An Autonomous Institute

MVJ COLLEGE OF ENGINEERING

Whitefield, Near ITPB, Bengaluru - 560067

PROJECT REPORT ON

"STRUCTURAL DESIGN AND FABRICATION OF TWO AXIS FOAM CUTTING MACHINE"

INTERNSHIP REPORT

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In Partial Fulfilment for the award of degree of

Bachelor of Engineering

In

Aeronautical Engineering, Electrical and Electronics Engineering &

Artificial Intelligence and Machine Learning

2022 – 2023

An Autonomous Institute

Affiliated to Visvesvaraya Technological University, Approved by AICTE, New Delhi

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Near ITPB, Channasandra, Bengaluru – 560067

DEPARTMENT OF MECHANICAL ENGINEERING

CERTIFICATE

Certified that the project work titled **"STRUCTURAL DESIGN AND FABRICATION OF TWO AXIS FOAM CUTTING MACHINE"** was caried out by **ADITYA SHASHIKANT GOLED (1MJ21AE003), SHAHAJI (1MJ21AE067), ABHINAV (1MJ21EE003)** and **UJWAL (1MJ21AI055)** in partial fulfilment for the award of Bachelor of Engineering in Aeronautical Engineering, Electrical and Electronics Engineering & Artificial Intelligence and Machine Learning of the **Visvesvaraya Technological University, Belagavi** during the year 2022 - 2023. It is certified that that all corrections / suggestions indicated for Internal Assessment have been incorporated in the report deposited in the department library. The project report has been approved as it satisfies the academic requirements in respect of internship work prescribed by the institution for the said degree.

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DECLARATION

We, **ADITYA SHASHIKANT GOLED (1MJ21AE003), SHAHAJI (1MJ21AE067), ABHINAV (1MJ21EE003)** and **UJWAL (1MJ21AI055)** student of Second Semester B.E., Department of Mechanical Engineering, MVJ College of Engineering, Bengaluru - 560067, hereby declare that the Internship titled **"STRUCTURAL DESIGN AND FABRICATION OF TWO AXIS FOAM CUTTING MACHINE"** has been carried out by us and submitted in partial fulfilment for the award of the degree of Bachelor of Engineering in Aeronautical Engineering, Electrical and Electronics Engineering & Artificial Intelligence and Machine Learning during the year 2022 - 2023.

Further, we declare that the content of the report has not been submitted previously by anybody for the award of any degree or diploma to any other University.

Place - Bengaluru

Date -

Regards,

Name	USN	Signature
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ACKNOWLEDGEMENT

The satisfaction and euphoria that accompany a successful completion of any task would be incomplete without the mention of people who made it possible. So, with gratitude we acknowledge all those who has guided and encouraged us as beacon of light and crowned our effort with success. We are thankful to the Management of **MVJ College of Engineering** Bangalore for their continuous support and encouragement for carrying out the project work.

We are thankful to our **Dr. SURESH BABU V**, Principal, MVJCE, Bengaluru and **Dr. BRINDHA M**, Vice Principal, MVJCE, Bengaluru for being a constant inspiration and providing all the facilities that was needed throughout the project.

We are thankful to our **Dr. SANTOSH N**, Professor and Head, Department of Mechanical Engineering, MVJCE, Bengaluru, for being a constant Support and providing all the facilities that was needed throughout the project work.

We consider it as a privilege and honour to express our sincere gratitude to our guide **Prof. KRISHNA PRASAD R**, ASSOCIATE PROFESSOR, Department of Mechanical Engineering, MVJCE, for his encouragement that has been a constant source of motivation to us for successful completion of our project.

We are in debt to the support of all the teaching and non-teaching members of Department of Mechanical Engineering, for their kind help and co-operation, throughout our graduation. Their constant support and love have made this journey a memorable.

ABSTRACT

This project aims to design and fabricate a two-axis computer numerical controlled (CNC) foam cutting machine, along with its control system. CNC technology enables the machine to follow complex cutting paths, replicate designs accurately, and produce consistent results, thereby enhancing the quality and versatility of foam cutting processes. Limited Design Complexity: Existing foam cutting machines often face limitations when it comes to cutting intricate or complex designs. By addressing these gaps, the proposed project of designing and fabricating a two-axis CNC foam cutting machine with an advanced control system can significantly improve the foam cutting process.

Designing and fabricating a two-axis computer numerical controlled (CNC) foam cutting machine involves several steps -

- Design the Mechanical Structure - Develop a mechanical design for the machine that includes the frame, cutting table, gantry, and axes.
- Design the Control System - Develop the control system for the CNC machine.
- Design the Cutting Tool - Determine the appropriate cutting tool for foam cutting.

Additionally, it is advisable to consult with experts in control systems, mechanical engineering, and CNC technology to ensure the successful design and fabrication of the foam cutting machine.

LabVIEW can be utilized to simulate and test the control system of the foam cutting machine. These simulation tools enable engineers to analyze and optimize the control system, mechanical design, and production processes of the foam cutting machine before physical fabrication, reducing the risk of errors and improving overall performance.

- Motor Drivers - Motor drivers are electronic devices that provide the necessary power and control signals to drive the motors responsible for the machine's two axes of motion.
- Precise and Accurate Cutting - A well-designed control system can enable precise positioning and accurate cutting of foam materials.
- Improved Cutting Speed - By optimizing the control algorithms and motion profiles, the cutting speed of the foam cutting machine can be increased while maintaining accuracy.

ACRONYMS

- **SDF2XFCM -** Structural Design and Fabrication of Two-Axis Foam Cutting Machine
- **SDFTCM -** Structural Design and Fabrication of Two-Axis Cutting Machine
- **SDFFCM -** Structural Design and Fabrication for Foam Cutting Machine
- **SDF2XFC -** Structural Design and Fabrication of Two-Axis Foam Cutter
- **SDTAFM -** Structural Design and Fabrication of Two-Axis Foam Machine
- **SDFM2X -** Structural Design and Fabrication of Foam Machine with Two Axes
- **SDF2XCCM -** Structural Design and Fabrication of Two-Axis CNC Foam Cutting Machine
- **SDCNC2XFCM -** Structural Design and CNC Fabrication of Two-Axis Foam Cutting Machine
- **SDFCFM -** Structural Design and Fabrication of Custom Foam Machine
- **SDFTAFCCM -** Structural Design and Fabrication of Two-Axis Foam Cutting and Contouring Machine

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CHAPTER - 1

INTRODUCTION

1. INTRODUCTION

The foam mold making for Unmanned Aerial Vehicles should be efficient and accurate to improve research and manufacturing. Hot wire cutting is a widely used method in foam cutting. In hot wire cutting, accuracy and quality of the foam cut mainly depends on the variable cutting parameters which affect the cutting process. To perform a proper cut with required quality the cutting parameters should be set precisely and accurately. This project is to design, fabricate and identify the variations and inter dependency of cutting parameters. It is important to estimate appropriate cutting parameter values before the actual cut. The results of this project work aid to improve the hot wire foam cutting by solving the limitations and drawbacks to select best cutting parameters.

The structure designed includes a plurality of rotary to linear converters for providing linear motion on a plurality of mutually perpendicular axes. In a further preferred embodiment said motor has a resolver resolution of not less counts per revolution, and a good resolver repeatability. In a particular embodiment there is provided a relatively fixed base. Precise control for the cutting parameters, proper mechanisms and controllers should be implemented by analyzing the behavior and characteristics of cutting parameters.

According to the invention a linear gantry robot includes a rotary-to-linear motion converter for providing linear motion on at least one axis, an electric motor, a direct driving connection between PMDC motor and the rotary element of said converter, a control circuit for said motor permanent magnet direct current motor. (PMDC)

The structure designed includes a plurality of rotary to linear converters for providing linear motion on a plurality of mutually perpendicular axes. In a further preferred embodiment said motor has a resolver resolution of high counts per revolution, and a resolver repeatability of not more than 25 arc seconds. In a particular embodiment there is provided a relatively fixed base and a plurality of robots as above defined, each of said robots having an out- put member which is linearly movable in three mutually perpendicular directions.

1.1. Project background

Flying aircraft modelling as a hobby has undergone significant development in the 21st century. This occurred because of miniaturization of power and radio electronics, increase in power density for both electric motors and batteries as well as availability of strong and lightweight and easy to process foamed polymer materials: EPP, EPS, XPS. Many companies produce RC model bodies from these materials with intricate shape either for advanced aerodynamics or resemblance to famous airplanes. Manufacturers use foam molding process. This process is well suited for mass production, since one high quality matrix can be used to produce many identical parts, like fuselage or wings (in case of RC models). Hobbyists that prefer to make their models at home with hand tools are usually limited to much simpler shapes that are obtained via bending plain Styrofoam sheets around multiple cross-sectional elements.

CNC hot wire foam cutting machines are used to cut solid shapes using foam, autonomously controlled by the commands obtained by computational model. The industry of Unmanned Aerial Vehicles (UAV) is lacking an effective method to produce components like wing and fuselage. The conventional method of making fiber glass wings is using a wooden plug. It is experienced the method does not yield sufficient surface finish in the outer surface. If the airplane parts are produced inside molds, high accuracy and surface quality can be acquired. Construction of foam molds to manufacture these components can be identified as a good solution.

However, proper methods should be implemented to cut foam materials with the required accuracy. CNC hot wire foam cutting is an effective way of producing foam products with high accuracy and surface finish. Development of a CNC hot wire foam cutting machine with required performance should be done paying attention to several factors. The attention should be given to the existing machines and their mechanisms. The literature emphasizes that there are limitations and drawbacks in hot wire foam cutting process.

Identifying and controlling the cutting parameters are considered as the main factors affecting the product quality. The controlling should be precisely done to move the hot wire in the correct path. Errors which occur when selecting and setting the cutting parameters will result in a faulty product. That is not compatible with its intended application. Precise control for the cutting parameters, proper mechanisms and controllers should be implemented by analyzing the behavior and characteristics of cutting parameters. There are quite a few research papers published in this area. The mechanisms used in advanced foam cutting machines are not published public. The main cutting parameters involved are cutting wire material and its dimensions, cutting speed, cutting temperature, tension of the cutting wire and kerf width.

Considering the existing mechanisms, the best method has to be selected and the improvements must be done to get the best possible output. In this study, a set of experiments were carried out to find these conditions and methods. After conducting the experiments on Styrofoam [Polystyrene (PS)] the results were analyzed. By plotting the obtained data, the best conditions for conducting the cutting operation were identified. A feed rate equation to obtain the constant kerf width with respect to variable temperature was developed by plotting multidimensional relationships between different parameters.

1.2. Source and identification of the problem

Current additive rapid prototyping technologies fail to efficiently produce objects greater than $0.5m^3$ due to restrictions in build size and build time. Conversely large hot-wire cutting machines, able to cut large objects, often lack the ability to create surfaces with complex geometrical features. Therefore, there is a need to develop rapid prototyping and manufacturing technologies capable of producing large objects in a rapid manner directly from CAD data.

Large sized freeform objects made of soft materials, such as polystyrene foam, have numerous uses including; conceptual design of commercial products, automotive design, aerodynamic and hydrodynamic testing, advertising, film making, medical supports, sporting equipment and props for the entertainment industry.

Plastic foam cutting rapid prototyping is a relatively new technology capable of producing large plastic foam objects directly from CAD data. This project work is aimed at developing one such technology to “STRUCTURAL DESIGN AND FABRICATION OF TWO AXIS FOAM CUTTING MACHINE”.

CHAPTER - 2

LITERATURE SURVEY

2. LITERATURE SURVEY

2.1. Papers

- RAPID PROTOTYPING AND MANUFACTURING: A REVIEW OF CURRENT TECHNOLOGIES
- HUGO I. MEDELLIN-CASTILLO, JOEL ESAU PEDRAZA TORRES
- FACULTY OF ENGINEERING, AUTONOMOUS UNIVERSITY OF SAN LUIS POTOSÍ, AV. MANUEL NAVA NO. 8, ZONA UNIVERSITARIA, 78290, SAN LUIS POTOSÍ, S.L.P., MEXICO.

The idea to develop processes capable to produce physical components quickly and without requiring tooling, led to the development of the "free form fabrication" (FFF) or "rapid prototyping" (RP) technologies in the early 1980s. RP systems generally build up a prototype directly from the computer-aided design (CAD) data by using an additive "layer by layer" method. The RP technologies have brought several advantages to the manufacturing industry in such a way that these technologies are evolving toward the production of end-use parts. This paper presents a review of rapid prototyping and manufacturing (RP&M) technologies from their origins. The review includes commercially available RP systems and RP technologies that are still at the development stage or that have been proposed. The operating principles and the features of these technologies are presented. Process parameters such as accuracy, layer thickness, operation speed is given. An extended classification of RP&M technologies is also included in this paper.

2.2. Selective coaxial ink 3D printing for single - pass fabrication of smart elastomeric foam with embedded stretchable sensor

- J IA asked x UA, Xing Hao Zhang A, Y UL IU ah, de, yang Zhang B, he ng-yon NGN IEC, G Au Yang Zhang A, Wei Lian GA OA
- School of Mechanical Engineering, Jiangnan University, Wuxi, 214122, China
- Department of Mechanical Engineering, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark
- Surface Science Western, The University of Western Ontario, London, N6A 3K7, Ontario, Canada

- Jiangsu Key Lab of Advanced Food Manufacturing Equipment and Technology, Jiangnan University, Wuxi, 214122, China.

Cellular materials are playing a critical role in a vast number of smart applications. Latest advances in additive manufacturing have catalyzed the structural metaproperties of the cellular materials. However, a major challenge remains for straightforward and rapid fabrication of smart cellular foams with embedded sensors while minimizing negative impacts on their mechanical performances. In this work, a selective coaxial ink 3D printing method is disclosed for manufacturing a smart elastomer cellular foam at a single pass, with its capability of precisely assigning a core–shell fiber segment as a strain sensor inside the cellular structure. Mechanical test results on these core–shell fiber segments point out that higher sensitivity can be obtained upon tension rather than compression. Therefore, in consideration of the effects of cellular structure i.e., face centered tetragonal (FCT) and simple cubic (SC), it is revealed that the FCT structure outperforms with a much higher strain sensitivity.

By assigning different number of cellular layers and tuning the line spacing inside the cellular structure, the mechanical effects with embedding the sensor in the smart foam are assessed and increasing the line spacing might increase the sensitivity but will degrade the repeatability. In final, the stretching performance of the smart foam is studied, and its application is demonstrated.

- Topology optimization of 3D continuum structures under geometric self-supporting constraint
- Mangham Bi, Phuong Tran, Yi Min Xia
- Centre for Innovative Structures and Materials, School of Engineering, RMIT University, Melbourne, Victoria 3001, Australia.

The potential of additive manufacturing (AM) in fabricating structurally efficient yet geometrically complicated designs generated from topology optimization is widely recognized. However, various constraints presented in the additive manufacturing process are not directly considered in conventional topology optimization frameworks, potentially impairing the manufacturability of the generated topology. A most noteworthy example is the presence of overhangs, which are downward-facing regions that are not self-supporting. In such areas, traditional AM processes utilize sacrificial supports to act as scaffoldings, which result in additional time, effort and the corresponding cost. Here we present a novel method that can effectively address overhanging features in the bi-directional evolutionary structural optimization framework, creating self-supporting yet structurally efficient designs. By using a simple expression, the overhang problem is formulated as a layer-wise relationship, and elements whose modification does not create overhang are selected as candidates for the element updating scheme. To validate the effectiveness of the algorithm, numerical examples under different design conditions are presented. A comparison of the self-supporting designs against their non-self-supporting counterparts obtained by conventional topology optimization demonstrates their competitiveness in structural performance. Subsequently, physical 3D prints of the examples further prove the effectiveness of the proposed method in creating self-supporting designs.

- Effects of interlayer notch and shear stress on interlayer strength of 3D printed cement paste
- Lewei He, Wai Tuck Chow, Hua Li
- School of Mechanical and Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Republic of Singapore

In this paper for investigation of the effect of interlayer notch and shear stress on interlayer strength of 3D printed cement paste, experimental work is conducted with emphasis on the effects of nozzle shape, nozzle height and printing speed on the interlayer strength. It is observed experimentally that the cement paste printed by the circular nozzle generally achieves a higher interlayer strength, compared with that printed by the rectangular nozzle. A smaller nozzle height may impair the interlayer strength if the interlayer notch is not treated properly. In addition, a higher printing speed marginally increases the interlayer strength, showing the promise of a higher productivity. Theoretically, the experimental phenomena are innovatively explained by the interlayer notch coupled with shear stress on the contact surface, through finite-element and computational-fluid dynamics simulations. Therefore, reducing the interlayer notch and increasing the interlayer shear stress become crucial in the cement paste for 3D printing process.

2.3. SCOPE AND OBJECTIVE

Large sized freeform objects made from soft materials have numerous uses including; conceptual design of commercial products, automotive design, aerodynamic and hydrodynamic testing, advertising, film making, medical supports, sporting equipment and the entertainment industry. One such soft material is polystyrene foam which exists in two basic forms; Expanded Polystyrene (EPS) and Extruded Polystyrene (XPS).

There are a number of well recognized manufacturing technologies capable of rapidly producing complex objects or large objects but there are few that can do both with low cost. Conventional additive rapid prototyping (RP) technologies are continuing to improve in speed and accuracy, however the ability to produce large (> $0.5m^3$) prototypes, molds or parts is still expensive, time consuming and often impossible.

2.3.1. The objectives and scope of this project work are as follows -

2.3.1.1. Conceptualization and Design -

To design a three degree of freedom 3D foam cutting machine with all the details and fabricate the foam cutting machine using the current interfacing circuiting and the controlling software.

2.3.1.2. Empirical Study and Mechanical design of the structure -

To quantitatively measure the cutting conditions. This includes the effects of feed rate, materials, electrical power, cutting element geometry and cutting tool temperature on cutting force, surface texture and kerf width.

2.3.1.3. CAD Modeling –

Develop transient CAD models of the foam cutting process – the straight-line cutting path case for both hot-wires and hot-ribbons and the curved cutting path case for hot-ribbons. Correct simulation will provide a means of predicting the results of future cuts and could lead to improved cutting tool design.

CHAPTER - 3

METHODOLOGY

3. METHODOLOGY

3.1. INTRODUCTION TO METHODOLOGY

Foam cutting RP machines have been developed which enable the manufacture of large and complex objects with low cost, they bridge the gap between conventional RP machines and conventional foam cutting machines. Development of foam cutting machines for rapid prototyping and manufacturing (RP & M) purposes began shortly after the first rapid prototyping machines became commercialized in the late 1980s. However, few RP foam cutting machines have been commercialized to-date leaving significant opportunities for research and development in this area. The following paper will describe novel foam cutting RP machines that have been developed or are currently being developed at institutions around the world.

STEPS IN THE PROJECT METHODLOGY IS LISTED BELOW

STEP - 1

KEY DESIGN DECISIONS

THIS SECTION COVERS THE FOLLOWING:

IDENTIFYING THE RIGHT DESIGN FOR PROJECT WORK

REQUIRED CUTTING AREA

SPACE AVAILABILITY

MATERIALS

TOLERANCES

CONSTRUCTING METHODS

AVAILABLE TOOLS

BUDGET

STEP - 2

The Base and X-axis Frame

This section covers the following:

Designing and Building the main base or x-axis base

A breakdown of different designs

Fully Supported Frames

Partially Supported Frames

STEP - 3

The Y- Axis Design

This section covers the following:

Designing and Building the Y-axis Gantry

A breakdown of different designs

Forces and Moments on the Gantry

Do's and Don't

STEP - 4

The Z- Axis Assembly Design

This section covers the following:

Designing and Building the Z-axis Assembly

Forces and Moments on the Z-axis Assembly

Linear rail/rods and bearing spacing

The Plunge arm Design

Foam Cutting RP Machines Foam cutting RP machines use a range of methods to produce plastic foam objects from CAD data. The criteria used to categorize foam cutting RP systems in this paper are as follows:

- The build material must be a plastic foam such as expanded or extruded polystyrene.
- The tool path and machining strategy should be determined directly from a 3D digital representation of the prototype.
- The system should be able to create complex freeform shapes.
- The system should have a software-based user interface for efficient transfer of information between the operator and the RP system. The following sections describe different foam cutting RP machines developed or currently under development around the world. The most common method of fabrication is layered manufacturing, in which the part is built up by assembling individual layers, however direct sculpting and heat ablation methods also exist.

STEP - 5

THE LINEAR MOTION SYSTEM

THIS SECTION COVERS THE FOLLOWING:

DETAILED OVERVIEW OF LINEAR MOTION SYSTEMS

CHOOSING THE RIGHT SYSTEM FOR YOUR MACHINE

DESIGNING AND BUILDING YOUR OWN

LINEAR SHAFT AND BUSHINGS

LINEAR RAILS AND GUIDE BLOCKS

STEP - 6

Mechanical Drive Components

This section covers the following topics:

Detailed overview of the drive components

Choosing the right components for your design

Stepper and Servo motors

Lead screws and ball screws

Drive nuts

Radial and thrust Bearings

Motor coupling and mounting

Direct drive vs. Geared

Rack and Pinions

Lead screw motor sizing

STEP - 7

Choosing The Motors

This section covers the following topics:

Detailed overview of the motors

Types of motors

Stepper vs Servo motors

How Stepper motors work

Types of steppers motors

How Servo motors work

Types of Servo Motors

NEMA Standards

Choosing the right motor type for your design

Motor Sizing

STEP - 8

THE CUTTING TABLE DESIGN

THIS SECTION COVERS THE FOLLOWING:

THE CUTTING TABLE DESIGNS OVERVIEW

T-SLOT TABLE

VACUUM TABLE

PERFORATED CUTTING BED

THE CUTAWAY BED

DESIGNING AND BUILDING YOUR OWN

STEP - 9

THE SPINDLE OPTIONS

THIS SECTION COVERS THE FOLLOWING:

SPINDLES OVERVIEW

TYPES AND FEATURES

PRICING AND COSTS

MOUNTING AND COOLING OPTIONS

COOLANT SYSTEMS

BUILDING YOUR OWN

HOW TO CALCULATE CHIP LOAD AND CUTTING FORCE

HOW TO FIND OPTIMAL FEED RATES

STEP - 10

The Electronics

This section covers the following:

Electronics overview

The Control panel

Wiring and Fusing

Buttons and switches

MPG's and Jog wheels

Power Supplies

GRBL is ready for light duty production. We use it for all our milling, running it from our laptops using great user-written GUIs or with a simple console script (included) to stream the G-code. It is written in optimized C utilizing all the clever features of the Arduino's Atmega328p chips to achieve precise timing and asynchronous operation. It is able to maintain more than 30kHz step rate and delivers a clean, jitter free stream of control pulses

STEP - 11

The CNC Controller options

This section covers the following:

The CNC Controller overview

Controller selection

Options available

Closed loop vs. Open loop systems

Best priced controllers

Building your own from scratch

STEP - 12

SELECTING THE SOFTWARE

THIS SECTION COVERS THE FOLLOWING:

THE CNC RELATED SOFTWARE OVERVIEW

WHAT SOFTWARE WILL I NEED

CAM SOFTWARE

CAD SOFTWARE

NC CONTROLLER SOFTWARE

BEST CHOICES

FREE WARE

STEP - 13

CAD MODELING

SELECTION OF MATERIALS

FABRICATION

SUBASSEMBLY

MAIN ASSEMBLY

TESTING

CHAPTER – 4

KINEMATICS AND MECHANICAL DESIGN

4. MECHANICAL DESIGN AND KINEMATICS

This project work relates to linear 3D machine, which are to be understood as 3D numerical control machine for tending machines or for executing processes, and being capable of linear output movement in at least one axis, to position the distal end of an output element. It is acknowledged to be desirable that the aforesaid distal end should be capable of being positioned at a desired location with a high degree of repeatable accuracy. It is an object of the present work to provide a linear gantry robot of simple construction and improved repeatability and accuracy. The structure is made as modular as possible.

4.1. CARTESIAN COORDINATE FRAME

The most used and familiar coordinate system is the Cartesian coordinate system. Most will be familiar with this as the X, Y; axis is at 90° to each other. A point can be located on a plane by locating the distance of a point from its origin (0, 0) along each axis. This is a 2-dimensional representation, hence the two axis X & Y.

To find a point in space it is necessary to add a third axis (Z). This third axis will form a 3-dimensional grid that matches a set of coordinates to a single point in space. The axes of machines are always defined by what is known as the right-hand rule. If we take the thumb as pointing in the direction of the positive X-Axis then the second finger is pointing towards the positive Y-Axis and the middle finger towards the positive Z-Axis. The Z axis is always in the direction of the spindle or grab arm as shown in the 'Cartesian Robot' below.

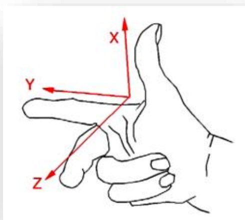


Figure – 4.1: The right-hand thumb rule

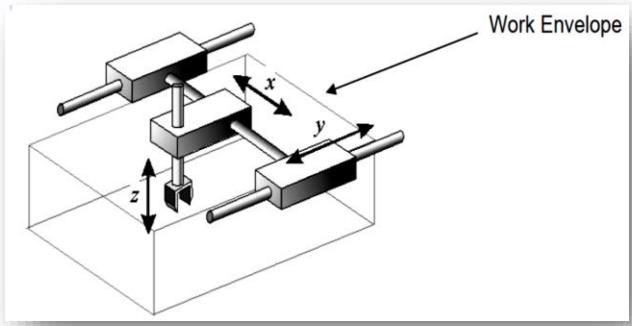


Figure – 4.2: The work envelope of the 3 axis Cartesian Coordinate Robot

Cartesian robots are used for pick and place work, application of sealant, assembly operations, handling machine tools and arc welding. It’s a robot whose arm has three prismatic joints, whose axes are coincidental with the Cartesian coordinators.

According to the invention a linear 3D machine includes a rotary-to-linear motion converter for providing linear motion on at least one axis, an electric motor, a direct driving connection between said motor and the rotary element of said converter, a control circuit for said motor, and a device for generating feed-back signals corresponding to the position of the linear element of said converter, said permanent magnet direct current motor.

The structure designed includes a plurality of rotary to linear converters for providing linear motion on a plurality of mutually perpendicular axes. In a further preferred embodiment said motor has a resolver resolution of not less than 50.000 counts per revolution, and a resolver repeatability of not more than 25 arc seconds. In a particular embodiment there is provided a relatively fixed base and a plurality of robots as above defined, each of said robots having an out- put member which is linearly movable in three mutually perpendicular directions.

The present work will be described by way of example only and with reference to the accompanying drawing which shows a linear gantry robot diagrammatically. A fixed base has a platform slid able thereon in the direction of the axis X-X. An electric motor, is secured to the platform. A screw is secured directly to the shaft of the motor and is in mesh with a nut secured to the base. A platform is slid ably mounted on the platform for movement on the axis Y-Y. An electric motor identical with the motor is also secured to the platform. A column is slid ably supported on the platform for movement in the Z-Z axis. A motor, identical with the y axis motor, is secured to the platform.

4.2. FORWARD KINEMATICS AND JACOBIAN MATRIX

A rigid multi-body system consists in a set of rigid objects, called links, joined together by joints. Simple kinds of joints include revolute (rotational) and prismatic (translational) joints. It is also possible to work with more general types of joints, and thereby simulate non-rigid objects. Well-known applications of rigid multi-bodies include robotic arms. Robot manipulators modeled with a set of links connected by joints. There are a variety of possible joint types. Perhaps the most common type is a rotational joint with its configuration described by a single scalar angle value. The key point is “the configuration of a joint is a continuous function of one or more real scalars; for rotational joints “, the scalar is the angle of the joint. Complete configuration in robot manipulators is specified by vectors, for example the position is described as:

$$q = \begin{bmatrix} q_1 \\ q_2 \\ \vdots \\ q_n \end{bmatrix} \quad \ldots\text{(i)}$$

Where $q \epsilon \mathbf{R}^{n\times 1}$. We assume there are n joints and each q_n value is called a joint position. The robot manipulator will be controlled by specifying target positions by the end-effectors. The desired positions are also given by a vector:

$$q_d = \begin{bmatrix} q_{d_1} \\ q_{d_2} \\ \vdots \\ q_{d_n} \end{bmatrix} \quad \ldots\text{(ii)}$$

Where q_{di} is the desired position for the ith end-effectors. We let ˜ qi = q_{di}− q_i, the desired change in position of the ith end effectors, also this vector is well-known as an error position. The end-effectors positions (x, y, z) are functions of the joint angles q; this fact can be expressed as:

$x_i = f_i(q)$ for i = 1, 2, . . ., k. This equation is well-known as forward kinematics.

4.2.1. FORWARD KINEMATICS OF CARTESIAN COORDINATE ROBOT

In order to understand application of Cartesian control in robot manipulators a case of study will be used, which all the concepts were evaluated. In this section we will obtain the forward kinematics of a three degrees of freedom Cartesian robot.

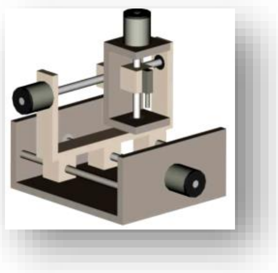


Figure – 4.3: Three degrees of freedom cartesian coordinate robot

In order to obtain the forward kinematics of three degrees of freedom Cartesian robot we need to draw a system diagram, where q1, q2, q3 are joint displacements; and m1, m2, m3 represent the masses of each link. A sit is observed, translation is the unique movement that realizes this kind of robots, then the forward kinematics are defined as:

$$\begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} = \begin{bmatrix} q_1 \\ 0 \\ 0 \end{bmatrix} \quad ; \quad \begin{bmatrix} x_2 \\ y_2 \\ z_2 \end{bmatrix} = \begin{bmatrix} q_1 \\ q_2 \\ 0 \end{bmatrix} \quad ; \quad \begin{bmatrix} x_3 \\ y_3 \\ z_3 \end{bmatrix} = \begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix} \quad \ldots(i)$$

We can observe, that in the first vector is contemplated only by the first displacement of valueq1, in the second one considers the movement of translation in q1 and q2 respecting the axis x and y, and finally, the complete displacement in third axis described in the last vector, being this representation the robot forward kinematics.

4.3. JACOBIAN MATRIX

The Jacobian matrix J (q) is a multidimensional form of the derivative. This matrix is used to relate the joint velocity $\dot{q}$ with the Cartesian velocity $\dot{x}$, based on this reason we are able to think about Jacobian matrix as mapping velocities in q to those in x:

$$\dot{x} = J(q)\,\dot{q} \ldots (i)$$

Where $\dot{x}$ is the velocity on Cartesian space; $\dot{q}$ is the velocity in joint space; and J(q) is the Jacobian matrix of the system.

In many cases, we use modeling and simulation as a tool for analysis about the behavior of a given system. Even though at this stage, we have not formed the equations of motion for a robotic manipulator, by inspecting the kinematic models, we are able to revel many characteristics from the system. One of the most important quantities (for the purpose of analysis) in (5), is the Jacobian matrix J(q). It reveals many properties of a system and can be used for the formulation of motion equations, analysis of special system configurations, static analysis, motion planning, etc. The robot manipulator's Jacobian matrix J(q) is defined as follow:

$$J(q) = \frac{\partial f(q)}{\partial q} = \begin{bmatrix} \frac{\partial f_1(q)}{\partial q_1} & \frac{\partial f_1(q)}{\partial q_2} & \cdots & \frac{\partial f_1(q)}{\partial q_n} \\ \frac{\partial f_2(q)}{\partial q_1} & \frac{\partial f_2(q)}{\partial q_2} & \cdots & \frac{\partial f_2(q)}{\partial q_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial f_m(q)}{\partial q_1} & \frac{\partial f_m(q)}{\partial q_2} & \cdots & \frac{\partial f_m(q)}{\partial q_n} \end{bmatrix} \quad \ldots\text{(ii)}$$

Where f (q) is the relationship of forward kinematics; n is the dimension of q; and m is the dimension of x. We are interested about finding what joint velocities $\dot{q}$ result in given v. Hence, we need to solve system equations.

4.3.1. JACOBIAN MATRIX OF THE CARTESIAN COORDINATE ROBOT

In order to obtain the Jacobian matrix of the three degrees of freedom Cartesian robot it is necessary to use the forward kinematics which is defined as:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix} \quad \ldots\textbf{(i)}$$

Now, doing the partial derivation of x in reference to q_1, q_2, q_3 we have,

$$\frac{\partial x}{\partial q_1} = \frac{\partial q_1}{\partial q_1} = \dot{q}_1$$

$$\frac{\partial x}{\partial q_2} = \frac{\partial q_1}{\partial q_2} = 0$$

$$\frac{\partial x}{\partial q_3} = \frac{\partial q_1}{\partial q_3} = 0 \qquad \ldots\text{(ii)}$$

The partial derivation of y in reference to q_1, q_2, q_3 are:

$$\frac{\partial y}{\partial q_1} = \frac{\partial q_2}{\partial q_1} = 0$$

$$\frac{\partial y}{\partial q_2} = \frac{\partial q_2}{\partial q_2} = \dot{q}_2$$

$$\frac{\partial y}{\partial q_3} = \frac{\partial q_2}{\partial q_3} = 0 \qquad \ldots\text{(iii)}$$

The partial derivation of z in reference to q_1, q_2, q_3, we have,

$$\frac{\partial z}{\partial q_1} = \frac{\partial q_3}{\partial q_1} = 0$$

$$\frac{\partial z}{\partial q_2} = \frac{\partial q_3}{\partial q_2} = 0$$

$$\frac{\partial z}{\partial q_3} = \frac{\partial q_3}{\partial q_3} = \dot{q}_3 \qquad \ldots\text{(iv)}$$

The system $\dot{x} = J(q)\,\dot{q}$ is described by following equation:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix} = \begin{bmatrix} \frac{\partial x}{\partial q_1} & \frac{\partial x}{\partial q_2} & \frac{\partial x}{\partial q_3} \\ \frac{\partial y}{\partial q_1} & \frac{\partial y}{\partial q_2} & \frac{\partial y}{\partial q_3} \\ \frac{\partial z}{\partial q_1} & \frac{\partial z}{\partial q_2} & \frac{\partial z}{\partial q_3} \end{bmatrix} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} \quad \ldots(v)$$

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix} = \underbrace{\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}}_{J(q)} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} \quad \ldots(vi)$$

4.3.2. JACOBIAN TRANSPOSE MATRIX OF THE CARTESIAN ROBOT

In particular case of Cartesian robot, the Jacobian matrix J(q) is equal to the identity matrix I, thus its transposed matrix J(q)T is the same, thus we have:

$$J(q)^T = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \ldots(i)$$

Singularities correspond certain configurations in robot manipulators which have to be avoided because they lead to an abrupt loss of manipulator rigidity. In the vicinity of these configurations, manipulator can become uncontrollable and the joint forces could increase considerably and may there would be risk to even damage the manipulator mechanisms. The singularities in a workspace can be identified mathematically when the determinant in the Jacobian matrix is zero.

Det J (q) = 0…(ii)

Mathematically this means that matrix J (q) is degenerated and there is, in the inverse geometrical model, infinity of solutions in the vicinity of these points.

4.3.3. DETERMINANT OF THE JACOBIAN MATRIX OF THE CARTESIAN COORDINATE ROBOT

In order to determine if there are singularities in the system, it is necessary to obtain the determinant on the system det J (q), considering a general structure of the Jacobian matrix, thus we have,

$$\det J(q) = j_{11}\begin{bmatrix} j_{22} & j_{23} \\ j_{32} & j_{33} \end{bmatrix} - j_{12}\begin{bmatrix} j_{21} & j_{23} \\ j_{31} & j_{33} \end{bmatrix} + j_{13}\begin{bmatrix} j_{21} & j_{22} \\ j_{31} & j_{32} \end{bmatrix} \quad \ldots\text{(i)}$$

$$\det J(q) = j_{11}\left(j_{22}j_{33} - j_{32}j_{23}\right) - j_{12}\left(j_{21}j_{33} - j_{31}j_{23}\right) + j_{13}\left(j_{21}j_{32} - j_{31}j_{22}\right) \quad \ldots\text{(ii)}$$

$$\det J(q) = 1 \quad \ldots\text{(iii)}$$

As it is observed, the determinant in the Jacobian matrix is not undefined in any point which indicates the workspace for the Cartesian Robot is complete.

CHAPTER – 5

MODELING

5. MODELING

5.1. MODELING OF THE HOT WIRE FOAM CUTTING MACHINE CAD MODEL

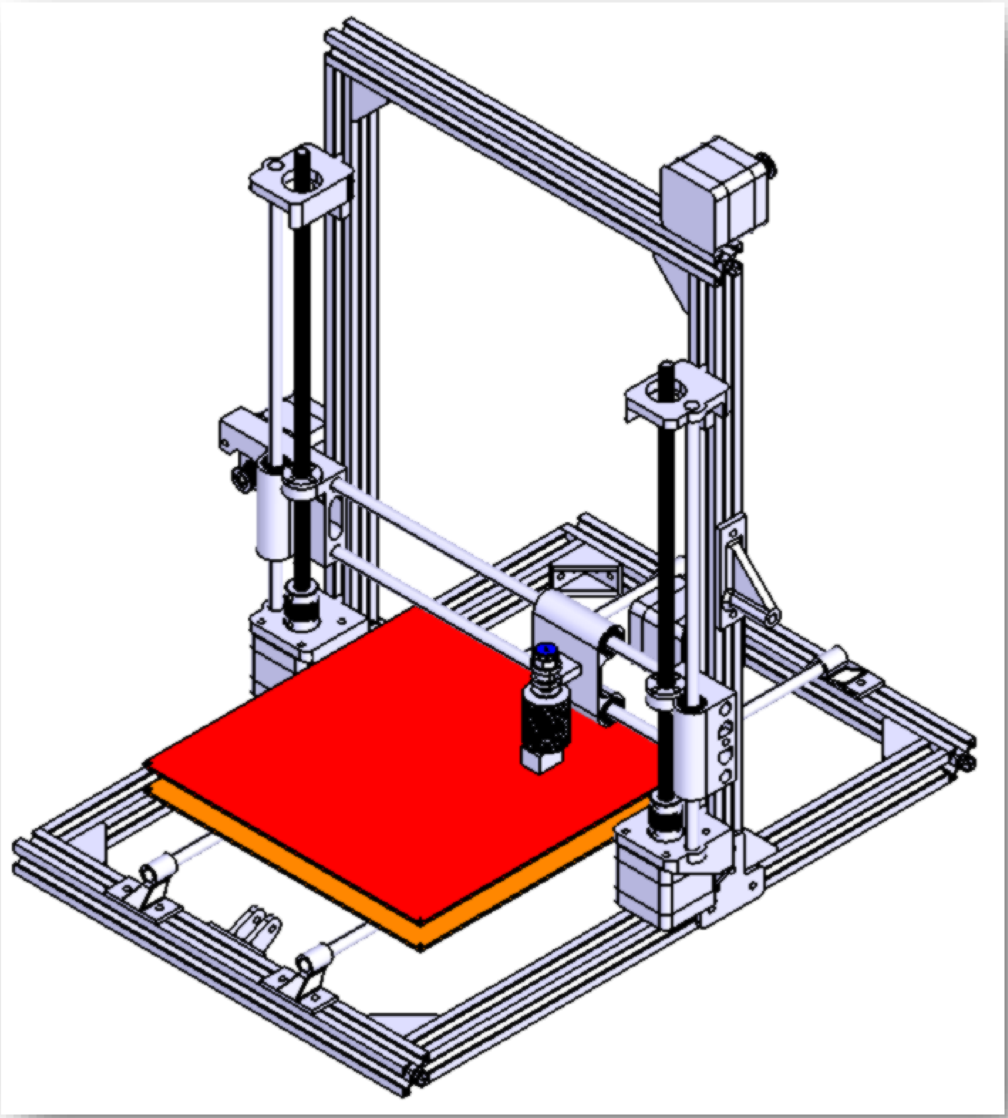


Figure – 5.1: 3D diagram of a Two – Axis Computer Numerical Controlled Foam Cutting Machine

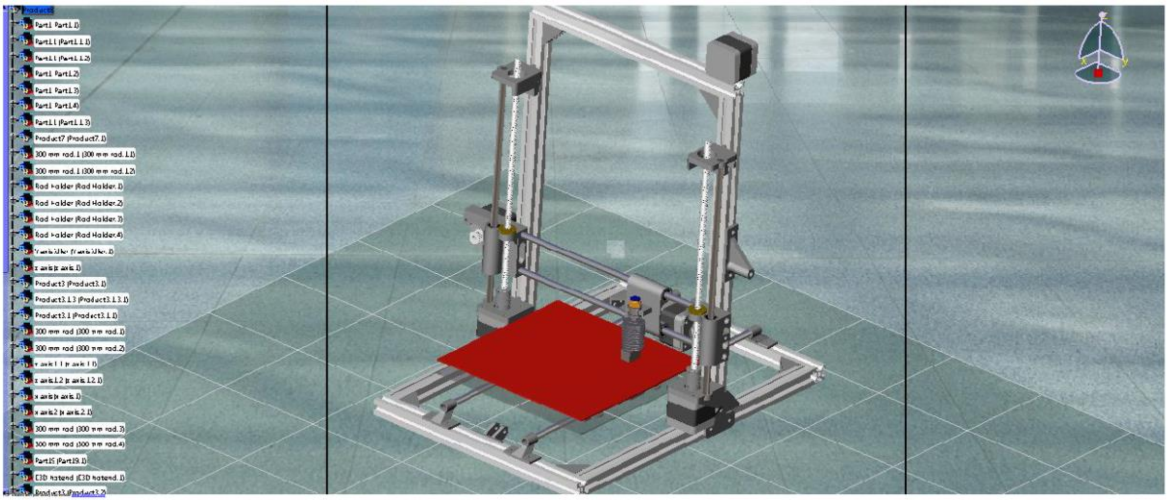


Figure – 5.2: Detailed 3D diagram of a Two – Axis Computer Numerical Controlled Foam Cutting Machine

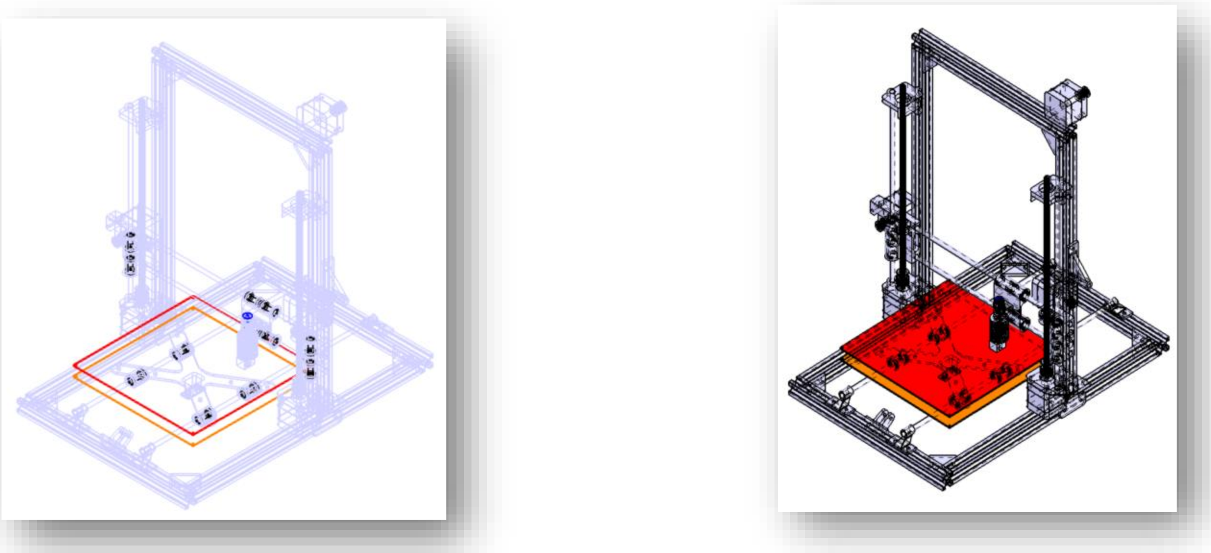


Figure – 5.3: Highlighted the work - piece area of a Two – Axis Computer Numerical Controlled Foam Cutting Machine

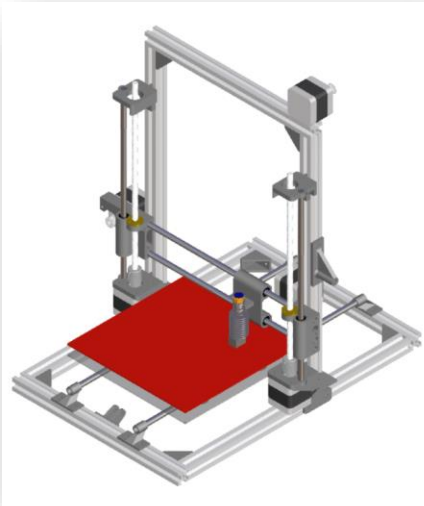


Figure – 5.4: Highlighted the work - piece area of a Two – Axis Computer Numerical Controlled Foam Cutting Machine

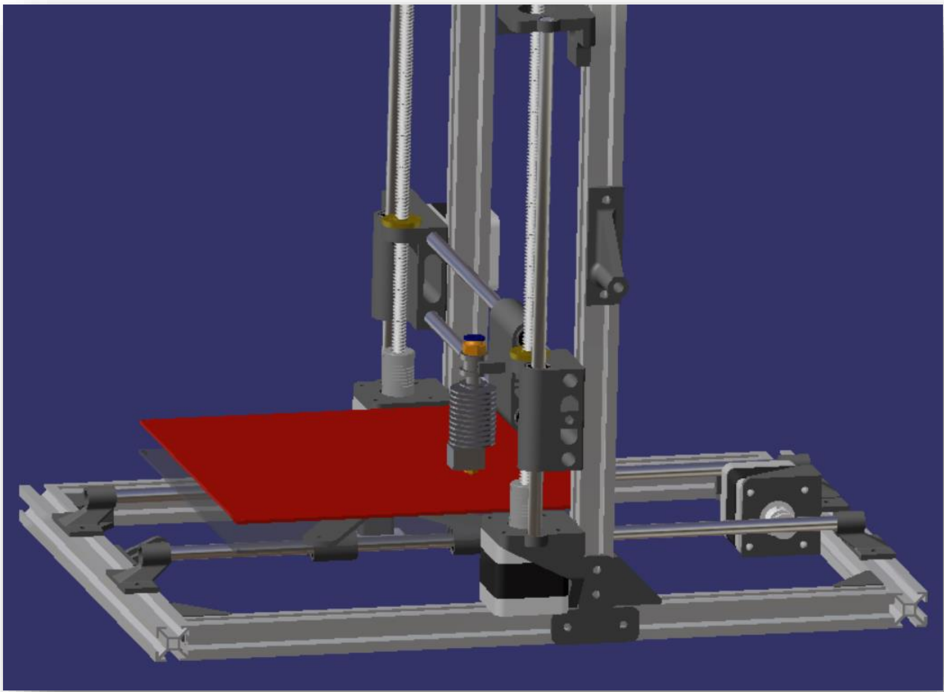


Figure – 5.5: Side view of the work – piece area in a Two – Axis Computer Numerical Controlled Foam Cutting Machine

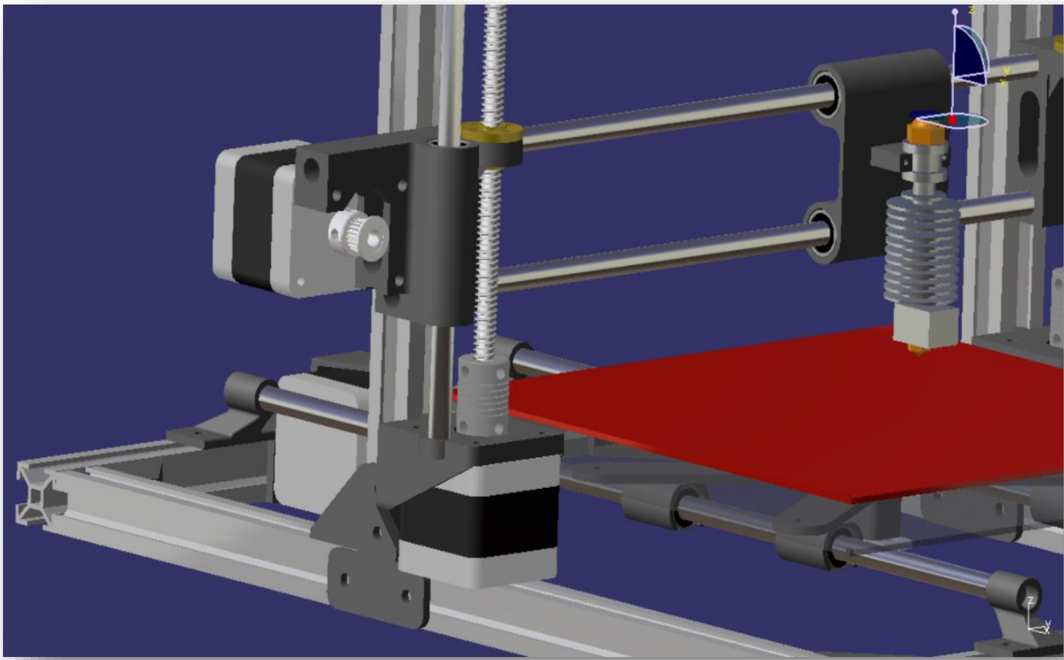


Figure – 5.6: Angled view of Two – Axis Computer Numerical Controlled Foam Cutting Machine

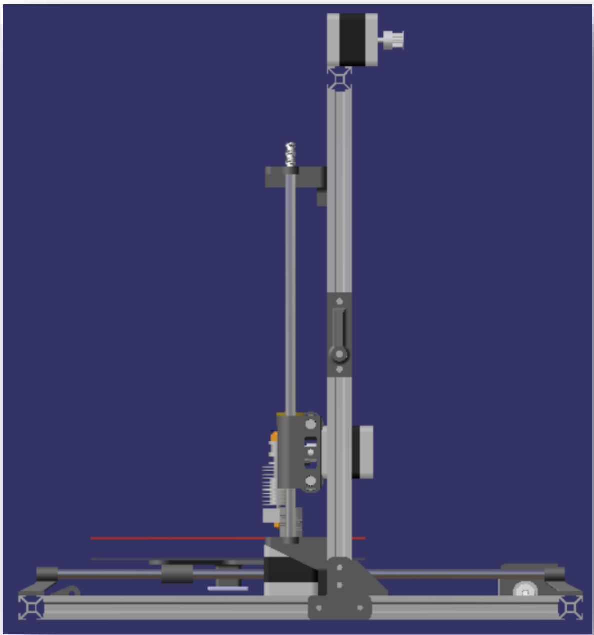


Figure – 5.7: Side view of a Two – Axis Computer Numerical Controlled Foam Cutting Machine

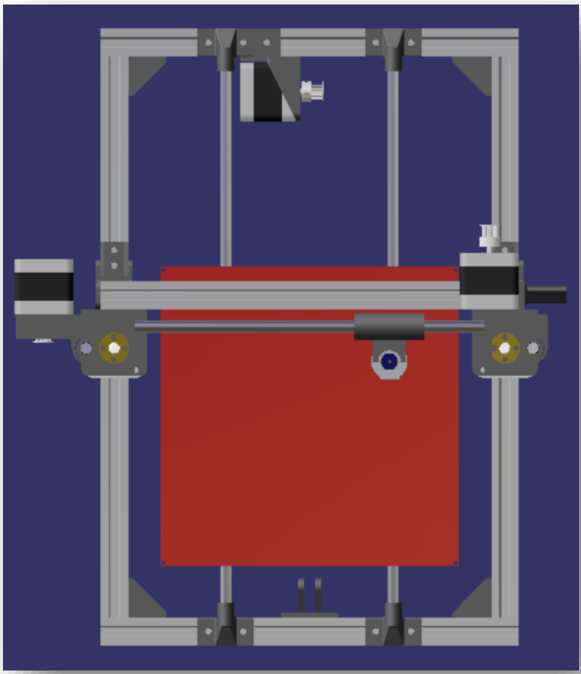
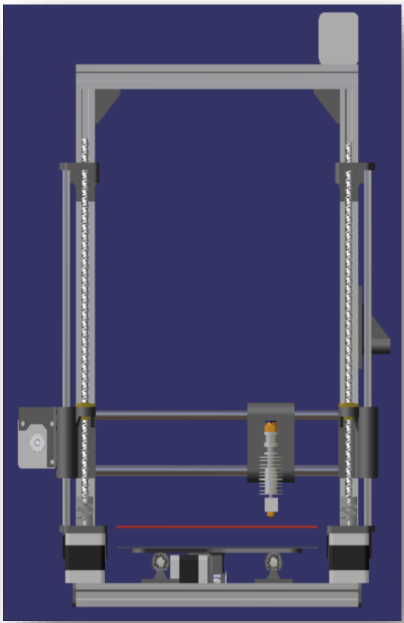


Figure – 5.8: Top view of a Two – Axis Computer Numerical Controlled Foam Cutting Machine



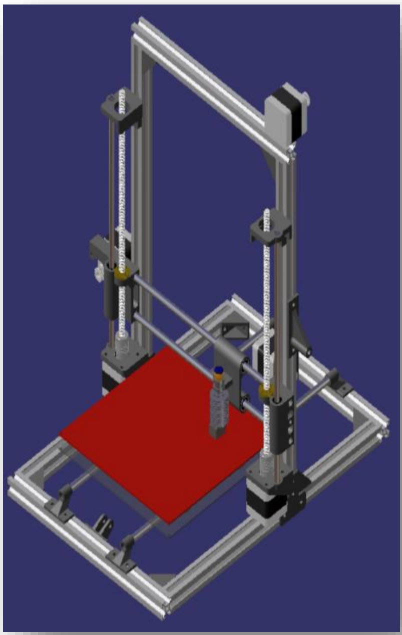


Figure – 5.9: Views from different angles of a Two – Axis Computer Numerical Controlled Foam Cutting Machine

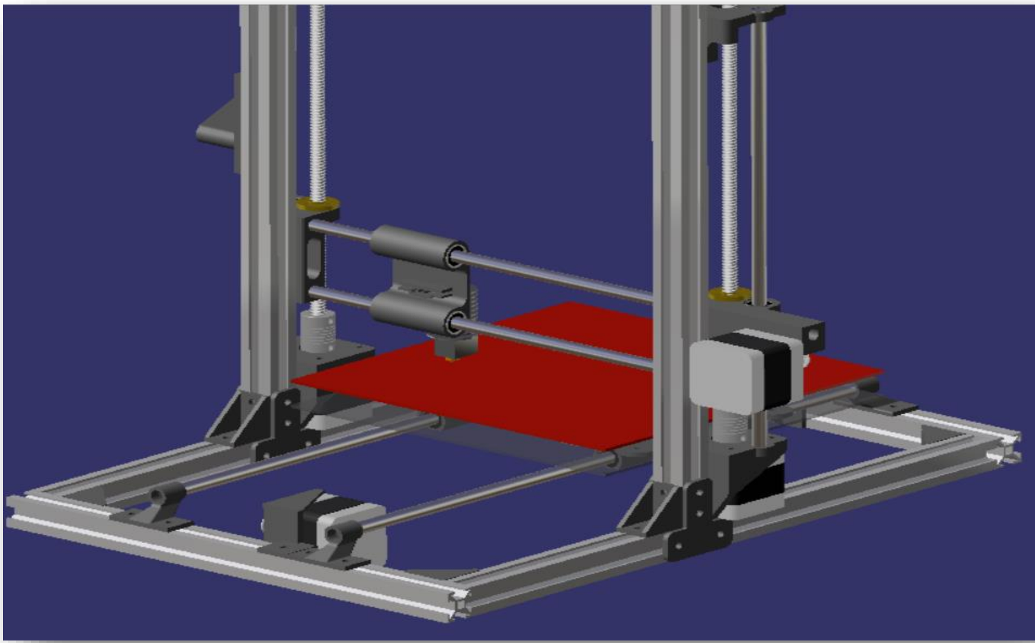


Figure – 5.10: View from a different angle of a Two – Axis Computer Numerical Controlled Foam Cutting Machine

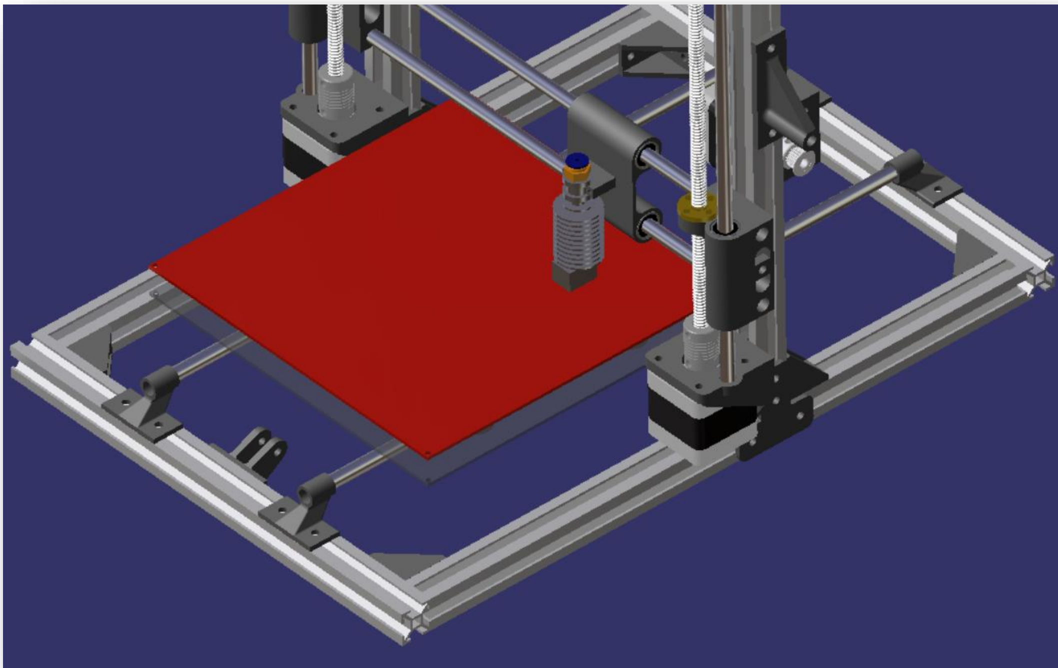


Figure – 5.11: View from a different angle of a Two – Axis Computer Numerical Controlled Foam Cutting Machine

5.2. SKETCHES

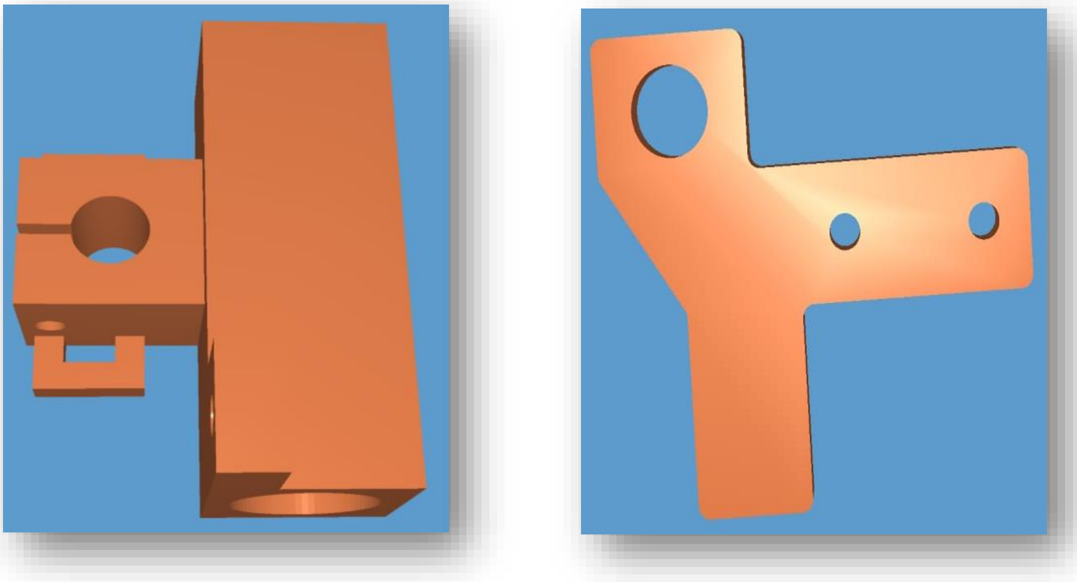


Figure – 5.12: CADD diagrams of 3D Printed parts used in making of Two – Axis Computer Numerical Controlled Foam Cutting Machine

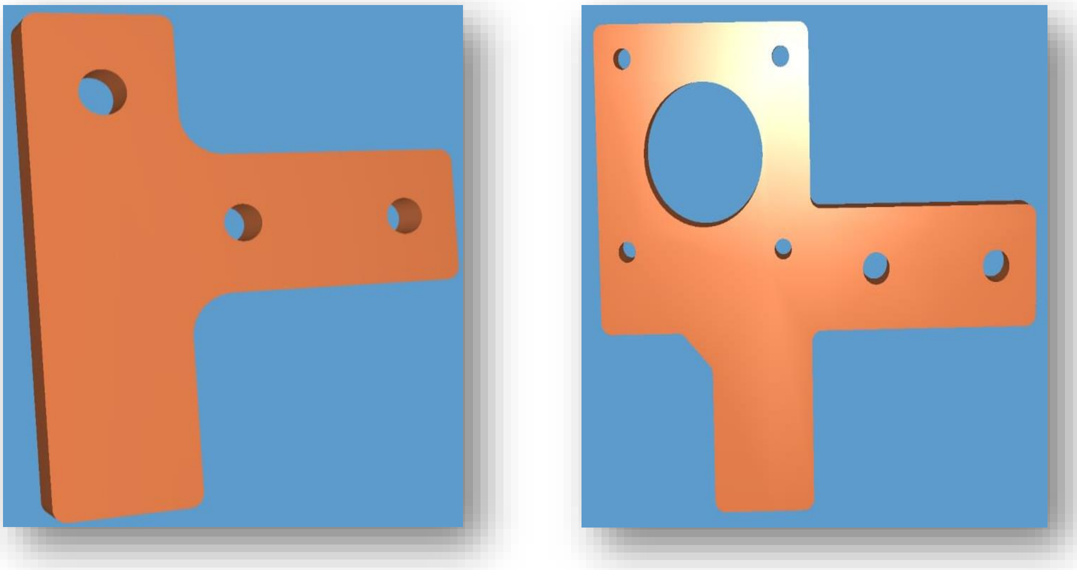


Figure – 5.13: CADD diagrams of 3D Printed parts used in making of Two – Axis Computer Numerical Controlled Foam Cutting Machine

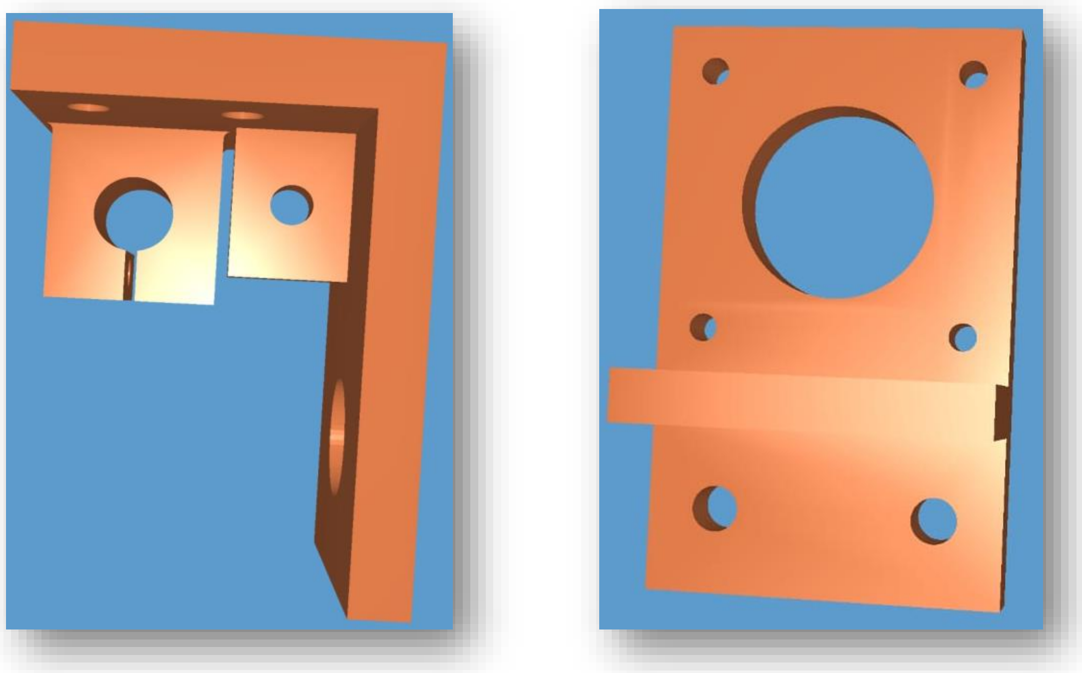


Figure – 5.14: CADD diagrams of 3D Printed parts used in making of Two – Axis Computer Numerical Controlled Foam Cutting Machine

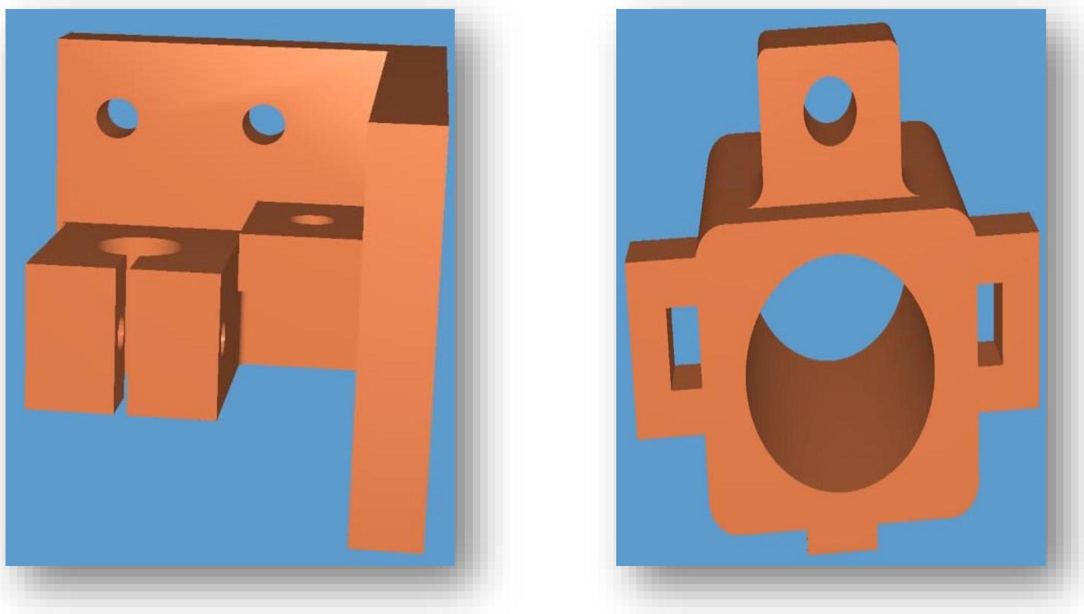


Figure – 5.15: CADD diagrams of 3D Printed parts used in making of Two – Axis Computer Numerical Controlled Foam Cutting Machine

5.3. DETAILED DRAWINGS

5.3.1. DRAWINGS OF THE HOT WIRE FOAM CUTTING MACHINE

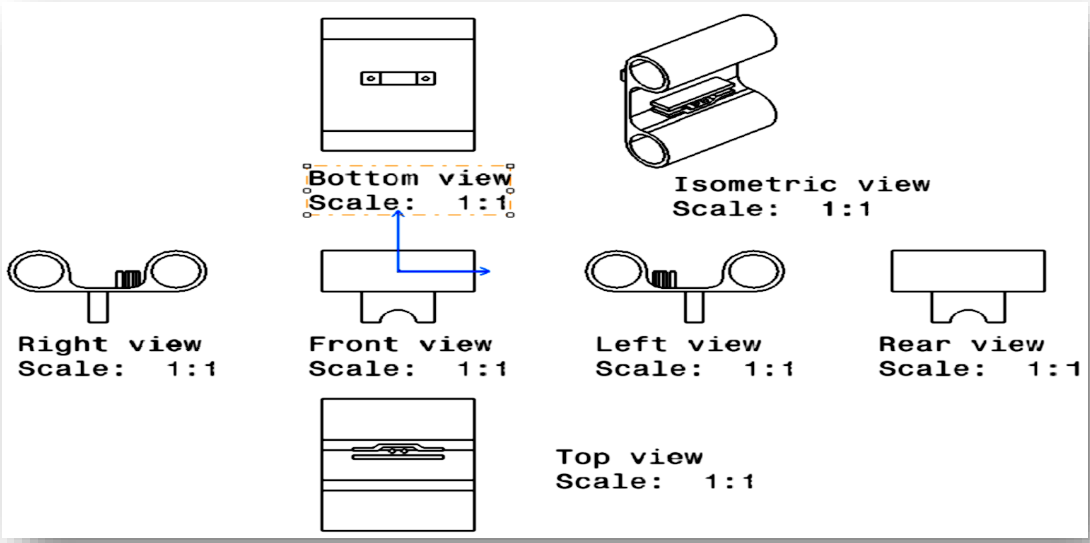


Figure – 5.16: 2D drawings of things required in making of a hot wire

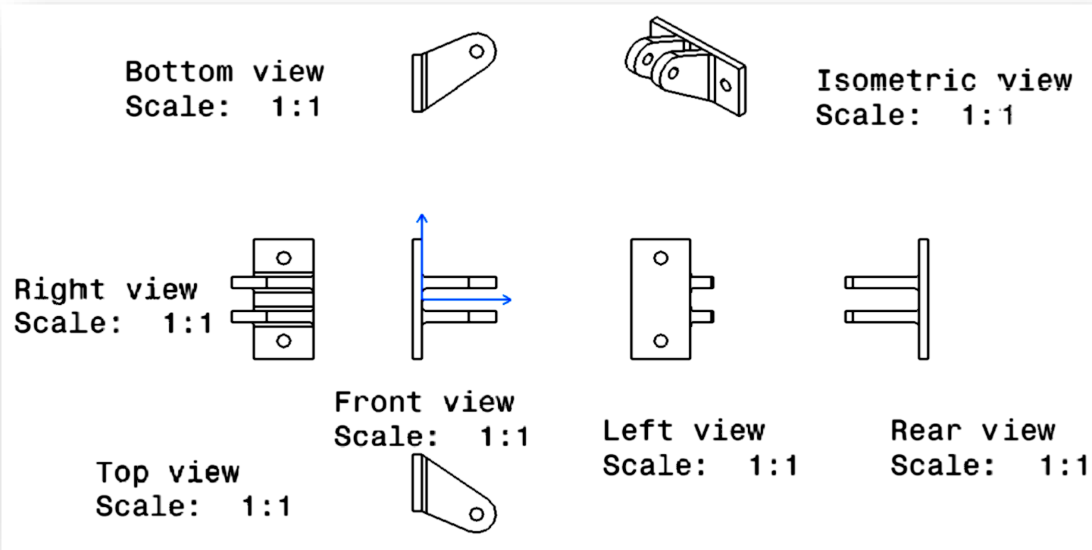


Figure – 5.17: 2D drawings of things required in making of a hot wire

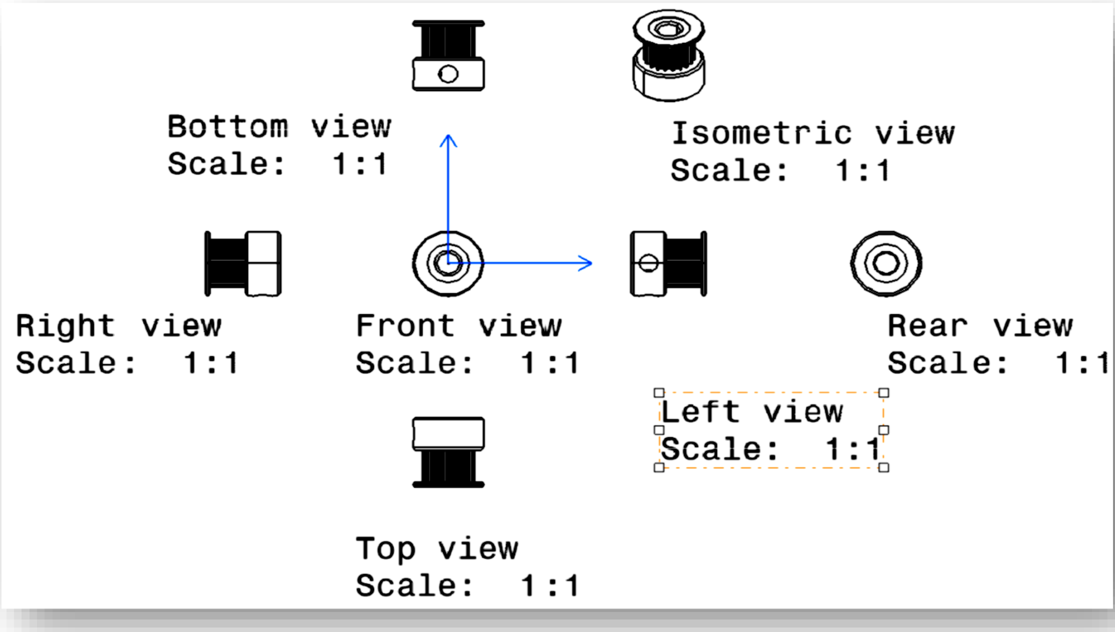


Figure – 5.18: 2D drawings of things required in making of a hot wire

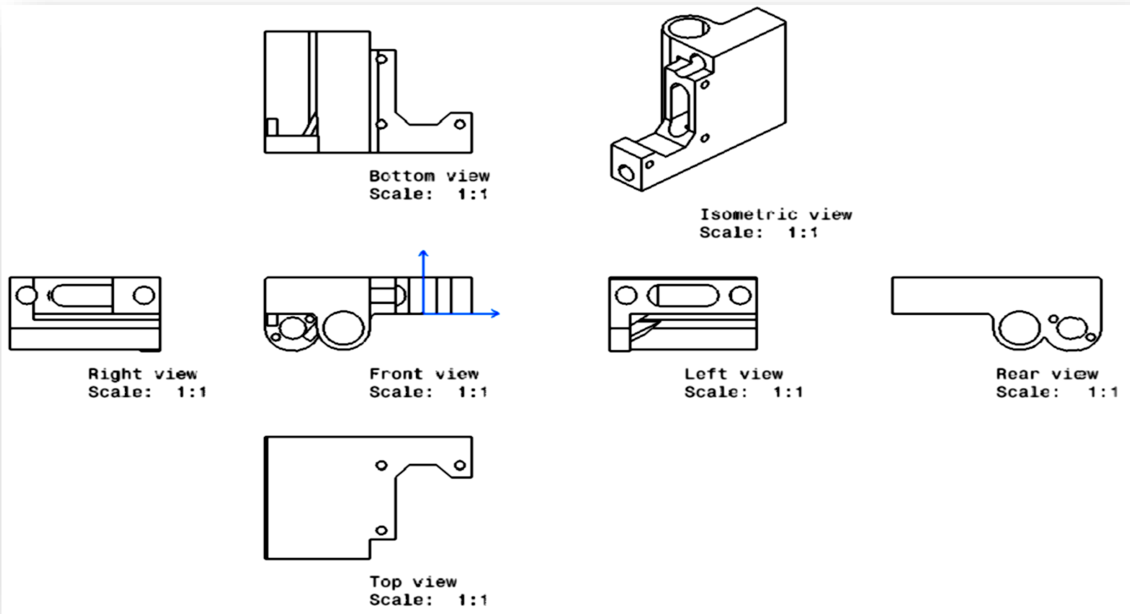


Figure – 5.19: 2D drawings of things required in making of a hot wire

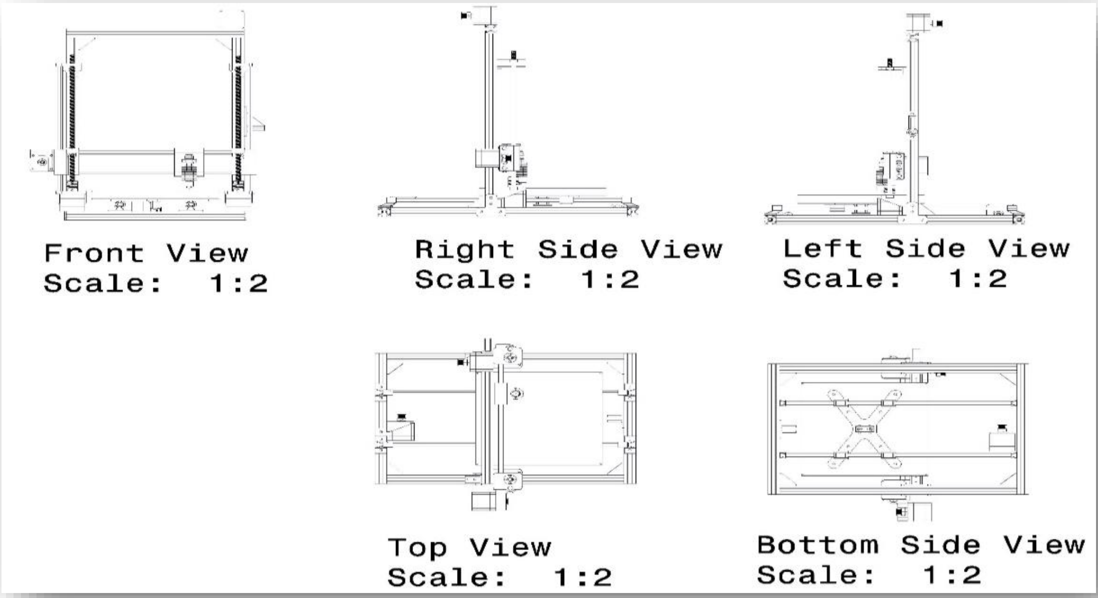


Figure – 5.20: 2D drawings of things required in making of a hot wire

5.4. SOFTWARE USED IN THE PROJECT WORK FOR THE CONTROL OF THE MACHINE

5.4.1. GRBL: MOTION CONTROL SOFTWARE

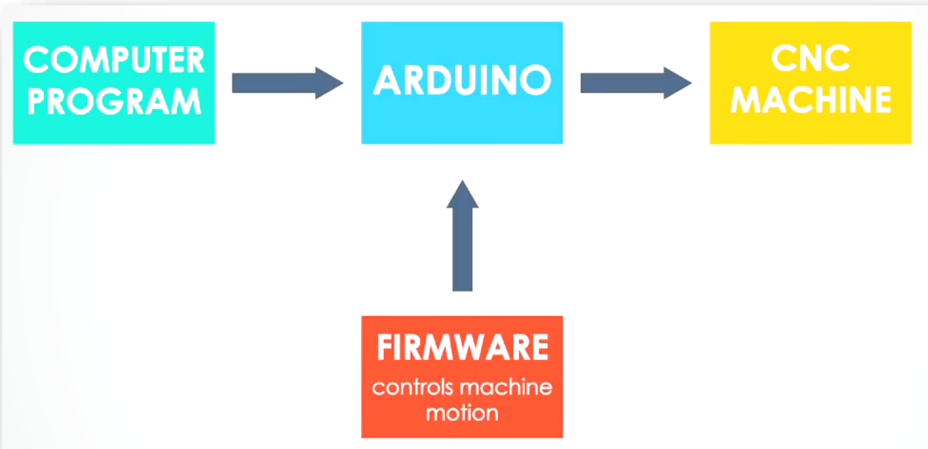


Figure – 6.21: Flow chart for a GRBL: motion control software

GRBL is ready for light duty production. We use it for all our milling, running it from our laptops using great user-written GUIs or with a simple console script (included) to stream the G-code. It is written in optimized C utilizing all the clever features of the Arduino's Atmega328p chips to achieve precise timing and asynchronous operation. It is able to maintain more than 30kHz step rate and delivers a clean, jitter free stream of control pulses.

GRBL is a no-compromise, high-performance, low-cost alternative to parallel-port-based motion control for CNC milling. It will run on a vanilla Arduino (Demilune/Uno) as long as it sports an At mega 328. The controller is written in highly optimized C utilizing every clever feature of the AVR-chips to achieve precise timing and asynchronous operation. It is able to maintain up to 30kHz of stable, jitter free control pulses. It accepts standards-compliant g-code and has been tested with the output of several CAM tools with no problems. Arcs, circles and helical motion are fully supported, as well as, all other primary g-code commands. Macro functions, variables, and most canned cycles are not supported, but we think GUIs can do a much better job at translating them into straight g-code anyhow.

GRBL includes full acceleration management with look ahead. That means the controller will look up to 18 motions into the future and plan its velocities ahead to deliver smooth acceleration and jerk-free cornering. GRBL is ready for light duty production. We use it for all our milling, running it from our laptops using great user-written GUIs or with a simple console script (included) to stream the G-code. It is written in optimized C utilizing all the clever features of the Arduino's Atmega328p chips to achieve precise timing and asynchronous operation. It is able to maintain more than 30kHz step rate and delivers a clean, jitter free stream of control pulses.

GRBL is for three axis machines. No rotation axes (yet) – just X, Y, and Z.

The G-code interpreter implements a subset of the NIST rs274/ngc standard and is tested with the output of a number of CAM-tools with no issues. Linear, circular and helical motion are all fully supported.

5.4.2. Supported G-Codes in v0.9i

G38.3, G38.4, G38.5: Probing

G40: Cutter Radius Compensation Modes

G61: Path Control Modes

G91.1: Arc IJK Distance Modes

Supported G-Codes in v0.9h

G38.2: Probing

G43.1, G49: Dynamic Tool Length Offsets

Supported G-Codes in v0.8 (and v0.9)

G0, G1: Linear Motions

G2, G3: Arc and Helical Motions

G4: Dwell

G10 L2, G10 L20: Set Work Coordinate Offsets

G17, G18, G19: Plane Selection

G20, G21: Units

G28, G30: Go to Pre-Defined Position

G28.1, G30.1: Set Pre-Defined Position

G53: Move in Absolute Coordinates

G54, G55, G56, G57, G58, G59: Work Coordinate Systems

G80: Motion Mode Cancel

G90, G91: Distance Modes

G92: Coordinate Offset

G92.1: Clear Coordinate System Offsets

G93, G94: Federate Modes

M0, M2, M30: Program Pause and End

M3, M4, M5: Spindle Control

M8, M9: Coolant Control

Most configuration options can be set at runtime and are saved in eircom between sessions and even retained between different versions of GRBL as you upgrade the firmware.

5.4.3. Acceleration Management

In the early days, Arduino-based CNC controllers did not have acceleration planning and couldn't run at full speed without some kind of easing. GRBL’s constant acceleration-management with look ahead planner solved this issue and has been replicated everywhere in the micro controller CNC world, from Marlin to Tiny. GRBL intentionally uses a simpler constant acceleration model, which is more than adequate for home CNC use. Because of this, we were able to invest our time optimizing our planning algorithms and making sure motions are solid and reliable.

When the installation of all the feature sets, we think are critical are complete and no longer requires us to modify our planner to accommodate them, we intend to research and implement more-advanced motion control algorithms, which are usually reserved for machines only with very high feed rates (i.e., pick-and-place) or in production environments. Lastly, here's a link describing the basis of our high-speed cornering algorithm so motions ease into the fastest feed rates and brake before sharp corners for fast yet jerk free operation.

5.4.4. Limitations by design

We have limited G-code-support by design. This keeps the GRBL source code simple, lightweight, and flexible, as we continue to develop, improve, and maintain stability with each new feature. GRBL supports all the common operations encountered in output from CAM-tools, but leave some human G-coders frustrated. No variables, no tool databases, no functions, no canned cycles, no arithmetic and no control structures. Just the basic machine operations and capabilities. Anything more complex, we think interfaces can handle those quite easily and translate them for GRBL. In this project work we have been intended to provide various instructions on how to compile GRBL. Once compiled, we should have a brand new .hex file to flash to your Arduino.

5.4.5. GRBL's Pins

Pin diagram for GRBL v0.8 and v0.9 with the traditional layout: (NOTE: The probe A5 pin is only available in GRBL v0.9.)

GRBL Pin Diagram with Variable Spindle PWM

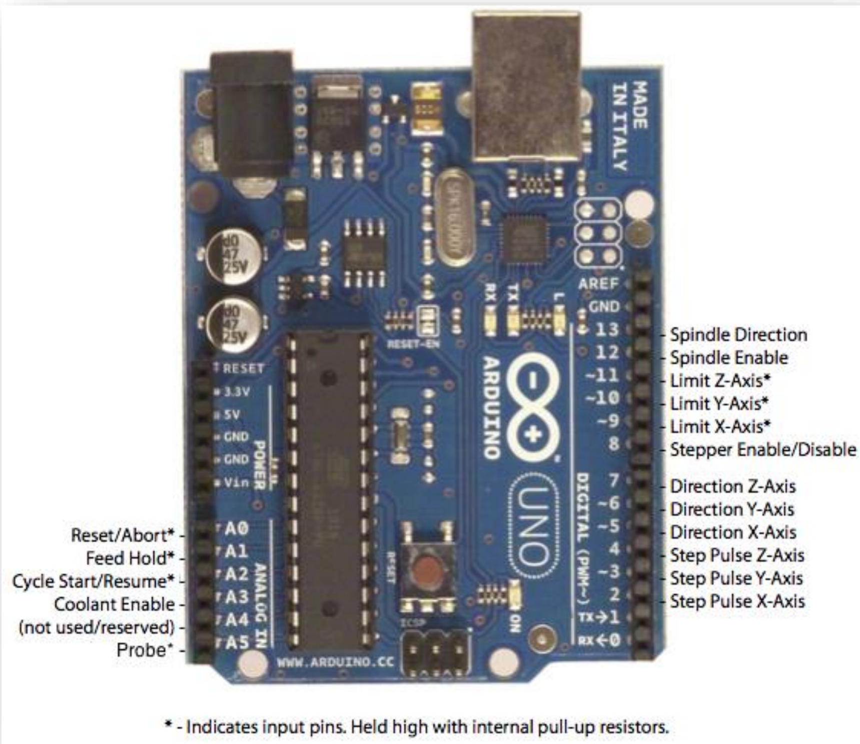


Figure – 5.22: Detailed view of a GRBL motheroard pins

First, to connect your stepper motors to GRBL, you'll need some stepper motor drivers to power the steppers and connect your driver inputs to the Arduino controller pins. There are a number of drivers that can do this, available as fully pre-built, partially pre-built, or completely DIY. The stepper drivers will need to share the stepper enable pin (D8) to their respective enable pins, while the direction and step pulse pins (D2-D7) will need to be connected to their respective pins on the drivers. Just make sure that all of your drivers and the Arduino share a common ground (star grounded with your motor driver power). This is about all you'll need to get started.

Afterwards, once you decide that you're ready or would like to enable homing and/or hard limits, you'll need to connect a normally-open limit switch to each of the limit pins (D9-D11). Homing and hard limits use the same switches. These limit pins are already held high with an internal pull-up resistor, so all you have to do is wire them to ground. So, when you close a switch, the switch will pull the limit pin to ground. If you'd like to have hard limit switches on both ends of travel of an axis, just wire two limit switches in parallel to the axis limit pin and ground. Make sure you have the switches installed before attempting to perform a homing cycle, and make sure you practice good wiring methods to minimize external electric noise on the input pins.

In GRBL v0.8 and later, there are pin-outs of the cycle start, feed hold, and reset runtime commands, so you can have physical control buttons on your machine. Just like the limit pins, these pins are held high with an internal pull-up resistor, so all you have to do is connect a normally-open switch to each pin and to ground. Again, make sure you practice good wiring methods to minimize external electric noise on the input pins.

If you have a desire or need for spindle or coolant control, GRBL will toggle these output pins (D12, D13, A3) high or low, depending on the G-code commands you send to GRBL. With v0.9 and variable spindle PWM enabled, the D11 pin will output a range of voltages from 0V to 5V depending the spindle speed G-code command. 0V indicates spindle off in this case. Since these pins are all application dependent in how they are used, we'll leave it to you to determine how to control and use these for your machine. You can also hack the spindle and coolant control source files to easily alter how they work and then compile and upload your modified GRBL through the Arduino IDE. After flashing GRBL to your Arduino, connecting to GRBL is pretty simple. You can use the Arduino IDE itself to connect to GRBL. Experiment or play with it, just to see if you like it. Other serial port programs, such as Cool Term or PuTTY, work great too. The instructions are pretty much the same.

5.4.6. Inkscape Software

Inkscape is a Free and open-source vector graphics editor for GNU/Linux, Windows and MacOS X. It offers a rich set of features and is widely used for both artistic and technical illustrations such as cartoons, clip art, logos, typography, diagramming and flowcharting. It uses vector graphics to allow for sharp printouts and renderings at unlimited resolution and is not bound to a fixed number of pixels like raster graphics. Inkscape uses the standardized SVG file format as its main format, which is supported by many other applications including web browsers.

It can import and export various file formats, including SVG, AI, EPS, PDF, PS and PNG. It has a comprehensive feature set, a simple interface, multi-lingual support and is designed to be extensible; users can customize Inkscape's functionality with add-ons.

The design process may begin by doodles on a napkin, a sketched mind map, a photo of a memorable object, or a mockup in software which really wouldn't work to complete the project. Inkscape can take you from this stage to a final, professional-grade design format which is ready for publication on the web or in physical form.

If you are new to the process of creating vector graphics it may feel different, but you will quickly be pleased by the flexibility, and power Inkscape offers. Vector design is often the preferred method of image creation for logos, illustrations and art which require high scalability. The Inkscape application is used across a wide variety of industries (marketing/branding, engineering/CAD, web graphics, cartooning) and individual uses.

All Inkscape projects may be exported in formats friendly to web browsers or commercial printer rooms. It is cross-platform, which means it is easy to run on Windows, Mac OS X, and Linux distributions. Visit the Download page to install or share this application now.

5.5. Fabrication

- Mechanical Design: Design the mechanical structure of the foam cutting machine, considering factors such as stiffness, stability, and ease of movement for the cutting head.

- Actuator Selection: Choose suitable actuators (e.g., stepper motors, servo motors) for the two axes that provide precise positioning and movement control.
- Cutting Tool Design: Select an appropriate cutting tool (e.g., hot wire, knife, laser) based on the specific requirements of the foam cutting application.
- Electrical System: Develop the electrical system of the CNC machine, including motor drivers, power supplies, and wiring.
- Assembly and Integration: Assemble all the mechanical and electrical components, ensuring proper alignment and integration of the control system.
- Testing and Calibration: Conduct thorough testing to verify the machine's performance, calibrate the control system, and make necessary adjustments

5.6. PHOTOS

5.6.1. PROJECT PHOTOS

Figure – 5.23: Aluminum 6063-16 T-Slotted Light Extrusion with Clear Anodize Finish, 48" Length x 1-1/2" Width x 1-1/2" Height

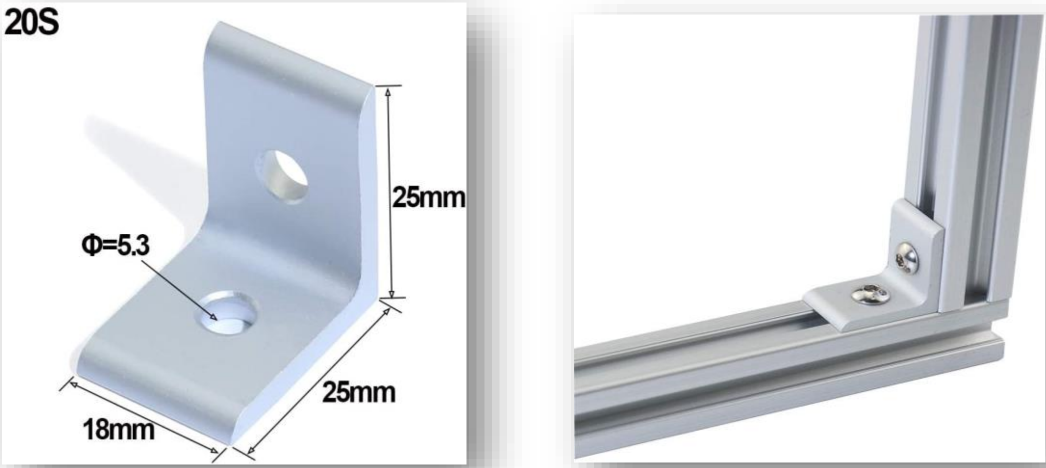


Figure – 5.24: Hole Inside Corner Bracket for 2020 Aluminum Extrusion Profile 20x20 with Slot 6mm

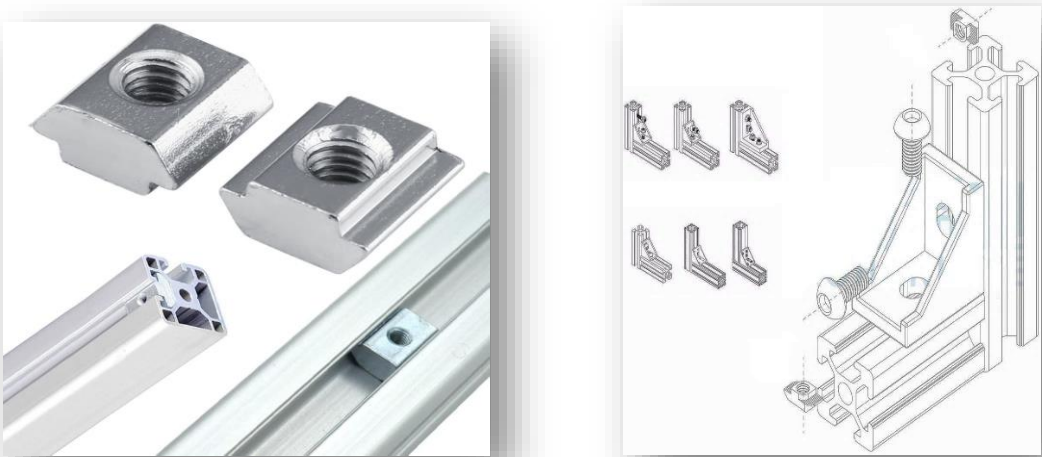


Figure – 5.25: Aluminum Profile Connector Set, 20pcs Corner Bracket,40pcs M5 x 10mm T-Slot Nuts, 40pcs M5x10mm Hex Socket Cap Screw Bolt for 6mm Slot

Figure – 5.26: Aluminum Profile Connector Set, 20pcs Corner Bracket,40pcs M5 x 10mm T-Slot Nuts, 40pcs M5x10mm Hex Socket Cap Screw Bolt for 6mm Slot

Figure – 5.27: Blind/Hidden Inside Corner Bracket for 20mm V-Slot/T-Slot Aluminum Extrusion 25x25x10mm

Figure – 5.28: 12mm Bore Zinc Alloy Inner Ball Mounted Pillow Block Insert Bearing

Table – 5.1: Size Chart of mechanical items

Unit No.	Shaft d(mm)	Dimensions (mm)										Bolt Size mm	Bearing No.	Housing No.	Weight (kg)
		H	J	A2	A1	A	N	L	S	Z	A3				
KFL000	10	60	45	6	6	12	7	36	4	16	20.3	M6	K000	FL000	0.07
KFL001	12	63	48	6	6	12	7	38	4	16.5	21	M6	K001	FL001	0.08
KFL002	15	67	53	6.5	6.5	13	7	42	4.5	18.5	23	M6	K002	FL002	0.11
KFL003	17	71	56	7	7	14	7	46	5	19.5	25	M6	K003	FL003	0.14
KFL004	20	90	71	8	8	16	10	55	6	23	28	M8	K004	FL004	0.23
KFL005	25	95	75	8	8	16	10	60	6	24.5	28.5	M8	K005	FL005	0.27
KFL006	30	112	85	9	9	18	13	70	6.5	27	30.5	M10	K006	FL006	0.39

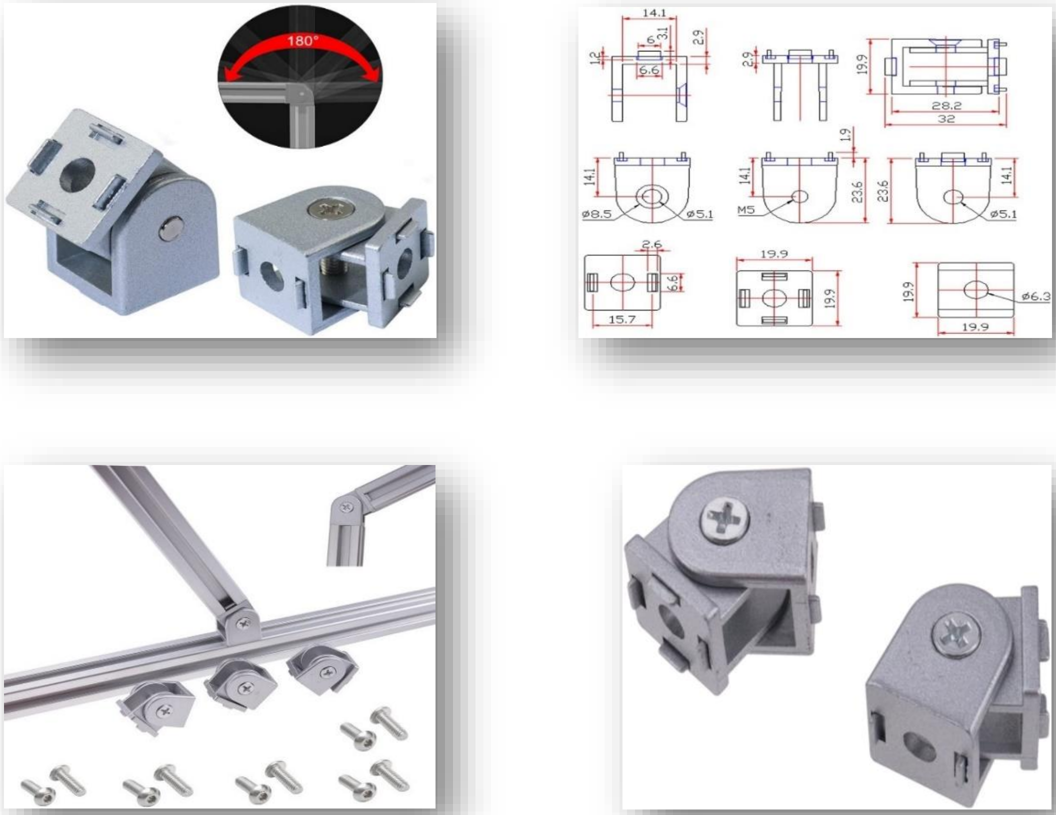


Figure – 5.29: Aluminum Extrusion Profile Die-Cast Zinc Alloy Pivot Joint, Flexible Pivot Joint for 2020 Aluminum Profile

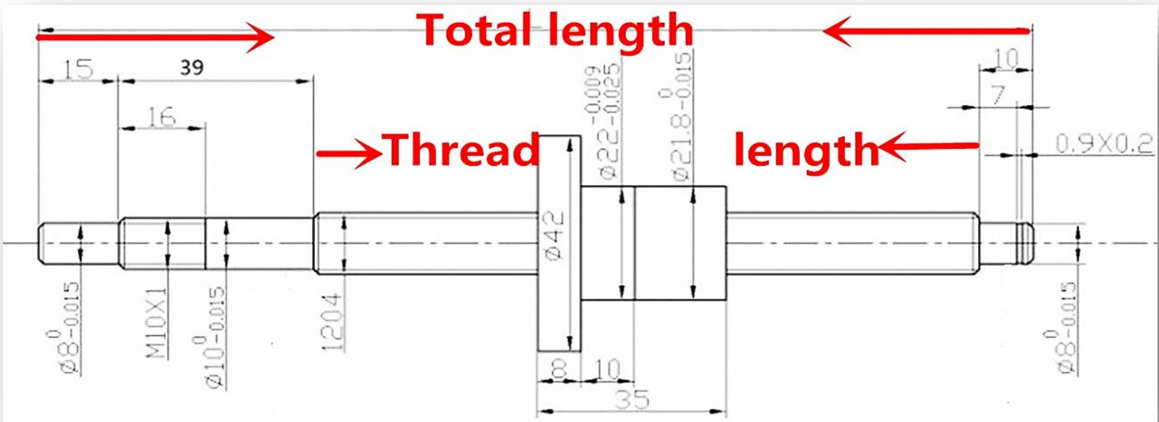


Figure – 5.30: Detailed description of a threaded rod

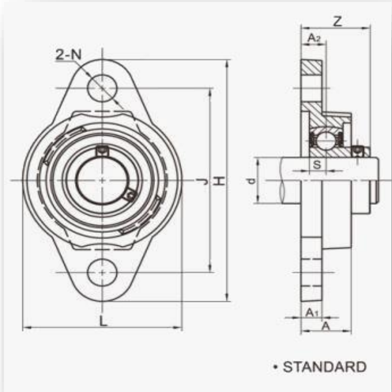
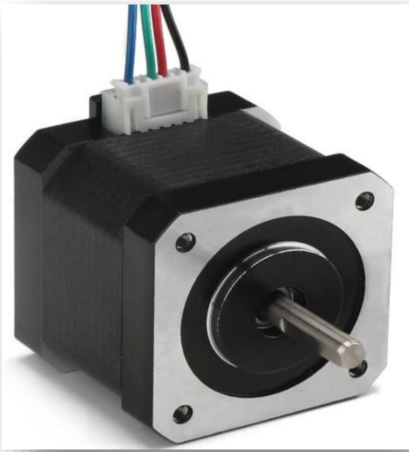


Figure – 5.31: 12mm Inner Diameter Zinc Alloy Pillow Block Flange Bearing

Figure – 5.32: 300mm Ball screw kit + Set BK/BF10 Kit + 1204 Ball screw RM1204 L300mm Ball Screw with Ball Nuts + Screw Nut Housing

Figure – 5.33: 8mmx10mm Clamp Tight Motor Shaft 2 Diaphragm Coupling Coupler

Figure – 5.34: 4mm Inner Diameter H13D10 Rigid Flange Coupling Motor Guide Shaft Coupler Motor Connector



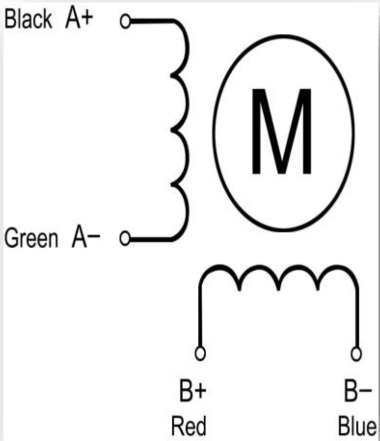


Figure – 5.35: 2 Nema 17 Stepper Motor, DROK 40mm High Torque Bipolar DC Step Motor Kit, 0.46Nm Low Noise 42 2-Phrase Universal Electric Motor DC motor

5.6.2. TEAM PHOTOS

Figure – 5.36: Students working on the base support of a Two – Axis Computer Numerical Controlled Foam Cutting Machine

Figure – 5.37: Students working on lathe machine for shaping a rod

Figure – 5.38: Students discussing about a topic with their guide

5.6.3. WORKING ON PROJECT PHOTOS

Figure – 5.39: Shaping of a rod in lathe machine

Figure – 5.40: Students working for the interaction of the software with the Two – Axis Computer Numerical Controlled Foam Cutting Machine

Figure – 5.41: Shaping of a rod in lathe machine (views from different angles)

Figure – 5.42: Students waiting for the connection with the software and Two – Axis Computer Numerical Controlled Foam Cutting Machine

CHAPTER – 6

CONCLUSION AND SCOPE FOR FUTURE WORK, RESULTS AND REFERENCES

6. CONCLUSION, ABSTRACT AND SCOPE FOR FUTURE WORK

6.1. CONCLUSION AND SCOPE FOR FUTURE WORK

The foam mound making for Unmanned Aerial Vehicles should be efficient and accurate to improve research and manufacturing in this regard the project work was designed. Hot wire cutting is a widely used method in foam cutting. In hot wire cutting, accuracy and quality of the foam cut mainly depends on the variable cutting parameters which affect the cutting process. To perform a proper cut with required quality the cutting parameters were set precisely and accurately. This project work was done to identify the variations and inter dependency of cutting parameters. In the project work it was important to estimate appropriate cutting parameter values before the actual cut. The results of this project work aid to improve the hot wire foam cutting by solving the limitations and drawbacks to select best cutting parameters of the Computer Numerically Controlled machine which is in progress.

The project work on the hot wire foam cutting is an efficient way of producing foam molds and different foam shapes. It was clearly observed that a thinner gauge wire gives a small kerf width higher accuracy, while thick wires have high durability. Numerical control methods can be used to control the feed rate and temperature to obtain a constant kerf width with good accuracy.

The control equation for the numerically controlled feed rate was derived using the experiment data. The conceptual design of a computer numerically controlled machine which can perform these tasks. An active temperature controlling method based on PID control should be incorporated with the design to control the temperature in a limited range to reach high accurate cutting.

The drive mechanism of the control axes should be designed by selecting the motors that can provide the appropriate feed rate. The control program should also develop considering the behavior of characteristics of the particular foam type. The preliminary study yielded important results about controlling and designing a numerically controlled hot wire cutting with high accuracy and reliability. Further research is recommended choosing the cutting parameter characteristic curves of different foam types.

All of the reviewed systems have proven themselves to be technically feasible; however, few have been developed to the commercial stage. This is partly due to economic considerations and partly because many of the systems are still in the developmental phase. To-date the most successful build strategy is to cut and assemble individual layers, however with current advances in robotic machining this may change. Direct sculpting with robots offers increased complexity and reduced post-assembly of layers which can be considered for future scope of work. A number of unique ideas found were deemed for special importance to the development of future foam cutting RP systems and are therefore listed here.

These include:

- For systems that use direct sculpting, the use of a two-axis turntable to tilt and rotate the work piece allows much greater reach-ability of the mechanism. This would greatly increase the potential build volume of the system.
- The layer-based manufacturing method adopted by most of the systems could also be used to increase the size of parts built using the direct sculpting build strategy.
- The direct sculpting method could be applied to individual layers in the layer-based systems to avoid the need for surface approximations.
- Many of the systems exhibited a high level of automation. In particular the automatic generation of tool paths directly from the CAD model was common among the systems. The automation of data creation (tool paths, control programs etc.) is very important if the fast, reliable and automated production of sculpted objects is to be realized.

This project work dealt with designing a numerically controlled hot-wires foam. The challenge involved multiple disciplines, starting with mechanical engineering, continuing with mechatronics and control engineering, ending with programming and information technology. The mechanical design showed limitations of conventional parts, but allowed to create a new kinematical layout of a 4-axis hot-wire foam cutter that allows a wide range of the wire’s positions while reducing the load on servo drives.

In the programming part of the design, it was showed that a quite small program with a little more than few lines of code when run on a 300 MHz processing unit may successfully use results of CAD software, which requires sometimes 10 gigabytes of disk space on a personal computer. While there are CAM programs that have hundreds of settings, a self-written program gives an extensive knowledge of how the machine works. Programming of the developed foam cutter required to create a new algorithm for processing of 3D shapes that would match the set objectives (use information about the shape from 3D modelling software in a common 3D format). The tool path planning software may become more customizable (concerning cutting parameters or input formats) and give the user more feedback about the progress of cutting.

6.2. RESULTS

6.2.1. Control System Design

- System Requirements: Determine the specific requirements of the foam cutting machine, such as cutting speed, precision, and cutting patterns.
- Mathematical Modeling: Develop a mathematical model that represents the dynamics of the foam cutting machine, considering factors like motor characteristics, structural dynamics, and foam material properties.
- Controller Design: Design a suitable controller (e.g., PID controller) to achieve desired performance criteria, such as tracking accuracy and disturbance rejection.
- Sensor Selection: Determine appropriate sensors to measure relevant variables, such as position, velocity, and force during the cutting process.
- Control Algorithm: Implement control algorithms that take sensor measurements and adjust the machine's actuators (e.g., stepper motors) to achieve desired cutting paths.

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