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Design of a wire electrical discharge machining machine

Presented by **MAMI Yacine**

Supervisor	Mr.TAKDENTI Mourad	University of Médéa
Co-Supervisor	Mr.KHELIL CHERFI Ismail	University of Médéa

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واللهم صل وسلم على سيدنا محمد وعلى آله وصحبـه أجمعين

Dedication

I dedicate this work to my parents

in the hope that they will find within it the evidence of my profound gratitude and appreciation.

To my siblings, grandparents, and extended family members who infuse my life with love and vitality.

To all those who have aided me—whether directly or indirectly—and stood by me during the emotional ups and downs of completing this work, offering unwavering support and encouragement throughout my journey.

To my friends who have consistently cheered me on, I wish you continued success.

Thank you all!

Yacine MAMI

ملخص

تقدم هذه المذكرة دراسة شاملة حول تصنيع القطع بواسطة التآكل الكهربائي بالأسلاك (WEDM)، مركزة على تطبيقها في عمليات التصنيع الدقيقة.

تبدأ الدراسة بنظرة عامة على مبادئ EDM (Electrical Discharge machining) وعملية EDM بالأسلاك، ثم تتعمق في التحليل الوظيفي لفهم متطلبات المشروع.

تسُهم الرؤى المكتسبة من التحليل في اختيار مكونات الآلة، مما يضمن الأداء الأمثل لآلة EDM بالأسلاك. تشمل المرحلة التصميمية التجميع ثلاثي الأبعاد وتحليل تفصيلي للمكونات، مما يسهل صناعة الآلة. من خلال التعامل المنهجي مع الجوانب الرئيسية لتصميم وتنفيذ EDM بالأسلاك، يسهم هذا العمل في تقدم تقنيات التصنيع بدقة، مع الآثار المحتملة على مختلف الصناعات.

كلمات مفتاحية : CNC، WEDM، التحليل الوظيفي، التجميع ثلاثي الأبعاد، التصنيع الدقيق.

Abstract

This thesis presents a comprehensive study on wire electrical discharge machining (WEDM), focusing on its application in precision manufacturing processes. Beginning with an overview of EDM principles and the wire EDM process, the study delves into functional analysis to understand project requirements. Insights gained from the analysis inform the selection of components, ensuring optimal performance of the wire EDM machine. The design phase includes 3D assembly and detailed component analysis, facilitating the realization of the machine. By systematically addressing key aspects of wire EDM design and implementation, this work contributes to advancing precision manufacturing technologies, with potential implications for various industries.

Key words: *CNC, WEDM, Functional analysis, 3D assembly, Precision Manufacturing.*

Résumé

Cette thèse présente une étude complète sur l'usinage par électro érosion par fil (WEDM), en se concentrant sur son application dans les processus de fabrication de précision. Commençant par une vue d'ensemble des principes de l'EDM et du processus de l'EDM par fil, l'étude plonge dans l'analyse fonctionnelle pour comprendre les besoins du projet. Les connaissances acquises à partir de l'analyse informent la sélection des composants, assurant ainsi des performances optimales de la machine EDM par fil. La phase de conception inclut l'assemblage 3D et une analyse détaillée des composants, facilitant la réalisation de la machine. En abordant systématiquement les aspects clés de la conception et de la mise en œuvre de l'EDM par fil, ce travail contribue à faire progresser les technologies de fabrication de précision, avec des implications potentielles pour diverses industries.

Mots clés : *CNC, WEDM, Analyse fonctionnelle, Fabrication de précision.*

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List of Abbreviations

EDM: Electrical discharge machining
CNC: Computer numerical control
PDS: product design specification
SADT: Structured analysis and design technique
FAST: Functional Analysis Systems Technique
APTE: APplication to business TEchniques
NPD: New Product Design
AFNOR: Association Française de Normalisation

General introduction

In the modern world, the demand for high-precision manufacturing processes is ever-increasing. Whether in the aerospace, automotive, medical, or electronics industries, the need for components that meet stringent specifications is paramount. Precision manufacturing is essential for ensuring the reliability, performance, and safety of countless products that people rely on daily. As technology advances, the complexity of these components grows, making traditional manufacturing methods less effective or even obsolete.

One of the solutions to meet these precision demands is the Wire Electrical Discharge Machining (Wire EDM) machine. The Wire EDM machine stands out due to its capability to cut extremely hard materials with high precision, which is often unattainable with conventional machining methods. This machine uses electrical discharges to erode the material in a controlled manner, allowing for the creation of complex shapes and fine details with exceptional accuracy. The importance of the Wire EDM machine in the manufacturing industry cannot be overstated, as it enables the production of intricate parts that are critical for advanced technological applications.

The primary objective of this project is to conduct a comprehensive study and design of a Wire EDM machine. This thesis will detail the theoretical and practical aspects of the machine, encompassing the selection of appropriate components and the design of the entire system. The goal is not only to understand the mechanics and electronics involved but also to explore the feasibility of realizing the machine in a practical setting. Throughout this study, we will identify and choose components that best meet the requirements of our Wire EDM machine, ensuring that our design is both effective and achievable.

This thesis is organized into four chapters:

The first chapter provides a comprehensive overview of the electrical discharge machining (EDM) phenomenon. It discusses the main types of EDM machines and focuses specifically on the Wire EDM machine, offering detailed information about the wire EDM process. Additionally, the chapter explores the CNC process and its application in the Wire EDM machine.

The second chapter is dedicated to a functional analysis of the project. Utilizing tools such as the horned beast, octopus, and FAST diagrams, this chapter highlights the importance of analytical study in the context of the project. This analysis provides a better understanding of the project's requirements and constraints.

The third chapter utilizes the insights gained from the functional analysis to select the most suitable solutions for the project. From the axis transmission system to the electrical motors, components were carefully chosen to best serve the needs of the Wire EDM machine.

The fourth chapter focuses on the 3D assembly of the machine, emphasizing its significance in the manufacturing process. All components are presented along with their 3D models. Following this, a detailed component analysis is conducted, specifying the type and real dimensions of each component. Subsequently, the chapter delves into the realization section, detailing the steps taken to achieve the actualization of the machine.

Chapter 1: Generalities

Chapter 1

Generalities

1.1 Introduction

In the rapidly advancing field of technology, the future of various industries hinges on materials with significantly enhanced properties such as high strength, low weight, and exceptional heat resistance. Achieving the precision required to effectively process these advanced materials is increasingly challenging with conventional machining methods.

For example, the manufacturing of gears presents a significant challenge when using conventional machining methods. Gears, which are crucial components in numerous mechanical systems, demand exceptional precision and surface finish to function effectively. Achieving the necessary accuracy and intricate detailing with traditional machining techniques often proves to be difficult, time-consuming, and costly. This complexity underscores the urgent need for innovative solutions that can enhance the efficiency and precision of gear production.

One of the most promising solutions to this problem is the Wire Electrical Discharge Machining (Wire EDM) process. Wire EDM is a non-conventional machining technique that utilizes electrical discharges to erode material from the workpiece, allowing for the precise cutting of complex shapes and fine details. Unlike traditional methods, Wire EDM does not involve direct contact between the tool and the workpiece, thereby eliminating mechanical stresses and reducing the risk of deformation.

The Wire EDM machine offers unparalleled precision and the ability to produce intricate geometries, This makes it an ideal choice for manufacturing high-precision components such as gears. Additionally, Wire EDM is highly versatile, capable of working with a wide range of materials, including hard and exotic alloys that are typically challenging to machine using traditional methods.

1.2 Objectives

- To provide an overview of Electrical Discharge Machining technology and its history.
- To explore different types of EDM machines.
- To introduce the Wire Electrical Discharge Machining machine.

1.3 Electrical discharge machining

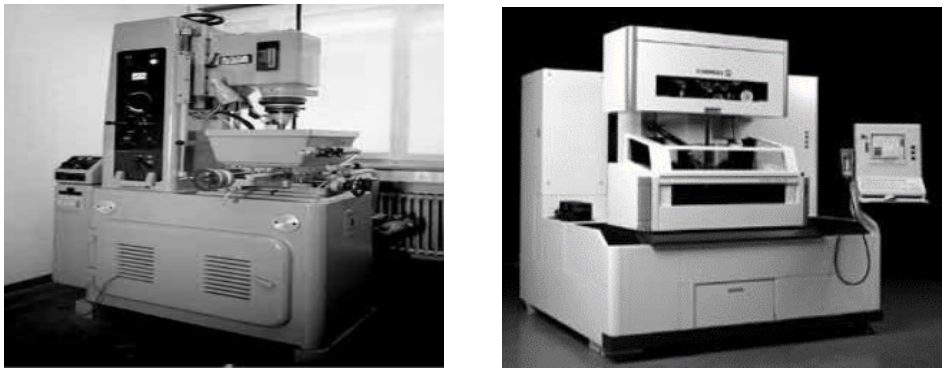
Electrical discharge machining (EDM), also known as spark machining, is a unique manufacturing process that removes metal by creating controlled electrical sparks between an electrode and the workpiece. The process can accurately produce intricate shapes and geometries in hard metals that would otherwise be impossible to machine with traditional techniques.

Electrical discharge machining is a non-traditional machining process where material is removed from the workpiece by a series of rapidly recurring electrical discharges between the tool, called the electrode, and the workpiece in the presence of a dielectric fluid. The process utilizes the heat from electrical sparks to erode material in the form of tiny craters on the workpiece. As the electrode approaches the workpiece, an electrical potential is applied, which ionizes the dielectric fluid and generates a plasma channel. As soon as the gap distance becomes small enough, the potential difference causes a strong electrical discharge, which generates an arc that melts and vaporizes a small amount of material from both the electrode and workpiece. The removed material is washed away by the continuously flushing dielectric fluid. These rapid, repetitive discharges occur in an area as small as 0.025mm, enabling EDM to remove material with extreme accuracy and detail. The absence of direct contact between the tool and the workpiece eliminates mechanical stresses, chatter, and vibration during machining.[1]

1.4 History

The history of EDM itself begins in 1943, with the invention of its principle by Russian scientists Boris and Natalya Lazarenko in Moscow. The Soviet government assigned them to investigate the wear caused by sparking between tungsten electrical contacts, a problem which was particularly critical for maintenance of automotive engines during the second world war. Putting the electrodes in oil, they found that the sparks were more uniform and predictable than in air. They had then the idea to reverse the phenomenon, and to use controlled

sparking as an erosion method . Though they could not solve the original wear problem, the Lazarenkos developed during the war the first E DM m achines, w hich w ere v ery u seful to erode hard metals such as tungsten or tungsten carbide. The "Lazarenko circuit" remained the standard EDM generator for years. In the 1950's, progress was made on understanding the erosion phenomenon . It is also during this period that industries produced the first EDM machines. Swiss industries were involved very early in this market, and still remain leaders nowadays. Agie was founded in 1954, and les Ateliers des Charmilles produced their first machine in 1955. Due to the poor quality of electronic components, the performances of the machines were limited at this time.[2]
Figure 1.1 presents the evolution of EDM machines.



(a) (b)

Figure 1.1: 50 years of evolution in EDM machines: (a) Eleroda D1 (1955) and (b) Robofil 2050 TW (2005) from Charmilles. [2]

In the 1960's, the development of the semi-conductor industry permitted considerable improvements in EDM machines. Die-sinking machines became reliable and produced surfaces with controlled quality, whereas wire-cutting machines were still at their very beginning. With the introduction of numerical position control in the late 1960's and early 1970's, the movements of electrodes became much more precise. This major improvement pushed forward the performance of wire-cutting machines. Computer numerical controlled systems (CNC) improved further the performance of EDM in the mid 1970's. During the following decades, efforts w ere principally m ade in generator design, p rocess automatization, s ervo-control and robotics. Applications in micro-machining became also of interest during the 1980's . It is also from this period that the world market of EDM began to increase strongly, and that specific applied E DM research took over basic E DM research Finally, new methods for EDM process control arose in the 1990's: fuzzy control and neural networks. [2]

1.5 Principle of working

The principle of EDM is to use the eroding effect of controlled electric spark discharges on the electrodes. It is thus a thermal erosion process. The sparks are created in a dielectric liquid, generally water or oil, between the workpiece and an electrode, which can be considered as the cutting tool. There is no mechanical contact between the electrodes during the whole process. Since erosion is produced by electrical discharges, both electrode and workpiece have to be electrically conductive. Thus, the machining process consists in successively removing small volumes of workpiece material, molten or vaporized during a discharge. The volume removed by a single spark is small, in the range of 10^-6 - 10^-4 mm3, but this basic process is repeated typically 10,000 times per second. Figure 1.2 gives a simple explanation of the erosion process due to a single EDM discharge.

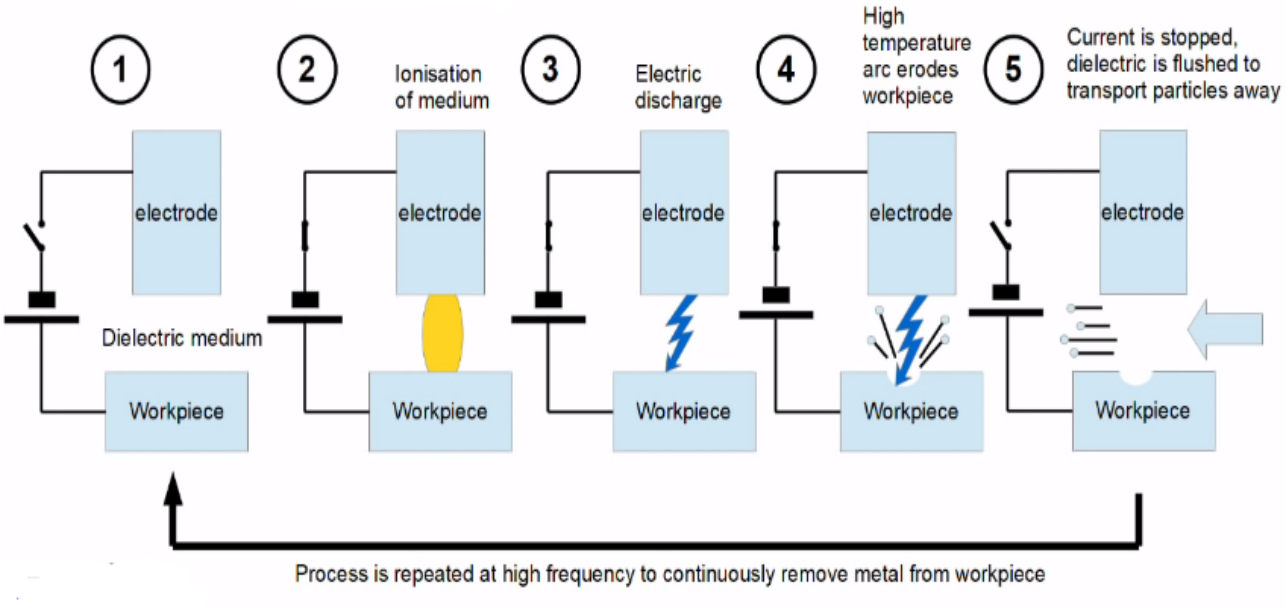


Figure 1.2: Principle of the EDM process [3]

First, voltage is applied between the electrodes. This ignition voltage is typically 200 V. The breakdown of the dielectric is initiated by moving the electrode towards the workpiece. This will increase the electric field in the gap, until it reaches the necessary value for breakdown. The location of breakdown is generally between the closest points of the electrode and of the workpiece, but it will also depend on particles present in the gap . When the breakdown occurs, the voltage falls and a current rises abruptly. The presence of a current is possible at this stage, because the dielectric has been ionized and a plasma channel has been

created between the electrodes. The discharge current is then maintained, assuring a continuous bombardment of ions and electrons on the electrodes. This will cause strong heating of the workpiece material (but also of the electrode material), rapidly creating a small molten metal pool at the surface. A small quantity of metal can even be directly vaporized due to the heating. During the discharge, the plasma channel expands. Therefore, the radius of the molten metal pool increases with time. The distance between the electrode and the workpiece during a discharge is an important parameter. It is estimated to be around 10 to 100 µm (increasing gap with increasing discharge current).

At the end of the discharge, current and voltage are shut down. The plasma implodes under the pressure imposed by the surrounding dielectric. Consequently, the molten metal pool is strongly sucked up into the dielectric, leaving a small crater at the workpiece surface (typically 1-500 µm in diameter, depending on the current). The liquid dielectric plays a crucial role during the whole process: it cools down the electrodes, it guarantees a high plasma pressure and therefore a high removing force on the molten metal when the plasma collapses, it solidifies the molten metal into small spherical particles, and it also flushes away these particles. The post-discharge is in fact a crucial stage, during which the electrode gap is cleaned of the removed particles for the next discharge. If particles stay in the gap, the electrical conductivity of the dielectric liquid increases, leading to a bad control of the process and poor machining quality. To enhance the flushing of particles, the dielectric is generally flowing through the gap. In addition, the electrode movement can be pulsed, typically every second, performing a large retreat movement. This pulsing movement also enhances the cleaning, on a larger scale, by bringing "fresh" dielectric into the gap.[2]

Figure 1.3 gives an explanation of the erosion process due to a single EDM discharge.

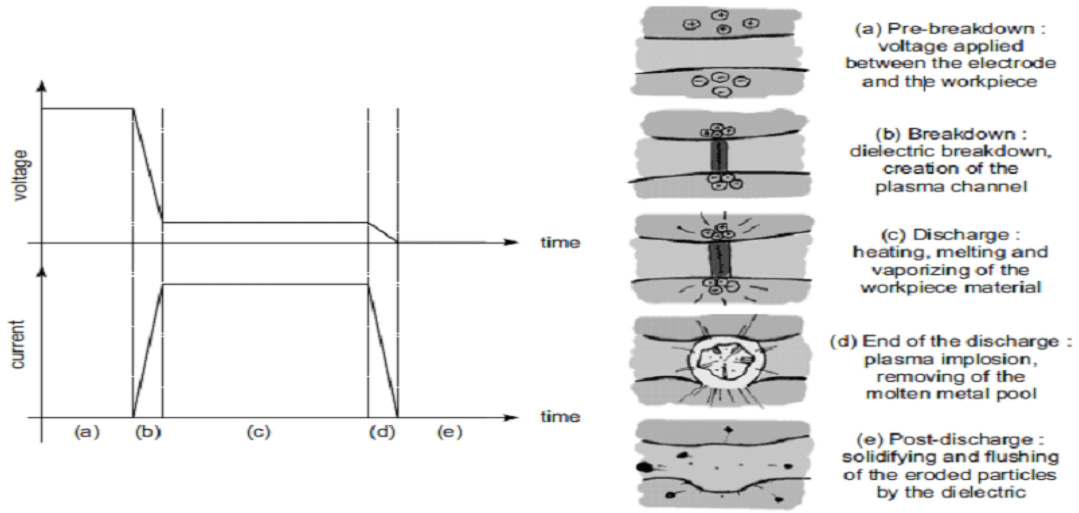


Figure 1.3: EDM process [2]

1.6 Types of Elictrical discharge machining machines

Electric discharge machining can be divided into three common types, Die sinking EDM, Wire EDM and hole drilling EDM.

1.6.1 Die sinking EDM

Die sink EDM (also known as Ram EDM, conventional EDM, or cavity-type EDM) is the best Electro Discharge Machining for creating parts with complex cavities. It is also the method chosen for solving the sharp internal corner issue when CNC machining. This method utilises graphite or copper electrodes, a dielectric fluid, and an electric spark induced between the electrode and the workpiece.

In the first step of this process, an electrode is produced in the reverse shape of the required cavity. This forms the die. A voltage is then induced between the die and the electrically conductive workpiece while submerged in a dielectric fluid like oil. The die is slowly lowered towards the workpiece until 'electric breakdown' occurs and a spark jumps the 'spark gap'. This vaporises and melts material from the workpiece while dielectric fluid subsequently carries any ejected particles away. A small amount of the electrode is also often eroded during this process. As the series of high-frequency sparks repeatedly removes a small amount of material from the workpiece, the desired shape will begin to take place and be precisely cut out. This sinker EDM process can be depicted in the image below:

Every aspect of this process, between the servers, power supply, and position of the electrodes, is completely controlled through precision machining.[4]

Figure 1.4 provides a brief explanation of the animation of the Die sinking EDM process.

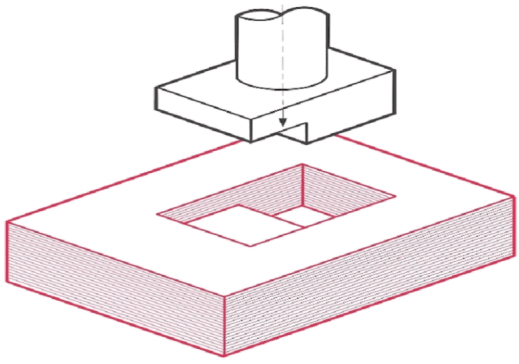


Figure 1.4: Die sinking EDM [4]

1.6.2 Wire EDM

Wire EDM, otherwise known as wire erosion, is commonly used to produce extrusion dies. It cuts using the same mechanism as die-sinking. However, the die is replaced with a very fine electrically charged wire which will work as the electrode. This machining method is comparable to a cheese cutter, making a two-dimensional cut in a three-dimensional part. The wire is usually very thin, with a diameter of around 0.05mm to 0.35mm. A fresh wire is automatically spooled throughout the machining process to avoid using burnt wire and to ensure precise cutting. This process will produce incredibly precise cuts. However, When the need is to cut sharp inside corners, it's important to note that wire EDM alone won't be able to give you true square corners. The wire and spark gap will create a tiny radius of about 0.13mm to 0.15mm, but this can be smaller or larger depending on the diameter of the wire. Sometimes it is necessary to start a cut from the centre of a part rather than from one of the edges. For example, machining a complex shape in the centre of an extrusion die. If that's the case, hole drilling EDM can make a small hole for the wire to be threaded through for wire EDM machining.[4]
Figure 1.5 provides a brief explanation of the animation of the wire EDM process.

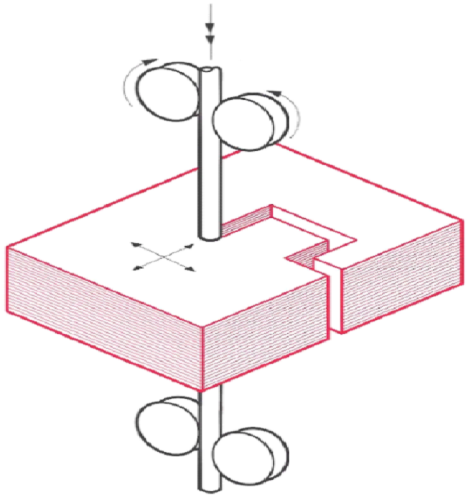


Figure 1.5: Wire EDM [4]

1.6.3 Hole drilling EDM

As the name implies, Hole drilling EDM (or small hole drilling EDM) is used to machine holes. However, this technique can accurately machine extremely small and deep holes that don't require deburring compared to traditional hole drilling methods. This method also uses

the same fundamental principles as die-sinking EDM. However, the cut is made with a pulsing cylindrical electrode with dielectric liquid fed into the cutting area while moving deeper into the workpiece. This method has been key to the advancement of high-temperature turbine blades, as it allows for very intricate cooling channels to be manufactured inside the turbine blades. [4]

Figure 1.6 provides a brief explanation of the animation of the Hole drilling EDM process.

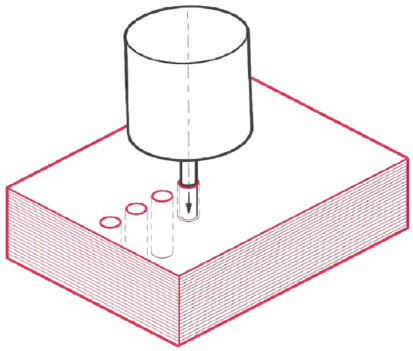


Figure 1.6: Hole drilling EDM [4]

The primary focus will be on Wire EDM and its unique characteristics, applications, and conception. This specialized form of EDM plays a crucial role in various industries. Throughout the course of this project, its principles, advantages, limitations, and real-world applications will be explored in greater detail.

1.7 Wire-cut edm components

The wire-cut machine's moves are controlled by servomotors, commanded by computer numerical control (CNC). There must always be an opening for the passage of the electrode wire. Precision machining with a wire-cut machine requires very close attention to the travelling-wire-feed system. This includes the top-and-bottom wire guides, the wire-tensioning mechanism, and the condition of the wire on the supply spool.[5]

Figure 1.7 provides a brief explanation of the wire EDM components.

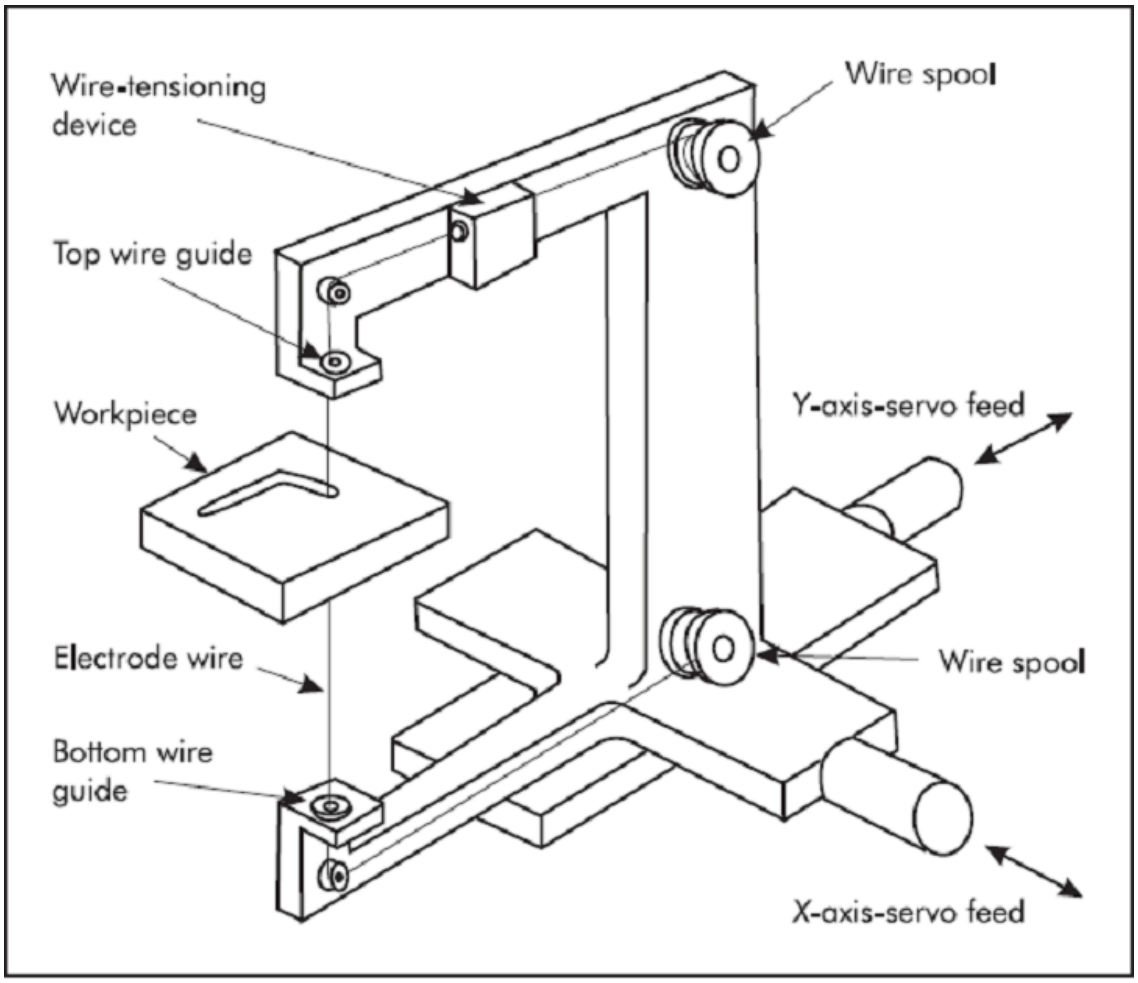


Figure 1.7: Wire-EDM components [5]

Electrode wire is only used once, since the material removed from the wire surface during the sparking process weakens it. Upon travelling through the sparking area, the used wire is collected for disposal on a spool, or cut into short lengths and dropped into a container.[5]

1.8 Computer numerical control (CNC)

Computer numerical control (CNC) is a technology that uses computers to control machines in manufacturing processes. It outlines a high-tech way to automate and precisely control the movements of tools and machinery in industries like metalworking, woodworking, and even 3D printing. In traditional manufacturing, skilled operators manually guide tools to create parts or products. CNC takes this further by using computer programming to guide these tools with exceptional accuracy.[6]

In the manufacturing field, and particularly in the area of metal working, Numerical Control technology has caused something of a revolution, even in the days before computers became standard fixtures in every company and in many homes, the machine tools equipped with Numerical Control system found their special place in the machine shops. The recent evolution of microelectronics and the never ceasing computer development, including its impact on Numerical Control, has brought significant changes to the manufacturing sector in general and metalworking industry in particular. Many descriptions have been used during the years, to define what Numerical Control (NC) is . The majority of all the known definitions can be summed up into a relatively simple statement: "Numerical Control can be defined as an operation of machine tools by the means of specifically coded instructions to the machine control system" The instructions are combinations of the letters of alphabet, digits and selected symbols, all instructions are written in a logical order and a predetermined form. The collection of all instructions necessary to machine a part is called an NC Program, CNC Program, or a Part Program. Such a program can be stored for a future use and used repeatedly to achieve identical machining results at any time. [7]

In the domain of Wire electrical discharge machining (WEDM), the CNC (Computer Numerical Control) system assumes a crucial role owing to the meticulous precision demanded by this procedure. WEDM encompasses intricate cutting through the use of electrical discharges, necessitating highly precise control and automation. The CNC element of a wire EDM configuration facilitates this precision by translating intricate design specifications into exact movements of the cutting wire. In a wire EDM machine, the CNC system operates as the brain, controlling every aspect of the cutting process. This includes managing the speed and movement of the wire, ensuring consistent and precise cuts according to the programmed design. Automation is crucial in WEDM to achieve repeatability and efficiency, especially when dealing with complex geometries or delicate materials. The CNC's role extends beyond mere control; it optimizes the workflow by coordinating multiple axes simultaneously, adjusting parameters based on real-time feedback, and ensuring minimal human intervention during operation. Its integration with WEDM technology enhances productivity and quality, allowing for intricate designs and tight tolerances that would be impractical or impossible to achieve manually. Ultimately, in the context of wire EDM, the CNC system is not just a tool but a fundamental element that enables the realization of intricate, precise, and automated machining processes, vital for industries demanding high accuracy and efficiency in production.

1.9 Conclusion

In terms of manufacturing technology, the Wire Electrical Discharge Machining (EDM) process and the Wire EDM machine represent a significant progress. This chapter has covered the fundamentals of EDM, the historical evolution of the EDM machine, and an analysis of its components. This precision machining tool allows for the consistently accurate creation of very complicated and elaborate structures out of conductive materials.

Chapter 2: Functional Analysis of the Wire Electrical Discharge Machining Machine

Chapter 2

Functional Analysis of the Wire Electrical Discharge Machining Machine

2.1 Introduction

A project cannot be effectively executed without thorough analysis and study, which helps identify and avoid potential problems.

Functional analysis is a crucial first step toward comprehending the complexities and demands of a project. By employing tools such as octopus and FAST diagrams, a thorough understanding of the functional features of the project can be obtained. During the design and implementation stages, this analysis helps to identify important functions, relationships, and constraints within the system, facilitating well-informed decision-making.

2.2 Objectives

- To introduce the concept of functional analysis.
- To demonstrate the application of functional analysis in project development.
- The application of functional analysis tools in the wire EDM project.

2.3 Definition of product design specification (PDS)

The product design specification (P D S) is the essential definition of what the product is required to provide. The PDS is a statement of what the customer wants the product to achieve. In some cases, the customer is external and in some cases the customer is internal (e.g. product range extensions for own-brand products). In every case, a PDS must be prepared to act as a reference for the objectives of the design. This is initially a statement by the customer of the design intent but it should be expanded by the design and development function to give all the technical detail and limits that are realistically achievable.[8]

2.3.1 Definition o f the problem

In the Wilaya of Médéa, a small workshop is specialized in molds machining by using a 3-axis CNC mill, and they need a machine for producing small and intricate metal components with high precision, such as gears, tooling and injection mold components.

2.3.2 Objective

The objective is to build a prototype of a Wire EDM machine capable of automatically cutting metal parts with high precision, within a workspace of 30x35 cm. This numerically controlled machine will be equipped with software that allows the operator to adjust the part on the machine, upload the part's sketch or G-code program from any computer, and send it to the machine. The machine will use the uploaded sketch or G-code program to cut the parts with superior quality.

2.4 Definition of functional analysis

Functional analysis is a breakdown on the basis of what a system does, in terms of the functions it performs or a sequence of operations. This is before considering how it is performed. "How" is a design solution, which we don't want to choose prematurely. Instead, we want to consider all the alternatives and optimizations, which we do in later steps of the process.[9]

2.4.1 Purpose of using Functional Analysis

Functional analysis helps with creative problem solving by shifting the focus from the desired outcome to the necessary performance or requirement.

There are three main methods of functional analysis including APTE (APplication to business TEchniques), FAST (Function Analysis System Technique) and SADT (Structured analysis and design technique).

2.5 Definition of A PTE method

One of the tools used by NPD (New Product Design) is APTE method (Application aux Techniques d'Enterprise or in English: APplication to business TEchniques). APTE has been created by Gilbert Barbey in 1964 and is focused on the functional analysis at the early stages of design. Currently, this method is deposed by APTE Company and designates a functional analysis method in addition to value analysis to drive innovations and projects optimization. APTE is applied for various applications including product design, manufacturing process, as well as organizations. The ultimate goal of APTE is achieving to two objectives:

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

APTE consists of six different algorithms to analysis different aspects of a product :

1) Octopus Diagram: to identify the functions.
2) La Bête A Cornes: to define the requirements.
3) The Functional Block Diagram: to identify the design logic.
4) The Array of Functional Analysis: to distinguish the cost of just necessary design function.
5) The Tree of Technological Pathways: to find principles and alternatives.
6) The list of States: to identify the functions of a process. [10]

In this chapter, the focus is on the application of two out of the six algorithms.

2.5.1 Horned Beast "La Bête à Cornes"

The horned beast diagram is used in functional design and project management, before drawing a horned beast diagram; we must answer the following three key questions:

- Whom will the project serve?
- What does it affect or interact with?
- For what goal?[11]
- Figure 2.1 presents the Horned Beast diagram.

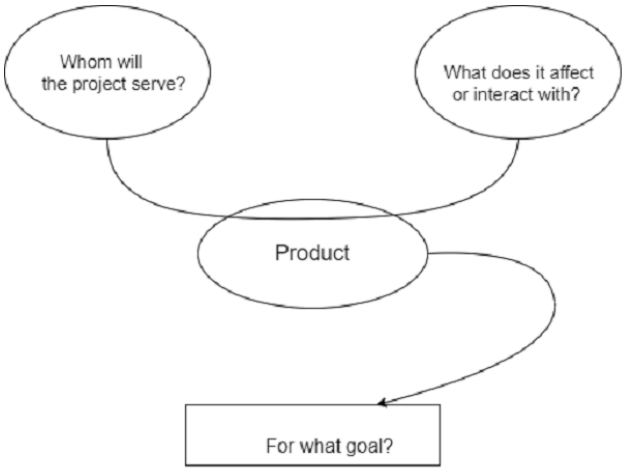


Figure 2.1: Horned Beast diagram [11]

The answer of these questions to create the horned beast diagram of the Wire EDM machine is in the Figure 2.2.

Whom will the project serve?

- The project serve the user.

What does it affect or interact with?

- The product has an effect on the part.

For what goal?

- To enable the user to automatically machine the part with high precision.

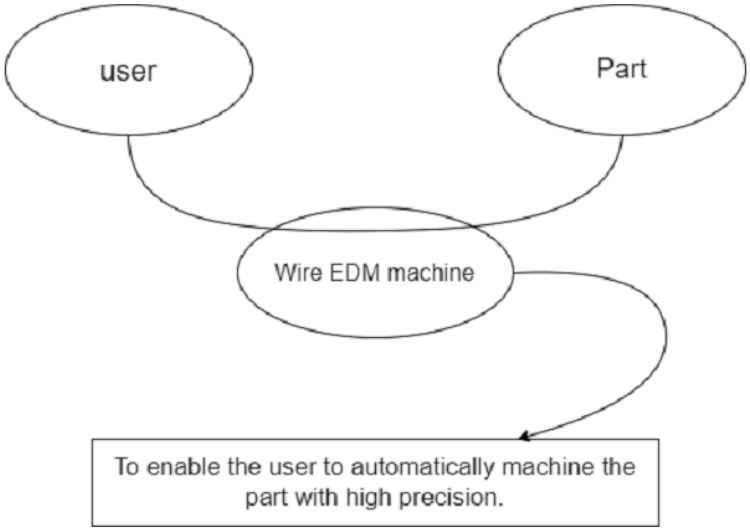


Figure 2.2: Horned Beast diagram of the Wire EDM machine

2.5.2 Octopus Diagram

Octopus diagram is applied after analyzing of the costumer need where functional analysis determines the functional requirements. The first step is to investigate on the connections between the product and the external environment. these connections are divided into two lists, as illustrated in Fig 2.3:

- Constraint Requirements (CR): refers to presents adoption or action of the product, in means of either the product has to be adopted with an element or it acts on an element.
- Functional Requirements (FR): interaction of the product with elements of the surroundings.

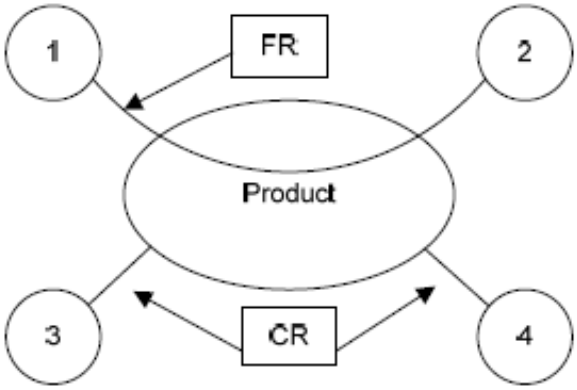


Figure 2.3: FR and CR in Octopus diagram [10]

This method defines the main functions in addition to the constraint functions to have an overview or a global view of the product. However, octopus diagram does not clarify which functions are received or generated by the main function; it merely expresses the needs of a user.[10]

2.5.3 The octopus diagram of the Wedm machine

Figure 2.4 presents the Octopus Diagram of the wire EDM machine:

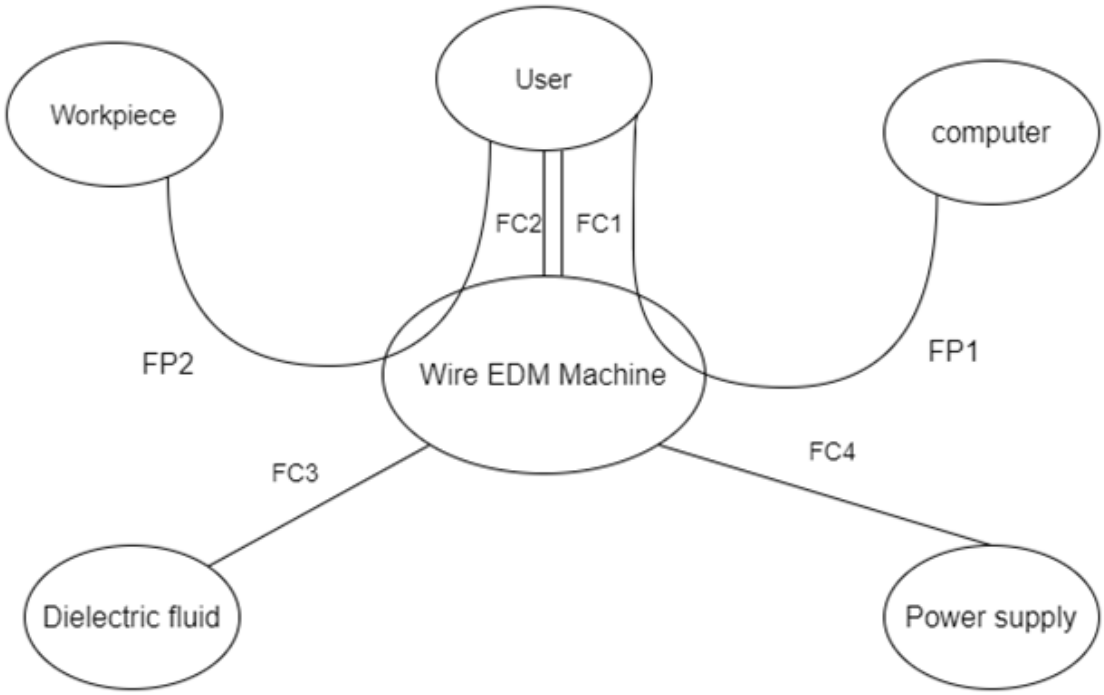


Figure 2.4: The Octopus diagram of the wire EDM machine

After defining the functions of the Wire EDM machine using this diagram, the functions can now be formally stated:

FP1: to automatically execute the machining operations.

FP2: to adjust the part and the machine.

FC1: to operate the machine.

FC2: to Comply with the safety and environmental regulations.

FC3: to flush away the debris and heat from the part surface and electric insulation.

FC4: to supply with an electrical source.

2.6 Functional description

Type	Function	Appreciation criteria	Levels and methods	Flexibility
FP1	to automatically execute the machining operations	CNC controller softwares	-GRBL -Mach3 -NC studio	F2
FP2	To adjust the part and the machine	Part's material	Conductive materials	F0
		Part's size	-Width <= 350 mm -Length <=300 mm	F1
FC1	to operate the machine	Operator skill	User manual or online tutorial	F2
FC2	to Comply with the safety and environmental regulations	Safety measurements	fire-extinguisher, warning sign, Protective enclosure	F0
FC3	to supply with an electrical source	Alimentation settings	-Voltage >50V -Amperage>=3A	F2
FC4	to flush away the debris and heat from the part surface and electric insulation.	Flushing pressure	- High-pressure - dielectric fluid	F3

Table 2.1: Functional description table of the Wire EDM

F1: Low Flexibility - This indicates limited options for choosing solutions.
F2: Moderate Flexibility - This represents a balanced level of flexibility.
F3: High Flexibility - This denotes a high degree of freedom in choosing solutions.

These levels of flexibility help in understanding the range of options available for imple-menting each function, guiding decision-making processes in project development.

2.7 Tools and Resources

To build the WEDM machine, several Tools and resources are necessary.
These resources include:
- Electronics circuits and wirings.
-Electric motors.
-Dielectric fluid.
-Translation systems.
-Power supply.
-Rolling elements.
-caliper.
-3 axis CNC machine.
-mechanical comparator.

2.8 Definition of FAST diagram

The Functional Analysis Systems Technique (FAST) was introduced by C. W. Bytheway an engineer at Sperry Univac (Unisys) in 1960. FAST diagram constitutes an essential data set enabling to have a good knowledge of a complex product. The Association of French Normalization (AFNOR) in NF EN 12973 describes the FAST diagram as one of usual methods of functional analysis. FAST methodology is based on decomposition of each basic function of a product and their classification using a logic diagram. The logic diagram helps to find and approves alternatives for inventive new model to complete the function. The method has different stages:
Stage 1: Brainstorm all the expected functions from costumer point of view.
Stage 2: Select the overall product function.
Stage 3: Apply a categorization for functions into basic and secondary.
Stage 4: Arrange functions in a critical path.
The method leans on an interrogative technique with asking three questions, regards to Fig 2.5 The following questions complete the diagram:

1. HOW is (function) to be accomplished? By (B)
2. WHY is it necessary to (function)? So you can (A)
3. WHEN (function) occurs, what else happens? (C) or (D)

The responses to each mentioned question are neither exclusive nor unique. They can be singular, multiple (using AND connection) or optional (using OR connection).

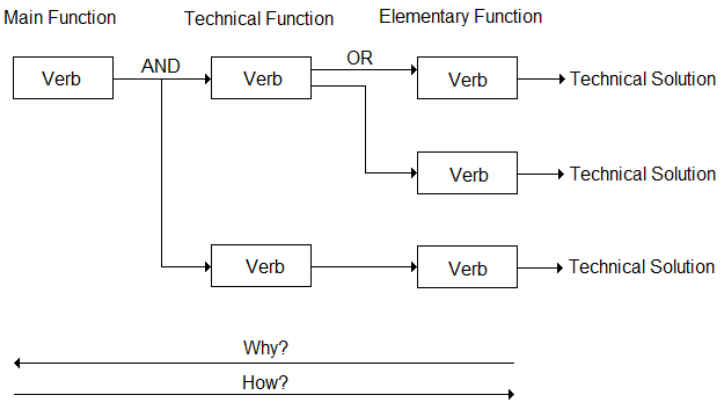
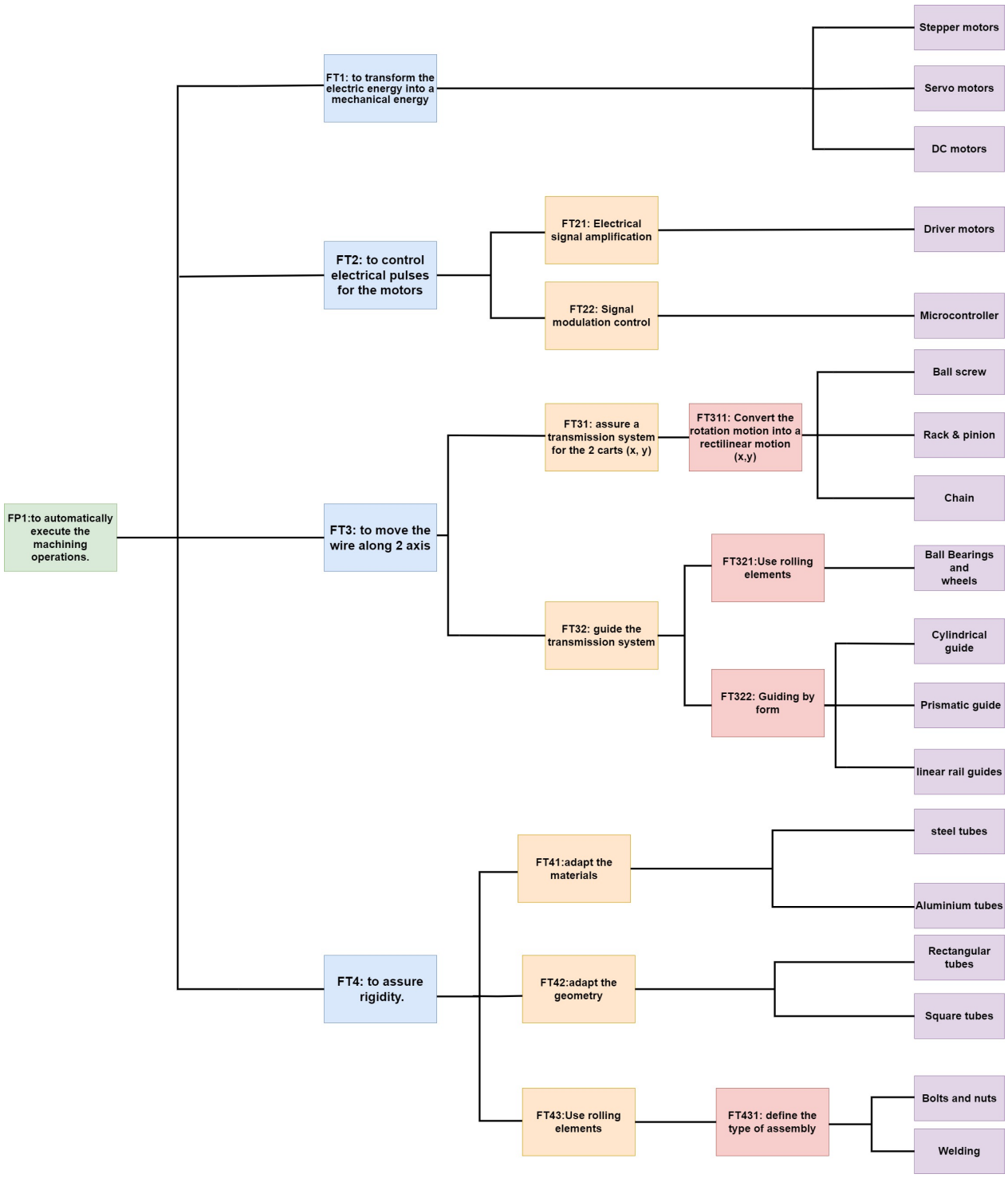


Figure 2.5: AND, OR decomposing in FAST diagram [10]

Functions in FAST are required to be described with a verb at the infinitive form. In order to enable an easy comprehension of all, this type of representation is normalized. [10]

2.9 FAST diagram of the Wire EDM machine



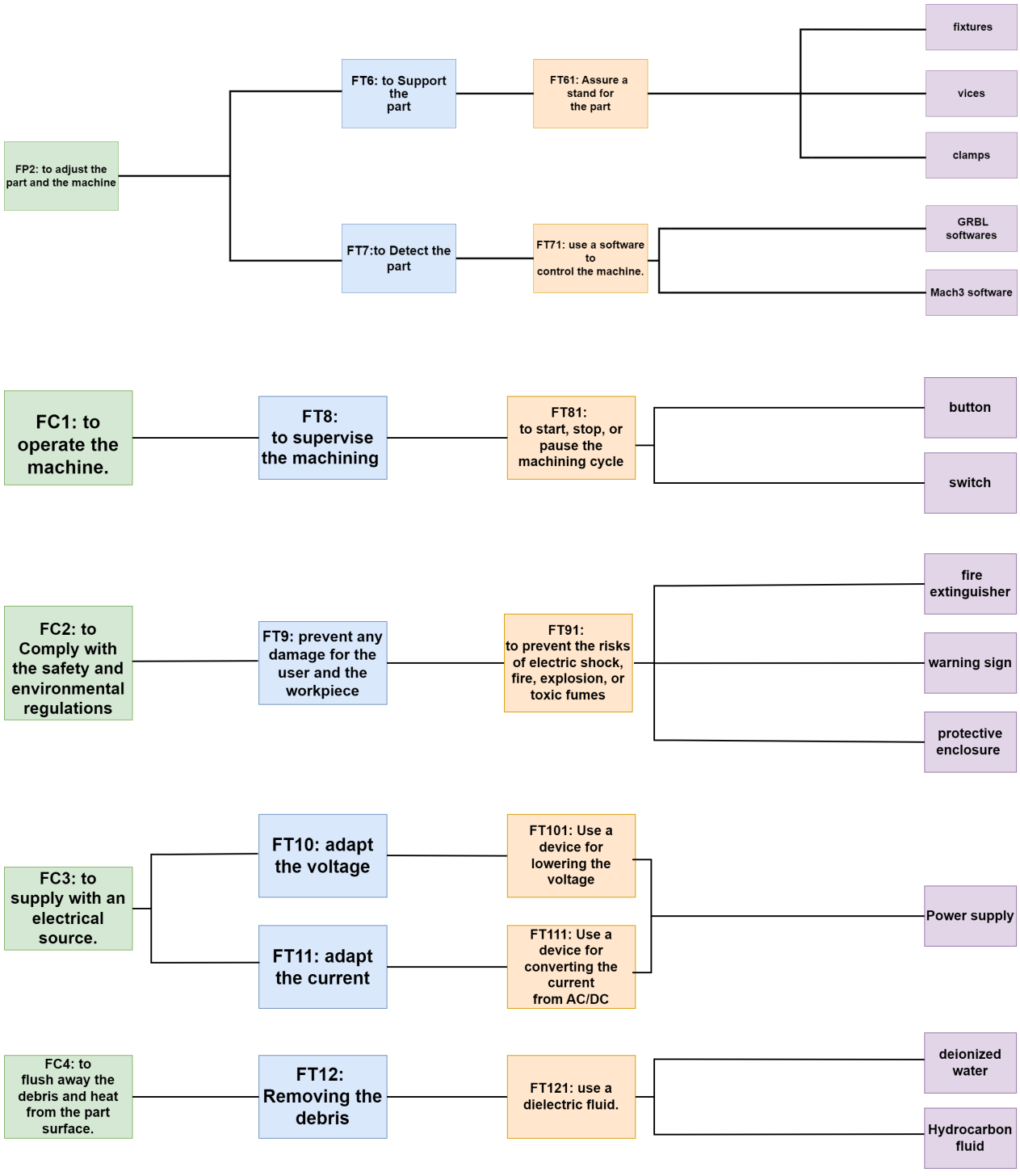


Figure 2.6: FAST diagram of the Wire EDM machine

2.10 Conclusion

The functional analysis is an essential step in the development of any project since it clarifies the functionality of the final product and how it interacts with its surroundings. There are many tools and techniques can be employed to make a functional analysis, In this study, the APTE method was applied. Following this, the functions of the product are translated into technological solutions through a process of logical decomposition, exemplified by the FAST diagram.

Chapter 3: Components Selection and Technical Considerations of the WEDM Machine

Chapter 3

Components Selection and Technical Considerations of the WEDM Machine

3.1 Introduction

After conducting a comprehensive functional analysis of the project, the most suitable solutions can now be selected based on a range of critical factors, including cost and component availability. This chapter is dedicated to exploring and discussing the specific solutions chosen for the project, highlighting the considerations, evaluations, and decision-making process behind each selection. By studying these selected solutions, the aim is to clarify their relevance and effectiveness in meeting project objectives while demonstrating the practical application of the functional analysis findings.

3.2 Objectives

- To evaluate and select optimal solutions.
- To present the chosen Components in detail.
- To justify the suitability of chosen solutions.

3.3 Selected components for the wire Electrical discharge machining machine

After defining the service functions using the APTE method and identifying technological solutions through the FAST diagram, multiple options were observed. Due to various factors such as production costs, material availability, performance, and production time, adopting all the technological solutions was not feasible. Therefore, the most suitable solutions for each service function were selected.

Electrical motors:

For a variety of reasons, electrical motors are essential to the operation of a wire EDM machine. The machine relies on these motors for axis and wire translation, which are critical for its functionality. These motors play a crucial role in ensuring the precision and efficiency of the wire cutting process. Electrical motors come in various forms such as:

- DC motors.
- servo motors.
- stepper motors.
- Brushless motors.

Each offering unique advantages suitable for different operational requirements. In this project, the servo motor was chosen as the best option for the wire EDM machine. The many benefits it provides, which are especially designed to improve the machine's performance and efficiency, are what motivated us to make this decision.

The decision to use a servo motor over DC or brushless motors is driven by the need for precise positional control rather than continuous rotation or variable speed. and it is used over a stepper motor because it offers closed-loop control systems with feedback mechanisms like encoders, enabling them to maintain precise position, speed, and torque.

3.3.1 Servo motors:

A servo motor is defined as an electric motor that allows for precise control of angular or linear position, speed, and torque. It consists of a suitable motor coupled to a sensor for position feedback and a controller that regulates the motor's movement according to a desired setpoint. Servo motors are widely used in industrial applications such as robotics, CNC machinery, and automated manufacturing, where high accuracy, fast response, and smooth motion are required. However, modern servo motors are capable of providing high performance and precision as main drives in various applications.[12]

Figure 3.1 presents a Servomotor.



Figure 3.1: Servomotor [13]

A servo motor consists of three main components:
- A motor: This can be either a DC motor or an AC motor depending on the power source and the application requirements. The motor provides the mechanical power to rotate or move the output shaft.
- A sensor: This can be either a potentiometer, an encoder, a resolver, or another device that measures the position, speed, or torque of the output shaft and sends feedback signals to the controller.
- A controller: This can be either an analog or a digital circuit that compares the feedback signals from the sensor with the desired setpoint signals from an external source (such as a computer or a joystick) and generates control signals to adjust the motor's voltage or current accordingly. The controller uses a closed-loop feedback system to regulate the motor's movement and ensure that it matches the desired setpoint within a certain tolerance.[12]

3.3.2 Servo Motor's working principle

The basic working principle of a servo motor involves the controller receiving two types of input signals:
A setpoint signal: This is an analog or digital signal that represents the desired position, speed, or torque of the output shaft.
A feedback signal: This is an analog or digital signal that represents the actual position, speed, or torque of the output shaft measured by the sensor. The controller compares these two signals and calculates an error signal that represents the difference between them. The error signal is then processed by a control algorithm (such as PID) (proportional integral derivative) that generates a control signal that determines how much voltage or current should be applied to the motor. The control signal is sent to a power amplifier (such as an H-bridge) that converts it into an appropriate voltage or current level for driving the motor. The motor then rotates or moves according to the control signal and changes its position, speed, or torque, and sends a new feedback signal to the controller. The process repeats until the error signal becomes zero or negligible, indicating that the output shaft has reached the desired setpoint.[12]

3.3.3 Types of Servo Motors

Servo motors can be classified into different types based on their power source, construction, feedback mechanism, and application.

AC Servo Motors:

AC servo motors are electric motors that operate on alternating current (AC). They have a stator that generates a rotating magnetic field and a rotor that follows the field. AC servo motors can be further divided into two types: synchronous and asynchronous.

- Synchronous AC servo motors: have a permanent magnet rotor that rotates at the same speed as the stator field. They are more efficient, precise, and responsive than asynchronous motors, but they require a more complex controller and a position sensor.
- Asynchronous AC servo motors: have a wound rotor that induces a current and a magnetic field that lags behind the stator field. They are simpler, cheaper, and more rugged than synchronous motors, but they have lower efficiency, accuracy, and speed. AC servo motors are suitable for high-power applications that require high speed, torque, and reliability. They are commonly used in industrial machines, robotics, CNC machines, etc.[12]

Figure 3.2 presents the AC Servomotor system.

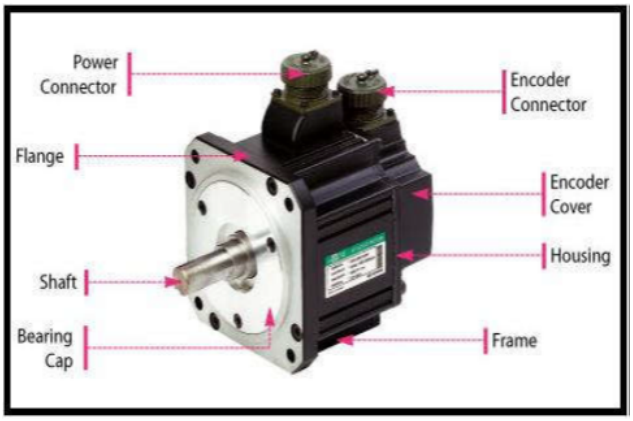


Figure 3.2: AC Servomotor system [13]

DC Servo Motors:

DC servo motors are electric motors that operate on direct current (DC). They have a permanent magnet stator that generates a fixed magnetic field and a wound rotor that rotates when a current is applied.

Figure 3.3 presents the DC Servomotor system.

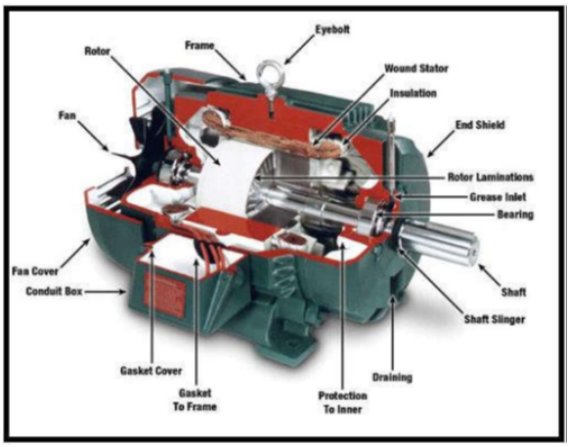


Figure 3.3: DC Servomotor system [13]

DC servo motors can be further divided into two types: brushed and brushless.

- Brushed DC servo motors: have a commutator and brushes that switch the current direction in the rotor windings. They are simple, inexpensive, and easy to control, but they have lower efficiency, lifespan, and speed due to friction and wear of the brushes.
- Brushless DC servo motors: have an electronic controller that switches the current direction in the stator windings. They are more efficient, durable, and fast than brushed motors, but they require a more sophisticated controller and a position sensor. DC servo motors are suitable for low-power applications that require high precision, responsiveness, and smooth motion. They are commonly used in hobby projects, toy cars, CD/DVD players, etc. [12]

3.3.4 Control of a Servo Motor

The control of a servo motor depends on the type of motor, the feedback mechanism, and the application requirements. Generally, there are two types of control signals that can be used to control a servo motor: analog and digital.

- Analog control signals are continuous voltage or current signals that vary proportionally to the desired setpoint. They are typically used for simple or low-cost servo systems that do not require high accuracy or resolution. For example, a potentiometer can be used to generate an analog control signal for a hobby servo motor.

- Digital control signals are discrete pulses or bits that represent the desired setpoint in a coded form. They are typically used for complex or high-performance servo systems that require high accuracy, resolution, or communication. For example, a pulse-width modulation (PWM) signal can be used to generate a digital control signal for a brushless DC servo motor.

The controller of a servo motor can be either an external device or an integrated circuit within the motor. The controller receives the control signals from an external source (such as a computer or a joystick), and the feedback signals from the sensor and generates the appropriate control signals for driving the motor.[12]

3.3.5 Driver motors

The motor driver in a wire EDM machine is a critical component responsible for controlling the movement and positioning of the wire electrode during the machining process. This driver translates electrical signals from the machine's control system into precise mechanical movements of the wire. The motor driver's capabilities, including speed control, torque output, and positional accuracy, directly influence the machine's cutting performance and overall efficiency. Advanced wi re EDM systems integrate sophisticated motor drivers with features like acceleration/deceleration control, backlash compensation, and error correction algorithms to ensure optimal wire movement and exceptional machining results. Effective motor control is essential for achieving tight tolerances, complex part geometries, and superior surface finishes in wire EDM operations.

How do they work?

First, the microcontroller sends signals to the motor driver. Then, the signals received by the motor driver, are interpreted and stepped up with the reference voltage provided for driving the motor. The motor has two voltage input pins. Pin 1 turns ON the motor by giving the voltage equal to the reference voltage, whereas pin 2 turns OFF the motor by giving 0V at the output pin. This entire process is controlled by the motor driver. We use motor drivers to give high power to the motor by using a small voltage signal from a microcontroller or a control system. If the microprocessor transmits a HIGH input to the motor driver, The driver will rotate the motor in one direction keeping the one pin as HIGH and one pin as LOW. And when the microcontroller transmits a LOW input to the motor driver, the motor driver makes the motor to rotate in other direction by making 2 motor pins as LOW and HIGH alternatively. Figure 3.4 presents the Motor driver system.

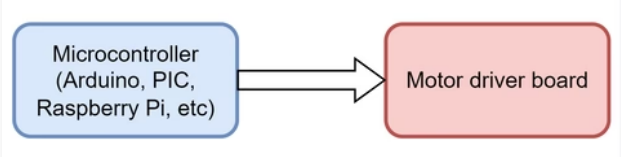


Figure 3.4: Motor driver system [14]

Motor drivers are important components in machines and robotic systems. They enable the operation of motors from a higher level signal, such as pulse-width modulation (PWM) or analog signals like those used with servos. Motor driver circuitry typically includes an integrated circuit that can supply enough current to drive the motor, while also providing shaft control for precise speed adjustment through power transistors connected in parallel with each other. By configuring these transistors correctly, voltage spikes resulting from rapid switching of motor coils on tight turns can be controlled effectively without compromising efficiency during normal operations. [14]

servo motor drivers:

Servo motor drivers are specialized controllers designed to precisely control servo motors, which are high-performance motors known for accurate positioning and speed control. These drivers receive command signals from a control system and use feedback from encoders or sensors to continuously adjust the motor's speed, torque, and position in real-time. Servo motor drivers employ closed-loop control systems, where feedback from the motor's position or velocity is compared to the desired setpoint to make rapid adjustments and correct any errors. This closed-loop control mechanism ensures accurate and responsive motor performance, making servo motors and their drivers ideal for applications requiring high precision and dynamic motion control, such as robotics, CNC machining, industrial automation, and motion systems. Figure 3.5 presents a servomotor driver.



Figure 3.5: Servo motor driver [15]

3.4 Axis Translation System

For some crucial reasons, the Axis Translation System is essential to the wire EDM process. the Axis Translation System is integral to the success of wire EDM operations, ensuring precision, consistency, efficiency, and quality in the manufacturing process. The smooth and accurate translation of the wire along the designated axis is a major factor in the accuracy and precision of wire EDM machining. Wire EDM is often employed for machining intricate and complex geometries that are challenging to achieve using conventional machining methods. The Axis Translation System enables the wire to traverse along intricate paths with exceptional precision, allowing for the creation of intricate and precise components. Let us now delve into the components of the axis translation system and examine the solutions that have been implemented for this crucial aspect of the project.

3.4.1 Rotary-to-Linear Motion Conversion Methods

In the axis translation systems, the conversion of rotary motion obtained from the stepper motor into linear motion is a critical aspect of operational functionality. This transformation is achieved through various methods, each offering distinct advantages and considerations. Key methods include the utilization of ball screws, lead screws, and chains.

- Ball Screws:

Employing recirculating ball bearings between the screw and nut, ball screws offer low friction and high efficiency, ideal for precise and high-speed linear motion applications.

Figure 3.6 presents Ball Screw & Nut Assembly.

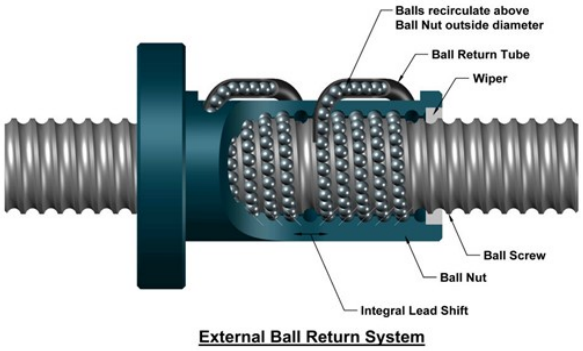


Figure 3.6: Ball Screw & Nut Assembly [16]

Lead Screws:

A lead screw is a kind of mechanical linear actuator that converts rotational motion into

linear motion. Its operation relies on the sliding of the screw shaft and the nut threads with no ball bearings between them. The screw shaft and the nut are directly moving against each other on a large contact area, so higher energy losses due to friction are produced. However, the designs of lead screw threads have evolved to minimize friction. Figure 3.7 presents the Components of a lead screw.

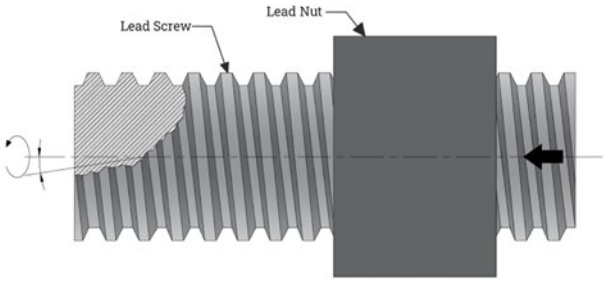


Figure 3.7: Components of a lead screw [17]

Chains:

commonly found in certain types of CNC machines, translate rotary motion into linear motion through sprockets and links. While versatile, they may introduce some backlash and require periodic maintenance. Figure 3.8 presents a chain.

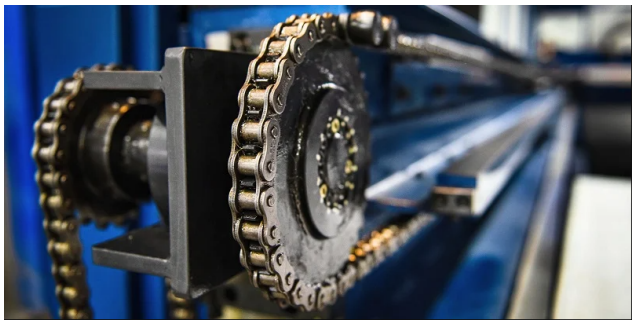


Figure 3.8: Chain [18]

In this case, the ball screw was selected as the rotary-to-linear motion converter due to its low friction and high efficiency, which align well with the system's requirements.

3.4.2 structural frame

The axis translation system's structural framing works as the fundamental structure that gives the entire mechanism rigidity, stability, and support. It is essential for preserving the integrity and alignment of other parts, including couplers, ball screws, and linear guides. In addition, by minimizing vibrations and flexing, the structural framing guarantees the translation system's accurate, improving the wire EDM machine's overall precision and performance.

There are different types of structural frames:

- Welded Steel Frames.
- Composite Frames.
- Extruded Aluminum Frames.

In this case, the utilization of Extruded Aluminum Frames, specifically the V-slot C-beam, was chosen due to its numerous advantages.

The V-Slot C-Beam:

The V-Slot C-Beam is a specialized aluminum profile system based on the V-Slot linear guide design. Its C-shaped profile offers increased functionality and strength. For Wire EDM machines, it is perfect for the following reasons:

1. Linear Movement: The smooth linear movement made by the V-Slot design is necessary for precision in WEDM machining.

2. Robustness: during operations, stability and durability are assured by its robust low-profile form factor.

3. Versatility: For machine building applications, the V-Slot C-Beam offers versatility.

Figure 3.9 presents a V-Slot C-Beam components.

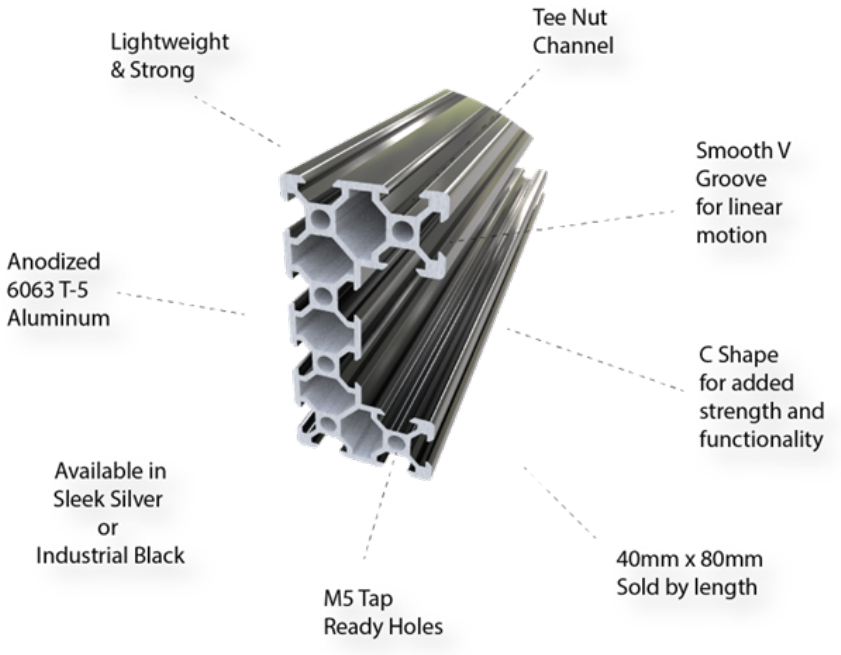


Figure 3.9: V-Slot C-Beam [19]

3.4.3 linear guide rails

Linear guide rails are essential components for a WEDM machine that facilitate precise and smooth linear motion. They consist of a rail, typically made of high-quality materials like steel or aluminum, along which linear bearings or slides move to guide the motion of machine components. These rails provide several benefits in the WEDM machine:
- Precision: Accurate wire movement is ensured by linear guide rails, which leads to precise machining operations.
- Smooth Motion: The linear guide rails-controlled movement lessens vibration and improves the WEDM machine's overall performance.
- Durability: Long-term dependability is ensured by the robust construction of high-quality linear guide rails, which can support large loads and constant use. Figure 3.10 presents a Linear guide rail.



Figure 3.10: Linear guide rail [20]

Guideways:

The guideways are the parts of linear guide rails that direct the carriage's motion along the rail. They enhance the linear motion system's overall performance by providing the carriage moves precisely and smoothly. Here's why guideways are so important:
- Precision Movement: Guideways play a crucial role in providing accurate and controlled movement of the carriage along the rail, ensuring precision in the positioning and motion of machine components.
- Load-bearing Capacity: Guideways are designed to support the weight and loads exerted on the carriage, maintaining stability and preventing deflection during operation.
- Durability: High-quality guideways are constructed from robust materials and engineered to withstand continuous use and heavy loads, ensuring long-term reliability in motion systems. Figure 3.11 presents a Schematic of linear guide structure .

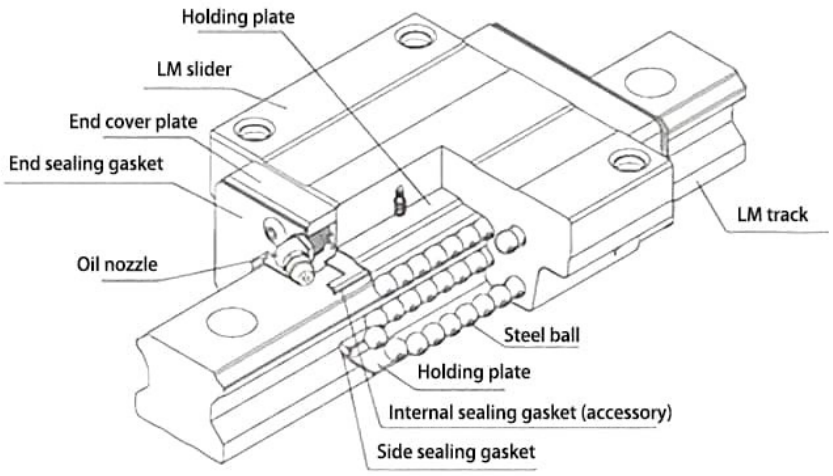


Figure 3.11: Schematic of linear guide structure [21]

3.4.4 coupler

The coupler plays a crucial role in the translation axis system of a CNC machine, particularly in wire EDM machines. Its primary function is to connect and transmit motion between the motor and the lead screw or ball screw. This component serves as a linkage point, ensuring smooth and synchronized movement between the rotary motion generated by the motor and the linear motion required for positioning the cutting wire. The coupler acts as a damping mechanism, It absorbs vibrations and shocks that may occur during operation. This helps to maintain stability and precision in the translation axis system, ultimately contributing to the quality of the finished machined parts. Figure 3.12 presents a Coupler.



Figure 3.12: Coupler [22]

3.5 Wire

The wire used in Wire Electrical Discharge Machining (WEDM) isn't just a tool, it's essential to the entire machining process. It serves as both a cutter and an electrode, making it a critical component in WEDM machines. after recognizing this dual functionality, it becomes evident that the wire is subject to a multitude of parameters crucial for its optimal performance. Typical wire diameters range from 0.004 inches to 0.012 inches (0.10mm to 0.30mm). The most common types of EDM Wires:

3.5.1 Brass Wires

Due to their high conducting qualities, brass is the most popular material for EDM wires. It is a copper and zinc alloy, and the wire cuts more quickly the more zinc there is in the alloy. There should be a balance, though, as brass wire's corrosion rate is decreased when the zinc concentration exceeds 40%.[23] Figure 3.13 presents a picture of Brass wire.



Figure 3.13: Brass wire [24]

3.5.2 Copper Wires

The first wire to be used in wire EDM was copper. At the time, copper seemed a sensible option for an EDM electrode due to its accessibility and high conductivity. Still, copper's slow cutting speed and low tensile force quickly became apparent as generators got more powerful. As a result, this wire is rarely advised, except for older equipment that calls for the use of copper wire.[23] Figure 3.14 presents a picture of Copper wire.



Figure 3.14: copper wire [25]

3.5.3 Zinc-Coated Wires

As the name suggests, these are produced by coating the surface of the wire with pure zinc or zinc oxide. Manufacturers use zinc-coated wires because they increase machining speed.[23] Figure 3.15 presents a picture of Zinc-Coated wire.



Figure 3.15: Zinc-Coated Wire [26]

3.6 EDM Wire Properties

3.6.1 Wire Tensile Strength

It's crucial to specify the tensile strength of EDM wire. The machine's wire drive feed mechanism, which comprises a wire tensioner, roller guides, and upper and lower feed contacts, stretches the wire even when it does not come into contact with the part during cutting (where the electric current is applied). The wire has tension preloaded on it, which may be changed to perform various cutting procedures. The wire's capacity to withstand stress during cutting depends on its tensile strength. The easier it is to break, the lesser the tensile strength. Lower wire tension for roughing allows the machine to cut faster without breaking the wire. For skim cuts, slower speeds and less power are used to achieve the best surface finish and precision. [23]
The tensile strength (σ_t) is calculated using the formula:

$$\sigma t = \frac{F}{A} \tag{2.1}$$

where F represents the maximum force applied to the wire (in Newtons, N) and A denotes the cross-sectional area of the wire (in square millimeters, mm^2).

For example, considering a copper wire with a diameter of 0.25 mm subjected to a maximum tensile force of 10 N. The cross-sectional area (A) is calculated using the formula for the area of a circle:

$$A = \pi \left(\frac{d}{2}\right)^2$$

where d is the diameter of the wire. For a wire with a diameter of 0.25 mm:

$$A = \pi \left(\frac{0.25\,\text{mm}}{2}\right)^2$$

$$A = \pi \left(0.125\,\text{mm}\right)^2$$

$$A = \pi \times 0.015625\,\text{mm}^2$$

$$A \approx 0.049\,\text{mm}^2$$

Using this cross-sectional area, the tensile strength is calculated as:

$$\sigma_t = \frac{10\ \text{N}}{0.049\,\text{mm}^2}$$

$$\sigma_t \approx 204.08\ \text{N/mm}^2$$

This calculation demonstrates that the tensile strength of the copper wire is approximately 204.08 N/mm² (or MPa), which is sufficient to endure the mechanical stresses during the wire EDM process. The permissible working stress with a safety factor applied is 125 N/mm². Since 153.06 N/mm² (adjusted for temperature) exceeds this value, the wire can safely endure the mechanical stresses during the wire EDM process.

3.6.2 Failure to Fracture

Since there is no real way to rate fracture resistance, it could be more accurate to refer to an EDM wire's fracture resistance as wire toughness or resilience. This alternate reference is because the wire can withstand the spark gap's extraordinarily dynamic environment. [23]

3.6.3 Conductivity

Electrical conductivity (σ) is a measure of a material's ability to conduct electric current, and it is inversely related to electrical resistivity (ρ). The relationship is given by the formula: $\sigma = \frac{1}{\rho}$

For exemple, considering a copper wire, which is commonly used in EDM due to its excellent conductive properties, its conductivity can be calculated. Copper has an electrical resistivity of approximately $1.68 \times 10^{-8}\,\Omega\cdot$m at room temperature. Therefore, the conductivity of copper is:

$$\sigma = \frac{1}{1.68 \times 10^{-8}\,\Omega \cdot \mathrm{m}}$$

$$\sigma \approx 5.95 \times 10^{7}\,\mathrm{S/m}$$

This high conductivity value underscores the suitability of copper for EDM applications, where efficient and consistent electrical discharge is essential for precise machining.

3.6.4 Temperature of Vaporization

For quick vaporization, a low wire melting temperature will work best. Then, instead of polluting the gap with resolidified chips, the wire surface should evaporate and swiftly transform into gases.[23]

3.6.5 Hardness

Tensile strength is frequently confused with hardness. A wire's elasticity or capacity for extension, elasticity, or capacity for extension is referred to as its hardness or temper. EDM wires fall into one of two categories here: soft or hard. A strong wire will thread better than a softer wire on closed-guide machines, but a soft wire will taper-cut better. Additionally, a hard wire will offer the most reliable auto-threading performance.[23]

3.7 Dielectric fluid

Dielectric fluid is an essential part of Wire EDM machines. It performs a number of crucial tasks that make it possible to machine electrically conductive materials precisely and effectively. Dielectric fluid serves as an electrical insulator between the workpiece and the electrode wire, controlled electrical discharges between the wire and the workpiece occur during the EDM process, eroding material from the workpiece surface. By keeping these discharges from short-circuiting straight to the workpiece, the dielectric fluid ensures precise material removal and shields the wire and workpiece surfaces from harm.

The dielectric system includes the liquid reservoir, filtration system, deionization system, and water chiller unit. During cutting, the dirty water is drained into the unfiltered side of the dielectric reservoir where the water is then pumped and filtered through a paper filter, and returned to the clean side of the dielectric tank. Following filtration, the clean water is measured for conductivity, and if required passes through a vessel that contains a mixed bed of anion and cation beads. This mixed bed resin (the ion exchange unit) controls the resistivity of the water to set values automatically. The clean water fills the clean side of the dielectric reservoir and proceeds to the cutting area. Used water is drained and returned to the unfiltered side of the dielectric reservoir to complete the cycle. A water chiller is provided as standard equipment to keep the dielectric, workpiece, worktable, control arms, and fixtures thermally stable. During the cutting process the chips from the material that is being eroded, gradually changes the water conductivity level. Resistivity levels of the water are set according to the cutting requirements of the workpiece material being machined.[27]

3.7.1 Dielectric-fluid functions

The main functions of dielectric fluid in a Wire EDM include:

- Electrical Insulation: Dielectric fluid acts as an electrical insulator between the electrode wire and the workpiece. It prevents electrical discharges from arcing directly to the workpiece, ensuring precise material removal and protecting the integrity of the wire and workpiece surfaces.
- Heat Dissipation: During the EDM process, intense heat is generated at the point of electrical discharge. Dielectric fluid serves as a coolant, dissipating this heat from the machining zone to maintain optimal operating temperatures. This prevents thermal distortion of the workpiece and preserves dimensional accuracy.
- Debris Flushing: Dielectric fluid functions as a flushing medium, carrying away debris and eroded material particles from the machining zone. By continuously flushing away debris, the fluid helps maintain a clean cutting environment, preventing clogging and ensuring uninterrupted machining operations.
- Surface Finish Enhancement: Controlling the properties of the dielectric fluid, such as viscosity and conductivity, can influence the surface finish of the machined part. By optimizing these properties, operators can achieve smoother finishes and tighter tolerances.
- Electrical Conductivity Control: The electrical conductivity of the dielectric fluid is carefully regulated to ensure stable and predictable electrical discharge conditions. Controlled conductivity maximizes material removal rates and minimizes machining time.

- Material Compatibility: Dielectric fluids are formulated to be compatible with a wide range of workpiece materials, including metals, alloys, and exotic materials. Compatibility ensures that the fluid does not react with or damage the workpiece surface, preserving material properties and dimensional accuracy.

3.7.2 Deionized water

The deionized water was chosen as the dielectric fluid in the WEDM machine for several reasons:
- Low Conductivity: The primary function of the dielectric fluid in WEDM is to act as an insulator between the wire electrode and the workpiece. Deionized water has extremely low conductivity because it lacks ions, making it an excellent electrical insulator.
- Thermal Properties: Deionized water has good thermal conductivity, which allows it to effectively dissipate the heat generated during the machining process. This helps in maintaining stable machining conditions and prevents overheating, which can lead to thermal damage to the workpiece. Other dielectric fluids may not have as good thermal properties, leading to less efficient heat dissipation and potentially compromising the machining accuracy and quality.
- Cost-Effectiveness: Deionized water is relatively inexpensive compared to some specialized dielectric fluids.
- Environmental Considerations: Deionized water is non-toxic and environmentally friendly compared to some alternative dielectric fluids, which may contain hazardous chemicals or additives.
Figure 3.16 presents a picture of Deionized water.



Figure 3.16: Deionized water [28]

3.8 Power supply

The power supply in Wire Electrical Discharge Machining functions as the heartbeat of the entire system, generating the electrical energy required for the interaction between the wire electrode and the workpiece. This interaction carefully erodes the material with precise control. The power supply typically delivers voltage in the range of 100-300V, ensuring stability and consistency throughout the machining process.

Historically, Direct Current (DC) power supplies have been the primary source of electrical current for Wire EDM machines. The constant flow of energy from DC power supplies facilitates reliable material removal. However, with advancements in technology, pulse power supplies have emerged as a cutting-edge alternative. These modern power supplies deliver energy to the machining zone in precisely timed pulses, allowing operators to exert finer control over erosion dynamics.

The advantages of pulse power supplies are immediately apparent, including improved surface finishes, reduced electrode wear, and increased machining velocities. Additionally, tailoring the voltage and current specifications to suit the specific requirements of the material being machined, its thickness, and the desired cutting speed is paramount for optimal performance.

An integral component of this system is the C-arc generator. The C-arc generator acts as the power supply in the Wire EDM machine and is responsible for producing the electrical arcs that facilitate the material removal process. It generates controlled electrical discharges between the wire and the workpiece, contributing to the high precision and efficiency of the cutting process.

Key Features and Functionality of the C-arc Generator:

- Pulse Control: The C-arc generator delivers energy in precisely timed pulses, a critical feature for controlling the rate of material removal and the quality of the cut. By adjusting pulse duration and frequency, the machining process can be finely tuned to achieve optimal results.
- Current and Voltage Regulation : The C-arc generator includes sophisticated circuitry to regulate the current and voltage supplied to the wire electrode. This regulation ensures that the electrical discharges remain consistent and stable, maintaining the accuracy and reliability of the machining process.
- Efficiency and Precision: The C-arc generator's ability to deliver controlled discharges con-tributes significantly to the precision of the Wire EDM process. This precision is essential for achieving high-quality cuts and intricate details, especially in complex and high-tolerance applications.

The C-arc generator consists of several critical components that work together to produce and control the electrical discharges necessary for Wire EDM. These include:

- Power Supply Unit: This unit converts the input electrical power to the desired voltage and current levels required for the EDM process. It typically includes transformers, rectifiers, and regulators to ensure a stable and controlled power output.
- Pulse Generator: The pulse generator creates the timed electrical pulses that are delivered to the machining zone. It controls the pulse frequency, duration, and amplitude, allowing for precise control over the erosion process. The pulse generator uses electronic switches, such as transistors or thyristors, to modulate the power supply's output.
- Discharge Circuit: The discharge circuit is responsible for generating the electrical arcs between the wire electrode and the workpiece. It includes components such as capacitors and inductors that shape and control the discharge pulses, ensuring that they have the correct characteristics for efficient material removal.
- Feedback and Control System: This system monitors the machining conditions, such as gap voltage and current, and adjusts the pulse parameters in real-time to optimize the cutting process. It uses sensors and microcontrollers to continuously adapt to changes in the ma-chining environment, ensuring consistent performance and high precision.
- Safety and Protection Mechanisms: The C-arc generator is equipped with various safety features to protect the equipment and operators. These include overcurrent protection, short-circuit protection, and thermal shutdown mechanisms to prevent damage and ensure safe operation.

The pulse duration is the length of each discharge, also known as on-time, which also has a direct impact on the quantity of material removed and the surface finish quality. Shorter on-times, which are typically measured in microseconds (µs), can result in finer finishes but may need more passes to remove significant material. The off-time, which is the time between successive pulses, allows for the dielectric fluid to flush away debris and cool the workpiece and the wire. The ratio of on-time to total cycle time (on-time + off-time) is known as the duty cycle, and it has an effect on both machining efficiency and sparking frequency. For the electrical discharge across the spark gap to begin and continue, the power source must deliver a peak current and voltage that is high enough. The sophisticated power supply found in modern wire EDM machines have programmable controls for voltage, peak current, on-time, and off-time settings. With this degree of control, operators can reduce electrode wear and heat-affected zones, maximize material removal efficiency, and maximize productivity by modifying machining parameters based on material type, thickness, and desired surface finish.

3.9 Electrical Discharge Calculations

The precision and efficiency of the Wire EDM process are significantly influenced by the electrical discharge parameters. Key calculations include discharge energy, average power, and material removal rate, each crucial for optimizing the process.

3.9.1 Discharge Energy

The discharge energy (E_d) is calculated to understand the energy released during each pulse, which impacts the material removal rate and surface finish. The discharge energy is given by:

$$E_d = \frac{1}{2} C V^2$$

where:

- E_d is the discharge energy (in Joules, J).
- C is the capacitance (in Farads, F).
- V is the discharge voltage (in Volts, V).

For a capacitance (C) of 1 µF and a discharge voltage (V) of 200 V, the discharge energy is:

$$E_d = \frac{1}{2} \times 10^{-6}\,\mathrm{F} \times (200\,\mathrm{V})^2$$
$$E_d = 20\,\mathrm{mJ}$$

3.9.2 Average Power

The average power (P) during the EDM process, which determines the rate of energy transfer, is calculated by:

$$P = V \cdot I \cdot \eta$$

where:
- P is the average power (in Watts, W).
- V is the discharge voltage (in Volts, V).
- I is the discharge current (in Amperes, A).
- η is the duty cycle (dimensionless, typically a value between 0 and 1).

The duty cycle (η) refers to the ratio of the time the electrical pulse is active (on-time) to the total time of one cycle (the sum of the on-time and off-time). It is a crucial parameter that affects the machining performance, efficiency, and surface quality of the material being processed.
The duty cycle (η) can be expressed as:

$$\eta = \frac{T_{\text{on}}}{T_{\text{on}} + T_{\text{off}}}$$

where:
- T_{on} is the on-time (the period during which the electrical pulse is applied).
- T_{off} is the off-time (the period during which the electrical pulse is not applied).

The duty cycle is typically expressed as a percentage. For example, if the on-time is 30 microseconds and the off-time is 70 microseconds, the duty cycle would be:

$$\eta = \frac{30}{30 + 70} = \frac{30}{100} = 0.3 \text{ or } 30\%$$

For example, with a discharge voltage (V) of 150 V, a discharge current (I) of 10 A, and a duty cycle (η) of 0.3, the average power is:

$$P = 150\,\mathrm{V} \times 10\,\mathrm{A} \times 0.3 = 450\,\mathrm{W}$$

The current value required for Wire EDM operations varies significantly based on the thickness and material of the workpiece. Thicker and harder materials typically necessitate higher currents to achieve effective material removal. Conversely, thinner and softer materials require lower currents for precision cutting. Adjusting the current accordingly ensures optimal performance, balancing cutting speed and precision for diverse machining applications. For instance, a current of 20A may be suitable for general operations, but this value must be fine-tuned to match specific material and thickness requirements.

3.9.3 Material Removal Rate (MRR)

The material removal rate (MRR) is a measure of the volume of material removed per unit time, calculated as:

$$\text{MRR} = \frac{K \cdot I \cdot t}{T}$$

where:
- MRR is the material removal rate (in mm^3/min).
- K is a constant related to the specific material (in $\text{mm}^3/\text{A} \cdot \text{min}$).
- I is the discharge current (in Amperes, A).
- t is the pulse duration (in microseconds, µs).
- T is the total cycle time (pulse duration + off time) (in microseconds, µs).

Assuming a material constant (K) of 0.1 mm^3/A.min, a discharge current (I) of 10 A, a pulse duration (t) of 100 µs, and a total cycle time (T) of 200 µs, the MRR is:

$$\text{MRR} = \frac{0.1 \times 10 \times 100}{200} = 0.5\,\text{mm}^3/\text{min}$$

These calculations provide a quantitative understanding of the EDM process parameters, aiding in the optimization and effective application of the wire EDM machine.

3.10 Wire transmission system

The wire transmission system employed in Wire EDM machines represents a pivotal component tasked with the precise feeding and management of the fine wire electrode utilized to facilitate material removal from the workpiece through controlled electrical discharges.
Figure 3.17 presents a picture of a basic Wire Cut EDM machine.

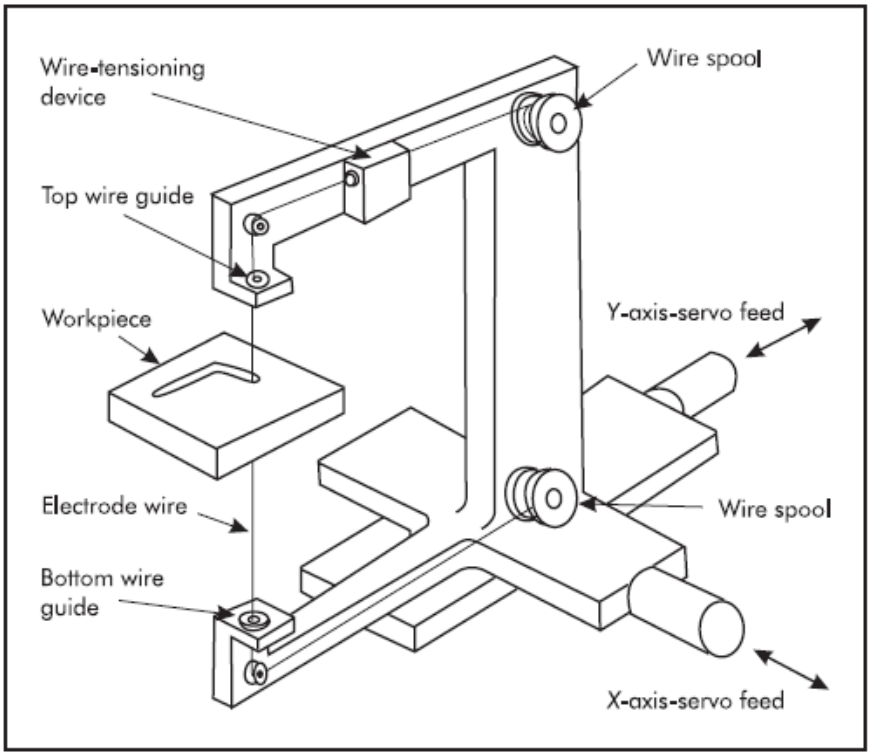


Figure 3.17: Basic wire-cut EDM machine [5]

Here are some details about the wire transmission system:

- Wire Spool and Feeding Mechanism: Wire EDM machines utilize a spool of fine metal wire, typically made of brass or coated with brass, as the electrode. The wire is wound on a spool and fed continuously through the machine during the cutting process. The wire feeding mechanism ensures a steady and consistent supply of wire to the cutting zone.
- Wire Tensioning System: To maintain optimal cutting performance and dimensional accuracy, the wire must be kept under precise tension. The wire tensioning system controls the tension of the wire as it is fed through the machine. This system often includes tension rollers or pulleys that apply controlled pressure to the wire to maintain consistent tension.
- Wire Straightening and Guidance: The wire transmission system includes components to straighten and guide the wire to ensure smooth and accurate movement during cutting. This may involve passing the wire through straightening rollers or ceramic guides to minimize vibrations and ensure precise positioning.
- Wire Drive and Transport Mechanism: The wire is driven by a system of rollers or pulleys that move the wire forward and guide it along the desired cutting path. The wire drive mechanism must operate with precision to prevent slack or tension variations that could affect cutting performance.

3.11 Control system

The control system of a Wire EDM machine, like many other CNC machines, serves as the brain of the operation, managing and coordinating all aspects of the machining process. In a wire EDM machine, the control system receives commands from the operator or a CAM system as a g-code and translates them into precise movements and operations. It controls the positioning of the wire electrode, regulates the power supply for sparking, manages the flushing of dielectric fluid, and monitors various parameters such as wire tension, cutting speed, and material removal rates.
G-code is the code generated by CAM software, which converts the desired part geometry into a series of numerical codes that dictate the tool paths, wire movements, cutting parameters, and machining sequences required to manufacture the component. This programming process involves defining intricate shapes, contours, and dimensions directly from CAD models, enabling precise replication of complex part designs with high fidelity. G-code serves as the communication language between the CAM software and the CNC machine, allowing operators to specify the wire electrode's path and control its movements. By leveraging G-code programming, operators can optimize cutting strategies, adjust machining parameters, and ensure consistent part production while minimizing errors and enhancing manufacturing efficiency. This integration of CAM-generated G-code empowers Wire EDM machines to accurately replicate intricate part geometries, meet tight tolerances, and deliver high-quality components.

In the machine setup, Mach3 will be used as the control system. Mach3 is a widely utilized software-based CNC control system, popular among users of wire EDM machines and other CNC equipment. It serves as the interface between the operator and the machine, providing control over the machining process. Mach3 offers comprehensive functionality for creating, editing, and executing G-code programs that dictate the movements and operations of the wire electrode during EDM machining. One of the key reasons for choosing Mach3 over other control systems is its versatility and user-friendly interface, making it accessible to both experienced CNC operators and beginners. Mach3 supports various input/output configurations, allowing integration with different types of wire EDM machines and peripheral devices. Its extensive features include toolpath simulation, multi-axis control, customizable

macros, and real-time feedback of machine status. Additionally, Mach3 is known for its reliability and robust performance, enabling precise and efficient machining operations while offering flexibility for customization based on specific application requirements. Overall, the advantages of Mach3 lie in its ease of use, versatility, comprehensive features, and reliability, making it a preferred choice for controlling wire EDM machines and enhancing productivity in manufacturing environments.

3.11.1 Breakout board

A Mach3 breakout board, also known as a CNC breakout board or interface board, is a vital component used in conjunction with Mach3 software to interface between a computer and external components of a CNC (Computer Numerical Control) machine, including servo drives when used in Wire EDM (Electrical Discharge Machining) setups. The breakout board serves as a central hub for receiving signals from Mach3 running on a computer and translating them into control signals tailored for servo motor operation in Wire EDM applications. This includes precise handling of position and velocity commands necessary for accurate wire positioning and cutting in the Wire EDM process. Figure 3.18 presents a picture of Copper wire.

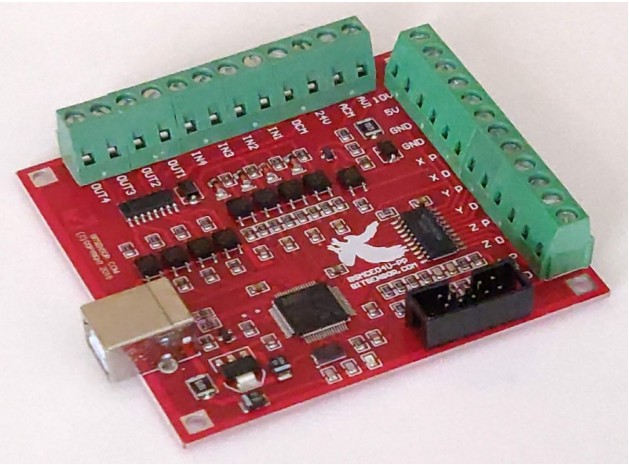


Figure 3.18: The breakout board [29]

Key functions and features of a Mach3 breakout board for Wire EDM include:
- Input/Output (I/O) Ports: The breakout board provides input and output ports (typically via screw terminals) for connecting limit switches, home switches, emergency stop buttons, and other control devices critical for safe and efficient Wire EDM operation.

- Servo Drive Interface: The breakout board communicates with servo drives or amplifiers, converting Mach3's position and velocity commands into analog or digital control signals suitable for precise servo motor control of wire positioning in the EDM machine.
- Feedback Interface: Wire EDM systems using servo motors require feedback signals (such as encoder or resolver feedback) to ensure accurate wire positioning and movement. The breakout board interfaces with these feedback devices, enabling closed-loop control to maintain dimensional accuracy and surface finish.
- Analog Output: Some breakout boards provide analog output channels for controlling servo motor speed or torque, which is essential for maintaining optimal wire feed rates and cutting conditions during Wire EDM operations.
- Optoisolation: Optoisolated inputs and outputs on the breakout board protect against electrical noise and voltage spikes, ensuring stable and reliable communication between Mach3 and the servo motor system in Wire EDM applications.
- Compatibility: Mach3 breakout boards are designed to integrate seamlessly with Mach3 software, enabling precise control and coordination of servo motors for wire positioning and cutting tasks in Wire EDM machines.
Selecting a suitable breakout board compatible with Mach3 and servo motors is crucial for achieving accurate and reliable Wire EDM performance. The breakout board plays a critical role in facilitating precise servo motor control, ensuring dimensional accuracy, surface finish quality, and overall operational efficiency in Wire EDM machining processes.

3.12 Safety measurements

Each user of the Wire EDM machine system is required to operate each machine and its components in accordance with the safety protocols that are explained in detail. If this isn't done, there could be death threats, harm to staff or property, and more. It is important for users to plan ahead for the protection of both their workspace and themselves when using the machine. The WEDM machines are built to function under precise specifications related to the given application while upholding the necessary degree of security.

3.12.1 Personal Safety Precautions

Here are some personal safety precautions that should be followed when operating a Wire EDM machine:
- Wear Personal Protective Equipment (PPE): Always wear appropriate PPE, including safety

glasses, gloves, hearing protection, and protective clothing, to safeguard against hazards such as flying debris, electrical shocks, and noise.
- Avoid Loose Clothing and Jewelry: Remove any loose clothing, jewelry, or accessories that could get caught in moving parts of the machine.
- Stay Alert and Focused: Remain attentive and focused on the task at hand while operating the machine. Avoid distractions and ensure clear communication with other personnel in the vicinity.
- Keep Hands Clear of Moving Parts: Never reach into the machine's work area while it is in operation. Keep hands and fingers clear of moving parts to prevent injury.
- Use Tools and Equipment Safely: Handle tools and equipment with care, following proper procedures for setup, adjustment, and maintenance.
By adhering to these personal safety precautions, operators can minimize the risk of accidents and ensure a safe working environment when operating a Wire EDM machine.
Figure 3.19 presents a High voltage danger sign.



Figure 3.19: High voltage danger sign [30]

3.12.2 Work area safety

Here are some work area safety guidelines for operating a Wire EDM machine:
- Clear Work Area: Ensure the work area is clean, organized, and free of clutter to prevent tripping hazards and facilitate safe movement around the machine.
- Secure Flooring: Use non-slip flooring materials to prevent slips and falls, especially in areas where fluids may be present.
- Proper Lighting: Maintain adequate lighting in the work area to enhance visibility and reduce the risk of accidents.
- Safe Material Handling: Use proper lifting techniques when handling heavy materials and

ensure they are securely positioned on the machine to prevent shifting during operation.
- Fire extinguishers should always be readily accessible.

By adhering to these work area safety guidelines, individuals can contribute to ensuring a safe and productive environment for operating a Wire EDM machine.

3.13 Conclusion

The design process of the Wire Electrical Discharge machining Machine has been guided by a thorough functional analysis, facilitating the selection of optimal solutions for key components. A solid foundation for the implementation phase has been established. The chosen solutions reflect a balance between performance and practicality, aligning with the project's objectives and paving the way for the successful realization of the Wire EDM machine. Moving forward, in-sights gained from this design process will inform subsequent stages of development, ensuring a cohesive and effective approach towards achieving project goals.

Chapter 4:
3D Assembly and Component Analysis

Chapter 4

3D Assembly and Component Analysis

4.1 Introduction

The design and development of advanced manufacturing equipment such as the Wire Electrical Discharge Machining machine necessitates precise planning and visualization prior to implementation. Effective planning enables engineers and designers to identify potential interferences, optimize component placement, and ensure functional integration of all machine parts.

4.2 Objectives

- To showcase the feasibility and effectiveness of utilizing advanced CAD tools in the development of precision manufacturing equipment.
- To demonstrate the comprehensive design and realization process of a Wire EDM machine through the utilization of SolidWorks for 3D modeling.
- To present a detailed assembly model of the Wire EDM machine and subsequent component analysis.

4.3 Importance of 3D Modeling in Machine Design

3D modeling provides a comprehensive and holistic approach to visualizing the entire ma-chine assembly. In the project, SOLIDWORKS was chosen due to the advantages it offers..

SolidWorks is a leading computer-aided design (CAD) software known for its robust capabilities in creating detailed and accurate 3D models. Its parametric modeling features enable dynamic design modifications and rapid prototyping, facilitating iterative refinement of the machine assembly. Figure 4.1 presents Solidworks brand.



Figure 4.1: Solidworks brand

Here are some of the advantages that SOLIDWORKS offers:

- Parametric Modeling: SolidWorks allows for the creation of parametric models, enabling designers to easily modify dimensions and features while maintaining design intent and accuracy.
- Assembly Modeling: The software offers robust assembly modeling capabilities, facilitating the integration of multiple components into a cohesive machine assembly with precise spatial relationships.
- Visualization and Simulation: SolidWorks supports realistic rendering and animation, enabling visualization of machine operations and potential dynamic behaviors before physical realization. Additionally, simulation tools can predict structural integrity and performance under various operating conditions.
- Comprehensive Design Tools: The software offers a wide range of design tools for creating parts, assemblies, drawings, and simulations, streamlining the entire product development process.

4.4 Complete 3D Model Presentation

In this section, a comprehensive 3D assembly of the Wire Electrical Discharge Machining machine will be presented, showcasing the detailed design and integration of key compo-

nents. The 3D model serves as a visual representation of the assembled machine, offering insights into the spatial arrangement, functional interactions, and overall configuration of the Wire EDM system. Each component within the assembly has been meticulously modeled and assembled using SOLIDWORKS, highlighting the engineering considerations and design decisions made during the development process.

4.4.1 The wire EDM machine assembly

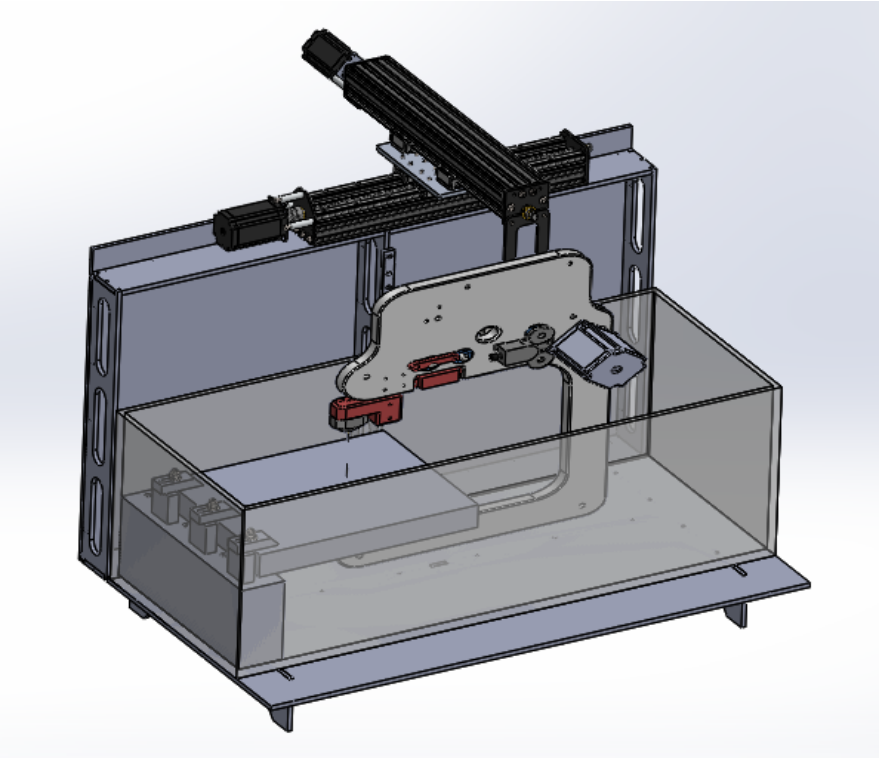


Figure 4.2: Wire EDM machine assembly

The main components of the assembly are: Support Structure, X and Y Axis, Tank of Dielectric Fluid and the wire transmission system.

4.4.2 support structure

To achieve the required strength efficiently, the support was designed with a thickness of 8 mm, optimizing material usage while meeting structural integrity standards.
Figure 4.3 presents a 3D model of the Structural support.

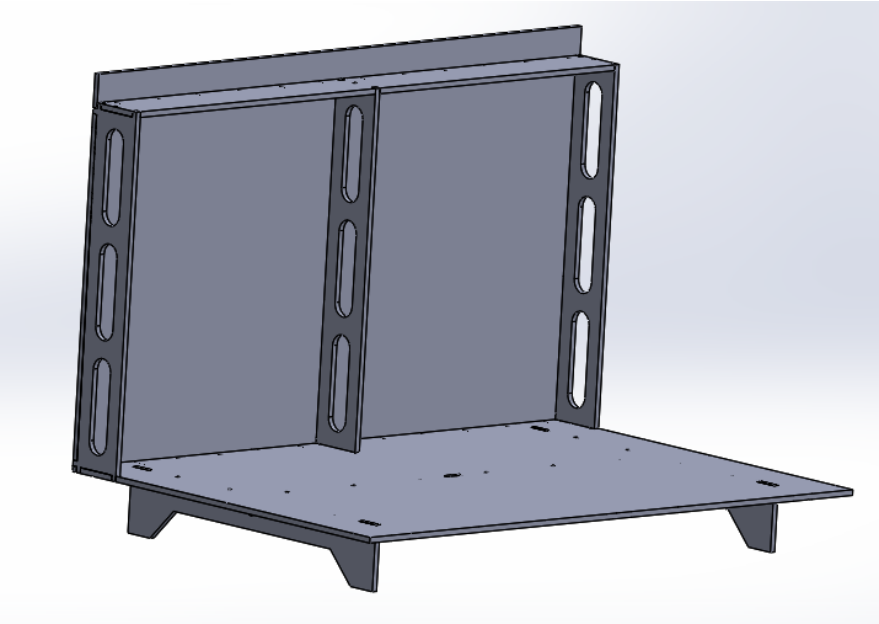


Figure 4.3: Structural support

4.4.3 X and Y Axes

The X and Y axes play a critical role in maintaining the transmission system's accuracy and efficiency within the Wire EDM ma chine. in the 3d model, These axes are identical in design and dimensions, providing precise linear movement and positioning of the wire electrode and workpiece during machining operations. Figure 4.4 presents a 3D model of the X and Y axes.

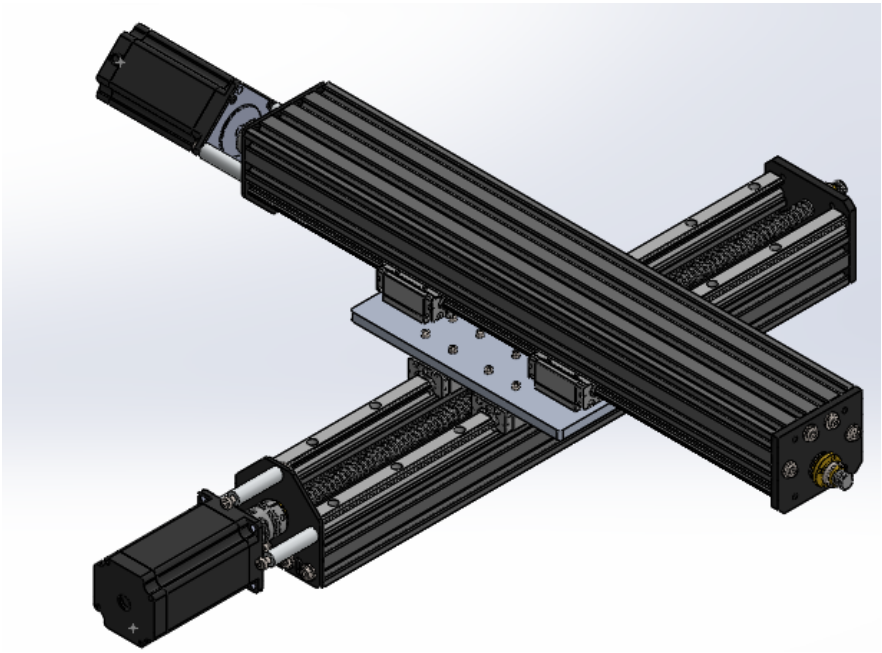


Figure 4.4: X and Y axes

And here is the view of a single axis:

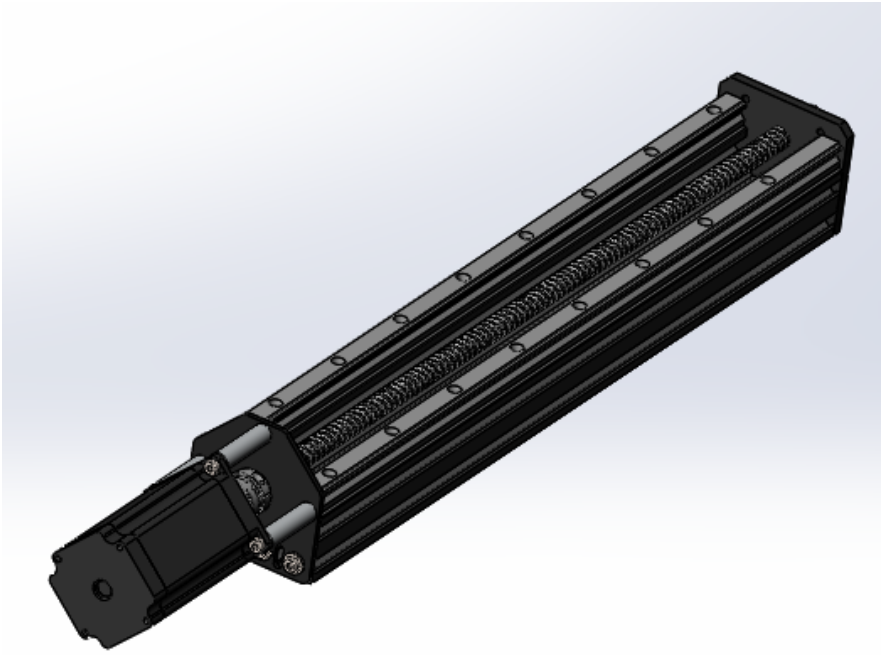


Figure 4.5: One axis

Key components of the X and Y axes include:

- **C-Beam V Slot:** The C-Beam V Slot serves as the structural backbone of the axes,

providing stability and support for other components.

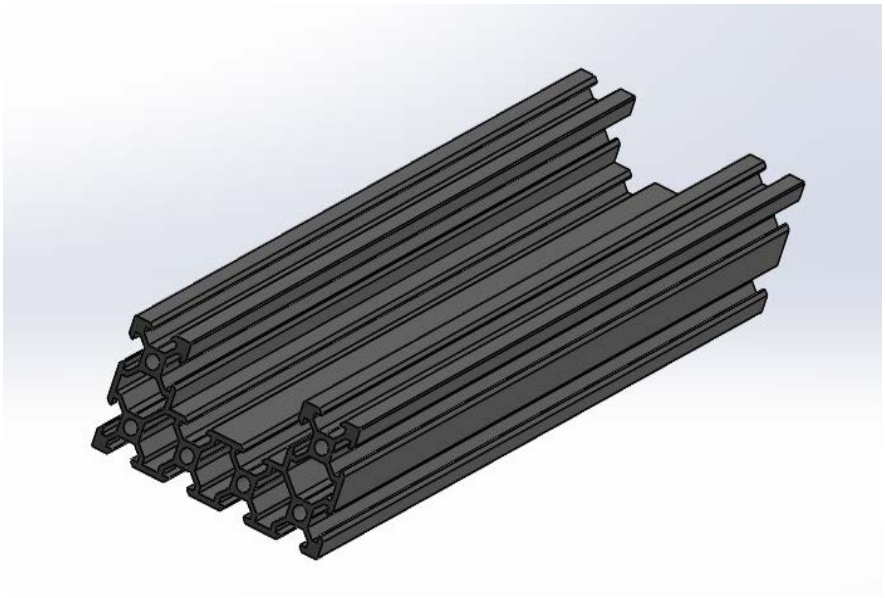


Figure 4.6: C-Beam V Slot

- Linear Guide Rails: Linear guide rails ensure smooth and accurate motion along the X and Y axes, minimizing friction and allowing for precise positioning.

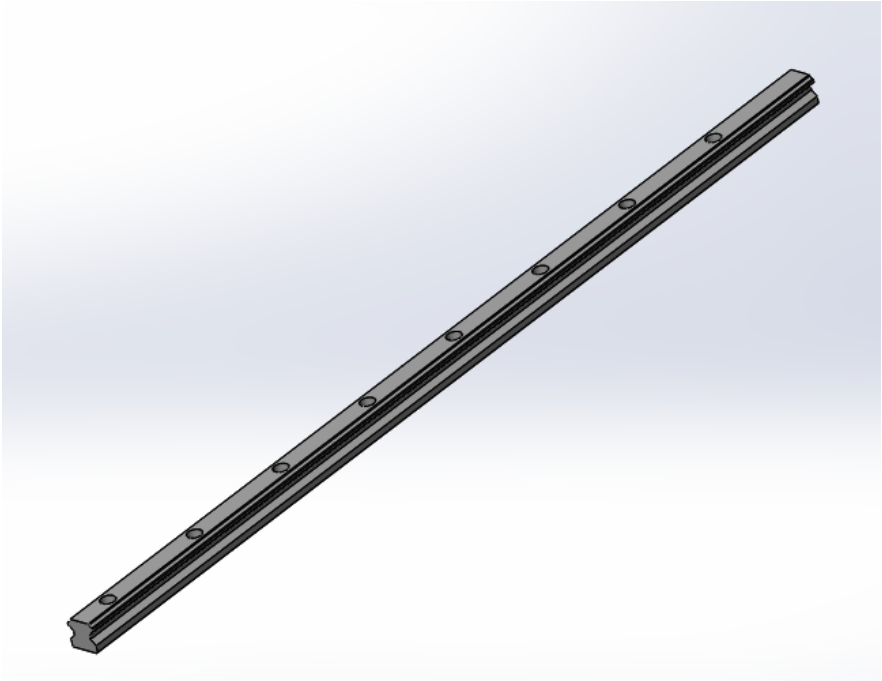


Figure 4.7: Linear guide rails

- Servomotors: Servomotors drive the movement of the axes, offering high precision and responsiveness for dynamic positioning and speed control.

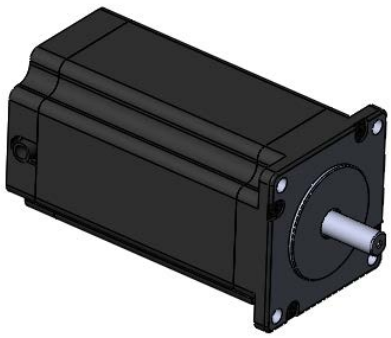


Figure 4.8: Servomotor

- Ball Screw: The ball screw mechanism converts rotary motion into linear motion, facilitating smooth and efficient movement along the axes.

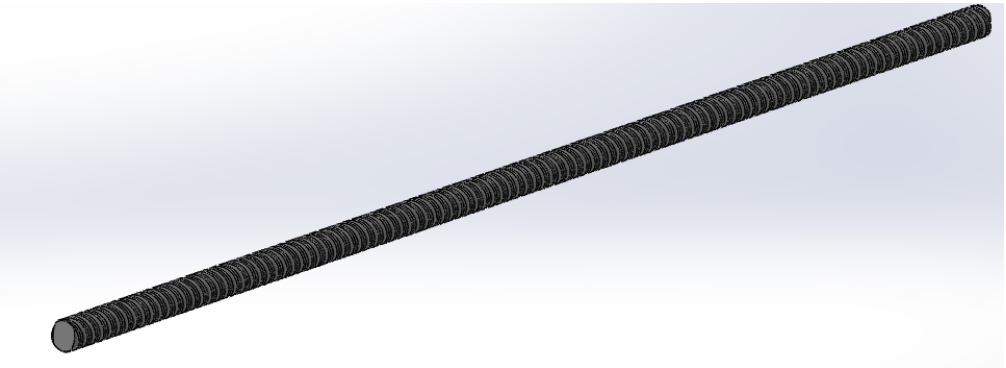


Figure 4.9: Ballscrew

- Ballnut: This component contains recirculating ball bearings that engage with the ball screw, enabling smooth and precise linear motion in the Wire EDM machine's X and Y axes, ensuring reliable transmission of motion.

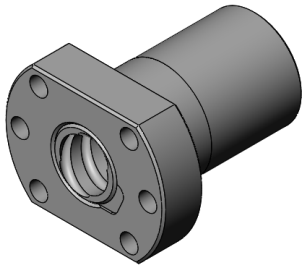


Figure 4.10: Ballnut

- The carriage plate: This plate connects and supports the X and Y axes. It is designed with four guideways on each side to provide stability and guidance for the axes linear motion. The carriage plate ensures synchronized movement between the X and Y axes, contributing to the machine's overall precision and reliability during cutting operations. Its robust construction and precise alignment of guideways are essential for maintaining dimensional accuracy and minimizing vibration.

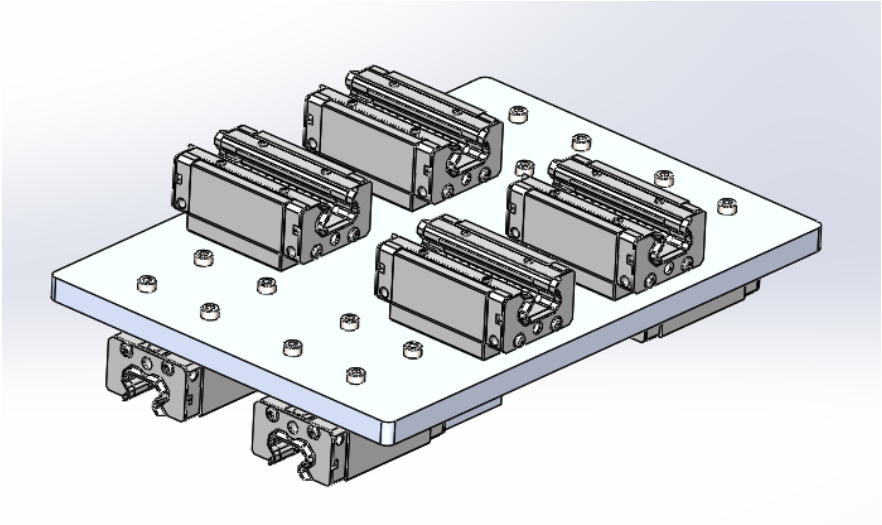


Figure 4.11: Carriage plate

4.4.4 Tank of dielectric fluid

The tank houses the work area, workpiece, and dielectric system in the Wire EDM machine. Its dimensions are 400x1000 mm, allowing accommodation of the wire transmission system along with the workpiece and the workpiece fixation system. The tank was modified to optimize space utilization, enabling containment of all these components while providing a work area of 350x300 mm for efficient machining operations.

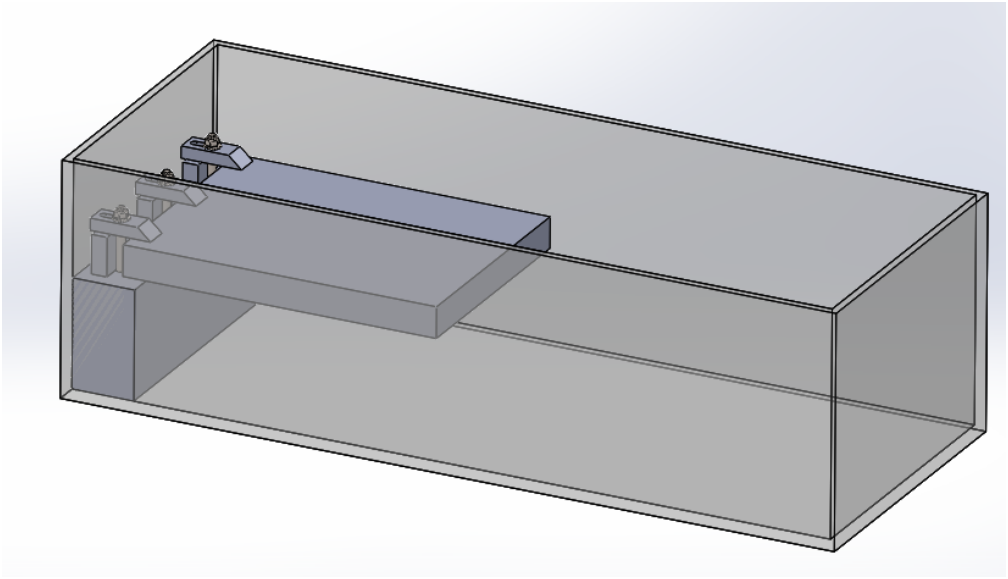


Figure 4.12: Tank of Dielectric Fluid

4.4.5 Wire transmission system

The wire transmission system employed in the Wire EDM machine contains two spools in reality: one for wire emission and another for receiving used wire. However, the focus was on the wire guide system. For this purpose, a downloaded 3D model of the wire guide from "Action BOX" [31] was utilized. This guide system features a sequence of pulleys that guide the wire along a U-shaped path. Additionally, the system incorporates a servo motor responsible for wire transmission and a tension sensor to monitor wire tension levels.

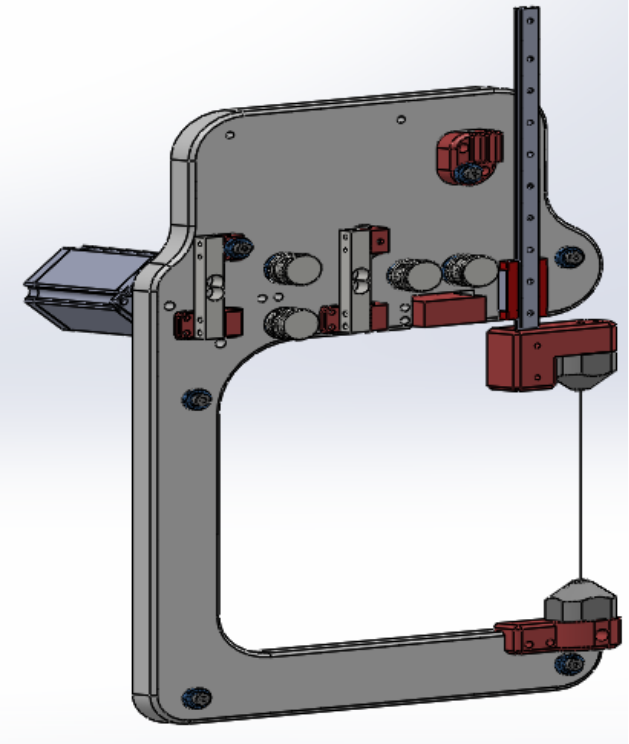


Figure 4.13: wire transmission system [31]

4.5 Component analysis

Translating a 3D model assembly of a machine into reality presents significant challenges, necessitating careful consideration of various factors. From the cost and availability of components to the complexities of realizing a functional machine, the journey of bringing the design to life is not straightforward, especially when aiming for practical utility rather than

merely prototyping. To progress towards the goal, essential components feasible for the current stage, particularly focusing on the CNC machining aspects such as the X and Y axes system, have been acquired. However, challenges persist in materializing the wire transmission system and the electrical discharge generator,which remains a focal point for resolution in future iterations of the project with optimism.
In this section, a detailed exposition will be provided regarding the components acquired for constructing the X and Y axes, integrated with the Mach3 control system to enable CNC functionality. The dimensions and specifications of these components will be outlined to underscore their compatibility and suitability for implementing the CNC system on the axes.

4.5.1 Servomotor

Actually, the 60HSE3N-D25 is a stepper motor with a closed-loop system, but the term "servomotor" is sometimes used broadly to describe any motor system that includes closed-loop feedback for precise control, including closed-loop stepper motors. The SERVO MOTOR 60HSE3N-D25 has been selected for the application due to several advantages it offers. Firstly, this servo motor provides high precision and accuracy in positioning, ensuring reliable performance for the Wire EDM machine. Additionally, it offers excellent torque characteristics and responsiveness, enabling dynamic and precise control of motion. Furthermore, the SERVO MOTOR 60HSE3N-D25 is widely available in the market, enhancing accessibility and simplifying procurement for the project needs. These factors collectively make it a suitable choice for implementing the servo motor system in the Wire EDM machine.
Figure 4.14 presents a picture of a SERVO MOTOR 60HSE3N-D25.



Figure 4.14: SERVO MOTOR 60HSE3N-D25

The servomotor's parameters:

Model No.	Phase No.	Step Angle (°)	Current (A)	Resistance (Ω±10%)
60HSE3N-D25	2	1.8	5.0	0.45

Inductance (mH±20%)	Holding Torque (N.m)	Motor Length (mm)	Encoder Resolution (PPR)	Weight (kg)
1.8	3.0	88	1000	1.55

Table 4.1: 60HSE3N-D25 servomotor parameters [32]

Motor Dimension:

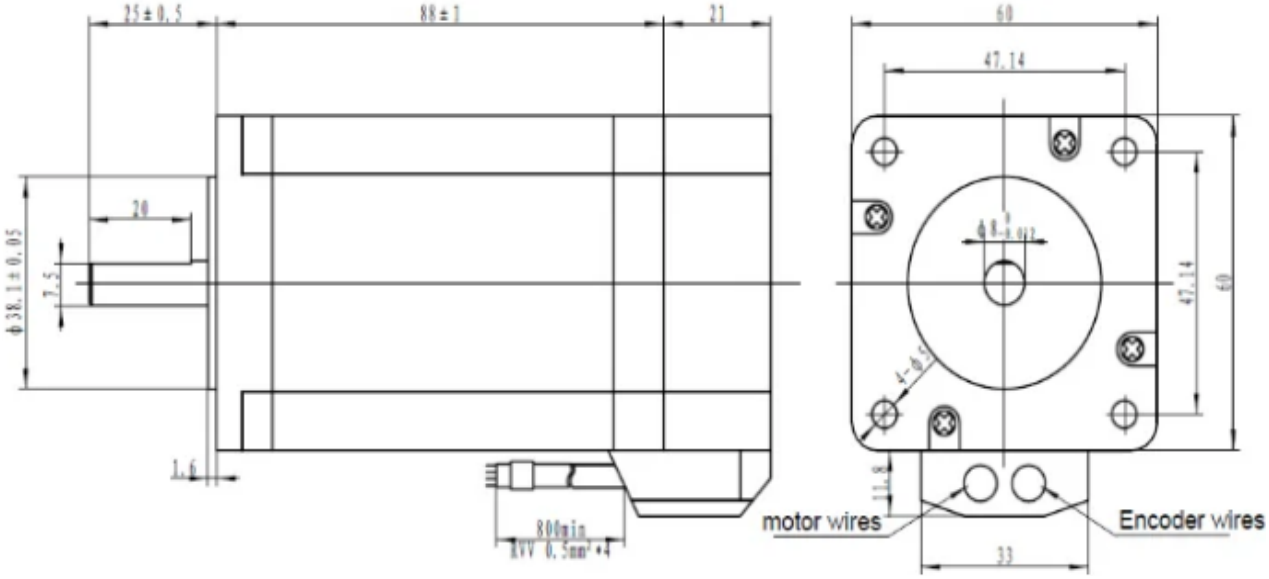


Figure 4.15: SERVO MOTOR 60HSE3N-D25 dimensions [32]

4.5.2 Servomotor driver

The HSS60 5A driver was chosen for the application based on its unique benefits and accessibility to the market. For the servo motor in the Wire EDM machine to operate smoothly and precisely, this driver is a prime example of exceptional performance qualities, such as precise control and high-speed response. Because of its compatibility with the SERVO MOTOR

60HSE3N-D25, the HSS60 5A driver was especially selected to enable optimal performance and dependability in the system design. Moreover, the extensive market availability of this product simplifies the sourcing and procurement procedure, so enhancing the project's practicality and viability by incorporating servo motor control.

Figure 4.14 presents a picture of a SERVO MOTOR 60HSE3N-D25.

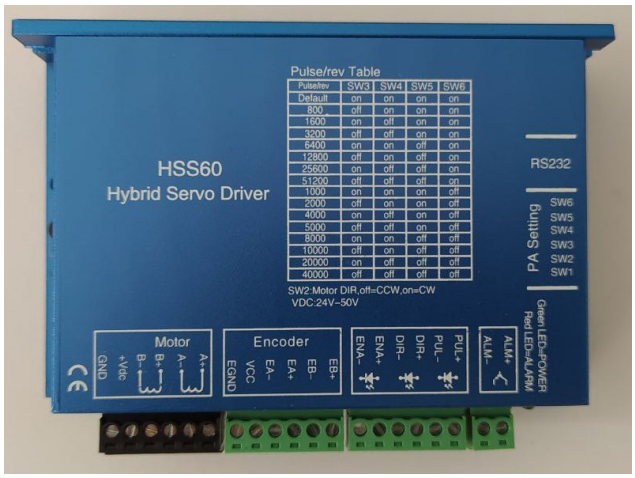


Figure 4.16: HSS60 5A driver

Driver Dimensions:

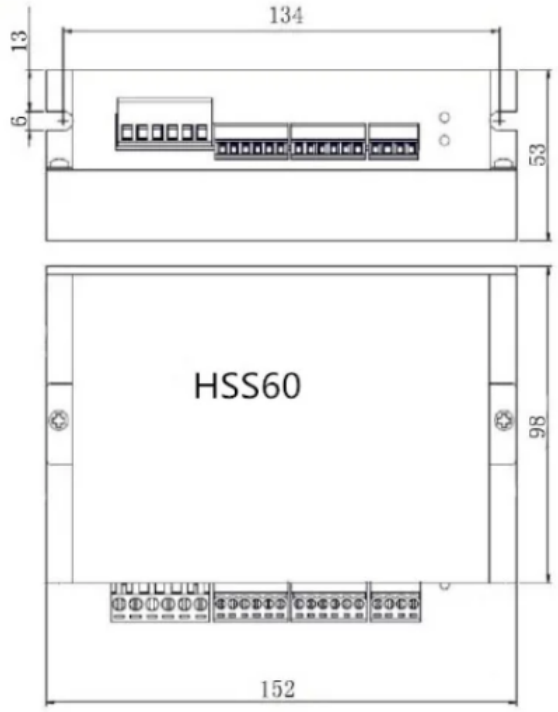


Figure 4.17: HSS60 driver dimensions [32]

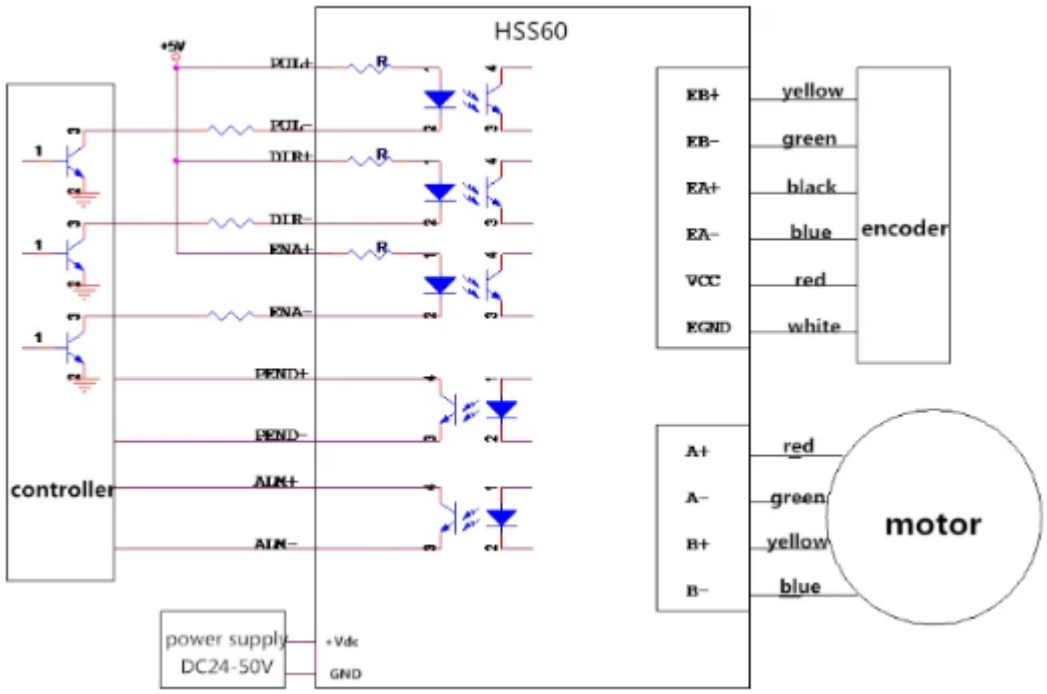


Figure 4.18: HSS60 driver wiring diagram [32]

4.5.3 Guideways

The selection of the HGH-15CA guideways for the application is based on several key factors that render them highly suitable for the project:

- Precision and Smooth Operation: The HGH-15CA guideways are known for their exceptional precision and smooth movement, which is crucial for achieving accurate positioning and motion control in the Wire EDM machine.

- Rigidity and Load Capacity: These guideways offer high rigidity and load-bearing capacity, providing stable support for the moving components of the machine. This ensures consistent performance even under varying loads and operating conditions.

- Durability and Longevity: The HGH-15CA guideways are constructed from high-quality materials and are designed to withstand repeated use and harsh environments. Their durability contributes to the reliability and longevity of the machine.

- Compatibility and Availability: These guideways are widely used in industrial applications and are compatible with various motion control systems and components. Their availability in the market ensures ease of procurement and maintenance for the project.

HGH15CA guideway parameters:

- Mass = 0.18 kg
  Figure 4.19 presents a picture of a HGH-15CA Linear guideways.



Figure 4.19: HGH-15CA Linear guideways

- HGH15CA dimensions:

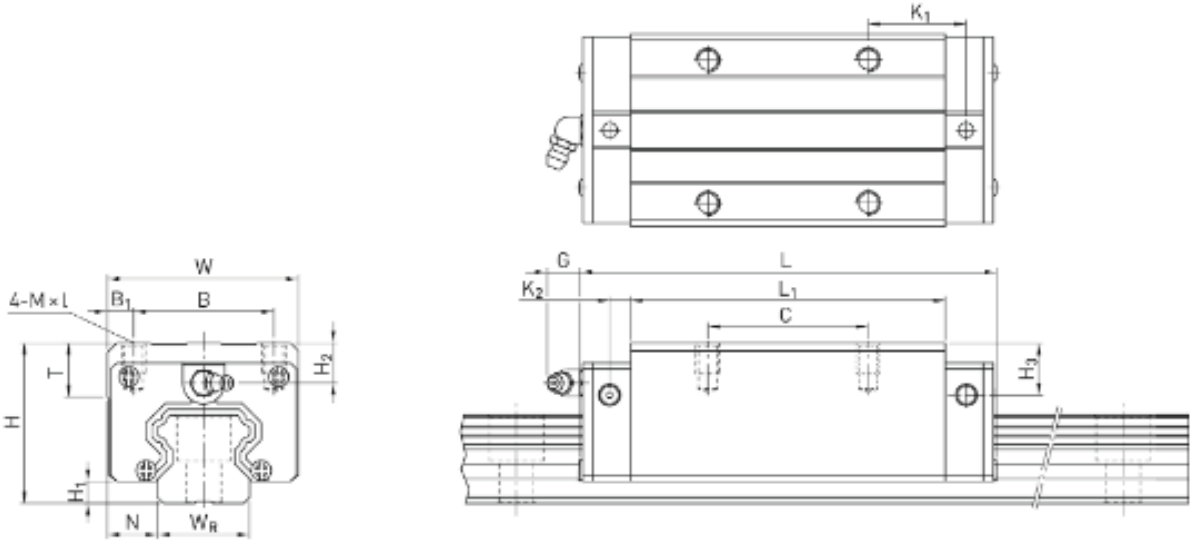


Figure 4.20: HGH-15CA Dimensions [33]

- HGH15CA dimensions table:

Series/ size	Installation dimensions [mm]	Dimensions of the block [mm]					
	H	W	B	C	L_1	L	M × I
HGH15CA	28	34	26,0	26	39,4	61,4	M4 × 5

Table 4.2: HGH Dimensions [33]

4.5.4 Linear guide rail:

Linear guide rails with a width of 15mm have been selected for the application based on several important considerations that render these dimensions particularly suitable for the project:

- Rigidity and Load Capacity: The chosen width provides an optimal balance between rigidity and load-bearing capacity, offering sufficient support for the moving components while maintaining the necessary stability and strength.

- Compatibility and Standardization: The 15mm width is a standard dimension commonly used in industrial applications, making it compatible with a wide range of components and accessories. This standardization simplifies integration and maintenance.

- Space Efficiency: The 15 mm guide rails offer a compact yet robust solution, efficiently utilizing space without compromising on performance. This dimension is ideal for the machine design, ensuring that the components fit well within the overall assembly while providing the required operational capabilities.

- Availability and Cost-Effectiveness: These guide rails are widely available in the market, ensuring ease of procurement. Their standard dimensions also make them a cost-effective choice, balancing performance with budget considerations.

Figure 4.21 presents a picture of a 15mm Linear guide rails.



Figure 4.21: 15mm Linear guide rails

Linear guide rails parameters:

- Material: steel
- Density: 7.85g/cm^3
- Length: 500 mm
- Volume: 15 mm x 15 mm x 500 mm = 112,500 mm^3 = 112.5 cm^3
- Mass = Volume x density = 112.5 cm^3 x 7.85 g/cm^3 = 883.12 g = 0.88 kg

Linear guide rails dimensions:

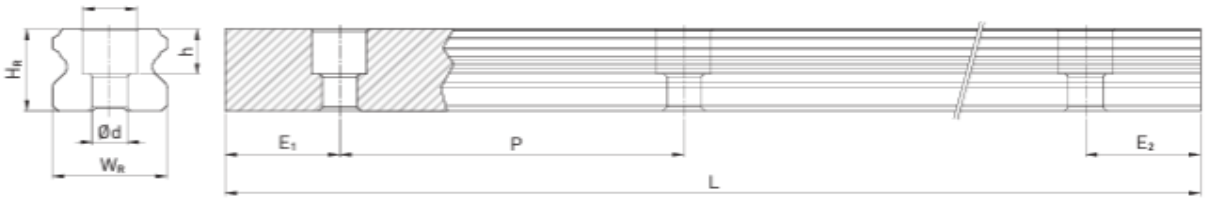


Figure 4.22: Linear guide rails dimensions [34]

Linear guide rails dimensions table:

Dimensions of rail													
Stock Numbers	Assembly screw for rail (mm)	Dimensions of rail (mm)						Max. length (mm)	Max. length $E_1 = E_2$ (mm)	Min. length (mm)	$E_{1/2}$ min (mm)	$E_{1/2}$ max (mm)	Weight (kg/m)	Rail length (mm)
		W_R	H_R	D	h	d	P							
1766684	M4 x 16	15	15.0	7.5	5.3	4.5	60	4,000	3,900	132	6	54	1.45	150
1766685	M4 x 16	15	15.0	7.5	5.3	4.5	60	4,000	3,900	132	6	54	1.45	230
1766686	M4 x 16	15	15.0	7.5	5.3	4.5	60	4,000	3,900	132	6	54	1.45	350
1766687	M4 x 16	15	15.0	7.5	5.3	4.5	60	4,000	3,900	132	6	54	1.45	430
1766688	M4 x 16	15	15.0	7.5	5.3	4.5	60	4,000	3,900	132	6	54	1.45	630
1766689	M4 x 16	15	15.0	7.5	5.3	4.5	60	4,000	3,900	132	6	54	1.45	1000

Table 4.3: Linear guide rails dimensions [34]

4.5.5 Coupler

The 8x12mm coupler (D25L30) has been chosen for the application based on several key considerations that make it well-suited for the project:

- Precision and Flexibility: The 8x12mm coupler offers precise and flexible coupling between the stepper motor shaft and the ball screw shaft, ensuring efficient transmission of rotational motion with minimal backlash.

- Durable and Resilient Design: This coupler is constructed from high-quality materials, providing durability and resilience to handle the demands of the Wire EDM machine's operation over time.

- Compatibility and Ease of Installation: The 8x12mm coupler is designed to interface seamlessly with standard stepper and servo motors and ball screw shaft sizes, making it easy to install and integrate into the machine setup.

- Cost-Effectiveness and Availability: It is a cost-effective solution that meets the performance requirements while being readily available in the market, facilitating procurement and maintenance.

Figure 4.23 presents a picture of a 8X12MM COUPLER - D25L30.

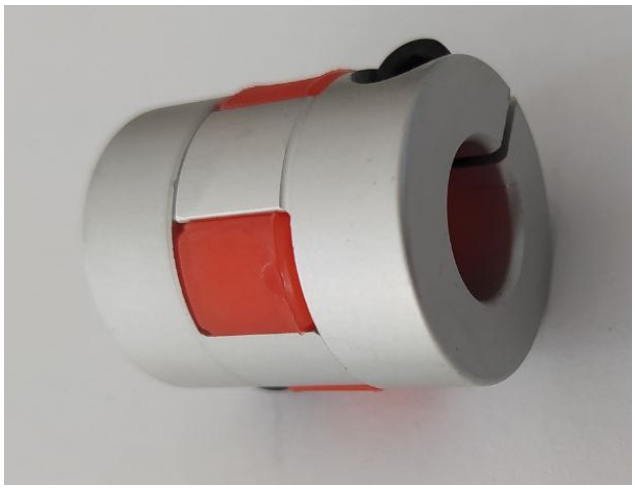


Figure 4.23: 8X12MM COUPLER - D25L30

D25L30 coupler dimensions

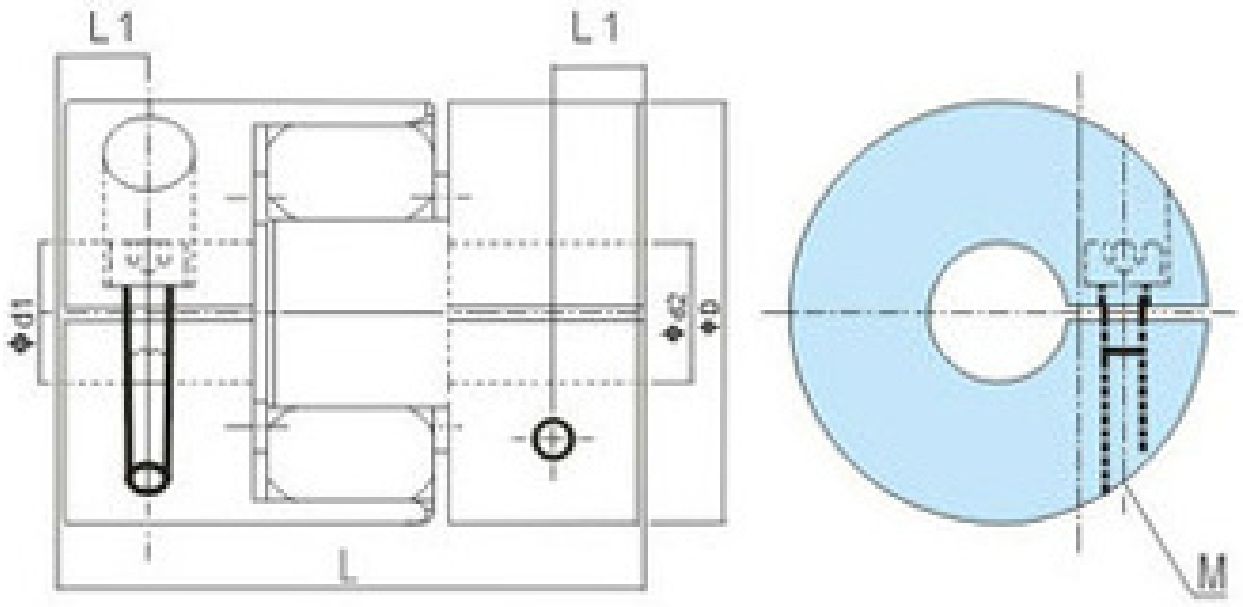


Figure 4.24: D25L30 coupler dimensions [35]

D25L30 coupler dimensions table

项目类型 Item type	d1 Bore	d2 Bore	D	L	L1	M	额定扭矩 Rated Torque (N.m)	最大扭矩 Max. Torque	偏心误差 eccentricity error	轴角偏角 Shaft angel	最高转速 Max. Rotational (rpm)	运转 Rated
B F	4-6	4-6	14	22	3	M3	1.5N.m	3N.m	±0.2mm	≤1°	6500	同步运转 In-phase operate
	5-8	5-8	20	34	5.5	M3-4	1.5N.m	3N.m	±0.2mm	≤1°	6500	
	5-10	5-10	25	34	5.5	M3-4	2N.m	5N.m	±0.2mm	≤1°	6500	
	5-15	5-15	30	42	5.5	M3-5	4N.m	6N.m	±0.2mm	≤1°	6500	

Table 4.4: D25L30 coupler dimensions [35]

4.5.6 Ball screw

The decision to opt for the SFU1204 ball screw coupled with its corresponding ball nut for the Wire EDM machine is based on several critical factors tailored to the project needs:

- Precision and Efficiency: The SFU1204 ball screw, paired with its compatible ball nut, ensures high precision and efficiency in translating rotary motion into linear motion. This precision is essential for achieving accurate positioning and smooth operation during the machining process.

- Low Friction and Smooth Operation: The ball nut assembly minimizes friction between the screw and nut interface, resulting in smooth and consistent motion. This reduction in friction enhances the overall performance of the machine and helps maintain accuracy over extended periods of use.

- Load Capacity and Rigidity: The SFU1204 ball screw and nut combination offer sufficient load-bearing capacity and rigidity to withstand the forces and stresses encountered during machining operations. This ensures stability and reliability even under demanding working conditions.

- Compact Design and Space Efficiency: The compact design of the SFU1204 ball screw and nut assembly allows for efficient use of space within the machine design without sacrificing performance. This space efficiency is crucial for optimizing the layout and functionality of the Wire EDM machine.

- Compatibility and Standardization: The SFU1204 ball screw and nut assembly is a standardized solution widely used in industrial applications, ensuring compatibility with other machine components and ease of integration. This standardization streamlines the design process and simplifies maintenance and replacement procedures.

- Availability and Cost-Effectiveness: The SFU1204 ball screw and nut assembly are readily available in the market, making procurement straightforward. Additionally, their widespread

use and standard dimensions contribute to their cost-effectiveness, providing a balance between high performance and affordability for the project.

SFU1204 ballscrew parameters:

- Material: Steel
- Density: 7.85 g/cm^3
- Length: 550 mm
- Volume: π x (6 mm)^2 x 550 mm = 62,832 mm^3 = 62.832 cm^3
- Mass = 62.832 cm^3 x 7.85 g/cm^3 = 0.493 kg

Figure 4.25 presents a picture of a Ball screw SFU1204.



Figure 4.25: Ball screw SFU1204

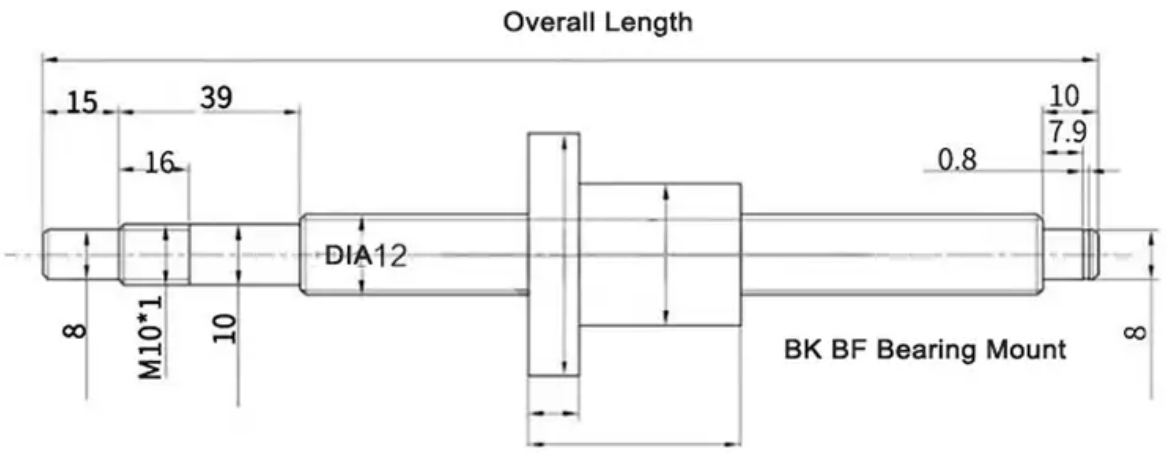


Figure 4.26: Ball screw dimensions [36]

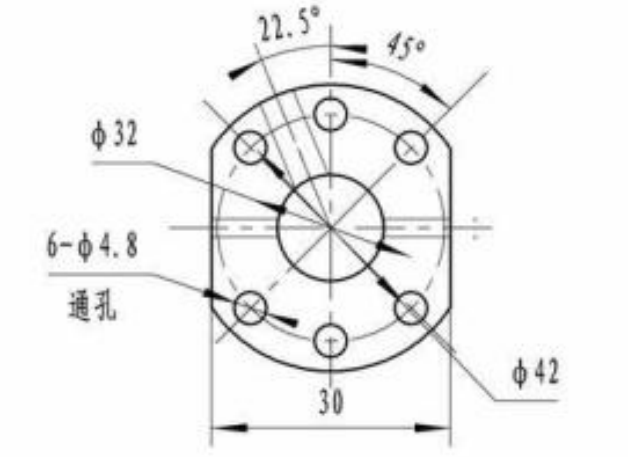


Figure 4.27: Ball nut dimensions [36]

4.5.7 C-beam v-slot:

The selection of the 8040 C-Beam V-Slot for the Wire EDM machine is based on several key factors that make it particularly well-suited for the project:

- High Structural Integrity: The 8040 C-Beam V-Slot provides excellent structural integrity and rigidity, ensuring a stable and robust framework for the machine. This is essential for maintaining precision and stability during the machining process.

- Versatile Design: The V-Slot design of the 8040 C-Beam allows for versatile mounting and movement options. It can accommodate linear guides, motion components, and other hardware, providing flexibility in the machine's design and functionality.

- Ease of Assembly: The modular nature of the C-Beam V-Slot system simplifies the assembly process. Its standardized dimensions and compatibility with various accessories make it easy to integrate into the overall machine setup.
- Precision and Smooth Motion: The V-Slot profile supports precise and smooth linear motion, which is crucial for the accurate positioning and operation of the Wire EDM machine. It minimizes friction and ensures consistent performance.
- Durability and Longevity: Made from high-quality materials, the 8040 C-Beam V-Slot is durable and designed to withstand the rigors of machining operations. Its robust construction ensures long-term reliability and minimal maintenance requirements.
- Compatibility and Standardization: The 8040 C-Beam V-Slot is a standardized component widely used in CNC and other precision machinery. This standardization ensures compatibility with other components and simplifies sourcing and maintenance.
- Cost-Effectiveness: Despite its high performance, the 8040 C-Beam V-Slot is cost-effective, offering a good balance between quality and affordability. Its widespread availability further enhances its practicality for the project.

C-Beam v-slot 8040 parameters:

- Material: aluminum
- Density: 2.7 g/cm^3
- Length: 500 mm
- Mass = 1 kg

Figure 4.28 presents a picture of a C-Beam v-slot 8040.

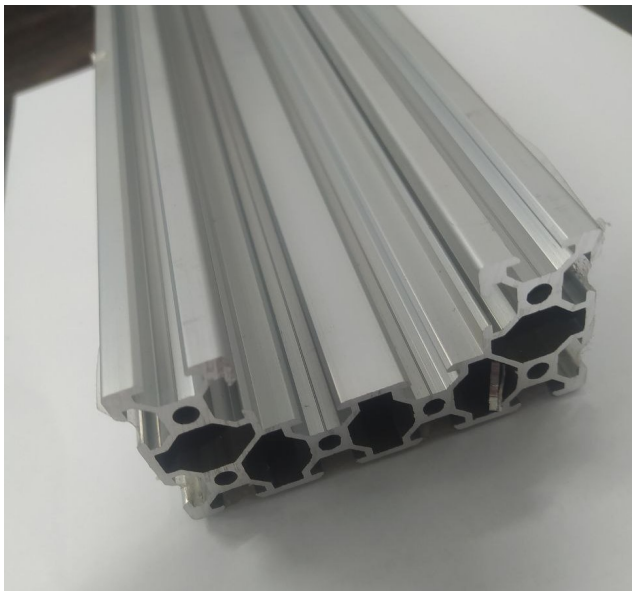


Figure 4.28: C-Beam v-slot 8040

C-Beam v-slot 8040 dimensions:

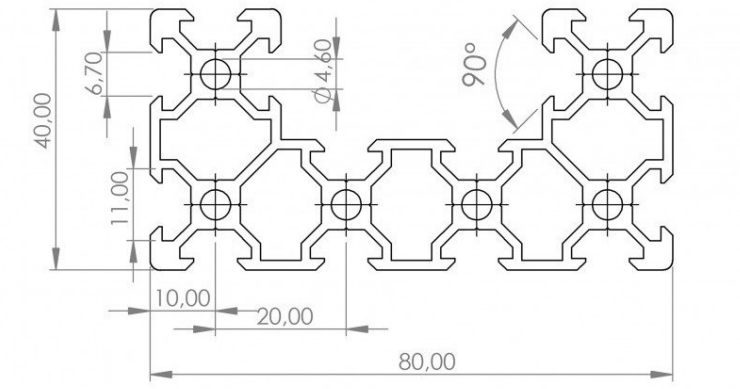


Figure 4.29: C-Beam v-slot 8040 dimensions [37]

4.5.8 Power supply

For this project, a power supply of 24V and 15A was selected to meet the requirements of the servomotors. The chosen servomotors, NEMA24 60HSE3N-D25, have specific voltage and current demands to operate efficiently and reliably. Here's an overview of why this particular power supply was chosen:

- Voltage: The servomotors operate at a nominal voltage of 24V, which ensures they can perform at their optimal efficiency. A 24 V power supply aligns perfectly with this requirement, providing stable and consistent power.

- Current: Each servomotor's current requirements depend on the load and operating conditions. With a power supply rated at 15A, there is ample current capacity to support the servomotors under various loads and conditions, ensuring smooth and reliable operation.
- Stability: The 24V output ensures that the servomotors receive a constant voltage, which is crucial for maintaining precise control and accuracy in the movement of the axes.
- Capacity: With a 15A current rating, the power supply can handle the peak currents required during high-torque movements without any risk of overloading or power drops.
- Compatibility: The power supply's specifications match the servomotors' requirements, making it a suitable choice that ensures optimal performance and longevity of the motors.

Figure 4.30 presents a picture of a Power supply 24V.



Figure 4.30: Power supply 24V

4.6 Calculations

To maintain the operating dependability and efficiency of a Wire Electrical Discharge Machine (Wire EDM), accurate mechanical calculations play an important role in the machine's design and development process. This section explores the key calculations that are required for the mechanical components, with a special focus on the needs for torque and static loads. Static Load Calculations are essential to determine the forces acting on various components of the machine when it is at rest. Understanding these loads helps in selecting appropriate materials and structural elements that can withstand the operational stresses without deformation or failure. It provides a foundation for ensuring the machine's durability and structural integrity under various operational conditions. Torque Calculations are important for determining the motor requirements to drive the machine's moving parts. By calculating the torque needed for the movement of axes,Ensuring that the selected motors can handle the operational demands is crucial, as they need to provide smooth and precise motion control. This aspect is particularly important in maintaining the accuracy and precision that Wire EDM machines are known for.

4.6.1 Load Capacities and Forces

To calculate the static load of the machine, the force exerted by the weight of the machine due to gravity needs to be determined. The static load F is calculated using the equation: F=m.g

Mass of the components:

Servo Motors (NEMA24 60HSE3N-D25):

- Mass: 1.54 kg
- Quantity: 2
- Total Mass: $1.54\,\text{kg} \times 2 = 3.08\,\text{kg}$

Linear Guide Rails:

- Mass: 0.88 kg
- Quantity: 4
- Total Mass: $0.88\,\text{kg} \times 4 = 3.52\,\text{kg}$

Guideways:

- Mass: 0.18 kg
- Quantity: 8
- Total Mass: $0.18\,\text{kg} \times 8 = 1.44\,\text{kg}$

SFU1204 Ballscrew:
- Mass: 0.493 kg
- Quantity: 2
- Total Mass: $0.493\,\text{kg} \times 2 = 0.986\,\text{kg}$

SFU1204 Ballnut:
- Mass: 0.11 kg
- Quantity: 2
- Total Mass: $0.11\,\text{kg} \times 2 = 0.22\,\text{kg}$

Carriage plate:
- Mass= 0.6 kg

C-Beam V-Slot (40x80, 500 mm):
- Mass: 1 kg
- Quantity: 2
- Total Mass: $1\,\text{kg} \times 2 = 2\,\text{kg}$

Wire Guide System:
- Mass: 2.5 kg (approximately)

calculating the Total Mass:

$$\text{Total Mass} = 3.08\,\text{kg} + 3.52\,\text{kg} + 1.44\,\text{kg} + 0.986\,\text{kg} + 0.22\,\text{kg} + 0.6\,\text{kg} + 2\,\text{kg} + 2.5\,\text{kg}$$

$$\text{Total Mass} = 14.346\,\text{kg}$$

Static Load calculation: The static load (force due to gravity) can be calculated using the formula:

$$F = m \times g \tag{4.1}$$

where m is the mass and g is the acceleration due to gravity ($9.81\,\text{m/s}^2$).

$$F = 14.346\,\text{kg} \times 9.81\,\text{m/s}^2$$

$$F = 140.73\,\text{N}$$

Structural Support Analysis:

Support Parameters:
- Dimensions: 80 mm x 1000 mm
- Material: Mild Steel
- Thickness: 8 mm

Stress Analysis:

The stress on the support due to the static load needs to be calculated and compared with the yield strength of mild steel. This comparison will provide insight into the structural integrity of the support under the applied load.

1. Cross-sectional Area (A):

$$A = \text{width} \times \text{thickness}$$

$$A = 80\,\text{mm} \times 8\,\text{mm} = 640\,\text{mm}^2 = 640 \times 10^{-6}\,\text{m}^2$$

2. Stress (σ):

$$\sigma = \frac{F}{A} \tag{4.2}$$

$$\sigma = \frac{140.73\,\text{N}}{640 \times 10^{-6}\,\text{m}^2}$$

$$\sigma = 219.02\,\text{kPa}$$

The calculated stress (219.02 kPa) is significantly lower than the yield strength of mild steel (250 MPa), indicating that the support structure can handle the static load without yielding.

This confirms that the structural support is adequate for the static loads exerted by the components of the Wire EDM machine.

4.6.2 Torque and Speed Requirements for Motors

The motor will be responsible for moving the C-Beam and the entire assembly attached to it. The combined mass that needs to be considered includes the carriage plate, linear guide rails, guideways, ballscrews, ballnuts, C-Beam, and the wire guide system.

Calculating the Total Mass for the Moving Parts of One Axis:

Relevant Masses for One Axis:

- Carriage Plate: 0.6 kg
- Servo Motor: 1.54 kg (assuming one servo motor per axis)
- Linear Guide Rails: 2 x 0.88 kg (assuming two per axis)
- Guideways: 4 x 0.18 kg (assuming four per axis)
- Ballscrew: 0.493 kg
- Ballnut: 0.11 kg
- C-Beam V-Slot: 1 kg
- Wire Guide System: 2.5 kg (shared across axes, assumed half for one axis)

Total Relevant Mass for One Axis:

$$\text{Total Relevant Mass} = 0.6 + 1.54 + (2 \times 0.88) + (4 \times 0.18) + 0.493 + 0.11 + 1 + \frac{2.5}{2}$$

$$\text{Total Relevant Mass} = 0.6 + 1.54 + 1.76 + 0.72 + 0.493 + 0.11 + 1 + 1.25$$

$$\text{Total Relevant Mass} = 7.473\,\text{kg}$$

Calculating the Force:

The force required to move the load can be calculated using the gravitational force (assuming movement in the horizontal plane, so only frictional forces are considered):

$$F = m \cdot g$$

Where m is the mass and g is the acceleration due to gravity ($g = 9.81\,\text{m/s}^2$).

$$F = 7.473\,\text{kg} \times 9.81\,\text{m/s}^2 = 73.32\,\text{N}$$

Calculating the Torque:

The torque required to move the load on the ballscrew can be calculated using:

$$T = \frac{F \cdot L}{2\pi \cdot \eta}$$

Where:
- T is the torque
- F is the force calculated above
- L is the lead of the ballscrew (typically 4 mm for SFU1204)
- η is the efficiency of the ballscrew (assumed to be around 0.9 or 90%)

$$T = \frac{73.32\,\text{N} \times 0.004\,\text{m}}{2\pi \times 0.9}$$

$$T = \frac{0.29328}{5.654} = 0.0519\,\text{Nm}$$

The torque required for moving the axis is approximately 0.0519 Nm.
Next, it needs to be checked if the servo motor (NEMA24 60HSE3N-D25) can handle this torque. The holding torque of the NEMA24 60HSE3N-D25 is typically around 3 Nm, significantly higher than the calculated torque requirement of 0.0519 N m. Therefore, the servo motor can handle the required torque for moving the axis.

4.7 Realization section

After obtaining the necessary components for the Wire EDM machine, the realization process faced certain time constraints, preventing the completion of the entire machine. However, significant progress was made with the realization of the X and Y axes, thereby achieving the essential CNC system functionality. This section provides a detailed overview of the realization process, encompassing the fabrication of required parts, the installation of components, and the integration of the CNC control system. The focus is on the steps taken to realize the X and Y axes of the Wire EDM machine, demonstrating the practical implementation of the designed system.

Fabrication of Parts:

The initial step in the realization process involved fabricating the essential parts for the machine, including the mount brackets for the C-Beam and Servomotors, and the carriage plate. These parts were made from aluminum. To achieve this, a CNC 3-axis milling machine (C-TEK CNT 830) was employed to cut and fabricate the parts. MASTERCAM software was utilized to create the CNC program for generating the G-code required for the parts fabrication.

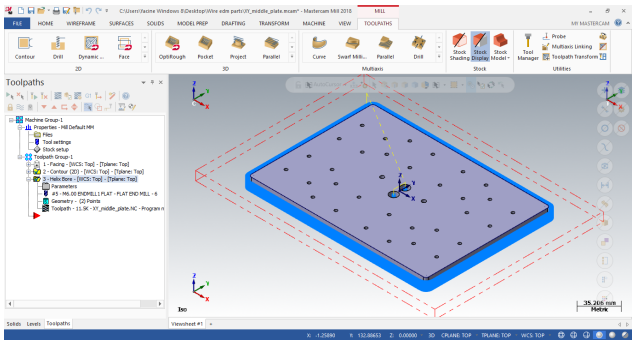


Figure 4.31: The CNC programming of the middle plate

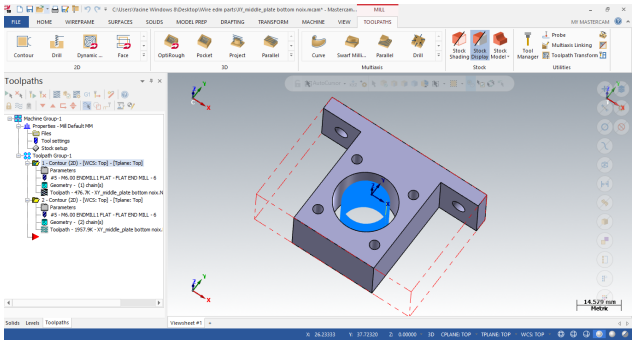
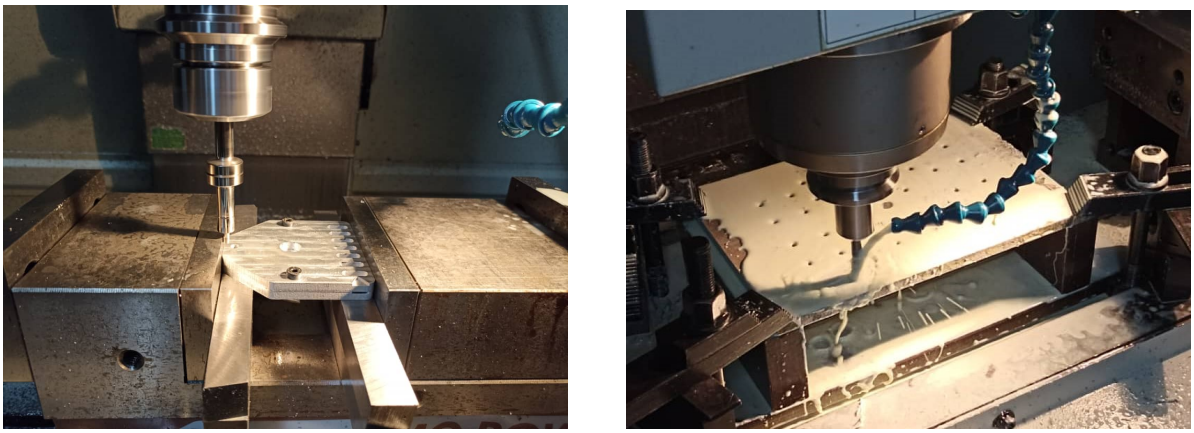


Figure 4.32: The CNC programming of the ballnut block



(a) The fabrication of the mount brackets (b) The fabrication of the middle plate

Figure 4.33: The fabrication of the parts in the CNC milling machine

Installation of Components and Parts: The second step in the realization process involves the meticulous installation of the fabricated components and parts. This stage is critical, as precision is paramount to ensure the optimal functioning of the Wire EDM machine. The process begins with the careful mounting of the C-beam, which serves as a structural support for various other components. Ensuring the proper alignment and secure attachment of the servomotor mount brackets to the C-beam is essential, as any misalignment could adversely affect the machine's performance.

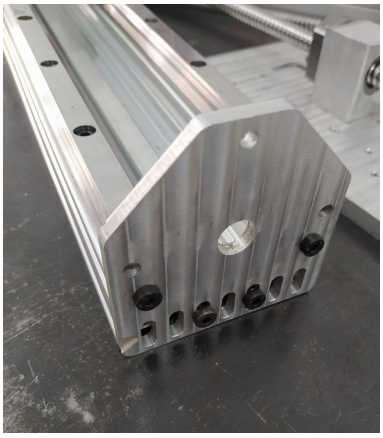


Figure 4.34: The installation of the mounting brackets into the C-Beam

Following this, the installation of the linear guideways onto the rails is undertaken. This step requires exceptional attention to detail, as the guideways must be precisely aligned to facilitate smooth and accurate motion along the axes. The precision required in this installation is crucial, as even minor deviations can lead to significant errors in the machine's operation. Figure 4.35 presents the installation of the Guideways into the rails

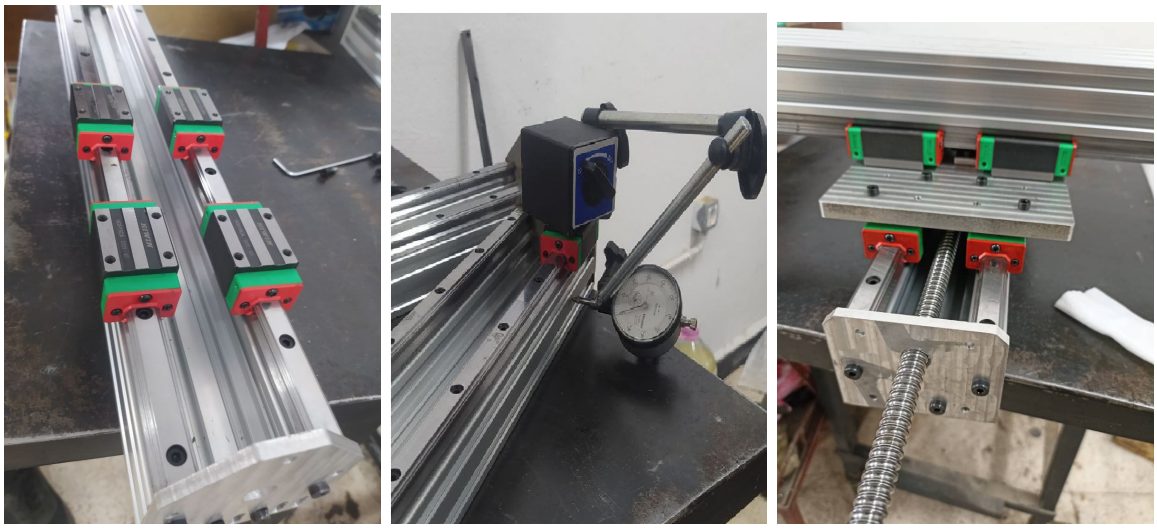


Figure 4.35: The installation of the Guideways into the rails

Following the precise installation of the C-beam, linear guideways, and other structural components, the next critical step is the installation of the servomotors. The servomotors, specifically the NEMA24 60 HSE3N-D25 models, play a vital role in providing the precise motion control necessary for the Wire EDM machine.

The process begins with securely mounting the servomotors onto their designated brackets. This step requires careful alignment to ensure that the motors are perfectly positioned to drive the ball screws without introducing any misalignment or mechanical stress. Proper alignment is crucial as it directly impacts the accuracy and efficiency of the machine's motion control.

Once mounted, the servomotors are connected to the ball screws via precision couplers. These couplers are designed to transmit torque effectively while accommodating minor misalignments, ensuring smooth and efficient power transfer from the motors to the linear motion system. It is essential to verify that the couplers are correctly installed and securely tightened to prevent any slippage or loss of motion control.

Figure 4.36 presents the installation of the Servomotors into the brackets



Figure 4.36: The installation of the Servomotors into the brackets

After securing the mechanical connections, the electrical connections were established. The servomotors were interfaced with the CNC control system by connecting the motor leads to the appropriate drivers and configuring the control software (Mach3) to recognize and manage the motors. Additionally, the power supply connections were made to ensure that all components received the necessary power. This setup ensures that the motors respond accurately to the commands from the CNC system, enabling precise control over the X and Y axes. Figure 4.36 presents the installation of the Electrical connections

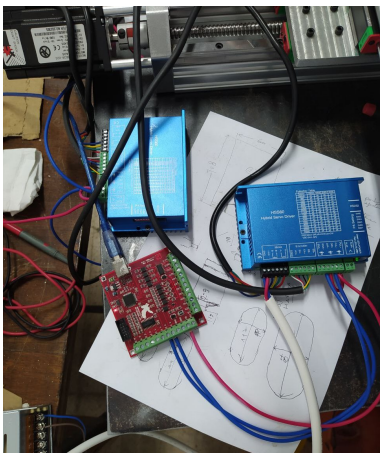


Figure 4.37: The installation of the Electrical connections

The simplified schema of the Electrical connections:

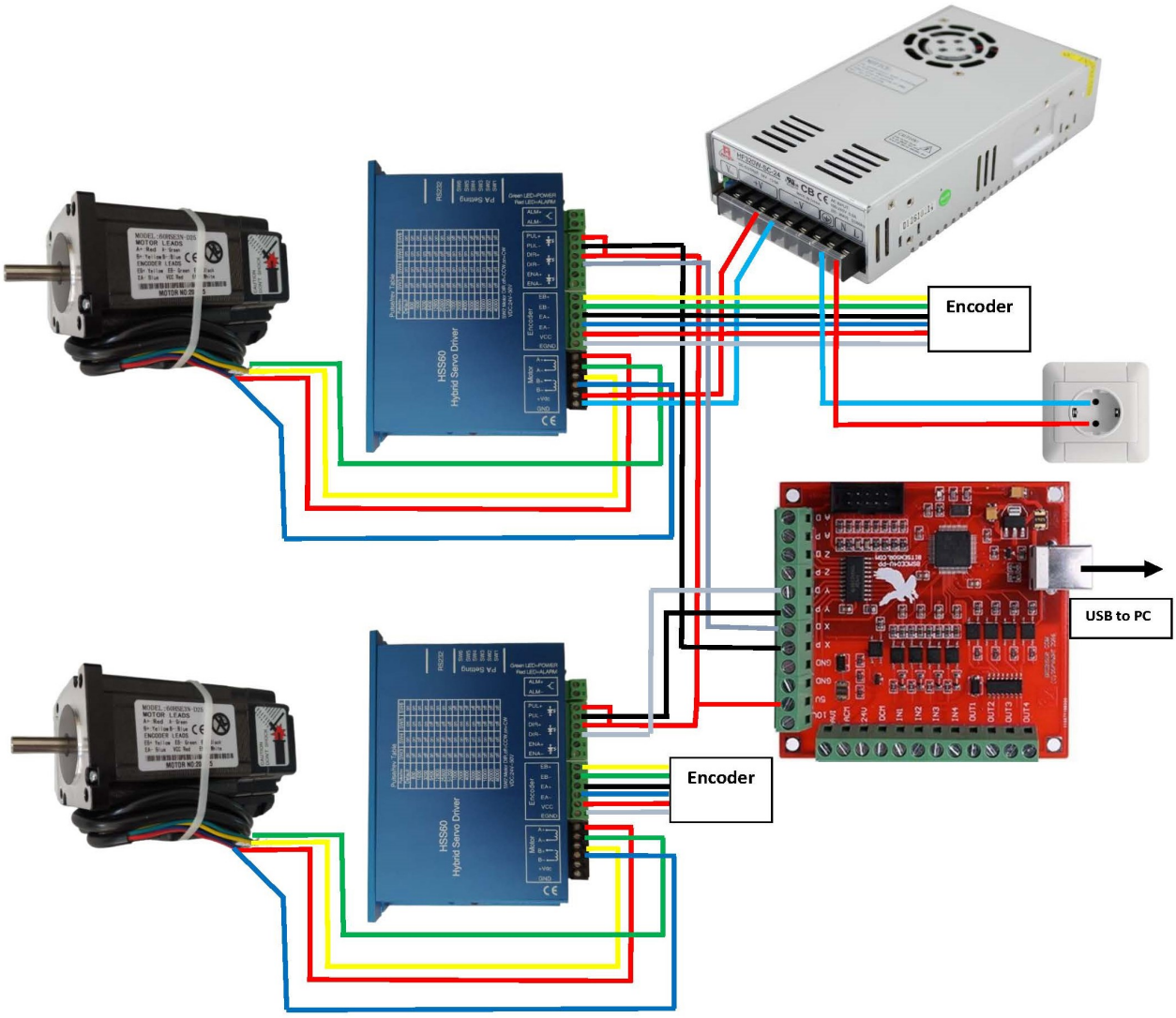


Figure 4.38: The pictorial diagram of the electrical wirings

After installing Mach3 on a personal computer, its functionality was tested to ensure compatibility and effectiveness for controlling the Wire EDM machine. Mach3, a robust CNC control software, offers extensive features and customization options, making it ideal for this application. The software was configured to interface with the machine's hardware, ensuring smooth and precise control of the X and Y axes.

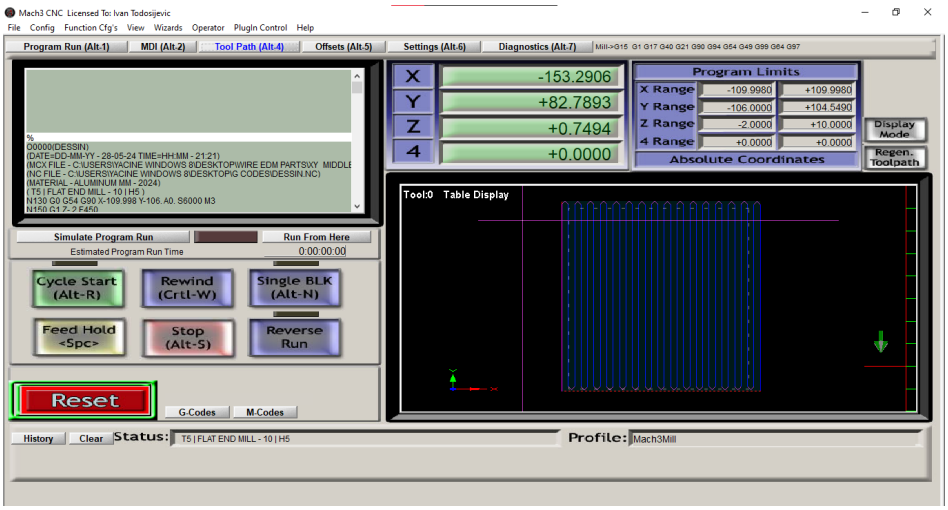


Figure 4.39: Mach3 interface

Components cost: the cost of the purchased components:

Item No.	Item description	Quantity	Unit price	Total price
1	Ball screw MACHIFIT SFU1204 with ball nut. 1200 MM	2	DZD 14,400.00	DZD 28,800.00
2	Linear guide rails 15mmx2000 mm	1	DZD 6,400.00	DZD 6,400.00
3	Linear blocks HGH15CA	8	DZD 1,700.00	DZD 13,600.00
4	8X12MM COUPLER - D25L30	2	DZD 1,500.00	DZD 3,000.00
5	C-beam linear rails 40x80 1000mm	1	DZD 4,000.00	DZD 4,000.00
6	Servo motors NEMA24 60HSE3N-D25 + HSS60 5A	2	DZD 38,000.00	DZD 76,000.00
7	Bolts and Nuts	1	DZD 6,000.00	DZD 6,000.00
8	Spacers	6	DZD 65.00	DZD 390.00
9	Electrical connections (Power supply, wirings ..etc)	1	DZD 5,000.00	DZD 5,000.00
10	Esitimated time of the parts fabrication with the CNC milling machine	1	DZD 30,000.00	DZD 30,000.00
			Total=	DZD 173,190.00

Table 4.5: Components cost

4.8 Conclusion

This Chapter provided a detailed overview of the 3D assembly process for the Wire EDM machine. Each component was meticulously presented along with its corresponding 3D model, highlighting the precision and care taken in the design phase. A thorough component analysis was conducted, specifying the type and real dimensions of each part, ensuring an accurate and functional assembly. This chapter laid the groundwork for the realization phase, illustrating the importance of precise design and assembly in achieving a fully functional Wire EDM machine.

General conclusion

This thesis has explored the design and partial realization of a Wire Electrical Discharge Machining (Wire EDM) machine, focusing on both the theoretical and practical aspects of the project. The work encompassed a comprehensive functional analysis, the selection of appropriate components, detailed mechanical and electrical design, and the initial stages of the machine's construction.

In the first part of the thesis, an in-depth study of the Wire EDM process was conducted, highlighting its principles, applications, and advantages in precision manufacturing. The subsequent functional analysis employed tools such as the horned beast, octopus, and FAST diagrams to elucidate the project's requirements and constraints, guiding the selection of the most suitable solutions for each function.

The design phase involved careful consideration of various components, including the axis transmission system, electrical motors, and power supply. The chosen components, such as the NEMA24 servomotors, ball screws, and the 24V, 15A power supply, were selected for their compatibility and ability to meet the machine's precision and performance demands.

The realization phase focused on the fabrication and assembly of the X and Y axes, utilizing advanced CNC milling techniques and software like Mastercam 2018. The installation of these components, including the servomotors and guideways, was meticulously carried out to ensure high accuracy and reliability.

Despite the progress made, the full realization of the Wire EDM machine is ongoing. Future work will concentrate on completing the machine, particularly the generation of electrical discharges and the integration of the wire guide system. These components are critical for achieving the desired precision and efficiency in the wire EDM process.

This thesis has laid a solid foundation for the development of a high-precision Wire EDM machine, addressing both theoretical considerations and practical implementation steps. The future completion of this project will contribute significantly to the field of precision manufacturing, providing a valuable tool for producing intricate and high-quality parts.

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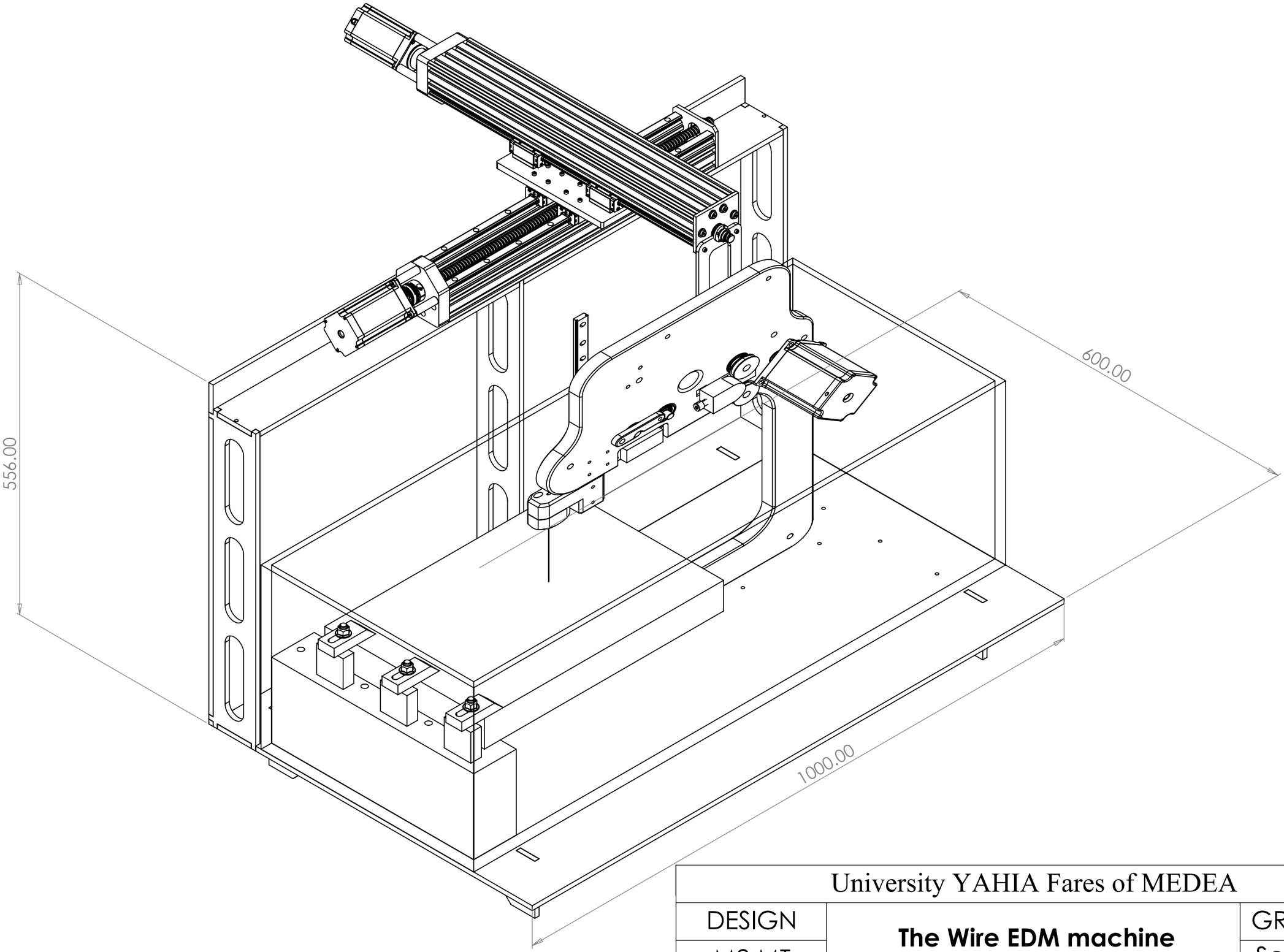
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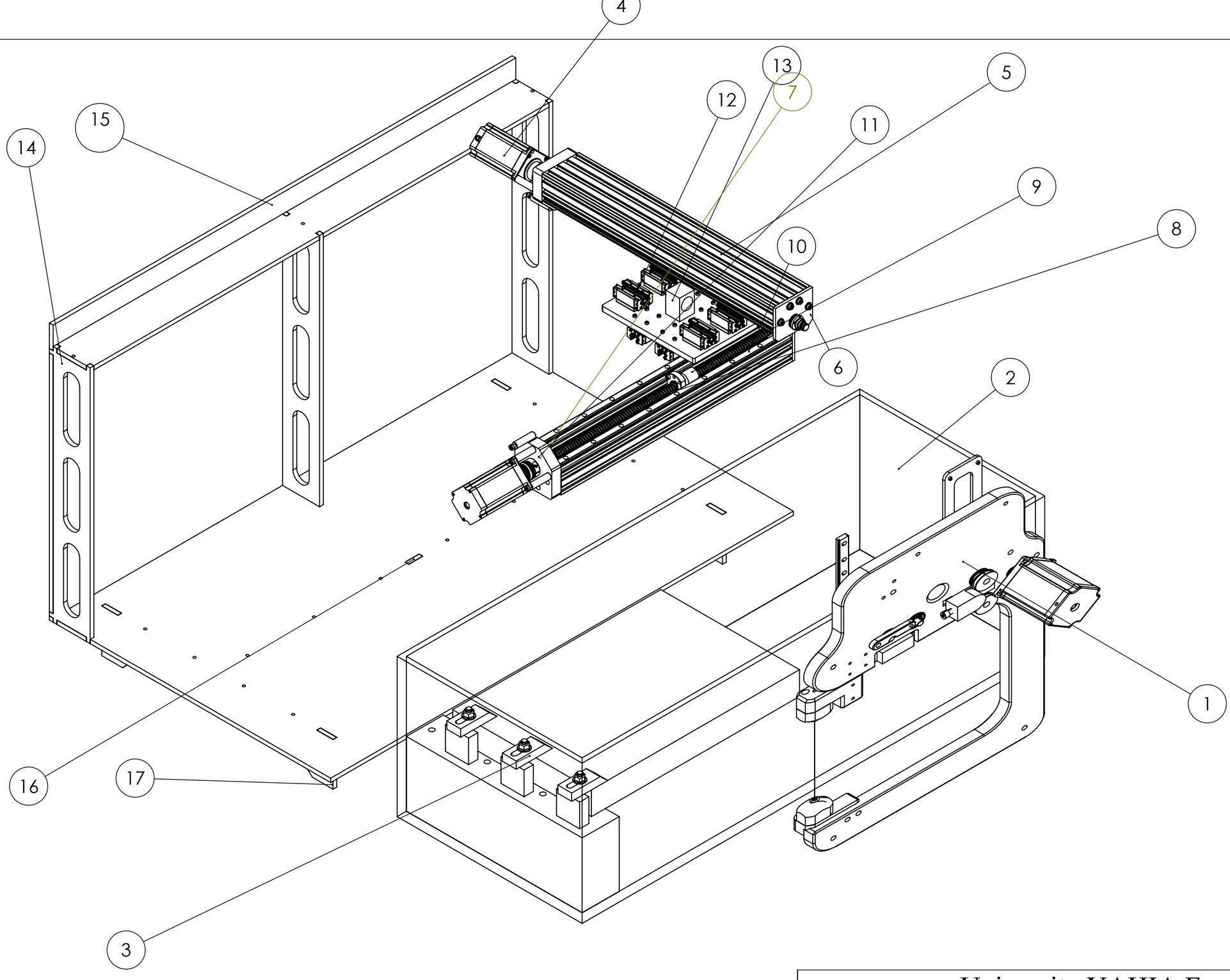
Appendix

Technical Drawings

This appendix contains the technical drawings that provide detailed specifications and dimensions for the components used in the 3D Assembly of the wire EDM machine.



University YAHIA Fares of MEDEA		
DESIGN	**The Wire EDM machine**	GROUP: 01
M2 MT		Scale 1:10
12/05/2024	MAMI Yacine	

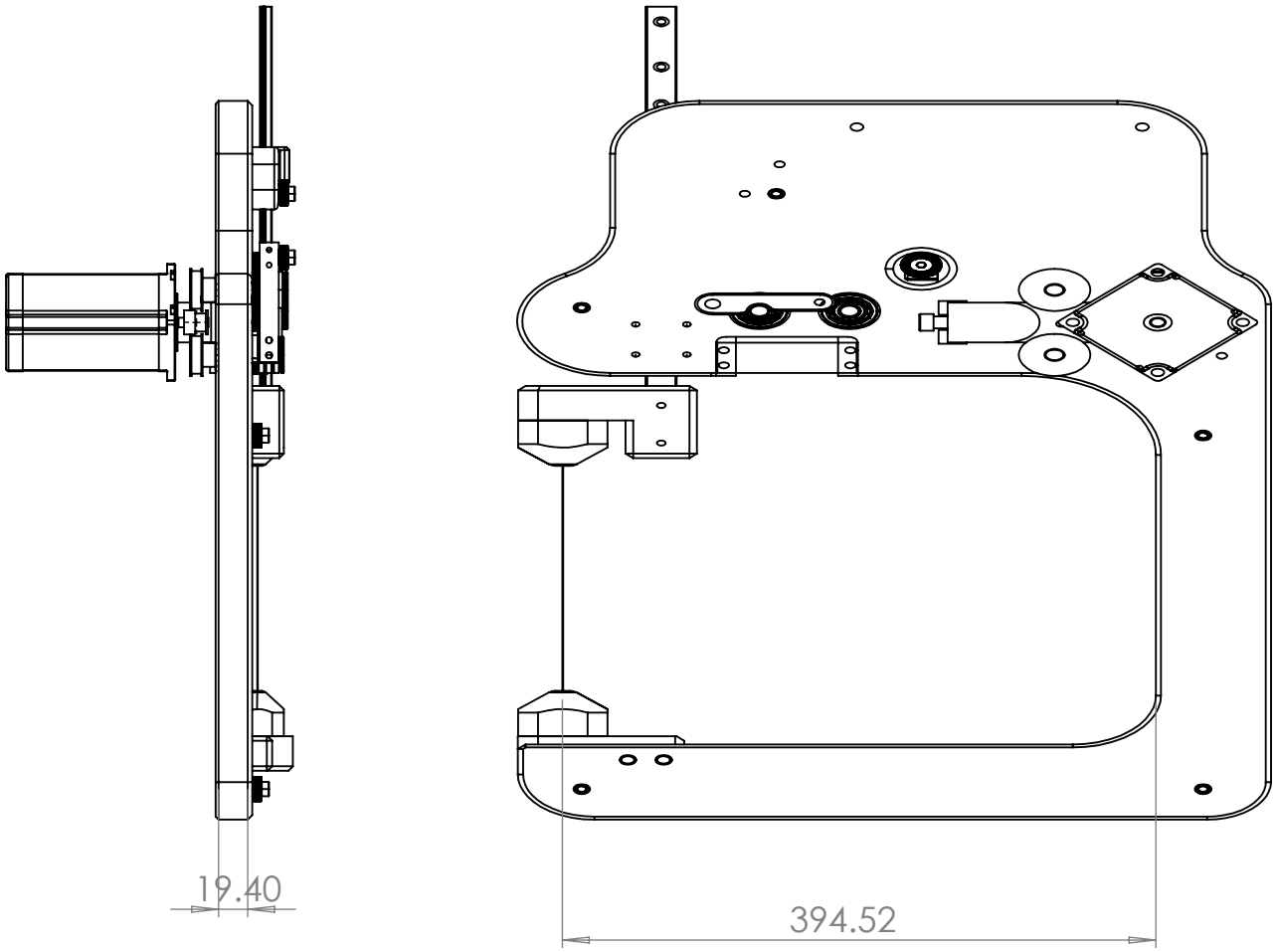


University YAHIA Fares of MEDEA		
DESIGN	**Exploded View of the Wire EDM machine**	GROUP: 01
M2 MT		Scale 1:6
12/05/2024	MAMI Yacine	

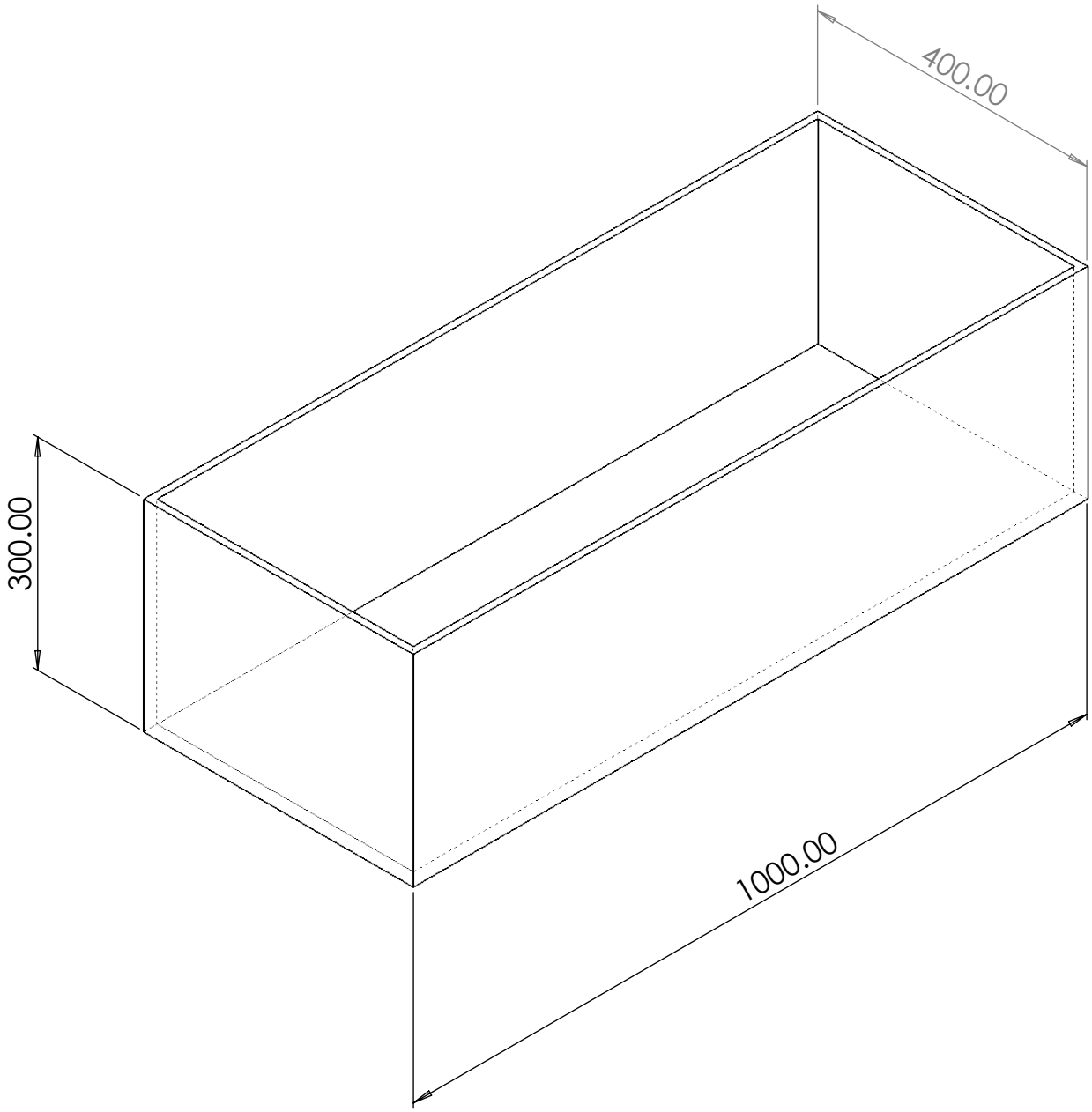
REP	NB	DESIGNATION	MATIÈRE
17	2	Side supports	
16	1	central support	
15	1	Main Support	
14	3	Upright Supports	
13	1	Carriage plate	
12	8	Guideways	
11	2	Coupler	
10	4	Linear guide rail	
9	2	Ball nut	
8	2	Ball screw	
7	2	Servomotor Mounting Bracket	
6	2	C-Beam mount	
5	2	C-Beam v slot	
4	2	Servo motor	
3	3	Fixation system	
2	1	Tank	
1	1	Wire transmission system	

University YAHIA Fares of MEDEA

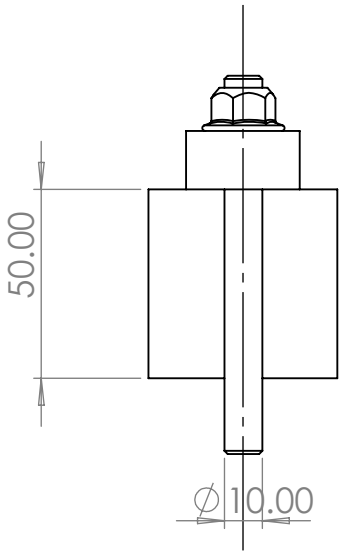
Bill of materials		GROUP: 01
M2 MT		Scale 1:1
12/05/2024	MAMI Yacine	

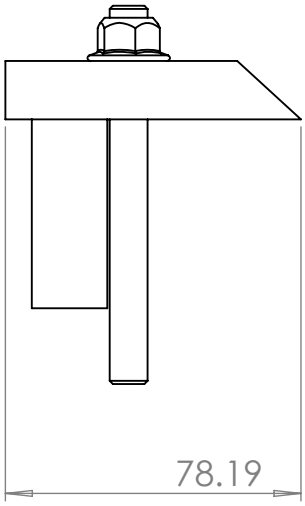


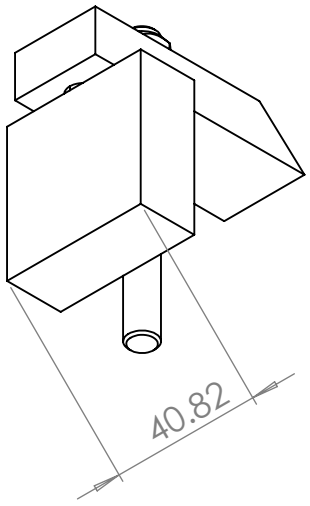
University YAHIA Fares of MEDEA		
DESIGN N° 01	**Wire transmission system**	GROUP: 01
M2 MT		Scale 1:10
12/05/2024	MAMI Yacine	

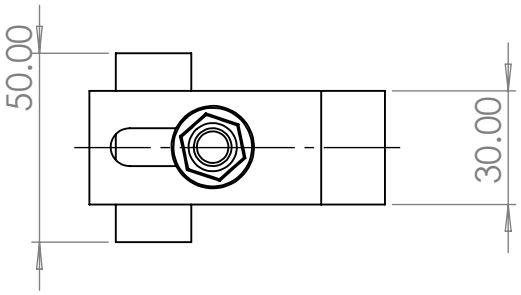


University YAHIA Fares of MEDEA		
DESIGN Nº 02	**Tank**	GROUP: 01
M2 MT		Scale 1:7
12/05/2024	MAMI Yacine	

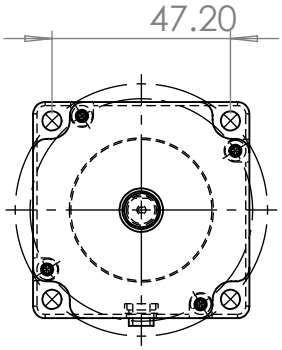


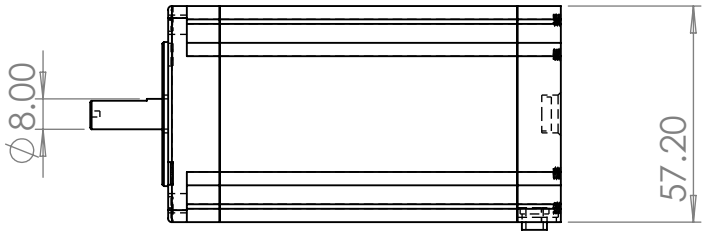


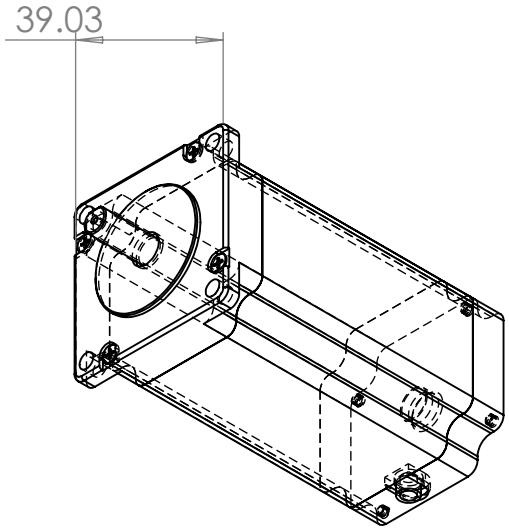




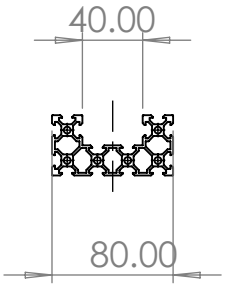
University YAHIA Fares of MEDEA		
DESIGN N°03	**Fixation system**	GROUP: 01
M2 MT		Scale 1:2
12/05/2024	MAMI Yacine	

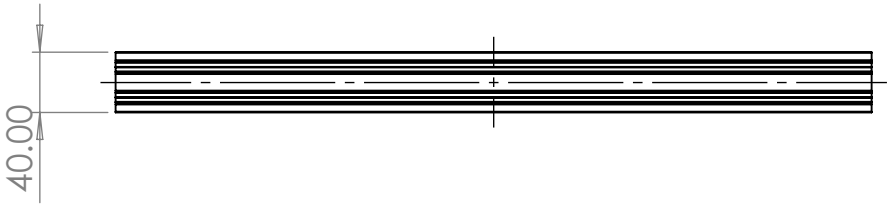


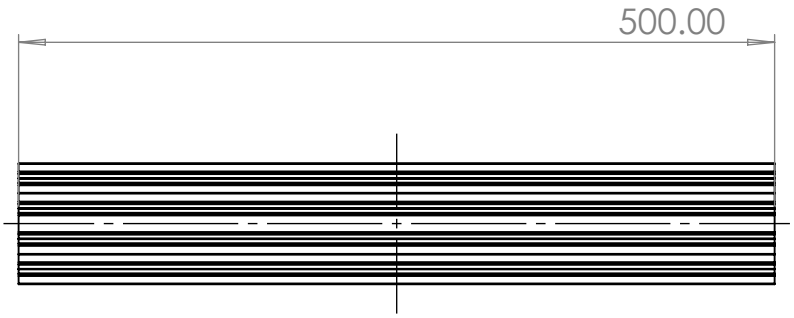




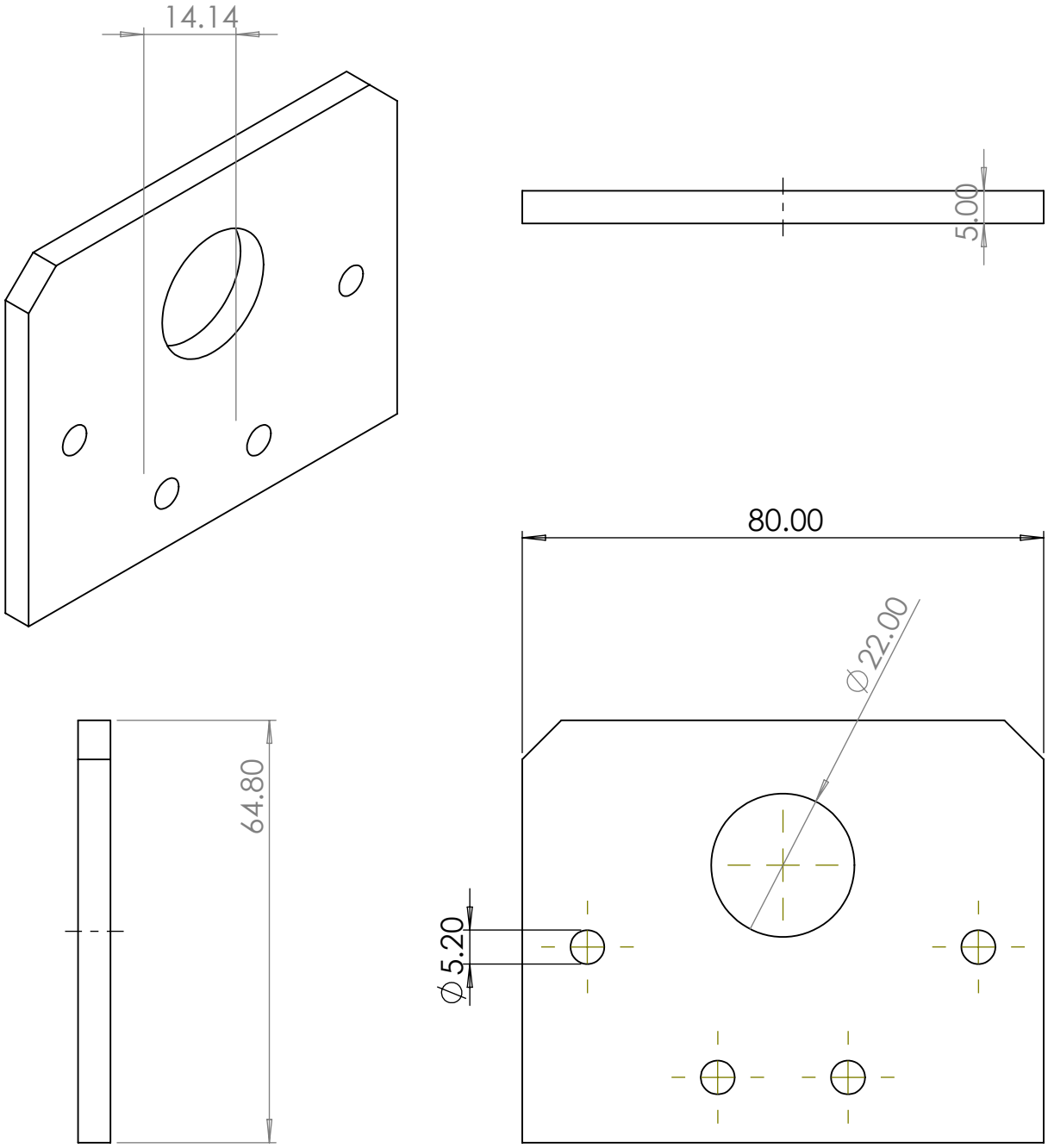
University YAHIA Fares of MEDEA		
DESIGN Nº 04	**Servomotor**	GROUP: 01
M2 MT		Scale 1:2
12/05/2024	MAMI Yacine	



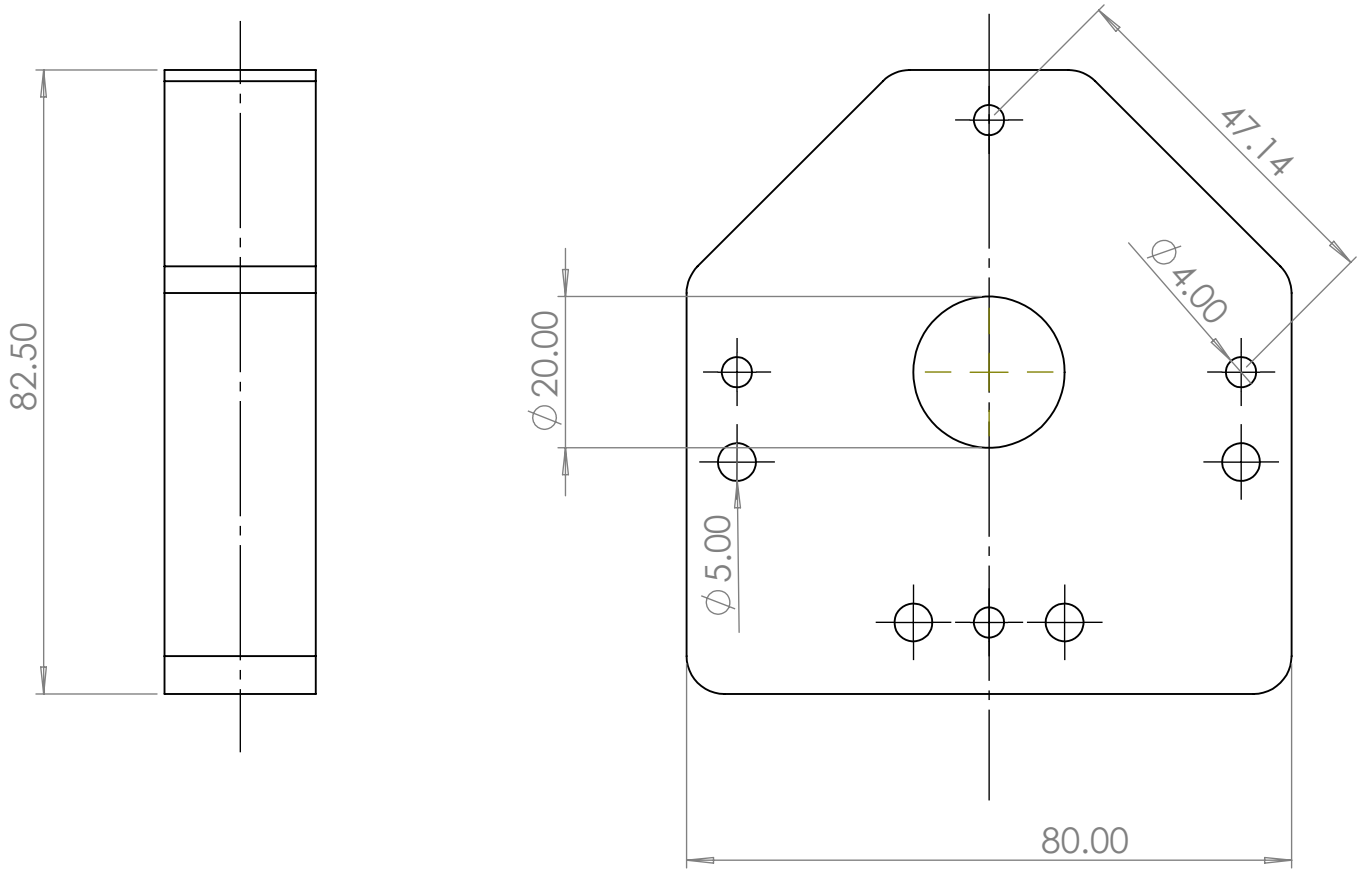


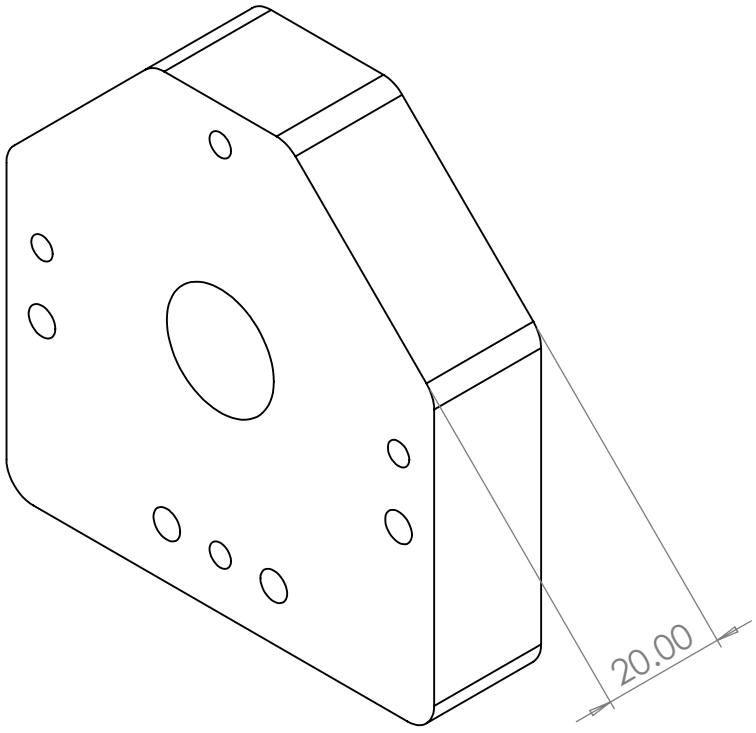


University YAHIA Fares of MEDEA		
DESIGN Nº 05	**C-Beam v-slot**	GROUP: 01
M2 MT		Scale 1:5
12/05/2024	MAMI Yacine	

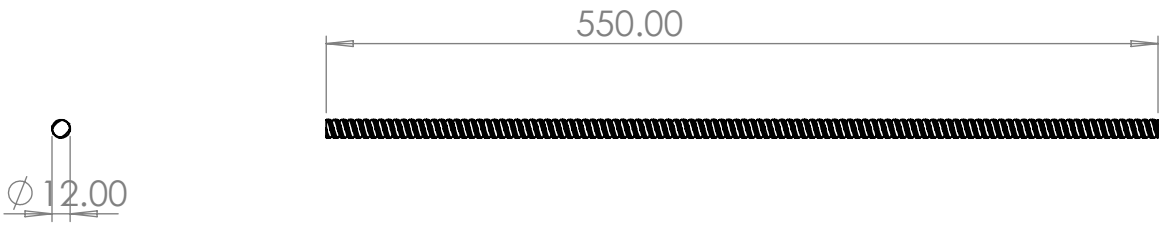


University YAHIA Fares of MEDEA		
DESIGN Nº 06	**C-Beam mount**	GROUP: 01
M2 MT		Scale 1:1
12/05/2024	Yacine MAMI	

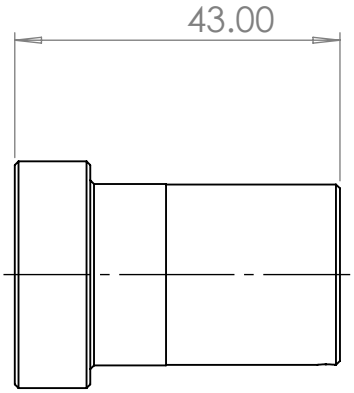


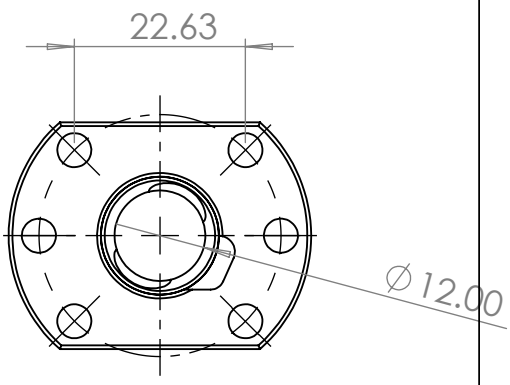


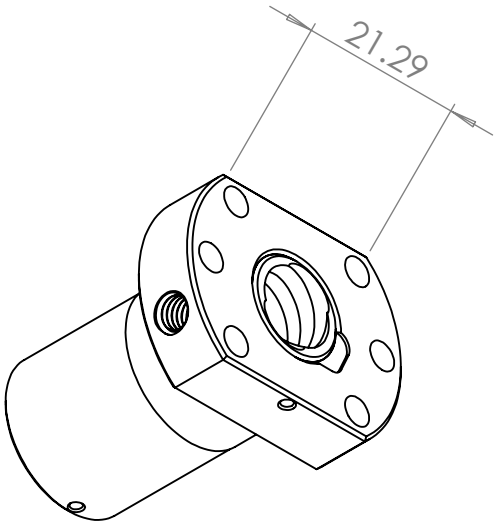
University YAHIA Fares of MEDEA		
DESIGN Nº 07	**Servomotor mounting bracket**	GROUP: 01
M2 MT		Scale 1:1
12/05/2024	MAMI Yacine	



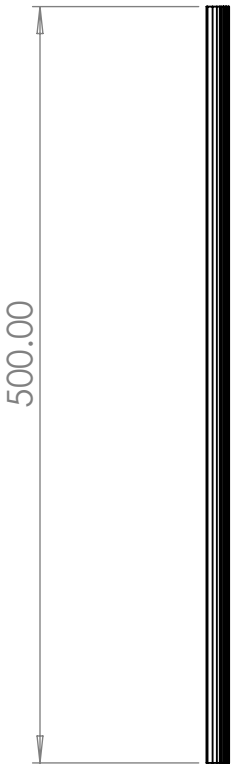
University YAHIA Fares of MEDEA		
DESIGN Nº 08	**Ball screw**	GROUP: 01
M2 MT		Scale 1:5
12/05/2024	MAMI Yacine	

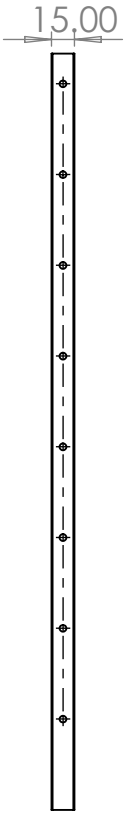


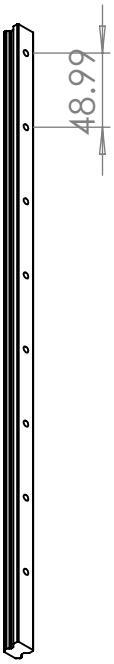


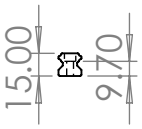


University YAHIA Fares of MEDEA		
DESIGN Nº 09	**Ball nut**	GROUP: 01
M2 MT		Scale 1:1
12/05/2024	MAMI Yacine	

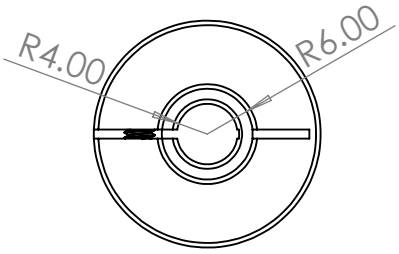


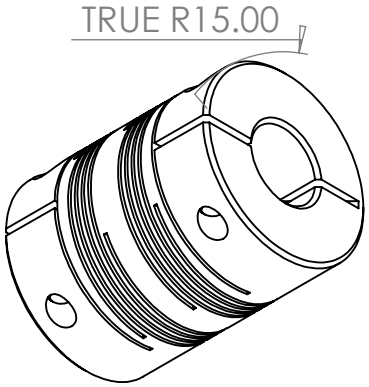


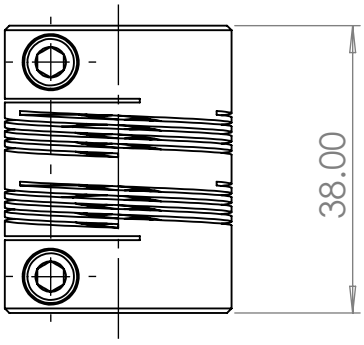




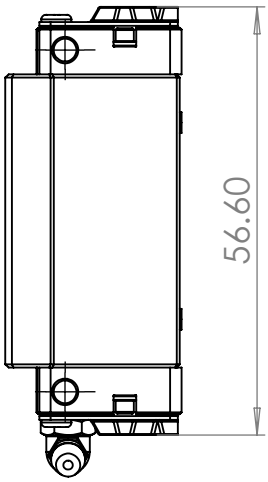
University YAHIA Fares of MEDEA		
DESIGN Nº 10	**Linear guide rail**	GROUP: 01
M2 MT		Scale 1:5
12/05/2024	MAMI Yacine	

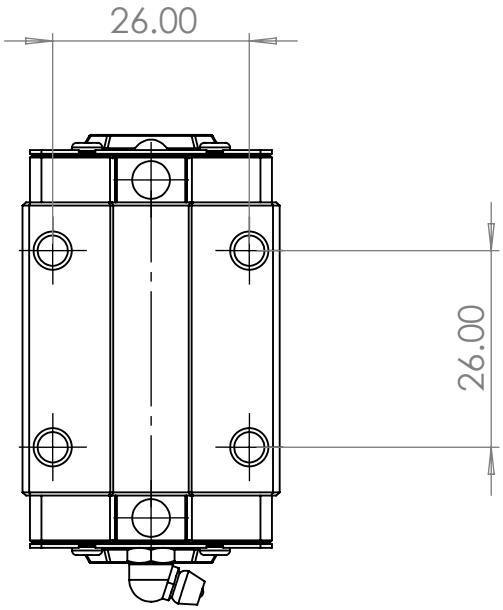


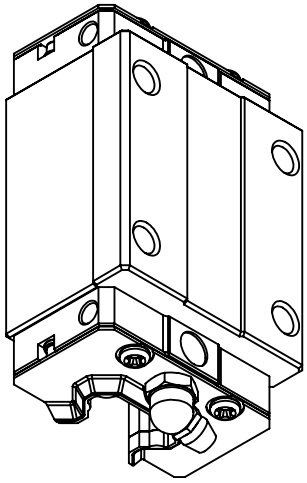


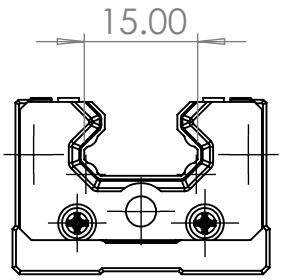


University YAHIA Fares of MEDEA		
DESIGN N°11	**Coupler**	GROUP: 01
M2 MT		Scale 1:1
12/05/2024	MAMI Yacine	

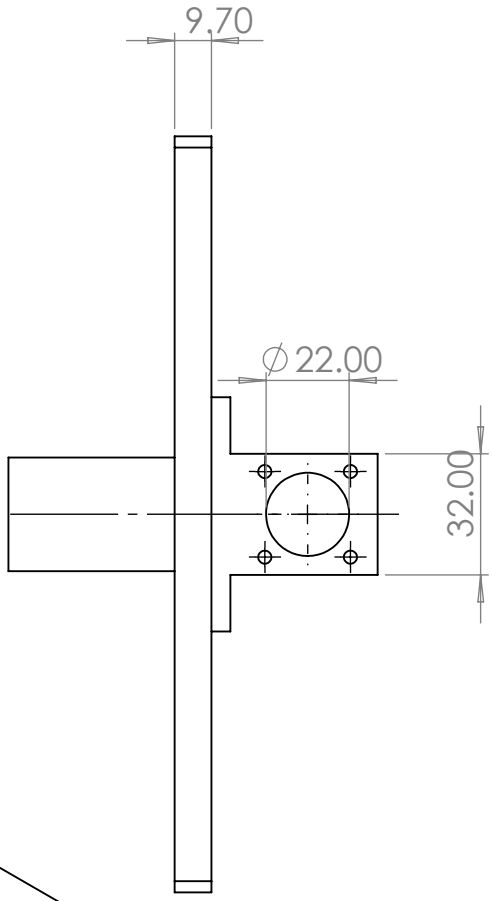


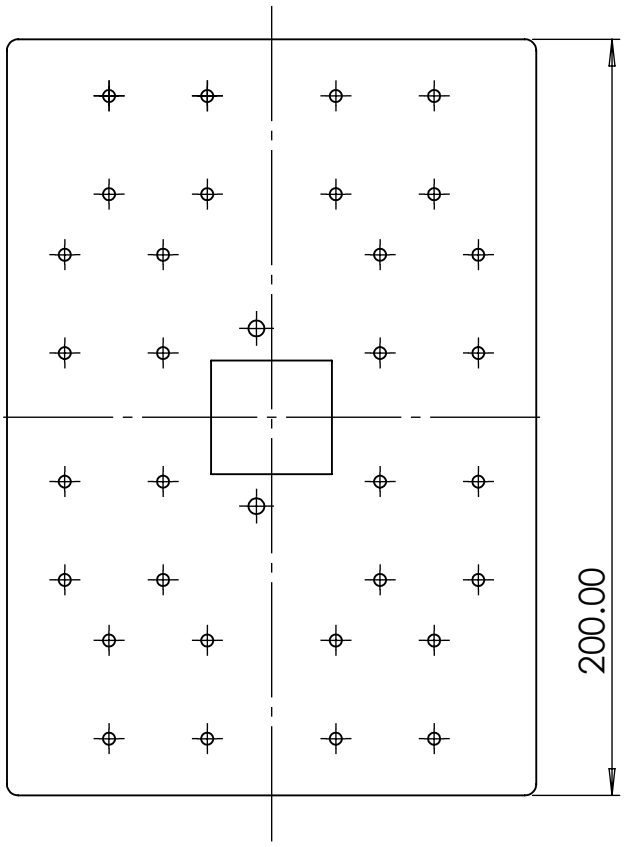


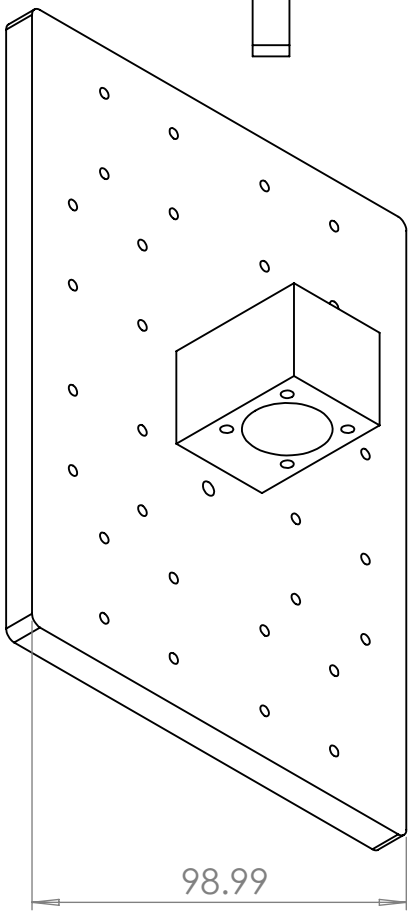


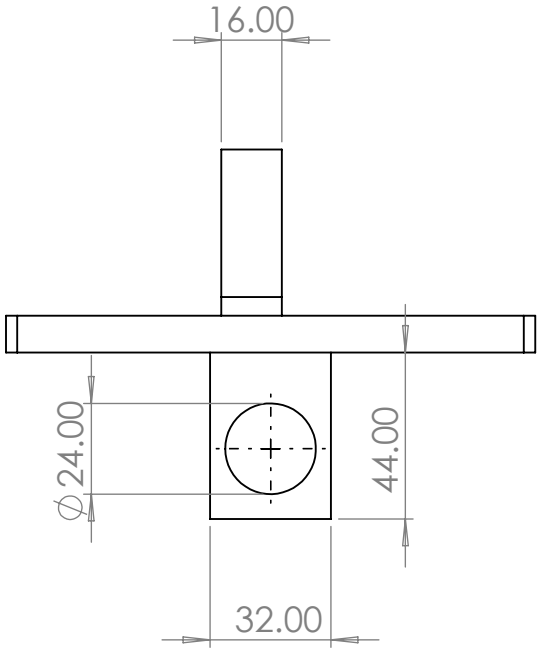


University YAHIA Fares of MEDEA		
DESIGN N°12	**Guideways**	GROUP: 01
M2 MT		Scale 1:1
12/05/2024	MAMI Yacine	

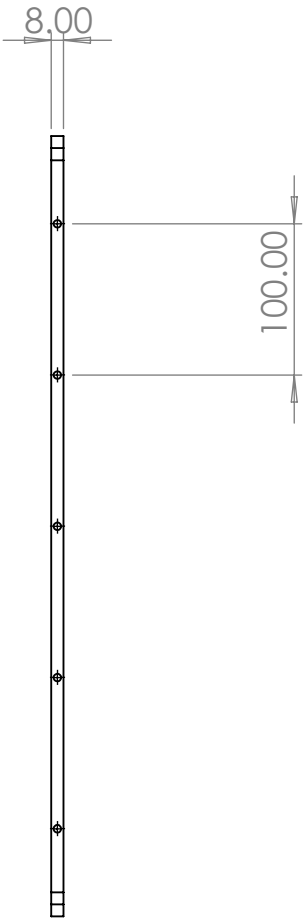


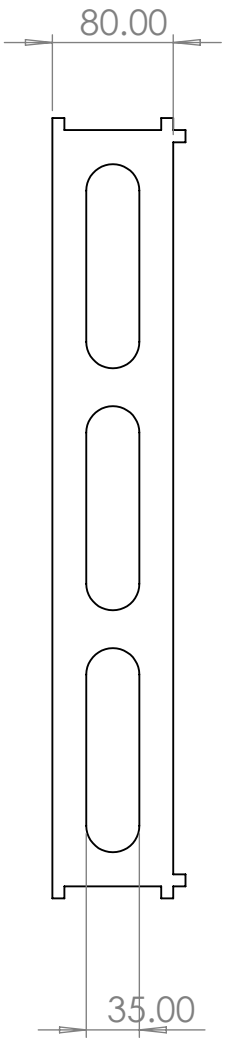




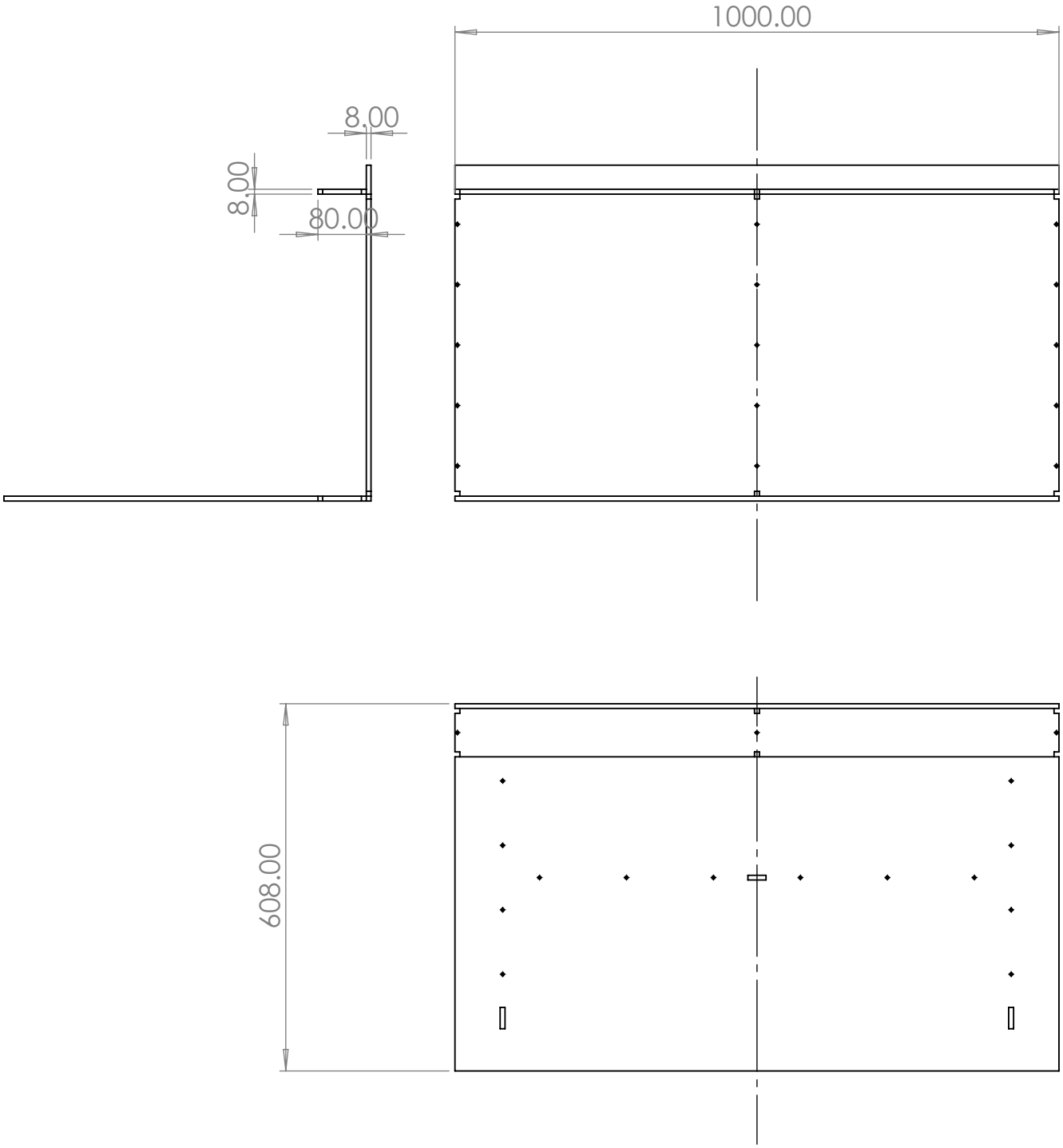


University YAHIA Fares of MEDEA		
DESIGN Nº 13	**Carriage plate**	GROUP: 01
M2 MT		Scale 1:2
12/05/2024	MAMI Yacine	

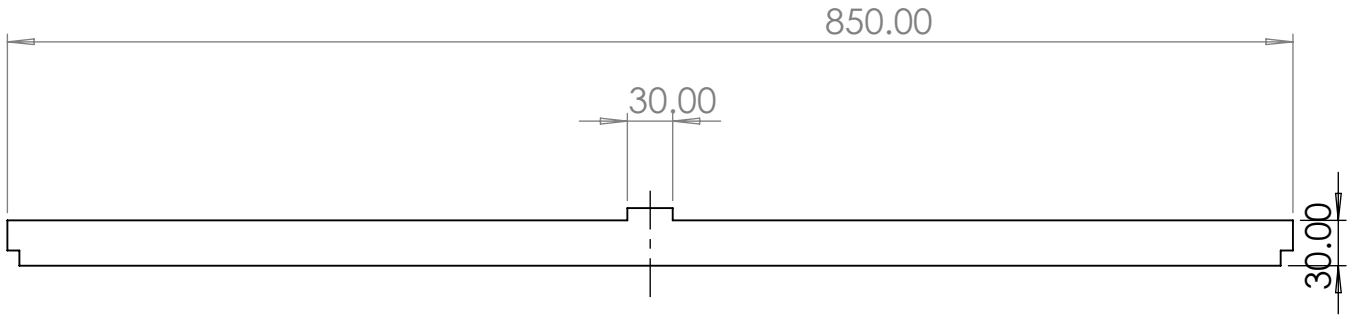


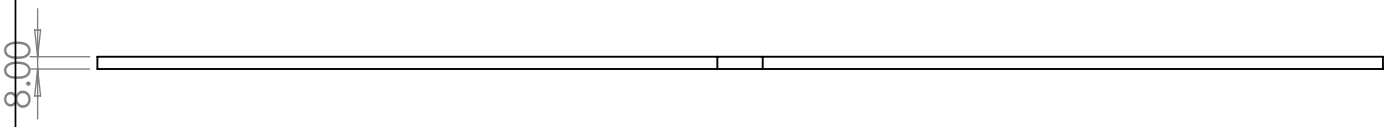


University YAHIA Fares of MEDEA		
DESIGN N°14	**Uppright support**	GROUP: 01
M2 MT		Scale 1:5
12/05/2024	MAMI Yacine	

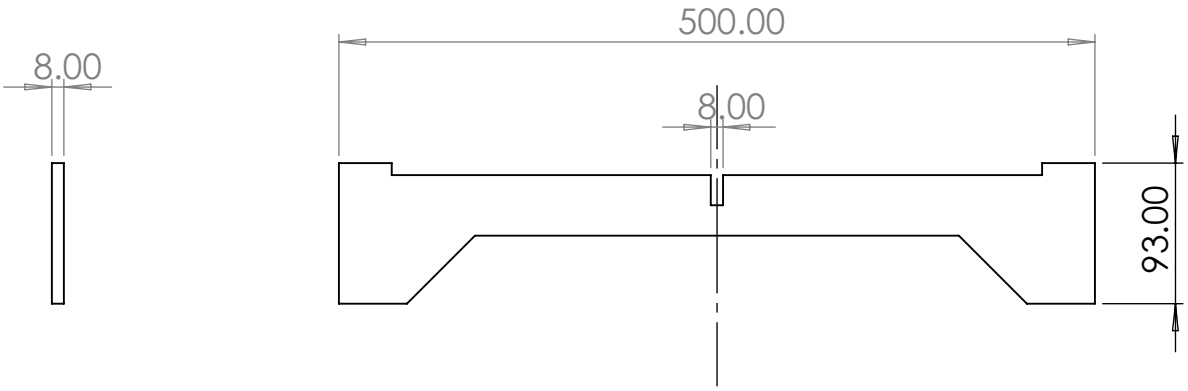


University YAHIA Fares of MEDEA		
DESIGN N°15	**Main support**	GROUP: 01
M2 MT		Scale 1:10
12/05/2024	MAMI Yacine	





University YAHIA Fares of MEDEA		
DESIGN Nº 16	**Central support**	GROUP: 01
M2 MT		Scale 1:5
12/05/2024	MAMI Yacine	



University YAHIA Fares of MEDEA		
DESIGN N°17	**Side support**	GROUP: 01
M2 MT		Scale 1:5
12/05/2024	MAMI Yacine	