Design, Fabrication and Control of CNC Plasma/Gas Cutter

A Final Year Project Report

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In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

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by

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ABSTRACT

This report covers the aspects of design, fabrication and control of a CNC Plasma Cutter Machine. The main objective of the project was to provide an automated low-cost alternative to manual plasma cutting techniques currently being used in the small industries of Pakistan. This involved an extensive literature review of the already present CNC plasma cutter machines and ways to make it cost effective. It also involves the design and calculations of the supporting table, the mechanical system driving the gantry in a two-dimensional plane and its linkage with a computer software to allow for numerically controlled precise cuttings.

ACKNOWLEDGMENTS

There were several people without whom the project would never have been possible. Their contributions towards the project were irreplaceable.

We would like to thank our supervisor **Dr. Jawad Aslam** for being a great mentor. Our guidance committee members **Dr. Riaz Ahmad Mufti** and **Dr. Aamir Mubashar** also deserve honorable mention. These people helped us throughout the project and gave us useful advices for this project. Once again, we give credit to our instructors whose assistance played a major role in the completion of the project.

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CNC Plamsa-FYP Report

ORIGINALITY REPORT

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ABBREVIATIONS

CNC	Computer Numerical Control
UGS	Universal G-Code Sender
PWM	Pulse Width Modulation
NEMA	National Electrical Manufacturers Association
DC	Direct Current
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
USD	United States Dollars
EDM	Electronic Discharge Machine
SWG	Standard Wire Gauge

NOMENCLATURE

l	Lead
I	Moment of Inertia
J	Polar Moment of Inertia
M	Masses
d_o	Pitch Diameter
F_a	Acceleration Force
F_r	Friction Force
μ	Friction Factor
F_u	Effective Pull
z	Teeth of Pulley
n	Revolutions per minute
i	Gear Ratio
S	Tooth Base Service Factor
F_v	Pre-Tension Force
S_{tm}	Tension Member Service Factor
L	Belt Length
d_c	Pulley Circumference
c_{spec}	Specific Spring Rate
Δs	Positional Error in Belt
T_{req}	Torque Required

CHAPTER 1: INTRODUCTION

Background:

The local industries in Pakistan comprises of a large portion of the products that require cutting of metal sheets. These industries include textile industries, fabrication and cutting industries and tanneries etc. In Pakistan the cutting methods used at local market scale are mostly manual. The conventional cutting machines which are operated by manual labor are also utilized for cutting of metal sheets. It results in the lower production rates as well as the inaccuracy in the cutting process. However, the local industries in Pakistan import CNC cutters from other countries which is very costly. So, small industries are reluctant to buy these CNC cutters from abroad. As a result, it has caused a decline in the production rates and precision in the local level.

Problem Statement:

The title of the project is “Design, Fabrication and Control of CNC Plasma/Gas Cutter”. The scope of the project includes to fabricate and design the plasma/gas cutter machine for local assistance along with the controls. The aim of this project to provide a CNC plasma/gas cutter to local market at a reasonable price as currently available CNC plasma/gas cutters cost around Rs. 1.5 lac. Also, the objective is to resolve all the issues mentioned above and increase the production rates and quality of products in local industries of Pakistan.

CNC:

Computer Numerical Control is the automated control of tools by using a computer by using a software. A program is being run in the computer that controls the motion of the parts of the machine. G-code is a computer language that is used to program CNC machines. To convert the CAD model into a G-code a CAM software is used. [1]

Types of CNC:

Different types of CNC machines are used for cutting processes. These machines use different types of cutting tools and different kinds of operations are performed by the CNC machines. A brief summary of these machines is given below:

CNC Laser Cutting Machine:

This type of CNC cutting machine uses laser in its cutting operations. The principle used in this cutting method is to focus the laser beam to a point with the help of the optics. This focused beam of light helps in cutting of material because of its higher temperature. This laser cutting tool is controlled by the CNC.

CNC Electronic Discharge Machine:

This type of CNC machine uses an electric charge for cutting process. The electric current flows between the electrodes to cut the metal sheet. The fluid between the electrode acts as a dielectric. EDM wire cut and Sinker EDM are two types of CNC Electronic Discharge Machines.

CNC Water Jet Cutting Machine:

This CNC machine is used for particular metal sheets that cannot bear high temperatures. An accelerated jet of water is used as a cutting tool in this machine. The water is used as a mixture along with other component such as sand which help in the cutting process.

CNC Plasma Cutting Machine:

This CNC uses an accelerated jet of plasma as a cutting tool. High velocity of gas is a blown through a nozzle. This high velocity gas is usually a compressed air. When this compressed air is passed through an electric arc it is turned into plasma which helps in cutting. To increase the precision of plasma cutter a plasma gun focuses the plasma to a point. This hot plasma though the plasma gun cuts metal.

Motivation of work:

The main motivation behind the project was to replace all the manual methods used in sheet metal cutting in the local market. As manual sheet metal cutting causes many problems. Some of the major problems are:

- Wastage of material
- Wastage of time
- Inaccuracy in sheet metal

Some other problems are also solved by using CNC plasma/gas cutter. It reduces the labor work. As one skilled operator can operate multiple machines while for manual methods one skilled operator is required for each job. The CNC sheet metal cutting has proved to be time effective hence it increases the production rate as well.

The motivation of the project is to provide a CNC plasma/gas cutter to the local market which is available internationally but at a relatively lower price.

Objectives:

The objectives of the project are as follows:

- To provide complete design and analysis of a CNC plasma/gas cutting machine
- To fabricate a CNC plasma/gas cutter that can cut a sheet of up to 800 x 800 mm metal at a moderate speed.
- To provide a controller box along with the CNC plasma/gas cutting machine
- To design a universal mount that can be used for any kind of plasma cutting tool
- The CNC plasma/gas cutting machine should have the positioning accuracy of at least 0.05 mm.

CHAPTER 2: LITERATURE REVIEW

The literature review was divided into two parts:

1. Mechanical
2. Electronics

Mechanical:

The mechanical section of CNC plasma cutting machine is divided into the table and travels.

Table design:

The table is the structural base of the whole CNC plasma cutting machine and it not only has to bear the weight of travels and equipment, but the weight of the metal sheet to be cut is also to be supported by the table. [2]

Structural strength:

The table needs to be of such structure and material such that it does not buckle/fracture under max specified load. This needs to be ensured beforehand via calculations[3] and finite element method[4]. The table can be made a number of materials. Currently, commercial-grade CNC cutting tables are being made out of aluminum and mild steel welded as per the proprietary design of the company to capable of bearing the design specification load. This gives a robust load bearing solution precisely according to needs but has the caveat of being a rather costly solution for a small-scale producer/vendor or even a startup. More project-based CNC tables are being made out of commercially available aluminum extrudes which leaves room for easy upgrades or changes with time as dimensions are industry standards. These tables have the advantage of being relatively cheaper but the simpler design means that they cannot be used for heavy-duty applications and also do not come with certifications as the commercial ones do.

Water table:

A very essential component of a CNC plasma cutting machine table is the water table that acts as a thermal buffer for the slats on top of which the metal sheet to be cut rests and the molten metal of the sheet after cutting that falls down. Water tables can be of several types. A very effective type is one which includes a false bottom. There is water under the false bottom as well and the two chambers are connected via pipe so the pressure is controlled[5]. This technique is rather difficult to maintain and bears additional costs resulting in complications. A simpler alternative which is used in smaller tables is a simple container filled manually with water which acts as a buffer for molten metal as intended. It is a simpler approach and fulfills the role effectively enough but needs continual checks which can be worth it considering the cost advantage.

Slats:

The metal sheets to be cut are rested on a frame of slats in the table that are replaceable. A slat is simply a thin metal strip. The grid of slats is arranged such that the slats offer maximum load bearing with least area of contact with the metal sheet which is to be cut. The replaceability is an important aspect of slats. As the plasma arc cuts a few mm below the metal sheet for effective cuts, the metal on which the sheets rest upon are bound to be damaged. For this reason, replaceable slats are employed and are relatively cheap considering the service life of the slats. It is also to be noted that the water table provides sufficient buffer to prolong the service life of the slats.

Travels:

The travels include the parts which enable x-axis, y-axis and z-axis movements. The travels include the metal structure on which the plasma gun rest and the parts responsible for making the whole pieces capable of motion. For the travels, materials used are mild steel and aluminum. Structural requirements are not as rigorous as the table itself but the structure does need to support the gantry weight for x and y-axis travel, drag chain etc. Overdesigning the travels invites unwanted complexity hence they are kept rectangular keeping costs to a minimum. The modes of travel can vary from one manufacturer to another based on scale, load, portability etc. Following are the various modes of travel used in CNC technologies.

Timing belt:

A timing belt is a rubber belt with equidistant grooves on the belt forming ‘teeth’ of sorts keeping the rotating pulleys timed as well. The belt is made of rubber along with reinforcing material such as glass fiber or Kevlar.

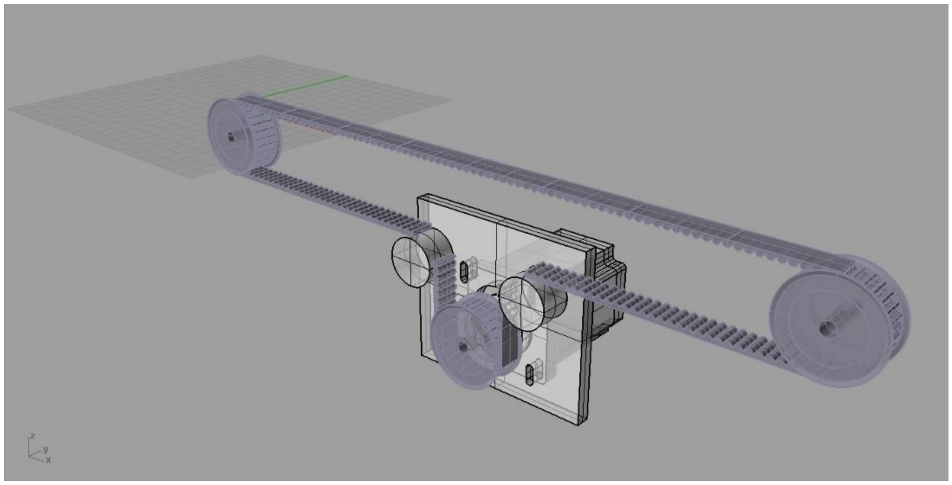


Figure 1: Timing belt.

Timing belts can be effectively used for longer ranges of motion. This is because the pulleys at both ends can be turned in a timed fashion, although with a tensioner, by a single, cheap yet accurate belt. This also results in the fact that using pulleys and timing belts is a relatively cheaper option. Timing belts carry several caveats as well. A major one being the fact that timing belts need regular calibration over usage. Production quality in the commercial belt section also limits the belts to have significant backlash which is not suitable for CNC plasma cutting application. The CNC plasma cutting application also dictates a need of fine precision for intricate cutting as used in modern metal applications. A timing belts offers low precision and control and offers only cost effectiveness in return.

Rack and pinion:

Rack and pinion are a circular gear driving a linear gear or vice versa. In a CNC application, the rack is driven by the pinion hence the motion in the axis.

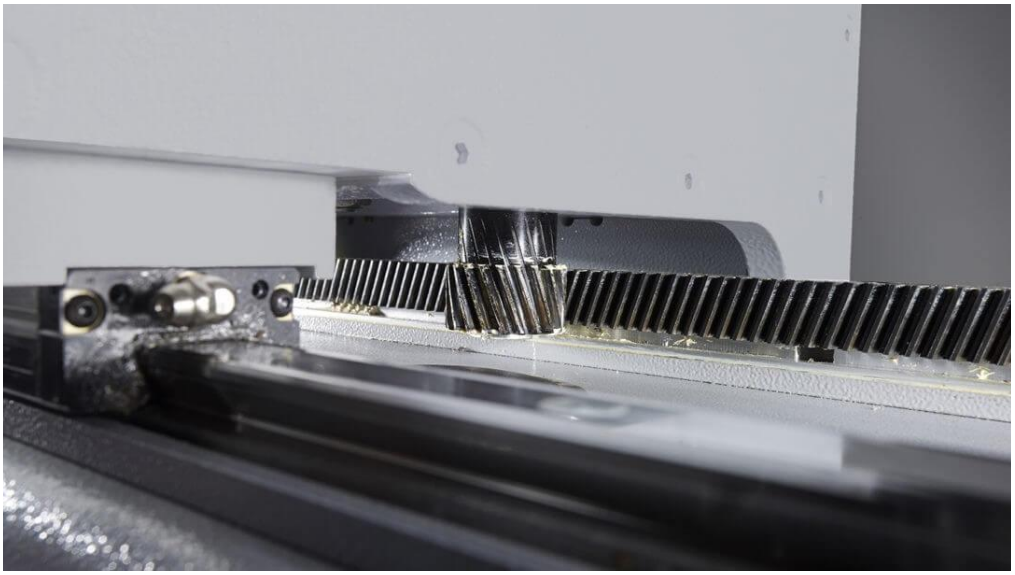


Figure 2: Rack and pinion.

The rack and pinion mechanism gives the advantage of have next to none backlash which give extreme accuracy and controllability. But the rack and pinion mechanism does offer a few problems as well. Designing a machine around pinions and racks is no ordinary feat. The rack and pinion mechanism is also expensive as per the tight machining tolerances. Also, the tight nature of gears meshing makes it unsuitable for continuous to and fro motion requirement as in CNC machines.

Power screws:

Power screw consists of a screw with a nut such that the screw rotates being driven by a motor which linearly translates the nut across the length of the screw. A continuous screw thread ensures continuous, jerk free motion while reduced friction can improve load bearing.

Figure 3: Ball Screw with Guides.

Several types of power screws are employed in the market of which the major type is lead screw and ball screw. A lead screw is a plain nut over a screw. It offers the advantage of being self-locking but requires powerful motors to drive bearing part to higher friction. A ball screw on the other hand is a nut with built-in ball bearings offering low friction yet is not self-locking. For CNC purposes, a ball screw offers more utility offering lower friction and self-locking is not a must-have requirement for a horizontal axis.

Electronics:

Electronics section is the brain of a CNC machine. They greatly affect the CNC's accuracy and workability. They define the resolution or the positional accuracy of the CNC. The electronic components used in the industries and DIY projects depends upon the complexity of the machine and the expertise of the operator. Also, each component is rated for different electrical specifications and the choice of one component depends upon the ratings of the other. The following components work together to form a CNC controller:

- Power Supply
- Stepper Motors
- Stepper Motor Drivers
- Microcontroller
- Computer Software

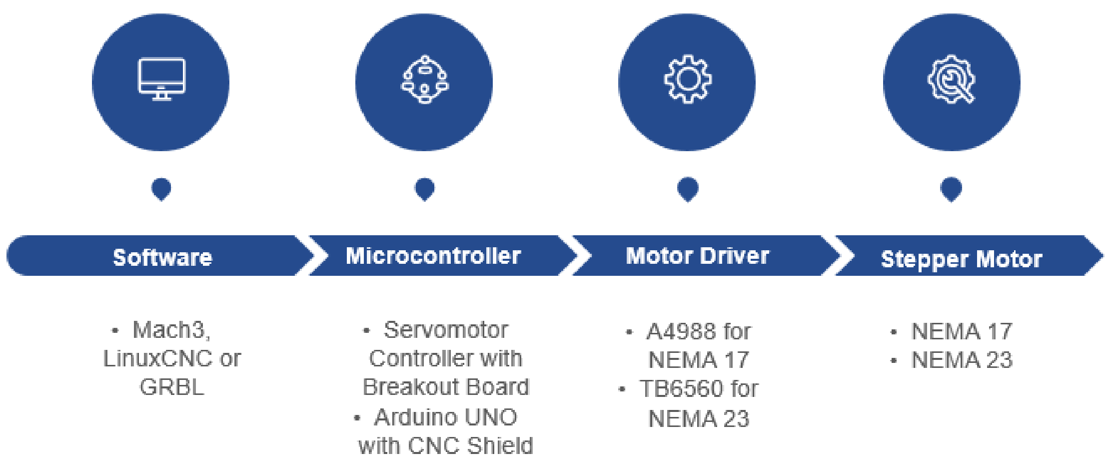


Figure 4: CNC Control Schematics.

Stepper Motors:[6]

A stepper motor is a DC motor whose whole rotation is divided into equal steps. They are ideal for high torque and low speed applications. A stepper motor has a rotor and a stator which consists of windings. The rotor rotates whenever the stator windings are energized due to a magnetic interaction. The correct winding to be energized is controlled by programming. So, a stepper motor can be thought of a digital actuator whose input is the energizing of the stator windings and the output is the angular rotation of the rotor (motor shaft).

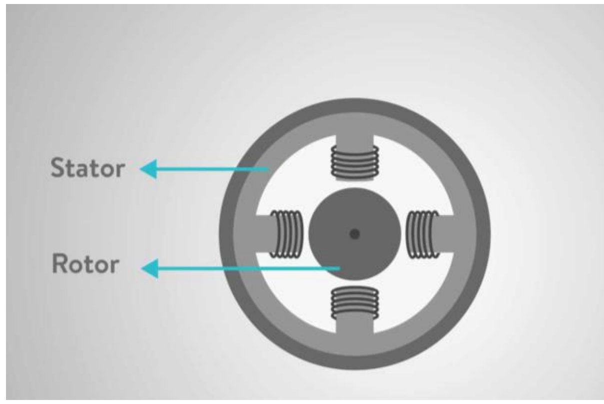


Figure 5: Stepper Motor Schematics.

Stepper motor can either be unipolar or bipolar depending upon the number of coils per phase. Bipolar stepper motors have one coil per phase while the unipolar steppers have two coils per phase. Unipolar steppers have high winding resistance thus offer less torque (40 percent lesser than bipolar). Bipolar steppers use complex circuitry of H-bridge to reverse the magnetic field of the stator poles but now it is no longer a

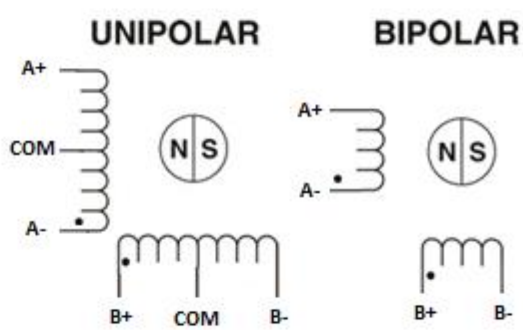


Figure 6: Unipolar vs. Bipolar Stepper Motors.

problem due to the use of motor drivers. So, a bipolar stepper motors are widely preferred. Also, bipolar stepper motors are usually four wired while unipolar are six wired.

Stepper motors are usually selected based on the torque requirements of the work piece to be moved. The two torque ratings[7] that need to be considered are:

- **Holding Torque:**

  It is the amount of torque provided by the motor when the rotor is stationary but the windings are energized. This is an important factor of a stepper motor that needs to be considered as this determines the capability of the stepper motor to hold the load in place.

- **Detent Torque:**

  It is the torque provided by the motor when the windings are not energized. It decreases the ideal torque produced by the motor. However, a high detent torque helps stopping the motor easily.

Most widely used stepper motors in CNC and 3D printers are the NEMA standard motor drivers. These motors are categorized in NEMA 14, 17, 23, 34 etc. depending upon the torque ratings of them.

Stepper Motor Drivers:[8]

Stepper motors usually operate at currents of 1.8 amperes or higher so an additional circuitry is needed to protect the microcontroller from this high current. Stepper motor drivers are used for this purpose. They help in regulating the current flow settings to the stepper motors. Modern motor drivers are also responsible for the micro-stepping of a stepper motor. Micro-stepping divides the total number of steps on a stepper into even further steps (by factors of 2,4,16 or 32) thus increasing its resolution but drastically decreasing the torque.

Motor drivers mostly used in the market includes A4988 for NEMA 17 and TB6560 or TB6600 for NEMA 23 and NEMA 34. The motor driver to be used depends upon its current rating and the current rating of the stepper motors. Some motor drivers have integrated microcontrollers so there is no need for a separate breakout board or an Arduino UNO. Heat sink is usually installed on the drivers as they may heat up on excess passage of currents.

Microcontroller:

The microcontroller is used to send the pulses command to the stepper motors via a motor driver. They are also responsible for the spindle control or the enabling and disabling of a plasma/gas/laser cutter. They use PWM to control the stepper motor and the spindle/plasma gun. The commands of the pulses are received by them through computer software.

Microcontroller used in the market may be a simple breakout board or an Arduino UNO. Breakout boards are used with computer software like Mach3 and LinuxCNC which are software developed specially for the CNC control. Arduino UNO is also a common microcontroller used to control small CNC machines with limited axis controls. GRBL is flashed onto the Arduino UNO which makes it into a CNC controller.

Computer Software:

Computer software are used to generate the G-code of a drawing file of the part that needs to be cut. G-code is a series of lines and arc commands, executed to generate the required toolpath. HSM Solidworks or SheetCAM can be used to generate the g-code of a drawing file. Similarly, Inkscape software is used to generate g-code from an image file or a sketch file of AutoCAD.

Yet another software must be used to send these G-codes to the microcontroller which drives the stepper motors and controls the spindle/plasma gun. The three most common software used to achieve this purpose includes:

- Mach3
- LinuxCNC
- Universal G-code Sender (UGS)

Mach3:[9]

It is one of the most widely used computer software to control the CNC machines. They offer 6-axis CNC control so it is used in both the industries and few DIY applications but its usage is often limited due to its high cost of about 175 USD. Also, it uses outdate parallel ports which is not found in PC these days.

LinuxCNC:[10]

It is yet another widely used software that also offers almost the same functionalities as Mach3. Its biggest advantage is that it is free to use software. But it is compatible only with Macintosh computers. Also due to its complex GUI (owing to the complex features), it is not suitable for smaller CNCs.

Universal G-Code Sender:[11]

It is another open-source free to use software which uses Arduino UNO, flashed by GRBL, to send the pulse commands to the stepper motors. The motor may lose some steps due to the de-synchronization between the USB ports and the controller as a USB-port, unlike parallel ports, is not suitable for tight timing requirements. This de-sync is overcome by Arduino as it handles all the time sensitive work. UGS has a simple and easy to understand GUI the use of Arduino can also be extended to remotely control the CNC machine using Wi-Fi.

SheetCAM:

SheetCAM is another open-source free to use software that is widely used for the Computer Aided Manufacturing operations. It can be used to generate G-code of part files and these G-codes can be edited using a very easy to use graphical user interface. These G-codes are then loaded either into the Mach3 software or the Arduino.

Power Supply:

Power supply converts the input AC voltage to a specified DC voltage depending upon its specifications. The power supply to be used depends upon the voltage rating of the motor controller and the sum of all the amperage of the stepper motors. Mostly used power supply in the DIY applications and small-scale CNC machines are 24 Volts and 15 Amperes.

CHAPTER 3: METHODOLOGY

A CNC machine's main task is to accurately move the tool/plasma and cut the material or the work piece. To achieve this task, the project can be divided into following 3 parts or subprojects as:

- Mechanical System Selection
- Electronics Selection/CNC Control
- Table Design

A water table is essential to hold the gantry and the mechanical and electronic system in place while also withholding all the stresses applied due to work piece. The mechanical system is responsible for providing power to the gantry to move. Electronics system or a CNC control is necessary to make sure that the gantry reaches the right space at the right time. The tasks performed to complete the 3 sub-projects are discussed in detail below:

Mechanical System Selection:

Mechanical system is the part responsible for moving the gantry, plasma gun and the auxiliaries on the water table. Literature review was done on 3 different mechanical systems and the advantages and disadvantages of each were compared, keeping in mind the scope of our project. The 3 systems analyzed were:

- Timing Belt
- Rack and Pinion

- Power Screw (Lead or Ball Screw)

After comparing the benefits and flaws of each of the system as discussed in the literature review, it was decided to use timing belts because of their highly cost-effective operation and high life. Also, they were most suitable for our project as per the scope defined.

Once the decision of using timing belts as our mode of gantry travel was made, the following calculations were done that helped in finalizing the specifications of timing belt to be used.

Timing Belt Calculations:[12]

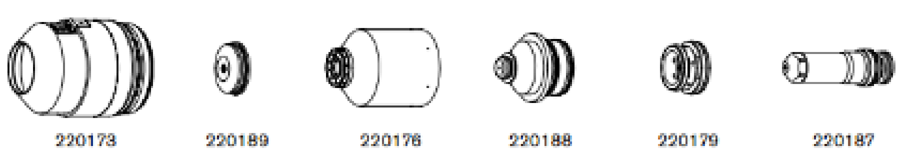
Timing belt Calculations are as follows:

Travel $s := 900\ mm$

Speed $v := 9810\ \frac{mm}{min}$ [13]

Mild steel
O_2 Plasma / Air Shield
80 A Cutting

Flow rates – lpm/scfh		
	O_2	Air
Preflow	0 / 0	76 / 161
Cutflow	23 / 48	41 / 87



Metric

Select Gases		Set Preflow		Set Cutflow		**Material Thickness**	Arc Voltage	Torch-to-Work Distance	Cutting Speed	Initial Pierce Height		Pierce Delay Time
Plasma	Shield	Plasma	Shield	Plasma	Shield	mm	Volts	mm	mm/m	mm	factor %	seconds
O_2	Air	48	23	78	23	**2**	112	2.5	9810	3.8	150	0.1
						2.5	115		7980			
						3	117		6145			0.2
						4	120	2.0	4300	4.0	200	
						6	123		3045			0.3
						10	127		1810			0.5
					10	**12**	130		1410	5.0	250	0.7
						15	133		1030			0.8
						20	135	2.5	545	6.3		0.9

Figure 7: Plasma Speed Chart.

Acceleration Time (Assumed) $t := 0.15\ s$

Acceleration $a := \frac{v}{t}$

$a = 1.09\ \frac{m}{s^2}$

Mass of Slide $m := 10\ kg$

Slide Length $l_l := 50\ mm$

Friction Factor $\mu := 0.5$

Pitch Diameter $d_o := 16\ mm$

Effective Pull[14]

Acceleration Force $F_a := m \cdot a$

$F_a = 10.9\ N$

Friction Force $F_r := \mu \cdot m \cdot g$

$F_r = 49.033\ N$

Effective Pull $F_u := F_a + F_r$

$F_u = 59.933\ N$

Mass of timing belt pulley and belt neglected.

Teeth of pulley $z := 24$

Gear Ratio $i := 1$

Teeth in Mesh Factor $c_1 := \frac{z}{2}$ For i=1

$c_1 = 12$

Required Effective Pull $F_{ureq} := \frac{F_u}{c_1}$

$F_{ureq} = 4.994\ N$

Required RPM

$$n := \frac{(v \cdot 19.1)}{d_o}$$

$$n = 195.178\ \frac{1}{s}$$

So, motor needs to be operated at 195 rpm.

Choosing the Belt to be HTD 3M.

Tooth Base Service Factor

For the 160 rpm of pulley, from the datasheet[15]

Allowable Shear Force $F_{ush} := 21.97\ N$

Tooth base service factor

$$S := \frac{F_{ush}}{F_{ureq}}$$

$$S = 4.399$$

It is greater than 1, so the belt teeth would not shear

Pre-tension Force $F_v := 1.5 \cdot F_u$

$$F_v = 89.9\ N$$

Pre-tension force is greater than one for Linear Drives.

Force Determining Belt Selection

Total Force $F_b := F_v + F_u$

$$F_b = 149.833\ N$$

For a belt of 15mm width, allowable force as per catalogue is

$$F_{all} := 510\ N$$

Tension Member Service Factor

$$S_{tm} := \frac{F_{all}}{F_b}$$

$$S_{tm} = 3.404$$

It is greater than one so the belt width chosen is adequate

Belt Length

If 50mm left on both extreme ends

Belt length required
For i=1

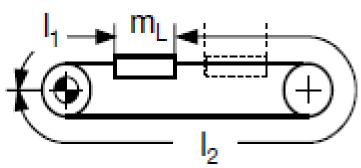
$$l := 2 \cdot \left(s + 100\ mm + l_l + \pi \cdot \frac{d_o}{2} \right) - 50\ mm$$

$$l = \left(2.1 \cdot 10^3 \right)\ mm \qquad l = 6.891\ ft$$

So 6.8 feet of belt is required for 900mm travel.

Spring Rate of System

Pulley Circumference $\quad d_c := \pi \cdot d_o \qquad d_c = 50.265\ mm$



At extreme left position:

$$l_1 := 50\ mm + \frac{d_c}{4} \qquad l_1 = 62.566\ mm$$

$$l_2 := \frac{d_c}{4} + 100\ mm + l_l + s + \frac{d_c}{2} + 50\ mm + s$$

$$l_2 = \left(2.038 \cdot 10^3 \right)\ mm$$

From the datasheet, specific spring rate is

$$c_{spec} := 127500\ N$$

$$c_{max} := \frac{l}{l_1 \cdot l_2} \cdot c_{spec} \qquad c_{max} = \left(2.1 \cdot 10^3 \right)\ \frac{N}{mm}$$

At extreme right position

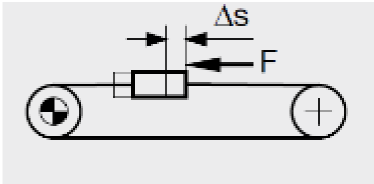
$$l_1 := \frac{d_c}{4} + 50\ mm + s \qquad l_1 = 962.566\ mm$$

$$l_2 := 50\ mm + \frac{d_c}{2} + 100\ mm + l_1 + s + \frac{d_c}{4} \qquad l_2 = \left(1.138 \cdot 10^3\right)\ mm$$

$$c_{min} := \frac{l}{l_1 \cdot l_2} \cdot c_{spec} \qquad c_{min} = 244.527\ \frac{N}{mm}$$

Positional Error due to External Force

External Force $F_r = 49.033\ N$



Minimum Error $\Delta s_{min} := \frac{F_r}{c_{max}}$

$\Delta s_{min} = 0.023\ mm$

Maximum Error $\Delta s_{max} := \frac{F_r}{c_{min}}$

$\Delta s_{max} = 0.201\ mm$

Frequency Analysis

Natural Frequency $f_e := \frac{1}{2 \cdot \pi} \cdot \sqrt{\left(\frac{c_{min}}{m}\right)}$

$f_e = 24.888\ \frac{1}{s}$

Excitation Frequency $f := \frac{n}{60}$

$f = 3.253\ \frac{1}{s}$

As the natural and excitation frequency do not match, there is no danger of resonance.

Torque Required:

Radius of the Pulley $r_p := 8\ mm$

Torque Required $T_{req} := F_u \cdot r_p$

$T_{req} = 47.947\ N \cdot cm$

Movement Accuracy:

Assuming a micro-stepping of 8 i.e. 1600 steps per revolution for stepper motor

Circumference of Pulley

$$c_p := 2 \cdot \pi \cdot r_p$$

$$c_p = 50.265 \ mm$$

Distance per Step

$$acc := \frac{c_p}{1600}$$

$$acc = 0.031 \ mm$$

So our design has an accuracy of about 0.03 mm per step

Timing Belt Specifications:

Table 1: Timing Belt Specifications

Properties	Specifications
Length	6.9ft (For one side)
Pitch	3mm
Width	15mm
Model	HTD 3M

Pulleys Specifications:

Table 2: Pulleys Specifications

Properties	Specifications
Pitch Diameter	16mm
Bore Diameter	10mm

Coupler:

The coupler needed to couple the motor shaft of 6.35mm and the pulleys for the timing belts with a bore diameter 10mm was finalized to be an aluminum flexible **D16L25 6.35*10mm.**

Linear Slides:

Timing Belts alone cannot be used to carry the mass of the gantry. Linear slides with bearings are used to help the ball screws in moving the gantry smoothly. We chose a railing after extensive market survey that had enough static and dynamic load rating. The railing finally selected was a **CPC MR12MN** that had the following specifications:[16]

Table 3: Linear Slide Specifications

Model Code	**Load Capacities (N)**		**Static Moment (Nm)**			**Weight**	
	Dynamic	Static	M_{ro}	M_{po}	M_{yo}	Block (g)	Rail (g/m)
MR 12MN SS/ZZ	2308	3465	21.5	12.9	12.9	34	602

Electronics Selection:

Selection of Stepper Motors:

As shown in the above calculations, the torque required by the motor to drive the gantry is about 48 N.cm. Considering a factor of safety of 1.5, the **required torque** becomes **72 N.cm.** So, **NEMA 23** Bipolar with holding torque of **90 N.cm** and 400 steps/revolution with **1/2 micro-stepping** was selected, the detailed specification of which is provided in Appendix I.

Selection of Motor Drivers:

For the 2 stepper motors, each of current rating 2.2 amperes. The motor driver that can handle this current and is also capable of micro-stepping was selected to be **TB6560**. Its specifications are provided in Appendix A.

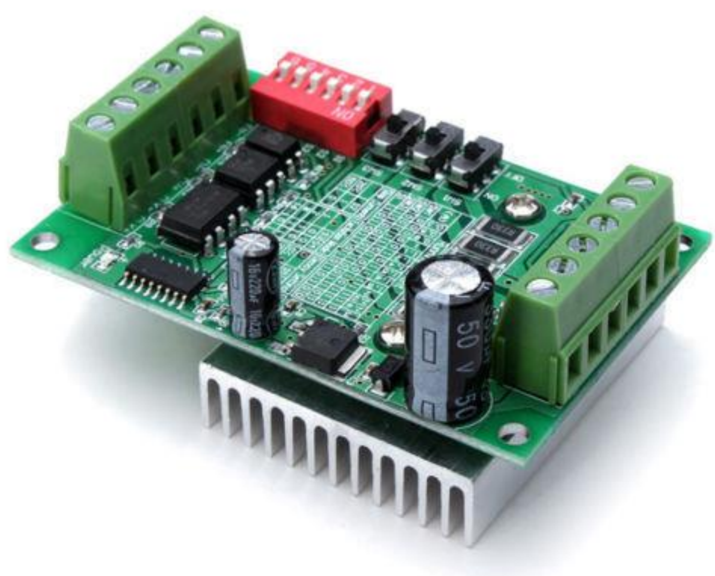


Figure 8: TB6560 Motor Driver.

Selection of Microcontroller:

The microcontroller was selected to be Mach3 interface board. It uses a parallel port for the connection with the PC so provides a significant advantage against the noise, which could be a major problem in Arduino due to its USB connection. SheetCAM was selected to send the G-code to the Mach3 software. The schematic for the microcontroller is:

Figure 9: MACH3 Interface Board.

Selection of Computer Software:

The software to be used needed to be easy to understand and use even for beginners. So, it needed to have a simple GUI. Also, our project scope was only limited to 2 axis control, so use of high-end software like CAM provided by solid works, offering 6 axis control was not feasible. The software selected to send the G-code to the Mach3 interface board and ultimately to the motor drivers was ‘**SheetCAM’.**

PC Selection:

PC and Windows selection was done on the recommended requirements[9] for the Mach3 software. The specifications of the selected PC were 32-bit version of **Windows XP**, **1Ghz** CPU, **512MB** RAM., Non-integrated Video Card with 32MB RAM.

Selection of Power Supply:

A power supply was needed to convert the phase AC into DC voltage that was to be used by different CNC control components. From the specifications of TB6560, it was found that its ideal voltage is 24V. Also, the motors combined needed a current of about 5 Amperes. So, with a factor of safety for current, the power supply selected was to be **24V and 10 Amperes**.

Electrical Shielding:

The plasma gun operates at several kilo Volts of electrical energy so it offers a lot of electrical interference or noise to the controller box and the connecting wires. It mostly results in step loss, thus decreasing the precision of the CNC. To avoid this, the controller box has to be enclosed in a Faraday's cage, a metal box. Also, the connecting wires need to be shielded with copper and braided coatings.

Table Design:

The table is divided into two parts based on the operation performed by each part:

1. Water Table
2. X-Y Travels

Water Table:

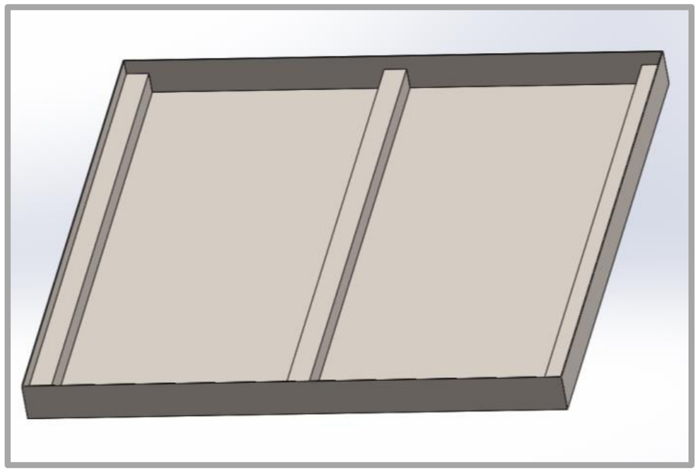


Figure 10: Design for the Water Table.

Not originally present in the preliminary design, water table is an essential component for high temperature plasma operation. The purpose of water table is to increase the life of slats and protect the table base from any permanent damage due to the molten metal residue.

Figure 10: Design for the Water Table shows the design for the water table. The table has a bottom area of 0.98m×0.98m and has a height of 7 cm. These design parameters are reflective

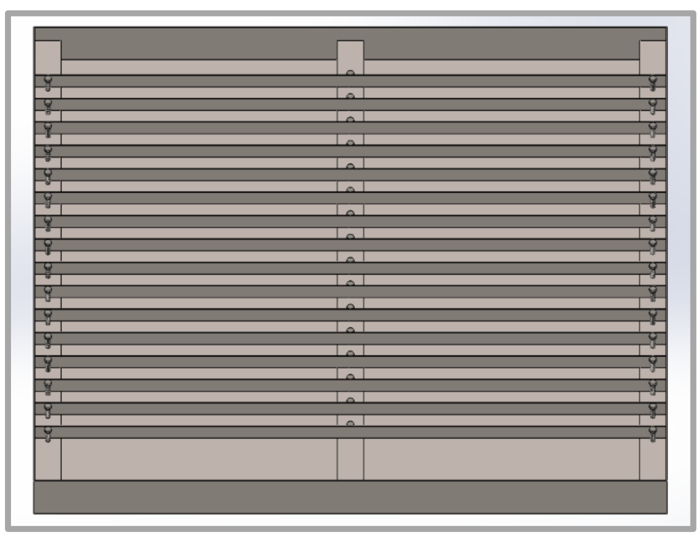


Figure 11: Slats Placement.

of the scope of the project. Three rectangular SS Bars that have a hollow cross-section of 1’’×1’’, and have 16 SWG thickness are placed inside the table and are bolted in place.

In order to support the weight of the targeted metal sheet, configuration shown in Figure 11 was utilized. The slats are held in place using M8×7 bolts placed 15cm from the starting end and 5 cm apart. Slats are 1’’ in height and SWG 18 MS Patti. Due to bolts placed at alternate places on the three supporting square bars, the slats acquire some degree of curvature, this curvature causes a certain amount of preload in the slats and increase the usage time. Small metal pieces that are cut using plasma does not fall inside the water table.

The water table is filled up-to 5 cm with water and can be drained easily using drain holes at the bottom of the table. The slats are non-permanently held in place and can be removed upon damage.

The table is supported using a 1m×1m×1m table frame made up of 1’’×1’’ SWG 16 rectangular bars. 1’’×1’’ Equal Angle bars are used to support the water table. The configuration of the support frame is shown in Figure 12.

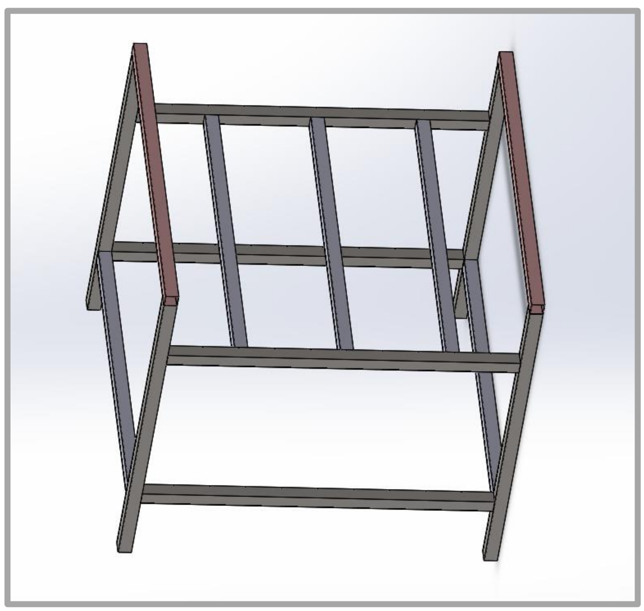


Figure 12: Support Frame.

X-Y Travels:

The water table incorporates the cutting area and residue collection. For the movement of the plasma torch in the desired cutting profile, X and Y-axis travels are utilized. For this purpose, the Nema-23 motors push the gantry or the plasma gun along the belts. The gantry is supported on each end by TBR16 circular guide rails. The selection of each component utilized in the X-Y travel design was based on the design calculations shown in the calculations section. The final configuration of the Table design is shown in Figure 13: Water Table with Gantry.

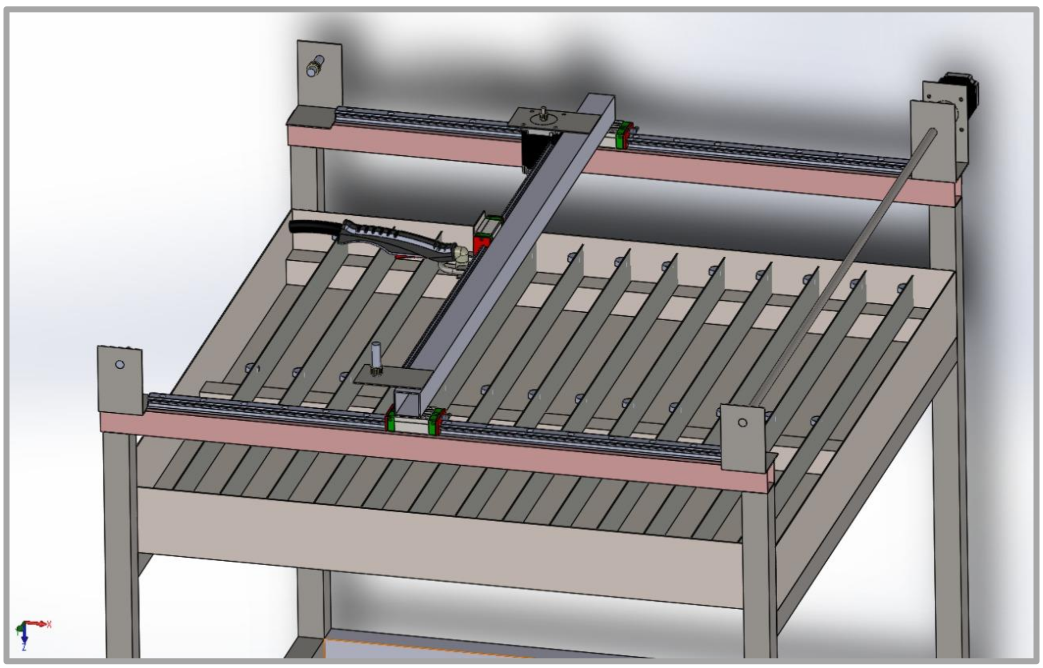


Figure 13: Water Table with Gantry.

TBR16 rails are supported on 3''×1.5'' SWG18 square MS bars that are also bolted in place. Nema-23 motors are held in place by standard mounts and coupled with the lead screw using 6.3 to 10 mm coupler. The plasma gun is held in place using U-clamp that can be loosened to adjust the height of the plasma gun.

The tool post that supports the U-Clamp holding the plasma gun is made of SWG18 metal sheet, the same as the water table base.

CHAPTER 4: RESULTS AND DISCUSSIONS

Keeping in view the objectives and the scope of the project, we were able to design and analyze the CNC Plasma Cutting Machine with the following major features and specifications.

Features of the Machines:

1. Working Area:

The design allowed a working area of **90 cm*90 cm**, which is much larger than the area provided in other low-cost CNC machines. This allows the user to more cutting options while remaining a cost-effective option.

2. Positional Accuracy:

The design allowed a positional accuracy of **0.03 mm** which is very much comparable to the accuracy of high-end and high cost machines. Furthermore, the positional error in the timing belt due to external load is also very low (maximum of 0.2 mm).

3. 2-D Cutting Capabilities:

The design allowed cutting of material through the gantry movement in 2 directions (x and y axis). The control in z-axis is manual and was omitted in the scope of the project for ease of use and low-cost manufacturing.

4. Easy to Use Interface:

The software interface incorporated in the project does not involve complex engineering analysis. The software and hence the machine can be operated with little to no engineering background. The software does not require any programming from the user. This makes the project ideal for use in local markets.

5. Universal Mount:

The gun mount on the machine can be adjusted to incorporate any gun for example, the plasma gun can be replaced with a laser gun. This requires very little change in electrical wiring and software interface thus making this machine a good choice for the local market.

6. Low Cost:

The project was designed with a main objective of keeping it low cost so that it can be used for the assistance of the local market. This target was achieved by careful consideration of material, mechanism and electronics selection as discussed in detail in the methodology's chapter. The total cost of the project is estimated to be around 65000 PKR.

Applications:

1. Local Market:

The main end-user for our project was the local market currently engaged in sheet metal works in Pakistan. Keeping that consumer in mind, the project was designed to be both cost-effective and easy to use, even for novice users. This CNC machine, being both low cost and easy to use, will prove to be a great assistance for the local market who currently uses manual cutting techniques which is not only uneconomical and inaccurate but also unsafe and hazardous for the user.

2. Medium Scale Industries:

Even though, the main target of this project was the local market. But, considering the positional accuracy that this design can offer with minimal positional errors, this machine can also find its application in medium scale industries which involves metal cutting.

With a few modifications, the machine can also be adjusted for use in other industries like textile and fabric cutting industries by incorporating a laser gun in place of the plasma gun.

Electronics Connections:

The CNC controller consists of the following components;

- Power Supply
- Mach3 Breakout Board
- 2 TB6560 Motor Drivers
- 2 NEMA 23 Motors
- 4 Limit Switches
- Emergency Switch
- Relay
- PC

Power Supply of 24V was connected to the motor drivers and Mach3 breakout board directly. The motor drivers were further connected to the NEMA 23 stepper motors. 4 limit switches and an emergency switch were also used in the controller circuit. A relay was used to control the working of Plasma Gun. The Mach3 breakout board was directly controlled by the PC.

Connection of Stepper Motor:

4 wire bipolar NEMA 23 stepper motors were used and were connected directly to the motor drivers.

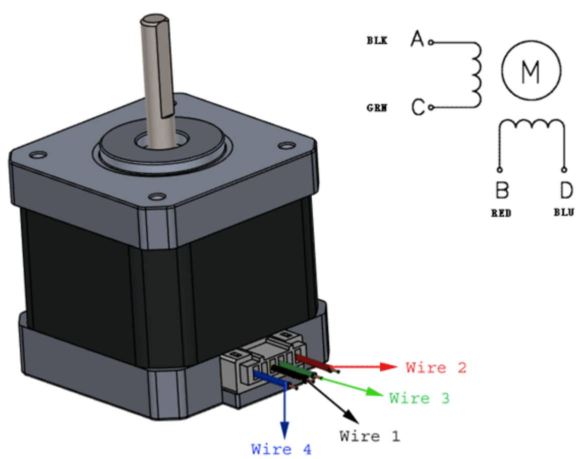


Figure 14: Connection of Stepper Motor.

Schematics:

The complete Schematics of the all the electronic components is shown below:

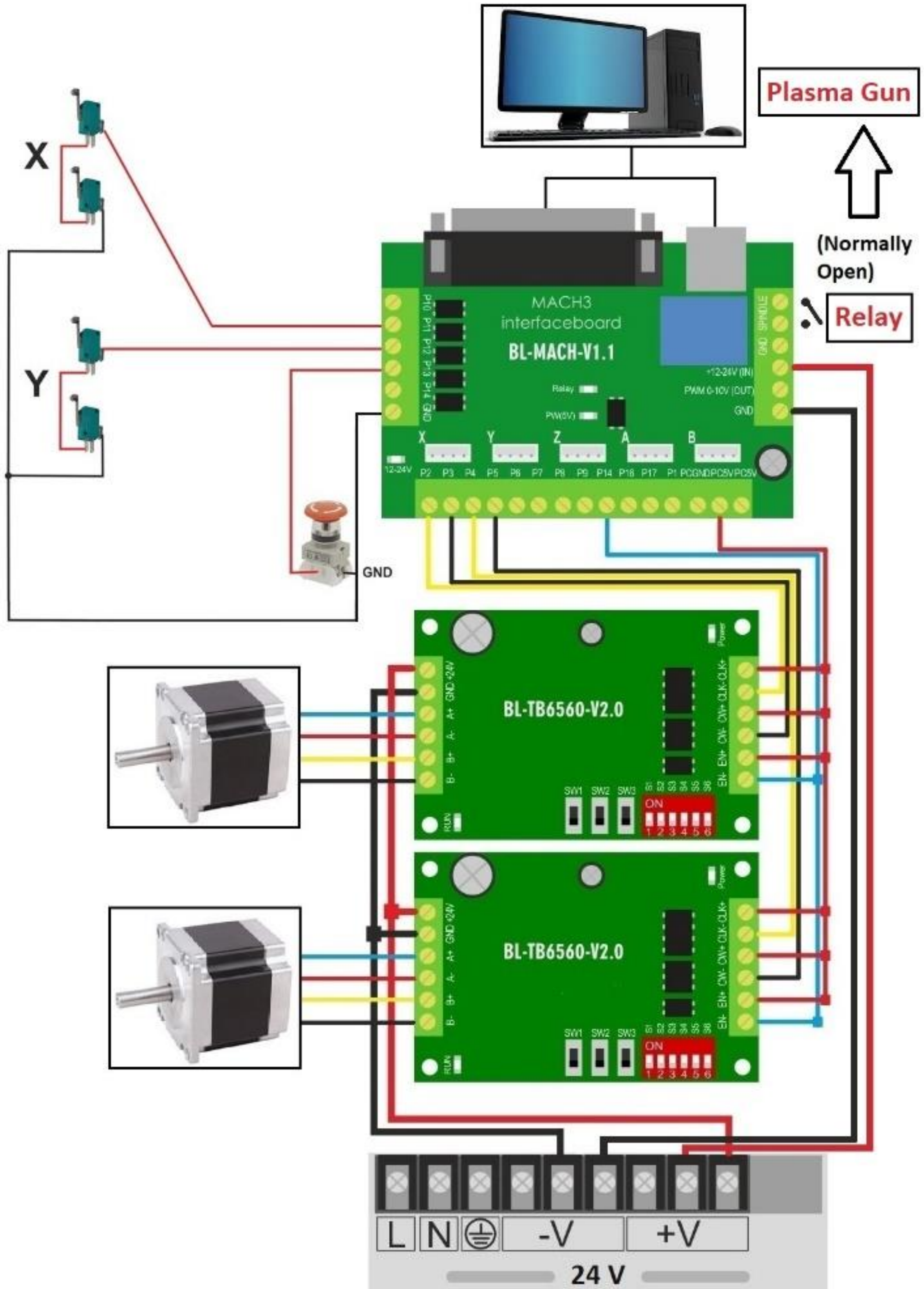


Figure 15: Schematics of Electronic Components.

Noise in Electronics:

One of the biggest caveats of plasma cutting is the RF noise produced due to the high voltage spark needed to make the pilot arc. This RF noise can cause quite a few problems with electronics, a major one being that any metal part connected to a wire can act as an antenna and transmit that noise to the electronics as a “signal”, hindering the original functions or halting them completely. Another problem with RF noise is that the noise deteriorates the signals in wires in turn hurting performance of the task to be performed or in case of fine signals such as step functions, the receiving end may not be able to interpret the signal correctly, hence stopping the function.

Noise in CNC Plasma Cutter:

In the present case of the CNC Plasma cutter, the RF noise generated by the plasma machine affects not only the Mach-3 boards with interference but also renders all USB connections useless while operation. This means, if let be, the controllers stop moving the motors as soon as the plasma torch starts to operate. The following measures are taken to ensure the working of the router table throughout the operation of the plasma cutting.

Controller Box:

The Mach-3 controllers are all put in a closed metal box which acts as a faraday’s cage and shields them from direct RF noise ensuring proper functioning during plasma cutting operation.

Problems with Closed Box:

The problem with a completely closed off box is two-fold. The first is the fact that wires need to be routed in and out of the box which needs a cutout of its own. The second is that the controllers generate heat and would fail at high temperatures so ventilation across the box is also imperative.

Although cutting out holes in the box walls decreases the RF noise protection efficiency but still remains sufficient enough to allow proper functioning of the controllers. The heat issue is solved by attaching heat sinks to the back of the controllers and placing an exhaust fan at one end and airflow cutouts at the other that help cool the controllers and help them remain within the operating temperature range.

Interface:

As mentioned before the more commonly used interface of USB is highly susceptible to RF noise and most USB devices do not function at all during the RF noise source being activated such as the plasma cutter. To overcome this problem, the USB interface was to be completely removed from the various data connections being made. For the controllers, Parallel port interface was used as it is quite resistant against RF noise hence operation continues in presence of RF noise from a source such as the Plasma cutter.

Cable shielding

The various cables such as motor cables, encoder cables, driver cables and whatnot are susceptible to signal degradation due to RF noise which may result in improper functioning or unexpected results/errors in motion. For this reason, the cables are shielded by metal foil which helps retain the actual signal resulting in proper functioning throughout the CNC operation.

Noise grounding:

The shielding of all sorts i.e.: cable shielding, controller box etc. are grounded along with the whole electrical ground which improves the shielding effect.

Warping of Metal during Welding:

As the thickness of the metal bars used for the frame of the CNC router table was only 1.6mm, the metal warped during welding and it was difficult to get exactly 90 degrees between the frame legs, in order to overcome this, a clamp was used to hold the frame legs in place during welding process. As the table frame included welding of bars in a square shaped frame, the warping made it difficult to insert in the 4th leg after three legs had been welded together in a “U” shape. Excessive force by hand was used to weld the 4th leg properly and at a 90 degrees angle. As the legs are already in a state of tension without applying any external load, a “pre-load” acts on the legs making the design more sturdy and rigid.

Stainless steel is the most preferable metal for water storage, but one downside of stainless steel is that it is really hard to cut, ordinary drill bits didn’t work on the hard surface texture of stainless steel. So, in order to drill holes for the drain, special bits were purchased to drill hole in the water table, and even though the drill bits were stainless steel specific, the drill machines available were not powerful enough and this caused the holes to become slightly oval. One drill bit could be used only to make about 14 holes in a 1.6mm thick SS sheet, and after that the bit becomes non-useable.

Software Interfaces:

1. SheetCAM:

SheetCAM software was used to generate the g-code of the drawing. This g-code is further used by the mach3 software which in turn runs the plasma gun.

The following figure shows the interface of the SheetCAM software:

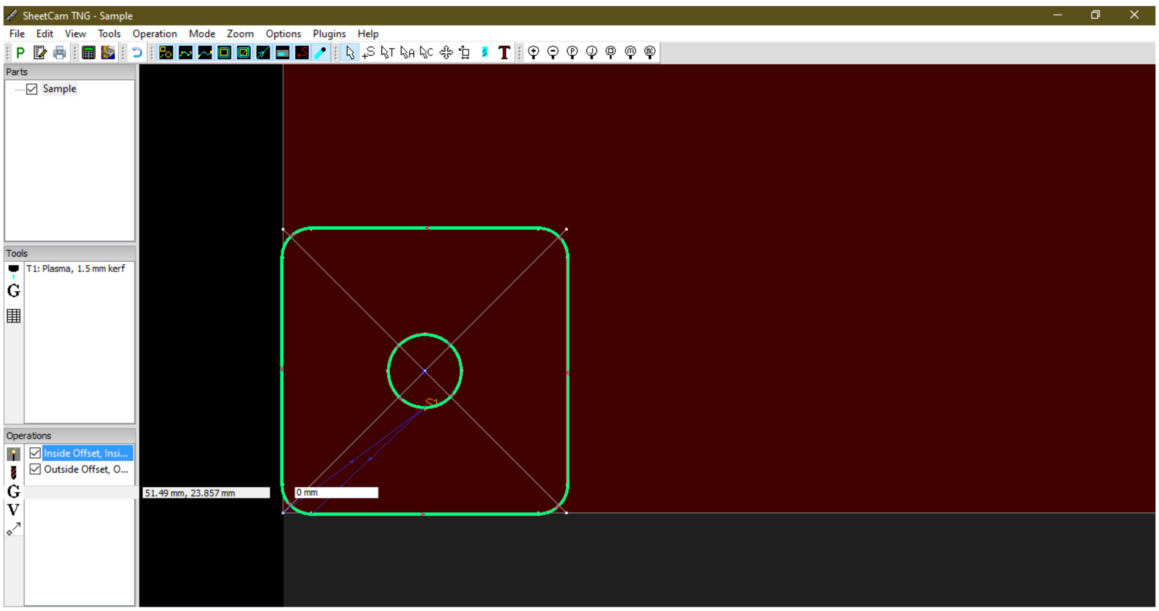


Figure 16: Software Interface of SheetCAM.

2. Mach3:

The g-code generated by the SheetCAM is used by Mach3 which is used to run the plasma gun.

The following figure shows the interface of Mach3 software:

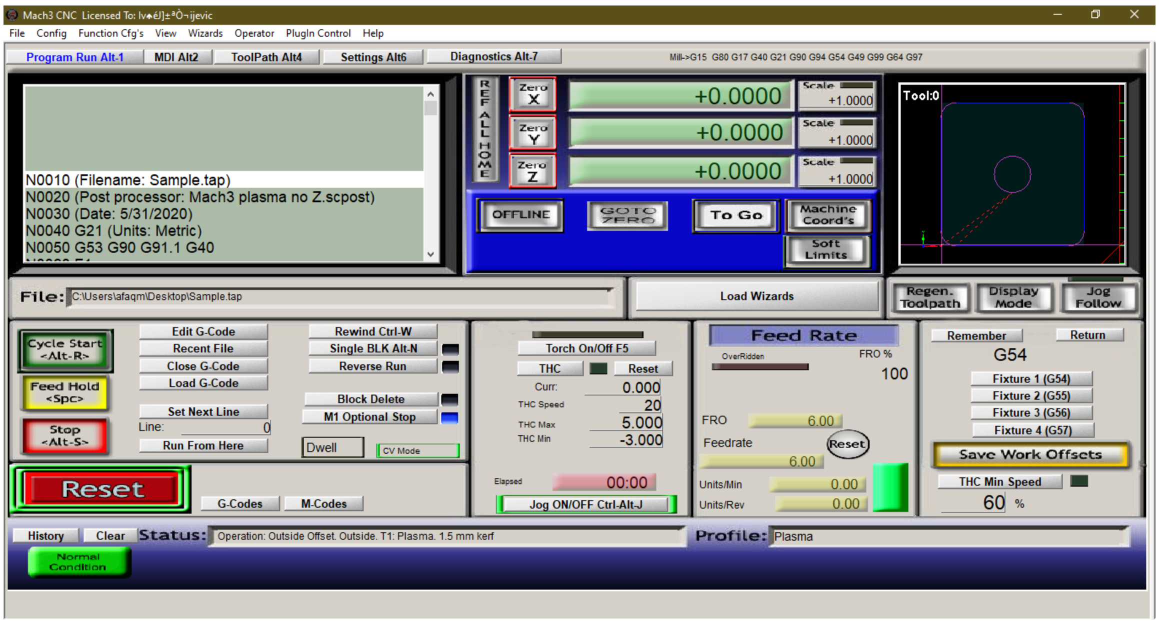


Figure 17: Software Interface of Mach3.

Stress Analysis:

The frame of the machine was analyzed for total deformation and stresses to ensure that the design is sufficient and can handle the force applied. The analysis was done in ANSYS 19 and the force was assumed to be a maximum of 3000 Newtons (Definition details in APPENDIX II: FRAME ANALYSIS). This force was due to combined effect of the weight of water in the water table and a 1m*1m 20mm thick metal sheet on top. Different analysis results are shown below:

1. Total Deformation of Frame:

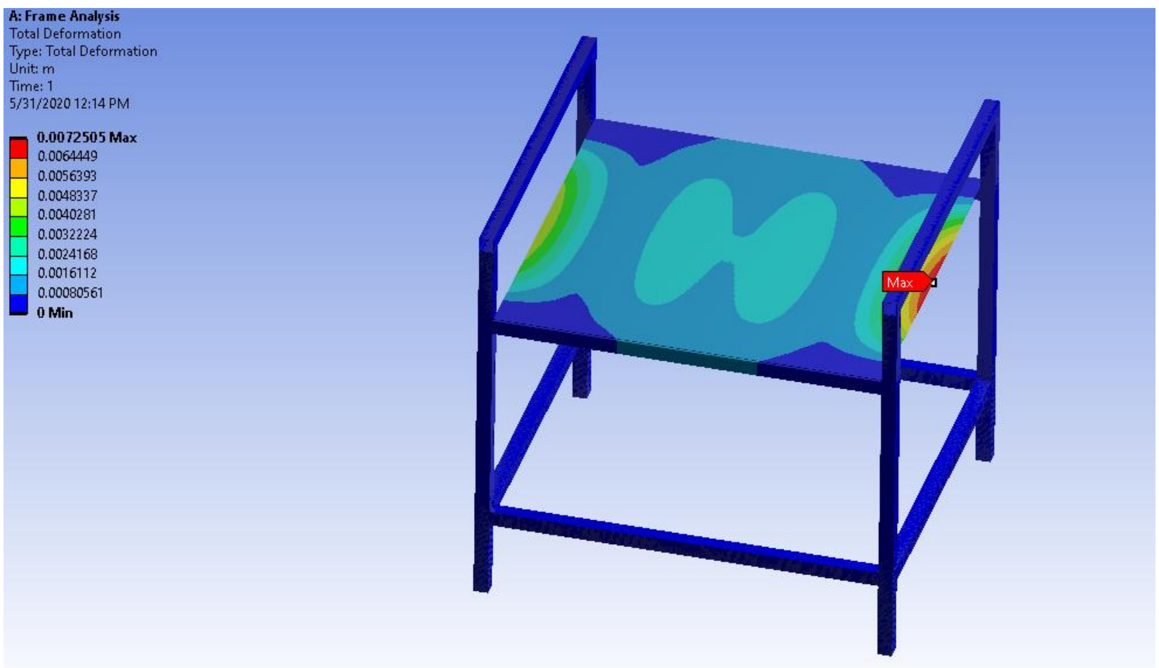


Figure 18: Maximum Deformation of Table Frame.

Table 4: Total Deformation Solution

Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation

Time [s]	Minimum [m]	Maximum [m]	Average [m]
1.	0.	7.2505e-003	7.6094e-004

2. Equivalent Stress:

The equivalent (Von-Mises) Stress was analyzed for the frame and the stress was found to be less than the yield strength of the materials. Hence the design is safe even for maximum load.

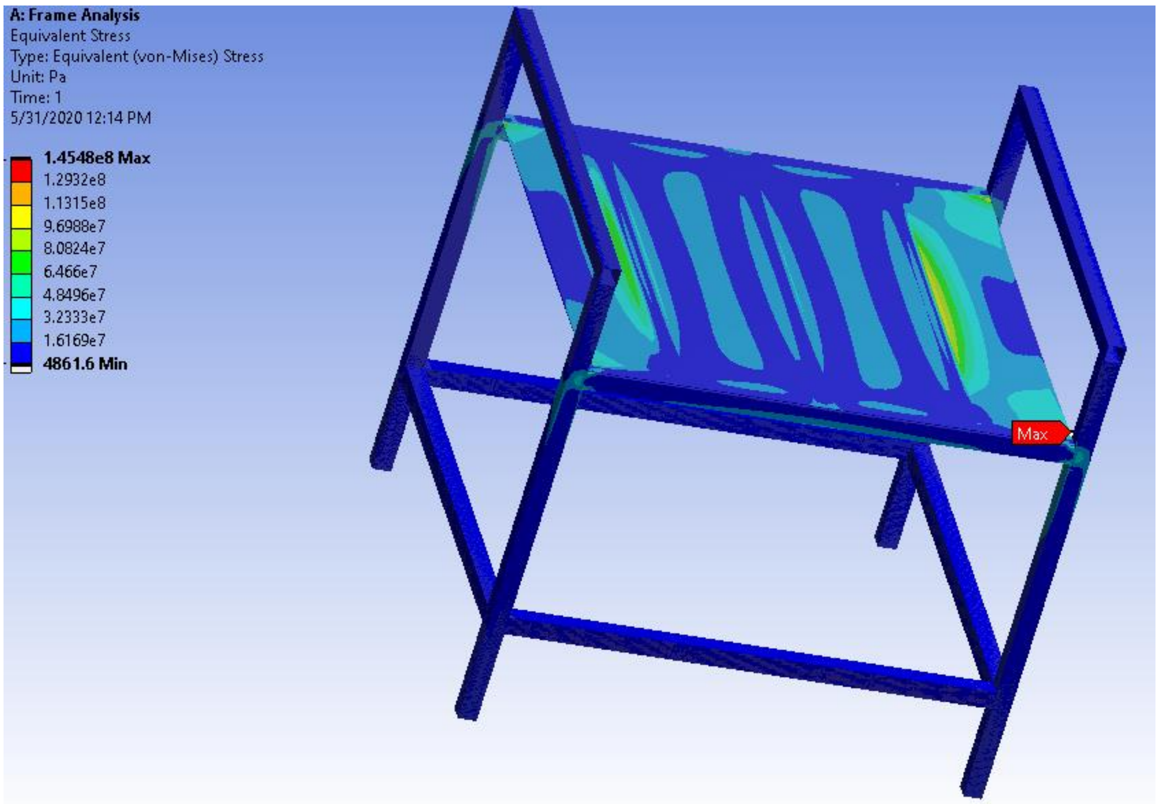


Figure 19: Equivalent Stress for Frame.

Table 5: Equivalent Stress Solution

Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent Stress

Time [s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
1.	4861.6	1.4548e+008	9.505e+006

3. Normal Stress:

Apart from equivalent stress, the normal stress was also analyzed to double check the safety of our design. The stress came out to be well below the yield strength of the materials.

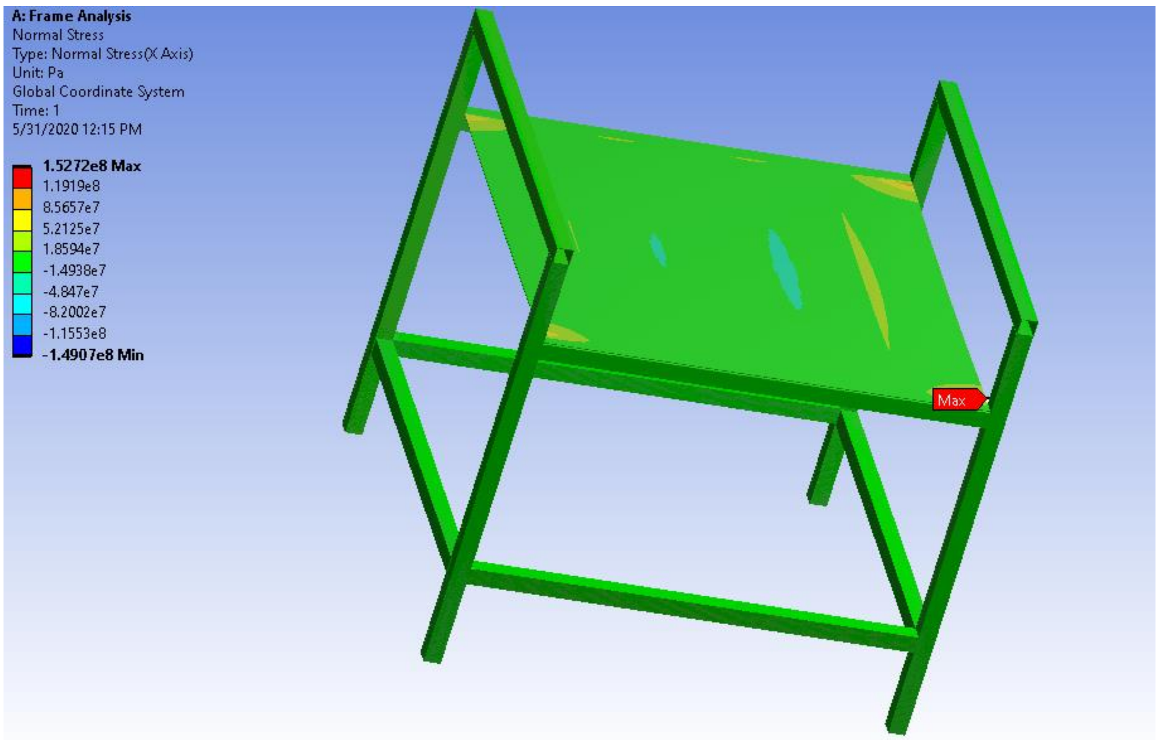


Figure 20: Normal Stress for Frame.

Table 6: Normal Stress Solution

Model (A4) > Static Structural (A5) > Solution (A6) > Normal Stress

Time [s]	Minimum [Pa]	Maximum [Pa]	Average [Pa]
1.	-1.4907e+008	1.5272e+008	83599

4. Buckling Analysis for Frame Legs:

The legs of the frame were also analyzed for buckling load. The load was estimated to be about 700 Newton on each leg. The maximum deformation came out to be about 6.7µm. The results of the total deformation are shown:

Figure 21: Legs Deformation.

Table 7: Buckling Deformation

Model (A4, B4) > Static Structural (A5) > Solution (A6) > Total Deformation

Time [s]	Minimum [mm]	Maximum [mm]	Average [mm]
1.	0.	6.692e-003	3.3437e-003

The factor of safety (Load Multiplier) for the buckling failure was also calculated to be about 73 as shown:

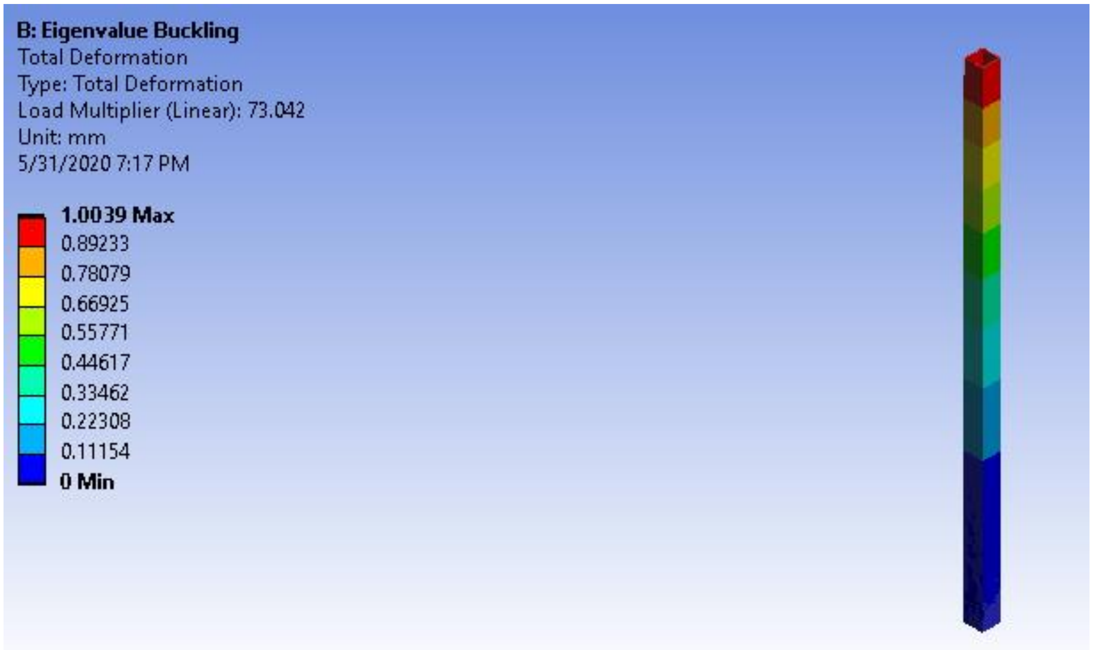


Figure 22: Buckling FOS.

Table 8: Buckling FOS Results

Model (A4, B4) > Eigenvalue Buckling (B5) > Solution (B6) > Results

Object Name	*Total Deformation*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Deformation
Mode	1.
Identifier	
Suppressed	No
Results	
Load Multiplier	73.042
Minimum	0. mm
Maximum	1.0039 mm
Average	0.3666 mm

Thermal Analysis for Water Table:

1. Water Depth:[17]

The amount of water to be filled is done after a careful choice between the smoke or the hot splash produced. The closer the water level is to the metal being cut, less will be the fumes or smoke produced but the splash will be more. We decided to fill the water table, with a total height of 10 cm, to be **filled up to 7 cm** to avoid excessive smoke formation without a very considerable splash.

2. Average Evaporation Rate:

The average evaporation rate for the water in the water table was calculated as follows:

For Plasma gun's max power $I := 80\ A$

$$V := 220\ V$$

$$Q := V \cdot I$$

$$Q = \left(1.76 \cdot 10^4\right)\ W$$

Assuming no energy losses to the water:

Now, enthalpy of vaporization for water is

$$h_{fg} := 2257 \cdot 10^3\ \frac{J}{kg}$$ (at atmospheric pressure)

As, $m := \frac{Q}{h_{fg}}$

$$m = 0.008\ \frac{kg}{s}$$

$$m = 7.798\ \frac{gm}{s}$$

It is the average evaporation rate for the whole water table.

3. Thermal Analysis using Ansys:

The analysis for the water table was also done using Ansys Fluent using the mixture model. The cell-zone assignments and the details of the model selected can be referenced from APPENDIX II: FRAME ANALYSIS. The results of the analysis are as shown:

Mass Transfer Rate:

The mass transfer rate for the water liquid to water vapors was analyzed and the result was as below:

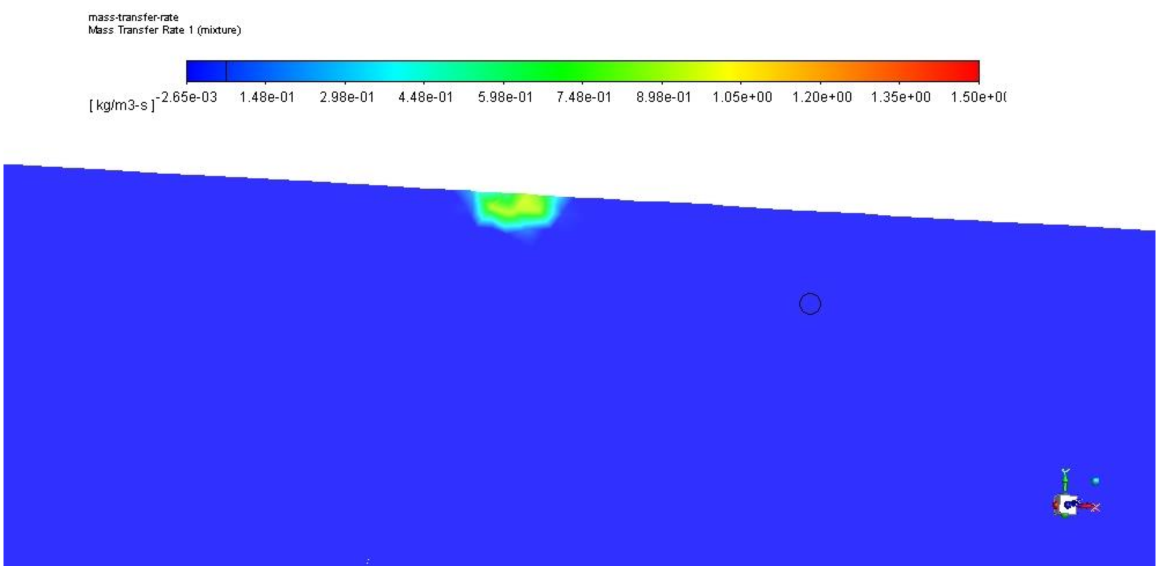


Figure 23: Water Evaporation Rate.

The maximum evaporation rate was found to be 1.5 kg/m^3s at the point of heating.

Temperature Profile:

The temperature profile for the air and water close to the plasma gun was analyzed and the result was as followed:

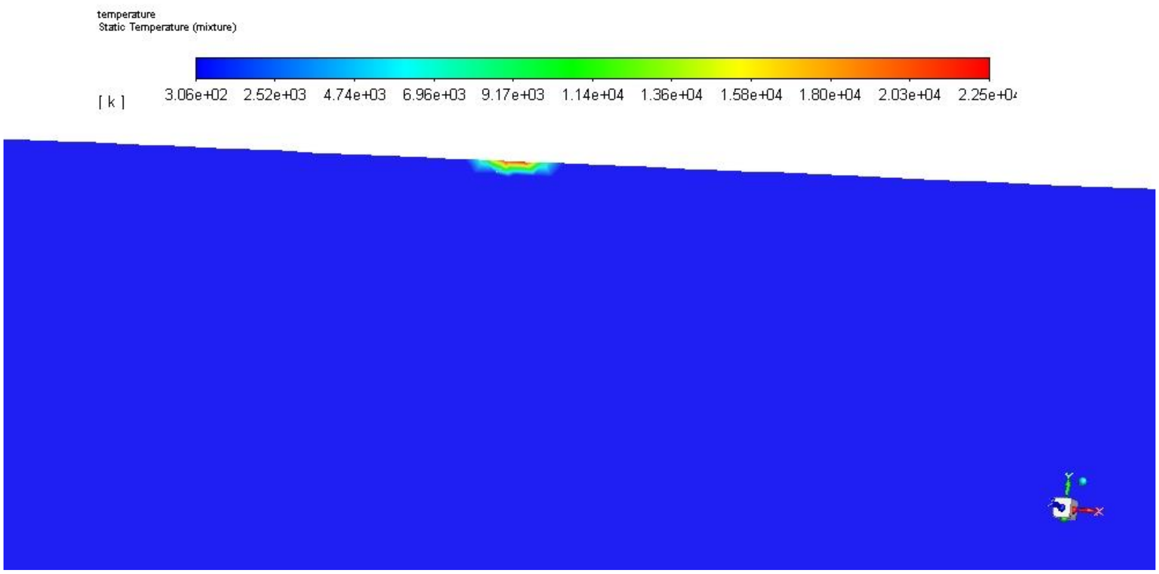


Figure 24: Temperature Profile.

The temperature of the water was found to be about 306 Kelvin.

Water Liquid Fraction:

The fraction of water in liquid phase for the whole water table (including 3 phases, water liquid, water vapors and air) was analyzed and the result was as followed:

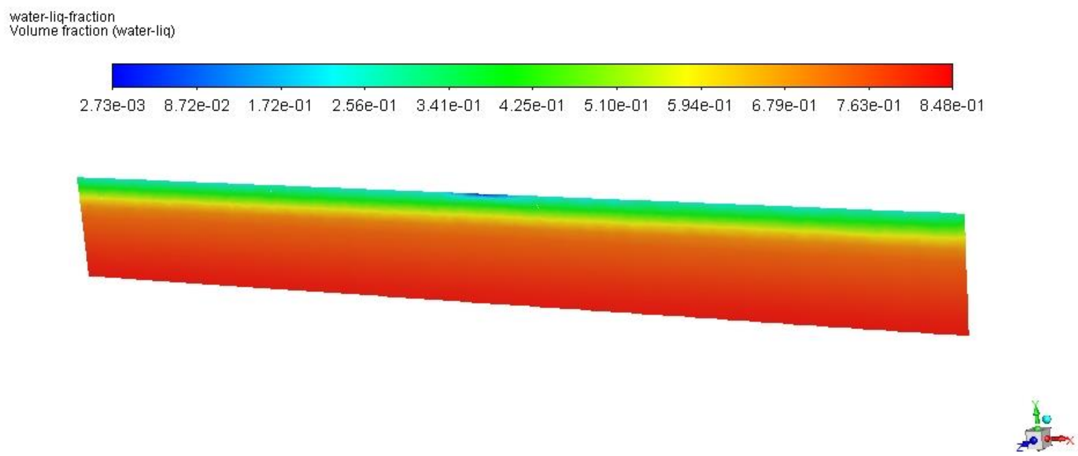


Figure 25: Water Liquid Fraction.

The water state was found to be all liquid at the bottom while some water vapors were found to exist close to the heating zone i.e. the plasma torch and some amount was also present in the air.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

The end result of this project was to deliver a CNC router table that will have a tool post to mount a plasma gun. Under ideal conditions, the CAD model that was prepared after adequate literature review reflected our understanding and grasp of the concerned engineering knowledge. One restriction that affected our accuracy was our tight budget, as aforementioned, a low-quality plasma table costs more than 1.5 lac PKR; in order to effectively translate this price into less than 70K PKR, local metal tubes and electronic equipment was used. This undoubtedly had an effect on out end accuracy but this compromise of accuracy was justified given the price range that was achieved.

The fabrication and manufacturing phase went smoothly, everything was cut, polished and assembled manually. One thing that exacerbated our timeline was the busy routine of manufacturing shop workers. But working around that; the project was completed (almost) within the given timeline. Overall it can be concluded that the modified project scope was achieved and the deliverables were provided to the concerned supervisors.

Future Recommendations:

If budget is not a concern, a few modifications can be performed in the current design to achieve a higher accuracy:

1. In the current design, the table frame is made by welding together SWG 16 MS pipes, having a per meter cost of 270 PKR. Problem with this selection is that the table frame cannot be modified in the future and new frame must be constructed if working area is to be increased.

Alternative: 6063 Aluminum extrude should be used to make the frame as these extrudes are produced specifically for CNC table frame. Costing around 875 PKR per meter, this choice significantly impacts manufacturing budget but provides greater workability and modification capabilities.

2. Currently for moving the gantry in plasma tables, timing belts are being used worldwide. The torque requirement of timing belt is more and they are easier to work with, but the downside is that they don't provide manufacturing grade accuracy and the belt should be under adequate tension. Per meter cost is 120-200 PKR.

Alternative: Ball or Lead Screw should be used instead, as they provide better accuracy, capable of transferring torque effectively and there are no worrisome tension problems to deal with. Per meter cost of a lead screw is 4000-7000 PKR, but the accuracy shift is significant.

3. The slats utilized in the water table were recyclable. The molten metal will fall in the table and then taps at the bottom of the table need to be opened to let the slag and waste water out. Some automated method can be adopted to this instead of manual operation to make the work flow smooth.
4. The current machine works only on 2 axis i.e. the gantry is allowed motion in two directions only. Third axis i.e. z-axis could be added to the project to allow better control of the machine and provide easier cutting but at the cost of simplicity in design and cost effectiveness.

5. Additional Methods could be applied for the noise reduction due to electromagnetic interferences caused by high frequency plasma gun. These may include installation of ferrite beads on the motor wires, placing the electronics farther away from the source i.e. plasma torch or using a better, but high cost plasma gun, that does not have a high frequency start to cause any noise.
6. Torch Height Control (THC)[18] function can be added to the project to further increase the precision and accuracy of the plasma gun movement in the z-axis. This addition would be costly, but it would increase the precision manifolds to industrial standards.

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APPENDIX I: SPECIFICATIONS OF COMPONENTS

TB6560 Motor Driver:[19]

Table 9: TB6560 Specifications

Input voltage	12V-36V DC
Output current	0.5A-3.5A (Peak)
Drive type	Pulse + Direction + Enable Signal Control (Bipolar constant-current PWM output)
Suitable motor	Nema17, Nema23, Nema24, Nema34 (Rated current: 0.5A-3.5A)
Net weight	390g (Driver)
Dimensions	174*142*38mm

NEMA 23 Stepper Motor:[20]

Table 10: NEMA 23 Specifications

Voltage	3.2 V
Current Rating	2.2 Amperes
Holding Torque	90 N.cm
Step Angle	1.8 degrees
Steps per revolution	200 (Without micro-stepping)
No. of leads	4
Rotor Inertia	0.3 $kg.cm^2$

APPENDIX II: FRAME ANALYSIS

Load and Supports Definition:

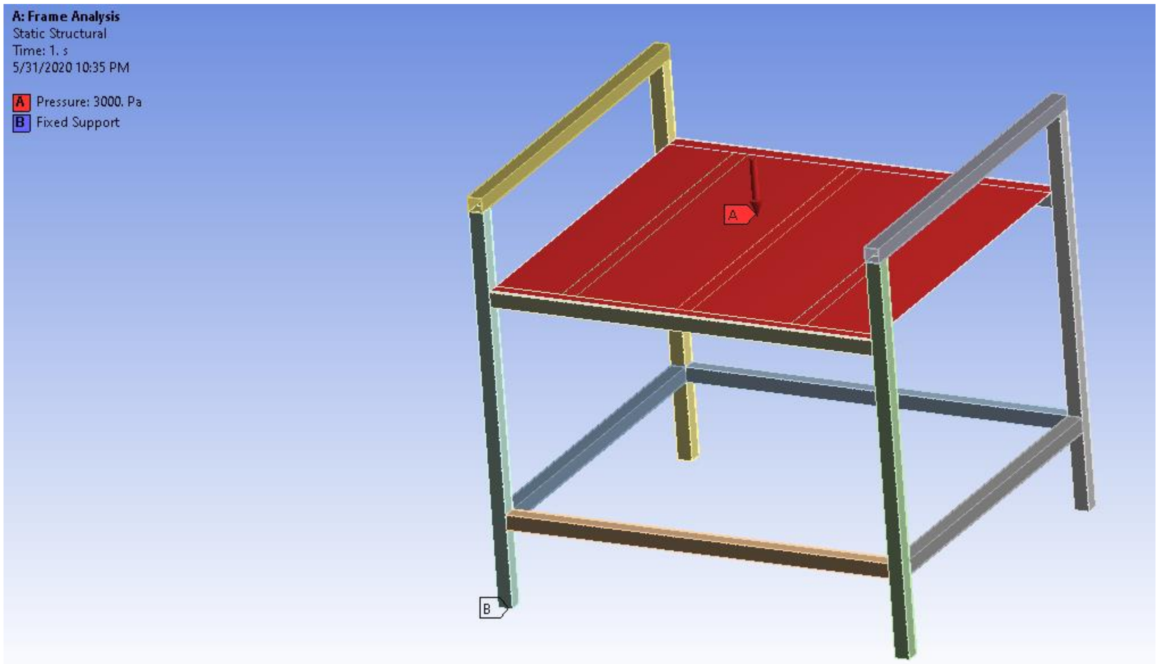

Figure 26: Load and Supports Definition.

Cell-Zones and Model for Thermal Analysis:

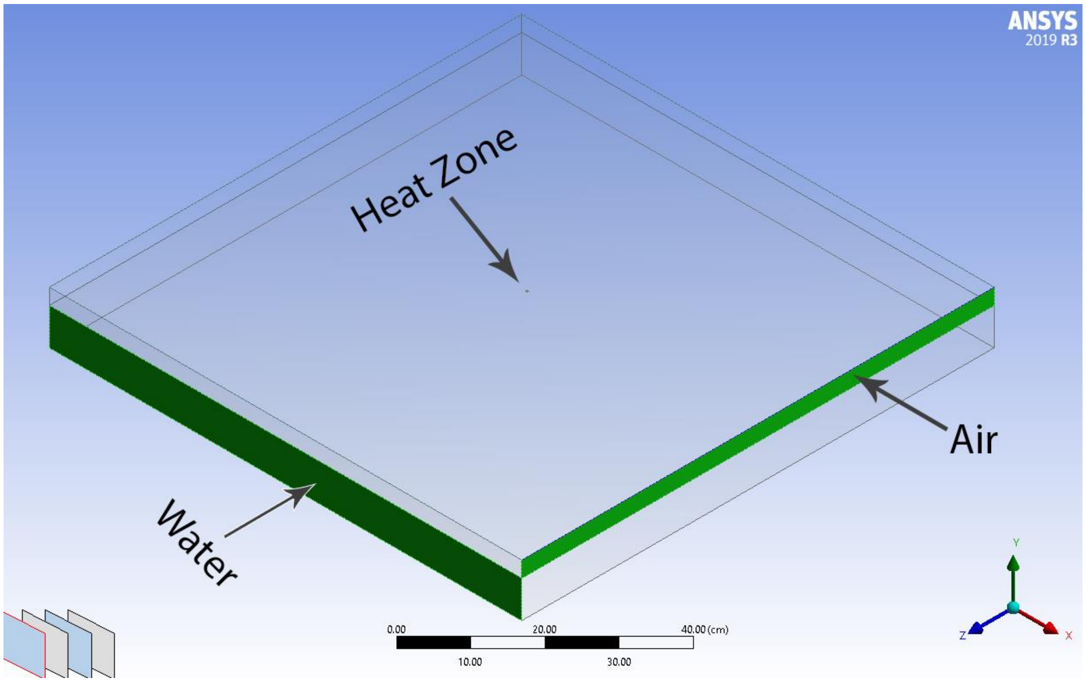

Figure 27: Cell Zones.

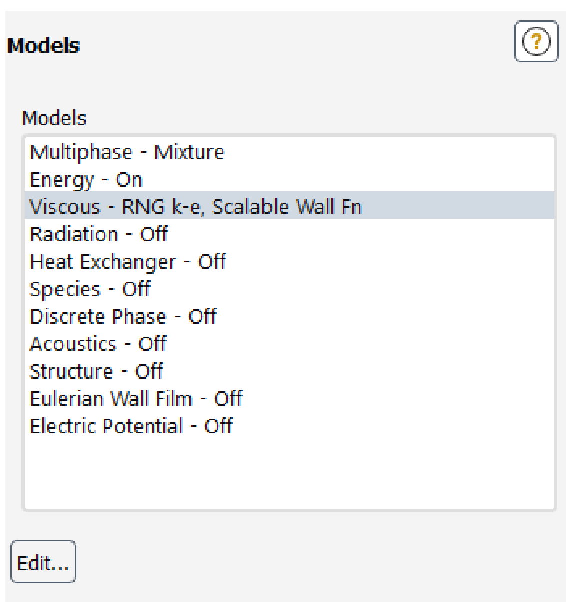

Figure 28: Models Selection.

APPENDIX III: DESIGN AND COMPONENT SCREENSHOTS

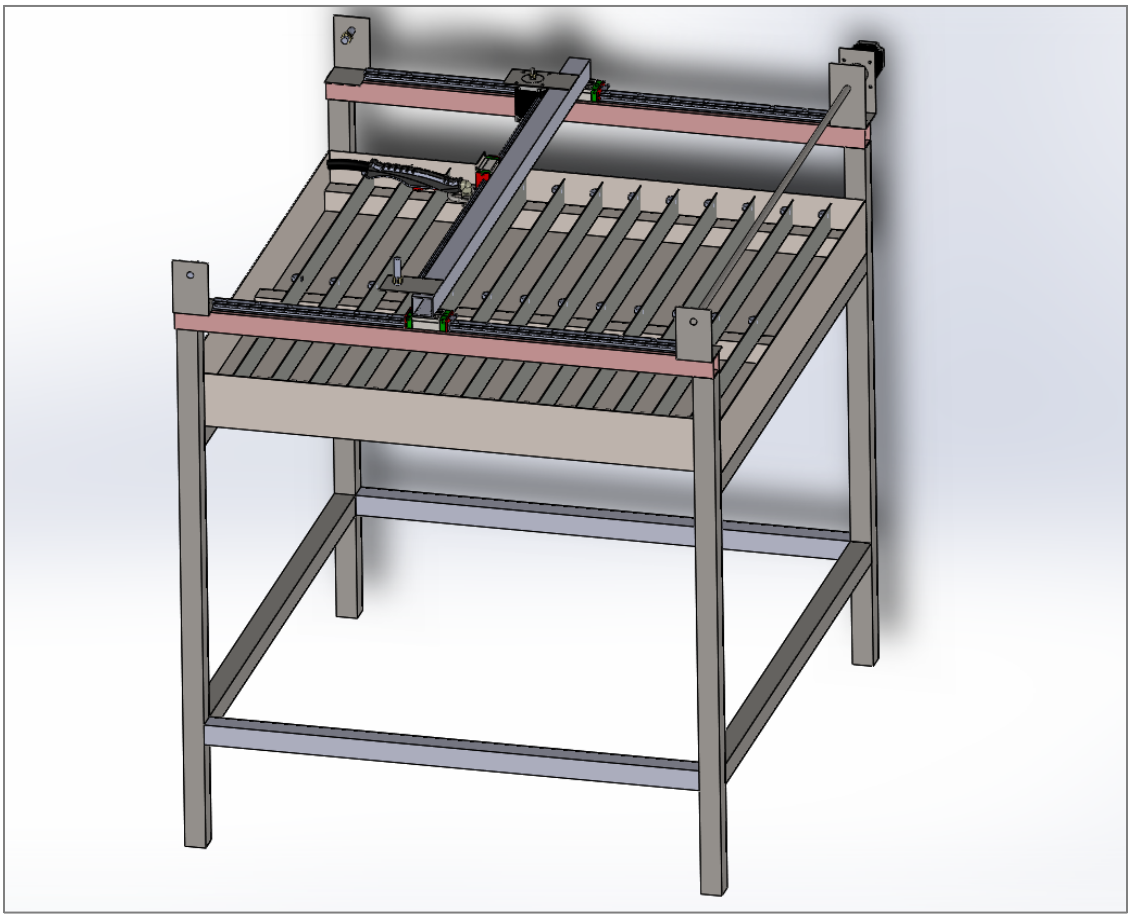

Figure 29: Complete Table Assembly.

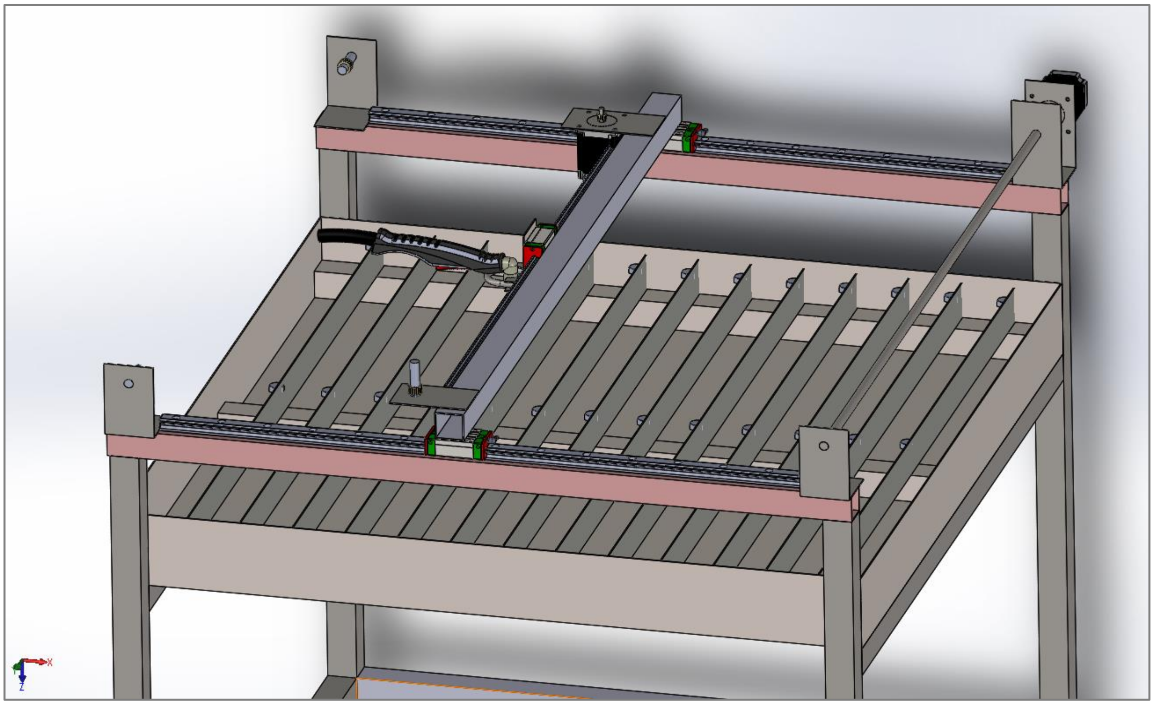

Figure 30: Enlarged X-Y axis.

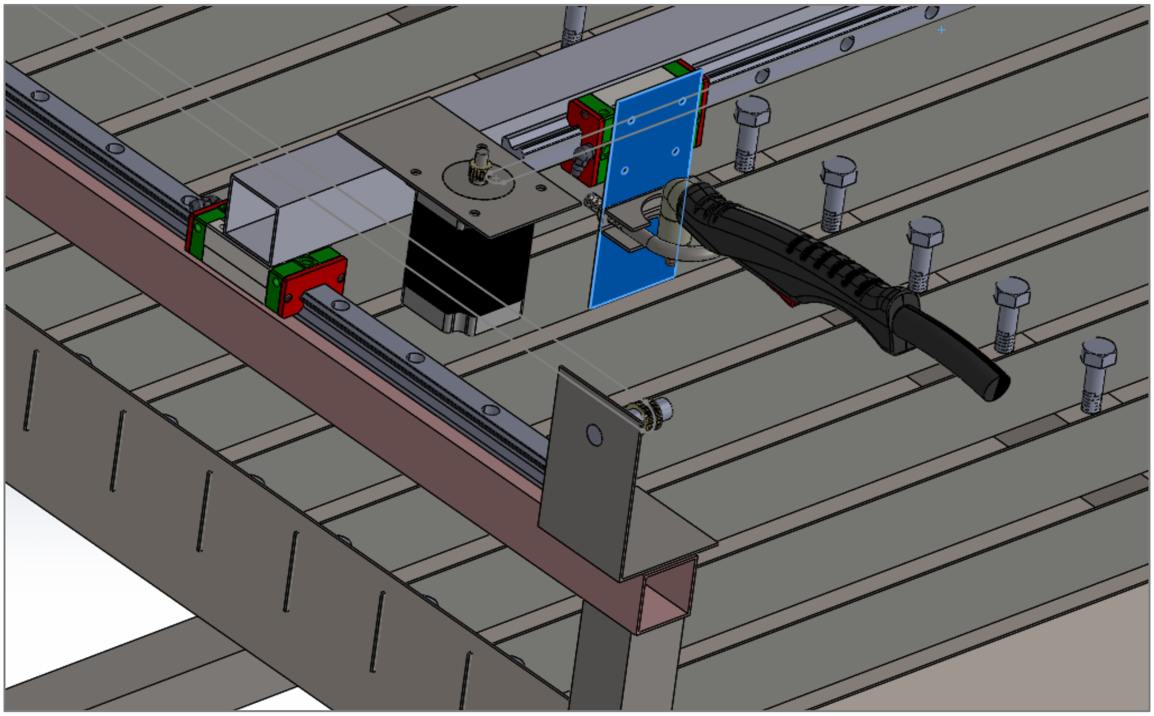

Figure 31: Tool Post and Gantry Setup.

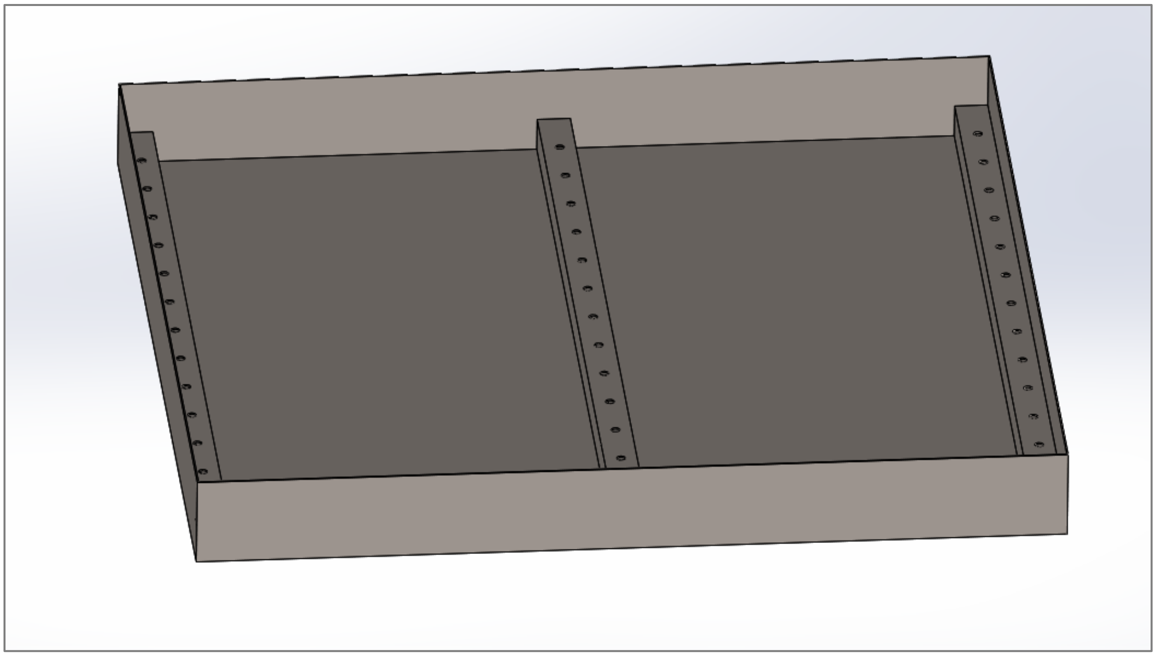

Figure 32: Water Table.

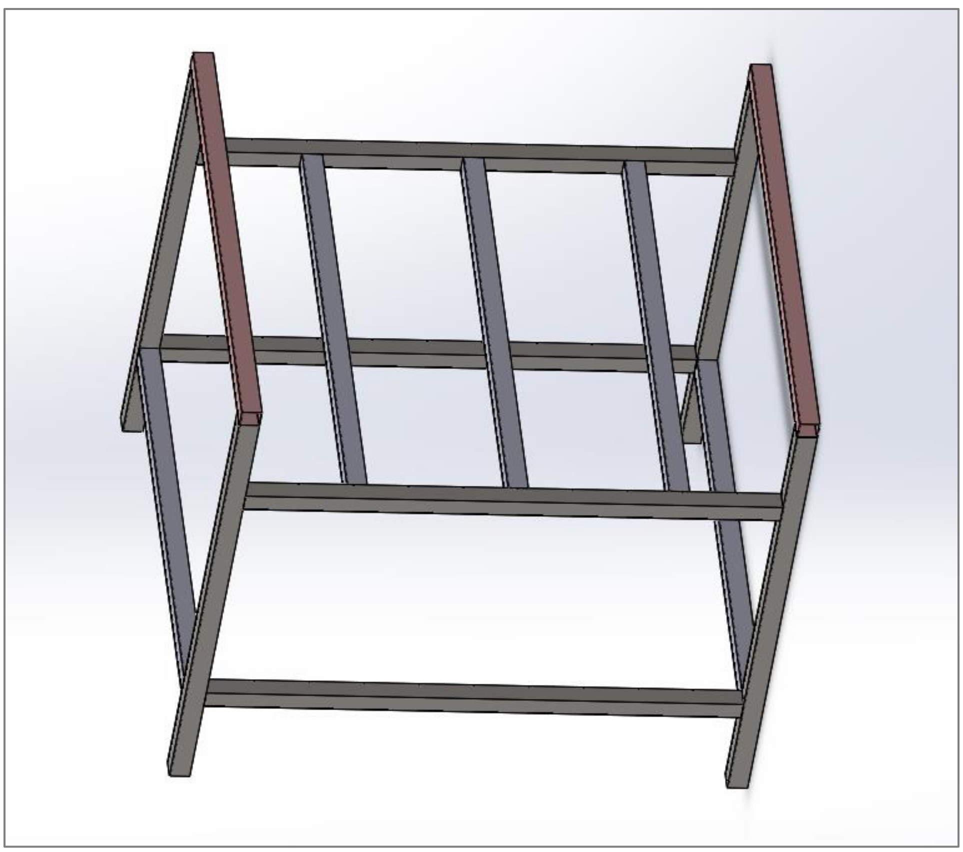

Figure 33: Table Frame.

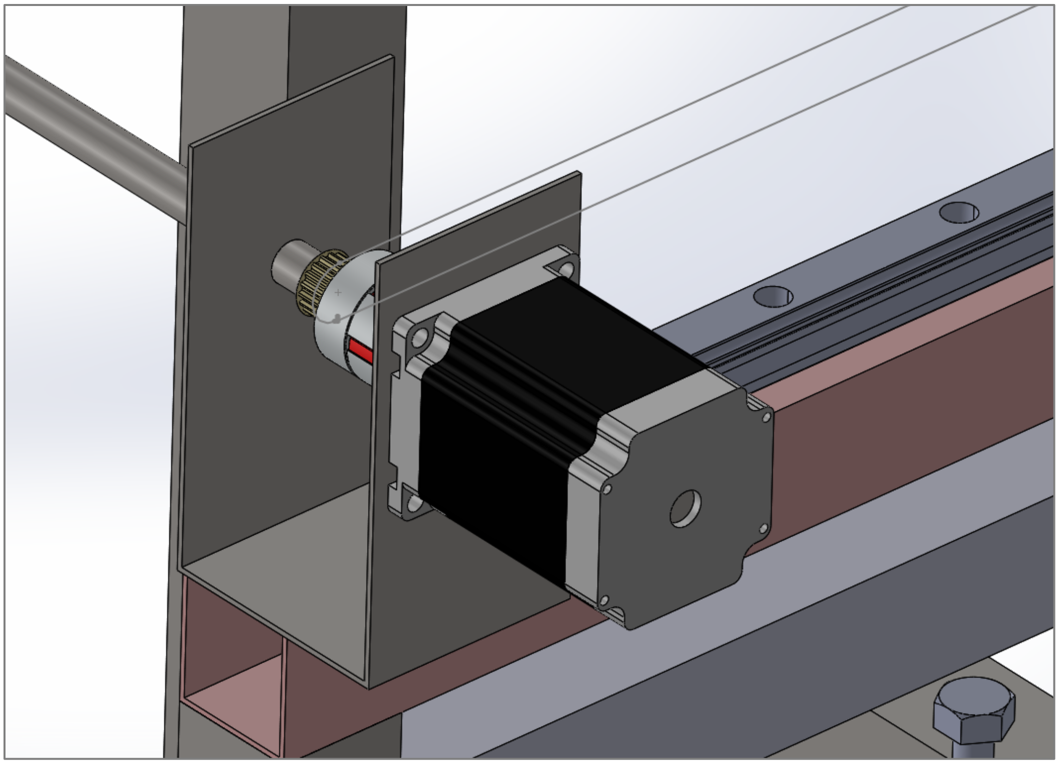

Figure 34: Motor, Coupler and Shaft Setup.

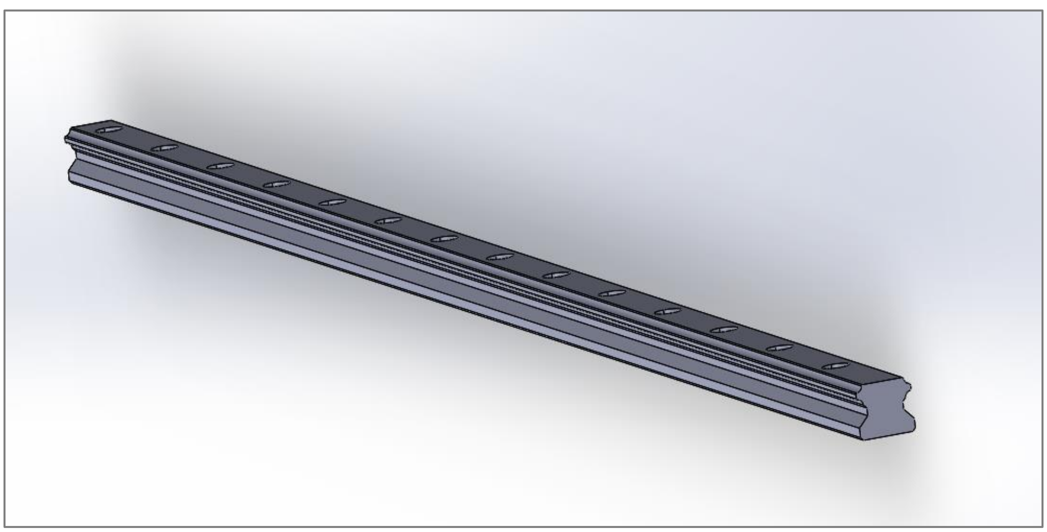

Figure 35: Linear Rail.

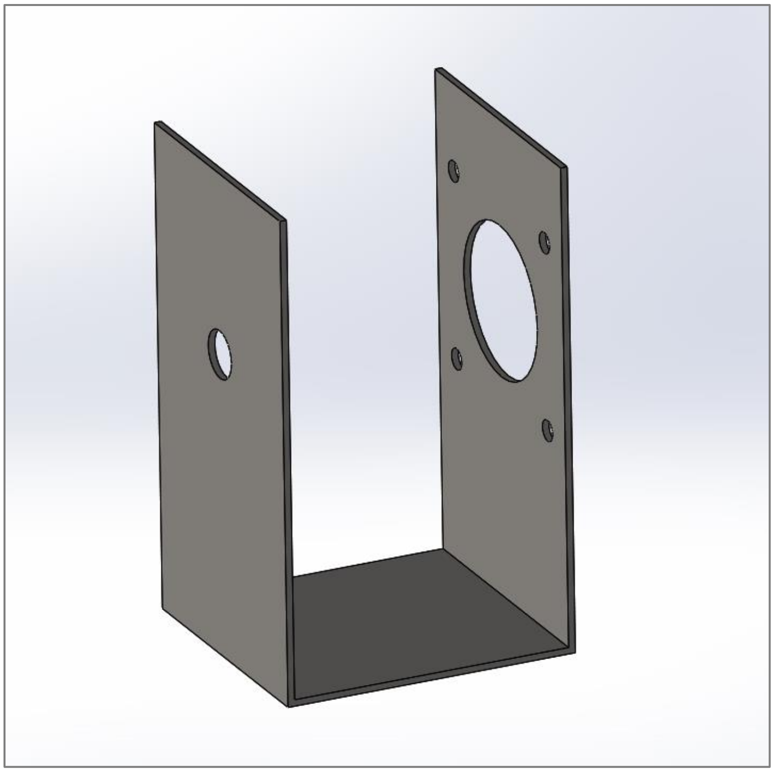

Figure 36: Motor mount for X-axis.

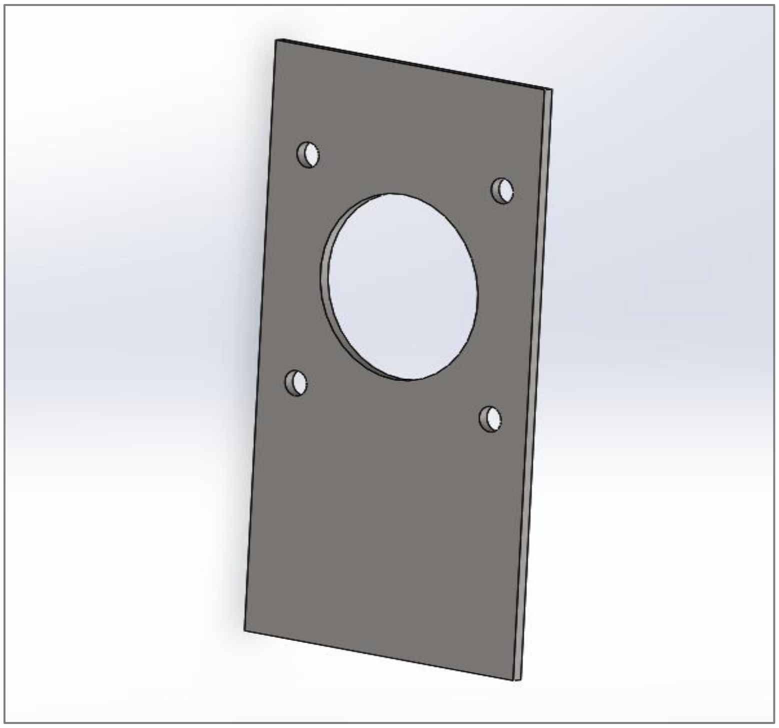

Figure 37: Motor mount for Y-axis.

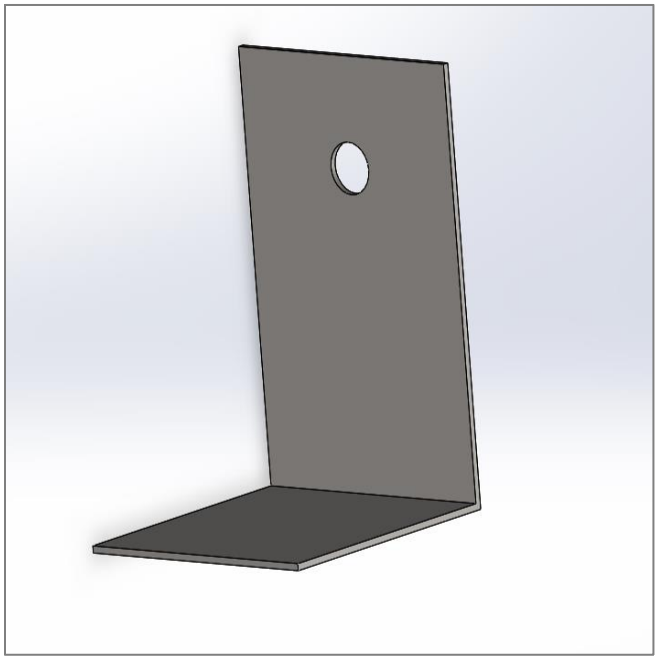

Figure 38: Pulley mount for X-axis.

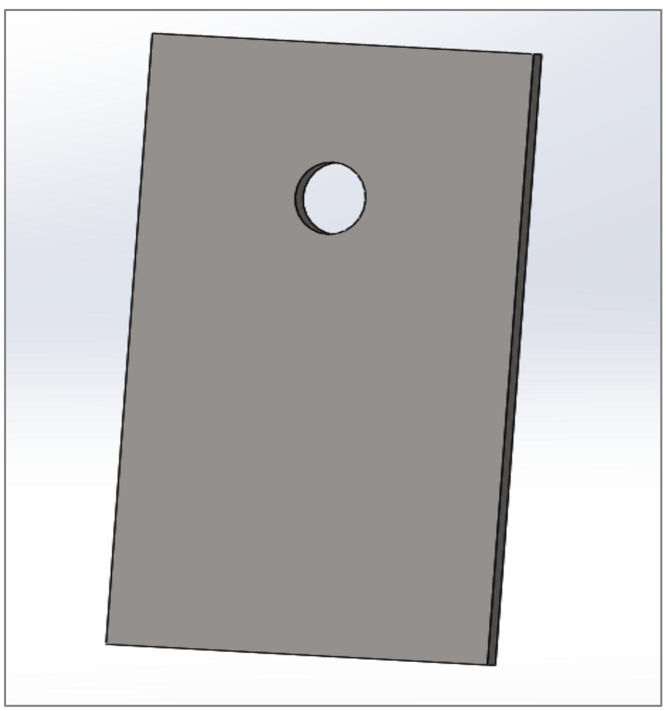

Figure 39: Pulley mount for Y-axis.

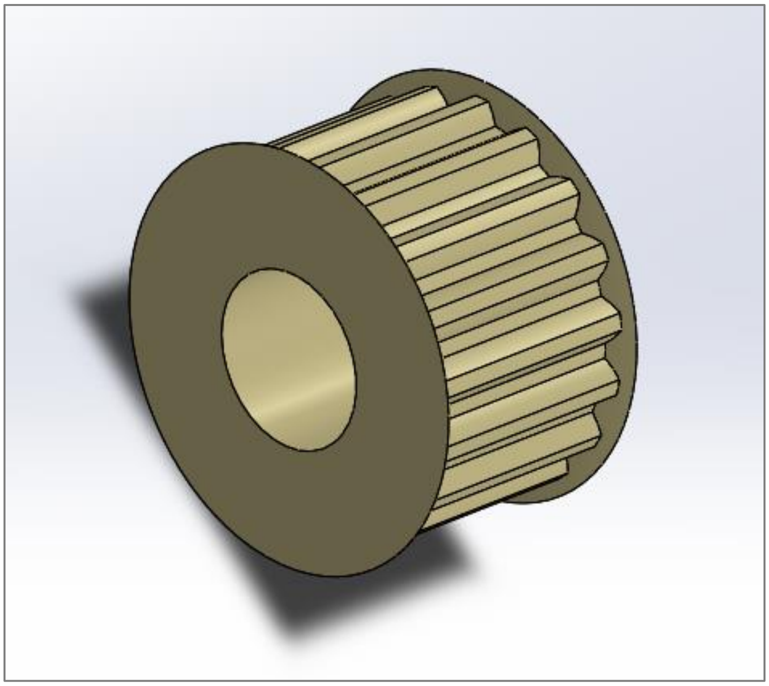

Figure 40: Pulley 6.3mm Bore Diameter.

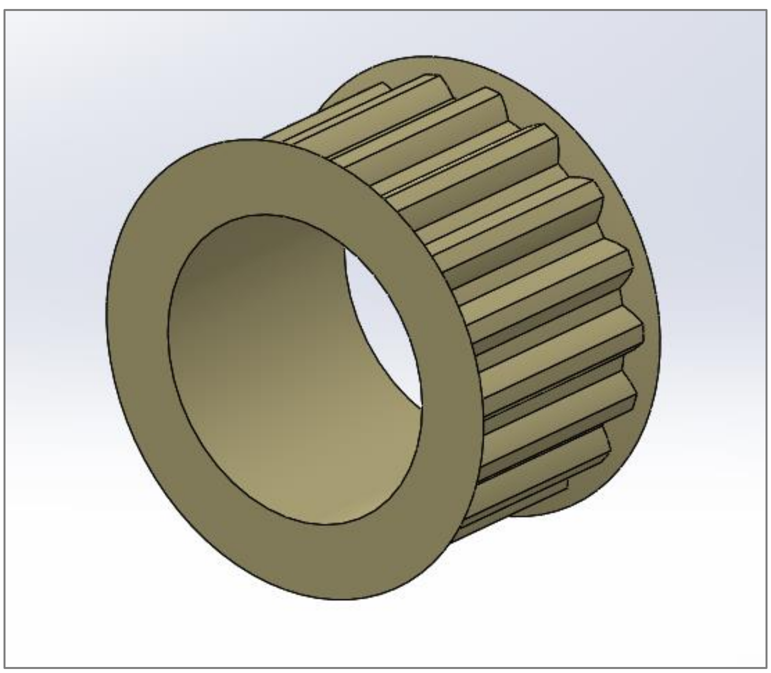

Figure 41: Pulley 10mm Bore Diameter.

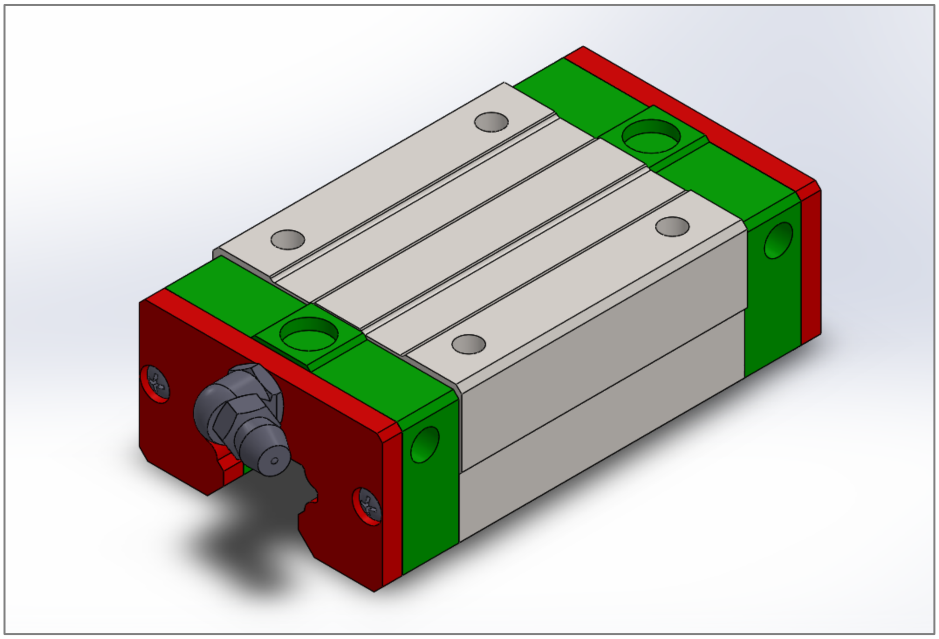

Figure 42: Rail Block.

APPENDIX IV: BILL OF MATERIALS

Table 11: Bill of Materials

Sr. No.	BOM Level	Brief Description of Part	Vendor's Name	Part No.	Quantity (numbers)	Dimensions in cm (L x W x H)	Weight (KG)	Specification (if any)	Rate (PKR)	Price (PKR)
1	0	CNC Plasma Router Table		0	1	120*120*160	85 (approx.)			
2	1	CNC Control Box		1	1	30*30*13	1	Material: Mild Steel		
3	2	DC Power Supply	Star Electronics	1-001	1	22.5*11.5*7	1	24 Volts-15 Amperes		1400
4	2	Motor Drivers	Star Electronics	1-002	2	12*6*3	0.2	TB6560 Stepper Driver	800	1600
5	2	Breakout Board	Star Electronics	1-003	1	14*7*3	0.2	5-Axis CNC Breakout Board	1400	1400
6	2	Emergency Stop Button	Star Electronics	1-004	1	Length: 10, Dia: 2	0.1	Model:ZB 2-BE102C, Max Current: 10A, Max. Voltage: 240V	270	270
7	2	Desktop PC	Dubai Plaza	1-005	1	45*20*60	3	Core 2-Duo, 2 GB RAM, 14 inch LCD	5100	5100
8	1	Router Table		2	1	100*100*160	80 (approx.)			
9	2	Static Assembly		2-001	1	100*100*160	70			
10	3	Metal Pipes	Sihala Steel	2-001	13	100*3.81*3.81	3	Material: Mild	333	4330

			Corporation	-1				Steel, SWG:16		
11	3	Water Table	Hasan Steel	2-001-2	1	90*90*10	30	Material: Stainless Steel, SWG:16	4200	4200
12	3	Stainless Steel Pipes	Hasan Steel	2-001-3	3	100*3.81*3.81	3.3	Material: Stainless Steel, SWG:16	500	1500
13	3	Slats	KF Iron Store	2-001-4	12	90*1.6*10	0.4	Material: Mild Steel	220	2650
14	3	Bolts	Chaudhary Hardware	2-001-5	36	M10 x 8	0.1		25	900
15	3	Place Holders	KF Iron Store	2-001-6	6	15*3*2	0.3	Material: Mild Steel	66	400
16	3	Levelling Screws	Chaudhary Hardware	2-001-7	4	M16 x 6	0.1		125	500
17	3	Valves	Chaudhary Hardware	2-001-8	2	Dia: 1.9	0.2	Ball Valve	340	680
18	3	Wire Hanger	KF Iron Store	2-001-9	1	100*3.81*3.81	0.2	Material: Mild Steel, SWG:16	500	500
19	3	Gun Mount	KF Iron Store	2-001-10	1	15*10*2	1.2	Material: MS, SWG:14	500	500
20	3	Drag Chain	Star Electronics	2-001-11	2	100*4*2	0.4		750	1500
21	3	Linear Rails	Star Electronics	2-001-12	3	85*1.5*1.5	1	Material: SS, CPC MR12MN	3500	10500
22	4	Allen Key Bolts	Manzoor Sons,	2-001-	15	M4 x 6	0.4	4mm Allen Key Bolts,	15	225

			Gawal mandi	12-1				Length: 6cm, 4mm Nuts included		
23	3	Motor/Pulley Mounts	KF Iron Store	2-001-13	6	10*6*4	0.5	Material: Mild Steel	100	600
24	3	Bearing	Star Electronics	2-001-14	2	Bore: 1.2	0.1	Journal Bearing	350	700
25	3	Limit Switches (Mechanical)	Star Electronics	2-001-15	6	3*1.5*2	0.1	5A, 125-250V, 3 Terminals	60	360
26	2	Mechanical Assembly		2-002	1	100*100*160	5			
27	3	Stepper Motors	Star Electronics	2-002-1	2	10*6*6	1.4	NEMA 23, Bipolar, 4 Wires. Holding Torque: 90 N.cm, Max Current: 3 Amp	1500	3000
28	3	Motor Pulley	Star Electronics	2-002-2	3	Bore: 0.8	0.1		250	750
29	3	Bearing Pulley	Star Electronics	2-002-3	3	Bore: 0.6	0.1		450	1350
30	3	Shaft Coupling	Star Electronics	2-002-4	1	Bore: 0.635*0.8	0.1	Flexible Shaft Coupling	1000	1000
31	3	Timing Belt	Star Electronics	2-002-5	3	190*2*2	0.5	3mm Pitch,GT3 Timing Belt	1650	5000