Misr University of Science and Technology

College of Engineering and Technology

Department of Mechatronics Engineering

Engineering Final Year Project

PROJECT TITLE: CNC Router machine (Table type)

By:

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DEDICATION

To all our parents who taught us since childhood and watched us nights. We would like to dedicate this project to you, where you can see with your own eyes the merit of this hard work that you worked for us, which made our character and led us to become realengineers after a few months, God willing, we will make you proud of us.

DECLARATION

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Bachelor of Science in Mechatronics Engineering is entirely my/our own work, that I/we have exercised reasonable care to ensure that the work is original, and does not to the best of my knowledge breach any law of copyright, and has not been taken from the work of others and to the extent that such work, if any, has been cited and acknowledged within the text of my work.

Signed:______________________________

Date: 10, November 2021.

Signed (repeat for all students): *Hassan Mohamed Mohamed Aboelela*

Karim Zakaria Amin Rashid

Farouk Emam Farouk Waked

Islam Wagih Hussein Safwat

Date: Day, 10, November 2021

ABSTRACT

This report was prepared by our group to explain our final year project idea. Since we started in this report with an introduction by which we know CNC and we mention how it started in numerical control to reach where we are now, and then we will address the goal of the project that we are doing, which is to create a CNC machine Table size(600mm x 400mm) but gives high accuracy as (The average accuracy is about 99.5 % for X and Y axis and 96% for Z Axis).

we will also mention the components and the estimated cost of the manufacturer of this machine, And finally, we mention how the work was divided among the four of us and the time line

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Chapter 1

1 Introduction & History

1.1 Introduction

Our project is about CNC Router where, the purpose of this project was to design and fabrication a Computer Numerical Control (CNC) based router machine for wood engraving machine. The idea behind this research was to help the traditional woods craft men over world to make a craft moreproductive and more efficient.

The router machine that is made is driven by the driver in the form of a stepper motor, with a 3-axis motion so that the results of wood engraving obtained are precision and homogeneous design.

1.2 Economic of computer numerical control

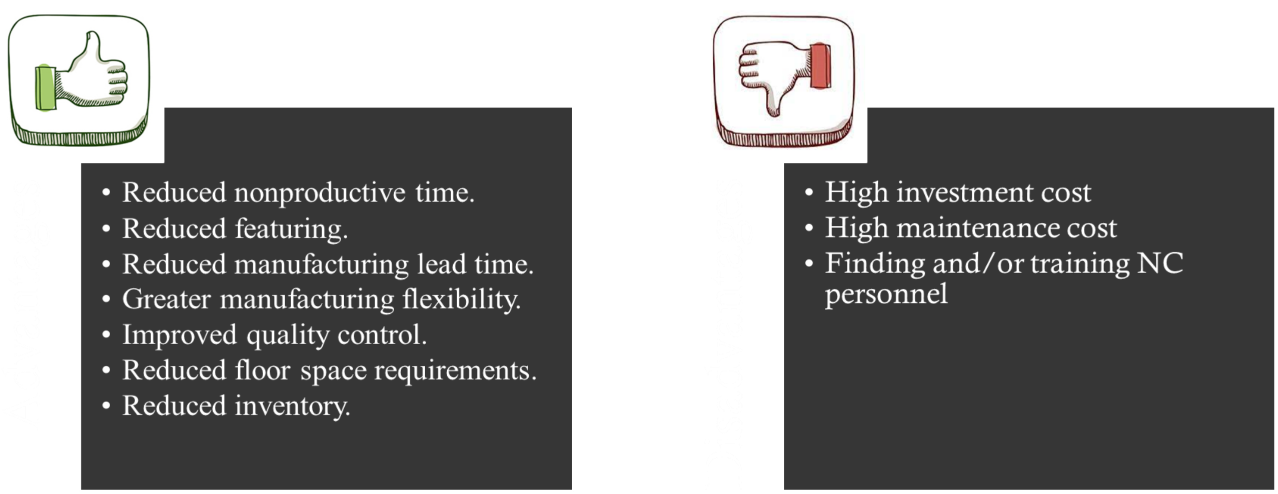


Figure 1 Adv. & Disadvantage of CNC

1.3 History

Digital control technology is defined as controlling the machine or the production process by using codes consisting of letters and numbers. The emergence of this technology 3 began in the middle of the twentieth century, specifically in 1952 AD, when the first development of digital control technology was made at the Massachusetts Institute of Technology (MIT) in cooperation with John Parsons Aircraft Corporation, Michigan, USA. This is due to the urgent need to produce very precise parts of complex geometric shapes that form parts of warplanes, especially helicopters. In 1952, the first numerical control machine was manufactured, and it was three-axis and operated by a Punched card. In 1954 AD, the application of digital control technology was officially announced, and about three years later, the first production of these machines was made and installed to be ready for use. Numerical control machines have gone through three phases of development since its inception until now the first generation of machines had a control unit and was used only for digital control to adjust the position of the workpiece in relation to several pieces, but the operator had to choose the type of tool used, speeds, feeding rates, and the rest of the engineering information. The second generation of numerical control machines in which the cutting process is carried out at the same time as the relationship between the workpiece and the cutting tool is controlled, and many mechanical parts have been developed that help, such as Hydrodynamic sliding bearing, and these machines are called NC numerical control machines. Information is entered to control in one process to the machine and after the completion of the implementation, the information about the next process is entered and the punch cards are used to enter the data, and no modification can be made in the program. To make any modification, a new program is required. One of the disadvantages of these machines is that the storage capacity is very limited. The third generation of computer numerical control and direct numerical control machines appeared. CNC/DNC. The great development in computers led to the emergence of the third generation of digital control machines. These machines perform a large number of operations such as milling, drilling, turning, hollowing, and boring.

1.4 The Objective

This goal in mind, fixed gantry design was decided for improved rigidity and design simplicity.

Where:

- Working Area= 600mm x 400mm

- Arduino based.

- 3-axis CNC machine.

The principles of CNC operation, movement of X, Y, Z axis are controlled by a motor which supplies either alternating current or Direct current. Movement of the machine is done by giving commands. All the operations are carried out by codes.

- Cutting material: Wood, Plastic, & Aluminum (with thin sheets).

-The mechanical systems of CNC machine build with low-budget material with a good quality > 10,000 LE. - The router machines that has been build was controlled by CNC program using Mach 3 or GRBL for the software.

1.5 Overview

The development of router machines based on CNC program for engraving machine was divided into three sections and it will be presented in:

1. Chapter 2 “Mechanical”

The mechanical system is composed of the frame section, the drive section, and the guide system.

2. Chapter 3 “Electrical & Software”

This chapter provides a detailed description of motion controller and power drive electronics and software.

Then chapter 4 interduce the team timeline.

Finally, some conclusions are drawn as a result of the research, and references Chapter 5.

Chapter 2

2 Mechanical design

2.1 Mechanical System Review

2.1.1 Frame

CNC frame materials need to have some strength to support the weight of the gantry and the cutting head as well as withstand forces resulting from the milling process. Stiffness is also required to prevent any deflections due to both static forces and dynamic forces resulting from the acceleration of the tool head. Weight is important because the mass of the frame contributes to both the static and acceleration forces. The best frame material would accomplish all three, offer excellent machinability, and be available at a low cost.

From the review of the materials, it was decided to use Polylactic acid (PLA). Among the plastics it was one of the lightest and least expensive choices. Also, as a plastic it will be very easy to machine, while still providing sufficient strength and rigidity.

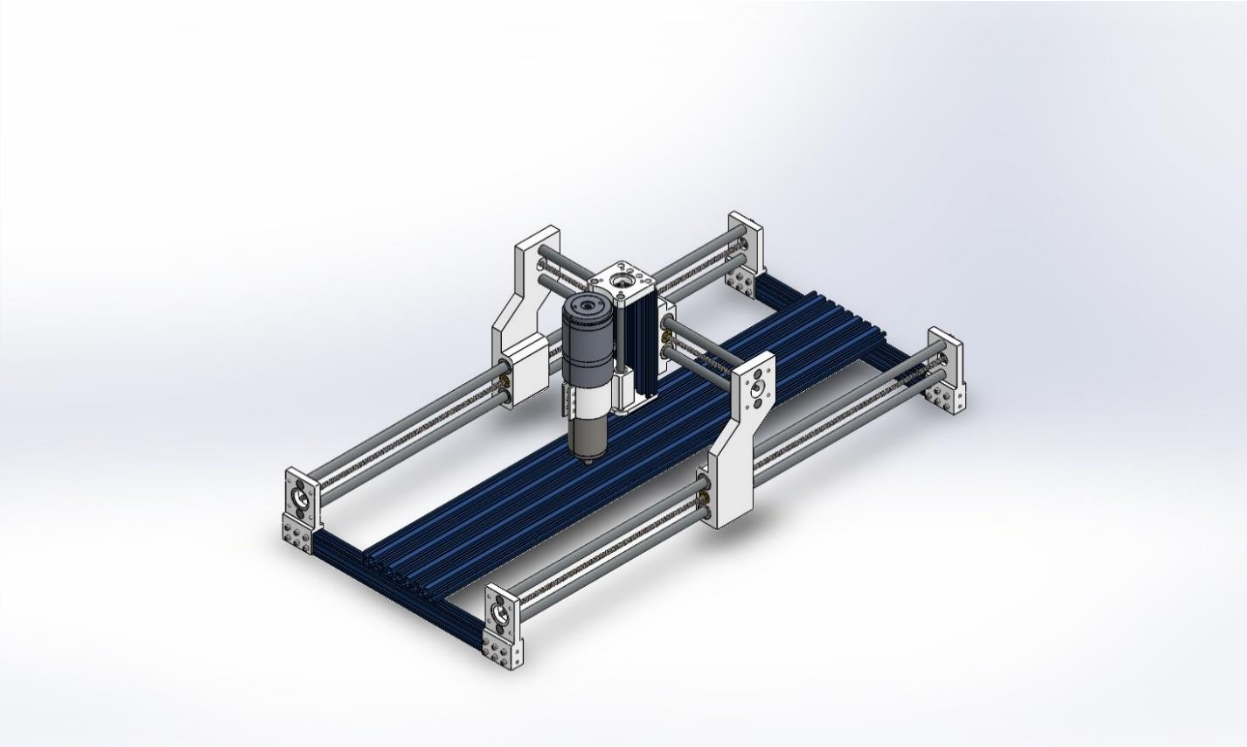


Figure 2 Frame

The machine frame is divided into:

1- Y-axis assembly
2- X-axis assembly
3- Z-axis assembly
4- Spindle clamp
5- Base table

Y-axis assembly

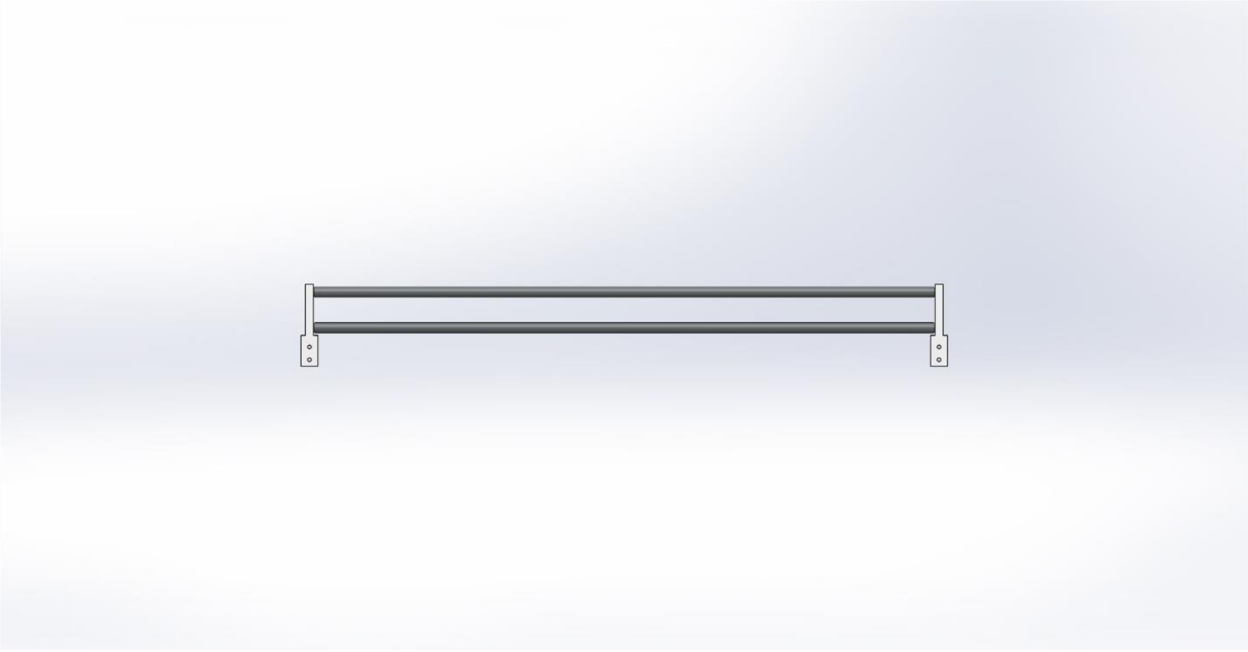


Figure 3 Y-axis assembly

X-axis assembly

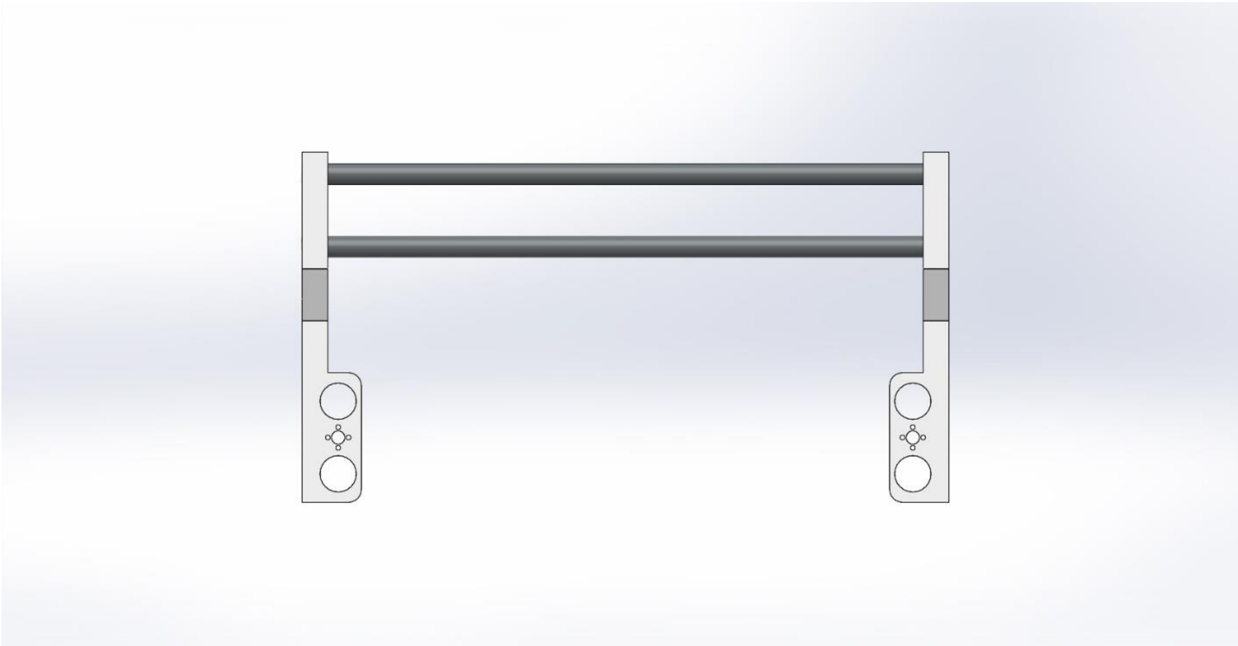


Figure 5 X-axis assembly

Z-axis assembly

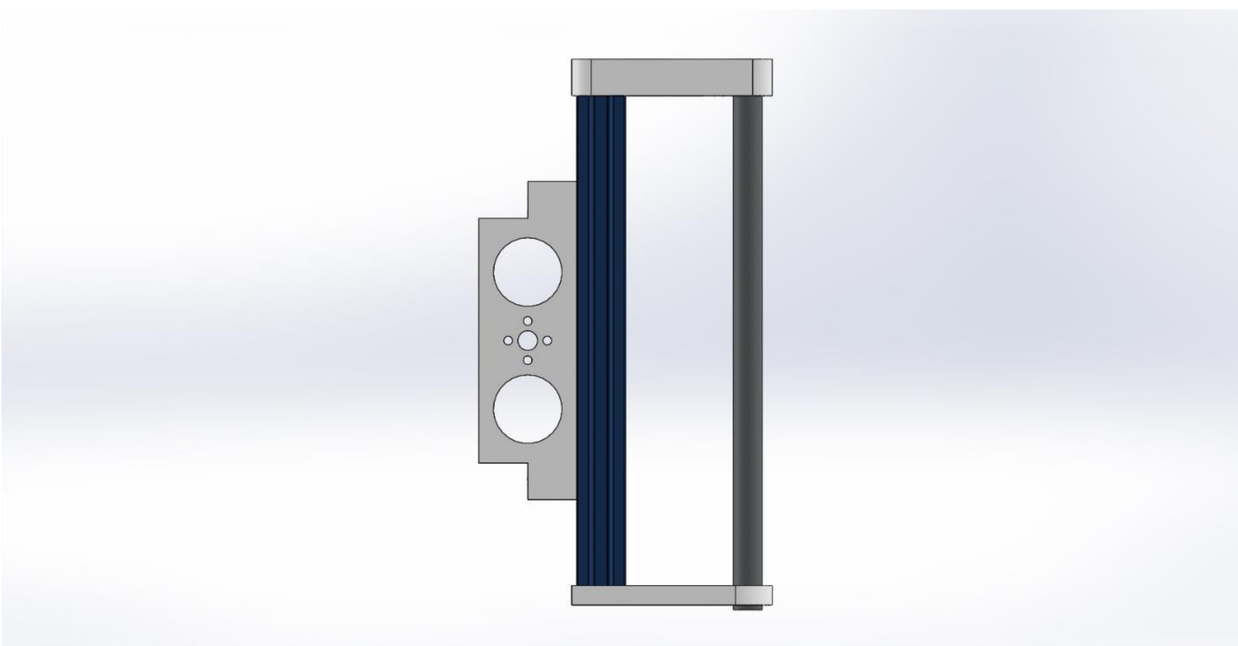


Figure 4 Z-axis assembly

Spindle clamp

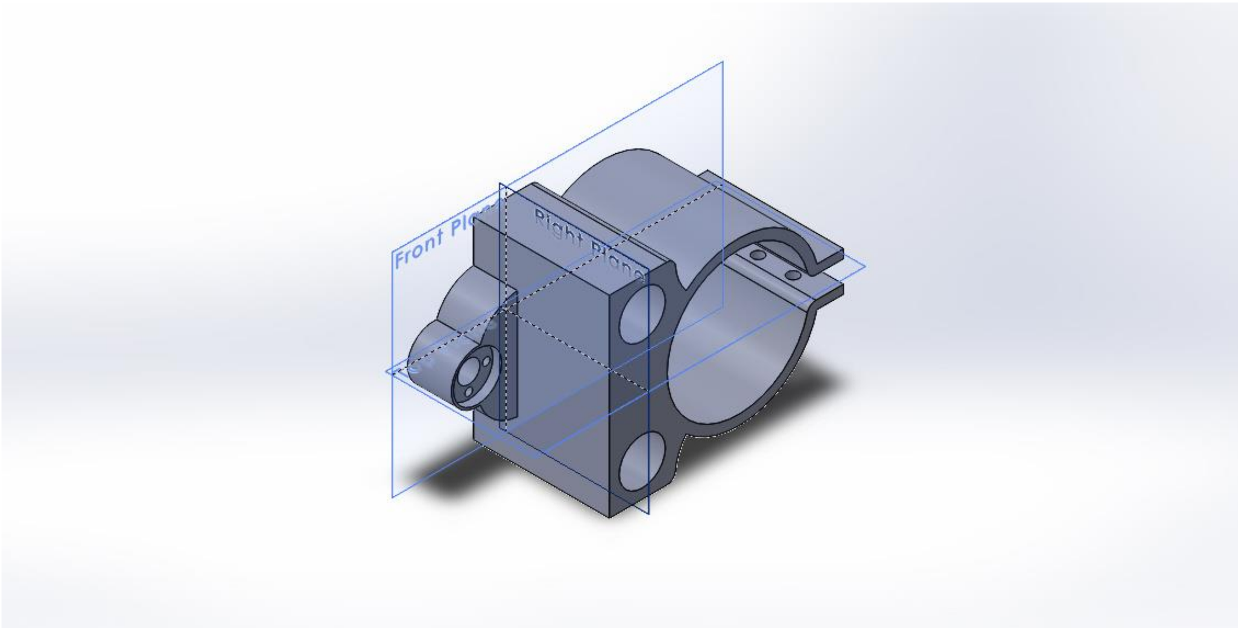


Figure 6 Spindle clamp

Base table

Figure 7 Base Table

2.1.2 Drive

The drive mechanics of CNC machines convert torque provided by the electric motors into linear motion of the tool head. Screws with threaded nuts provide a simple and compact way to transmit this power. So, we decided to use lead screw for transmit rotational motion from the motor into linear motion.

Figure 8 Drive

2.1.3 Guide

The guide rails support the weight of the gantry and tool head, while providing the alignment during the movement of the gantry. The linear rod guide rails will be case hardened steel shafts with ball bushings.

Figure 9 Guide

2.1.4 Bearing Selection

Linear motion bearing:

- LM12UU
- LM16UU

Deep groove ball bearings 608

Figure 10 Bearing

2.1.5 Pins Size

Socket head cap screw M5

Figure 11 pin

2.2 Drawing - Dimensions - Material

2.2.1 CNC Router Components

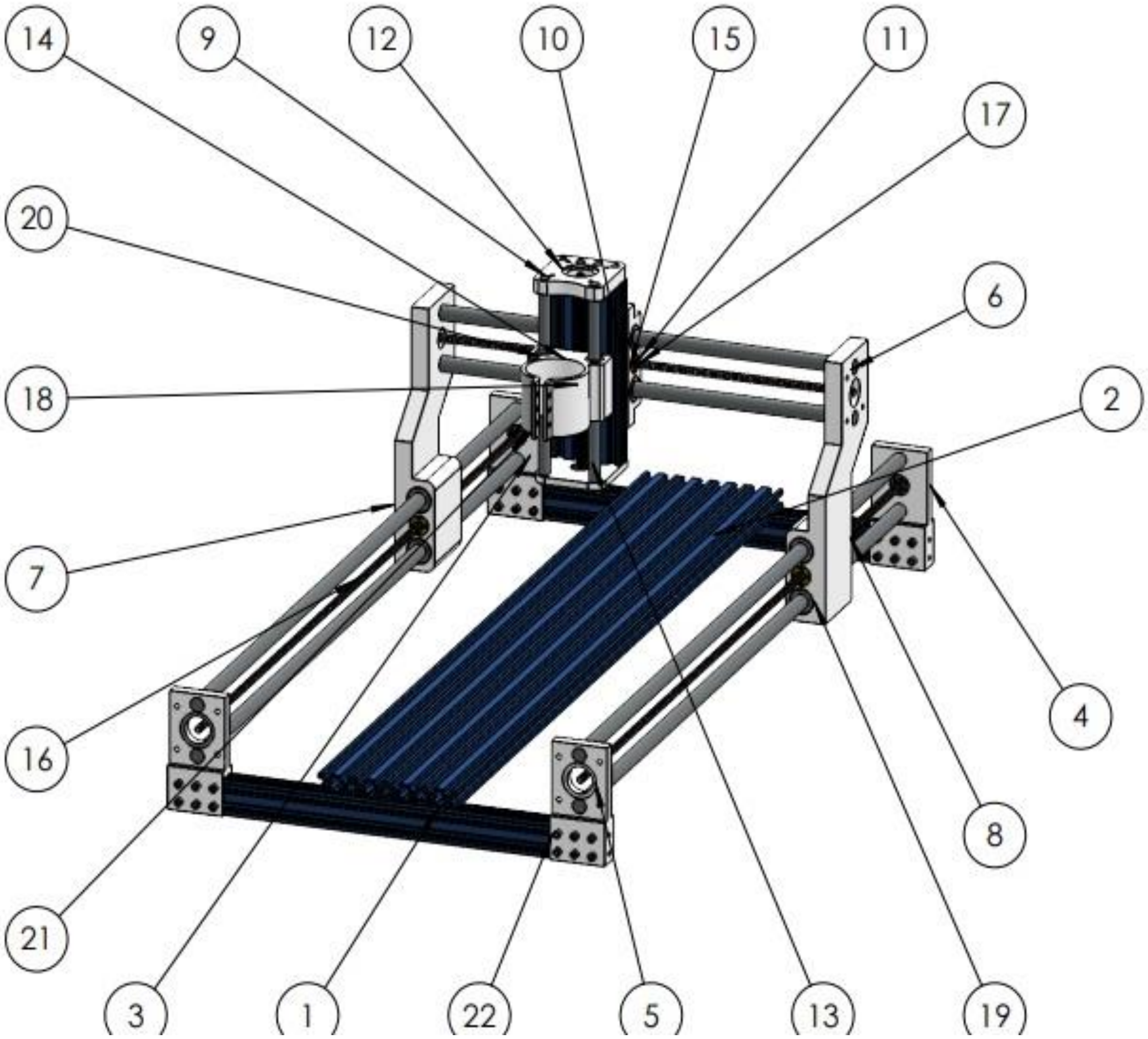


Figure 12 CNC Router Components

NAME	CNC Router 3-axis
SCALE	1:7

Table 1 Scale of Assembly Fig.12

Table 2 information of Parts

Item No.	Part Number	Material	Qty.
1	Aluminum Extrusion 2040 V-Slot 600mm	6063.T5 Aluminum	4
2	Aluminum Extrusion 2040 V-Slot 400mm	6063.T5 Aluminum	2
3	16X600mm Shaft	GN-31	4
4	y_axis_bearing_holder	PLA	2
5	y_axis_stepper_motor_holder	PLA	2
6	16X400mm Shaft	GN-31	2
7	x_axis_bearing_holder	PLA	1
8	x_axis_stepper_motor_holder	PLA	1
9	16X200mm Shaft	GN-31	2
10	Aluminum Extrusion 2040 V-Slot 200mm	6063.T5 Aluminum	2

11	x_axis_z_axis_connecter	PLA	1
12	z_axis_stepper_motor_holder	PLA	1
13	z_axis_bearing_holder	PLA	1
14	z_axis_spindle_holder	PLA	1
15	lead screw nut	Brass	4
16	lead screw 600	Stainless steel	2
17	lead screw 400mm	Stainless steel	1
18	lead screw 200mm	Stainless steel	1
19	LM16UU	Stainless steel	12
20	LM12UU	Stainless steel	4
21	SKF - 608 - 8, SI, NC,8_68	Stainless steel	4
22	B18.3.1M - 5 x 0.8 x 8 Hex SHCS -- 8NHX	Stainless steel	48

2.2.2 Assembly

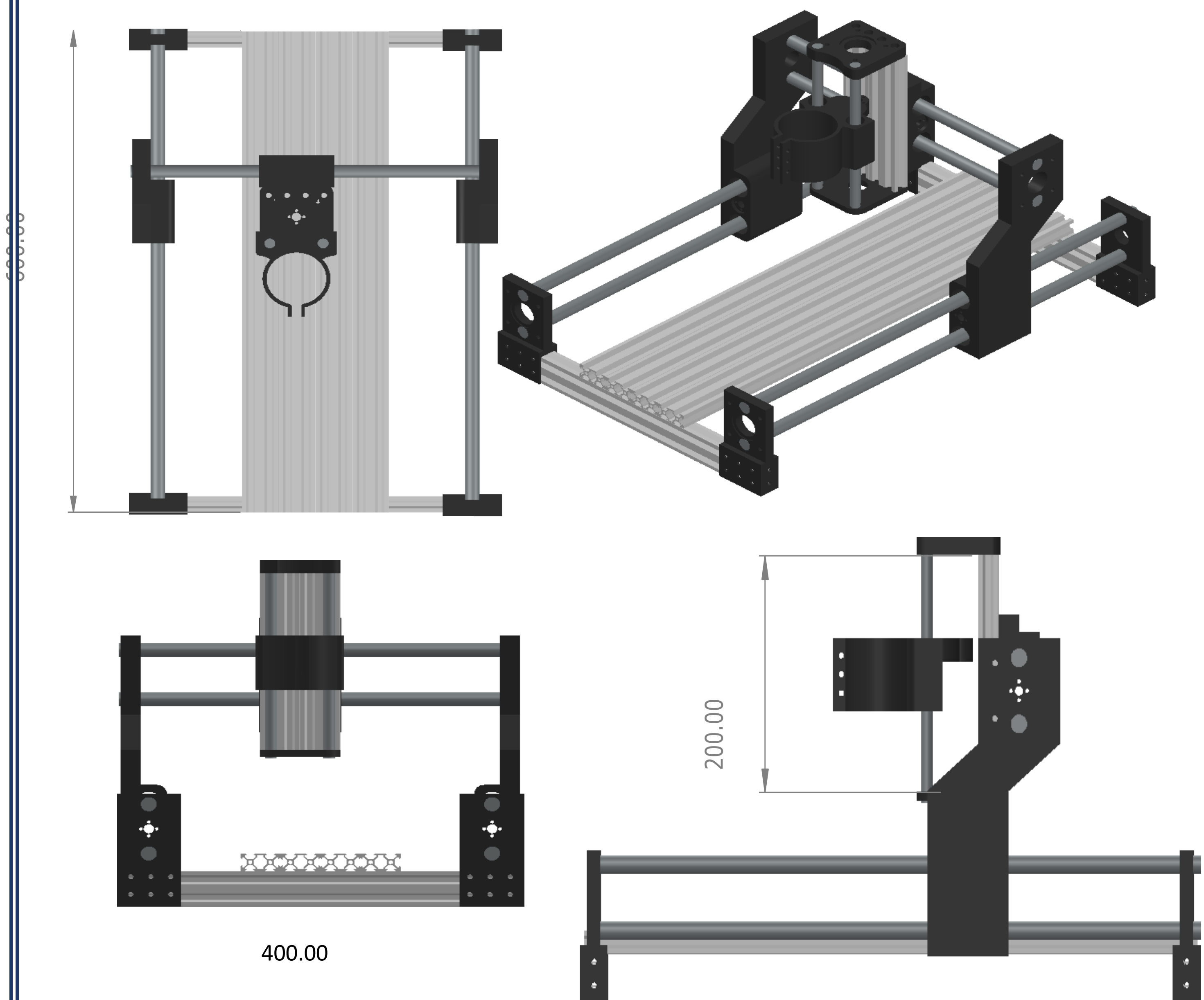


Figure 13 Assembly

Name	CNC router 3-axis
Scale	1:6

Table 3 Scale of assembly Fig.13

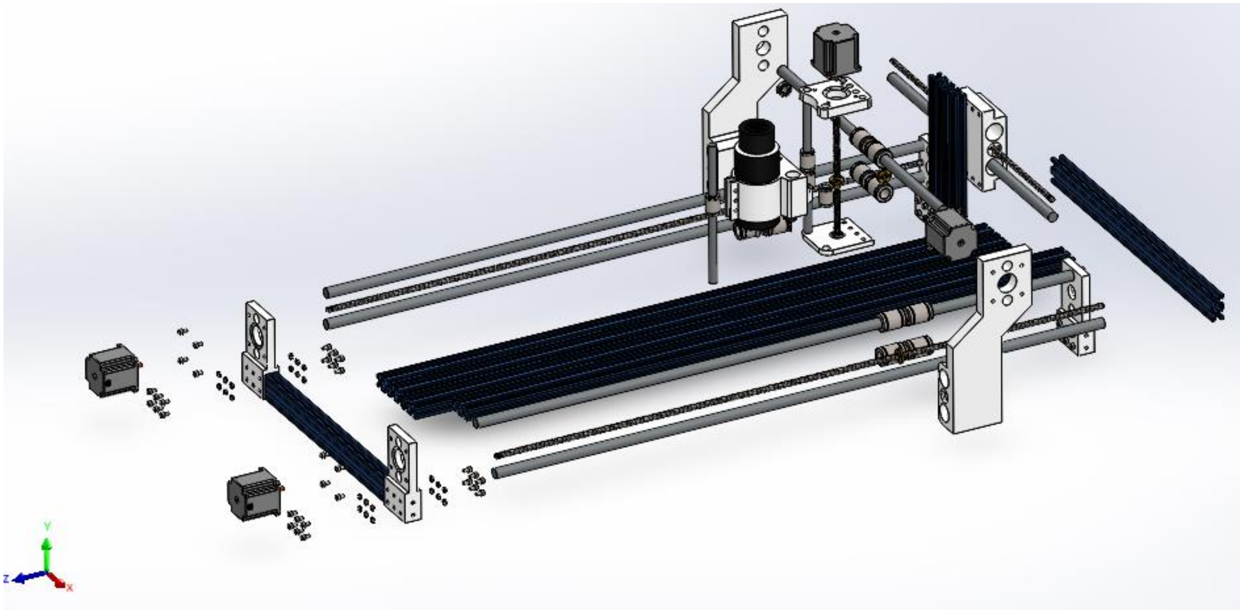


Figure 14 exploded view of cnc router

2.2.3 Drawings and Dimention

Part No.4

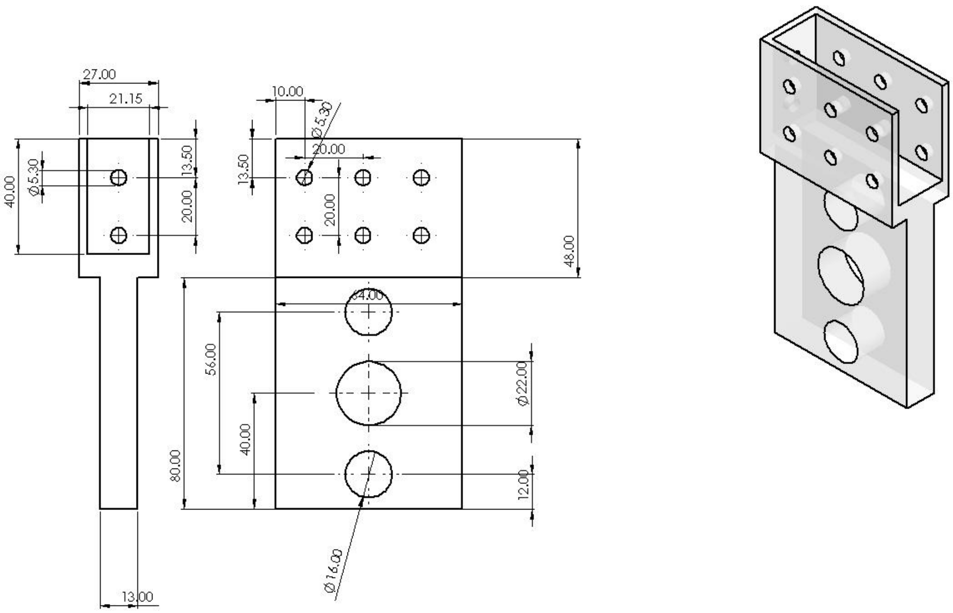


Figure 15 Drawing Part No.4

Table 4 Scale & Material part No.4

Part Name	y_axis_bearing_holder
Scale	1:2
Material	PLA

Part No.5

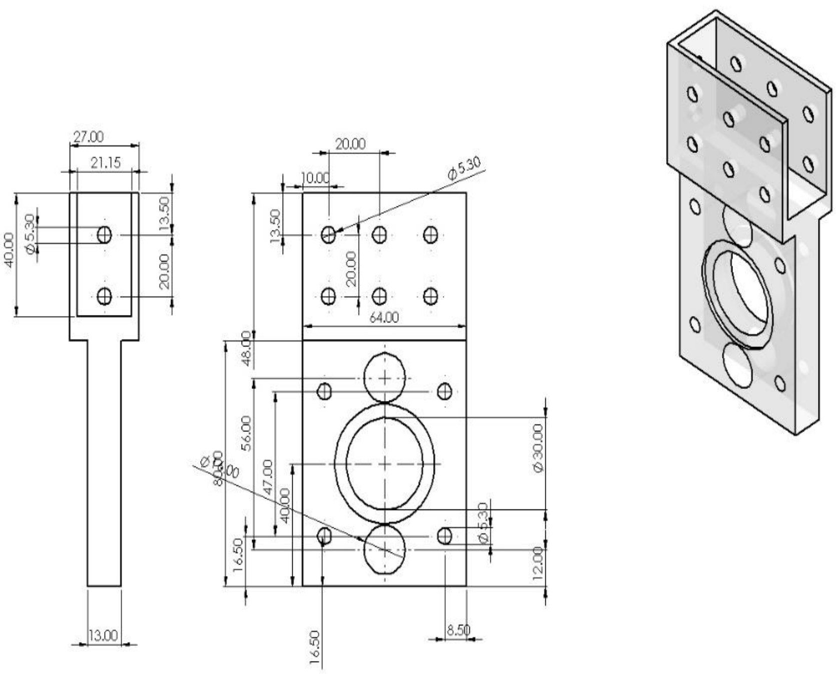
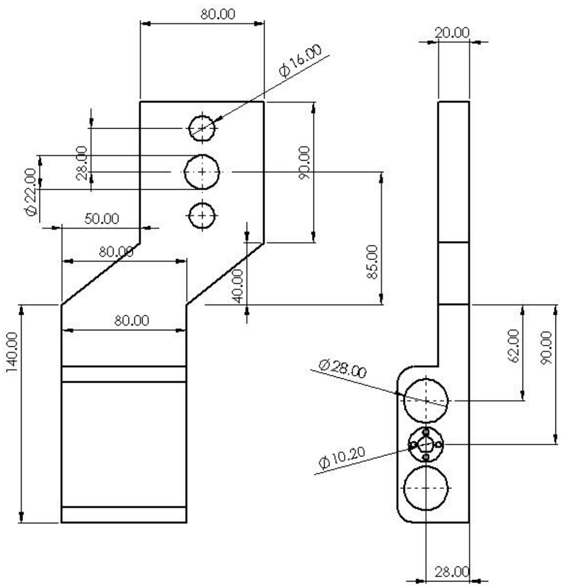


Figure 16 Drawing Part No.5

Table 5 Scale & Material part No.5

Part Name	y_axis_stepper_motor_holder
Scale	1:2
Material	PLA

Part No.7



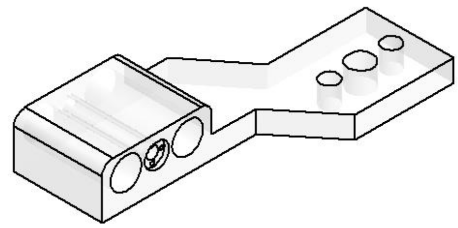


Figure 17 Drawing Part No7.

Table 6 Scale & Material part No.7

Part Name	x_axis_bearing_holder
Scale	1:2
Material	PLA

Part No.8

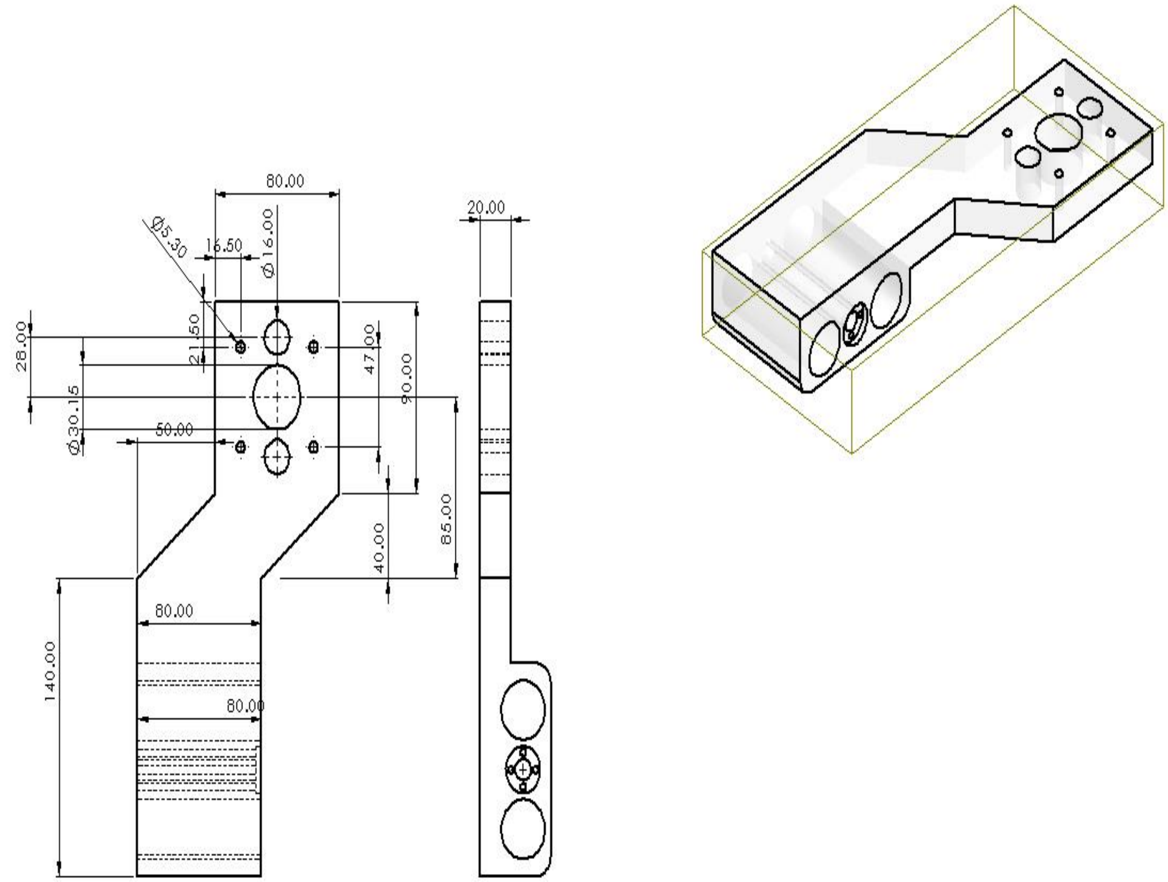


Figure 18 Drawing Part No.8

Table 7 Scale & Material part No.8

Part Name	x_axis_stepper_motor_holder
Scale	1:2
Marerial	PLA

Part No.11

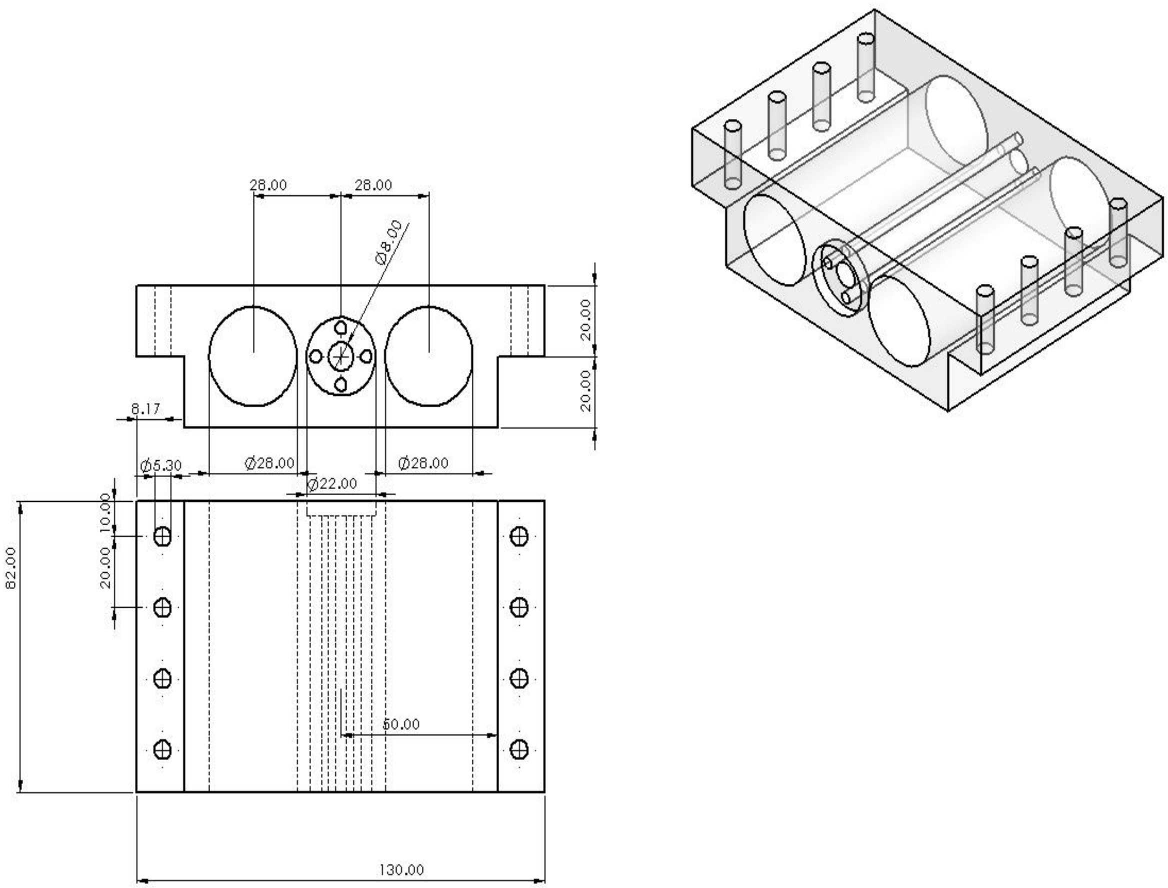


Figure 19 Drawing Part No.11

Table 8 Scale & Material part No.11

Part Name	x_axis_z_axis_connecter
Scale	1:2
Material	PLA

Part No.12

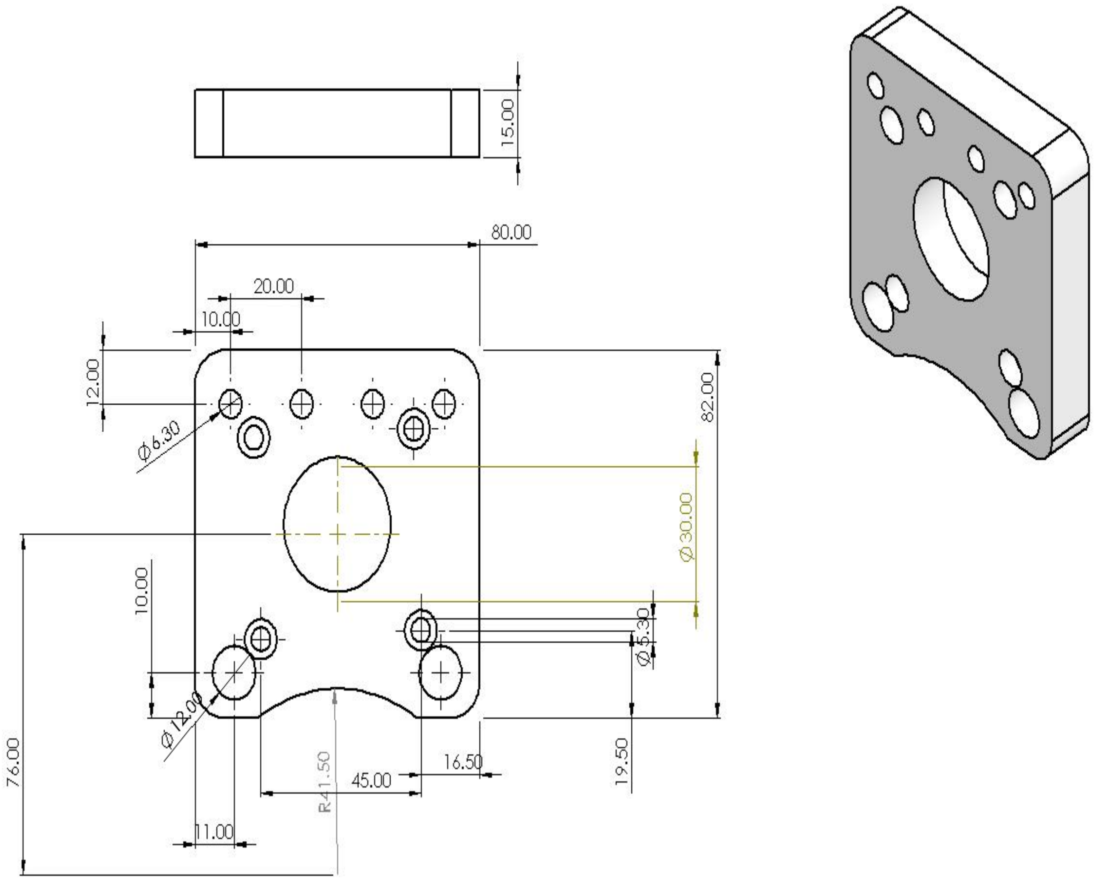
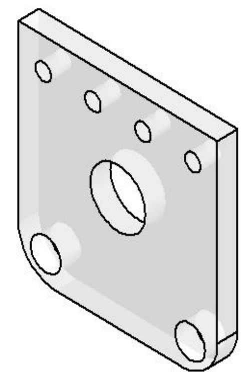


Figure 20 Drawing Part No.12

Table 9 Scale & Material part No.12

Part Name	z_axis_stepper_motor_holder
Scale	1:2
Material	PLA

PART NO.13



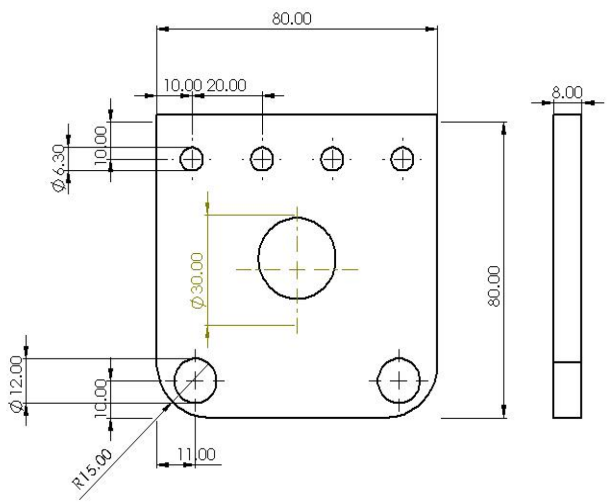


Figure 21 Drawing Part No.13

Table 10 Scale & Material part No.13

Part Number	z_axix_bearing_holder
Scale	1:2
Material	PLA

Part No.14

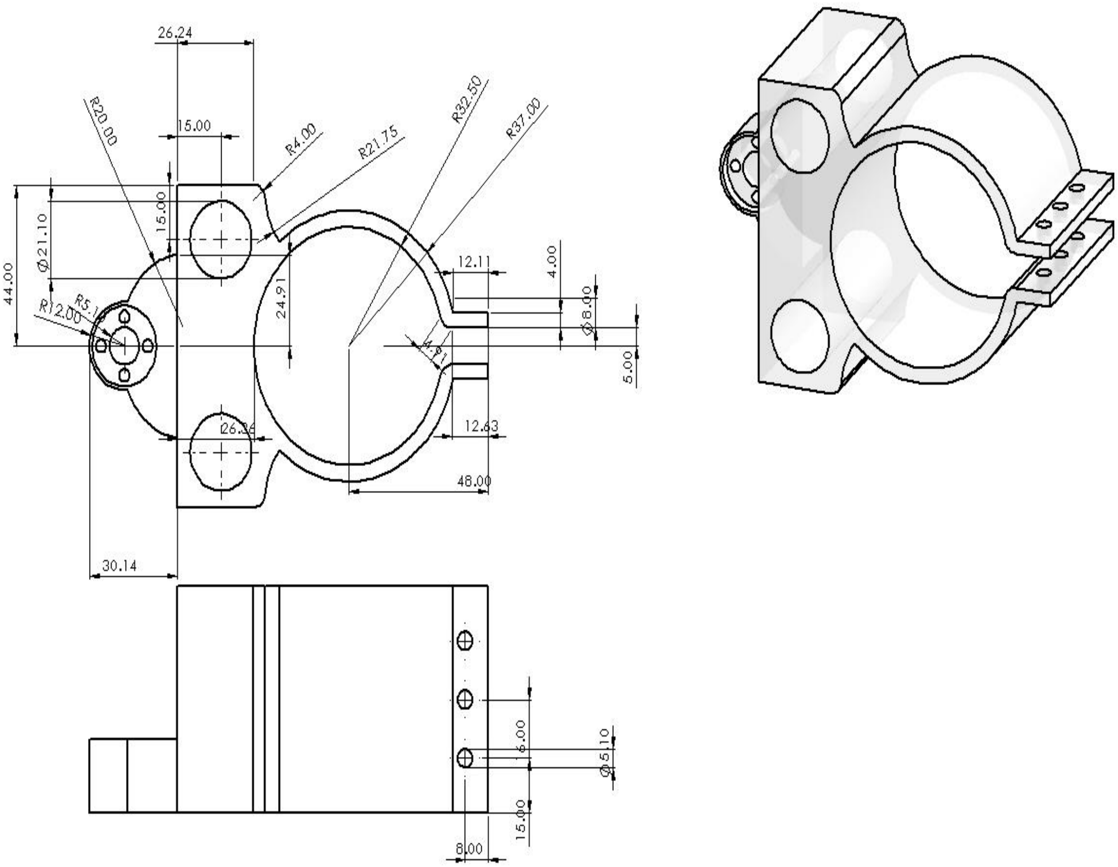


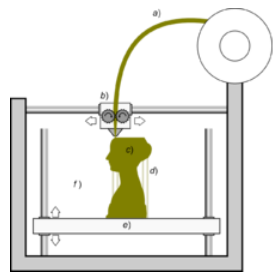
Figure 22 Drawing Part No.14

Table 11 Scale & Material part No.14

Part Number	z_axis_spindle_holder
Scale	1:2
Material	PLA

2.3 Detailed Process Sheets of 3D Parts

Table 12 Detailed Process Sheets of 3D Parts

No.	Part	Machine used & operation	Materials	Time/piece
1	z_axis_spindle_holder	3d printing Material extrusion 	PLA(Plastics)or ABSPC	1.7day for printing
2	z_axis_bearing_holder	3d printing Material extrusion	PLA or ABSPC	0.3 day for printing
3	z_axis_stepper_motor_holder	3d printing Material extrusion	PLA or ABSPC	0.3 day for printing
4	y_axis_stepper_motor_holder	3d printing Material extrusion	PLA or ABSPC	day for printing
5	y_axis_bearing_holder	3d printing Material extrusion	PLA or ABSPC	1 day for printing
6	x_axis_side_support	3d printing Material extrusion	PLA or ABSPC	3 day for printing
7	x_axis_z_axis_connecter	3d printing Material extrusion	PLA or ABSPC	1day for printing
8	x_axis_support_1	3d printing Material extrusion	PLA or ABSPC	3 days for printing

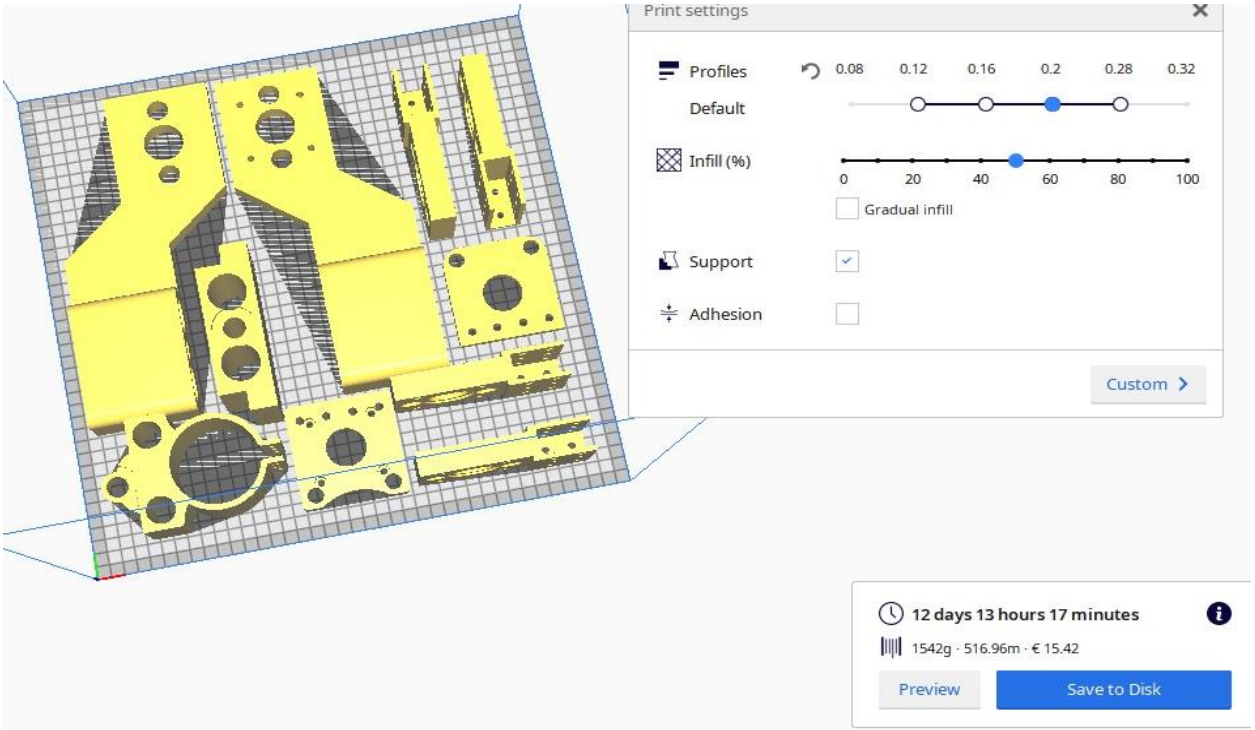


Figure 23 3D printing program

Comment: This image of a 3D printing program explains, shows the parts and the time specified for printing.

2.4 Requirements Analysis

2.4.1 Milling Process Calculation

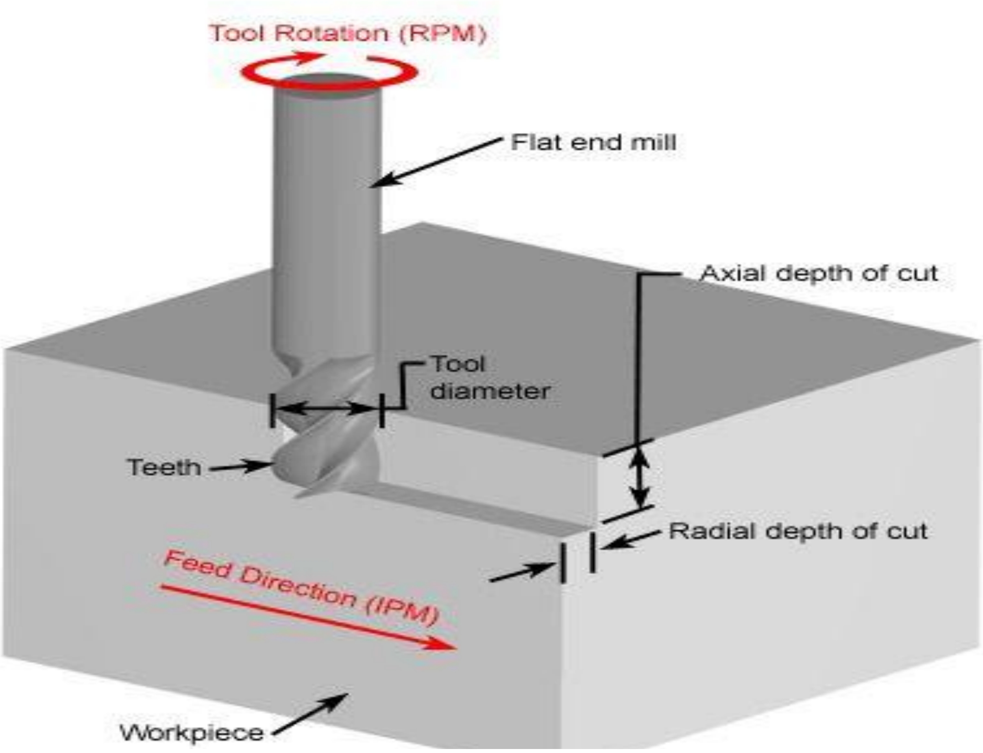


Figure 24 Milling process.

Recommended cutting speed:

CUTTING MATERIAL		Cutting speed (m/s)	Feed rate (mm/z)
Softwood	Cutting along grain	58÷100	0,5÷3,0
	Cutting across grain	60÷100	0,2÷0,4
Hardwood	Cutting along grain	61÷100	0,3÷1,0
	Cutting across grain	65÷100	0,2÷0,8
Exotic timber	Cutting along grain	58÷100	0,3÷1,0
Plywood		55÷80	0,1÷0,2
Particle board		60÷85	0,3
HDF		60÷80	0,1÷0,3
MDF		60÷80	0,1÷0,3
Playwood boards, veneered or coated on both sides		60÷100	0,2
Laminated boards		55÷80	0,1-0,25
Melamine		58÷80	0,15
Thermoplastic		50÷75	0,05-0,1
Duroplastic		30÷60	0,02-0,05
Aluminium profiles		35÷70	0,005-0,08

Table 13 Recommended cutting speeds

***Case study of face milling (MDF wood)**

- Face milling operation is used to machine 3mm from the top of a rectangular piece (MDF wood) of 400mm long by 100mm wide.
- The cutter has 2teeth (High Speed Steel)
- And is 8mm in diameter.

Machinig Calaulations "MILLING":

Spindle speed – N "RPM"

v = cutting speed $N=\frac{v}{\pi D}$

D = cutter diameter

Feed rate - f_r "mm/min or in/min"

f = feed per tooth per rev $f_r = N\, n_t\, f$

n_t = number of teeth

Machinig time – T_m "min"

Slap Milling: $T_m = \frac{L+\sqrt{d(D-d)}}{f_r}$

L = length of cut

d = depth of cut

Face Milling: $T_m = \frac{L+D}{f_r}$ or $T_m = \frac{L+2\sqrt{W(D-W)}}{f_r}$

w = width of cut

Second form is multi-pass

Material removal rate – MRR"mm^3/min or in^3/min" MRR = w d f_r

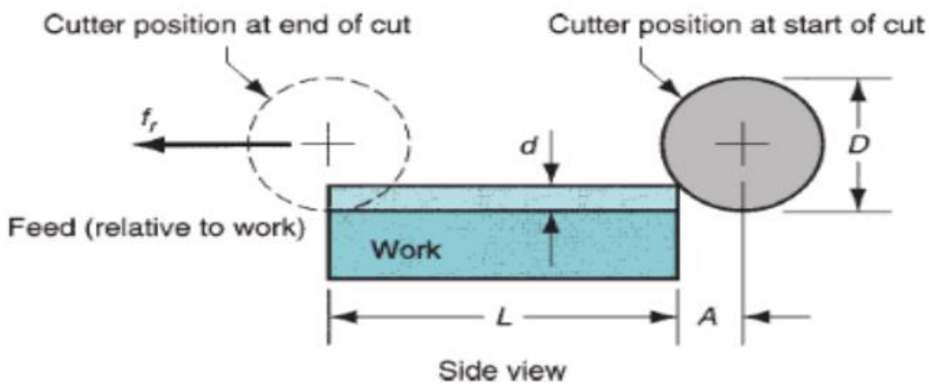


Figure 25 Milling Parameters

Cutting speed law → $(V) = \frac{\pi DN}{1000}$

Where:

V = Cutting speed (mm/min)

D = Cutter diameter (mm)

N = Spindle Speed (RPM)

(V) =60/80 (m/s)× $60 = 45(m/min)$

$45 = \frac{\pi(8)(N)}{1000}$

∴N= 1790 (RPM)

Feed rate law → $(f_r) = f \times N \times n_t$

Where:

f_r = Feed rate (mm/min)

f = Feed per tooth per tooth (mm/Z/rev)

N = Spindle speed (rpm)

$n_t = Z =$ Number of flutes

$f = \frac{0.1}{0.3}\left(\frac{mm}{Z}\right) = 0.33mm/z/rev$

$Given\ from\ table$

f_r = (0.333) × (2) × (1790)
f_r=1192mm/min

Machining Time → $(T) = \frac{L+D}{f_r}$

$(T) = \frac{200+8}{9.9}$ T= 10.45sec

Where:

T = Machining Time (min)

L= Length of cut (mm)

d = Depth of cut (mm)

Ac → cutting/shear force

Ac = f * z * d = 0.333 * 2* 3

$= 1.99\ mm^2$

Fc = Ac * τ = 1.9 * 1.99 = 3.8N

Ac = f * z * d = 0.333 * 2* 3

$= 1.99\ mm^2$

Fc = Ac * τ = 1.9 * 1.99 = 3.8N

Fc → cutting force

MRR = Material Removal Rate (cm^3/min)

w= width of cut (mm)

d = Depth of cut (mm)

f_r = Feed rate (mm/Z)

(MRR) = $w \times d \times f_r/1000$

(MRR)= 50× 3 × 597/1000

(MRR)= $178.8 cm^3/min$

Pc → power requirement

Pc = Fc * V = 3.8* $\frac{45}{60}$ = 2.9 watt

Kc → Specific Cutting force

Pc = (MRR × Kc)/1000× 60 × 0.85

2.4.2 Static Analysis

2.4.2.1 Parts Properties

Mass properties of z_axis_spindle_holder Part no. 14

Density = 0.00102 grams per cubic millimeter

Mass = 191 grams

Volume = 1.88e+05 cubic millimeters

Surface area = 5.4e+04 square millimeters

Center of mass: (millimeters)

X = 12.6 Y = 0 Z = 29.2

Principal axes of inertia and principal moments of inertia: (grams*square millimeters)

Taken at the center of mass.

Ix = (0.99, 0, 0.12) Px = 1.73e+05

Iy = (0, 1, 0) Py = 2.33e+05

Iz = (-0.12, 0, 0.99) Pz = 2.82e+05

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 1.75e+05 Lxy = 0 Lxz = 1.33e+04

Lyx = 0 Lyy = 2.33e+05 Lyz = 0

Lzx = 1.33e+04 Lzy = 0 Lzz = 2.81e+05

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 3.38e+05 Ixy = 0 Ixz = 8.38e+04

Iyx = 0 Iyy = 4.26e+05 Iyz = 0

Izx = 8.38e+04 Izy = 0 Izz = 3.11e+05

Mass properties of 16X200mm Shaft Part no.9

Density = 0.0078 grams per cubic millimeter

Mass = 198 grams

Volume = 2.54e+04 cubic millimeters

Surface area = 8.71e+03 square millimeters

Center of mass: (millimeters)

X = 0 Y = 0 Z = 113

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (0, 0, 1) Px = 3.57e+03

Iy = (0, -1, 0) Py = 8.39e+05

Iz = (1, 0, 0) Pz = 8.39e+05

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 8.39e+05 Lxy = 0 Lxz = 0

Lyx = 0 Lyy = 8.39e+05 Lyz = 0

Lzx = 0 Lzy = 0 Lzz = 3.57e+03

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 3.35e+06 Ixy = 0 Ixz = 0

Iyx = 0 Iyy = 3.35e+06 Iyz = 0

Izx = 0 Izy = 0 Izz = 3.57e+03

Mass properties of 16X400mm Shaft Part no.6

Density = 0.0078 grams per cubic millimeter

Mass = 784 grams

Volume = 1.01e+05 cubic millimeters

Surface area = 2.55e+04 square millimeters

Center of mass: (millimeters)

X = 0 Y = 0 Z = 250

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (0, 0, 1)   Px = 2.51e+04

Iy = (0, -1, 0)   Py = 1.63e+07

Iz = (1, 0, 0)   Pz = 1.63e+07

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 1.63e+07   Lxy = 0   Lxz = 0

Lyx = 0   Lyy = 1.63e+07   Lyz = 0

Lzx = 0   Lzy = 0   Lzz = 2.51e+04

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 6.54e+07   Ixy = 0   Ixz = 0

Iyx = 0   Iyy = 6.54e+07   Iyz = 0

Izx = 0   Izy = 0   Izz = 2.51e+04

Mass properties of 16X600mm Shaft   Part no.3

Density = 0.0078 grams per cubic millimeter

Mass = 1.57e+03 grams

Volume = 2.01e+05 cubic millimeters

Surface area = 5.07e+04 square millimeters

Center of mass: (millimeters)

X = 0 Y = 0 Z = 500

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (0, 0, 1) Px = 5.02e+04

Iy = (0, -1, 0) Py = 1.31e+08

Iz = (1, 0, 0) Pz = 1.31e+08

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 1.31e+08 Lxy = 0 Lxz = 0

Lyx = 0 Lyy = 1.31e+08 Lyz = 0

Lzx = 0 Lzy = 0 Lzz = 5.02e+04

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 5.23e+08 Ixy = 0 Ixz = 0

Iyx = 0 Iyy = 5.23e+08 Iyz = 0

Izx = 0 Izy = 0 Izz = 5.02e+04

Mass properties of Aluminium Extrusion 2040 V-Slot 200mm Part no.10

Density = 0.0027 grams per cubic millimeter

Mass = 153 grams

Volume = 5.67e+04 cubic millimeters

Surface area = 5.97e+04 square millimeters

Center of mass: (millimeters)

X = 0.02 Y = 0.01 Z = 100

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (0, 0, 1) Px = 3.11e+04

Iy = (1, 0, 0) Py = 5.17e+05

Iz = (0, 1, 0) Pz = 5.35e+05

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 5.17e+05 Lxy = 26.9 Lxz = 0

Lyx = 26.9 Lyy = 5.35e+05 Lyz = 0

Lzx = 0 Lzy = 0 Lzz = 3.11e+04

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 2.05e+06   Ixy = 27   Ixz = 235

Iyx = 27   Iyy = 2.07e+06   Iyz = 194

Izx = 235   Izy = 194   Izz = 3.11e+04

Mass properties of Aluminium Extrusion 2040 V-Slot 400mm   Part no.2

Density = 0.0027 grams per cubic millimeter

Mass = 383 grams

Volume = 1.42e+05 cubic millimeters

Surface area = 1.48e+05 square millimeters

Center of mass: (millimeters)

X = 0.02   Y = 0.01   Z = 250

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (0, 0, 1)   Px = 7.79e+04

Iy = (1, 0, 0)   Py = 7.99e+06

Iz = (0, 1, 0)   Pz = 8.03e+06

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 7.99e+06   Lxy = 67.3   Lxz = 0

Lyx = 67.3   Lyy = 8.03e+06   Lyz = 0

Lzx = 0   Lzy = 0   Lzz = 7.79e+04

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 3.19e+07   Ixy = 67.4   Ixz = 1.47e+03

Iyx = 67.4   Iyy = 3.2e+07   Iyz = 1.21e+03

Izx = 1.47e+03   Izy = 1.21e+03   Izz = 7.79e+04

Mass properties of Aluminium Extrusion 2040 V-Slot 600mm   Part no.1

Density = 0.0027 grams per cubic millimeter

Mass = 765 grams

Volume = 2.83e+05 cubic millimeters

Surface area = 2.96e+05 square millimeters

Center of mass: (millimeters)

X = 0.02   Y = 0.01   Z = 500

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (0, 0, 1)   Px = 1.56e+05

Iy = (1, 0, 0)   Py = 6.38e+07

Iz = (0, 1, 0) Pz = 6.39e+07

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 6.38e+07 Lxy = 135 Lxz = 0

Lyx = 135 Lyy = 6.39e+07 Lyz = 0

Lzx = 0 Lzy = 0 Lzz = 1.56e+05

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 2.55e+08 Ixy = 135 Ixz = 5.88e+03

Iyx = 135 Iyy = 2.55e+08 Iyz = 4.84e+03

Izx = 5.88e+03 Izy = 4.84e+03 Izz = 1.56e+05

Mass properties of lead screw 200mm Part no.18

Density = 0.0078 grams per cubic millimeter

Mass = 73.5 grams

Volume = 9.42e+03 cubic millimeters

Surface area = 1.06e+04 square millimeters

Center of mass: (millimeters)

X = 120 Y = 0 Z = 0

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (1, 0, 0) Px = 495

Iy = (0, 0.72, -0.69) Py = 3.52e+05

Iz = (0, 0.69, 0.72) Pz = 3.52e+05

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 495 Lxy = 13.1 Lxz = -6.45

Lyx = 13.1 Lyy = 3.52e+05 Lyz = -9.35

Lzx = -6.45 Lzy = -9.35 Lzz = 3.52e+05

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 495 Ixy = 21.2 Ixz = -2.62

Iyx = 21.2 Iyy = 1.41e+06 Iyz = -9.35

Izx = -2.62 Izy = -9.35 Izz = 1.41e+06

Mass properties of lead screw 600 Part no.16

Density = 0.0078 grams per cubic millimeter

Mass = 306 grams

Volume = 3.93e+04 cubic millimeters

Surface area = 4.41e+04 square millimeters

Center of mass: (millimeters)

X = 500 Y = 0 Z = 0

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (1, 0, 0) Px = 2.06e+03

Iy = (0, 0.71, -0.7) Py = 2.55e+07

Iz = (0, 0.7, 0.71) Pz = 2.55e+07

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 2.06e+03 Lxy = 71.4 Lxz = -40.4

Lyx = 71.4 Lyy = 2.55e+07 Lyz = -171

Lzx = -40.4 Lzy = -171 Lzz = 2.55e+07

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 2.06e+03 Ixy = 75.4 Ixz = -24.7

Iyx = 75.4 Iyy = 1.02e+08 Iyz = -171

Izx = -24.7 Izy = -171 Izz = 1.02e+08

Mass properties of lead screw nut Part no.15

Density = 0.0085 grams per cubic millimeter

Mass = 13.2 grams

Volume = 1.55e+03 cubic millimeters

Surface area = 2.03e+03 square millimeters

Center of mass: (millimeters)

X = 0 Y = -0.01 Z = 0

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (0, 0.97, 0.25) Px = 507

Iy = (0, -0.25, 0.97) Py = 507

Iz = (1, 0, 0) Pz = 679

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 679 Lxy = -0.33 Lxz = 0.03

Lyx = -0.33 Lyy = 507 Lyz = 0

Lzx = 0.03 Lzy = 0 Lzz = 507

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 679 Ixy = -0.33 Ixz = 0.03

Iyx = -0.33 Iyy = 507 Iyz = 0

Izx = 0.03 Izy = 0 Izz = 507

Mass properties of x_axis_stepper_motor_holder Part no.8

Density = 0.00102 grams per cubic millimeter

Mass = 522 grams

Volume = 5.12e+05 cubic millimeters

Surface area = 8.6e+04 square millimeters

Center of mass: (millimeters)

X = -34.3 Y = 15.3 Z = 23.6

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (-0.27, 0.06, 0.96) Px = 3.85e+05

Iy = (0.96, 0.03, 0.27)   Py = 3.45e+06

Iz = (-0.02, 1, -0.06)   Pz = 3.7e+06

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 3.23e+06   Lxy = -4.27e+04   Lxz = -7.9e+05

Lyx = -4.27e+04   Lyy = 3.69e+06   Lyz = 1.83e+05

Lzx = -7.9e+05   Lzy = 1.83e+05   Lzz = 6.16e+05

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 3.64e+06   Ixy = -3.16e+05   Ixz = -1.21e+06

Iyx = -3.16e+05   Iyy = 4.59e+06   Iyz = 3.71e+05

Izx = -1.21e+06   Izy = 3.71e+05   Izz = 1.35e+06

Mass properties of y_axis_bearing_holder   Part no.4

Density = 0.00102 grams per cubic millimeter

Mass = 91.3 grams

Volume = 8.95e+04 cubic millimeters

Surface area = 3.02e+04 square millimeters

Center of mass: (millimeters)

X = -0.79   Y = 61.4   Z = 0

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (-0.04, 1, 0) Px = 3.98e+04

Iy = (-1, -0.04, 0) Py = 1.15e+05

Iz = (0, 0, 1) Pz = 1.47e+05

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 1.15e+05 Lxy = -3.37e+03 Lxz = 0

Lyx = -3.37e+03 Lyy = 4e+04 Lyz = 0

Lzx = 0 Lzy = 0 Lzz = 1.47e+05

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 4.59e+05 Ixy = -7.82e+03 Ixz = 0

Iyx = -7.82e+03 Iyy = 4e+04 Iyz = 0

Izx = 0 Izy = 0 Izz = 4.91e+05

Mass properties of y_axis_stepper_motor_holder Part no.5

Density = 0.00102 grams per cubic millimeter

Mass = 84.3 grams

Volume = 8.26e+04 cubic millimeters

Surface area = 3.07e+04 square millimeters

Center of mass: (millimeters)

X = -0.86 Y = 63.2 Z = 0

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (-0.05, 1, 0) Px = 3.85e+04

Iy = (-1, -0.05, 0) Py = 1.1e+05

Iz = (0, 0, 1) Pz = 1.41e+05

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 1.1e+05 Lxy = -3.24e+03 Lxz = 0

Lyx = -3.24e+03 Lyy = 3.86e+04 Lyz = 0

Lzx = 0 Lzy = 0 Lzz = 1.41e+05

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 4.47e+05 Ixy = -7.82e+03 Ixz = 0

Iyx = -7.82e+03 Iyy = 3.87e+04 Iyz = 0

Izx = 0 Izy = 0 Izz = 4.77e+05

Mass properties of z_axis_stepper_motor_holder Part no.12

Density = 0.00102 grams per cubic millimeter

Mass = 75.1 grams

Volume = 7.37e+04 cubic millimeters

Surface area = 2.04e+04 square millimeters

Center of mass: (millimeters)

X = 0 Y = 1.42 Z = 7.64

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (1, 0, 0) Px = 4.36e+04

Iy = (0, 1, 0) Py = 4.68e+04

Iz = (0, 0, 1) Pz = 8.77e+04

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 4.36e+04 Lxy = 0 Lxz = 0

Lyx = 0 Lyy = 4.68e+04 Lyz = 158

Lzx = 0 Lzy = 158 Lzz = 8.77e+04

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 4.82e+04 Ixy = 0 Ixz = 0

Iyx = 0 Iyy = 5.12e+04 Iyz = 975

Izx = 0 Izy = 975 Izz = 8.78e+04

Mass properties of z_axis_bearing_holder Part no.13

Density = 0.00102 grams per cubic millimeter

Mass = 46.8 grams

Volume = 4.59e+04 cubic millimeters

Surface area = 1.57e+04 square millimeters

Center of mass: (millimeters)

X = 0 Y = 2.08 Z = 4

Principal axes of inertia and principal moments of inertia: (grams * square millimeters)

Taken at the center of mass.

Ix = (0, 1, 0) Px = 2.56e+04

Iy = (-1, 0, 0)   Py = 2.63e+04

Iz = (0, 0, 1)   Pz = 5.14e+04

Moments of inertia: (grams * square millimeters)

Taken at the center of mass and aligned with the output coordinate system.

Lxx = 2.63e+04   Lxy = 0   Lxz = 0

Lyx = 0   Lyy = 2.56e+04   Lyz = 0

Lzx = 0   Lzy = 0   Lzz = 5.14e+04

Moments of inertia: (grams * square millimeters)

Taken at the output coordinate system.

Ixx = 2.73e+04   Ixy = 0   Ixz = 0

Iyx = 0   Iyy = 2.63e+04   Iyz = 390

Izx = 0   Izy = 390   Izz = 5.16e+04

2.4.2.2 Stress Analysis

Allowable stresses:

50% from yield stress or 30% from tensile stress

So for the Materials:

6063.T5 Aluminum v-slot

Yield 145 MPa

Tensile 186 MPa

Shear 117 MPa

Allowable stress:

145 MPa × 50% =72.5 MPa

186 MPa× 30% =55.8 MPa

so Allowable stress =55.8 MPa

GN-31 Bars

yield 2.03 GPa

Tensile 2.24 GPa

Allowable stress:

2.03 GPa× 50% = 1.015 GPa

2.24 GPa× 30% = 672 kPa

so Allowable stress =672 kPa

PLA 3D-Printing Parts

yield 60 MPa

Tensile 59 MPa

Allowable stress:

60 MPa× 50% =30 MPa

59 MPa× 30% =17.7 MPa

so Allowable stress =17.7 MPa

Stress Analysis by Equations:

1- $\sigma = \frac{P}{A}$ FOR TENSILE LOAD & $\sigma = \frac{M.C}{I}$ FOR BENDING LOAD

2- $\sigma_{Max} = \frac{\sigma_x+\sigma_y}{2} + \sqrt{(\frac{\sigma_x-\sigma_y}{2})^2 + {\tau_{xy}}^2}$ 3- $\sigma_{Min} = \frac{\sigma_x+\sigma_y}{2} - \sqrt{(\frac{\sigma_x-\sigma_y}{2})^2 + {\tau_{xy}}^2}$

4- $\tau_{max} = \frac{\sigma_{max}-\sigma_{min}}{2}$ or $\frac{\sigma_{max}-0}{2}$ or $\frac{0-\sigma_{min}}{2}$ 5- $\sigma_x \; and \; \sigma_y = \frac{P}{A} \pm \frac{M.C}{I}$

6- $\tau_{xy} = \frac{T.R}{J}$

m = Clamp + Spindle weight

m = (0.191+0.45) Kg

m= 0.641Kg ×9.81 = 6.288 N

$\sum M = 0$

$X_1 = X_2 = \frac{6.288\times 29\times 10^{-3}}{58\times 10^{-3}}$ = 3.144 N

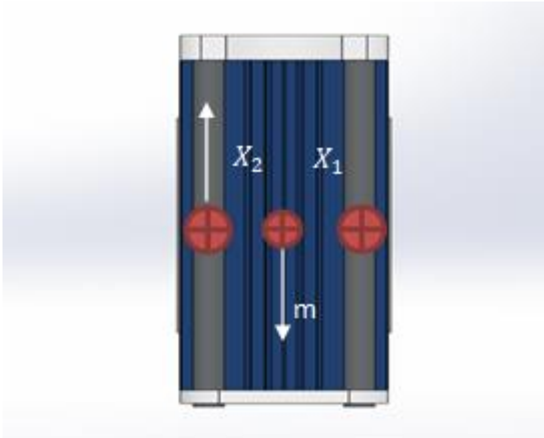


Figure 26 Clamp and Spindle stress analysis

For rod X_1, X_2

$\sigma_X = \frac{F}{A} = \frac{3.144}{\pi\times(6\times 10^{-3})^2} = 27.79\ KPa \quad \sigma_Y = 0 \qquad \tau_{xy} = 0$

$\therefore \sigma_{Max} = \sigma_X = 27.79\ KPa$

σ_{Min} = ZERO

$\tau_{max} = 0.5\ \sigma_{Max} = 13.89\ KPa$

z-axis

m_1 previous = (0.641+2× 0.1985)

= 1.038 Kg ×9.81 = 10.18 N

$m_2 = 0.5\ Kg$ × 9.81 = 4.905 N

$M_z = 4.905\times 39\times 10^{-3} + 10.18\ \times 72\times 10^{-3}$

$M_z = 0.92\ N.m$

$X_1 = \frac{M.C}{I} = \frac{0.92\times 7.5\times 10^{-3}}{46690\times(10^{-3})^4}$

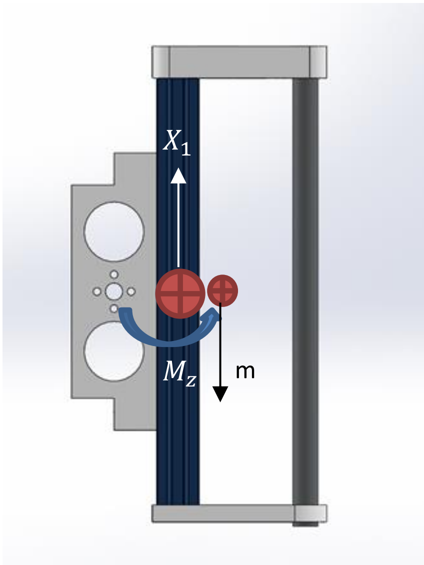


Figure 27 Z-axis stress analysis

$X_1 = 147\ KN/m^2$

$\sigma_X = X_1 = 147\ \ KPa \quad \sigma_Y = 0 \qquad \tau_{xy} = 0$

$\therefore\ \sigma_{Max} = \sigma_X = 147\ KPa$

σ_{Min} = ZERO

$$\tau_{max} = 0.5\ \sigma_{Max} = 73.5\ KPa$$

x-axis

m = Spindle + motor

m = (1.2858 + 0.450)+ 0.500

m = 2.24 Kg × 9.81= 21.97 N

$X_1 = X_2 = 21.97$ N

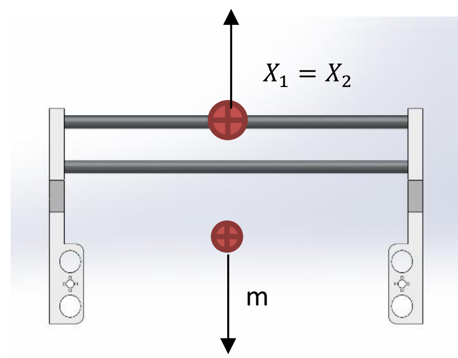


Figure 28 X-axis stress analysis

$\sigma_X = \frac{M.C}{I} = \frac{(21.97 \times 0.200) \times 8 \times 10^{-3}}{3.2 \times 10^{-9}} = 10.98\ GPa \quad \sigma_Y = 0$

$\tau_{xy} = 0$

$\therefore\ \sigma_{Max} = \sigma_X = 10.98\ GPa$

σ_{Min} = ZERO

$\tau_{max} = 0.5\ \sigma_{Max} = 5.49\ GPa$

y-axis (motor 1)

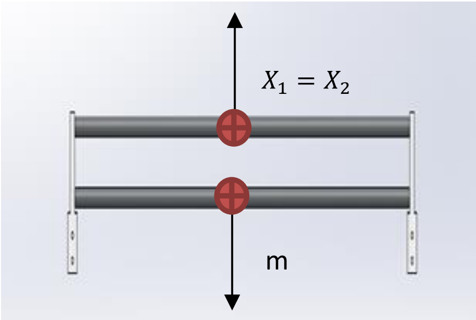


Figure 29 Y-axis (motor 1) stress analysis

m = 4.14 Kg × 9.81 =40.61 N

$X_1 = X_2 = 20.3\ N$

$\sigma_X = \frac{M.C}{I} = \frac{(20.3\times0.200).(8\times10^{-3})}{3.2\times10^{-9}} = 10.15\ GPa$

$\sigma_Y = 0 \qquad \tau_{xy} = 0$

$\therefore \sigma_{Max} = \sigma_X = 10.15\ GPa$

σ_{Min} = ZERO

$\tau_{max} = 0.5\ \sigma_{Max} = 5.075\ GPa$

y-axis (motor 2)

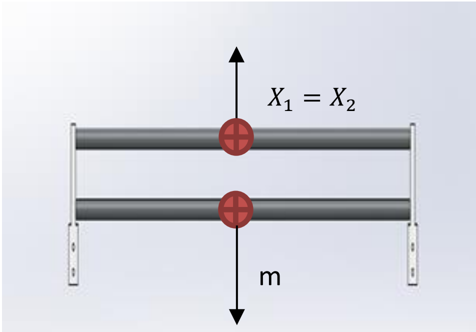


Figure 30 Y-axis (motor 2) stress analysis

$X_1 = X_2 = \frac{20.3}{2} = 10.15\ N$

$\sigma_X = \frac{M.C}{I} = \frac{(10.15\times0.200).(8\times10^{-3})}{3.2\times10^{-9}} = 5.075\ GPa$

$\sigma_Y = 0 \qquad \tau_{xy} = 0$

$\therefore \sigma_{Max} = \sigma_X = 5.075\ GPa$

σ_{Min} = ZERO

$$\tau_{max} = 0.5\ \sigma_{Max} = 2.53\ GPa$$

2.4.2.3 Solidworks Finite Element Analysis

SolidWorks simulation was used to identify high and low stress zones of the upright in different situations, so material can be added or removed accordingly. The goal was to achieve an even stress distribution throughout the part.

2.4.2.3.1 Mesh Information

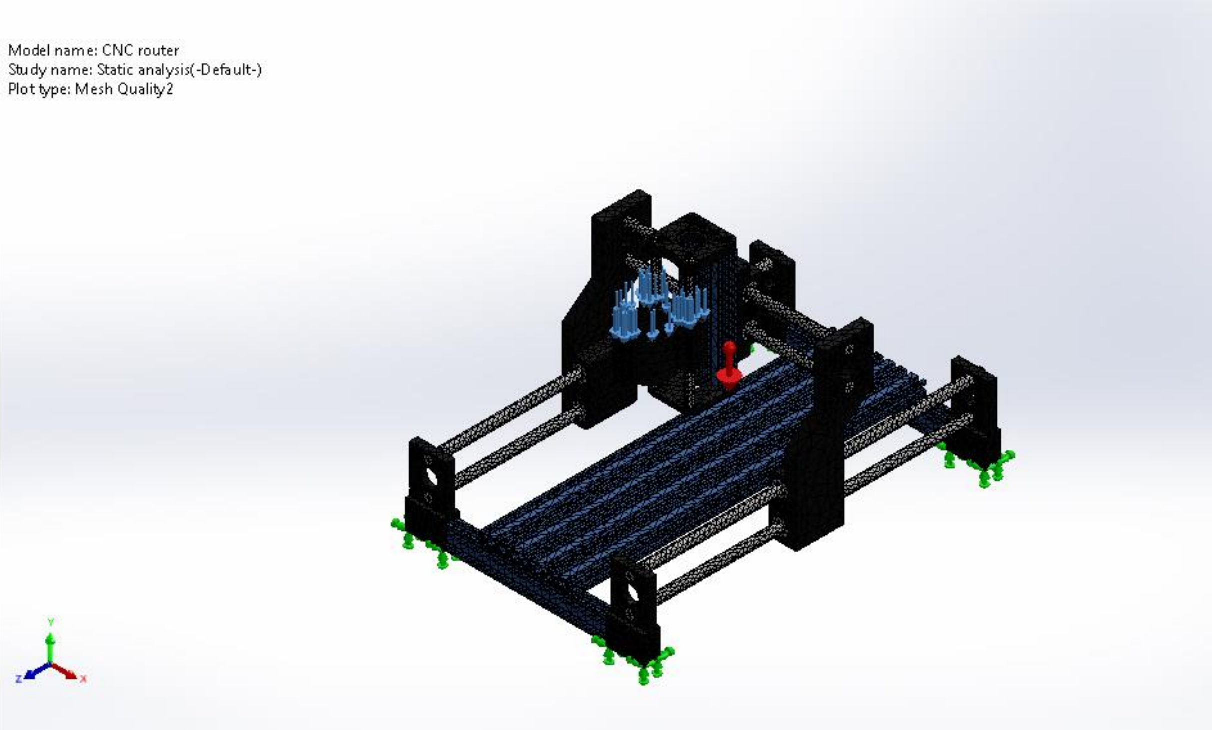
Table 14 Mesh Information

Mesh type	Solid Mesh
Mesher Used:	Curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	41.3241 mm
Minimum element size	8.26482 mm
Mesh Quality	High
Remesh failed parts with incompatible mesh	Off
Total Nodes	313606
Total Elements	164258
Time to complete mesh(hh;mm;ss):	00:00:40

2.4.2.3.2 Mesh Plot

Table 15 Mesh Plot

Name	Type	Min	Max
Quality2	Mesh	-	-



CNC router-Static analysis-Quality-Quality2

2.4.2.3.3 Resultant Forces

Table 16 Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.000426218	118.958	0.00103623	118.958

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Free body forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.028775	81.6756	0.0602387	81.6756

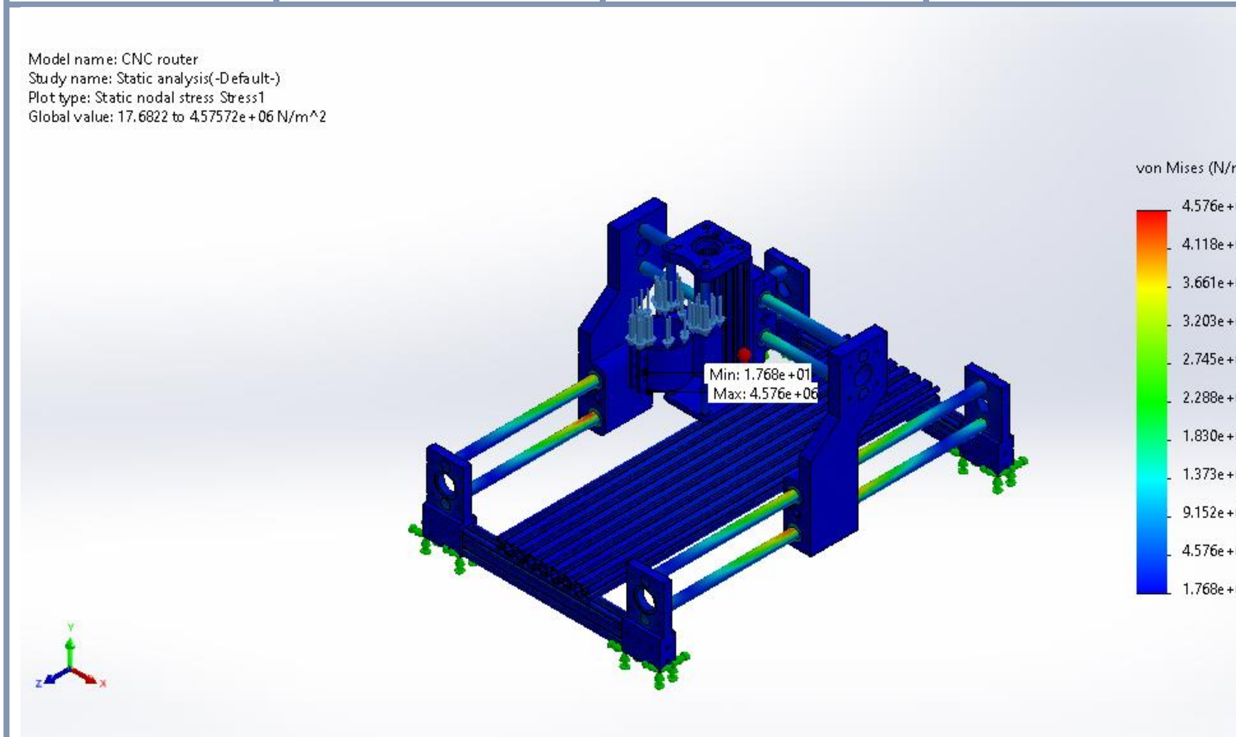
Free body moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

2.4.2.3.4 Study Results

Table 17 Study Results 1 (von mises stress)

Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.768e+01N/m^2 Node: 312336	4.576e+06N/m^2 Node: 21211

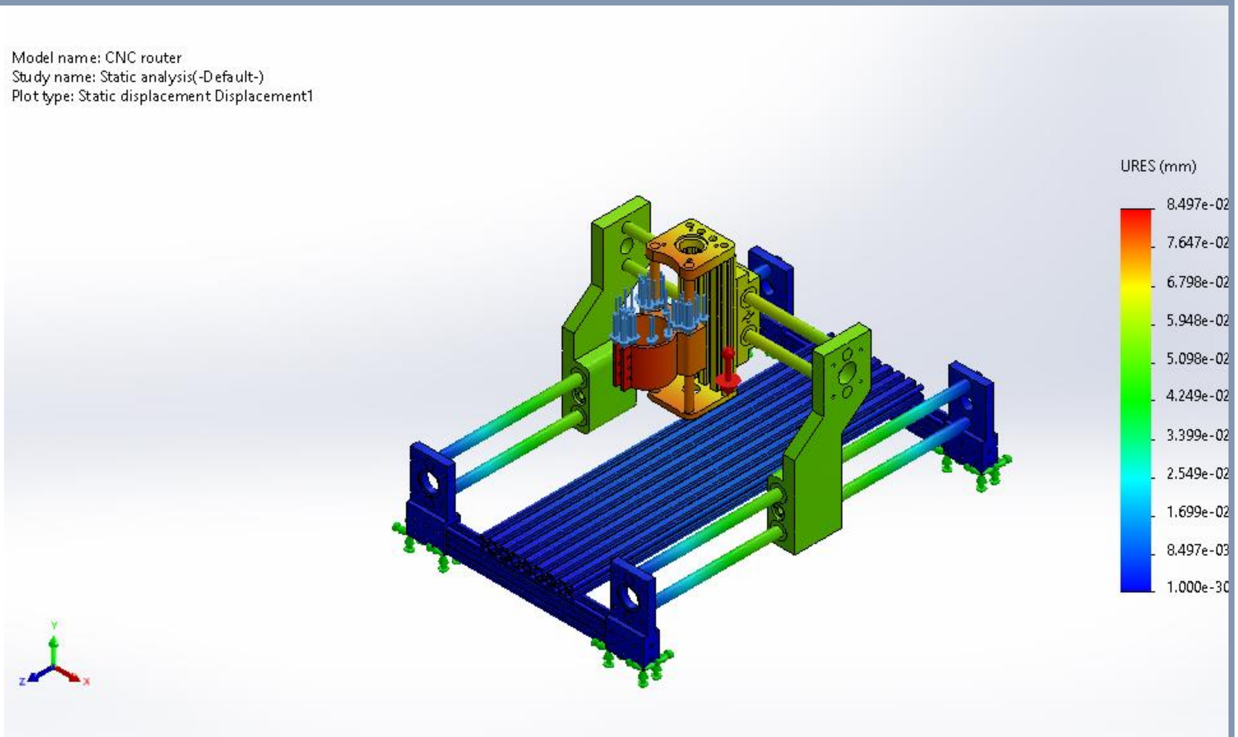


CNC router-Static analysis-Stress-Stress1

The point of maximum Von Mises stress is indicated by the red arrow in each result. Notice that the max stress point is in one of the bushings for all load cases.

Table 18 Study Results 2 (displacement)

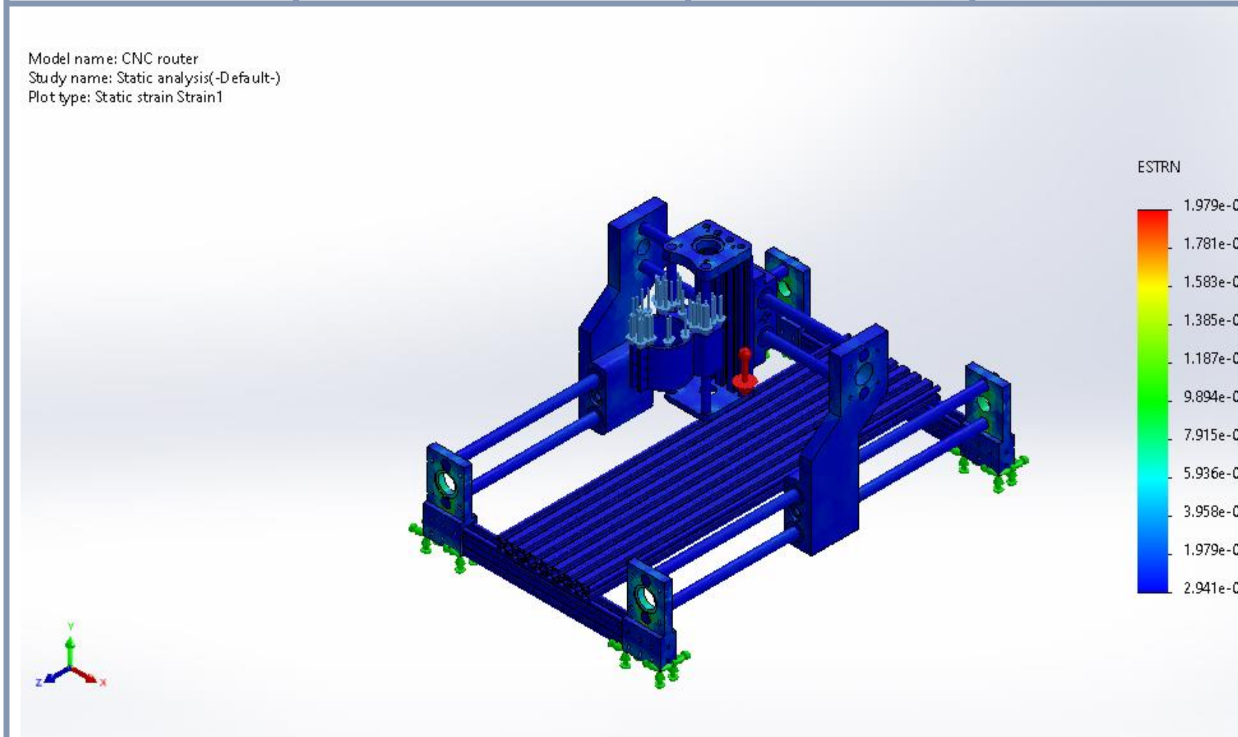
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 284921	8.497e-02mm Node: 307783



CNC router-Static analysis-Displacement-Displacement1

Table 19 Study Results 3(strain)

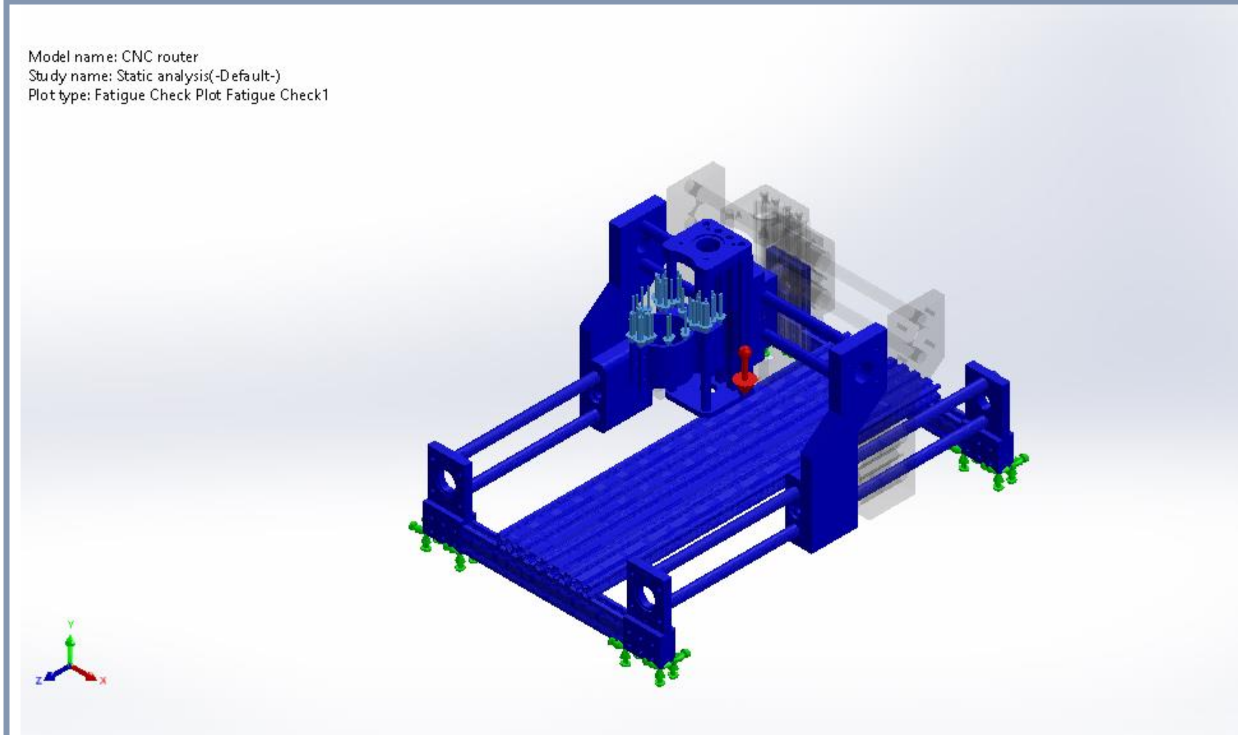
Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	2.941e-09 Element: 132604	1.979e-04 Element: 154520



CNC router-Static analysis-Strain-Strain1

Table 20 Study Results 4 fatigue check

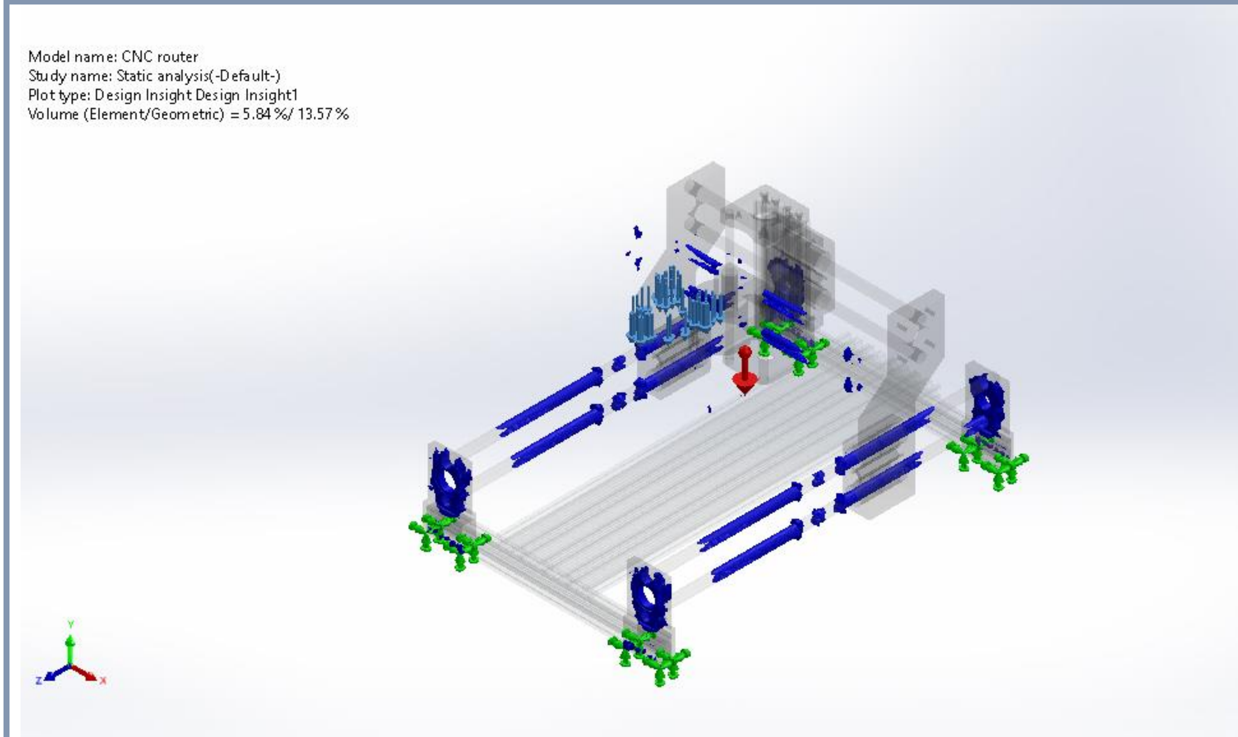
Name	**Type**
Fatigue Check1	Fatigue Check Plot



CNC router-Static analysis-Fatigue Check-Fatigue Check1

Table 21 Study Results 5(insight)

Name	Type
Design Insight1	Design Insight



CNC router-Static analysis-Design Insight-Design Insight1

2.4.3 Requirement Torque

The equation: $T = W\left[r_m \times \left(\frac{\tan\alpha + (f/\cos\theta n)}{1-(f\tan\alpha/\cos\theta n)}\right)\right] + f_c r_c$

Where

T = torque applied to run screw or nut, whichever is being rotated

W= load parallel to screw axis

r_m= mean thread radius

r_c= effective radius of rubbing surface against which load bears called collar radius

f= coefficient of friction between screw and nut threads

f_c= coefficient of frication at collar

α=helix angle of thread at mean radius

θn =angle between tangent to tooth profile (on the loaded side) And a radial line, measured in plane normal to thread helix at mean radius.

So Required torque in y axis =

when (W= 4kg ×9.81=39.24 N) & (r_m= 5-0.5=4.5mm) & (r_c= 5mm) & (f =0.15) &($Lead$ =Pitch= 2mm) & ($\alpha = \tan^{-1}\frac{lead}{2\pi r_m} = 4.04°$)

& ($\theta n = \tan^{-1}(\tan\theta \times \cos\alpha = 4.95°)\ where\ \ \theta = 5°$)

T= 39.47 N.mm

Required torque in x axis =

When: (W= 2kg ×9.81= 19 .62 N) & (r_m= 5-0.5=4.5mm)

& (r_c= 5mm) & (f =0.15) & ($\alpha = \tan^{-1}\frac{lead}{2\pi r_m} = 4.04°$)

& $(\theta n = \tan^{-1}(\tan\theta \times \cos\alpha = 4.95°)\ where\ \ \theta = 5°)$

T= 19.73 N.mm

Required torque in z axis =

When (W= 0.5kg ×9.81=4.905 N) & (r_m= 5-0.5=4.5mm)

& (r_c= 5mm) & (f =0.15) & $(\alpha = \tan^{-1}\frac{lead}{2\pi r_m} = 4.04°)$

& $(\theta n = (\tan^{-1}(\tan\theta \times \cos\alpha = 4.95°)\ where\ \ \theta = 5°)$

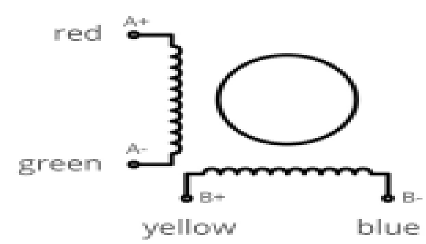
T= 4.93 N.mm

So we decided to use stepper motor nema 23

SPECIFICATIONS

Standard	NEMA 23
Step angle	1.8° ±5%
Current / Phase	3.0A
Voltage / Phase	3.9V
Phase No.	2
Resistance	1.3 ±10% Ω
Insulation resistance	100MOhm (500V DC)
Inductance	2.2 ±20%mH
Insulation class	B
Holding torque	15kgf.cm

DIAGRAM



DIMENSIONS UNIT: mm

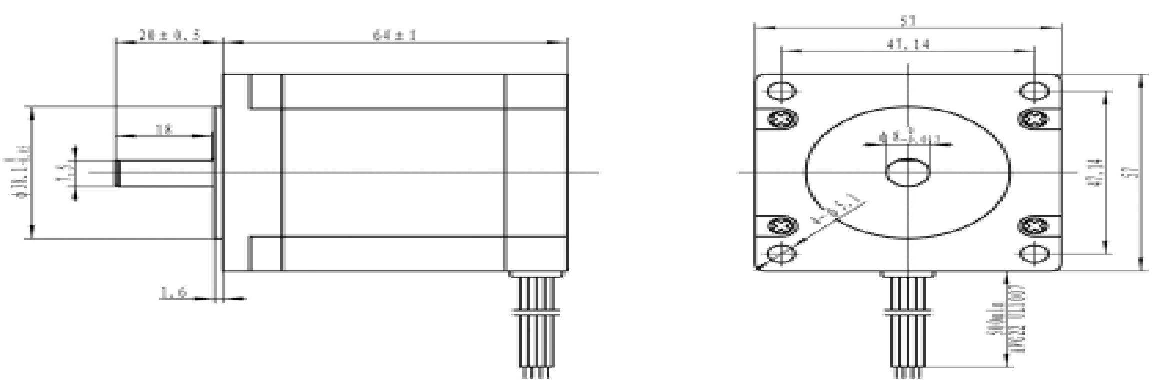


Figure 31 information about stepper Nema23

Chapter 3

3 Electrical Design & Software

This chapter provides a detailed description of motion controller, power drive electronics & Software.

3.1 Block diagrams

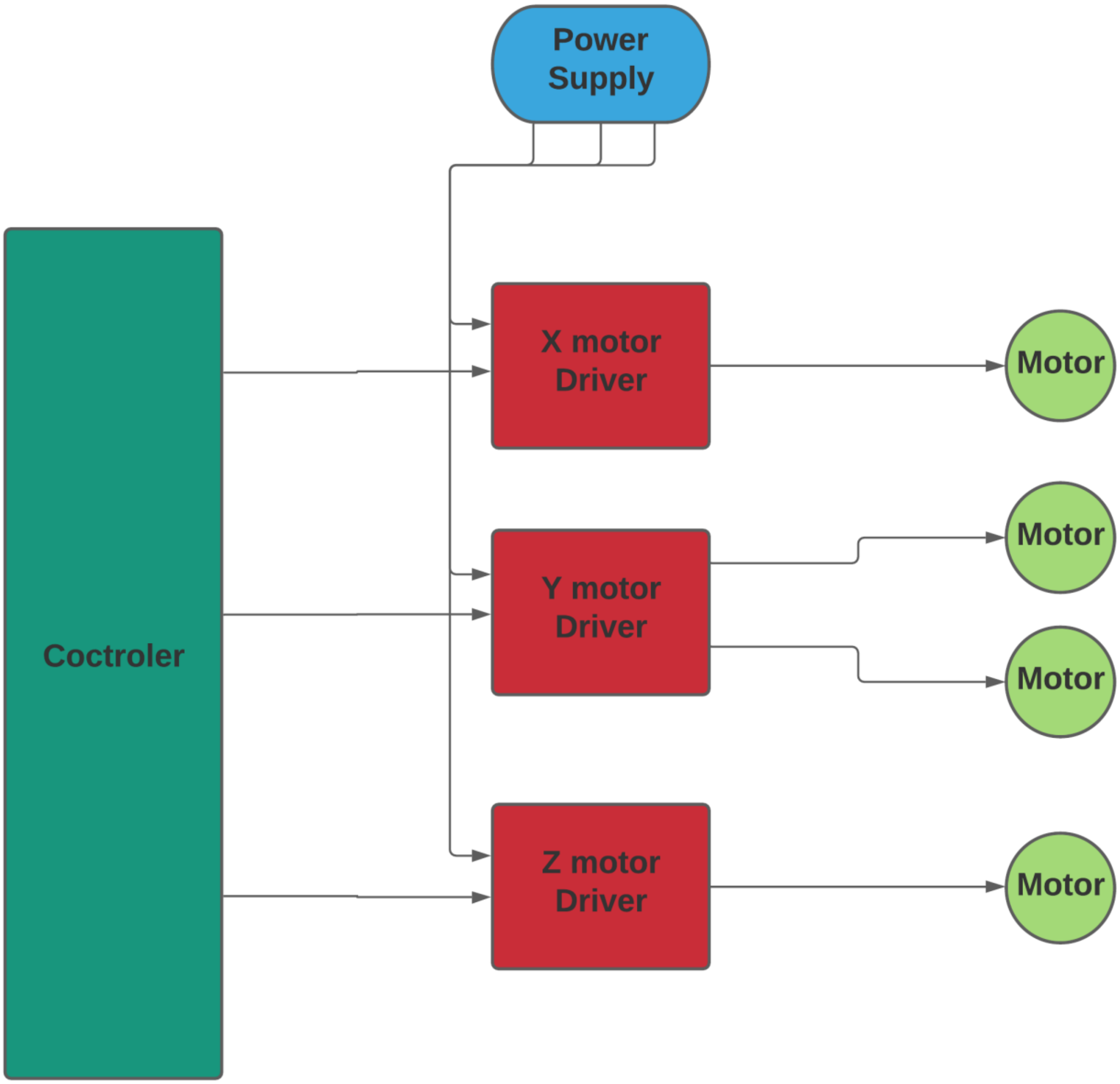


Figure 32 Block diagrams

3.2 Controller

Arduino can work as the brains of a CNC controller, it isn't “strong” enough to power the “limbs”. ... On top of that shields connect the Arduino to stepper drivers that provide the pulses required to control the stepper motors.

Arduino CNC Shield – For connecting the stepper drivers to the Arduino, the easiest way is to use an Arduino CNC Shield. It utilizes all Arduino pins and provides an easy way to connect everything, the stepper motors, the spindle/ laser, the limit switches, cooling fan.

Figure 33 Arduino

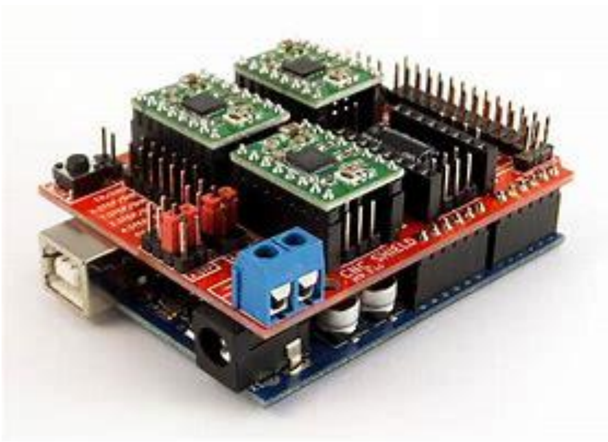


Figure 34 Grbl shield (V3)

3.3 Driver

The driver will provide the required amount of current to the motor. Tb6600 or A4988 driver will be used because it improves the high-speed performance of the motor. By overdriving the motor, the toque at higher speeds will be increased. The driver will receive two main control signals from the controller: step and direction.

3.3.1 Tb6600 Motor Driver

Figure 35 Tb6600 Motor Driver

3.3.1.1 Specifications:

- Input Current: 0-5.0A
- Output Current: 0.5-4.0A
- Power (MAX): 160W
- Micro Step: 1, 2/A, 2/B, 4, 8, 16, 32

- Temperature: -10～45℃
- Humidity: No Condensation
- Weight: 0.2 kg
- Dimensions: 96x56x33 mm

3.3.1.2 TB600 motor driver wiring system

3.3.1.2.1 INPUT & OUTPUT:

Signal Input:

- PUL+ Pulse +
- PUL- Pulse -
- DIR+ Direction +
- DIR- Direction -
- EN+ Off-line Control Enable +
- EN- Off-line Control Enable –

Motor Machine Winding:

- A+ Stepper motor A+
- A- Stepper motor A-
- B+ Stepper motor B+
- B- Stepper motor B-

Power Supply:

- VCC VCC (DC9-42V)
- GND GND

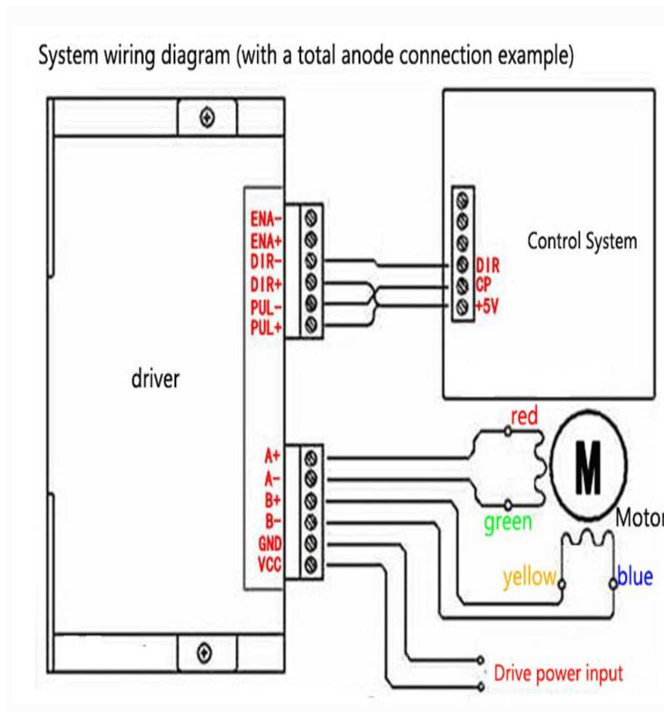


Figure 36 TB600 motor driver wiring system

3.3.1.3 Current Control Setting

Figure 37 Current Control Setting

Micro Step	Pulse/Rev	S1	S2	S3
NC	NC	ON	ON	ON
1	200	ON	ON	OFF
2/A	400	ON	OFF	ON
2/B	400	OFF	ON	ON
4	800	ON	OFF	OFF
8	1600	OFF	ON	OFF
16	3200	OFF	OFF	ON
32	6400	OFF	OFF	OFF

Current (A)	S4	S5	S6
0.5	ON	ON	ON
1.0	ON	OFF	ON
1.5	ON	ON	OFF
2.0	ON	OFF	OFF
2.5	OFF	ON	ON
2.8	OFF	OFF	ON
3.0	OFF	ON	OFF
3.5	OFF	OFF	OFF

Table 22 Current Control Setting

3.4 Circuit diagrams

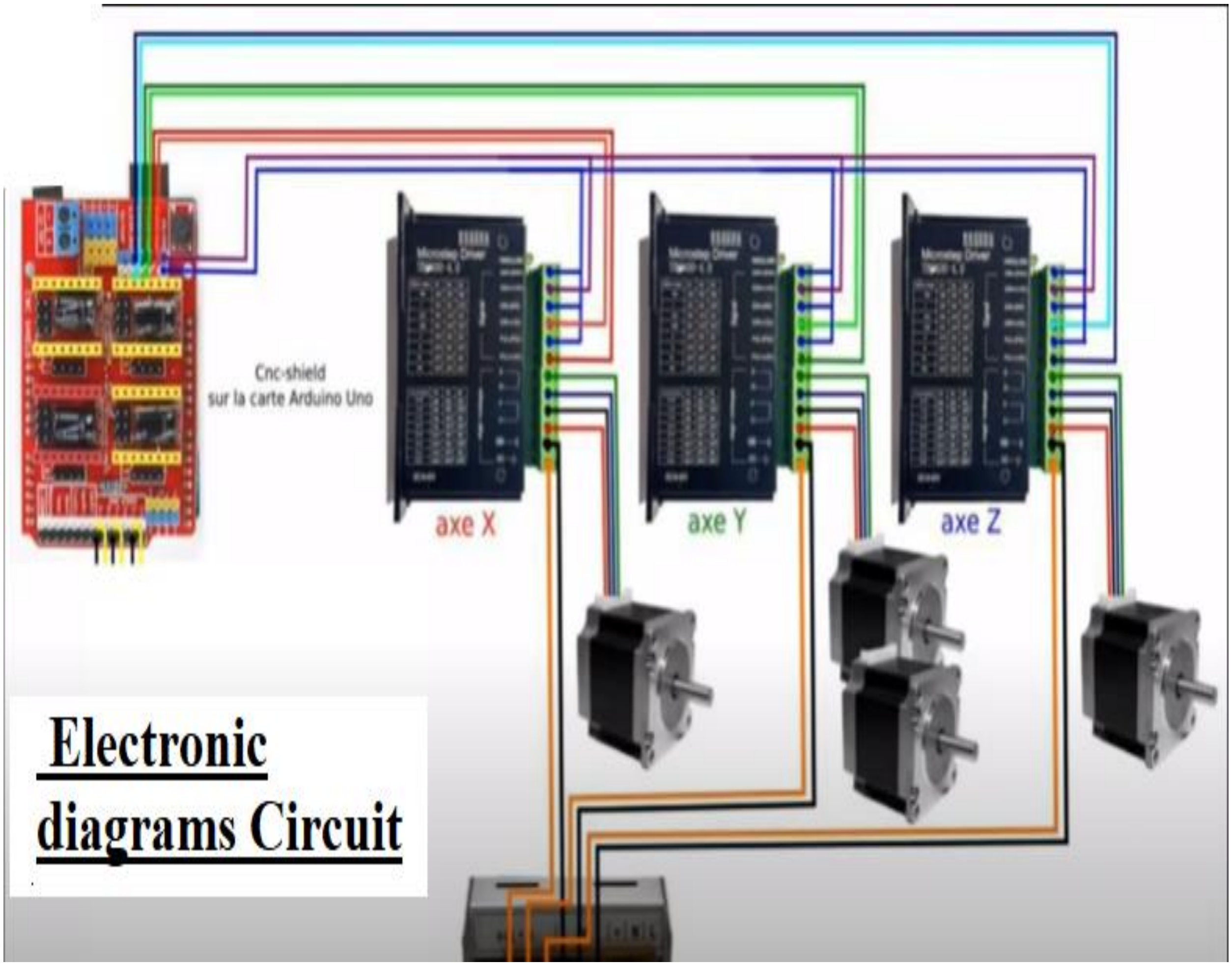


Figure 38 Electronic Circuit diagrams

3.4.1 Control Circuit Of CNC Router By Arduino Uno

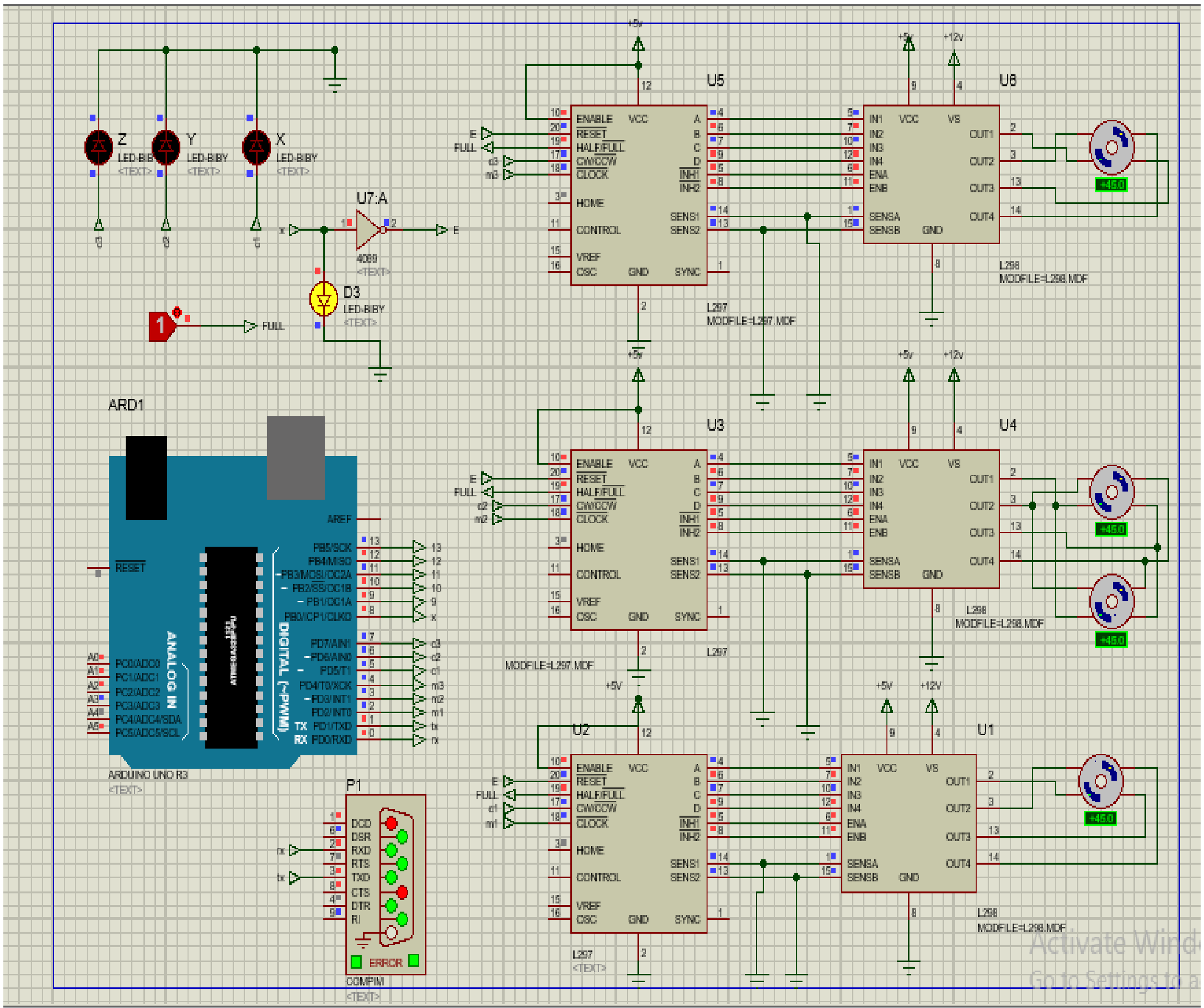


Figure 39 Control Circuit By Arduino Uno

Selected port of Arduino for control signals are connected to step and direction of each driver as shown in figure( ).

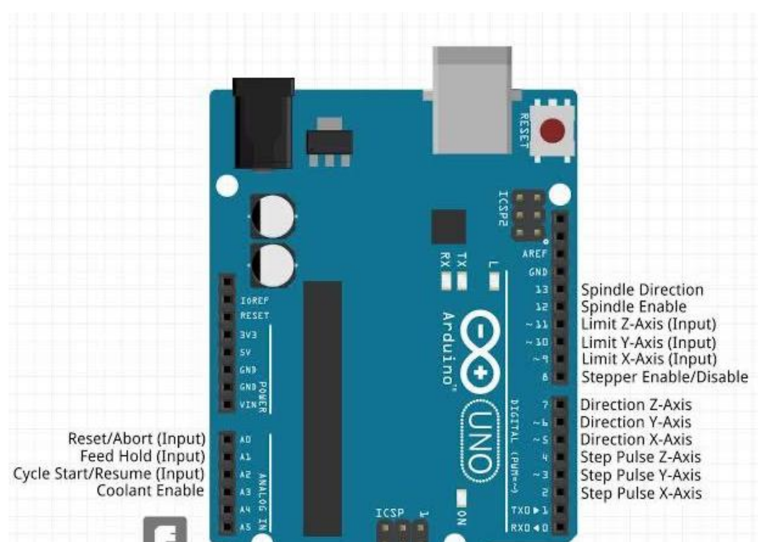


Figure 40 Arduino Uno

3.4.2 Control Circuit Of CNC Router By Arduino Nano

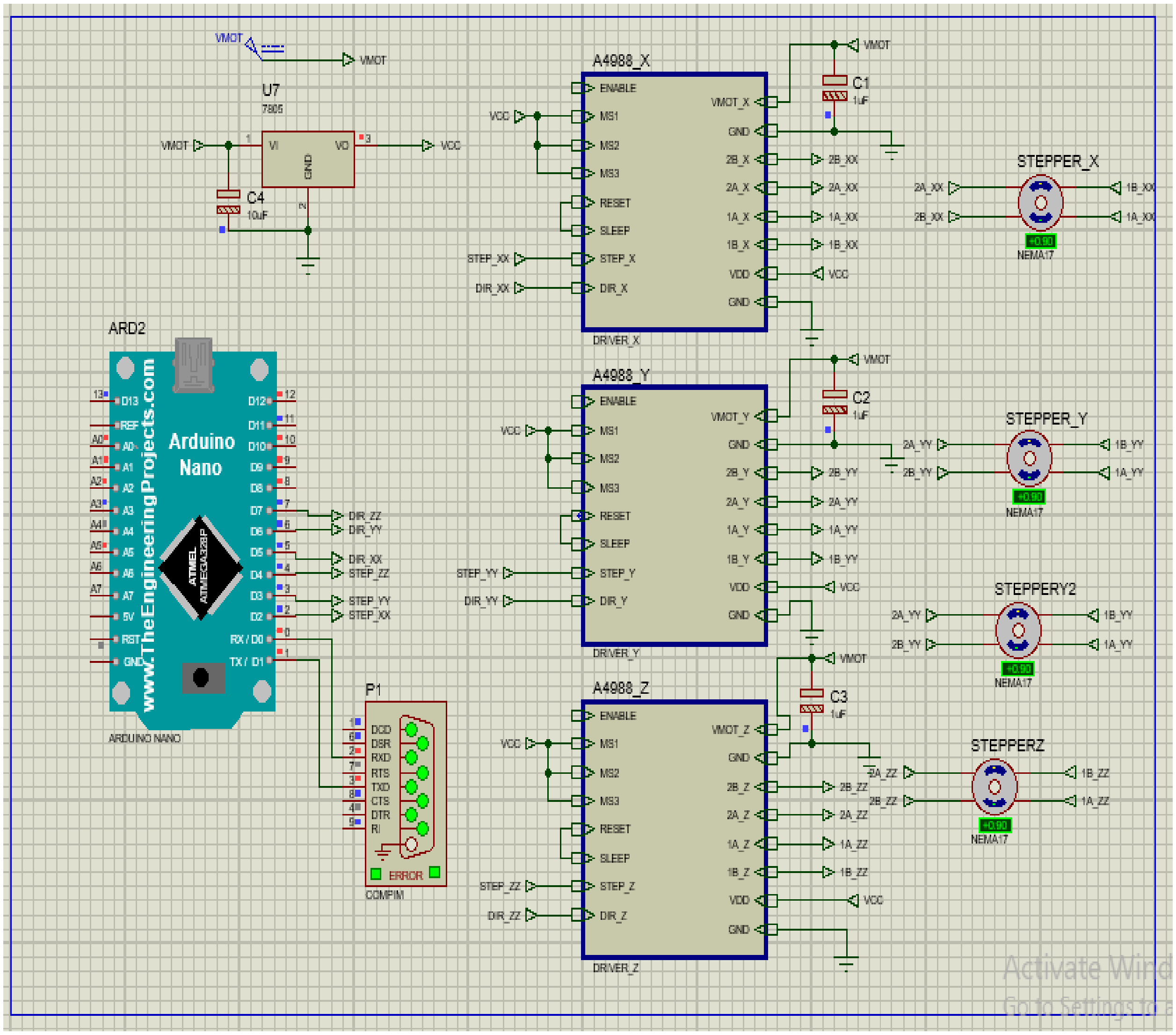


Figure 41 Control Circuit By Arduino Nano

This is the way to connect the driver to motor & controller

Figure 42 Arduino Nano

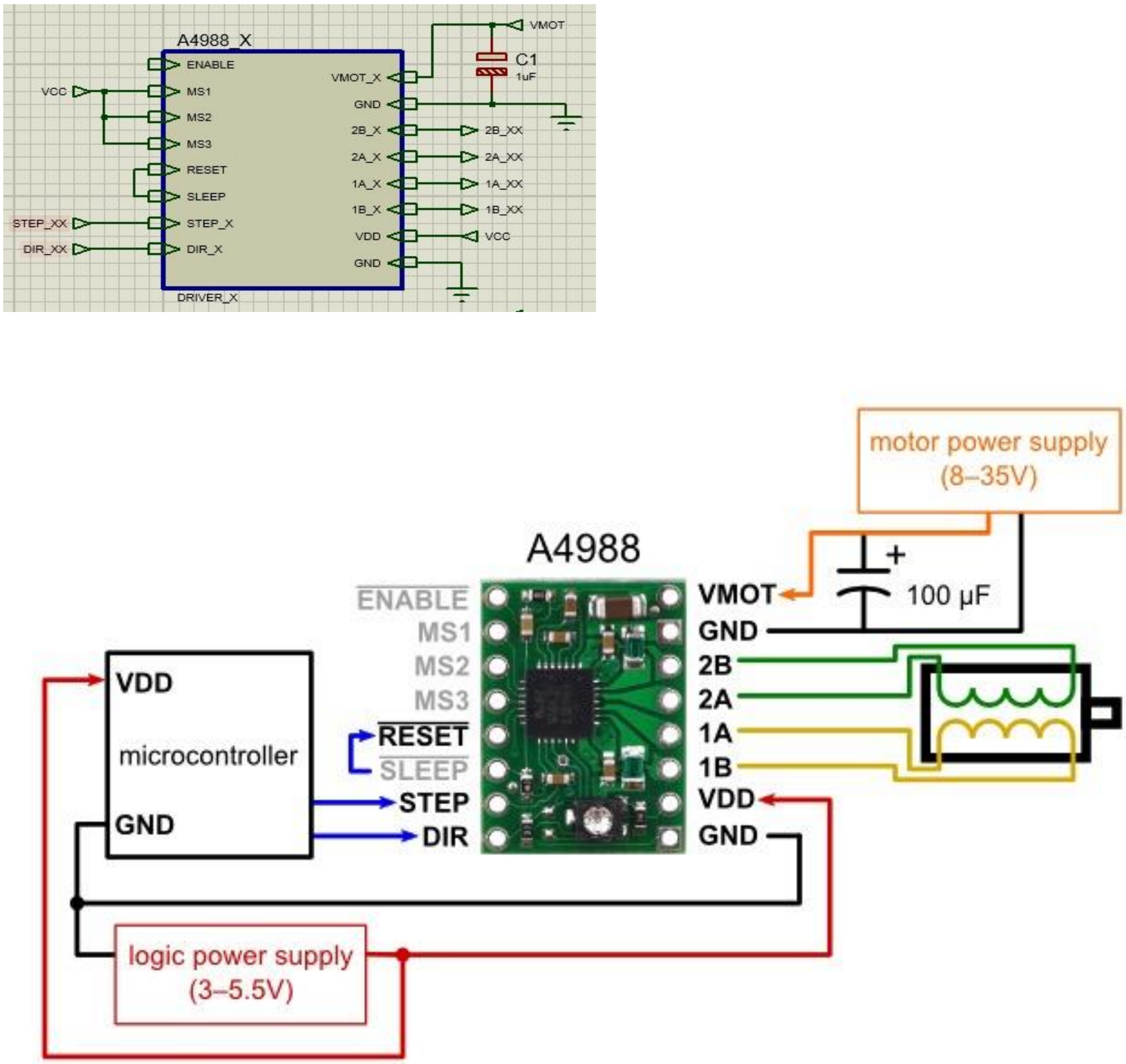


Figure 43 A4988 Driver pinout

Motor driver A4988 includes drivers L298 & L297 as an internal subsystem. So, we create a subsystem on proutes included the two drivers and the connection between them is sound in datasheet of A4988 motor drivers.

Finally, we use this subsystem as A4988 motor driver to make a control on stepper motors by using signals that coming from the controller.

4988 motor driver wiring system

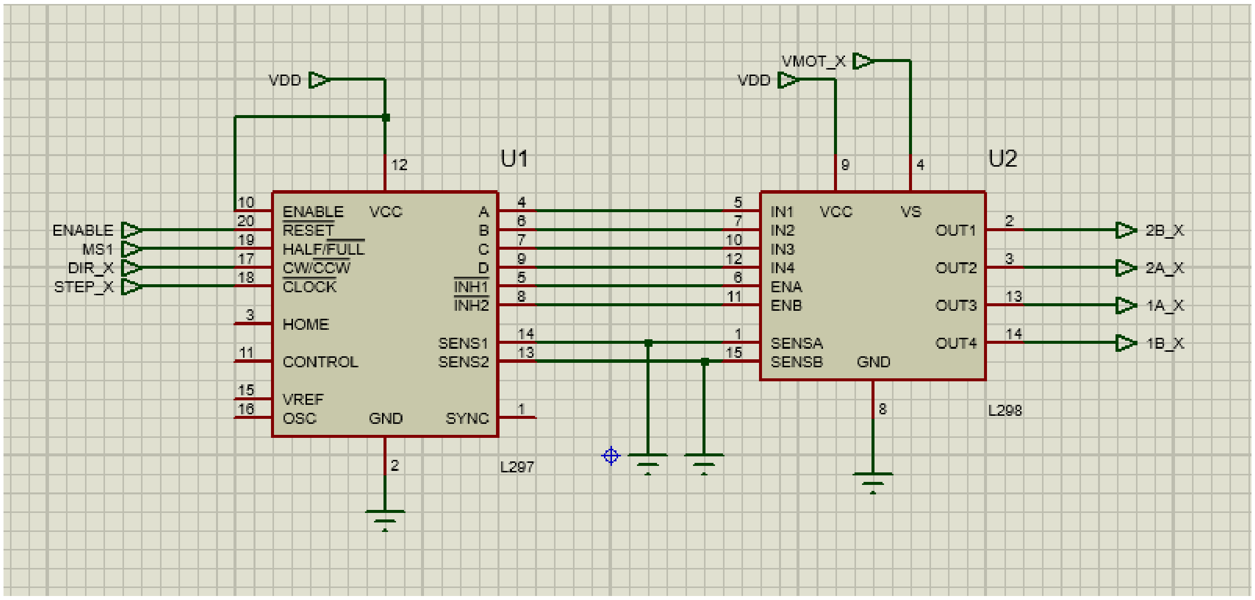


Figure 44 motor driver wiring system

3.5 Universal G-code Sender

Universal G-code Sender is a full featured gcode platform used for interfacing with advanced CNC controllers like GRBL , TinyG, g2core and Smoothieware. Universal Gcode Sender is a self-contained Java application which includes all external dependencies and can be used on most computers running Windows, MacOSX or Linux

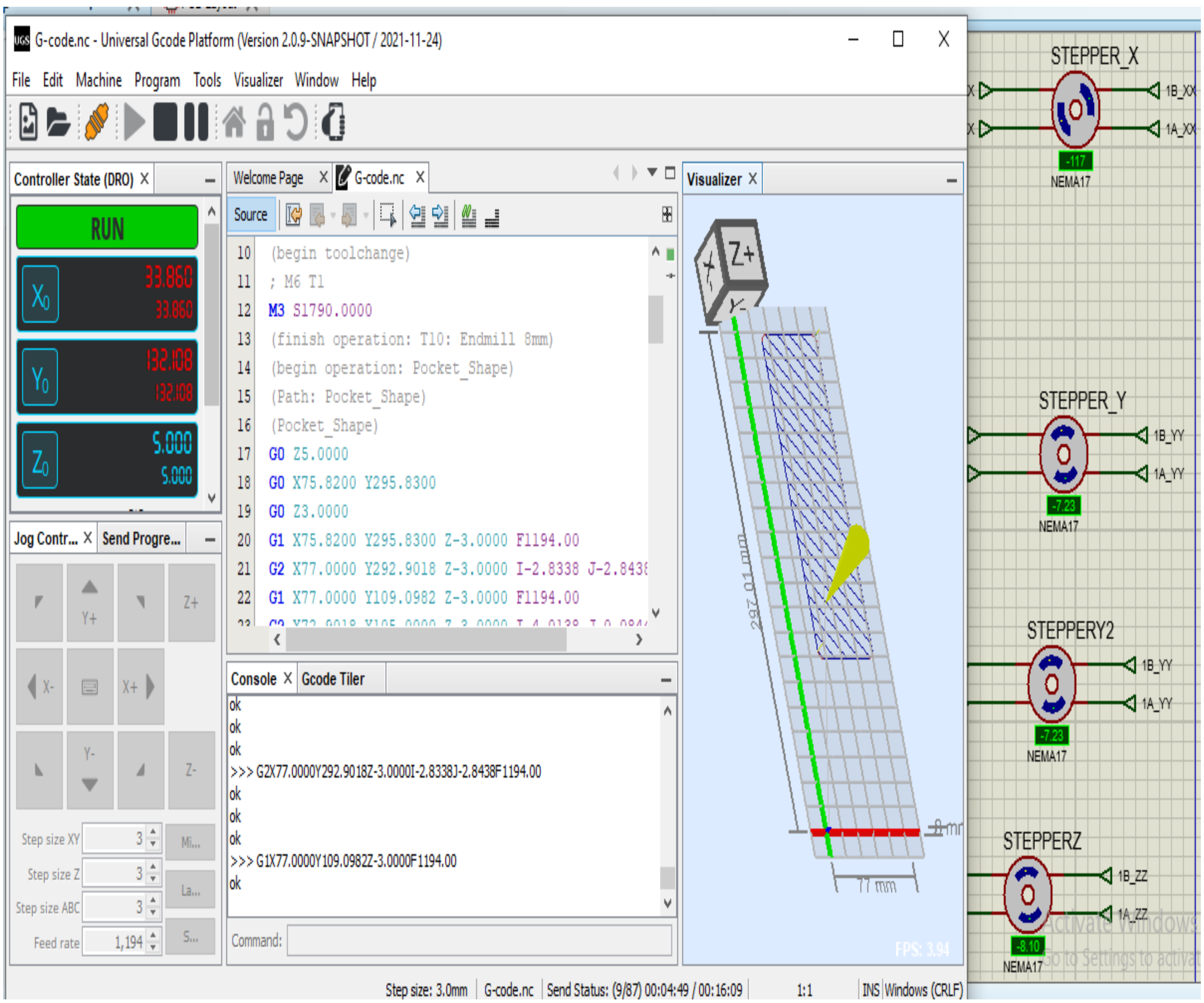


Figure 45 Universal G-code Sender

3.6 Software

The software for this project will be, GRBL is a free, open source, high performance software for controlling the motion of machines that move, that make things, or that make things move, and will run on a straight Arduino. If the maker movement was an industry, GRBL would be the industry standard.

UGS Universal G-Code Sender is a Java based; cross platform G-Code sender compatible with GRBL.

And the code will be presented on the CD.

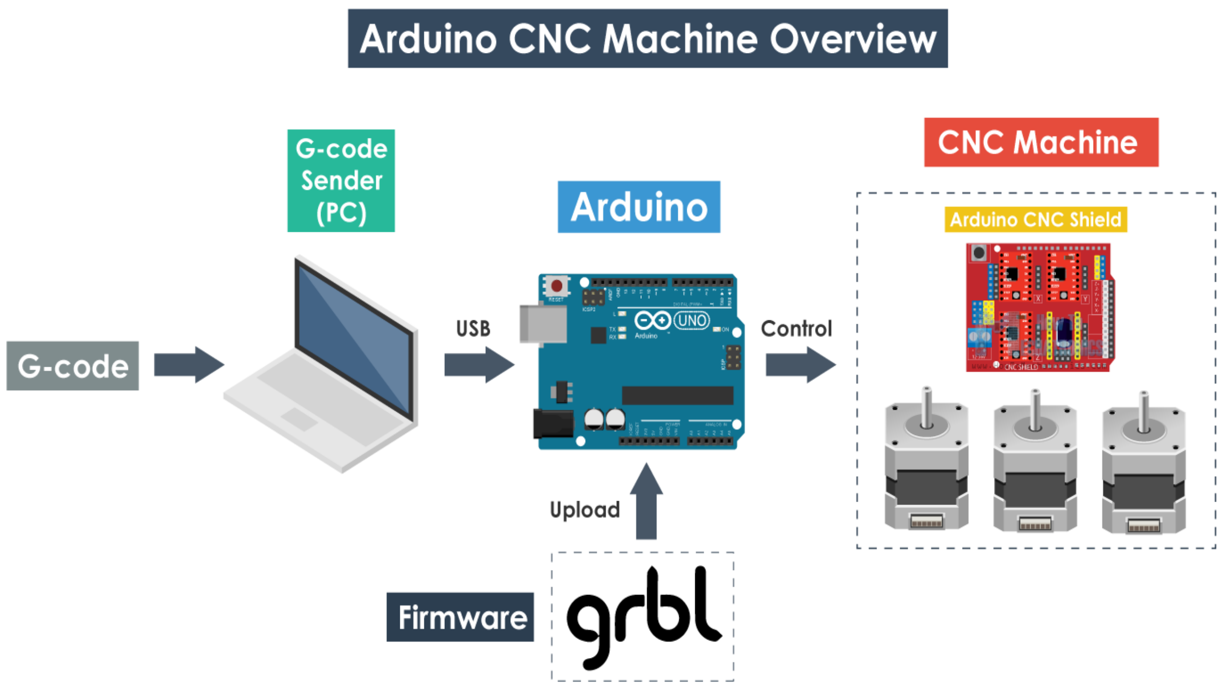


Figure 46 Arduino CNC Machine control overview

3.7 Flow charts

3.7.1 Methodology

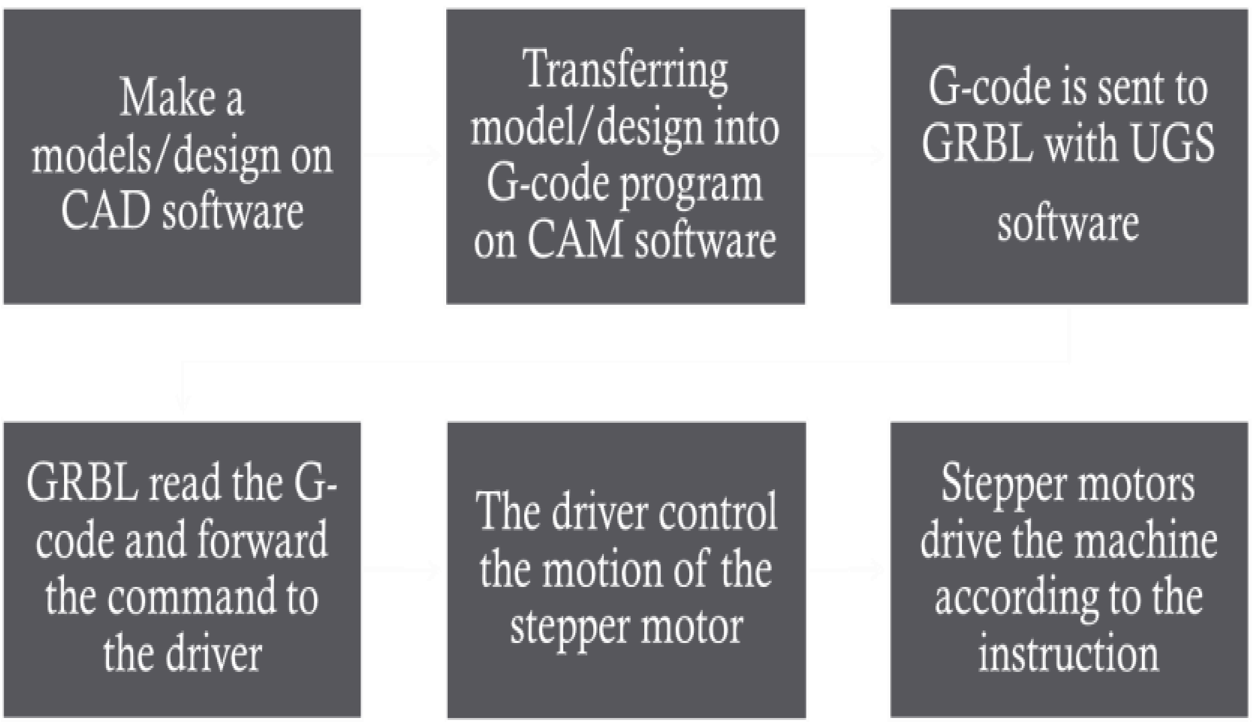


Figure 47 Design flow

3.7.2 GRBL Flow Chart

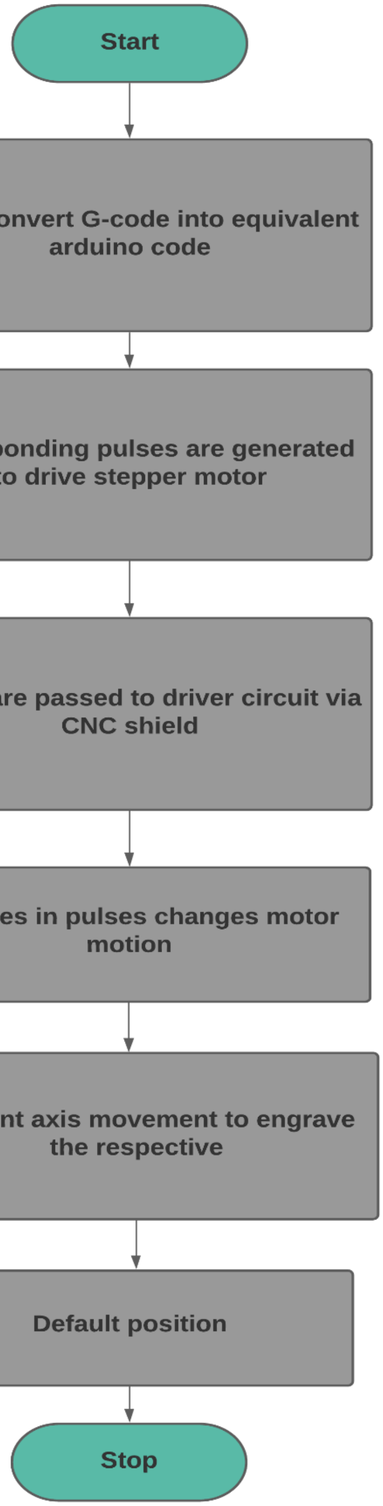


Figure 48 GRBL Flow Chart

3.8 G codes.

3.8.1 G codes Instructions.

- **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:** Feedrate Modes
- **M0, M2, M30:** Program Pause and End
- **M3, M4, M5:** Spindle Control
- **M8, M9:** Coolant Control

3.8.2 G codes (CADCAM) With using FreeCAD).

(Exported by FreeCAD)

(Post Processor: Grbl_post)

(begin preamble)

G17 G90

G21

(begin operation: T10: Endmill 8mm)

(Path: T10: Endmill 8mm)

(T10: Endmill 8mm)

(begin toolchange)

; M6 T1

M3 S1790.0000

(finish operation: T10: Endmill 8mm)

(begin operation: Pocket_Shape)

(Path: Pocket_Shape)

(Pocket_Shape)

G0 Z5.0000

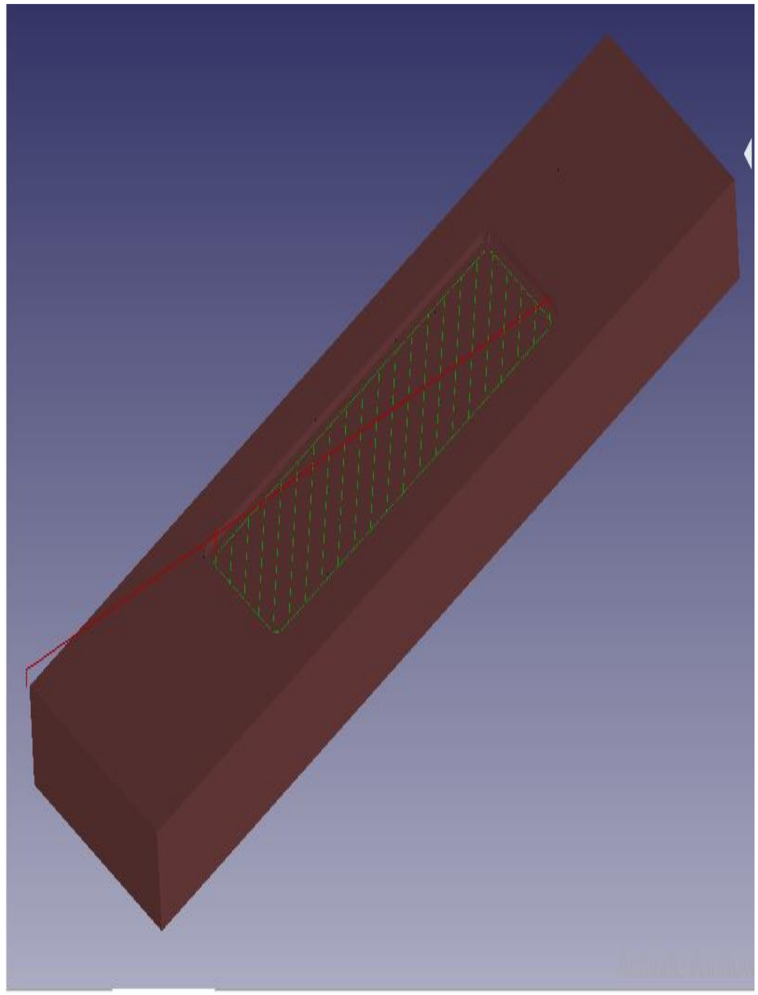


Figure 49 With using FreeCAD

G0 X75.8200 Y295.8300

G0 Z3.0000

G1 X75.8200 Y295.8300 Z-3.0000 F1194.00

G2 X77.0000 Y292.9018 Z-3.0000 I-2.8338 J-2.8438 F1194.00

G1 X77.0000 Y109.0982 Z-3.0000 F1194.00

G2 X72.9018 Y105.0000 Z-3.0000 I-4.0138 J-0.0844 F1194.00

G1 X29.0982 Y105.0000 Z-3.0000 F1194.00

```
G2 X25.0000 Y109.0982 Z-3.0000 I-0.0844 J4.0138 F1194.00
G1 X25.0000 Y292.9018 Z-3.0000 F1194.00
G2 X29.0982 Y297.0000 Z-3.0000 I4.0138 J0.0844 F1194.00
G1 X72.9018 Y297.0000 Z-3.0000 F1194.00
G2 X75.8200 Y295.8300 Z-3.0000 I0.0844 J-4.0138 F1194.00
G0 X75.8200 Y295.8300 Z5.0000
G0 X75.8250 Y295.8250 Z5.0000
G0 X75.8250 Y295.8250 Z0.0000
G1 X75.8250 Y295.8250 Z-3.0000 F1194.00
G3 X72.9018 Y297.0000 Z-3.0000 I-2.8457 J-2.8560 F1194.00
G1 X63.3363 Y297.0000 Z-3.0000 F1194.00
G1 X77.0000 Y283.3363 Z-3.0000 F1194.00
G1 X77.0000 Y272.0226 Z-3.0000 F1194.00
G1 X52.0226 Y297.0000 Z-3.0000 F1194.00
G1 X40.7089 Y297.0000 Z-3.0000 F1194.00
G1 X77.0000 Y260.7089 Z-3.0000 F1194.00
G1 X77.0000 Y249.3952 Z-3.0000 F1194.00
G1 X29.3952 Y297.0000 Z-3.0000 F1194.00
G3 X25.1769 Y294.1597 Z-3.0000 I-0.3491 J-4.0342 F1194.00
G3 X25.0000 Y292.9018 Z-3.0000 I4.1517 J-1.2251 F1194.00
G1 X25.0000 Y290.0815 Z-3.0000 F1194.00
G1 X77.0000 Y238.0815 Z-3.0000 F1194.00
G1 X77.0000 Y226.7678 Z-3.0000 F1194.00
G1 X25.0000 Y278.7678 Z-3.0000 F1194.00
G1 X25.0000 Y267.4541 Z-3.0000 F1194.00
```

```
G1 X77.0000 Y215.4541 Z-3.0000 F1194.00
G1 X77.0000 Y204.1404 Z-3.0000 F1194.00
G1 X25.0000 Y256.1404 Z-3.0000 F1194.00
G1 X25.0000 Y244.8267 Z-3.0000 F1194.00
G1 X77.0000 Y192.8267 Z-3.0000 F1194.00
G1 X77.0000 Y181.5129 Z-3.0000 F1194.00
G1 X25.0000 Y233.5129 Z-3.0000 F1194.00
G1 X25.0000 Y222.1992 Z-3.0000 F1194.00
G1 X77.0000 Y170.1992 Z-3.0000 F1194.00
G1 X77.0000 Y158.8855 Z-3.0000 F1194.00
G1 X25.0000 Y210.8855 Z-3.0000 F1194.00
G1 X25.0000 Y199.5718 Z-3.0000 F1194.00
G1 X77.0000 Y147.5718 Z-3.0000 F1194.00
G1 X77.0000 Y136.2581 Z-3.0000 F1194.00
G1 X25.0000 Y188.2581 Z-3.0000 F1194.00
G1 X25.0000 Y176.9444 Z-3.0000 F1194.00
G1 X77.0000 Y124.9444 Z-3.0000 F1194.00
G1 X77.0000 Y113.6307 Z-3.0000 F1194.00
G1 X25.0000 Y165.6307 Z-3.0000 F1194.00
G1 X25.0000 Y154.3170 Z-3.0000 F1194.00
G1 X74.1441 Y105.1729 Z-3.0000 F1194.00
G2 X72.9018 Y105.0000 Z-3.0000 I-1.2082 J4.1309 F1194.00
G1 X63.0033 Y105.0000 Z-3.0000 F1194.00
G1 X25.0000 Y143.0033 Z-3.0000 F1194.00
G1 X25.0000 Y131.6896 Z-3.0000 F1194.00
```

G1 X51.6896 Y105.0000 Z-3.0000 F1194.00

G1 X40.3759 Y105.0000 Z-3.0000 F1194.00

G1 X25.0000 Y120.3759 Z-3.0000 F1194.00

G1 X25.0000 Y109.0982 Z-3.0000 F1194.00

G1 X25.0019 Y109.0603 Z-3.0000 F1194.00

G1 X29.0603 Y105.0019 Z-3.0000 F1194.00

G2 X25.0019 Y109.0603 Z-3.0000 I-0.0523 J4.0061 F1194.00

G0 Z5.0000

(Finish operation: Pocket Shape)

(Begin postamble)

M5

G17 G90

; M2

3.8.3 Simulation G-Code With using NC Corrector

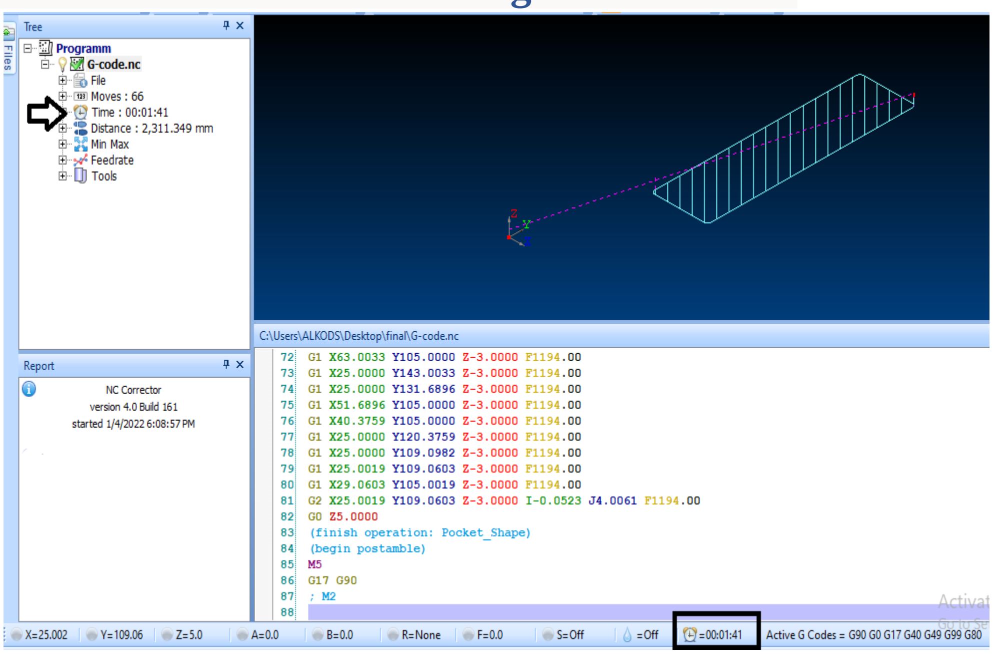


Figure 50 Simulation G-Code

Chapter 4

4 Project Execution

4.1 Time line

Table 23 Team Time line

	Task Name	Duration	Start	Finish	Accountant
	CNC Router Project	**81 days**	**Wed 10/27/21**	**Fri 2/2/22**	**Group 7**
✓	**Scope**	**6 days**	**Wed 10/27/21**	**Wed 11/3/21**	**Hassan**
✓	**introduction about project**	**6 days**	**Wed 11/3/21**	**Wed 11/10/21**	**Islam**
✓	**Design (CAD& CAM)**	**11 days**	**Wed 11/10/21**	**Wed 11/24/21**	**Farouk**
✓	**Selecting materials**	**6 days**	**Wed 11/24/21**	**Wed 12/1/21**	**Islam**
✓	**Assembly & Simulation**	**11 days**	**Wed 12/1/21**	**Wed 12/15/21**	**Farouk**
✓	**Electric circuits**	**6 days**	**Wed 12/15/21**	**Wed 12/22/21**	**Hassan**
✓	**Electric circuits Simulation**	**6 days**	**Wed 12/22/21**	**Wed 12/29/21**	**Karim**
✓	**Software & programing**	**11 days**	**Wed 12/29/21**	**Wed 1/12/22**	**Karim**
	Hard Copy	**4 days**	**Wed 1/12/22**	**Sat 1/15/22**	**Farouk Islam**
	Final discussion	**14 days**	**Sat 1/15/22**	**Wed 2/2/22**	**Group 7**

4.2 cost

Table 24 Cost

Components	Cost
Frame **PLA** **Wood** **Aluminum** **Steel**	 2000 1500 2300 3500
Motors (4 Stepper Nema 23)	1600
Drives (3 TB6600)	900
LEAD Screw + nut(4)	(1) 300 (4) 1200
Linear Guide (6)	(1) 300 (6) 1800
Spindle (15K RPM) + Clamp + Power	2100
Power Supply 24 Volt, 20 Amp	1100
Arduino uno	150
Mechanical Tooling Cutting	200
Total	9050+2000 =11050 LE

Chapter 5

5 Conclusions & References

5.1 Conclusions

In This research, Design, and fabrication of a CNC router machine for wood engraving, a medium size of router machine for wood engraving has been build. The router machines that have been build was controlled by CNC program using Mach 3 or GRBL for the software.

The mechanical systems of CNC machine build with low-budget material with a good quality. Experiment test result of the machineshown a good accuracy of the machine.

5.2 References

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Grbl codes presented in this CD