PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA

MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH

UNIVERSITY YAHIA FARES OF MEDEA



Faculty of Technology

Department of Mechanical Engineering

Master's dissertation

Field: Electromechanics

Option: Electromechanics

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Theme

Design of an Automatic Machine for Cutting Long Rods

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June 2025

ACKNOWLEDGMENTS

First of all, I thank God for guiding me to the path of light and knowledge, and for giving me the courage and determination to complete this work. I would like to express my deep gratitude to my parents for their constant support and sacrifices.

I sincerely thank my supervisor

Dr. OULD CHERCHALI Noureddine

for their guidance and follow-up throughout the work.

My thanks also go to all the teachers of the Institute of Electromechanical Engineering who contributed to my academic training. May all those who supported and helped me, whether closely or from a distance, find here the expression of my heartfelt and sincere appreciation — especially my family and friends.

DEDICATON

*I dedicate this work, with deep love and respect, to my dear **parents**, whose endless support, sacrifices, and prayers have shaped the person I am today especially to **my beloved mother**, the symbol of patience and strength in my life.*

To my family, who stood by me through every challenge and moment of doubt.

to my loyal friends who walked with me on this journey particularly:

"Abderrahmane MAZARI- Abderrahmane ZEMIR,"

"Abdelali SAADAOUI - Abdelhak ETTAHRI "

"Akram DJERRAR."

and all my other dear friends — thank you for your encouragement and companionship.

Finally, I extend this dedication to all the teachers who have guided and inspired me throughout my entire academic life.

Chebeli Zakaria ... 

ملخص:

يركز هذا المشروع على تصميم آلة قطع أوتوماتيكية. وتتمثل وظيفتها الأساسية في تنفيذ عمليات قطع دقيقة ومتكررة على القضبان الطويلة دون تدخل يدوي. تعمل الآلة على تحسين السلامة، تقليل الهدر، وزيادة الإنتاجية في البيئات الصناعية.

الكلمات المفتاحية:

تصميم، آلة قطع أوتوماتيكية، قطع دقيقة، القضبان الطويلة، الإنتاجية، البيئات الصناعية.

Résumé :

Ce projet porte sur la conception d'une machine de découpe automatique. Son rôle principal est d’effectuer des coupes précises et répétitives sur des barres longues sans intervention humaine. La machine améliore la sécurité, réduit le gaspillage et augmente la productivité dans les applications industrielles.

Mots-clés:

Conception, Machine de Découpe Automatique, Coupes Précises, Barres Longues, Productivité, Applications Industrielles.

Abstract:

This project focuses on the design of an automatic cutting machine. Its main role is to perform accurate and repetitive cuts on long rods without human effort. The machine improves safety, reduces waste, and increases productivity in industrial applications.

Keywords:

Design, Automatic Cutting Machine, Accurate Cuts, Long Rods, Productivity, Industrial Applications.

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List of Abbreviations

ATB	Aluminum T-slot Base
CAD	Computer-Aided Design
CNC	Computer Numerical Control
GND	Ground
GT2	2 mm Pitch Timing Belt
HDPE	High-Density Polyethylene
HMI	Human-Machine Interface
HTD	High Torque Drive
IDE	Integrated Development Environment
I2C	Inter-Integrated Circuit
IP	Ingress Protection
IP67	Ingress Protection: Dust-tight, Protected Against Immersion up to 1 m
IS015552	International Standard for Automatic Identification and Data Capture
ISO 21287	International Standard for Pneumatic Cylinders - Compact Design
LCD	Liquid Crystal Display
MDF	Medium Density Fiberboard
NPN	Negative-Positive-Negative
PET	Polyethylene Terephthalate
PLC	Programmable Logic Controller
PPR	Polypropylene Random Copolymer
PVC	Polyvinyl Chloride
SCL	Serial Clock Line
SDA	Serial Data Line
T5	5 mm Pitch Timing Belt

TCG Transparent Conductive Glass

TCT Tungsten Carbide Tipped

TTL Transistor-Transistor Logic

VCC Voltage at the Common Collector

General Introduction

The process of cutting long bars such as metal rods, pipes is a fundamental operation in industries [1]. Despite its importance, this process has historically relied on manual labor or semi-automated machinery, which comes with significant drawbacks [2]. Manual cutting, for instance, is highly dependent on the skill and attention of the operator, leading to inconsistencies in cut length, angles, and overall quality [2] [3]. Even semi-automated systems, while an improvement, often fall short in terms of speed, precision, and adaptability to different materials or bar dimensions [1] [3] .These inefficiencies result in increased material waste, higher production costs, and longer lead times [4]. Additionally, the physical demands of manual cutting pose safety risks to workers. As industries continue to demand higher precision, faster turnaround times, and cost-effective solutions. This project seeks to address these challenges by developing a fully automated machine capable of delivering consistent high-quality cuts while minimizing waste and operational risks.

Chapter I –This chapter presents a comprehensive review of existing literature related to cutting machines and industrial automation. It explores the classification of cutting systems, common cutting methods, materials used in cutting, and the main components of automation systems including sensors, controllers, and HMIs. Additionally, it highlights the limitations of manual cutting methods and outlines technological solutions.

Chapter II –This chapter outlines the conceptual and technical design of the proposed automatic cutting machine. It includes a general description of the system, a comparative analysis between manual and automated cutting, preliminary sketches, technical specifications, and an operational flowchart that defines the system’s workflow.

Chapter III –This chapter focuses on the virtual assembly and simulation of the machine using specialized software. It presents the 3D mechanical model, key structural and functional mechanisms, electrical circuit design, and control system logic. The chapter concludes with simulation results that validate the system's operation and performance.

Chapter I

Literature

Review

I. Literature review

I.1 Introduction

Cutting processes are fundamental in modern manufacturing, enabling the transformation of raw materials into accurate components used across various sectors including automotive, aerospace, and electronics [2].

The efficiency, accuracy, and versatility of cutting processes directly influence product quality, production speed, and cost-effectiveness. With advancements in automation and computer-aided manufacturing, cutting machines have evolved to meet the demands of high-precision engineering, reduced material waste, and enhanced operational safety.

The selection of a cutting machine type is an important factor to consider when planning a successful machining operation [6].

I.2 Overview of Cutting Machines

I.2.1 Classification of Cutting Systems

Cutting machines used in industrial manufacturing can be broadly classified into three main categories based on the degree of automation involved in their operation.

a-Manual Cutting Machines:

- Operated entirely by hand.
- The operator controls cutting speed, feed, and positioning.

b-Semi-Automated Cutting Machines:

- Combine manual setup with powered or assisted cutting functions.
- Some processes are automatic, Hydraulic or pneumatic clamps Automatically hold the material during cutting.

c-Fully Automated Cutting Machines:

- Controlled by CNC or computer systems.
- Perform cutting operations with high precision and minimal human input.

I.2.2 Cutting Methods and Machine Types

Cutting processes can be categorized into two distinct a:

I.2.2.1 Traditional (Mechanical) Cutting Methods

Traditional cutting processes represent the foundation of material removal in manufacturing, relying on direct mechanical interaction between a cutting tool and workpiece. These methods, including turning, milling, drilling, and sawing, operate through shear deformation where a hardened tool physically contacts and removes material in the form of chips. Common machines used in these operations include [7].

1-Lathe machine:

A lathe is a machine tool that rotates a workpiece about an axis of rotation to perform various operations such as cutting, sanding, knurling, drilling, deformation, facing, threading and turning, with tools that are applied to the workpiece to create an object with symmetry about that axis [8].

The Figure I-1 is shown below [9].



Figure I-1: Lathe Cutting

2-Bandsaw machine:

They are of two types:

a-Horizontal band saw machine:

A horizontal band saw uses a thin, flexible, continuous steel strip with cutting teeth on one edge. Horizontal band saws are used primarily for cutting metal stock, such as angle iron and other round and flat stock. The blade runs horizontally on two pulleys through two separate guides. The operator secures the stock on the table and manually assists the saw as it cuts [10]. The Figure I-2 is shown below [11].



Figure I-2: Horizontal bandsaw machine

b-Vertical band saw machine:

A vertical band saw uses a thin, flexible, continuous steel strips with cutting teeth on one edge. It is a versatile saw used to cut both wood and metal stock and also to cut and trim meat. The blade runs on two pulleys, driver and idler, and through a work table where material is fed manually [10] . The Figure I-3 is shown below [12].



Figure I-3: Vertical band saw machine

Miter saw machine:

A miter saw is a power tool used to make precise crosscuts and angled cuts, especially in framing, shaping and decorative work. It consists of a circular blade mounted on a rotating arm, which can be set at different angles, allowing the user to cut at different degrees. The cutting process is done by manually lowering the rotary saw handle, with the piece to be cut pre-installed, then returning the handle to its original position after ensuring the cut is complete. often equipped with a fence to help guide the material [13].

The Figure I-4 is shown below [11].



Figure I-4: Miter saw machine

I.2.2.2 Non-Traditional (Advanced) Cutting methods

Non-traditional cutting machines use methods beyond conventional blade-based machining, relying instead on alternative energy forms such as thermal, electrical, chemical, or abrasive energy to remove material. Processes such as laser cutting, plasma cutting, and waterjet cutting are particularly suitable for hard, brittle, or complex materials. These technologies offer high precision, minimal thermal distortion, and reduced mechanical stress on the workpiece. In modern manufacturing, these systems are often integrated with fully automated CNC or robotic platforms, allowing for complex geometries, rapid operation, and minimal human intervention making them ideal for high-volume, precision driven industries [14].Common machines used in these operations include.

1-Plasma Cutting Machine:

Plasma cutting is a unique technique used to cut through any type of electrically conductive metal. it works by using electrically ionized and superheated gas to cut through conductive metal. The jet of gas is so hot that it can reach temperatures of more than 20,000°C [15].

The figure I-5 is shown below [16].

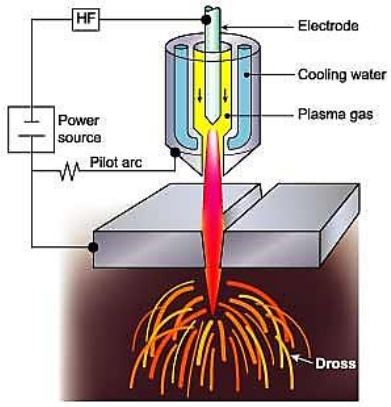


Figure I-5 : Schematic diagram of method plasma cutting machine

2-Laser cutting machine:

Laser cutting machine utilizes a high-power, focused laser beam guided by CNC systems to precisely cut materials through melting, burning, or vaporization. The laser beam is generated by stimulating lasing materials (via electrical discharges or lamps) in a sealed chamber, where internal reflections amplify the energy until it emits as a concentrated, monochromatic light beam. Optics or fiber optics focus the beam to a spot as small as 0.10 mm, enabling extremely fine cuts [17]. The figure I-6 is shown below [18]

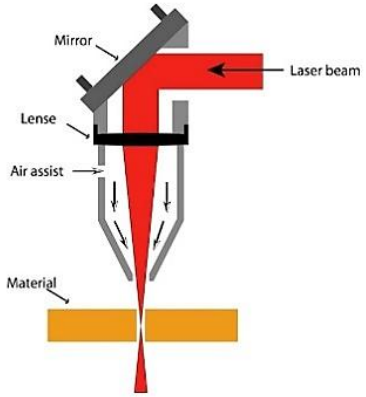


Figure I-6 : Schematic diagram of CO2 laser

3-Water jet cutter machine:

A Water jet cutter is an industrial tool able to cut lots of materials using a high-pressure jet of water mixed with an abrasive substance. When a waterjet uses a mixture of water and abrasives, it can be called abrasive jet, if the waterjet does not use abrasives, the term of pure waterjet or water-only cutting can be used. Pure waterjet (or water-only cutting) is used for wood or rubber, because they cannot cut hard materials.

The figure I-7 is shown below [19].

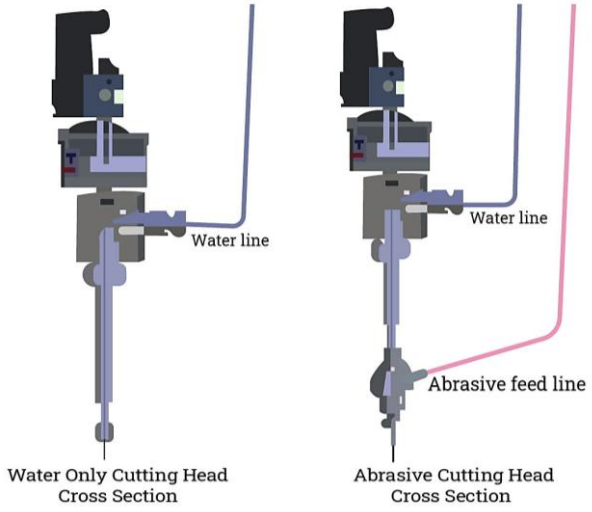


Figure I-7:Tool of water-only and abrasive waterjet cutting

Waterjets are able to cut hard materials by pressurizing water to ultra-high pressures and creating a powerful cutting stream (up to 6000 bars). The stream moves at a velocity of up to three times the speed of sound. When this high-speed water is focused on a precise point, it can cut nearly everything [19].

I.3 Main Materials for Longitudinal Cutting in Industry

In industry, longitudinal cutting also known as slitting is widely used to divide materials into narrower strips or segments along their length. This process is essential in sectors such as metal fabrication, woodworking, textiles, and packaging. Below are the most commonly used materials that undergo longitudinal cutting. The figure I-8 is shown below [19].

The following table presents typical materials commonly used in longitudinal cutting processes across various industries:

Table I-1:Materials for Longitudinal Cutting in Industry

Material Type	Examples	Common Cutting Methods
Metals	Steel, Aluminum, Copper, Brass	Rotary shears, laser/plasma cutting, slitting lines
Plastics/Polymers	PVC sheets, PET films, Polycarbonate, HDPE	Rotary knives, thermal cutters, high-speed blades
Wood Panels	Plywood, MDF, Laminated boards	Circular saws, CNC routers, automatic saw lines
Paper/Cardboard	Printing paper, Kraft paper, Corrugated board	Razor slitting, shear cutting, rewinding machines



Figure I-8:Types of Materials commonly used in longitudinal cutting processes

I.4 Principles of industrial automation

The term automation was coined in the automobile industry about 1946 to describe the increased use of automatic devices and controls in mechanized production lines. The origin of the word is attributed to D.S. Harder, an engineering manager at the Ford Motor Company at the time [20].

I.4.1 Industrial Automation

Definition: Industrial automation refers to the use of advanced technologies, such as robotics, computer systems, and electrical control systems, to operate and control industrial processes and machinery. It involves the integration of various components to automate tasks that were previously performed by humans, thereby increasing efficiency, productivity, and safety [21].

I.4.2 Basic Components of Industrial Automation Systems

Industrial automation relies on the seamless interaction between sensors, controllers **(**PLC**),** and actuators. These elements interact within a structure sequence known as Closed Loop Control System. These elements enable machines to monitor, decide, and act with precision.

I.4.2.1 Closed Loop Control System

a-Definition: A closed-loop control system is a type of control system in which the controlling action shows dependency on the generated output of the system. In simple words, in these systems, the output of the system controls the input applied to the system [22].

The figure I-9 is shown below.

The objective of a closed-loop control system is to enhance the system's stability, accuracy, and overall performance.

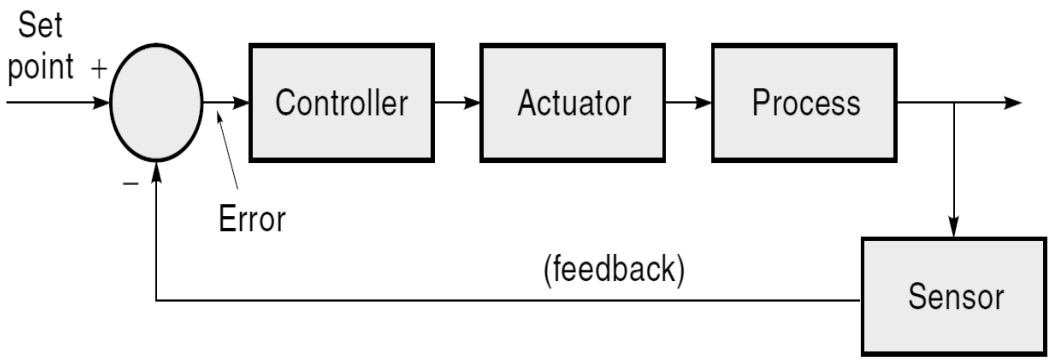


Figure I-9:Closed Loop Control System Block Diagram

b-Advantages:

The advantages of the closed loop control system include the following.

- These systems are very precise & less error-prone.
- Errors can be corrected through the feedback signal.
- High bandwidth.

c-Disadvantages:

The disadvantages of the closed loop control system include the following.

- The designing of this system is complicated.

- Huge maintenance is needed.
- The control system oscillates sometimes due to feedback signals.

I.4.2.2 Sensors

They are the bridge between the physical world and electronic systems, allowing for the automation and digitalization of various processes.

a-Definition*:* sensor is a transducer that converts a physical, biological or chemical parameter into an electrical signal, for example: temperature, pressure, flow, or vibration sensor [23].

b-Classification of Sensors:

All sensors may be of two kinds: passive and active**.**

- **The passive sensor** does not need any additional energy source and directly generates an electric signal in response to an external stimulus; that is, the input stimulus energy is converted by the sensor into the output signal [24].
- **The active sensors** require external power for their operation, which is called an excitation signal. That signal is modified by the sensor to produce the output signal [24].

c-The types of sensors:

There are various types of sensors, some of which are mass-produced and readily available. The common types of sensors:

- **Position sensors:** can measure the movement of an object or its position relative to a reference point.
- **Pressure sensors:** are essential for monitoring pressure changes in fluids or gases, ensuring safe and efficient operations.
- **Flow sensors:** are crucial for measuring the flow rate of fluids or gases within a system, optimizing throughput, and reducing downtime.
- **Temperature sensors:** measure and monitor temperature variations within manufacturing processes.
- **Force sensors:** detect mechanical forces such as tension, weight, and compression.
- **Proximity sensors:** are key to detecting the presence or absence of an object without physical contact.

- **Level sensors:** keep track of liquid or solid material levels within containers or vessels.

The figure I-10 is shown below [25].



Figure I-10: The types of sensors

d-Criteria for selection:

Choosing the right sensor is critical to control system design. are a few features to be factored in during selection.

- **Sensitivity:** Ability to detect minute changes in the environment.
- **Range:** The span of environmental change a sensor can detect.
- **Accuracy:** The degree to which the sensor's measurement corresponds to the actual value.
- **Response Time:** How quickly a sensor reacts to a change in the environment.

I.4.2.3 Programmable Logic Controller

a-Definition: A Programmable Logic Controller (PLC) is a specialized microprocessor-based system that utilizes programmable memory to store user-defined instructions for executing functions such as logic operations, sequencing, timing, counting, and arithmetic. PLC are primarily used to control machinery and industrial processes and are typically designed for ease of use by engineers with minimal programming background [26].

1--History of PLC:

In 1968, the invention of the first Programmable Logic Controller (PLC) marked a major turning point in the automation industry. Initially developed to meet the automotive industry's need for flexible and reliable control systems, General Motors began implementing PLCs in its production lines as early as 1969. Since then, PLCs have become the standard control system across a wide range of manufacturing industries [27].

2--PLC Components:

The basic hardware components that make up a PLC are:

The figure I-12 is shown below [28].

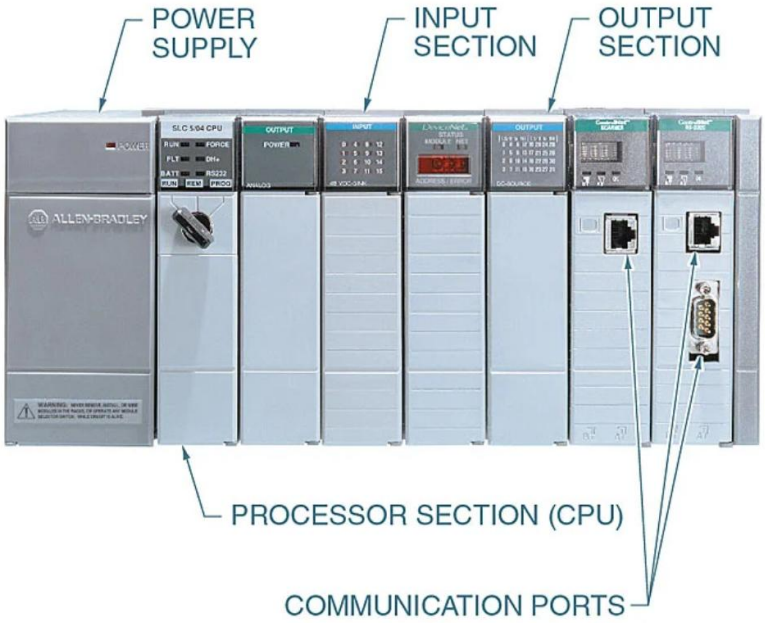


Figure I-11:Programmable logic control

a-Central Processing Unit: is the processing unit of the PLC. CPU module generally lives in the slot beside the power supply. These modules mainly consist of microprocessor, memory chip and other integrated circuits to control logic, monitoring and communications [29].

b-Input Modules: These modules act as interface in between real-time status of sensors and the CPU. They are basically encoder to the CPU [29] .

- **Analog input module**
- **Digital input module**

- **Discrete input/ Digital Input*:*** discrete input, is an input that has two functions ON or OFF that are attached to the PLC. In high condition it is referred to as logic 1 and in the low condition maybe referred to as logic 0.

c-Output Modules: The output singleton act as bridge in between the output devices and processing unit. They are basically decoders [29].

- **Analog output module**: Example: Control faucet, Speed trembling.
- **Digital output module:** Example: Solenoid faucet, alert light.

d- Power Supply: The power source provides the required voltage level for electronic equipment the PLC from the line supply to the PLC [29].

e- communication interface: in a PLC allows the controller to exchange data with external devices and systems using standardized protocols like Modbus, Profibus, or Ethernet/IP [29].

3-Criteria for selection:

To determine the most suitable PLC to be used in the automation task, there are several basic considerations to be made:

- Necessary input/output capacity.
- Types of I/O required.
- Size of memory required.
- Speed and power required of the CPU and instruction set.

I.4.2.4 Actuators

a-Definition: Actuators are mechanical or electro-mechanical devices that generate controlled motion or positioning, operating through electrical, manual, pneumatic, or hydraulic power sources. They primarily produce two types of motion: linear and rotary [30].

The figure I-13 is shown below.

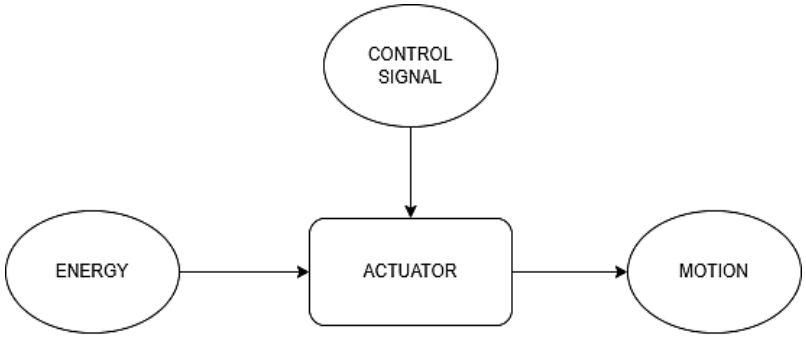


Figure I-12: Diagram of Actuators

b-Types of Actuators:

Actuators can be categorized into several types based on their principle of operation. Here are some common types of actuators:

- **Electrical Actuators:**

Electric actuators are powered by electricity and typically use DC motors, stepper motors, or servo motors to generate motion. These actuators offer high precision, excellent control, and low maintenance requirements [31]. The figure I-14 is shown below [32].

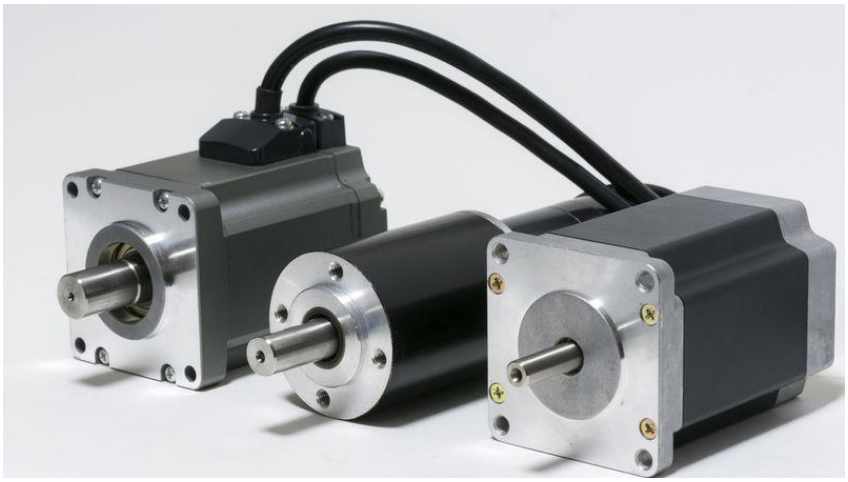


Figure I-13:Electric Motors (AC Servo Motor, DC Brushless Motor, Stepper Motor)

- **Hydraulic Actuators:**

Hydraulic actuators use fluid pressure to generate motion. Hydraulic actuators offer high levels of force, durability, and reliability [33]. The figure I-15 is shown below [12].



Figure I-14:Hydraulic Cylinder

- **Pneumatic Actuators:**

Pneumatic actuators use compressed air to generate motion. They are commonly found in fast-moving automation environments, where speed and repeatability are paramount [33]**.** The figure I-16 is shown below [12].



Figure I-15:Pneumatic cylinder

I.5 Human Machine Interface

Human Machine Interface, often known by the acronym HMI, refers to a dashboard or screen used to control machinery. Line operators, managers and supervisors in industry rely on HMI to translate complex data into useful information [34].
The figure I-17 is shown below [35].



Figure I-16: HMI Display

I.5.1 History of the HMI

HMI products were originally designed to meet the need for easily operational machinery, while producing optimal outputs. Predecessors of the HMI include the Batch Interface (1945-1968), Command-Line User Interface (1969-Present), and the Graphical User Interface (1981-Present) [35].

I.5.2 Operating Principles of Human-Machine Interfaces

HMI are typically used in conjunction with a PLC to monitor and control processes in an automated system. In general terms, the HMI allows the user to communicate with the PLC via a graphical interface (typically a touchscreen). This interface allows commands to be given, and also receives and translates feedback data from the PLC, which is then presented in an easily accessible visualization on the screen [35].

I.6 Limitations of Traditional Manual Cutting Machines

Traditional cutting methods, particularly manual operations, have long been used in various industries due to their simplicity and low initial cost. However, they present several significant limitations in modern manufacturing environments [36].

- High dependency on operator skill and fatigue.
- Increased material waste and processing time.
- Greater risk of operator injury.
- Limited repeatability for large production volumes.

I.6.1 Solution to the Limitations of Manual Cutting:

To overcome the limitations of manual cutting methods, industries are increasingly turning to automated systems. The implementation of an automatic cutting machine represents a strategic shift toward smarter manufacturing. By integrating programmable control systems and user-friendly interfaces, such machines provide high-quality, repeatable results making them ideal for:

- High cutting accuracy and repeatability.
- Reduced material waste and human error.
- Faster processing time.
- Improved operator safety.

I.7 Conclusion

This chapter gave an overview of how cutting machines function, the main cutting techniques, and key elements used in industrial automation. It also pointed out the challenges of manual cutting methods, such as low precision and safety concerns. To solve these issues, automated systems provide a more effective and reliable solution. The next chapter will focus on presenting the design of an automatic cutting machine developed to improve speed, accuracy, and overall safety in the cutting process.

Chapter II

Design of the Automatic Cutting Machine

II. Design of the Automatic Cutting Machine

II.1 Introduction

In recent years, the demand for precision and efficiency in the fabrication of doors and windows has increased significantly, driven by increasing demands for high-quality finishes and efficient production workflows. Among the key processes in this sector is the cutting of long PVC bars, which serve as primary structural components. Traditionally, this operation was performed manually, leading to variability in dimensions, material waste, and risks to operator safety.

To address these challenges, the development of an automatic cutting machine dedicated to PVC profiles has become essential. The machine under study in this project is designed to automate the cutting process, ensuring high accuracy, repeatability, and operational safety. Equipped with Arduino, motorized systems, and pneumatic actuators, the machine provides an integrated and adaptable solution that meets varying production requirements to different production requirements.

This chapter provides a detailed presentation of the automatic PVC cutting machine, including its overall architecture, operating principle, and technical specifications. The objective is to offer a comprehensive understanding of the machine's design, its functionality, and its contribution to the automation of modern door and window manufacturing processes.

II.2 General Description of the Machine

The automatic PVC cutting machine is an integrated electromechanical system designed to automate the process of cutting long PVC rods into precise lengths. It is composed of four main functional sections:

1. the storage unit, responsible for storing raw PVC rods.
2. the transport system, which moves the rods to the cutting zone.
3. the cutting mechanism, driven by a circular saw and controlled pneumatic.
4. the control unit, which coordinates all operations based on user defined parameters.

II.3 Comparative Analysis of Manual and Automated Cutting System

This part shows the main differences between the traditional bar cutting machine and the improved version. It highlights the evolution from manual operation to an automated approach, showing how each stage of the process has evolved to increase efficiency and reduce human intervention.

1-Parameter Input:

In traditional cutting systems, the operator is responsible for manually measuring the length of each rod, marking the desired cutting points, and tracking the number of cuts completed using physical indicators or basic counters. This process is prone to human error and inefficiency. The figure II-1 is shown below[63].



Figure II-1:Manually measuring the length

In contrast, the automated system uses an HMI where the operator enters the total rod length, desired cut length, and number of pieces. This digital setup minimizes errors, ensures repeatability, and significantly reduces setup time.

2-Rod Loading:

Traditionally, rods are manually placed on the cutting table one by one, requiring constant handling by the operator. The figure II-2 is shown below[63].



Figure II-2: Place the rods manually on the cutting table

In the improved system, PVC rods are preloaded into a storage box and pushing system move the rod into the transfer zone without operator intervention, ensuring a smooth and secure positioning of the material

3-Rod Advancement:

In conventional manual machines, operators must manually position and align the rod, resulting in inconsistent placement and cutting length inaccuracies. The figure II-3 is shown below[63].



Figure II-3:Manually position and align the rod.

The automated system eliminates this variability by integrating motor driven pushing mechanism with linear scale position tracking. This electromechanical advancement system

ensures precise rod displacement along the cutting table, significantly improving both reliability and cutting accuracy compared to manual operation.

4-Cutting Operation

Manual cutting involves activating the saw and manually securing the rod, usually with clamps or by hand, introducing risks of injury and inconsistency. The figure II-4 is shown below[63].



Figure II-4:Manual cutting operation.

In the automated system, two pneumatic cylinders grip the rod firmly once it reaches the desired position. A hydraulic cylinder then lowers a circular saw to perform the cut. This process is entirely automated and repeatable, improving safety, speed, and cut quality.

5-Repetition of Cuts:

Manually repositioning the rod for each cut is labor intensive.

In the improved system, the motor resumes movement after each cut, advancing the rod by the exact length needed for the next cut.

6-Rod Replacement:

traditional systems, where a new rod must be manually loaded after each one is used.

In the improved system, When first rod ends. Another is taken with the same process as the first, and thus the process remains in sequence until all the bars in the storage box are finished without operator intervention.

II.4 Preliminary Design of the Automatic Cutting Machine

The following diagrams show the initial design scheme of the automatic cutting machine, highlighting the main functional units, their spatial organization, and their dimensions in millimeters. The figure is shown below

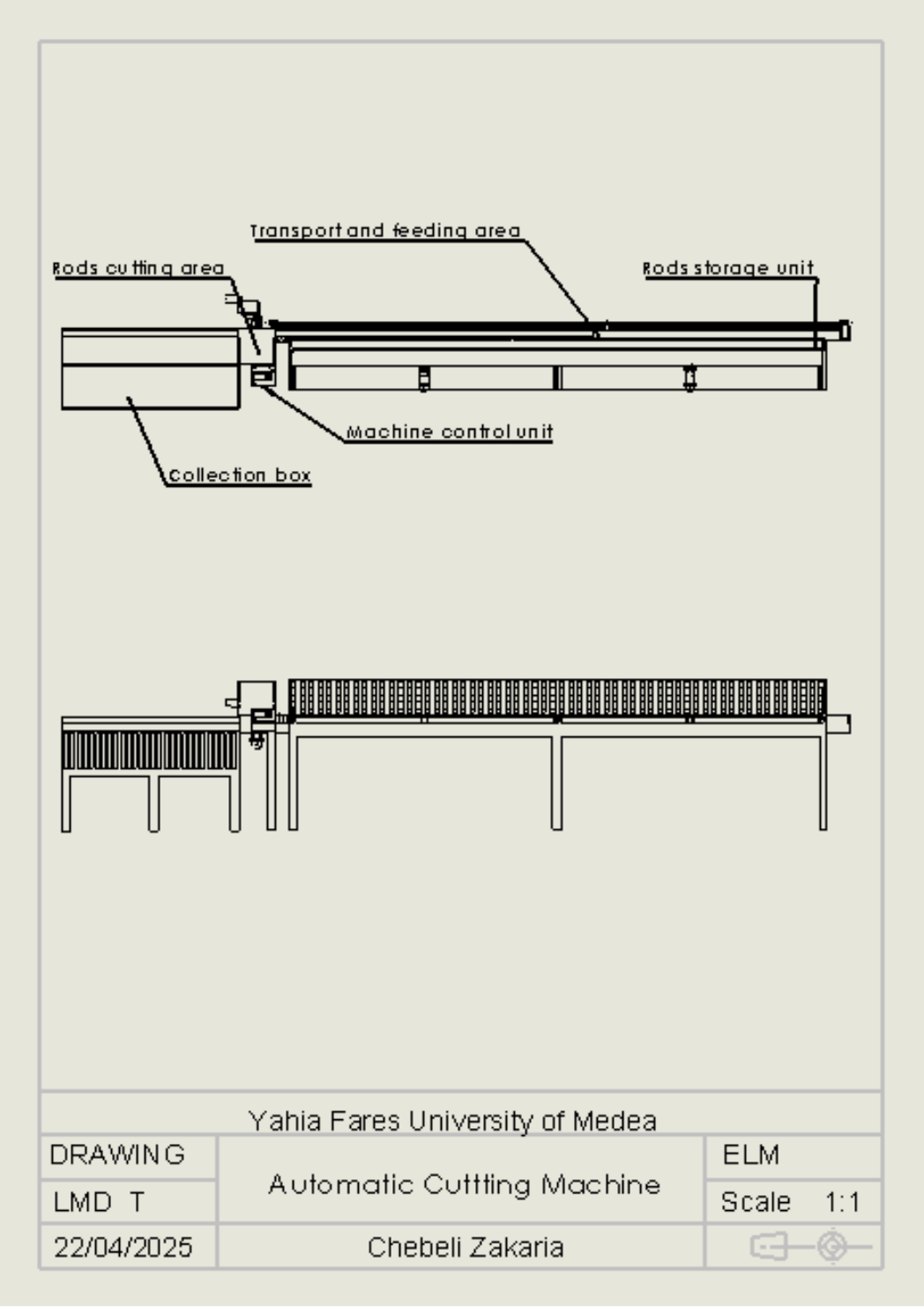


Figure II-5: 2D Design of an Automatic Cutting Machine

II.5 Technical Specifications of the Automatic PVC Cutting Machine

The following table summarizes the main technical specifications of the automatic PVC cutting machine, detailing its operating parameters, and functional capabilities.

Table II-1:Technical Specifications of the Automatic PVC Cutting Machine

Parameter	Specification
Machine Type	Automatic PVC Rod Cutting Machine
Material Type	PVC Rods
Cutting Method	Circular saw blade with pneumatic actuation
Diameter of Rods	Length Width Height (6000 into1000) × 80 × 80 mm
Maximum Input Length	Up to 6000 mm
Maximum Cut Length	2000 mm (Length of collection box)
Minimum Cut Length	200 mm (Length of cut zone)
Blade Diameter	200 mm
Blade Motor Power	Approx. 1.5 kW (220V AC)
Feeding Mechanism	Automated feeding with linear motion control
Pushing System	Mechanized push table for material transfer
Positioning System	Precision-driven linear positioning system
Clamping Mechanism	Automatic rod fixation system
Control System	Microcontroller-based control unit
User Interface	Integrated display and input interface
Sensors	Multiple position and detection sensors
Safety Features	Emergency stop and safety interlock mechanisms
Power Supply	220V AC, 50 Hz
Operating Mode	Automatic
Dimensions (L × W × H)	Length Width Height 8850 × 700 × 1700 mm

II.6 Detailed Process of the Automatic PVC Cutting Machine

1-Initial Setup and Process Steps:

Before any automatic operation begins, the operator must first load the PVC rods horizontally into the storage box, which has a height of approximately 0.5 meter. Next, the machine is powered on, and the operator uses the HMI to enter the required parameters:

- the total length of the rod.
- the desired cut length.
- the number of pieces to be produced.

Once these values are confirmed, the automated cutting sequence can begin and the saw motor is activated.

2-Loading the Rods:

A sensor at the bottom of the storage box detects when a rod is present. Upon detection, it sends a signal to the Arduino to initiate the transfer process. Two pneumatic cylinders are then activated to push the rod horizontally into the transfer zone.

Initially, the two cylinders are in their extended positions, holding the rods above the push table. When the push table is activated, it retracts, allowing the first PVC rod to fall into position. The cylinders then return to their initial (extended) positions. This return motion pushes the PVC rod into the feeding area, where it will proceed to the next stage of the operation.

3-Advancing the Rod:

After the rod enters the transfer zone, a second sensor detects its presence and sends a signal to the Arduino controller. At this point, a stepper motor is activated to push the rod precisely along the feed table. The stepper motor is connected to a timing belt mechanism that drives a rectangular pusher block, which physically moves the rod forward.

The rod advances toward the cutting zone, where an sensor detects its arrival and signals the controller to begin the precise positioning phase. The motor pauses briefly, allowing the system to stabilize, and then resumes movement. The Arduino controller tracks the distance traveled by counting the step signals from the stepper motor, ensuring accurate length

measurement. Once the predefined number of steps corresponding to the target cut length is reached, the controller immediately stops the motor, positioning the rod precisely for the cutting operation.

4-Cutting Process:

When the target length, entered via the HMI, is reached, the stepper motor stops, and the system proceeds to the cutting phase. Before the saw operates, two pneumatic clamping cylinders extend to hold the rod firmly in place, ensuring stability during the cutting process. Once the rod is securely clamped, and a pneumatic cylinder lowers the circular saw blade to perform the cut.

When the blade reaches its lowest point, a second optical sensor detects its position, signaling that the cutting operation is complete. This triggers the hydraulic cylinder to retract the blade to its original position, and the clamping cylinders also return to their initial (retracted) state. The system is then ready for the next cutting cycle.

5-Advancing for the Next Cut:

After the first piece is cut, the stepper motor begins rotating forward again, advancing the rod by a calculated distance. Each time the rod reaches the specified cutting length, the motor stops, and the cutting operation is carried out. This cycle repeats until the required number of cuts from the rod is completed.

Afterward, the motor pauses briefly, then resumes forward rotation until the rectangular pusher reaches the cutting area. When the pusher passes the first optical sensor located in the cutting zone, the sensor sends a signal to the Arduino controller to reverse the motor’s direction. The motor then rotates in reverse until the pusher returns to its initial position. This entire sequence is fully automated and controlled by the Arduino program.

6-Completion of Operation:

After the last piece of the first rod has been cut and the rectangular pusher returns to its starting position, a green indicator light turns on to signal the completion of the cutting process. At the same time, the HMI interface displays a message indicating that the first rod has been fully processed. This serves to notify the operator to collect the cut pieces, which are now assembled in the collection area, and to prepare for feeding the next rod into the system.

II.6.1 General Operation Flowchart

This Flowchart illustrates the overall process flow of the automatic PVC rod cutting system. Each main block represents a key phase of the automated sequence, starting from the initial setup to the final completion of the cutting process. The figure II-6 is shown below.

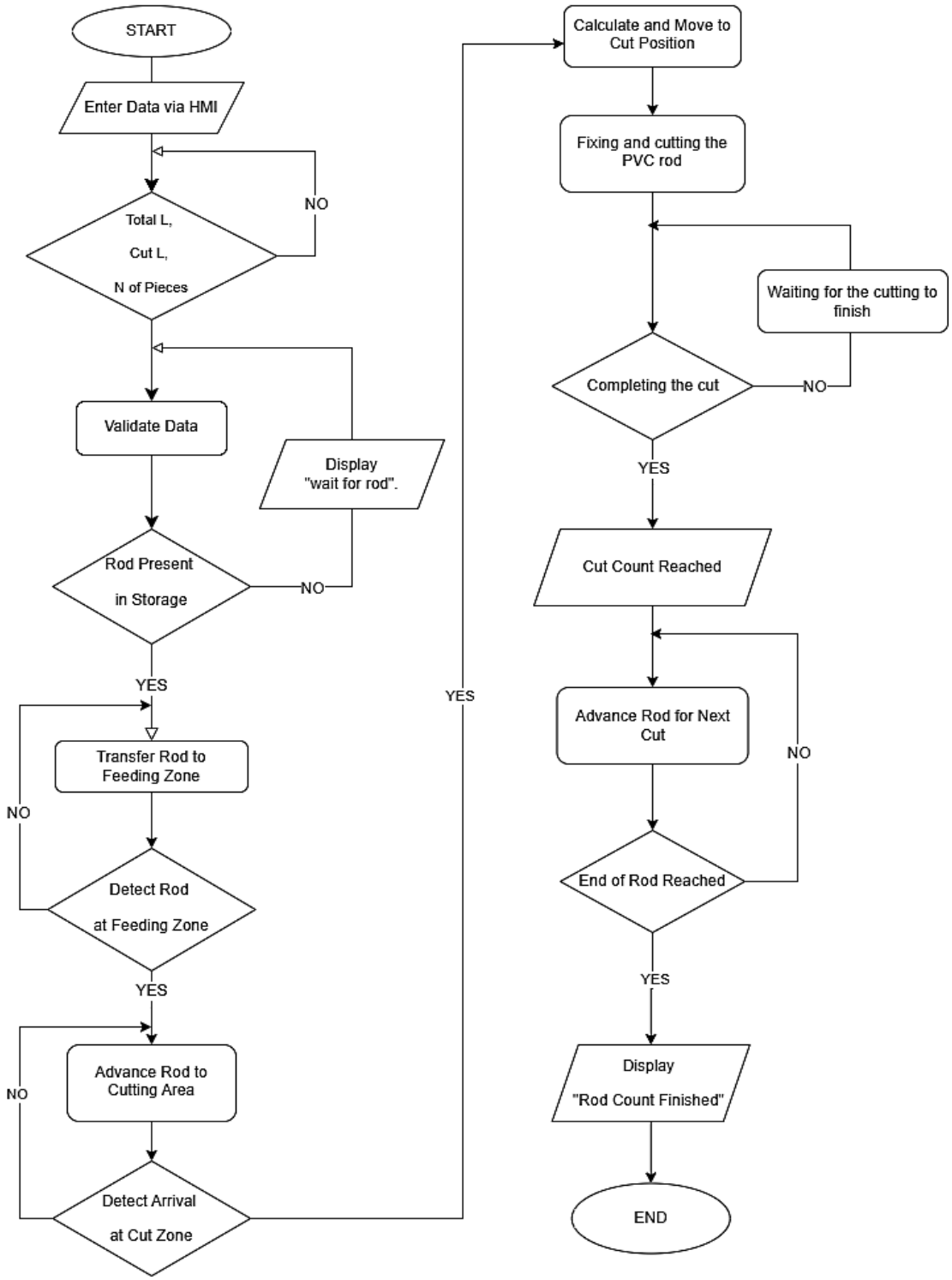


Figure II-6:General Flowchart of the Automatic PVC Rod Cutting Process.

II.7 Conclusion

The development of the automated PVC cutting machine represents a major step toward improving industrial performance. By combining precise mechanical construction, Arduino-based control, and pneumatic actuation, the system achieves high accuracy, faster operation, and improved safety. Compared to traditional manual methods, the new design minimizes human error, reduces material waste, and increases productivity. These advancements demonstrate the effectiveness of automation in modernizing cutting processes

.

Chapter III

System Assembly and Functional Simulation

III. System Assembly and Functional Simulation

III.1 Introduction

Design and simulation are essential steps in the development of any automated system. Before physical construction begins, virtual modeling allows for the verification of system functionality, identification of potential errors, and optimization of component integration. This approach reduces costs, saves time, and enhances system reliability.

In this work, the system was carefully designed across electrical, mechanical, and interface levels to meet specific functional and safety requirements. Simulation tools were then used to test control logic, sensor responses, actuator behavior, and user interactions. This process ensures that the machine will work correctly and safely during real operation.

The platforms were used to model mechanical assemblies, simulate pneumatic processes and design electronic circuits, allowing comprehensive testing and validation of the system prior to physical implementation.

III.2 Design and Simulation Software Used

1-for 3D modeling and mechanical design:

In this project, SolidWorks was utilized to model the structural and mechanical elements of the automatic rod cutting machine. The software was employed to create detailed representations of the frame, supports, and moving components, allowing for design verification prior to any physical construction.

a-Application:

- Designed the machine's structural frame.
- Simulated part assembly.
- Generated technical drawings for manufacturing.

III.2.1 SolidWorks

The SOLIDWORKS® CAD software is a mechanical design automation application that lets designers quickly sketch out ideas, experiment with features and dimensions, and produce models and detailed drawings [59].



Figure III-1: SolidWork's LOGO

Using SolidWorks significantly reduced design errors and allowed for virtual testing and measurements. This ensured that the components were accurately dimensioned and compatible with the real-world assembly [60].

2-For electronic control and simulation:

In this project, Cirkit Designer was used to design and simulate the electrical circuit of the automatic cutting machine. It helped visualize the connections between components, verify wiring accuracy, and test the logic of input and output signals before physical implementation

a-Application:

- Designing power and control circuitry for Arduino and peripheral components.
- Simulating the interaction between input sensors, control logic, and output actuators.

III.2.2 Cirkit Designer IDE

Cirkit Designer is an interactive, web-based platform designed for creating and simulating electronic circuits in an intuitive environment. It allows users to build schematics, simulate basic electronic behavior, and visualize component interactions in real time. Its user-friendly interface makes it suitable for both educational and prototyping purposes, especially when working with microcontrollers and sensor-based systems [61].



Figure III-2: Cirkit Designer IDE

Its simulation capabilities allowed us to virtually test power distribution, logic signals, timing sequences, and error-handling scenarios.

3-For simulate the pneumatic system

FluidSIM was used to simulate the pneumatic system of the automatic rod cutting machine, including cylinder movement, sensor feedback, and valve control logic. This ensured safe and functional design before actual implementation.

a-Application:

- Pneumatic cylinders for rod clamping/unclamping.
- Air pressure regulation for consistent cutting force.

III.2.3 Festo FluidSIM

Festo FluidSIM is a simulation software designed for modeling and analyzing pneumatic, hydraulic, and electrical circuits [62].



Figure III-3:FESTO's logo

III.3 Detailed Presentation of the Complete 3D Mechanical Model of the Machine:

The 3D mechanical model of the machine was developed to visualize and validate the structural design before physical construction. This model includes all key components frame, actuators, cutting unit, and material handling systems ensuring proper alignment, functionality, and integration within the defined spatial and operational constraints.

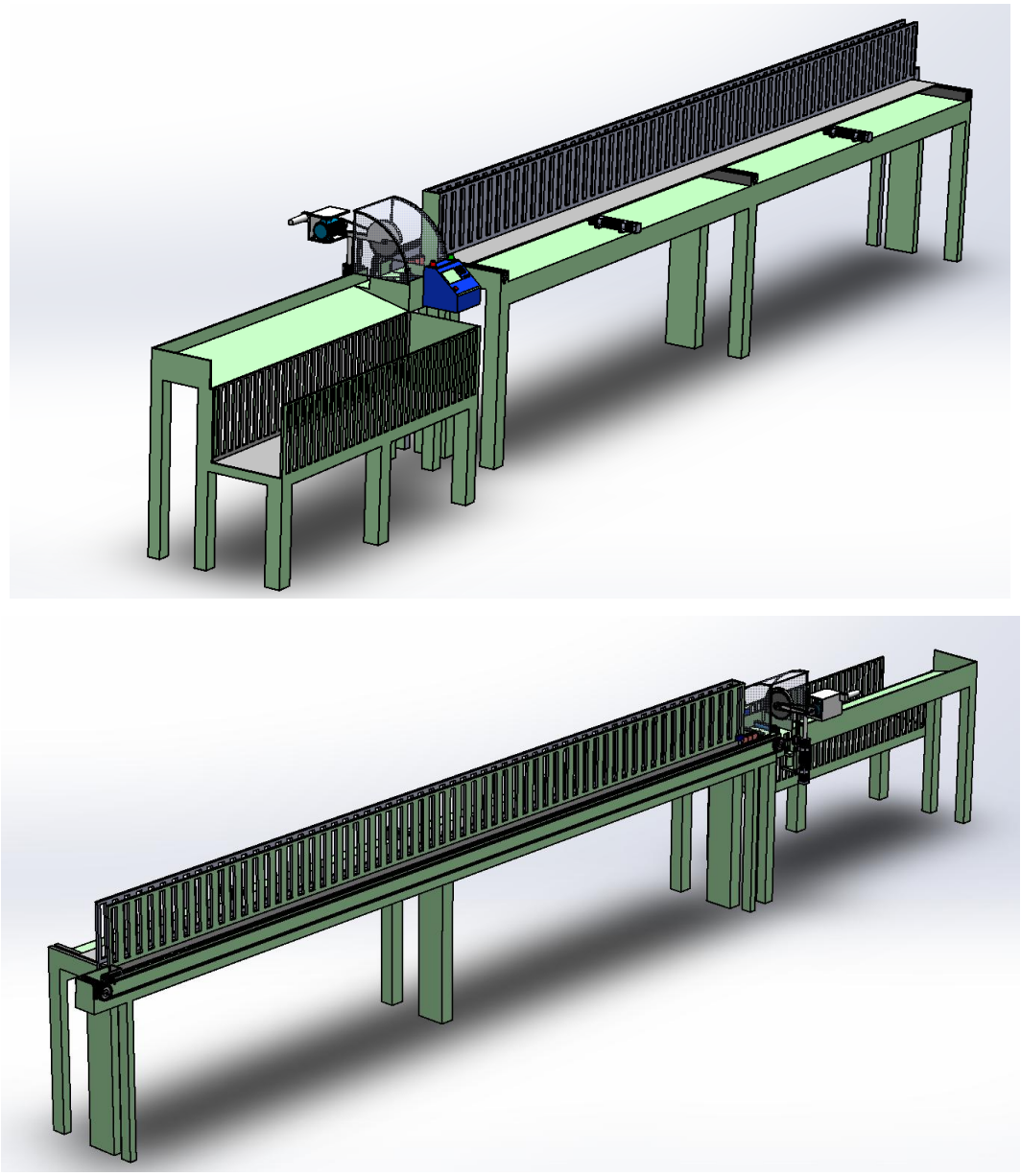


Figure III-4:Complete 3D mechanical model of the automatic cutting machine from two different viewing angles

III.4 Presentation of the Main Mechanical Components of the Machine

The following section presents the main mechanical parts of the machine, highlighting their purpose, placement, and interaction within the complete design.

III.4.1 Basic structural components of the machine

This section outlines the foundational mechanical elements that form the framework of the automatic cutting machine. These components ensure structural stability, proper alignment of moving parts, and support for the integrated functional units throughout the system.

III.4.1.1 Main Support Table

The principal table serves as the foundation of the entire machine, providing structural support and alignment for the cutting process. It is divided into three functional zones:

- **Push table area**: It takes up the largest area of the table, where the pneumatic cylinders and push table are installed together. Until we form a mechanism that pushes the bars to the transport area.
- **Storage area**: Located in the center of the table, it collects the bars, allowing for an organized output.
- **Feeding area**: This is the section where raw materials are pushed to the table, through an automated feeding system.

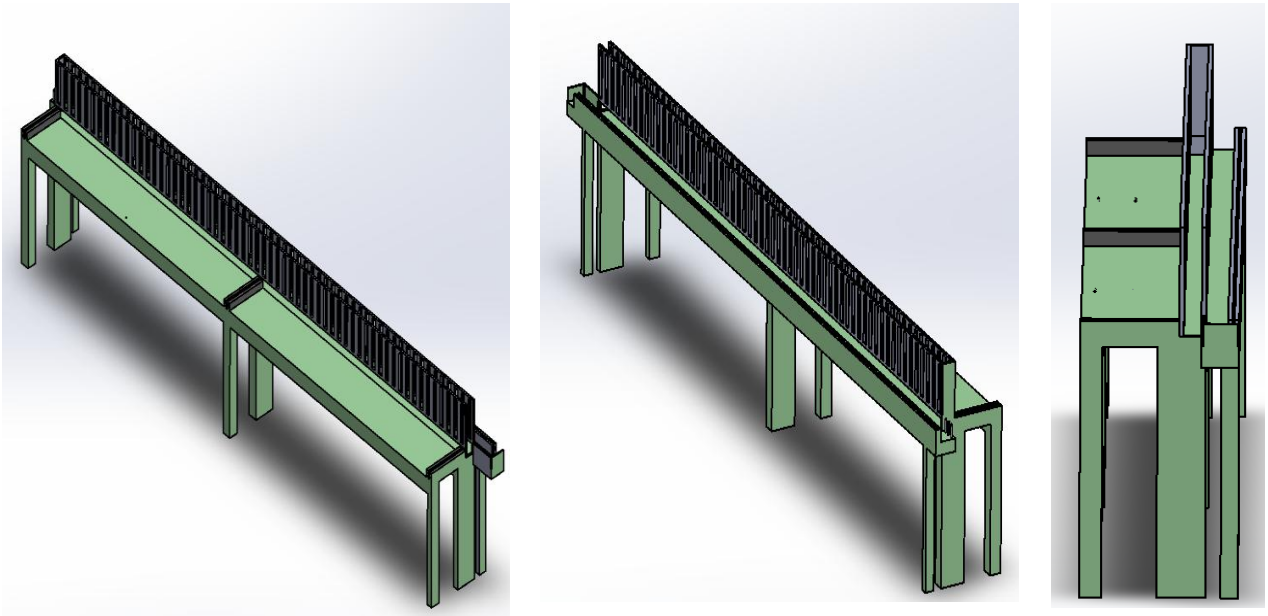


Figure III-5: Main Support Table From three different viewing angles

III.4.1.2 Cutting table

The second table integrates critical functional components, including the cutting zone, control unit, and assembly for cut pieces.

- **The cutting zone:** is securely to ensure operator safety and precise blade operation during rod cut.
- **HMI control unit**: is positioned at the front of the table, allowing the operator to input cutting parameters.
- **The assembly zone**: collects and temporarily stores the cut pieces, ensuring they are neatly arranged for easy collection.

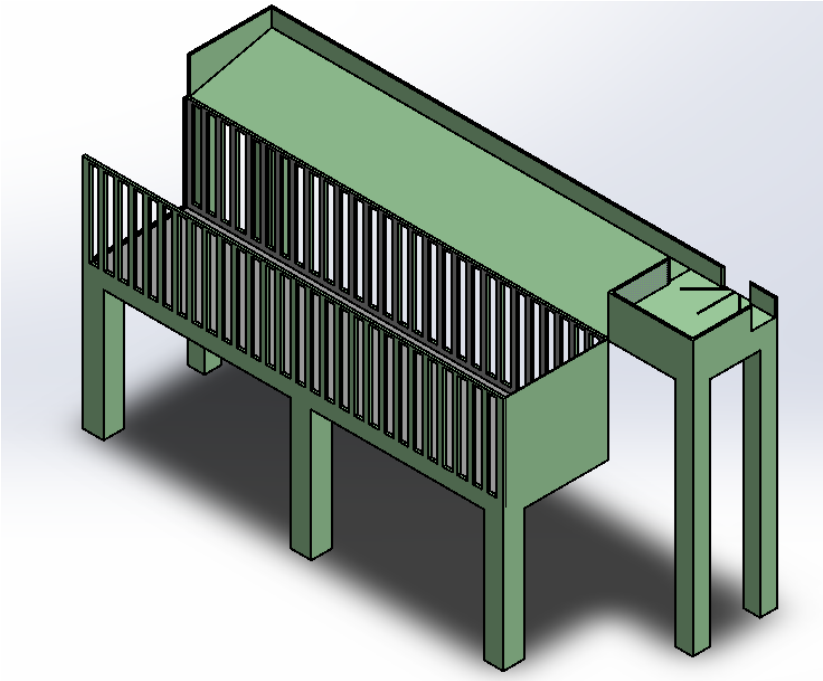


Figure III-6: Cutting table

III.4.1.3 Rod Push Table

The rod push table (Figure III - 7) is designed as a rectangular parallelogram that runs the length of the main body. It is attached to pneumatic cylinders that provide linear motion for push. The profile of the table is specially shaped to match the geometry of the rods, ensuring stable steering and precise alignment during movement. This configuration allows for smooth and precise pushing of the bars into the cutting zone, minimizing displacement errors and enhancing overall process reliability.

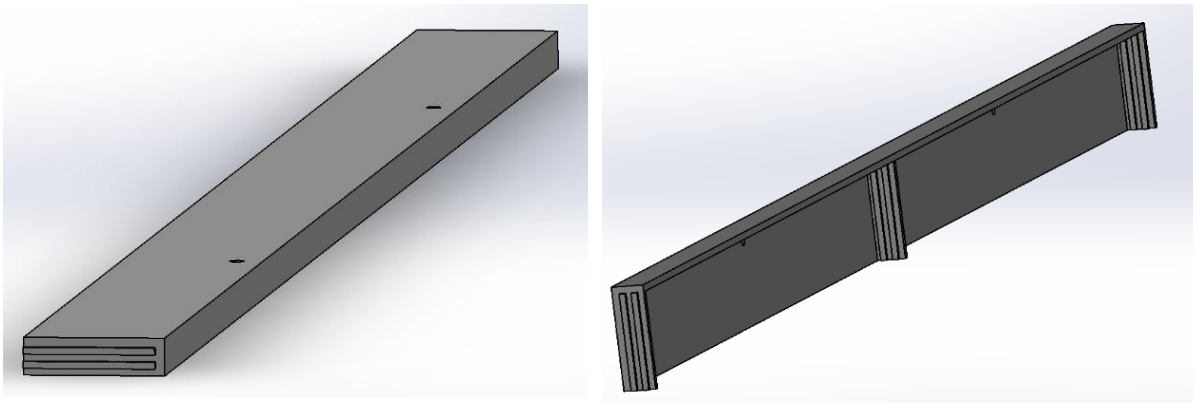


Figure III-7:Rod Push Table From two different viewing angles

III.4.1.4 Rotating mounting bracket

It is vertically installed on the cutting and control table, serving as the mounting point for the cylinder that drives the vertical movement of the saw. It incorporates a circular base, which enables controlled rotation of the entire assembly including the saw motor. This rotational function allows precise adjustment of the cutting angle to suit various material shapes and cutting requirements.

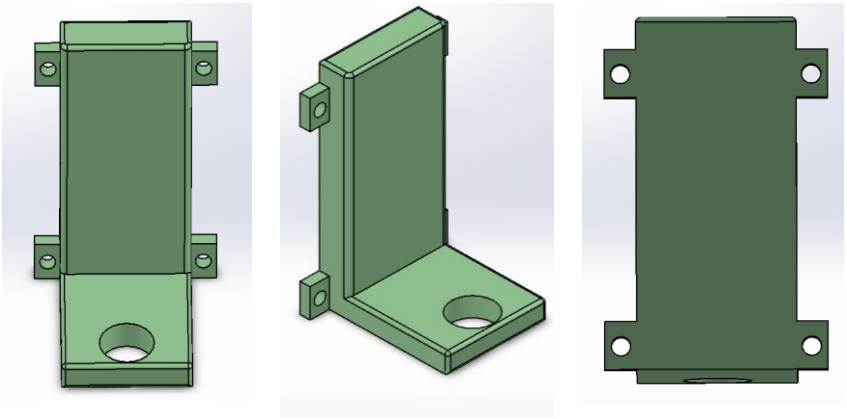


Figure III-8:Rotating mounting bracket from three different viewing angles

III.4.2 Main Functional Elements of the Machine Mechanism

This section presents the key components that ensure the proper operation of the automatic cutting machine. Each element was selected and integrated based on its role in achieving automation, precision, and safety.

III.4.2.1 Rods push Mechanism

Two double-acting pneumatic cylinders (Figure III -9) are used to push the rods into the transfer position. Both cylinders are fixed to the main table (Figure III -5), while the push table (Figure III -7) is mounted on them. This configuration ensures linear movement,

contributing to precise alignment of the rods. The force generated is sufficient to overcome friction and support the mass of long rods without slippage.

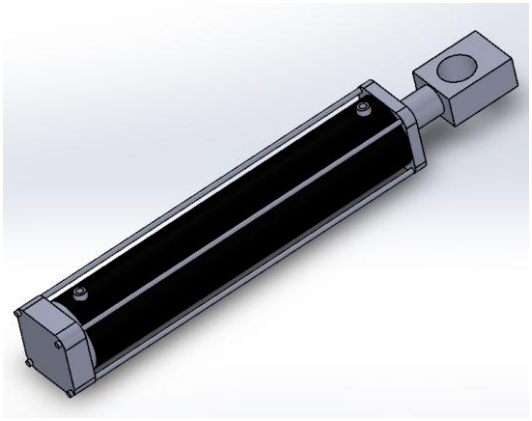
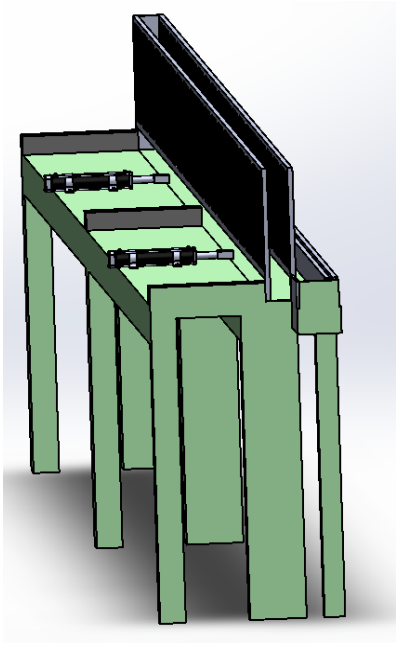
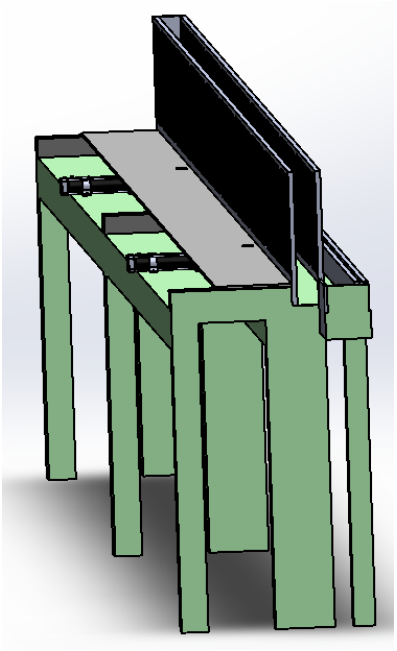


Figure III-9:Double-acting pneumatic cylinder



Installing pneumatic cylinders without a push table



Installing a push table with cylinders

Figure III-10: Installation of Cylinders and push Table in the main table

III.4.2.2 Rods Feeding Mechanism

The Rods Feeding System ensures accurate and controlled movement of the rod from the storage area to the cutting zone.

1-Stepper Motors:

Stepper motor is responsible for advancing the rod to the desired length before each cutting cycle. By interfacing with a microcontroller. the motor receives pulse trains that correspond to the required distance based on user input. Given its ability to provide incremental movement and hold position under load, the stepper motor ensures not only dimensional accuracy but also process stability during rods feeding.

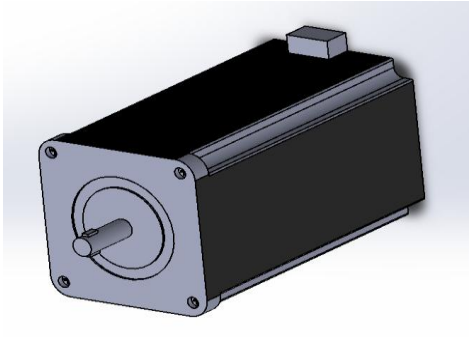


Figure III-11: NEMA 34 Stepper motor

The stepper motor is installed at the far end of the main table (Figure III -5), specifically at the corner of the transport area. This strategic placement facilitates smooth and efficient movement, allowing the rod to be pushed directly toward the cutting zone.

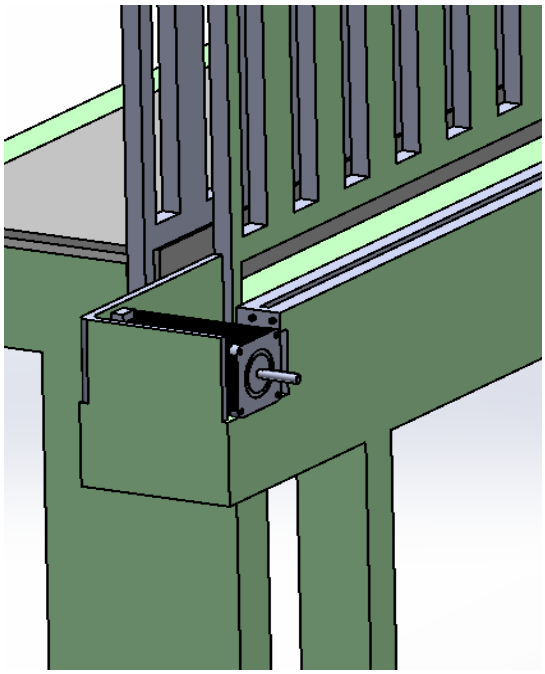


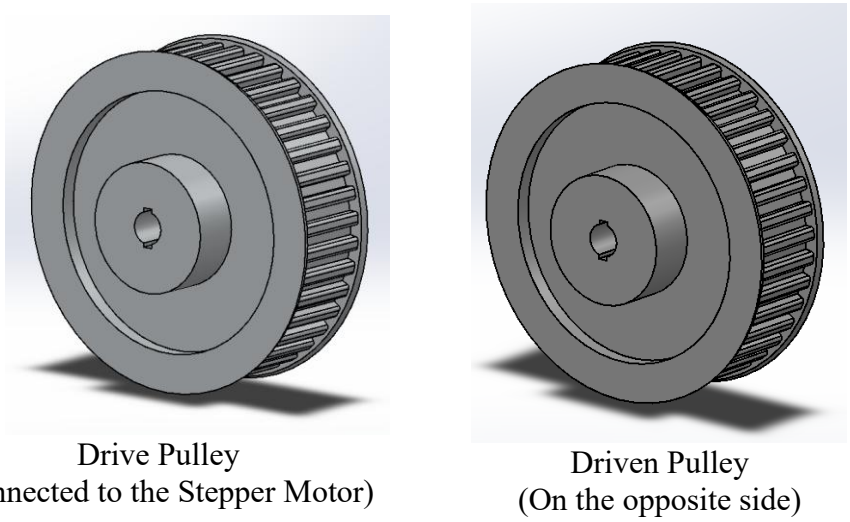
Figure III-12:Position of the stepper motor on the main

2-Synchronous Motion Transmission System:

This system is demonstrated through the following components.

a-Timing belt pulley:

The timing belt pulley plays a crucial role in the linear motion system. It is used to convert the rotary motion of the stepper motor into precise linear movement of the carriage that positions the material for cutting. The teeth of the pulley engage with the timing belt to ensure slip-free, synchronized motion, which is essential for maintaining accuracy during each cutting cycle.



Drive Pulley
(Connected to the Stepper Motor)

Driven Pulley
(On the opposite side)

Figure III-13 : GT2 Pulley Pair for Linear Drive Mechanism

b-Industrial Timing Belt:

It is a central component of the linear motion system. It is responsible for transferring the rotational motion of the stepper motor into precise linear movement along the guide rails. The belt features molded teeth that fit exactly into the grooves of the timing pulley, forming a positive engagement that eliminates slippage and ensures accurate positioning of the moving parts.

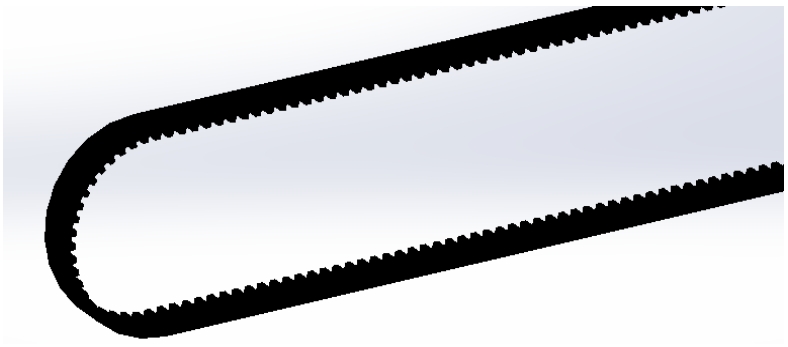


Figure III-14 : Industrial Timing Belt

c-The push piece

It is mounted on the moving part of the system and connected to the belt through a rigid bracket. As the stepper motor drives the system, rotary motion is converted into linear movement, guiding the push piece along the main axis of the machine. Its role is to smoothly and accurately push the rod from the Transport area to the cutting zone.

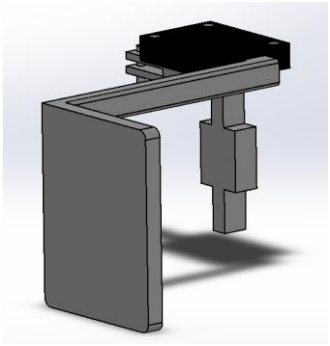


Figure III-15:The push piece

3-Complete assembly of rod feeding system components:

The motion transmission system consists of two GT2 timing pulleys (Figure III -13) connected by a GT2 timing belt (Figure III -14). One pulley is mounted on the stepper motor shaft (drive pulley), while the second pulley (driven pulley) is placed at the opposite end of the transport axis. The GT2 belt features precision-molded teeth that mesh perfectly with the grooves on the pulleys, ensuring non-slip, synchronous movement. A push piece (Figure III -15) is firmly mounted onto the belt through a fixed bracket, allowing it to move linearly along with the belt. This configuration provides accurate linear motion, essential for transporting rods with high positional accuracy toward the cutting zone.

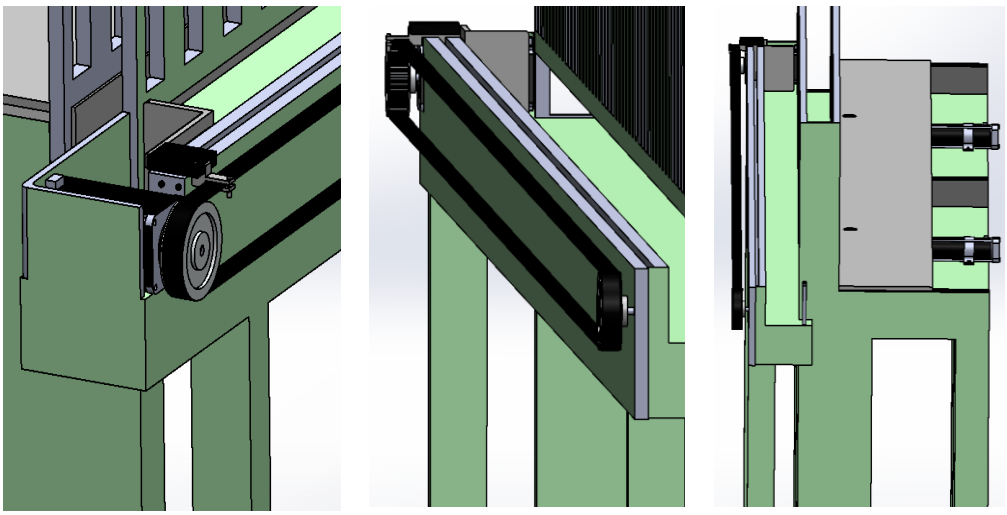


Figure III-16:Synchronous Motion Transmission System from three different viewing angles.

III.4.2.3 Rods Cutting Mechanism

1-Movement of the Cutting Mechanism:

A single-acting pneumatic cylinder (Figure III -17) is installed on a rotating bracket (Figure - III -8) that provides strong support for the saw motor. This setup allows the blade to move up and down accurately during cutting. Additionally, the rotating bracket enables the blade to tilt in both directions, allowing cuts at two different angles: 45° to the left and 45° to the right.

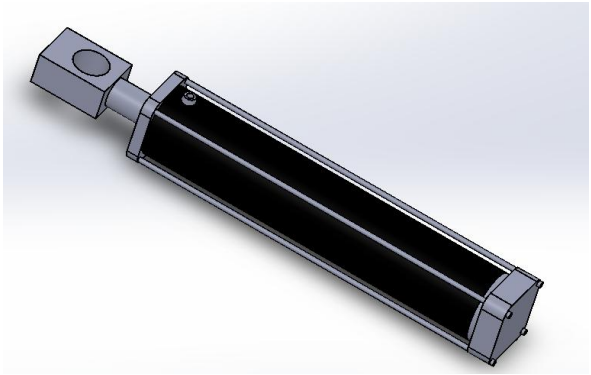
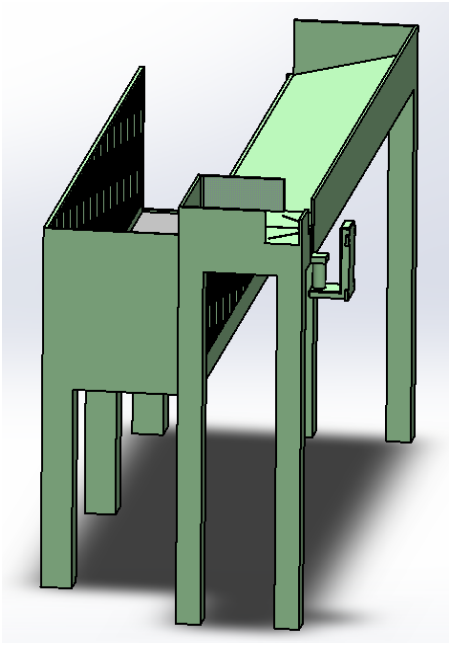
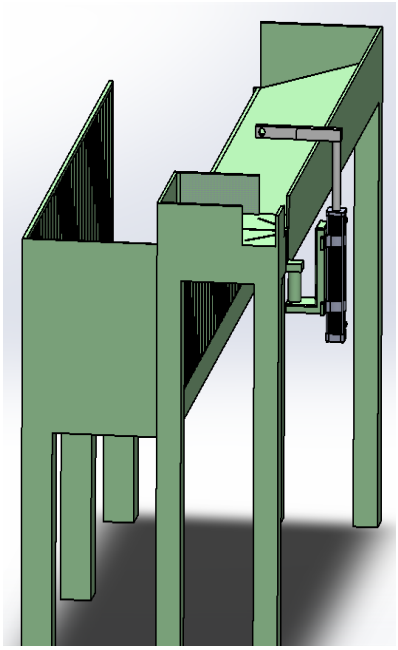


Figure III-17:Single-acting pneumatic cylinder



-Installation of the Rotating Bracket on the cutting Table (Without Pneumatic Cylinder).



Installation of the pneumatic cylinder on the Rotating Bracket.

Figure III-18:Integration of Cylinders and Rotating mounting bracket in the cutting table

2-Cutting Motion Mechanism:

This system is illustrated by the components listed below:

a-AC induction motor:

The AC induction motor is a key component responsible for driving the cutting mechanism. The motor provides the necessary rotational power to perform precise and consistent cutting operations.

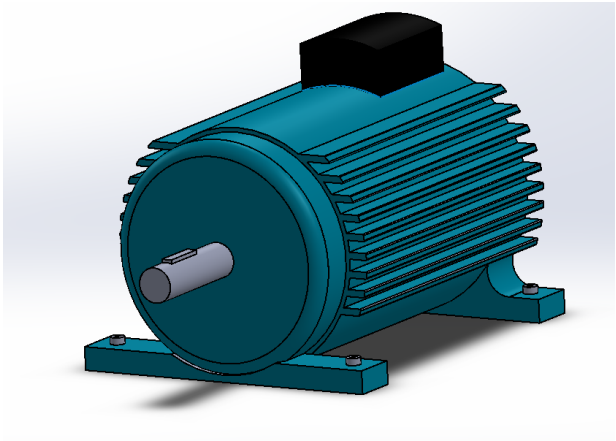
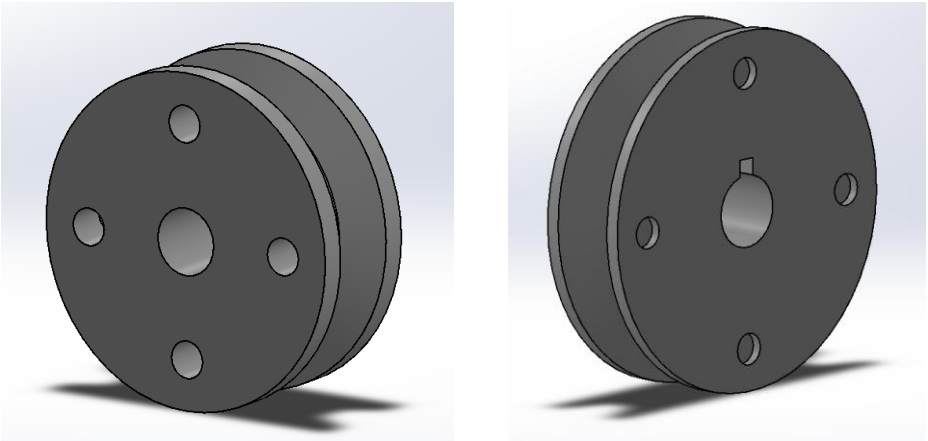


Figure III-19: AC induction motor

b-V-Belt Pulley:

The V-Belt Pulley serves as a crucial link between the AC motor and the saw blade. The pulley is mounted on the motor shaft and connected to the saw blade pulley via a belt, enabling the transfer of rotational motion from the motor to the cutting blade.



Driven Pulley
(Connected to the Saw Blade)

Drive Pulley
(Connected to the AC Motor)

Figure III-20: V-Belt Pulley Pair for Cutting Motion Mechanism

c-V-belt:

The V-belt is responsible for in transmitting power from the AC motor to the saw blade. It allows rotational motion generated by the motor to be transferred smoothly and efficiently to the cutting blade. And also helps absorb vibrations and mechanical shocks, protecting both the motor and the blade during cutting operations.

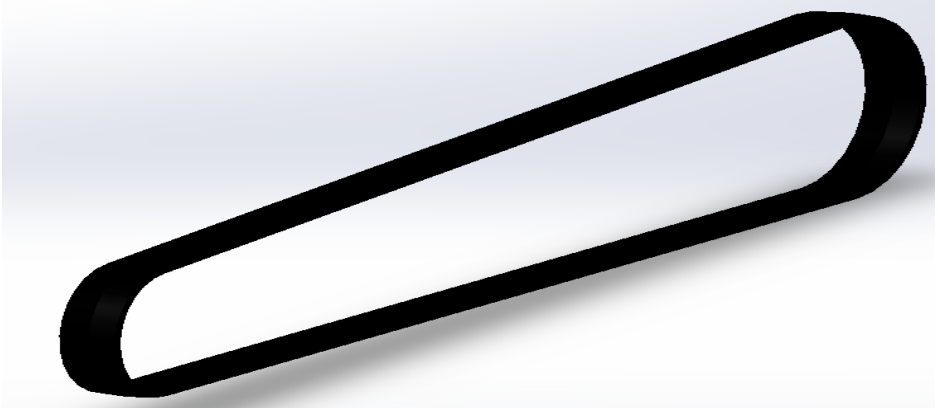


Figure III-21: V-belt

d-Linear guide rails:

Linear guide rails are used in several critical areas to ensure smooth movement. They carry and stabilize the cutting saw assembly, maintaining correct alignment of the cylinder shaft.

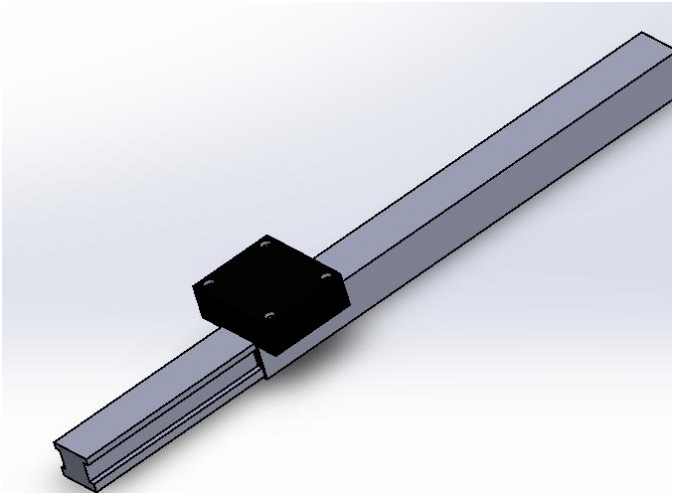


Figure III-22:Linear guide rails:

e-Circular saw blade:

To cut PVC materials, a specialized circular saw blade was used to achieve clean and precise cut.

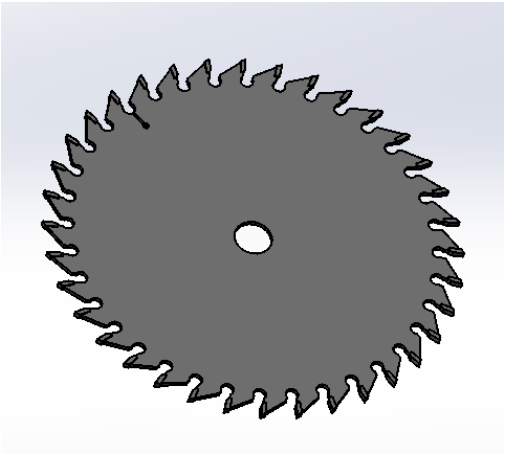
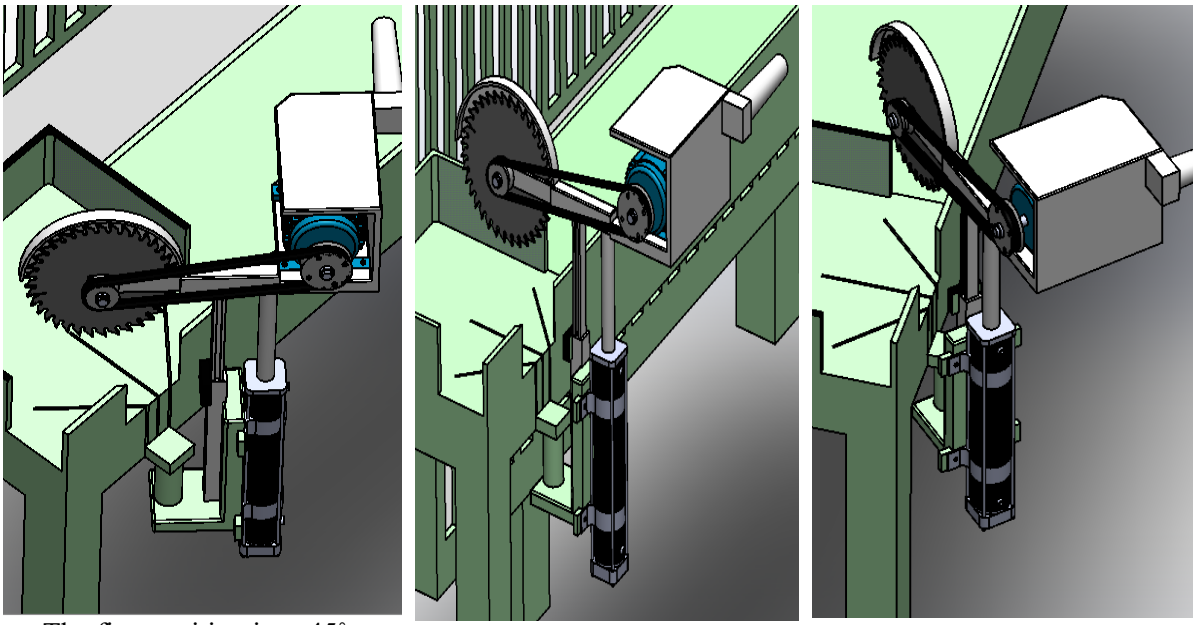


Figure III-23: PVC Circular saw blade

3-Complete assembly of Rod Cutting system components:

The cutting system includes an AC induction motor (Figure III -19) that powers the saw. This motor is connected to the circular saw blade using a V-belt (Figure III -21) and two pulleys (Figure- III -20). The V-belt transfers the motor's rotation to the blade (Figure III -23) smoothly and helps reduce vibration during cutting. Linear guide rails (Figure III -22) support the saw assembly and help it move straight and smoothly. A strong circular saw blade is used to cut PVC materials with accuracy. These parts work together to ensure the cutting process is stable and efficient.



The first position is at 45˚ The second position is at 90˚ The third position is at -45˚

Figure III-24: Cutting Motion Mechanism from three different viewing angles.

III.4.2.4 Rods fixing mechanism

Single-Acting Pneumatic Cylinder:

A single-acting compact pneumatic cylinders are used to clamp the rods securely during the cutting process.

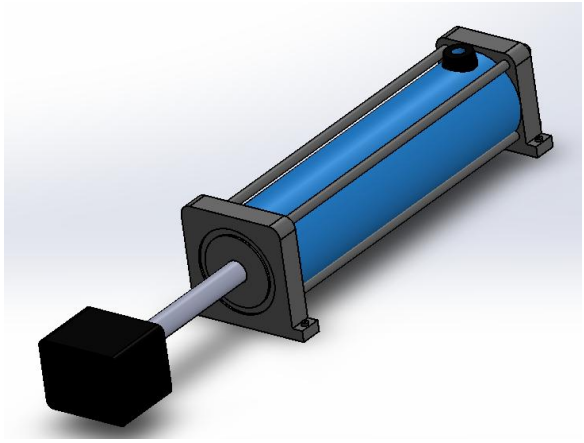


Figure III-25:Single-Acting Pneumatic Cylinder

The single-acting pneumatic cylinder is installed on the cutting table, positioned in the cutting zone to apply direct force onto the rod. This strategic placement ensures quick and reliable clamping during the cutting process. By securing the rod firmly in place, the cylinder prevents any movement, contributing to accurate and safe cutting operations.

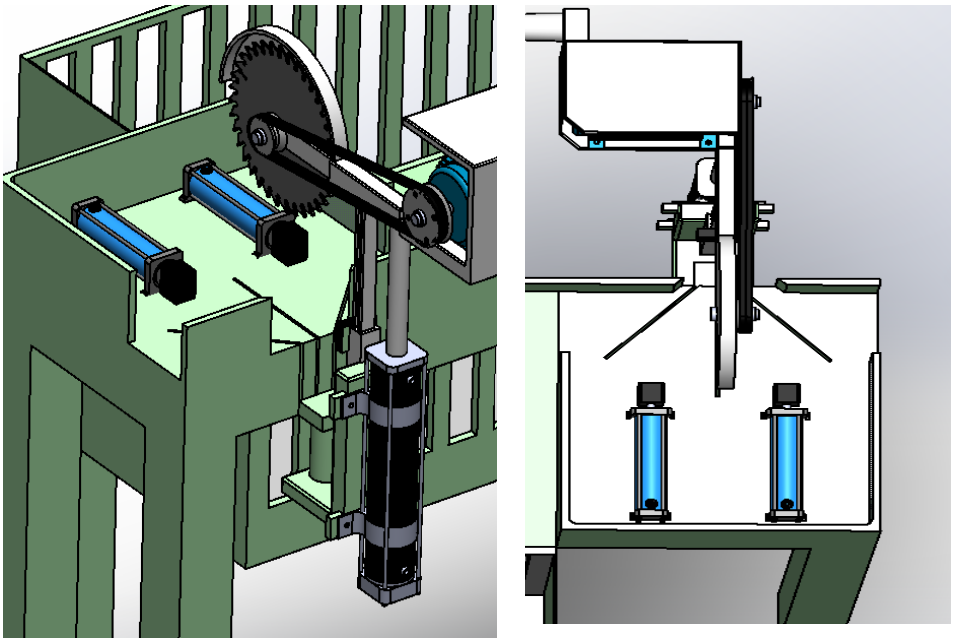


Figure III-26: Rod Clamping Mechanism from two different viewing angles.

III.4.2.5 Rods Guide Mechanism

In the automatic cutting machine, the alignment roller is responsible for ensuring that the bars are properly guided, helping to correct any deviations in their path as they are transported to the cutting area.

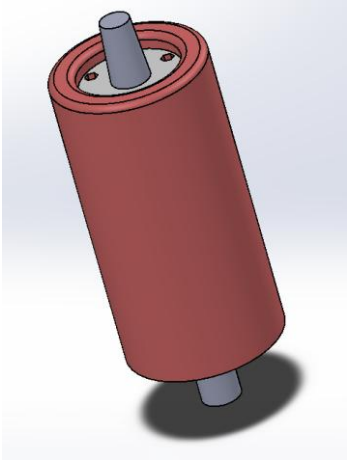


Figure III-27: Alignment roller

The alignment rollers are installed at the end of the main table, just before the cutting zone. They are placed after the transport section, at the entry point to the cutting area. A set of three rollers is used to guide and align the rods as they approach the saw. This ensures the rods maintain a straight path and are correctly positioned before cutting. The alignment system reduces friction, prevents deviation.

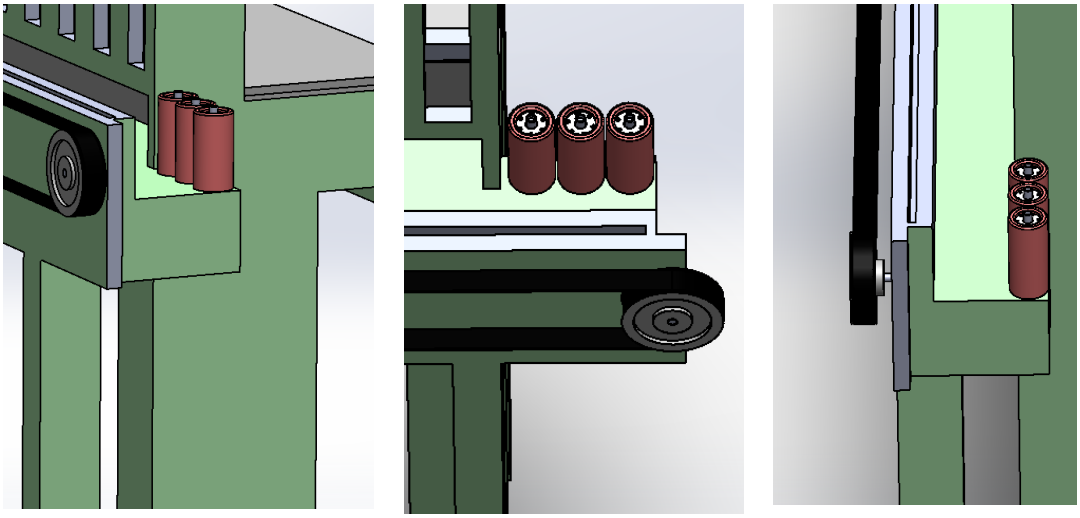


Figure III-28:Rod Guidance System from three different viewing angles.

III.4.3 Machine control and sensing system

This system is responsible for detecting the status of various components through sensors.

1-Capacitive proximity sensor

The capacitive proximity sensor is installed at the machine, where it continuously monitors the presence of the PVC bar before the cutting cycle begins. This function ensures that the machine only proceeds with the operation if rod is detected.

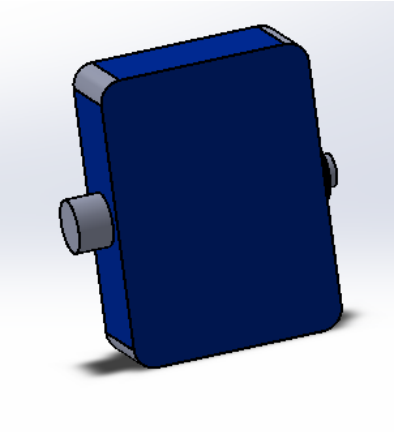


Figure III-29: Capacitive Proximity Sensor

a-Storage Box:

A capacitive sensor is installed at the end of the storage box to detect the presence of rods and This helps avoid machine operation when the rods is exhausted.

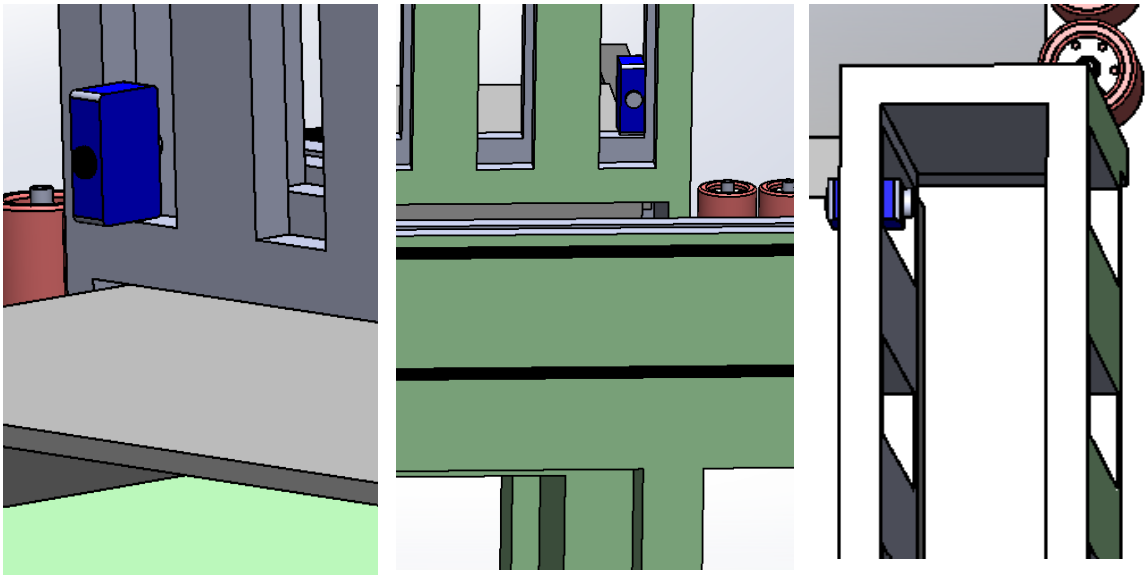


Figure III-30: Capacitive Sensor Installed at the Storage box from three different viewing angles

b- Feeding area:

The capacitive sensor is used in the transport path, after the rod is pushed from the storage box, to ensure the presence of the bars until they are transported to the cutting area.

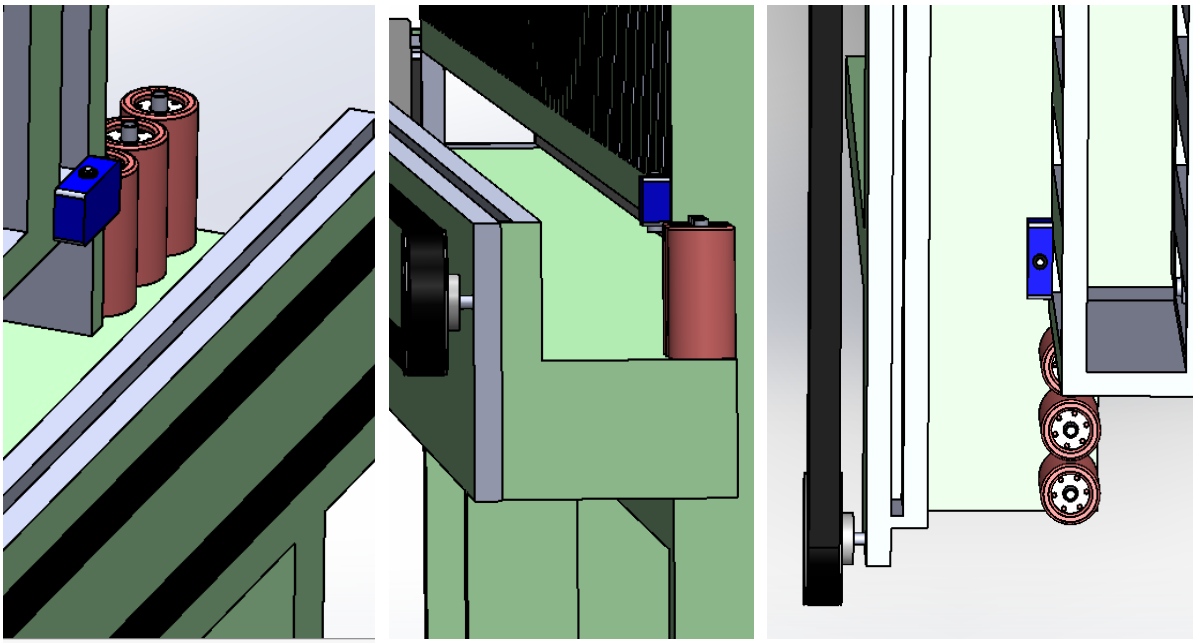


Figure III-31:Capacitive Sensor at Transport Path from three different viewing angles.

1-Photoelectric Sensor:

In this project, a photoelectric sensor was chosen due to its ability to accurately detect the presence of objects during the last two stages of the cutting process. Its high sensitivity and contactless operation ensure reliable detection of the PVC rod when it reaches the measuring and cutting positions, which greatly contributes to the accuracy and automation of the system.

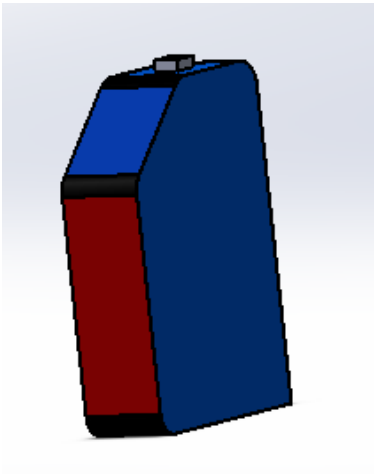


Figure III-32: Photoelectric Sensor

a-Cutting Area:

A photoelectric sensor is placed near the cutting zone. It detects when the rod reaches the cutting position. Once the rod is detected, the sensor sends a signal to the control unit, which initiates the cutting sequence based on the pre-set length measurements.

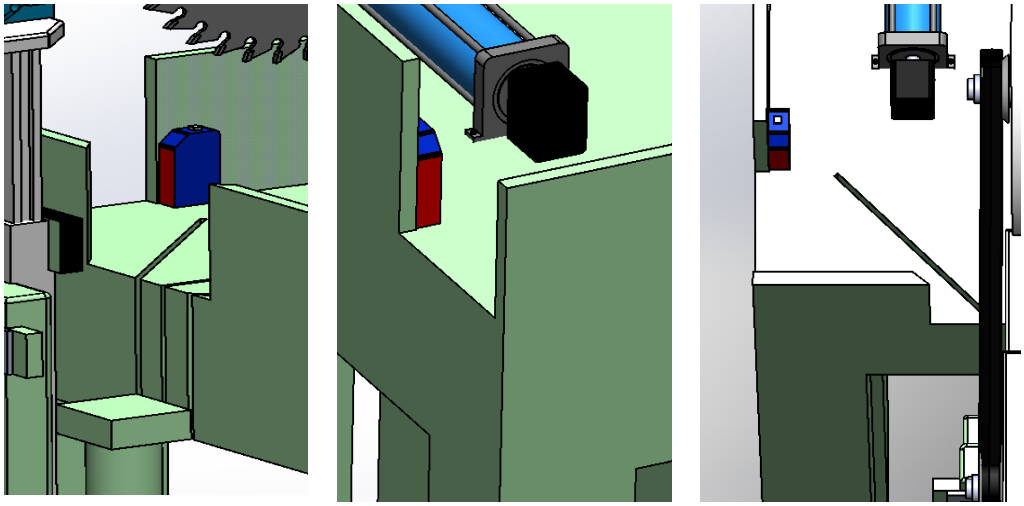


Figure III-33: Photoelectric Sensor at Cutting Zone Entry from three different viewing angles.

b-Finished cutting:

A photoelectric sensor is installed on the cutting table (Figure III -6), aligned with the vertical path of the saw assembly. Its function is to confirm that the saw has reached its lowest position during the cutting cycle. Once the sensor detects the presence of the saw at this point, it sends a confirmation signal to the control system, verifying that the cut is complete. This ensures both process accuracy before resetting the system for the next operation.

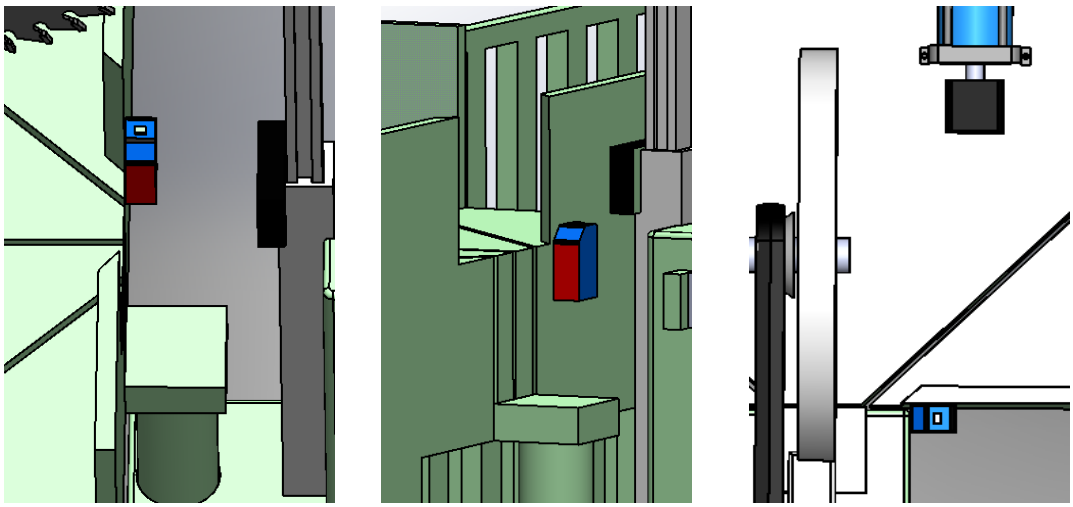


Figure III-34: Saw Position Confirmation Sensor from three different viewing angles.

3-Human Machine Interface:

The role of the Human-Machine Interface is to facilitate interaction between the user and the machine by providing visual feedback and real-time data display. Its primary functions include displaying system status and operational messages, as well as allowing the operator to input numerical values and control commands, such as:

- Specifying the rod length
- Setting the number of pieces to cut
- Issuing start/stop commands

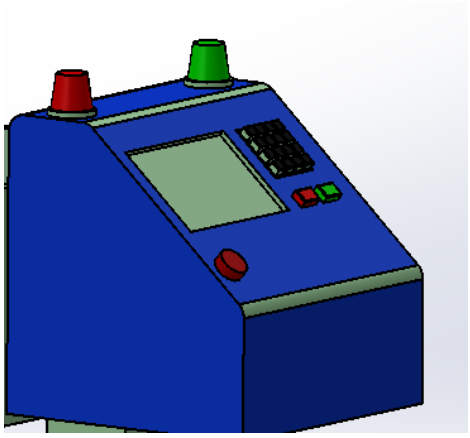


Figure III-35: Control unit

The control unit is installed on the cutting table (Figure III -6), positioned at an accessible height near the operator's side. This strategic placement ensures easy interaction with the Human-Machine Interface.

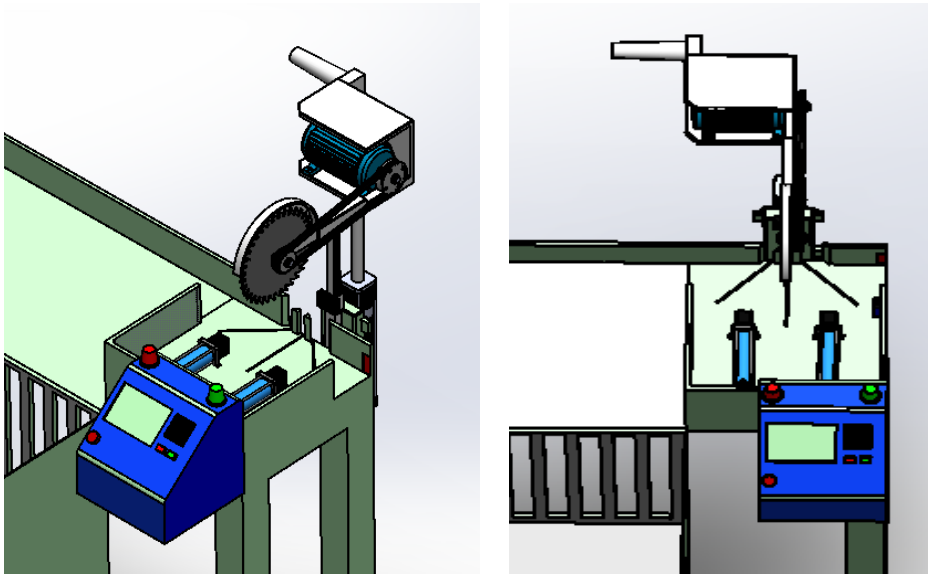


Figure III-36: Control Unit Placement from two different viewing angles.

III.4.3.1 The protective cover

A protective cover is placed over the cutting zone to keep the operator safe during machine operation. It prevents contact with moving parts, especially when the operator approaches the control unit. This helps avoid accidents and ensures safer working conditions.

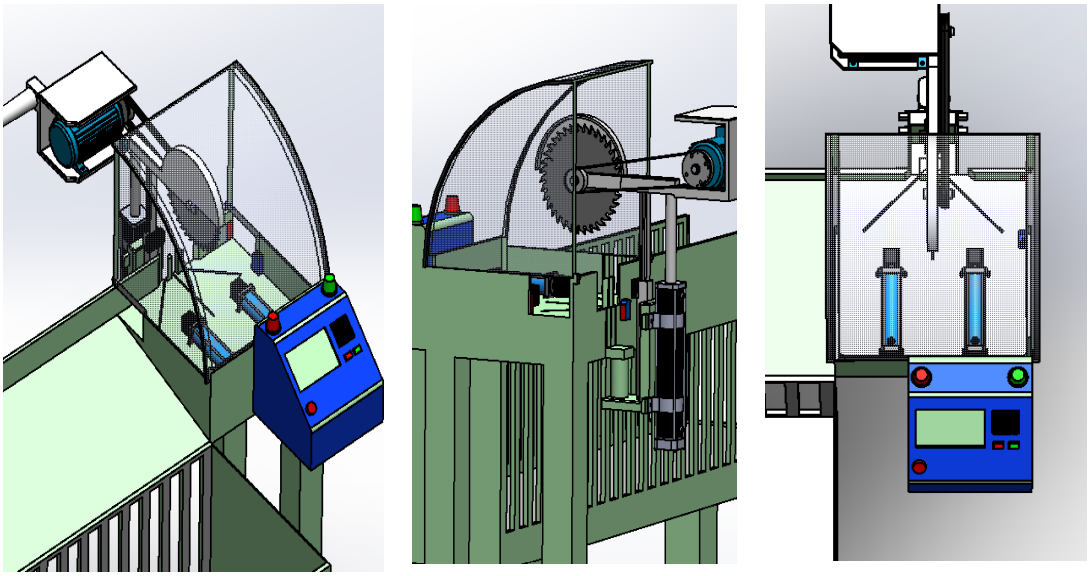


Figure III-37: Protective Cover Installed at Cutting Zone.

III.4.4 Complete Assembly of the Machine Systems

The assembly process concludes with the integration of all components onto the main table, where the transport system, push mechanism, and sensors have been installed. In parallel, the cutting table has been equipped with the saw motor, vertical actuator, clamping cylinders, and safety cover. After preparing both tables, they were precisely aligned and assembled to form a complete and operational machine. This final integration ensures that all mechanical and pneumatic systems function in coordination, resulting in a reliable and automated cutting system ready for operation.

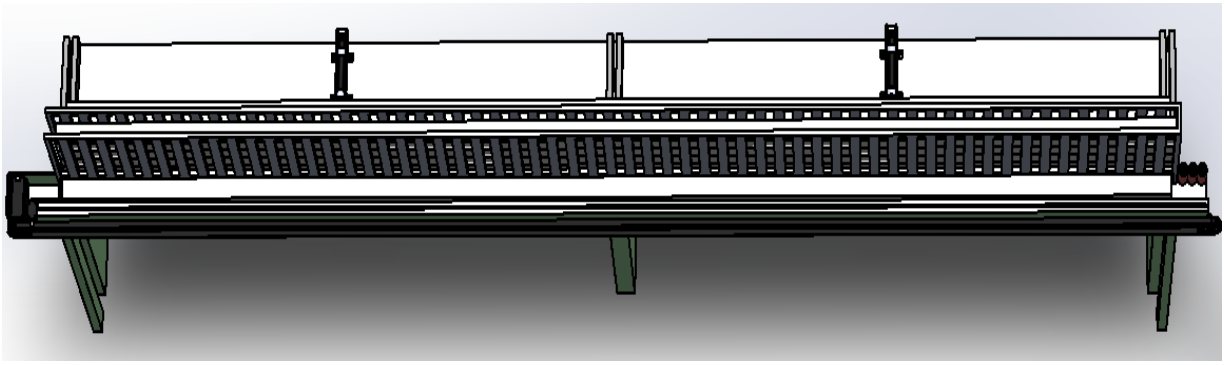


Figure III-38:The integration of all components onto the main table.

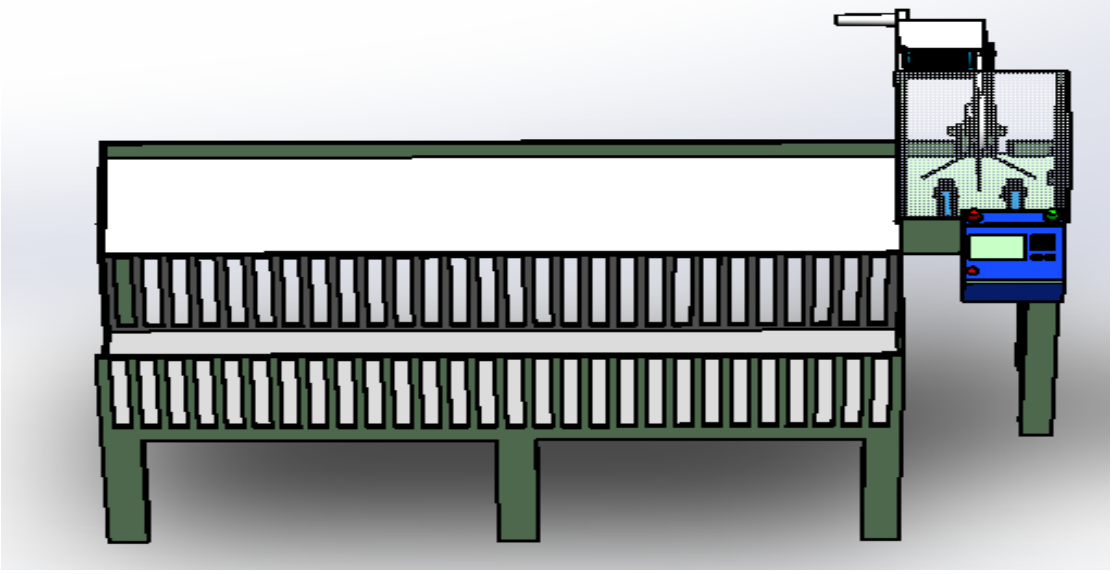


Figure III-39:The integration of all components onto the cutting table.

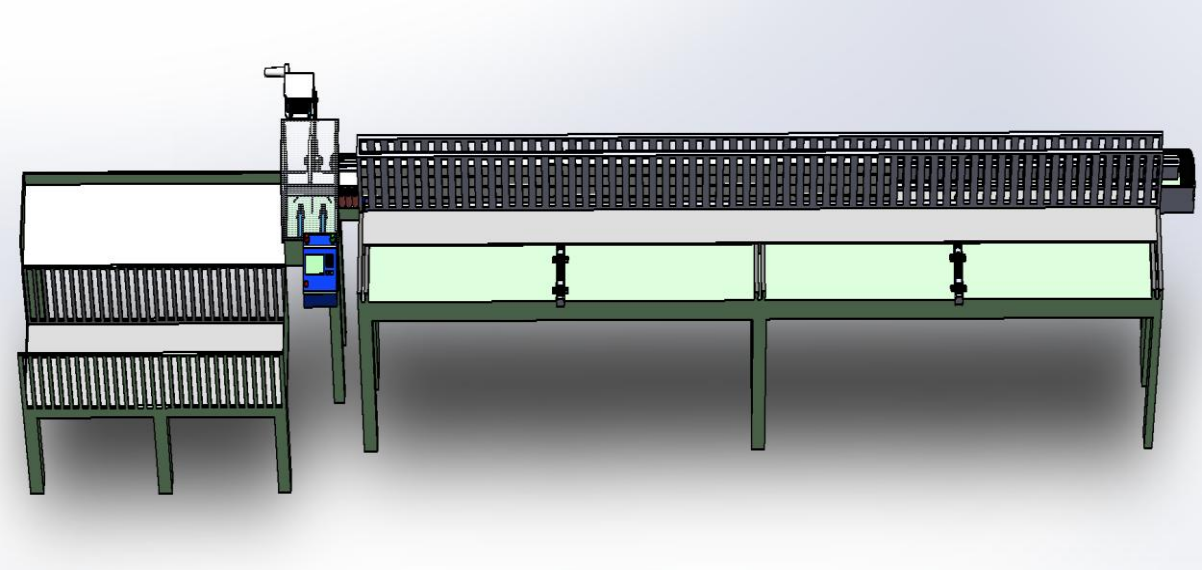


Figure III-40:Comprehensive assembly of the automated cutting machine.

III.5 Electrical circuit design and control system simulation

To ensure accurate integration of all selected components, a complete electrical circuit was carefully designed and simulated. Each element including sensors, actuators, and interface modules was connected to the Arduino Mega microcontroller according to its specific functional role within the system. This circuit layout reflects the actual control architecture of the automated cutting machine, ensuring proper communication and operation. The schematic below illustrates the detailed wiring and pin assignments used in the design.

III.5.1 Electrical circuit design

The electrical circuit design outlines the configuration and connection of all electrical components required for the machine's operation.

The electrical circuit was designed using the Cirkit Designer online platform. You can view the full project at the following link: https://app.cirkitdesigner.com/project/65065da9-4ad9-4763-8b2e-99fa8ca4325a.

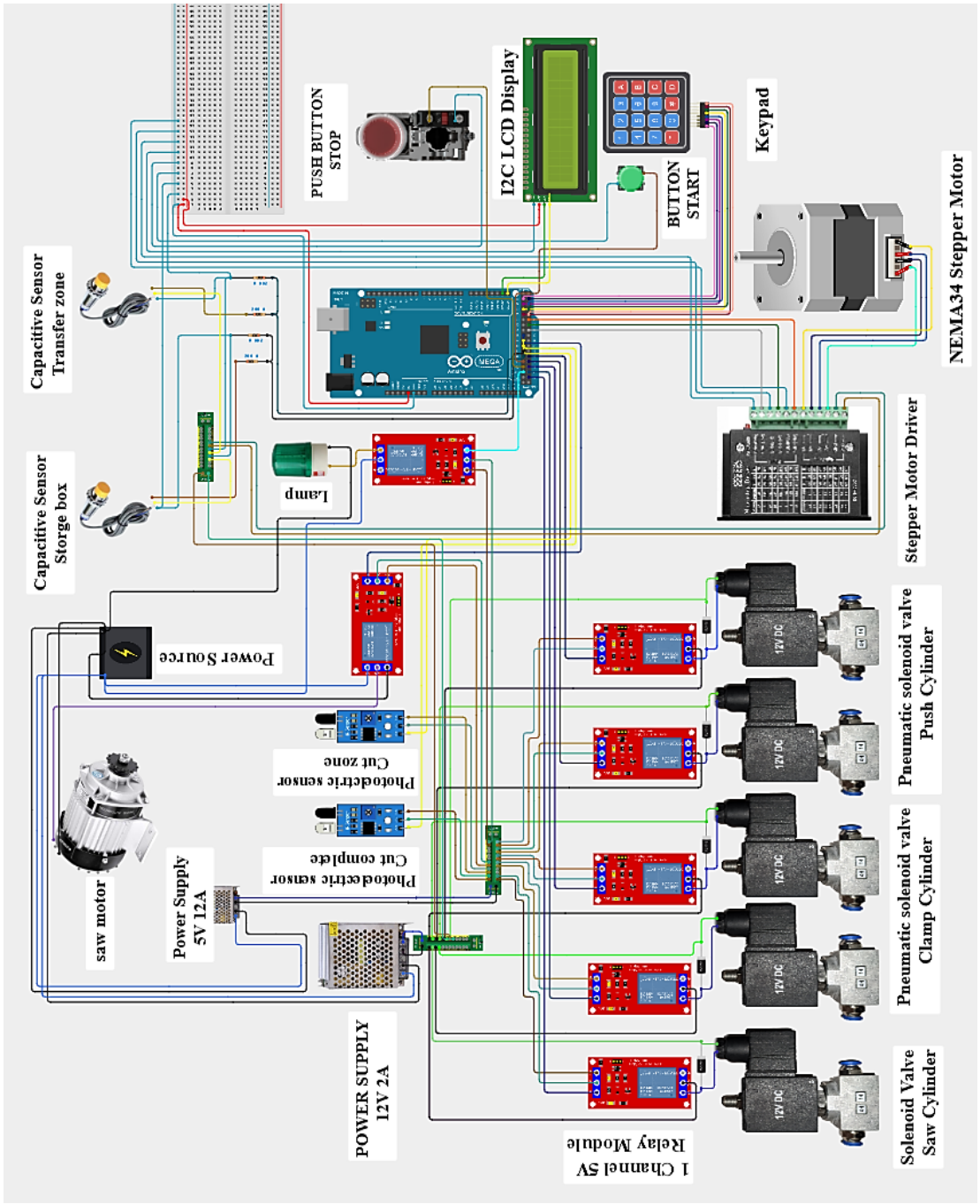


Figure III-41:Complete Electrical Schematic of the Cutting Machine

III.5.1.1 Arduino Mega Pin Configuration for Connected Components

This table shows the assigned pin numbers for the inputs and outputs of the control system:

Table III-1:Pin Configuration and I/O Connections of the Control System

Component	Arduino Mega Pin(s)	Direction
Stepper Motor Driver	STEP: 31, DIR: 33, EN: 35	OUTPUT
4x4 Matrix Keypad	(Rows: 22–25, Cols: 26–29)	INPUT
I2C LCD 16x2	SDA: 20, SCL: 21	OUTPUT
Solenoid Valve – Push Cylinder	45,47	OUTPUT
Solenoid Valve – Clamp Cylinder	49,51	OUTPUT
Solenoid Valve – Saw Cylinder	53	OUTPUT
Relay – Saw Motor	36	OUTPUT
Capacitive Sensor – Storge box	42	INPUT
Capacitive Sensor – Transfer zone	44	INPUT
Photoelectric Sensor – Cut zone	38	INPUT
Photoelectric Sensor – Cut Complete	40	INPUT
Button – Start (Enter data)	46	INPUT
Push Button – Stop	48	INPUT
Lamp (Rod full cut)	50	OUTPUT

III.5.2 Control System Simulation

The electrical system was simulated using a complete circuit (Figure III 42) that includes all the necessary machine components. Since some parts, like pneumatic valves and sensors, are not available in the simulation software, equivalent components were used (Table III.2). LEDs replaced actuators to show their states, and push buttons were used instead of capacitive and photoelectric sensors. All elements were connected to the same pins as in the first design (Figure III-41) to keep the control logic and system behavior accurate. This method allows easy testing and validation of the system.

This table summarizes the types and number of components used in the simulation model:

Table III-2:Types and Quantities of Components Used in the Simulation

Component	Quantity
Push Button	6
LED	5
Resistor	3
Arduino Mega	1
Keypad 4x4	1
LCD 16x2 (I2C)	1
Stepper Motor	1
Stepper Driver	1
Breadboard	1

III.5.2.1 Electrical circuit used in the simulation

The following table provides an overview of each component used in the simulation, including its assigned pin number, pin type (input or output), and its specific role within the control system:

Table III-3:Pin Assignments, Types, and Roles of Simulated Components

Component	Type	Function
Button (Pin 42)	Input Sensor Capacitive	Detects presence of a rod in the storage box
Button (Pin 44)	Input Sensor Capacitive	Detects if the rod has reached the transfer zone
Button (Pin 38)	Input Sensor Photoelectric	Photoelectric sensor to detect if the rod is in cutting position
Button (Pin 40)	Input Sensor Photoelectric	Detects when the cutting is finished
Led blue (Pin 45)	Output Solenoid Valve –Push Cylinder	Activates pneumatic push cylinder
Led yellow (Pin 49)	Output Solenoid Valve –Clamp Cylinder	Activates pneumatic clamping cylinder
Led red (Pin 53)	Output Solenoid Valve – Saw Cylinder	Activates pneumatic cylinder of saw motor
Led green (Pin 36)	Output Saw Motor	Powers the cutting motor

The image below illustrates the electrical circuit designed for simulation. You can view the full project at the following link: https://app.cirkitdesigner.com/project/33f1edbe-d067-4899-901c-9c02bc7d1e39

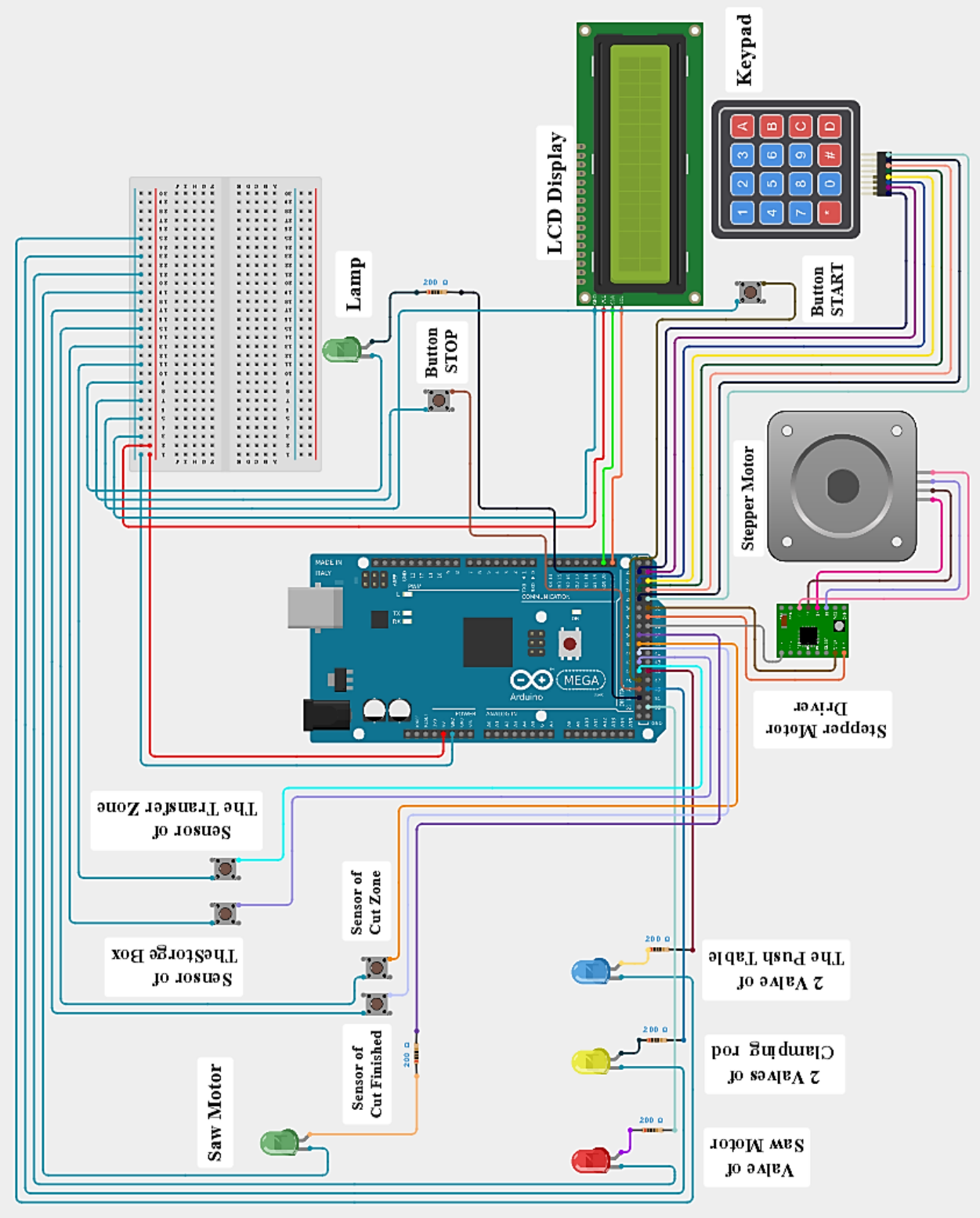


Figure III-42:Desing of Simulated Electrical Control Circuit

III.5.2.2 Operational Sequence and HMI Display Messages

This section presents the step-by-step operational sequence of the automated cutting machine. Each stage is linked to a specific message shown on the HMI LCD screen, providing clear guidance to the operator. The process follows a logical flow, starting from data input and continuing through to the completion of the cutting operation.

The following image shows the HMI interface used in the simulation. It includes an LCD display for showing system messages and a keypad for entering input data.

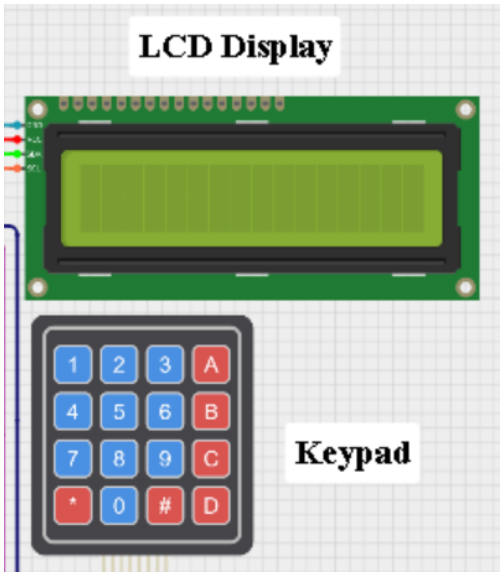


Figure III-43:HMI interface

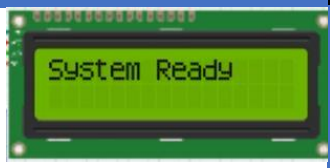
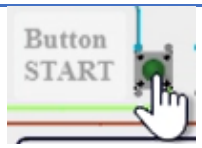
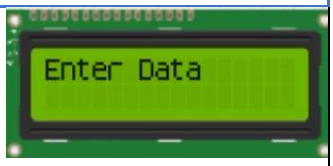
The following table outlines the functions assigned to each key on the keypad during system operation:

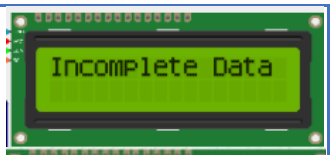
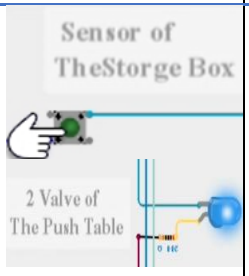
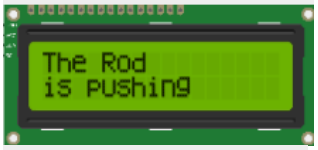
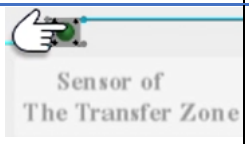
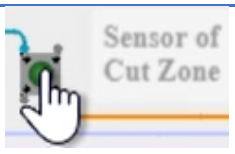
Table III-4:Functional assignment of keyboard inputs in system operation

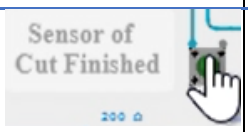
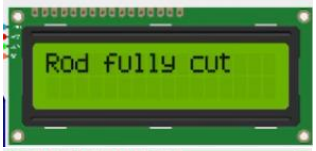
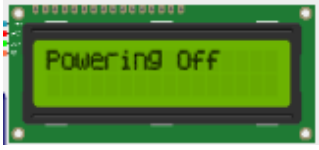
Key	Function	Description
0-9	Number Entry	Used to enter numerical values (lengths, quantities).
A	Confirm Rod Length	Sets the total rod length entered.
B	Confirm Piece Length	Sets the individual piece length to be cut.
C	Confirm Number of Pieces	Sets how many pieces will be cut from the rod.
D	Start Cutting Process	Starts the process if all data is entered.
*	Backspace / Delete One Digit	Deletes the last digit entered.
#	Clear Input	Clears the entire current input on the LCD screen.

The following table outlines each step in the simulation process of the automated cutting machine. Each row includes the corresponding input interaction (button press or sensor trigger), the expected system response, and the LCD message displayed to the use.

Table III-5:Detailed Step-by-Step Process of the Automatic Cutting Machine Simulation

Step Description	User Interaction / System Reaction	LCD Message
1-System initialized: When the machine is powered on, at this point, the Arduino Mega has initialized all connected components.	/	
2- Start Command: When the operator presses the Start button, the system prompts the user to enter required data. to begin receiving cutting specifications.		
3-Entering Cutting Parameters: **a**-Press '**A**' to enter the rod's total length.		
b-Press '**B**' to enter the desired length for each piece.		
c-Press '**C**' to enter the number of pieces to cut		
3- Validation and Process Start: Press '**D**' to validate the entered data.		

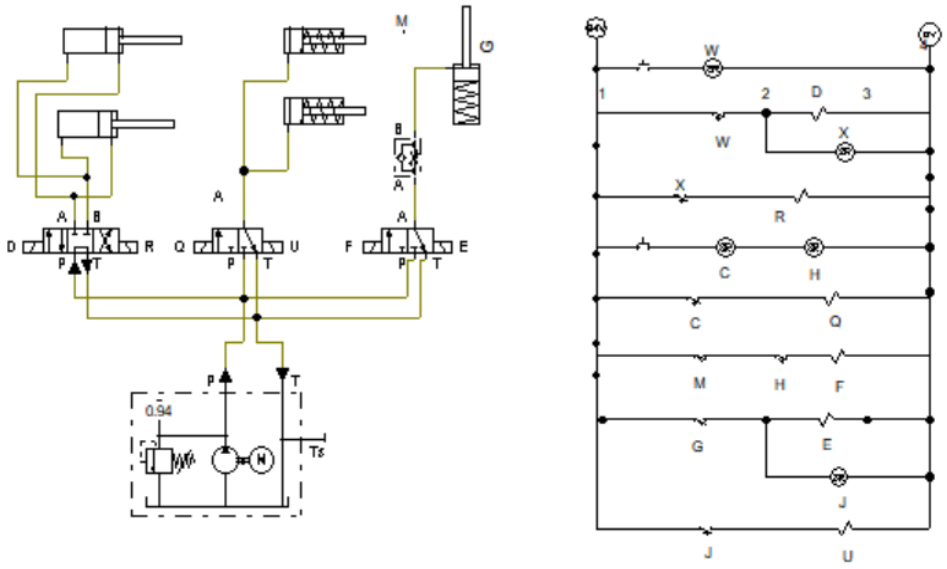
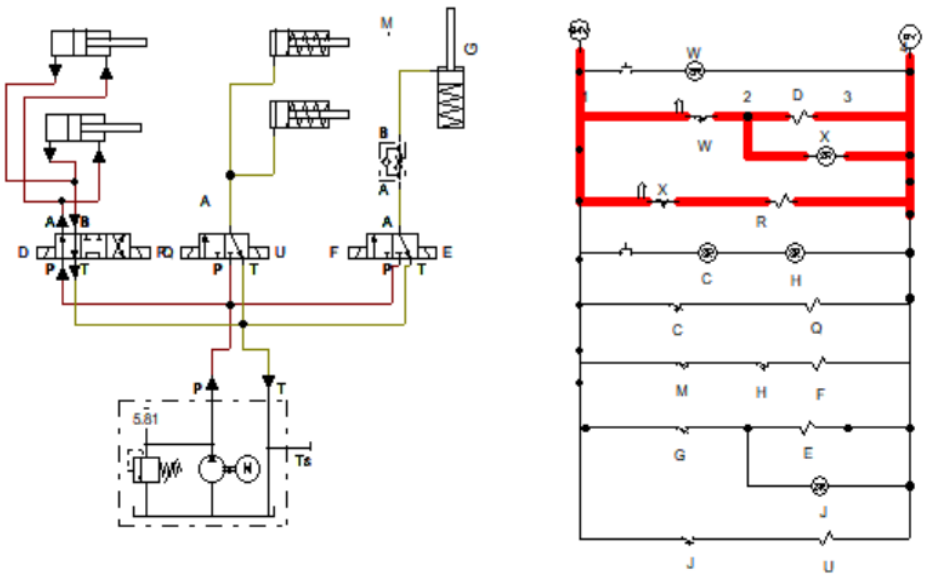
• If all required data is not entered, you'll be prompted to enter it again.	/	 
• If all data is confirmed, the saw is activated immediately, while waiting for the sensor to detect the rod.		 
4-Rod Presence Detection in Storage Box: When the button (the capacitive sensor) is pressed, it confirms the presence of the rod and sends a command to push it. And the pneumatic push mechanism is activated.		 
5-Rod Presence Detection in the Feeding Zone: When the button (the capacitive sensor) is pressed, it indicates that the rod is in the transfer zone and sends a command to the motor to move the rod**.** When the rod is in motion.	 	 
6-Positioning the rod in the cutting zone: When the button (Photoelectric Sensor) is pressed, it confirms that the rod has reached the cutting area. The motor stops briefly, then begins the process of measuring the required length.		

7-Cutting Cycle Begins For each piece: The stepper motor moves again to start the loop of calculating each piece's length and performing the cut.		
When the motor stops rotating after reaching the desired length, it sends a signal to clamp the rod by activating the clamping valve.		
When the bar is clamped, the saw motor valve is activated, and the cutting process begins.		
When the button (Photoelectric Sensor) is pressed, it detects that the saw has reached its lowest point and the first piece of the bar has been cut. **NOTE**: This loop continues until the required number of pieces is completed		
8-Cutting of First Rod Completed: After all the pieces have been cut from the first rod, a lamp alerts the operator that the process is complete, allowing the pieces to be collected.		 
9-Prepare the process again to cut the next rod The stepper motor returns to its initial position to pick up another rod, if one is detected in the storage area.		 
10-Powering Off the System: When the stop button is pressed, the entire system powers off.		

III.6 Simulation of Cylinder Movements

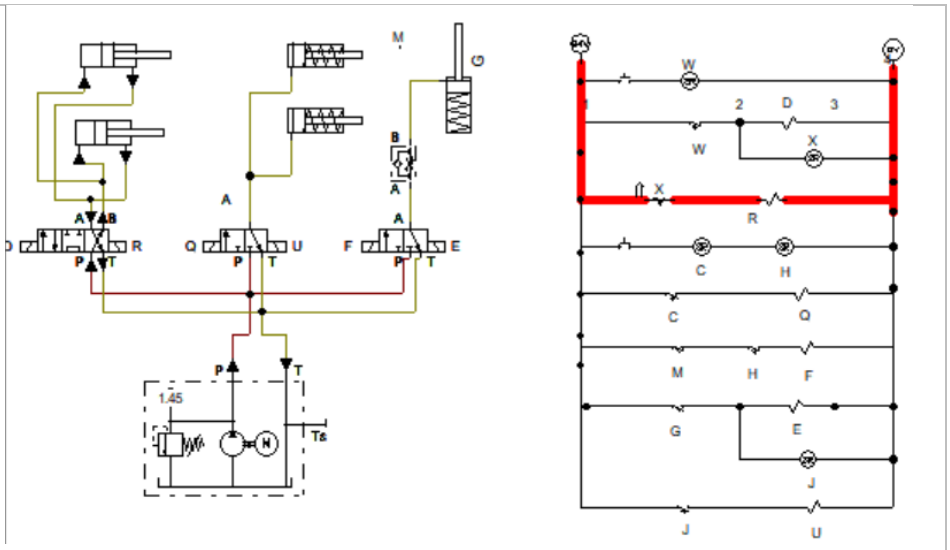
This simulation demonstrates the operation of an automatic cutting machine using Festo components. The focus is on the behavior of pneumatic cylinders during each stage of the process.

Note: The direction of the arrows indicates the movement of the cylinders and the flow of compressed air.

System at Rest: Initial state All cylinders are in their initial positions. **(a):** Push table cylinders. **(b):** fixing cylinders. **(c):** Saw motor cylinder.	(a) (b) (c) 
(a): Push table cylinders: The push cylinder Retracts. As it does, the rod drops.	

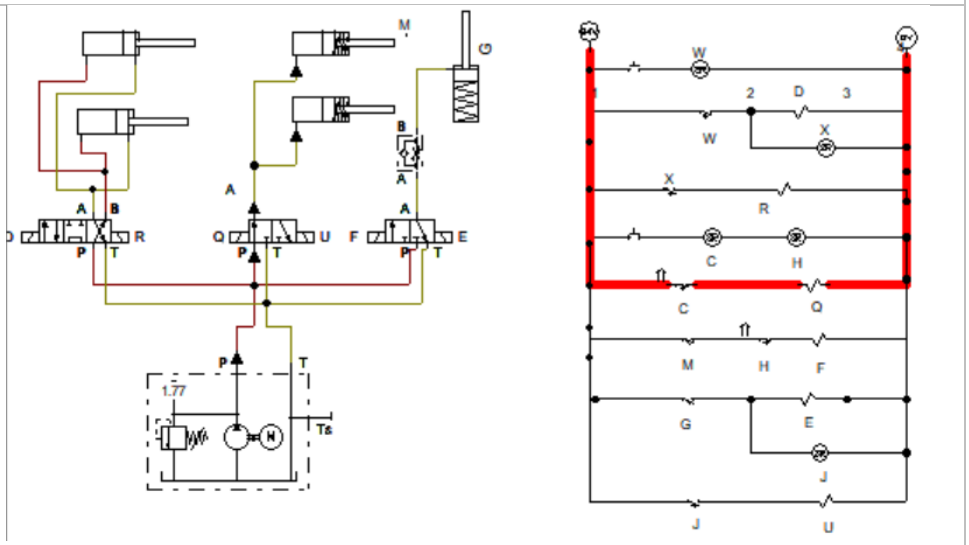
(a): Push table cylinders:

The cylinder extends forward to push the rod into the feeding position.



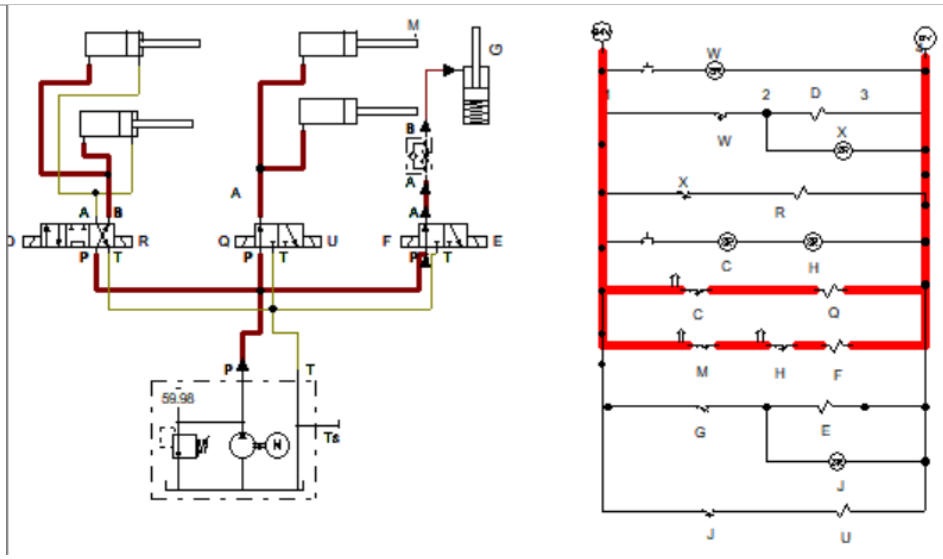
(b): fixing cylinders:

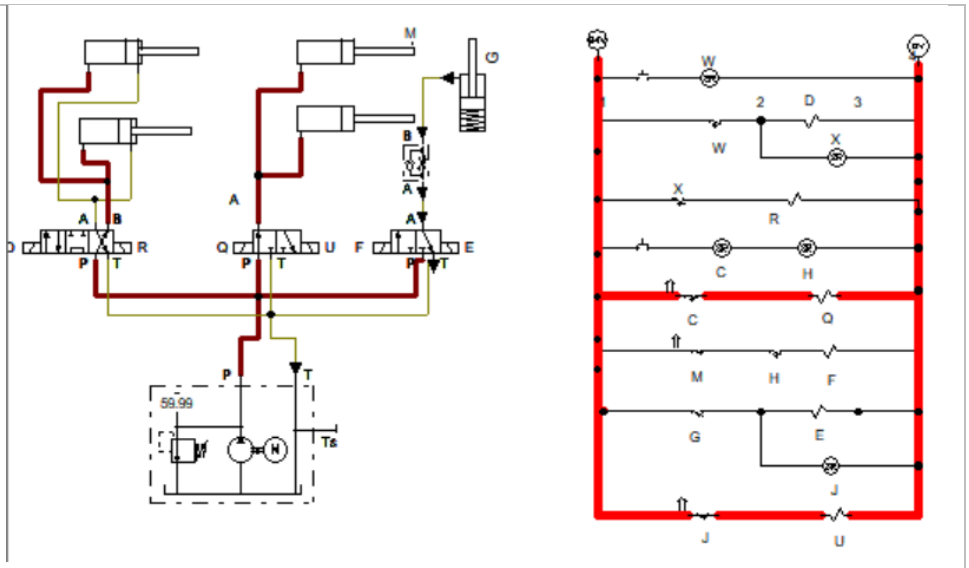
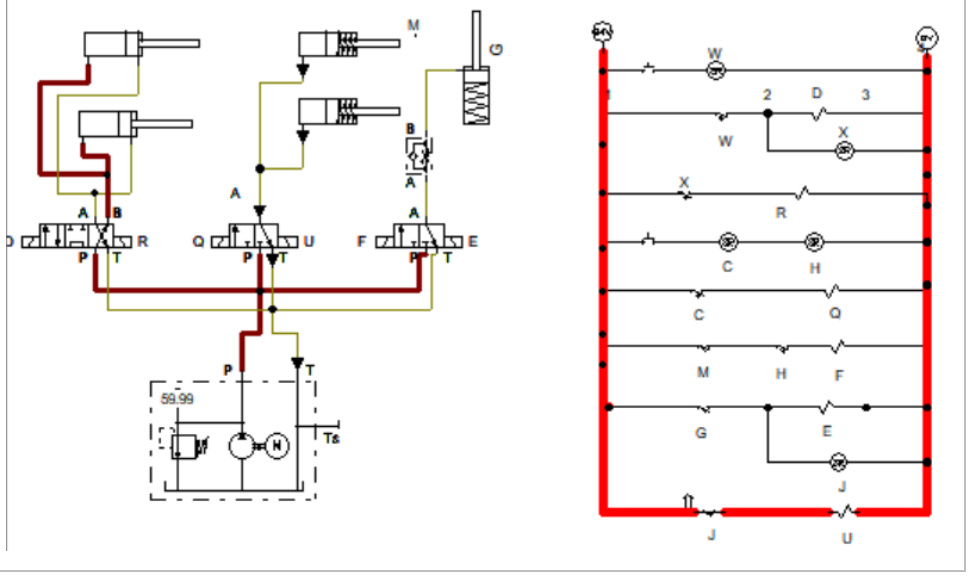
Clamp cylinder extends for clamp the rod firmly before cutting.



(c): Saw motor cylinder:

The saw cylinder retracts and moves down to cut the rod and the clamp cylinder continues to fixing.



(c): Saw motor cylinder: After the cut, saw cylinder extends and returns to its top position.	
(b): fixing cylinders: the clamp cylinder retracts to release the rod	

III.7 Conclusion

This chapter provided a comprehensive overview of system assembly and functional simulation of an automatic cutting machine. It started by introducing the design and simulation tools used, including SolidWorks for 3D modeling, Cirkit Designer for circuit simulation, and Festo FluidSIM for pneumatic system validation. The mechanical assembly was described in detail, highlighting both structural and functional components such as drive, feed, cut, clamp and guide mechanisms. Functional simulation clarified the operational logic of the control system, and was validated through step-by-step simulations that reflect the realistic behavior of the machine components.

General Conclusion

This project focuses on the development of an automatic cutting machine that combines electrical, mechanical, and pneumatic technologies to perform precise and efficient profile cutting. The machine was designed to solve specific challenges found in traditional manual cutting methods, such as inaccuracy, safety hazards, and slow production speeds. By automating the cutting process, the system ensures consistent output, reduces the risk of human error, and increases overall efficiency in workshop or factory environments.

One of the key motivations for this project was to address common problems in manual cutting systems. These include non-uniform cuts, operator fatigue, production delays, and material waste. Through automation and sensor-based monitoring, this machine solves these issues by providing accurate length measurement, stable clamping, and precise blade movement. Safety is also improved, as the operator no longer needs to be close to the blade during operation.

Throughout this project, I was able to apply and integrate several areas of my academic training in electromechanical engineering. The mechanical structure was designed and assembled using SOLIDWORKS, ensuring accurate dimensions and efficient assembly. The pneumatic system was planned and simulated using Festo Fluidsim, allowing for proper cylinder movement and valve control. On the electrical side, I focused on motion control, signal processing, and the development of customized automation logic to coordinate the machine's functions.

During this project, several technical and practical challenges were encountered. For example, SolidWorks simulations were sometimes limited by computer performance or missing component models. In programming, achieving a clear and accurate sequence of operations was difficult, especially when trying to avoid logic conflicts or code duplication. Troubles also appeared during sensor integration, timing adjustments, and system testing, all of which required careful analysis and repeated corrections.

The machine can be improved by adding automatic cutting angle adjustment, optimizing the user interface with a touchscreen and remote control, and designing solutions to handle larger or more complex materials.

This machine could become a cost-effective solution for small and medium workshops working with PVC, wood, or aluminum. Its ease of use, precision, and safety make it a good alternative to expensive CNC machines. It also has strong potential for local markets.

This project was a valuable opportunity to apply everything I've learned as a student of electromechanical engineering. It combined mechanics, electricity, electronics, pneumatics, and control programming into one complete system. Beyond the technical skills, I also learned the importance of planning, testing, problem-solving, and documentation

Annexes (A)

Electrical system components

The electrical system is essential for powering and controlling the machine's operations. This section presents the key electrical components that ensure proper functioning and coordination of all parts. It includes power supply units, motors, wiring, and sensors that interact with the control system. Together, these components provide automation, safety, and accuracy throughout the cutting process.

Stepper Motor Closed-Loop

Stepper motors are electromechanical actuators that translate digital pulses into discrete angular displacement. They are widely used in motion control systems due to their simplicity, repeatability, and cost-effectiveness in open-loop configurations. However, traditional stepper motors may lose steps under load variations or acceleration. To improve reliability and accuracy, closed-loop stepper motors integrate feedback via rotary encoders, allowing real-time correction of position errors. This hybrid approach enhances performance while retaining the benefits of stepper control systems [37]. The figureA-1 is shown below [38].

Characteristics of closed-loop stepper motor

- **No Step Loss:** Ensures precise positioning, smoother motion, and reduced vibration compared to traditional stepper motors.
- **Easy to Use:** It requires no complex parameter tuning and offers fast position response, ideal for rapid start-stop operations.
- **High Speed Performance:** Closed-loop control with a position encoder prevents step loss and improves torque at high speeds.
- **Power Efficiency:** Reduces heat generation by adjusting driver output current based on load and speed.
- **Fast and Stable Response:** Nearly real time response to input commands with stable zero-speed holding and no braking vibration.



Figure A-1: Stepper Motors Closed-Loop

Working Principle of Stepper Motor Closed-Loop

Stepper motors operate based on the principle of electromagnetism. The stator of the motor contains multiple windings arranged in phases, while the rotor is typically a toothed permanent magnet. When electrical current is sequentially applied to the stator windings, a rotating magnetic field is produced, which causes the rotor to move in discrete steps [39].

The direction and magnitude of the magnetic field depend on the current's sequence and timing. The energization of the stator phases is controlled by an external driver circuit, which sends signals from a microcontroller. Depending on the stepping method used, different levels of precision and torque can be achieved:

- **Full Step Mode**: Energizes two phases simultaneously, generating maximum torque and rotating the rotor by 1.8° per step.
- **Half Step Mode:** Alternates between one and two energized phases, doubling the resolution (0.9° per step) with smoother operation.
- **Micro-stepping Mode:** Energizes multiple phases with varying current levels to achieve sub-step movements, reducing vibration and improving accuracy.

The figure A-2 is shown below [40].

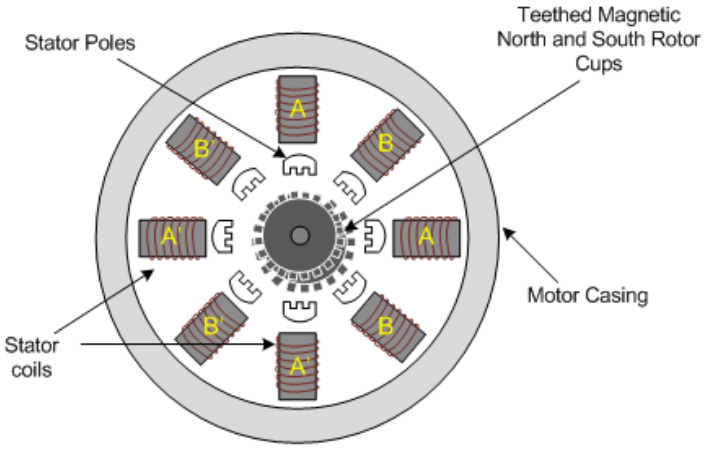


Figure A-2: Stepper motor circuit schematic diagram

Selected Motor Type:

A Closed-loop NEMA 34 stepper motor has been selected for this purpose due to its high torque capabilities and mechanical robustness, making it suitable for handling long and relatively heavy profiles. Its precise step angle (1.8° per step) and compatibility with micro-stepping drivers ensure fine resolution and smooth motion without requiring feedback systems.

Moreover, its high holding torque prevents slippage during pauses, ensuring consistent dimensional accuracy. The motor's standardized mechanical interface and electrical characteristics also simplify integration and maintenance.

Technical Properties of Closed-loop NEMA 34 Stepper Motor:

a- the mechanical characteristics of the NEMA 34 stepper motor:

- **Motor Size (Frame):** 86 mm × 86 mm.
- **Shaft Diameter:** 14 mm**.**
- **Motor Length:**118 mm to 156 mm (depends on torque) **.**
- **Step Angle:** 1.8° per step.
- **Steps per Revolution:** 200 steps**.**
- **Holding Torque:** 6 – 12 Nm.
- **Encoder Resolution:** 1000 – 2500 PPR
- **Weight:** 2.5 – 4.0 kg

b- the electrical characteristics of the NEMA 34 stepper motor:

- **Phase:** 2-phase
- **Rated Voltage:** 24 – 48 V DC .
- **Rated Current:** 4.2 – 6.0 A .
- **Encoder Type:** Incremental rotary encoder.
- **Encoder Supply Voltage:** 5 VDC.
- **Signal Output:** A+, A-, B+, B-, Z+, Z-.

Closed-loop Stepper Drivers

A stepper motor driver is an essential electronic device that controls the operation of a stepper motor by converting control signals from a microcontroller into precise current pulses to drive the motor windings. Stepper motors do not receive signals directly from a microcontroller; instead, the driver acts as an interface between the logic-level controller and the power-demanding motor [41].The figure A-3 is shown below [12].



Figure A-3 :Closed Loop Stepper Driver

Purpose and Function:

The main functions of a stepper motor driver include:

- **Pulse Translation:** Converts digital STEP/DIR pulses into controlled phase signals for the motor.
- **Current Regulation**: Dynamically adjusts the motor current based on load and position feedback.

- **Direction Control:** Sets motor rotation direction based on the DIR input signal.
- **Micro-stepping:** Divides full steps into smaller steps for smooth and precise motion.
- **Encoder Feedback Processing**: Continuously monitors motor position from the encoder and corrects for any missed steps or positioning errors.
- **Position Correction:** Ensures real-time alignment between commanded and actual position, improving accuracy and reliability.
- P**rotection Features:** Provides safety features such as over-current, over-temperature, and under-voltage protection.

Since the project requires accurate cutting and uses a NEMA 34 stepper motor, a reliable closed-loop driver is needed. The HBS86H driver was chosen because it supports encoder feedback, offers precise positioning, smooth motion, and works well under heavy loads.

This driver ensures real-time correction of positioning errors.

Stepper Motor Driver Specifications:

The main specifications of the HBS86H stepper motor driver

- **Supply Voltage:** 24 – 80 V DC.
- **Output Current:** 2.4 – 7.2 A (adjustable).
- **Micro-stepping Resolution:** Up to 51200 steps/rev (micro-step).
- **Encoder Input Differential encoder:** (A/B/Z) – 1000 PPR.
- **Feedback Type:** Real-time position correction.
- **Position Accuracy:** ±0.01 mm (with encoder feedback).
- **Protection Features**: Over-voltage, Over-current, Over-temp.

AC Induction Motor

An AC induction motor is one of the most widely used types of electric motors in industrial and commercial applications. It operates on the principle of electromagnetic induction, where an alternating current applied to the stator winding generates a rotating magnetic field. This field induces a current in the rotor, which in turn produces torque and causes the rotor to turn [42]. The figure A-4 is shown below [11].



Figure A-4: AC Induction Motor

Type and Specifications:

- **Motor Type**: Three-phase AC induction motor.
- **Power Rating**: Approximately 1.5 kW.
- **Speed Range:** Around 2800 to 3500 RPM.
- **Voltage:** 220V three-phase supply for industrial use.

Sensing System

Sensors are critical components in the automatic cutting machine, providing the system with real-time information. They enable precise monitoring of material presence, position, and machine operation, ensuring accurate and safe performance.

Capacitive Proximity Sensor

A capacitive proximity sensor is a non-contact sensor that detects the presence or absence of virtually any object, regardless of material, by sensing changes in capacitance. It operates by generating an electrostatic field in front of its sensing face. When a target with a dielectric constant higher than air (such as plastic, glass, wood, or liquid) enters this field, the capacitance changes, and the sensor switches its output [43].

The figure A-5 is shown below [11].



Figure A-5: Capacitive Proximity Sensor

Key Specifications:

- **Model**: LJ12A3-4-Z/BY.
- **Sensing Distance**: ~4 mm.
- **Output Type:** NPN.
- **Power Supply:** 12V.
- **Output Current**: Up to 300 mA.
- **Response Time**: Fast (50 Hz).
- **Protection Level:** IP67 (dust/water resistant).

Photoelectric Sensor

A photoelectric sensor is an electronic device that detects the presence, absence, or distance of an object by using a light transmitter and a photoelectric receiver. It operates by emitting a light beam, usually in the infrared or visible spectrum, and sensing the reflected or interrupted light to determine if an object is present [44]. The figure A-6 is shown below [11].



Figure A-6:Photoelectric Sensor

Key Specifications:

- **Sensing Distance:** 10 cm.
- **Output Type:** NPN.
- **Power Supply:** 12V.
- **Output Current**: Up to 200 mA.
- **Response Time**: Very fast (< 1 ms).
- **Protection Level**: IP65–IP67 (dust and splash resistant).

Human-Machine Interface

The HMI allows the user to interact with the machine easily. In this project, it includes an LCD screen to display information and a keypad for data entry.

LCD Display

A 16x2 LCD is a widely used alphanumeric display capable of showing 16 characters per row across two rows. It is popular in embedded systems, microcontroller projects, and industrial interfaces due to its low cost, efficiency, and ease of use [45]. The figure A-7 is shown below [46].

The I2C version of the LCD simplifies connectivity by reducing the number of required data lines, making it more practical for systems with limited I/O availability.



Figure A-7:16x2 LCD Display with I2C

The main advantages:

- **Display Capacity:** 16 characters × 2 lines (32 characters total).
- **Character Format**: 5x8 pixel dot matrix per character.
- **Interface:** I2C protocol.

- **Operating Voltage:** 5V.
- **Backlight**: LED with controllable brightness.
- **Communication Pins:** VCC, GND, SDA, SCL.

keypad

A keypad is an input device consisting of a set of buttons arranged in a matrix format. It is widely used in embedded systems and automation interfaces to enter numeric or alphanumeric data into a system [47]. The figure A-8 is shown below [11].



Figure A-8:4x4 Matrix Membrane Keypad

The main advantages:

- **Electrical Interface**: Requires 8 I/O pins.
- **Layout:** 4 Rows × 4 Columns (16 keys total).
- **Input Method**: Membrane based pressure.
- **Interface Type**: direct connection to microcontroller.
- **Operating Voltage**: Compatible with 3.3V or 5V systems.

Arduino Mega

The Arduino Mega 2560 is an open-source microcontroller board based on the ATmega2560 microcontroller. Designed for complex electronics applications, it offers a significant upgrade in I/O capabilities and memory compared to other Arduino boards, such as the Uno. The Mega is widely used in industrial prototyping, robotics, control systems, and educational platforms [48]. The figure A-9 is shown below [48].

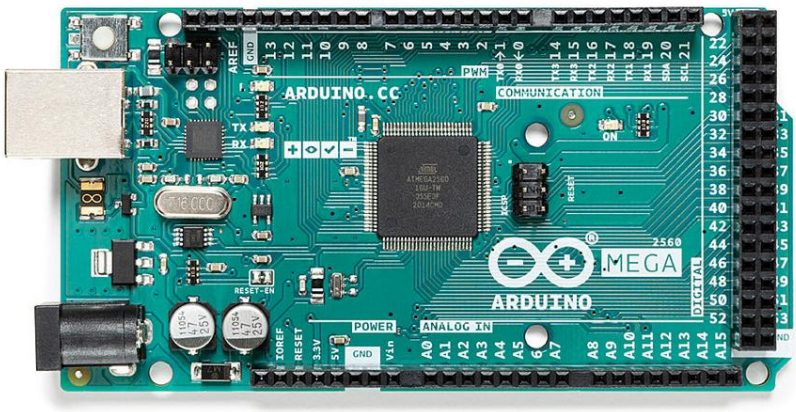


Figure A-9: The Arduino Mega 2560

Power and Initialization:

- **Power Supply**: The board can be powered via USB or an external adapter (7–12V recommended). An onboard voltage regulator converts the supply to 5V and 3.3V levels.
- **Microcontroller Boot**: When powered on, the ATmega2560 reads the program stored in its non-volatile flash memory and begins execution from the reset vector.
- **Bootloader**: A small program in memory allows code to be uploaded via USB without requiring a programmer device.

Input/Output Capabilities:

- **Input/Output**: Operations the Mega 2560 can interact with the physical world through it's I/O pins.
- **Digital I/O:** 54 pins used to read (input) or control (output) binary devices (buttons, LEDs, relays).
- **Analog Input**: 16 pins that convert analog voltages (0–5V) into 10-bit digital values.
- **PWM Output:** 15 digital pins capable of Pulse Width Modulation to simulate analog signals (motor control, LED dimming).

Electrical Characteristics:

The key electrical characteristics of the Arduino Mega microcontroller board.

- **Operating Voltage:** 5V.
- **Input Voltage (recommended):** 7–12V.

- **Input Voltage (limits):** 6–20V.
- **DC Current:** per I/O pin 20 mA (max).
- **DC Current:** for 3.3V pin 50 mA.
- **Power Source Options:** USB or external adapter.

Role of Arduino Mega:

The Arduino Mega 2560 serves as the central control unit (controller) for the automatic cutting machine. Its role is critical in coordinating all hardware components such as motors, sensors, actuators, and the HMI interface by executing a precise sequence of operations based on real time input and programmed logic.

Central Processing and Decision-Making:

Arduino Mega continuously reads data from various input devices, such as:

- Photoelectric Sensor sensors for detecting material presence.
- Capacitive Proximity sensors for position detection.
- Buttons and emergency switches for manual control.
- Keypad and HMI inputs for parameter configuration.

a-Motor Control:

The Arduino Mega is responsible for generating control signals for:

Stepper motors (via drivers) to position the rod according to the specified cutting length

b-Actuator Operation:

It activates and deactivates pneumatic cylinders via relay modules of solenoid valves, for:

- Push the bars out of the storage box
- Clamping and stabilizing the rod before cutting
- Controlling the saw blade mechanism

c-User Interface Integration:

The Arduino Mega interfaces with:

- LCD to display messages such as “Ready to Cut,” “Error,” or “No Rod Detected”.

- Keypad to allow numeric input (length, quantity).
- Emergency and stop/start buttons to ensure manual control and operator safety.

Power supply unit

The electrical power unit is responsible for supplying the necessary electrical energy to all components of the automatic cutting machine. It converts the main AC voltage into the required DC or lower AC voltages, ensuring that the control systems, motors, sensors, and actuators operate reliably and safely. A stable and well-designed power unit helps prevent voltage drops or overloads that could affect system performance [49].

The figure A-10 is shown below [50].



Figure A-10:Power supply unit

Selected Power Supply Units for this project:

Voltage Rail and Recommended Power Supply

- 12 V DC :12 V / 2A regulated switching power supply.
- 5 V DC :5 V / 2A supply.
- 5 V DC: Supplied via Arduino or external 5V regulator.

Wires of various types and sizes are selected based on current requirements, signal sensitivity, and mechanical durability. The right choice of wire gauge and insulation improves performance, reduces interference, and protects components from electrical faults.

Mechanical System components

The mechanical system plays a vital role in the operation of the automatic cutting machine. It provides the structure and motion needed to perform all physical actions, such as moving, positioning, and cutting the material. Designed for efficiency and precision, the system ensures smooth mechanical performance and seamless integration with the control system for fully automated operation.

Pulley

The pulley is a key part of the transmission system, used to guide and transfer rotary motion. In this project, two types are used:

V-Belt Pulley

A V-Belt Pulley is a mechanical component attached to the shaft of a motor to transfer rotational motion to other parts of a machine. It typically works in combination with a belt, which wraps around the pulley and connects it to a driven component (another pulley, shaft, or mechanism) [52]. The figure A-11 is shown below [11].



Figure A-11: round Groove Pulley

Type of V-Belt Pulley:

- **Belt Type Compatibility:** Classical V-belt (profile B) used with V-groove pulleys for efficient and reliable power transmission.
- **Pulley Diameter**: Motor pulley: 70 mm Blade pulley: 50 mm Selected to optimize cutting speed and torque.
- **Material:** Cast iron pulleys chosen for high durability and vibration damping.
- **Bore Size and Fixing Method:** Pulley bores matched to shaft diameters; keyway and set-screw used for secure attachment and stable operation.

Timing Belt Pulley

A timing belt pulley is a mechanical component used in motion transmission systems to synchronize the rotation between shafts. It has evenly spaced teeth that match the profile of a timing belt, allowing for precise, slip-free engagement. This ensures accurate positioning and consistent speed control, making it ideal for applications requiring timing accuracy, such as robotics, CNC machines, and automated equipment [53].

The figure A-12 is shown below [11].



Figure A-12: timing belt pulley

The type was selected based on several key factors:

- **Belt Type Compatibility:** A GT2 profile pulley was chosen to match the GT2 timing belt used in the system, ensuring accurate engagement between belt and pulley teeth.
- **Pulley Diameter:** A 100 mm pulley was selected to achieve the desired linear movement per motor revolution, based on the stepper motor's steps/rev and belt pitch.
- **Material**: The pulley is made of aluminum, which provides a good balance of strength, durability, and low weight, reducing the load on the motor.
- **Bore Size and Fixing Method:** The inner diameter (bore) was matched to the motor shaft size, and a set-screw fixing system was used to securely attach the pulley to the motor.

Belt

The belt system is used to transfer motion and power between machine components. In this project, we use two types:

Industrial Timing Belt

An industrial timing belt is a specialized type of belt used in mechanical systems to transmit power and synchronize motion between rotating components. Unlike traditional flat or V-belts, timing belts have molded teeth that fit precisely into matching grooves on pulleys. This toothed design eliminates slippage and ensures accurate timing between the driving and driven shafts. They are available in various tooth profiles (GT2, HTD, T5) and pitches, depending on the application's speed, load, and precision requirements [54].

The figure A-13 is shown below [11].



Figure A-13: Industrial timing belt

The type was selected based on several key factors:

- **Type:** GT2 Timing Belt.
- **Tooth Pitch**: 2 mm (high precision).
- **Length**: 13 m.
- **Width**: 10 mm (recommended for better strength and stability over long distance).
- **Materia**l: Rubber with fiberglass reinforcement.

V-belt

A V-belt is a type of belt used in mechanical systems to transmit power between pulleys. It has a trapezoidal (V-shaped) cross-section, which helps it grip the sides of the pulley and prevents slipping [55]. The figure A-14 is shown below [11].



Figure A-14:V-belt

Type of the V-Belt:

- **Type:** Classical V-Belt – B Profile.
- **Top Width:** 17 mm.
- **Height**: 11 mm.
- **Length**: 1 m.
- **Material:** Rubber with polyester/aramid cord reinforcement.

Bearings

Bearings are mechanical components designed to reduce friction between moving parts and support rotational or linear motion. They allow shafts or other components to rotate smoothly within machines while carrying radial and axial loads. By minimizing resistance, bearings increase efficiency, reduce wear, and extend the lifespan of equipment [56].

The figure A-15 is shown below [11].



Figure A-15:Bearing

Role of Bearings:

Bearings are used in important parts of the machine in enabling smooth and precise movement of mechanical parts. They are used to support rotating shafts. By reducing friction between moving elements, ensuring stable and smooth rotation. ensuring that the movement

remains consistent and free of vibration. Bearings are used in important parts of the machine to enable smooth and precise movement of mechanical components. They support rotating shafts and reduce friction between moving elements, ensuring stable and smooth rotation. By minimizing resistance, bearings help maintain consistent motion and eliminate vibrations.

Alignment Roller

An alignment roller is a mechanical component used to guide and correct the path of moving materials, such as bars, pipes, or sheets, during processing. It helps maintain accurate positioning, prevents misalignment, and ensures smooth movement through the system. The roller is often rubber-coated to provide good grip and protect the material surface. It is commonly used in cutting lines, conveyors, and assembly systems.

The figure A-16 is shown below [11].



Figure A-16:Alignment roller

The roller body made of steel or aluminum, providing the necessary mechanical strength, and is covered with a layer of high-friction rubber to ensure good grip on the bar surface while preventing damage.

- **Length:** 95 mm.
- **Outer Diameter:** 8 mm (rubber-coated surface).
- **Shaft Diameter**: 12 mm.

Linear Guide Rails

Linear guide rails are mechanical components designed to provide smooth, precise, and low-friction linear motion in a defined path. They consist primarily of a rail and a carriage, which travels along the rail using rolling elements such as recirculating ball bearings or rollers. Commonly used in CNC machines, robotics, and automation, they reduce wear and maintenance while ensuring reliable, repeatable positioning [57].

The figure A-17 is shown below [11].



Figure A-17: Linear guide rails.

Circular Saw Blade

A circular saw blade is a cutting tool consisting of a round, flat disc with sharp teeth on its outer edge. It rotates at high speed to cut through various materials such as wood, metal, plastic, or composites. The figure A-18 is shown below [11].



Figure A-18: Circular saw blade

For cutting PVC materials, a specialized circular saw blade is recommended to achieve clean, precise cuts without melting or chipping the material.

Key characteristics:

- **Diameter**: 200 mm.
- **Blade type:** Circular saw blade for PVC.
- **Material:** High-quality carbide-tipped (TCT) blade.
- **Tooth type:** Triple Chip Grind (TCG) or Alternate Top Bevel (ATB), these geometries are ideal for plastics and PVC.
- **Number of teeth:** Generally, between 60–80 teeth for a 200 mm blade, more teeth provide a smoother cut.

- **Blade body:** Laser-cut steel body to reduce vibration and noise.

Machine Chassis

The Chassis of the machine is the main structure that supports all the parts of the system. It holds the storage box, the pushing table, the transfer area, the cutting zone, and the assembly unit. The frame is made of welded steel profiles, which are strong and stable. This strong base helps keep all the moving parts aligned and reduces vibration when the machine is working. That way, the cuts are more accurate and the system works more reliably.

Pneumatic System Components

In this project, a pneumatic system is used to perform various linear movements and actuation tasks within the machine. Pneumatics provides a simple, reliable, and fast method to control mechanical motion using compressed air.

pneumatic cylinders

Double-acting pneumatic cylinder

A double-acting pneumatic cylinder is a type of actuator that uses compressed air to produce linear motion in both directions forward and backward. Unlike single-acting cylinders, which rely on air pressure in one direction and a spring return, double-acting cylinders use air pressure on both sides of the piston [58]. The figure A-19 is shown below [11].

Main Components:

- Cylinder barrel.
- Piston and piston rod.
- End caps with air ports (inlet/outlet).
- Seals and cushions.



Figure A-19:Double-Acting pneumatic cylinder

Push table

- **Type:** ISO 15552 standard cylinder.
- **Bore size**: 40 mm (chosen to provide sufficient pushing force).
- **Stroke**: variable, depending on the rod length to be positioned.

Single-Acting Pneumatic Cylinder:

A single-acting pneumatic cylinder is a type of actuator that uses compressed air to produce linear motion in one direction only. The return movement is achieved by an internal spring or by an external force [58]. The figure A-20 is shown below [11].

Main Components:

- Cylinder barrel.
- Piston with piston rod.
- End cap with airport.
- Internal spring for return.



Figure A-20: Single-Acting Pneumatic Cylinders

Saw motor movement:

- **Type:** guided ISO 15552 profile cylinder (with guide rods or heavy-duty cylinder)
- **Bore size:** 63 mm (to handle the weight of the saw motor and cutting forces)
- **Stroke**: depends on the required vertical travel, 200 mm

Fixing the Rod:

- **Type:** single-acting compact cylinder (ISO 21287 standard or manufacturer-specific)
- **Bore size**: 50 mm (to provide strong clamping force).
- **Stroke:** short stroke, 120mm.

Pneumatic Directional Valves

Pneumatic directional control valves are components used to control the flow of compressed air to the cylinders, determining the direction of movement and controlling when and how the air is supplied or exhausted [58]. The figure A-21 is shown below [11].

Directional valves are defined by:

- Number of ports (air inlets and outlets)
- Number of positions (switching states)
- Actuation method (manual, electric solenoid, pneumatic pilot, etc.)
- A common way to describe them is with the notation "X/Y valve", where:

X = number of ports

Y = number of positions



Figure A-21:Pneumatic Directional Valves

For double-acting cylinders:

- **Valve required:** 4/3-way valve
- **Actuation**: Electric solenoid
- **Function:** The valve controls forward and backward movement of each positioning cylinder by switching air to one side of the cylinder while exhausting the other.

For single-acting cylinders:

- **Valve required:** 3/2-way valve
- **Actuation:** Electric solenoid
- **Function:** The valve controls air supply to the clamping cylinder. When air is applied, the cylinder clamps. When the valve switches, air is exhausted and the spring returns the cylinder.

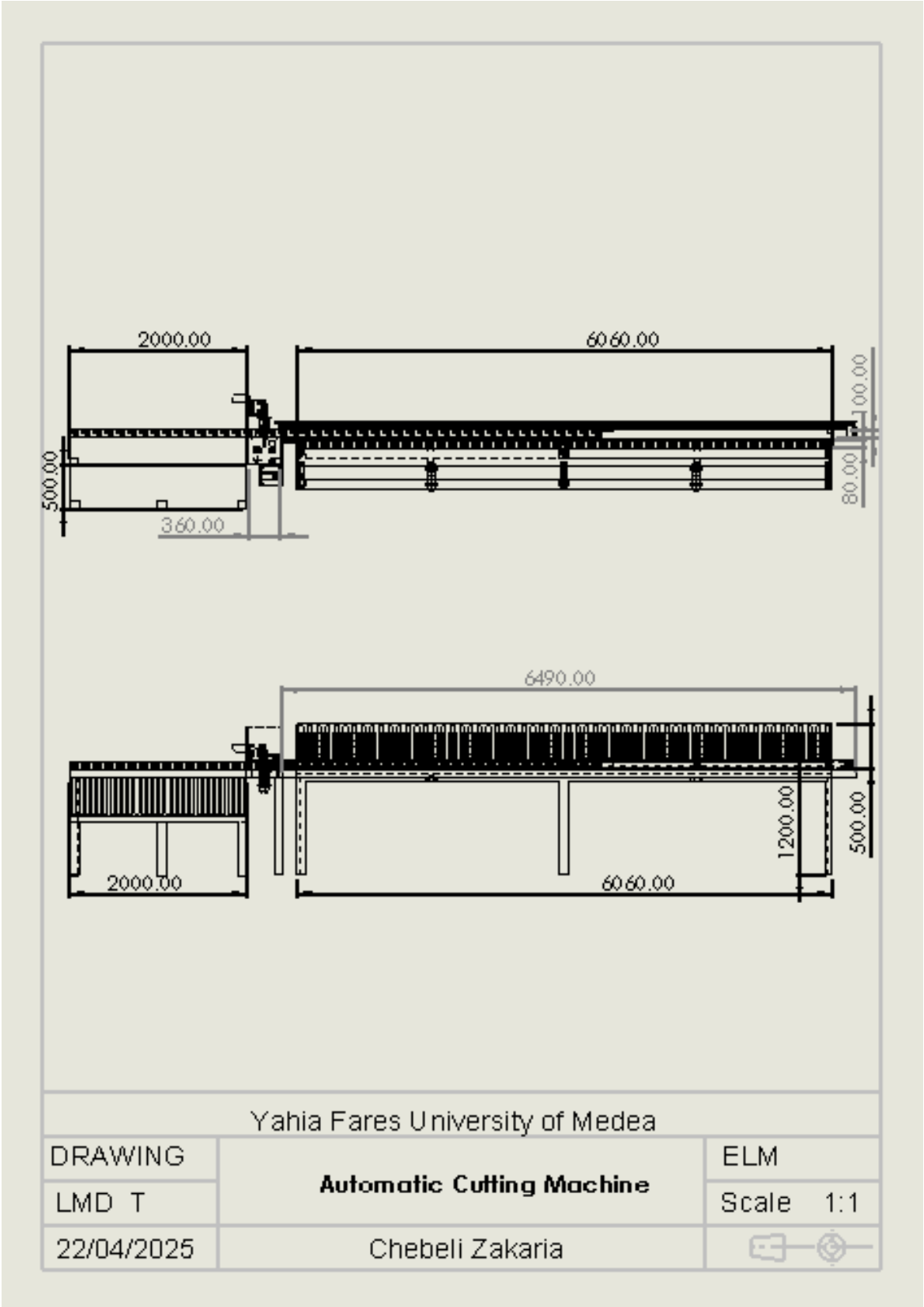
Table of Machine Components and Quantities

The table presents the main components utilized in the construction of the automatic cutting machine, categorized into electrical, mechanical, and pneumatic systems.

Table A-1:Table of Machine Components and Quantities

Component Category	Component Type	Quantity
Electrical System Components	Stepper motors closed-loop	1
	Stepper motor drivers closed-loop	1
	AC induction motor	1
	Capacitive sensors	2
	Photoelectric sensors	2
	LCD display	1
	Keypad	1
	Arduino Mega microcontroller	1
	Power supply units	3
Mechanical System Components	Timing pulleys	2
	V-belt pulleys	2
	Timing belts	1
	V-belts	1
	Bearings	8
	Alignment rollers	3
	Linear guide rails	2
	Circular saw blade	1
Pneumatic System Components	Double-acting pneumatic cylinders	2
	Single-acting pneumatic cylinders	3
	4/3 pneumatic directional valves	2
	3/2 pneumatic directional valves	3

Annexes (B)


2000.00
6060.00
500.00
360.00
80.00
6490.00
1200.00
500.00
2000.00
6060.00
Yahia Fares University of Medea
DRAWING
Automatic Cutting Machine
ELM
LMD T
Scale 1:1
22/04/2025
Chebeli Zakaria

Bibliography

[1] M. Groover, Automation, Production Systems, and Computer-Integrated Manufacturing, 4th ed. Boston, MA, USA: Pearson, 2015.

[2] S. Kalpakjian and S. R. Schmid, Manufacturing Engineering and Technology, 7th ed. Boston, MA, USA: Pearson, 2014.

[3] R. H. Todd, D. K. Allen, and L. Alting, Manufacturing Processes Reference Guide, New York, NY, USA: Industrial Press Inc., 1994.

[4] "The Advantages of Fully Automatic Cutting Machines," Industry Today, [Online]. Available: https://industrytoday.com/the-advantages-of-fully-automatic-cutting-machines/. Accessed Mar. 25, 2025.

[5] [Omitted intentionally, not in original list.]

[6] Advances, Traditional Machining Processes: Research. [Online]. Available: https://example.com/advances-traditional-machining-processes. Accessed Mar. 26, 2025.

[7] M. P. Groover, Fundamentals of Modern Manufacturing: Materials, Processes, and Systems, 6th ed., Hoboken, NJ, USA: Wiley, 2015.

[8] Department, in Chapter 7 of US Army Training Circulation published in 1996 (Chemical Engineering), [Online]. Available: https://example.com/us-army-training-circulation. Accessed Mar. 27, 2025.

[9] Excelsior Inc., "Lathe Cutting," Excelsior Inc., [Online]. Available: https://www.excelsiorinc.com/lathe-cutting. Accessed Mar. 28, 2025.

[10] Occupational Safety and Health Administration (OSHA), "29 CFR 1910.212 – General Requirements for All Machines," [Online]. Available: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.212. Accessed Mar. 29, 2025.

[11] Product Title, IndiaMART. [Online]. Available: https://www.indiamart.com/your-product-url. Accessed Mar. 30, 2025.

[12] [Omitted intentionally, not in original list.]

[13] R. J. Hurst, Electric Power Tools Handbook, New York, NY, USA: McGraw-Hill, 2003.

[14] V. K. Jain, Advanced Machining Processes. New York: McGraw-Hill, 2019.

[15] Kanyana Engineering, "What is Plasma Cutting?" [Online]. Available: https://kanyanaengineering.com.au/plasma-cutting/#What_Is_Plasma_Cutting. Accessed Mar. 31, 2025.

[16] L. Beltrán et al., "Quantitative Analysis of the Dehumidification Parameters of Compressed Air for CNC Plasma."

[17] TWI Ltd. [Online]. Available: https://www.twi-global.com. Accessed Apr. 1, 2025.

[18] Artisan Model Makers, “How does CO_2 laser cutting work?” Artisan Model Makers Blog, May 17, 2016. [Online]. Available: https://www.artisanmodelmakers.co.uk/blog/how-does-co2-laser-cutting-work/laser-beam/. Accessed Apr. 2, 2025.

[19] Industrial Quick Search (IQS) Directory, "Water Jet Cutting: Types, Uses and Processes," [Online]. Available: https://www.iqsdirectory.com/articles/water-jet-cutting.html. Accessed Apr. 3, 2025.

[20] D. S. Harder, "Automation," Ford Motor Company, 1946. [Online]. Available: https://www.britannica.com/technology/automation. Accessed Apr. 4, 2025.

[21] “What is Industrial Automation?” Process Control, Celtex.com. [Online]. Available: https://www.celtex.com. Accessed Apr. 5, 2025.

[22] Closed-Loop Control System, Electronics Coach. [Online]. Available: https://electronicscoach.com/closed-loop-control-system. Accessed Apr. 6, 2025.

[23] National Institute of Standards and Technology, defined in IEEE 1451.2.

[24] V. Yadav, "Sensors," Veer Bahadur Singh Purvanchal University, Jaunpur, India. [Online]. Available: https://www.vbspu.ac.in/e-content/Vishal-Yadav/Sensors.pdf. Accessed Apr. 7, 2025.

[25] C. Cartiman, "Product Types of Allen Bradley Inductive-Proximity-Sensors…" Program-PLC, Jan. 16, 2017. [Online]. Accessed Apr. 8, 2025.

[26] W. Bolton, Programmable Logic Controllers, 6th ed. Oxford, UK: Newnes, 2015.

[27] J. W. Webb and R. A. Reis, Programmable Logic Controllers: Principles and Applications, 5th ed., Upper Saddle River, NJ, USA: Prentice Hall, 2002.

[28] F. D. Petruzella, Programmable Logic Controllers, 5th ed., New York, NY, USA: McGraw-Hill Education, 2016.

[29] International Journal of Engineering and Techniques, Volume 4 Issue 3, May – June 2018.

[30] "Actuators: Types and Working Principles," ThomasNet, [Online]. Available: https://www.thomasnet.com/articles/hardware/actuators-types-and-working-principles/. Accessed Apr. 9, 2025.

[31] M. J. D. Powell, Industrial Automation: Hands-On, 1st ed., New York, NY, USA: McGraw-Hill Education, 2018.

[32] A. Prabakaran, "Stepper vs Servo Motors…" [Online]. Available: https://example.com/stepper-vs-servo. Accessed Apr. 10, 2025.

[33] S. R. Majumdar, Oil Hydraulic Systems: Principles and Maintenance, New Delhi, India: Tata McGraw-Hill, 2002.

[34] AVEVA Group plc. [Online]. Available: https://www.aveva.com. Accessed Apr. 11, 2025.

[35] Anaheim Automation, "Human Machine Interface Guide," [Online]. Available: https://anaheimautomation.com/blog/post/human-machine-interface-guide. Accessed Apr. 12, 2025.

[36] Codinter Editorial Team, “How to Transition from Manual to Automated Cutting,” Codinter, Nov. 8, 2024. [Online]. Available: https://www.codinter.com/en/how-to-transition-from-manual-to-automated-cutting/. Accessed Apr. 13, 2025.

[37] J. R. Hurst, Electric Power Tools Handbook, New York, NY, USA: McGraw-Hill, 2003.

[38] OMC-Stepper Online, "What is a closed-loop stepper motor?" [Online]. Available: https://www.omc-stepperonline.com/support/what-is-a-closed-loop-stepper-motor. Accessed Apr. 14, 2025.

[39] K. Venkata Ratnam, Special Electrical Machines. Hyderabad, India: Universities Press, 2008, pp. 122–126.

[40] "Stepper Motor,” Electronics Tutorial, [Online]. Available: https://www.electronics-tutorial.net/electronic-systems/stepper-motor/. Accessed Apr. 15, 2025.

[41] Texas Instruments. DRV8825 Stepper Motor Controller Datasheet, [Online]. Available: https://www.ti.com/lit/ds/symlink/drv8825.pdf. Accessed Apr. 16, 2025.

[42] “Induction motor,” Wikipedia, [Online]. Available: https://en.wikipedia.org/wiki/Induction_motor. Accessed Apr. 17, 2025.

[43] M. D. Laughton and D. F. Warne, Electrical Engineer's Reference Book, 16th ed., Elsevier, 2003, pp. 15–21.

[44] R. Smith, "Photoelectric Sensors: Principles and Applications," [Online]. Available: https://example.com/photoelectric-sensors. Accessed Apr. 18, 2025.

[45] A. Banerjee, Interfacing 16x2 LCD with I2C Module. Circuit Digest, [Online]. Available: https://circuitdigest.com/microcontroller-projects/interfacing-16x2-lcd-with-i2c-module. Accessed Apr. 19, 2025.

[46] Electronic Wings, "LCD16x2 (I2C) Interfacing with ESP32," [Online]. Available: https://www.electronicwings.com/nodemcu/lcd16x2-interfacing-with-nodemcu-using-i2c. Accessed Apr. 20, 2025.

[47] A. J. Mahajan and A. A. Shinde, "Design and Implementation of Password Based Security Door Locking System Using 8051 Microcontroller," International Journal of Engineering Research and General Science, vol. 3, no. 2.

[48] Arduino Official Documentation. “Arduino Mega 2560 Rev3,” [Online]. Available: https://docs.arduino.cc/hardware/mega-2560. Accessed Apr. 21, 2025.

[49] J. W. Nilsson and S. A. Riedel, Electric Circuits, 11th ed., Pearson, 2018.

[50] D. Greenfield, “5 Critical Functions of Modern Industrial Power Supplies,” Automation World, Feb. 13, 2024. [Online]. Available: https://www.automationworld.com. Accessed Apr. 22, 2025.

[51] Firefly Electric and Lighting Corporation, "Top 5 Things You Should Know About Wires & Cables," [Online]. Available: https://fireflyelectric.com/blogs/news/top-5-things-about-wires-and-cables. Accessed Apr. 23, 2025.

[52] “Belt and Gear Driven Systems,” Mechanics Map – Penn State, [Online]. Available: https://mechanicsmap.psu.edu/websites/belt-and-gear-driven-systems/. Accessed Apr. 24, 2025.

[53] Motion Systems, Inc., “What is a Timing Belt Pulley?” [Online]. Available: https://motionsystems.us/blogs/news/what-is-a-timing-belt-pulley. Accessed Apr. 25, 2025.

[54] “Timing Belts,” Pixtrans.com, [Online]. Available: https://www.pixtrans.com/timing-belts.html. Accessed Apr. 26, 2025.

[55] R. L. Mott, Machine Elements in Mechanical Design, 5th ed., Pearson Education, 2013.

[56] “Bearing (mechanical),” Wikipedia, [Online]. Available: https://en.wikipedia.org/wiki/Bearing_(mechanical). Accessed Apr. 27, 2025.

[57] R. E. Bolz & G. L. Tuve (Eds.), CRC Handbook of Tables for Applied Engineering Science. CRC Press, 1973.

[58] A. Esposito, Fluid Power with Applications, 7th ed. Pearson Education, 2009.

[59] SOLIDWORKS Introduction Guide, Dassault Systems, [Online]. Available: https://www.solidworks.com. Accessed Apr. 28, 2025.

[60] R. Anderson, "Benefits of 3D Modeling in Product Development," Mech. Eng. Mag., vol. 143, no. 6, pp. 32–35, 2021. [Online]. Accessed Apr. 29, 2025.

[61] Cirkit Designer, "Web-based Circuit Design and Simulation Tool." [Online]. Available: https://app.cirkitdesigner.com. Accessed Apr. 30, 2025.

[62] Festo Didactic, “FluidSIM – Software for Creating and Simulating Circuits,” [Online]. Available: https://www.festo-didactic.com/int-en/industrial-education/training-software/fluidsim/. Accessed May 1, 2025.

[63] “Carpenter at work cutting laminate with a buzz saw,” *Dreamstime*, [Online]. Available: https://www.dreamstime.com/stock-photos-carpenter-work-cutting-laminate-buzz-saw-image36040843. Accessed Apr. 05, 2025.