18,000,000**	**20,700,000**	**24,600,000**

Table A.5 *Consumption Increase.*

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Consumption	**21,153,088**	**23,797,224**	**26,441,360**	**30,407,564**	**37,043,292**
CNC Spindle					
Cost	272,030	272,030	272,030	272,030	272,030
Quantity	32	36	40	46	58
Consumption	**8,704,960**	**9,793,080**	**10,881,200**	**12,513,380**	**15,777,740**
CNC Laser					
Cost	259,336	259,336	259,336	259,336	259,336
Quantity	48	54	60	69	82
Consumption	**12,448,128**	**14,004,144**	**15,560,160**	**17,894,184**	**21,265,552**

Table A.6 *Income statement table.*

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Sales	25,600,000	28,800,000	32,000,000	36,800,000	44,900,000
Consumption	-21,153,088	-23,797,224	-26,441,360	-30,407,564	-37,043,292
Gross Margin	**4,446,912**	**5,002,776**	**5,558,640**	**6,392,436**	**7,856,708**
Rental Expenses	-240,000	-240,000	-240,000	-240,000	-240,000
Energy, Water	-72,000	-73,440	-74,909	-76,407	-77,935
Telecommunications	-172,200	175,644	-179,157	-182,740	186,395
Subscriptions	-24,000	-24,480	-24,970	-25,469	-25,978
Marketing	-240,000	-252,000	-264,600	-277,830	-291,722
Other Charges	-140,000	-144,200	-148,526	-152,982	-157,751
Staff	-3,402,000	-3,402,000	-3,402,000	-3,402,000	-3,402,000
Gross Operating Income	**156,712**	**691,012**	**1,224,479**	**2,035,008**	**3,475,107**
Amortization Grants	-28,500	-28,500	-28,500	-28,500	-28,500
Profit Before Tax	**128,212**	**662,512**	**1,195,979**	**2,006,508**	**3,446,607**
Income Tax	0	0	0	0	0
Net Income	**128,212**	**662,512**	**1,195,979**	**2,006,508**	**3,446,607**

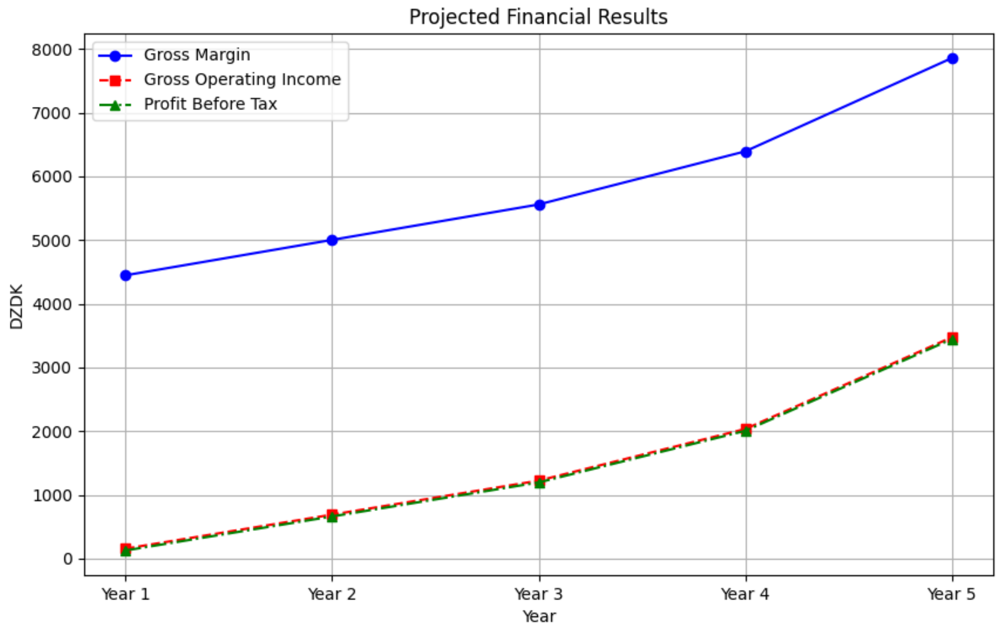

Figure A.2 *Enter Caption.*

Conclusion: Sales increased in both cases over the period studied. However, the optimistic case grew faster than the second case, with an average increase of 13.21% versus 13.94% for the pessimistic case.

Gross margin also increased in both cases over the period studied. However, it is lower in the second case, with an average increase of 12.25% versus 14.37% for company 2.

In summary, both cases show positive financial results, but Case 1 emerges as the better performer thanks to its superior growth and exceptional performance, particularly in terms of profitability.

conclusion

In conclusion, this thesis has provided an in-depth exploration of CNC machines, from their historical origins to their contemporary applications. We have discussed how CNC machines work, their structure, classification based on function, number of axes, motion systems, and operating modes. Additionally, we have examined key advantages of CNC machines, such as their automaticity, flexibility, safety features, and industrial impact.

Furthermore, this thesis has analyzed the requirements and specifications involved in choosing a CNC machine, including the types of materials to be worked, precision and tolerance requirements, machine dimensions and capacity, and the choice between laser and mechanical CNC types. The mechanical and electronic design aspects, as well as the integration of laser and spindle systems, have also been discussed in detail.

By exploring these aspects, this thesis aims to provide a comprehensive overview of CNC machines and their role in modern manufacturing processes. It is hoped that this research will contribute to the advancement of knowledge in the field of CNC technology and inspire further research and innovation in this area.

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