A PROJECT REPORT

ON

“DESIGN OF COST EFFECTIVE CNC USING ARDUINO UNO”

Submitted by

DIWAN ZAID M.HARIS	**15DME124**
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In partial fulfillment for the award of the Degree

Of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

UNDER THE GUIDANCE

Of

Prof. ASLAM HIRANI

DEPARTMENT OF MECHANICAL ENGINEERING

ANJUMAN-I-ISLAM’S

KALSEKAR TECHNICAL CAMPUS, NEW PANVEL,

NAVI MUMBAI – 410206

UNIVERSITY OF MUMBAI

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ANJUMAN-I-ISLAM

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(Approved by AICTE, recg. By Maharashtra Govt. DTE,

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Head of Department
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Declaration

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Abstract

CNC Technology has proven to be of great use in the sector of contemporary CNC system along with higher computational and memory storage capacity of modern computer, redefined the shop floor automation strategies. For the modern sector one of the biggest challenge today is how to make a CNC technology affordable, simpler and available to an extent that even an occasional user can think of owning such technology. Our proposed work was to achieve the objective of developing a low-cost effective CNC that can perform the basic operations.

Based on our design and requirements, standard components required for developing the low-cost machine were selected. This resulted in developing CNC control by using Arduino microcontroller. The Z-Axis motion was obtained by moving the spindle motor housing, the X axis motion was obtained by moving the table and, the Y-axis movement was achieved by the sliding of spindle housing in Y direction. Thus completing the three basic Axes of the required.

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Mb =Bending moment	n= No. Of threads
F= Cutting force	L = length
T= Torque	d= Diameter of lead screw
p= Pitch	Tau= Shear stress
Ft=Tangential force	MCU= Machine Control Unit
NC= Numerical Control	CNC= Computerized Numerical Control

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Based on our design and requirements, standard components required for developing the low-cost machine were selected. This resulted in developing CNC control by using Arduino microcontroller. The Z-Axis motion was obtained by moving the spindle motor housing, the X axis motion was obtained by moving the table and, the Y-axis movement was achieved by the sliding of spindle housing in Y direction. Thus completing the three basic Axes of the required.

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CHAPTER 01: INTRODUCTION

INTRODUCTION

1.1 BACKGROUND

Manufacturing technology and specifically machine tools are used to create the products and goods on which modern economies are based. Over time, different types of machines with different purposes were developed; in 1818, during the industrial revolution, Eli Whitney is credited with building the first milling machine. Since that time, the milling machine has been constantly improved and with the application of CNC technology; it is arguably the most versatile machine tool available today. Part of the evolution of the milling machine has been the miniaturization of the technology. The miniaturization of the CNC milling machine has reached a point where a machine can be placed on a desktop enabling low cost machines to become widely available to educators, inventors, and hobbyists. A milling machine is a type of machine tool defined by a rotating tool with cutting edges which is used to mechanically remove material, in the form of chips, from a work piece though relative motion between the rotating cutting tool and the work piece. Unlike drilling, the milling process is capable of relative motion between the rotating tool and the work piece in directions other than the axis of tool rotation. A large variety of milling machine configurations and sizes have been developed and are usually distinguished by the orientation of the cutting tool, the number of linear and/or rotational motion axes, and the working volume of the machine.

Figure 1.1 : Modern day CNC M/C

A Computer Numerical Control (CNC) machine tool is a machine tool that uses a set of instructions to automatically position the cutting tool relative to the work piece. A computer reads instructions from a data file and sends motion commands to motors, which control the position of each axis. Numerical control of a machine tool was first demonstrated at the Massachusetts Institute of Technology in 1952 and the technology first became commercially available in 1955. Since that time, numerical control technology has been continuously refined to keep pace with advances in computing technology.

Today a number of different CNC control options have become commercially available including low cost software that can turn a common PC into a multi-axis motion controller. The emergence of PC control of machine tools has enabled the development of small, lowcost, CNC machine tool products including desktop size CNC milling machines.

1.2 PROBLEM DEFINITION:

Acrylic in its various forms enters so largely into the industry of the nation that its economical and rapid conversion from forest trees into articles of general utility cannot be of paramount interest. Machining of acrylic is costly and requires a lot financial requirement.

The proposed machine aims at developing a small scale industrial CNC machine that will aim to reduce the cost of machining of acrylic. Also the aim is to reduce the overall cost of manufacturing of CNC machine so that it can be be used for empowering small scale industries. Also the overall all cost of the machine can be reduced by using ardino for interfacing of the machines with the desktop. Thus the proposed machine aims at developing a miniature model of CNC m/c that can reduce the overall all cost of machining of acrylic and various other material and develop small scale m/c that in near future help development of small scale industries or can be used for educational purpose.

1.3 SIGNIFICANCE OF THE PROBLEM:

Desktop size CNC milling machines are almost exclusively used in non-production environments such as offices, classroom, or garages. Larger and more efficient machining centers are typically used for production manufacturing. A desktop machine would likely be used for prototyping, education, or making one-off parts. Independent of the usage, lowering the cost of advanced manufacturing technologies and making those technologies available to a wider audience is significant to promoting economic growth.

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CHAPTER 02: LITERATURE REVIEW

LITERATURE REVIEW

2.1 LITERATURES

In this chapter the literature relevant to the present work has been presented. As the objective of the present work is to design a low cost CNC ENGRAVING M/C.

Detailed study from basics has been carried out and an idea for building a modular structure was developed:

Lin et.al [1] has studied effect of preloading of linear guides on dynamic characteristics of vertical column spindle system which is of importance for enhancing the structural performance of a vertical milling machine.

Lee et.al [2] observed that of the primary reasons for low productivity is large mass of the Moving parts of machine tools, which cannot afford high acceleration and deceleration, encountered during operation.

Xiangsheng et.al [3] analysed the influence of configuration parameters on dynamic characteristics on machine tools in working space, the configuration parameters have been suggested based on the orthogonal experiment method. Dynamic analysis of newly designed milling machine for producing turbine blades has been conducted by utilizing the model synthesis method.

Hung et.al [4] emphasised that prediction of machining stability is of great importance for the design of a machine tool capable of high-precision and high-speed machining. The machining performance is determined by the frequency characteristics of the machine tool structure and the dynamics of the cutting process expressed in terms of a stability lobe diagram.

Abele at [5] presented the state of the art in machine tool main spindle units with focus on motorized spindle units for high speed and high performance cutting. Detailed information is provided about main components of spindle units regarding the historical development, recent challenges and future trends.

Fenghe at [6] observed that ram is a very important component of super heavy duty computer numerical control (CNC) floor type boring-milling machine and deformation of ram is a significant source causing errors in machining process.

Namazi et.al [7] considered majority of the chatter vibrations in high-speed milling which originates due to flexible connections at the tool holder–spindle, and tool–tool holder interfaces.

Aknouche et.al [8] described some interesting results about the tool wear. In a machining process of the North African Aleppo pine, the correlation between the tool wear and cutting forces show that, the running period is about 850m of cutting length. In this period, anglevariation is unstable before it is around−1.1in the stability zone. This confirms the existenceof the first two separate areas that characterize the behaviour of the tool edge recession, which are running (abrupt wear) and the linear wear (known as stability period).

Cao et.al [9] observed that chatter stability of machine tool is dependent on the dynamic behaviour of spindle systems. The alternative method was presented to predict the chatter stability lobes of high-speed milling with consideration of speed-varying spindle dynamics. Based on the dynamic model of the high-speed spindle, systematically investigations were carried out on the speed effects. It was found that the gyroscopic moment of the spindle shaft can increase the cross FRFs, but can hardly affect the direct FRFs (frequency response function) at the tool tip due to the damping of the spindle system.

Jonsson et.al [10] highlighted that while designing CNC machine tools it is important to consider the dynamics of the control, the electrical components and the mechanical structure of the machine simultaneously. The concept includes a real control system, simulation models of the dynamics of the machine and a virtual reality model for visualisation. However, already fromthe initial simulation results presented in the paper it could be concluded that the influence ofstructural flexibility on manufacturing accuracy is of importance at desired feeding rates andaccelerations.

Zulaikaet.al [11] has presented an integrated approach for designing large milling machines, taking both mass reduction of mobile structural components and the maximum material removal rate into account.

Son et.al [12] described the development of a three-degrees-of-freedom (DOF) desktop reconfigurable machine tool. In this paper, the conceptual design of a desktop reconfigurable machine, which is capable of controlling the three DOF orientation of a spindle, was presented. Then, static and dynamic structural analyses were performed to characterize the effect of vibration on the manufacturing performance.

Dong et.al [13] discussed the development and performance evaluation of a high-speed, 3-axis milling machine using a novel parallel kinematics x-y table. The x-y table is based on an inversion of the Oldham coupling.

Padayachee et.al [14] developed reconfigurable Manufacturing System (RMS) paradigm address challenges in the design of manufacturing systems and equipment that will meet the demands of modern manufacturing.

Youssef et.al [15] stated that modularity and reconfigurability of the building blocks of modern manufacturing systems have to be considered when evaluating their performance. The paper proposed a model for evaluating system availability and expected production ratesfor manufacturing systems that were composed of unreliable modular machines with multiple functionally parallel production units.

Gallardoet.al [16] addressed the kinematics, including position, velocity and acceleration analyses, of a modular spatial hyper-redundant manipulator built with a variable number of serially connected identical mechanical modules with autonomous motions.

Eyma et.al [17] explained that the correlation between density and cutting forces in wood machining was not perfect and that some exceptions could not be explained. These difficulties have easily been explained by the anisotropy of wood material. It is appeared that mechanical properties could explain some exceptions in the relationship between density and cutting forces.

Z.M. Bi et.al [18] research presented an automated method to build kinematic and dynamic models for assembling modular components of modular robotic systems. By comparison with other approaches, the proposed method is applicable to any robotic configuration with serial, parallel, or hybrid structures.

Brisan et.al [19] reconfigurable robotic system permits multiple configurations having different characteristics, using mostly modularized building blocks. The goal of paper is to investigate how the shape, dimensions and the distribution of singularities in the workspace for different configurations, with different degrees of freedom, of a reconfigurable robotic system, are changed.

Neugebauer et.al [20] reviewed current developments in mechatronic systems for metal cutting and forming machine tools. The integration of mechatronic modules to the machine tool and their interaction with manufacturing processes were presented. Sample mechatronic components for precision positioning and compensation of static, dynamic and thermal errors were presented as examples. The effect of modular integration of mechatronic system on the reconfigurability and reliability of the machine tools was discussed along with intervention strategies during machine tool operation.

Wakasawa et.al [21] after research elaborated that main factors generating the damping capacity in machine structure by packed balls are the collision and friction among the packed balls and between the packed balls and the inner surface of the square section of the rail. These square sections can be installed anywhere on the machine particularly where do damp the vibrations, where it is needed that the vibrations should not be travelled further.

Hung et.al [22] predicted after observing machining stability is of great importance for the design of a machine tool capable of high-precision and high-speed machining. The machining performance is determined by the frequency characteristics of the machine tool structure andthe dynamics of the cutting process, and could be expressed in terms of a stability lobe diagram.

2.2 HISTORY OF CARVING MACHINERY

Figure 2.1: Engraved Work piece from Modern CNC

Acrylic in its various forms enters so largely into the industry of the nation that its economical and rapid conversion from forest trees into articles of general utility cannot be of paramount interest. Occasional efforts were made to perform the work mechanically, but not until the end of the eighteenth century were any definite and practical ideas described.

Sir Samuel Bentham, an Englishman, patented in 1791 and 1793 principles which are in use today. His inventions included "planning machines with rotary cutters to cut on several sides of the wood at once veneer cutting machines, moulding and recessing machines, bevel sawing machines, saw sharpening machine, tendon cutting machine by means of circular saws, boring tools".

2.3 AUTOMATION OF CUTTING OPERATIONS

The need for new technology to control machine movement was felt somewhat around 1940to meet the challenges in the production of aerospace components. The major contribution tothis development was made by persons who developed a technique to machine accuratetemplates to develop helicopter blades. This involved calculation of few hundred points on acurve and drilling them in precision mill. The successive settings of the tools were determined using the IBM purchased card reader; the US air force was the funding agency for the NC development. The Servo mechanisms laboratory of MIT developed the first NC machine in 1952.

The development of NC technology can be categorised into various generations as listed below:

1.First Generation: The control system of the first generation numerically controlledMachines was built with vacuum tubes and associated devices. This was bulky, consumes a lot of power, while reliability and the storage capacity was poor.

Figure 2.2: Earlier Development of CNC.

2.Second Generation: The advent of PCB in to the field of electronics impacted to reducethe size of the controller for the NC machine. These machines were built with transistors. However, the number of printed circuit boards (PCB) was large. Since there werethousands of components and connections involved, the reliability again was not so satisfactory.

Figure 2.3: Development in the field of CNC.

3.Third generation: During mid-60s, the concept of Integrated Circuit (IC) revolutionised the electronics world further. Thyristor Controlled DC drive became popular during this period. With the integration of NC machine tools helped in flexibility. From the totally hard wired design, the design of NC machine become soft wired. The other development was the concept of evolution of direct numerical control technique by which several NC machines could be controlled by a single host computer.

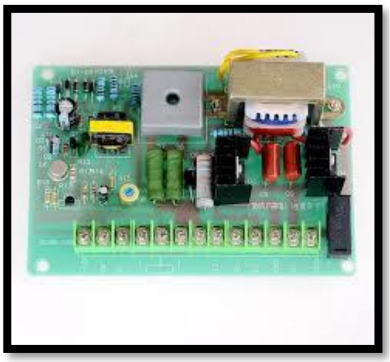


Figure 2.4: Thyristor Controlled DC drive

4.Fourth generation: Towards the end of 1970, microprocessors came to use as a CPU ofthe computers. This change also impacted in the design of NC machine tools. Initially 8 or16 bit microprocessors were used. Later control systems with several processors were introduced. The reliability of the system was improved. Today many CNC systems are based on 32 bit as well as 64 bit microprocessors.

2.4 MAIN COMPONENTS IN CNC MACHINING CENTRE

The figure shows the schematic diagram depicting the overall organization of CNC system.

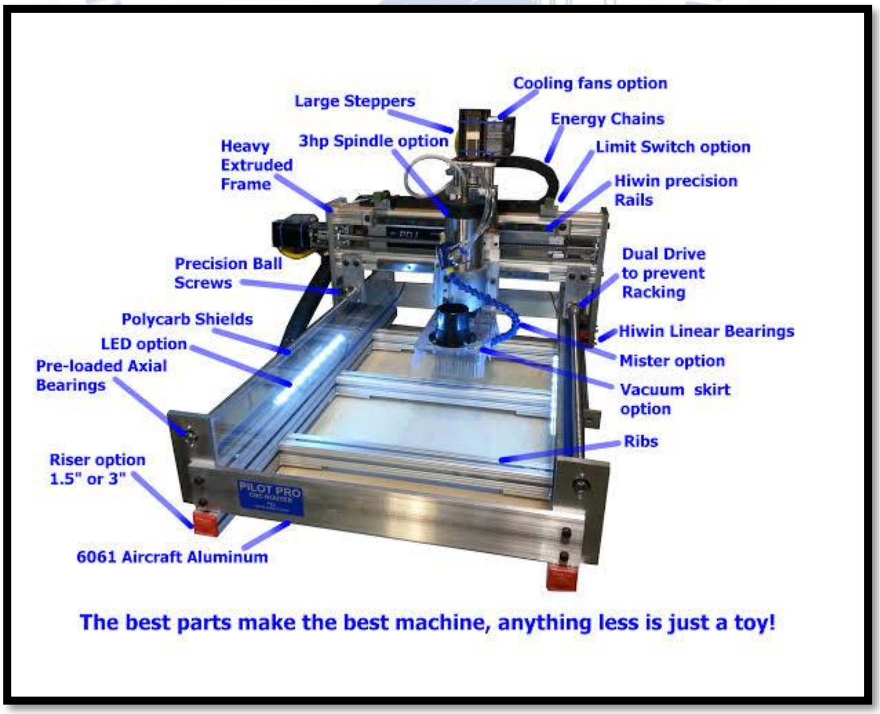


Figure 2.5: Labelled Diagram of CNC

The main components for a CNC system are listed below:

1. NC Part Program
2. Machine structure, which is composed of:

    a) Machine bed and columns

    b) Drive unit

    c) Spindle/Router

    d) Guide ways and Sideways, which are further build on:

        i. Linear Motion ways

        ii. Ball Screw

3. Machine control unit (MCU)

4. Tooling

In the following sections, the above listed main components of CNC are discussed in detail:

2.4.1 NC PART PROGRAM

In NC Machining centre controlling instructions are fed through a program to the machine. Such program is called Part Program. A part program is detailed set of sequential instructions defined to prescribe the relative movement between tool and work piece and hence complete the machining of the parts. Those set of instructions also control several other functions like spindle speed and feed selection, selection and controlling the tool and coolant etc. A part program is generated using geometric parameters of the part model.

2.4.2 MACHINE STRUCTURE

Machines structure constitutes the load carrying and supporting member of the CNC machine. All the motors driver mechanisms and the other functional assemblies of machine tools are aligned to each other and rigidly fixed to the machine structure. The machine structure is subjected to static and dynamic forces and it is therefore essential that the structure does not vibrate beyond the limits under the action of these forces. The machine structure component is also influenced by the consideration of manufacture, assembly and operation. The basic design involved in the design of machine structure is discussed below:

1. Static load: The static load of a machine tool results from the weights of the slide and thework piece and the forces due to cutting. To keep the deformation of the structure due to static loading within permissible limits the structure should have adequate stiffness and proper structural configuration.

2. Dynamic loads: Dynamic load is a term used for the constantly changing factors acting on the structure while movement is taking place. These forces cause the whole machine to vibrate. The origin of such vibration is:

(a) Unbalanced rotating part
(b) Improper meshing of gears
(c) Bearing irregularities
(d) Interrupted cuts while machining

The effects of these vibrations can be reduced by following measures:

(a) Reducing the mass of the structure

(b) Increase the stiffness of the structure

(c) Improving the damping properties of structure

2.4.3 BEDS AND COLUMNS

The way machining forces are directed into the bed of the machine can have considerable influence on accuracy. Cutting forces are transmitted in a loop from the spindle when the operation on the work-piece is being done and then to the bed and back towards the spindle. Its necessary to minimize the length of force loop. This results in rigidity and accuracy Without excessive dead weight. A major advantage is the reduced need for setting up work pieces in special jigs and fixtures thus reducing overall production time.

2.4.4 DRIVE UNIT

Mainly three types of drive technologies are used in modern CNC system, which are:

a) Stepper drives
b) D.C. servo drives
c) A.C. drives

Stepping motor would appear to be particularly well suited to small NC machine tools, havinglow feed rates of the range of 300 mm/ min because they are able to directly convert digitalpath data into actual mechanical displacement of axes. They need no analog intermediate equipment no feedback from techno-generators, and no path measuring systems.

Additionally, they require practically no maintenance as these motors are fully enclosed, also these drives are relatively economical.

Figure 2.6: Stepper Motors, Servomotors and Drivers used for Driving the M/c

1. Stepping frequencies and consequently possible feed rates are too low.

2. Maximum available torques are relatively low, that is acceleration characteristics are poor

3. Even short term overload can cause “dropping out of step”.

4. Resolution is insufficient so that even at a resolution of 0.004 inches per step the rapidtraverse speeds achievable are too low.

Today, modern NC machine tools have servomotor drivers fitted as standard equipment, and they provide infinitely variable feed and speed rates both the machine axes and the main spindle. Usually such a servo drive comprises of the following components:

1. Motor with tachometer and brake

2. Control unit with power amplifier-for spindle drives with integrated field controller

3. Main transformer and smoothing choke

4. Mechanical clutch, with overload protection

5. Motor protection unit guarding against current overload or excess temperature

For spindle drivers a gearbox with fixed or variable gearing to achieve fine adjustment of the motor speed in order to move should match speed and torque requirements at the spindle. It is the task of the feed drive to accurately position each individual axis of a machine tool and to precisely control all movements so that work piece with specified tolerance can be machined. The required accuracy require demands a strict adherence to the NC programmed position. With the simultaneous motion control of several axes the relative motion between the cutting tool and work piece create three dimensional motion. So, dynamic behaviour is the main criterion for the selection of a drive. All programmed movements must be executed with the minimum possible declaration or overshoot, independent of other factors such as cutting power fluctuations or varying frictional losses. So, feed motion of axis of an NC machine tool have to be very precise, with as little deceleration and high repeatability as possible, in order to fulfil the accuracy requirements demanded. All motions must be independent of any counteraction forces much as those resulting for cutting or inertia. Positioning speed should be as fast as possible to avoid any lags in any programmed parameters. Developments over the past few years in drive technologies have made it possible to meet all the requirements of drive counts. Another important characteristic is uniformity and smoothness of motion jumps of oscillation being totally unacceptable. Even the slightestbuzzing noise or any resonance ofthe motor will impair the surface finished of the machined work piece to a point where it may be rejected. To meet these requirements high speed / high rpm and low torque routers are preferred instead of high torque motors of spindle drive. General speed of spindle drive is from 25000 r.p.m to 33000 r.p.m.

2.4.5 SPINDLE/ ROUTER

For cutting, caving, milling and drilling on a work-piece in a machine tool various other operations spindles are used. For wooden carving machines spindle should have high rpm and low torque and special tools so that the wooden surface doesn't burn and give a smooth finish. Ordinary machine tool cannot achieve such high rpm which are in range of 25000 to 33000 rpm. So, special routers are used instead of ordinary spindles for wood machining.

The general requirements of spindles for CNC machine are:

1. High stiffness both static and dynamic
2. Running accuracy
3. Axial load carrying capacity
4. Thermal stability
5. Axial freedom for thermal expansion
6. High speeds of operations

Special requirement for ACRYLIC Carving Machines

1. Low reaction from components.
2. Friction should not cause over heating of metallic cutting tool. That is why wood cutting is done at high speed and low feed.

2.4.6 GUIDEWAYS AND SLIDEWAYS

Figure 2.7: Guideways and Its Mechanism

Guide ways are used in machine tools to:

1. Control the direction or line of action of the carriage or the table on which a tool or a work piece is held.

2. To absorb all the static and dynamic forces.

The shape and size of work produced on a CNC machine tool depends on the accuracy of themovement and on the geometric and kinematic accuracy of the guideways. The geometric relationship of the slide and the guide way to the machine base determines the geometric accuracy of the machine. Kinematic accuracy depends on the straightness, flatness ofguideway. These errors further result in variety of tracking errors like pitch, yaw and the rollthat are difficult to measure and correct. Further, over a period of usage, any kind of wear inthe guideway reduces the accuracy of the guide motion, resulting in errors in movement andpositioning.

The following points must be considered while designing guideways:

1. Rigidity

2. Damping capabilities

3. Geometric and kinematic accuracy

4. Velocity of slide

5. Friction characteristics

6. Wear resistance

7. Provision for adjustment of play

8. Position in relation to work area

9. Protection against fine chips and damage

These criteria vary depending upon a particular application and hence the selection ofguideway and their geometry can be quite critical in some cases. This will ensure uniformwear on guideways.

Guideways are primarily of two types:

(a) Friction guideways.

(b) Antifriction linear motion guideway.

Frictional guideways are not used in CNC machines as they are most widely applied inconventional machine tools due to their low manufacturing cost and good damping properties. These guideways operate under condition of friction. It acts under stick-slip phenomenon toreduce the possibility of stick slip there should be a minimum but constant friction betweenthe surfaces in contact.

Antifriction linear motion guideways are used in CNC machines where friction plays a vital role in the movement of the parts. Generally, the coefficients of friction in the components ofCNC machine are very less.

The guideways of CNC machines are composed of following parts:

(i) Linear Motion ways: Linear motion guideways are used in CNC machines which in turnuse rolling elements in between moving and the stationary elements of the machines. They are used to overcome the relatively high coefficient of friction in metal to metal contacts and resulting in limiting the amount of wear, heat generation and improve the smoothness. Linear motion guideways have become very common in machine tools on account of theirhigher rapid transverse rates

ii) Ball Screw: Ball screws are primarily employed in feed mechanisms of CNC machinetools. When compared with conventional trapezoidal and ACME threads, ball screwsprovide many advantages, which are listed below:

• In a ball screw, the load between the threads of the screws is not transmitted by directcontact, but though immediate rolling members. The balls rotate between the helicalgrooves of the screws and nut in a manner similar to their function in ball bearings. Anessential feature of almost all balls.

• Low coefficient of friction is of the order of 0.004 as compared to 0.1 to 0.5 which istypical of sliding friction power screws. Wear is therefore less and there is very little needof frequent adjustment.

• High transmission efficiency is there which is particularly marked at low values of helixangle of screw (2-5) degree that are typical of power screws This high efficiency allows larger thrust load to be carried with less torque.

• Frictional forces are virtually independent of the travel velocity and the friction at rest is very small consequently, the stick up phenomenon is absent ensuring uniformity of motion.

Uses of Reticulating Ball Screw Ball Screw

1. ACME Screw

2. Fluid Power

3. Belt, Chain

4. Rack and Pinion

5. Cam Follower

Pneumatic Cylinders Inexpensive Low Power Use Low Maintenance High Accuracy High Repeatability High Efficiency High Load Capacity Compact Size. The basic of ball screw is to interpose a series of the balls between the screw and the nut. These balls roll in the grooves as the nut or screw moves and the rolling friction thus replaces the sliding friction of the conventional acme or trapezoidal screws. The balls rolling in the grooves exit from the trailing end of the nut and are picked up by the return tube inserted from outside and are re circulated into the leading end of the nut. There are also systems in which the rolling balls circulate within the nuts. The ball screws can have circular or gothic arch grooves. Gothic arch grooves have a small axial clearance when they are used in single nut, while circular arch grooves allow little axial deformation and a greater load capacity. The greater the number of balls in a circulating system, the greater is the frictional resistance. Therefore, use of an excessive number of balls is not recommended from designing point of view.

2.4.7 MACHINE CONTROL UNIT

The main function of the CNC system is to convert the part program instructions into motion of operative units of the machine tool through CPU and servo-control system. The system interprets this data and converts it into output signals. It is based on the use of numerical data for directly controlling the operative units of machine tool during a machining operation CPU decodes the part program instructions into position and velocity signals and feeds these signals to the servo-control unit which further generate suitable signals as command signals. The command values are converted into actual movement of operative units; by the servo-drive unit. The amount and rate of movement are controlled by CNC system depending upon the type of feedback system whether it is a closed loop or open loop. Position feedback signals are generated by the feedback devices like linear scales, rotary encoders and velocity signals are obtained by tacho-generators

2.4.8 TOOLING AND ACCESSORIES

A touch trigger is the most valuable accessory which can be mounted in standard tool holders and loaded into the spindle via the automatic tool changer (ATC) to send information to the Numerical controllers about the real condition of the work pieces. They require special Software in the numerical controller to interpret these findings. Different tools are mounted on ATC according to their need in machining.

CHAPTER 03: CALCULATIONS OF THE PROJECT

CALCULATIONS OF THE PROJECT

3.1 GENERAL CALCULATIONS:

3.1.1 FOR WOOD:

Figure 3.1: Wood used for Base

Size of wooden bed= 350×350×12 mm

3.1.2 FOR ACRYLIC

Figure 3.2: Acrylic used for the Project.

Yield strength of acrylic= 10.889 Mpa

Tensile stress(σ_t)=$\frac{\sigma yt}{FOS}$=$\frac{10.889}{2}$ = 5.44 Mpa

Shear stress(τ)= 0.5×σ_t=0.5×5.44= 2.72 Mpa

Bending stress(σ_b) =1.5×σ_t=1.5×5.44= 8.16 Mpa

3.2 CALCULATIONS FOR LEAD SCREW:

3.2.1 CALCULATION OF LEAD SCREW IN X DIRECTION

WEIGHT:

W of wood=2 kg,

W of fixtures=0.5 kg,

Total W=2.5 kg

BENDING MOMENT:

$$M_b= \frac{WL}{4} \text{ (for SSB)}$$

$$M_b = \frac{\pi}{32} \times \sigma_b \times d^3$$

THREADS IN CONTACT:

$$\tau = \frac{F}{\Pi \times d \times n \times p}$$

CUTTING FORCE:

$$F = 2 \times \tau \times \text{dept of cut} \times \text{dia of cutting tool}$$

TORQUE:

$$T = F_t \times \text{radius of cutting tool}$$

FINAL DIMENSIONS:

M_b=5.625 Nm

F=98.01N

T=0.369 Nm ≤ 1.9 Nm

Depth of cut=3mm

Pitch =F_t=123.01N

d =7.082 mm

N=0.03627

L=0.9m

Dia. of cutting tool=6mm

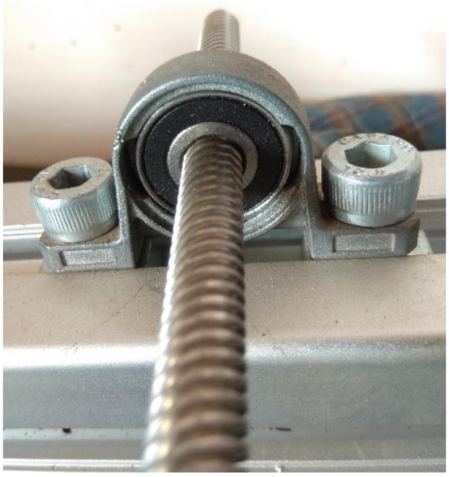


Figure 3.3: X Axis lead screw of the machine

3.2.2 CALCULATION OF LEAD SCREW IN Y DIRECTION:

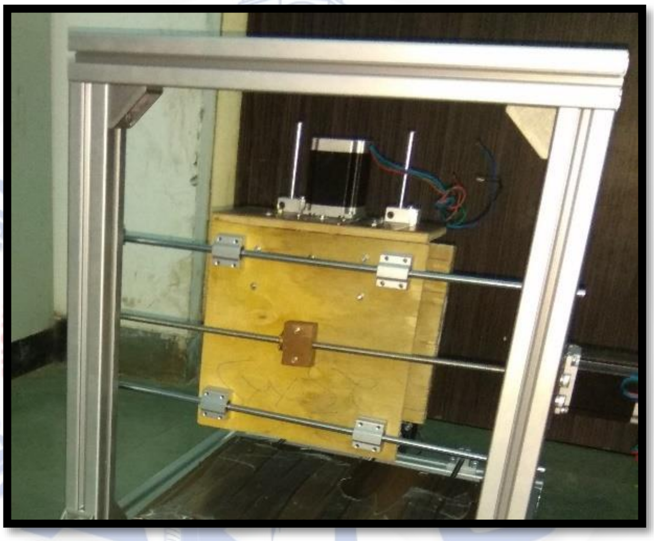


Figure 3.4: Y Axis lead screw of the machine

WEIGHT:

W of motor=1.2kg, W of servo=2kg, W of wood=2kg,

W of other supports= 2kg, Total weight= 7.2 kg

BENDING MOMENT:

$$M_b = \frac{WL}{4} \text{ (for SSB)}$$

$$M_b = \frac{\pi}{32} \times \sigma_b \times d^3$$

THREADS IN CONTACT:

$$\tau = \frac{F}{\Pi \times d \times n \times p}$$

CUTTING FORCE:

$$F = 2 \times \tau \times \text{dept of cut} \times \text{dia of cutting tool}$$

TORQUE:

$$T = F_t \times \text{radius of cutting tool}$$

FINAL DIMENSIONS:

M_b=9Nm	d =8.2 mm
F=98.01N	n =0.03627
T=0.369Nm ≤1.9Nm	L=0.5m
Depth of cut=3mm	Dia. of cutting tool=6mm
Pitch =2mm	F_t=123.01N

3.3.3 CALCULATION OF LEAD SCREW IN Z DIRECTION:

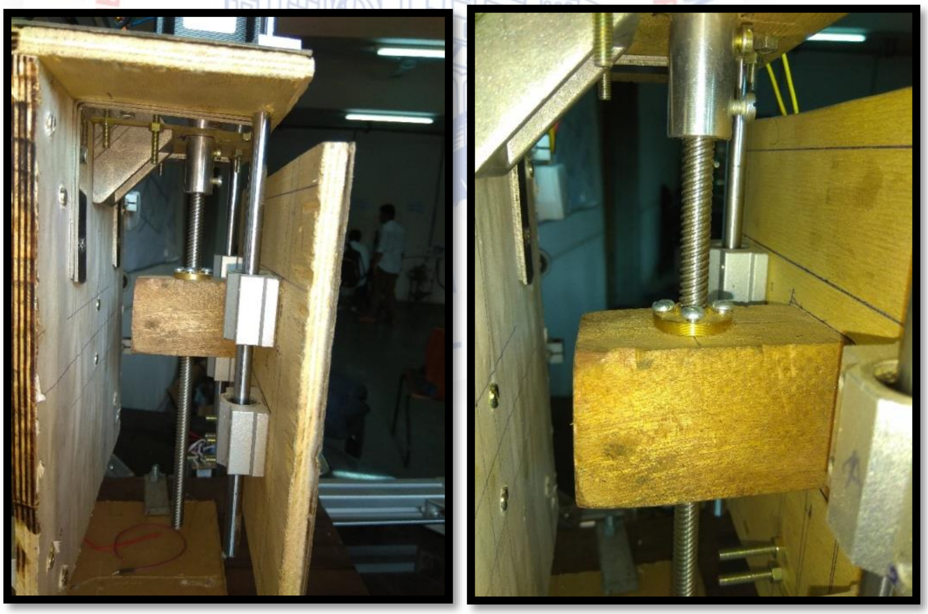


Figure 3.5: Z Axis lead screw of the machine

WEIGHT:

W of assembly=1kg,	W of servomotor=2kg,
W (to overcome chatter vibrations) = 0.5kg,	Total W=3.5kg

THREADS IN CONTACT:

$$\tau = \frac{F}{\Pi \times d \times n \times p}$$

CUTTING FORCE:

$$F = 2 \times \tau \times \text{dept of cut} \times \text{dia of cutting tool}$$

TORQUE:

$$T = F_t \times \text{radius of cutting tool}$$

TENSILE FAILURE:

$$\sigma_t = \frac{F}{\frac{\pi}{4} \times d^2}$$

FINAL DIMENSIONS:

W=F= 3.5kg= 35N

d =0.103 mm (shear criteria)

n=0.04

L=0.3

Depth of cut=3mm

Dia. of cutting tool=6mm

Pitch = 2mm

F_t=133.01N

d =0.64 mm

CHAPTER 04: MARKET SURVEY AND SELECTION OF STANDARD COMPONENT.

MARKET SURVEY AND SELECTION OF STANDARD COMPONENTS

The standard components that were selected were as follows and will be explained in detail.

4.1 STEPPER MOTOR

A **stepper motor** or **step motor** or **stepping motor** is a brushless DC electric motor that divides a full rotation into a number of equal steps. The motor's position can then be commanded to move and hold at one of these steps without any position sensor for feedback (an open-loop controller), as long as the motor is carefully sized to the application in respect to torque and speed.

Switched reluctance motors are very large stepping motors with a reduced pole count, and generally are closed-loop commutated.

Figure 4.1: Disassemble view of Stepper Motors

Brushed DC motors rotate continuously when DC voltage is applied to their terminals. The stepper motor is known by its property to convert a train of input pulses (typically square wave pulses) into a precisely defined increment in the shaft position. Each pulse moves the shaft through a fixed angle.

Stepper motors effectively have multiple "toothed" electromagnets arranged around a central gear-shaped piece of iron. The electromagnets are energized by an external driver circuit or a micro controller. To make the motor shaft turn, first, one electromagnet is given power, which magnetically attracts the gear's teeth. When the gear's teeth are aligned to the first electromagnet, they are slightly offset from the next electromagnet. This means that when the next electromagnet is turned on and the first is turned off, the gear rotates slightly to align with the next one. From there the process is repeated. Each of those rotations is called a "step", with an integer number of steps making a full rotation. In that way, the motor can be turned by a precise angle.

The circular arrangement of electromagnets is divided into groups, each group called a phase, and there is an equal number of electromagnets per group. The number of groups is chosen by the designer of the stepper motor. The electromagnets of each group are interleaved with the electromagnets of other groups to form a uniform pattern of arrangement. For example, if the stepper motor has two groups identified as A or B, and ten electromagnets in total, then the grouping pattern would be ABABABABAB.

Electromagnets within the same group are all energized together. Because of this, stepper motors with more phases typically have more wires (or leads) to control the motor.

There are three main types of stepper motors:

1. Permanent magnet stepper
2. Hybrid synchronous stepper
3. Variable reluctance stepper

There are two basic winding arrangements for theelectromagnrtic coils in a two phase stepper motor: bipolar and unipolar.

Unipolar motors

A unipolar stepper motor has one winding with center tap per phase. Each section of windings is switched on for each direction of magnetic field. Since in this arrangement a magnetic pole can be reversed without switching the direction of current, the commutation circuit can be made very simple (e.g., a single transistor) for each winding. Typically, given a phase, the center tap of each winding is made common: giving three leads per phase and six leads for a typical two phase motor. Often, these two phase commons are internally joined, so the motor has only five leads.

A micro controller or stepper motor controller can be used to activate the drive transistors in the right order, and this ease of operation makes unipolar motors popular with hobbyists; they are probably the cheapest way to get precise angular movements.

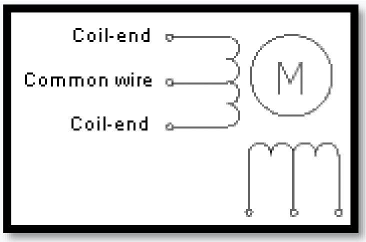


Figure 4.2: Circuit Diagram of Unipolar Motor

For the experimenter, the windings can be identified by touching the terminal wires together in PM motors. If the terminals of a coil are connected, the shaft becomes harder to turn. One way to distinguish the center tap (common wire) from a coil-end wire is by measuring the resistance. Resistance between common wire and coil-end wire is always half of the resistance between coil-end wires. This is because there is twice the length of coil between the ends and only half from center (common wire) to the end. A quick way to determine if the stepper motor is working is to short circuit every two pairs and try turning the shaft. Whenever a higher than normal resistance is felt, it indicates that the circuit to the particular winding is closed and that the phase is working.

Bipolar motors

Bipolar motors have a single winding per phase. The current in a winding needs to be reversed in order to reverse a magnetic pole, so the driving circuit must be more complicated, typically with an H-bridge arrangement (however there are several off-the-shelf driver chips available to make this a simple affair). There are two leads per phase, none are common.
Static friction effects using an H-bridge have been observed with certain drive topologies.
Dithering the stepper signal at a higher frequency than the motor can respond to will reduce this "static friction" effect.

Because windings are better utilized, they are more powerful than a unipolar motor of the same weight. This is due to the physical space occupied by the windings. A unipolar motor has twice the amount of wire in the same space, but only half used at any point in time, hence is 50% efficient (or approximately 70% of the torque output available). Though a bipolar stepper motor is more complicated to drive, the abundance of driver chips means this is much less difficult to achieve.

An 8-lead stepper is wound like a unipolar stepper, but the leads are not joined to common internally to the motor. This kind of motor can be wired in several configurations:

- Unipolar.
- Bipolar with series windings. This gives higher inductance but lower current per winding.
- Bipolar with parallel windings. This requires higher current but can perform better as the winding inductance is reduced.
- Bipolar with a single winding per phase. This method will run the motor on only half the available windings, which will reduce the available low speed torque but require less current.

4.1.1 STEPPER MOTOR DRIVER CIRCUITS

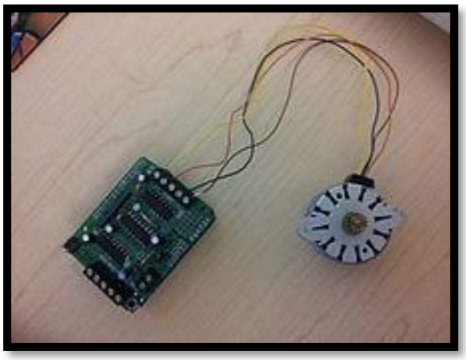


Figure 4.3: Stepper Motors and its Driver

Stepper motor performance is strongly dependent on the driver circuit. Torque curves may be extended to greater speeds if the stator poles can be reversed more quickly, the limiting factor being a combination of the winding inductance. To overcome the inductance and switch the windings quickly, one must increase the drive voltage. This leads further to the necessity of limiting the current that these high voltages may otherwise induce.

An additional limitation, often comparable to the effects of inductance, is the back-EMF of the motor. As the motor's rotor turns, a sinusoidal voltage is generated proportional to the speed (step rate). This AC voltage is subtracted from the voltage waveform available to induce a change in the current.

4.1.2 STEPPER MOTOR AND ITS RATING AND SPECIFICATION

Stepper motors' nameplates typically give only the winding current and occasionally the voltage and winding resistance. The rated voltage will produce the rated winding current at

DC: but this is mostly a meaningless rating, as all modern drivers are current limiting and the drive voltages greatly exceed the motor rated voltage.

Steppers should be sized according to published torque curve, which is specified by the manufacturer at particular drive voltages or using their own drive circuitry. Dips in the torque curve suggest possible resonances, whose impact on the application should be understood by designers.

Step motors adapted to harsh environments are often referred to as IP65 rated.

The US National Electrical Manufacturers Association (NEMA) standardises various aspects of stepper motors. They are typically referred with NEMA DD, where DD is the diameter of the faceplate in inches × 10 (e.g., NEMA 17 has diameter of 1.7 inches). There are further specifiers to describe stepper motors, and such details may be found in the ICS 16-2001 standard.

4.1.3 APPLICATIONS OF STEPPER MOTOR:

Computer controlled stepper motors are a type of motion-control positioning system. They are typically digitally controlled as part of an open loop system for use in holding or positioning applications.

In the field of lasers and optics they are frequently used in precision positioning equipment such as linear actuators, linear stages, rotation stages, goniometers, and mirror mounts. Other uses are in packaging machinery, and positioning of valve pilot stages for fluid control systems.

Commercially, stepper motors are used in floppy disk drives, flatbed scanners, computer printers, plotters, slot machines, image scanners, disc drives, intelligent lighting, camera lenses, CNC machines and, more recently, in 3D printers

From the calculation done in chapter 3, **we have selected NEMA 23 having diameter of 6mm.**

4.2 SERVO MOTOR

A **servomotor** is a rotary actuator or linear actuator that allows for precise control of angular or linear position, velocity and acceleration.[1] It consists of a suitable motor coupled to a sensor for position feedback. It also requires a relatively sophisticated controller, often a dedicated module designed specifically for use with servomotors. Servomotors are not a specific class of motor although the term *servomotor* is often used to refer to a motor suitable for use in a closed-loop control system. Servomotors are used in applications such as robotics, CNC machinery or automated manufacturing.

Figure 4.4: 12 V DC Motors

A servomotor is a closed-loop servomechanism that uses position feedback to control its motion and final position. The input to its control is a signal (either analogue or digital) representing the position commanded for the output shaft.

The motor is paired with some type of encoder to provide position and speed feedback. In the simplest case, only the position is measured. The measured position of the output is compared to the command position, the external input to the controller. If the output position differs from that required, an error signal is generated which then causes the motor to rotate in either direction, as needed to bring the output shaft to the appropriate position. As the positions approach, the error signal reduces to zero and the motor stops.

The very simplest servomotors use position-only sensing via a potentiometer and bang-bang control of their motor; the motor always rotates at full speed (or is stopped). This type of servomotor is not widely used in industrial motion control, but it forms the basis of the simple and cheap servos used for radio-controlled models.

More sophisticated servomotors use optical rotary encoders to measure the speed of the output shaft and a variable-speed drive to control the motor speed.[3] Both of these enhancements, usually in combination with a PID control algorithm, allow the servomotor to be brought to its commanded position more quickly and more precisely, with less overshooting.

4.3 T TYPE EXTRUSION

80/20 is a framing system using extruded beams of 6105-T5 aluminum alloy. The integral T-slots create the foundation for the profile's assembly technology. Accessories are also available, which are specific to each framing system. Many of these accessories are made in-house, while most of the specialty products, such as panels and casters, are made by third party companies.

Profile type	Profile name	Profile size	Distance from edge of profile to centerline of T-slot
fractional	10 series	1"	0.5"
	15 series	1.5"	0.75"
metric	20 series	20 mm	10 mm
	25 series	25 mm	12.5 mm
	30 series	30 mm	15 mm
	40 series	40 mm	20 mm
	45 Series	45 mm	22.5 mm

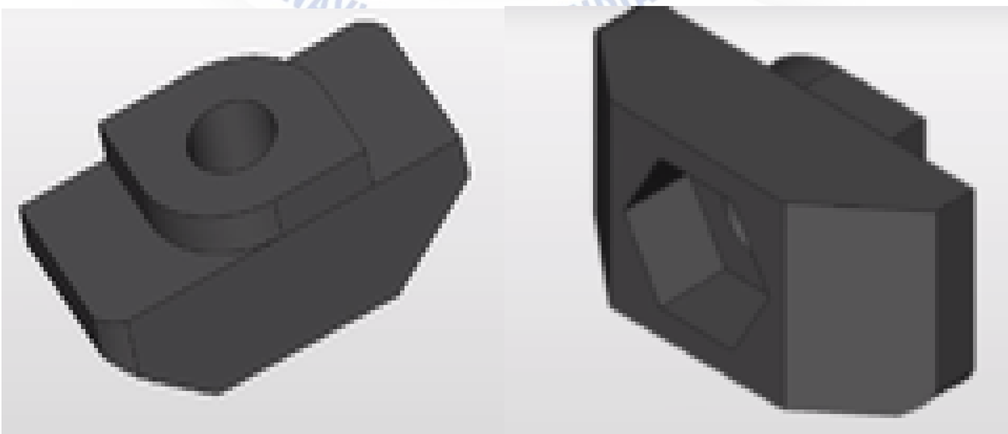


Figure 4.5: Section of T-type Extrusion

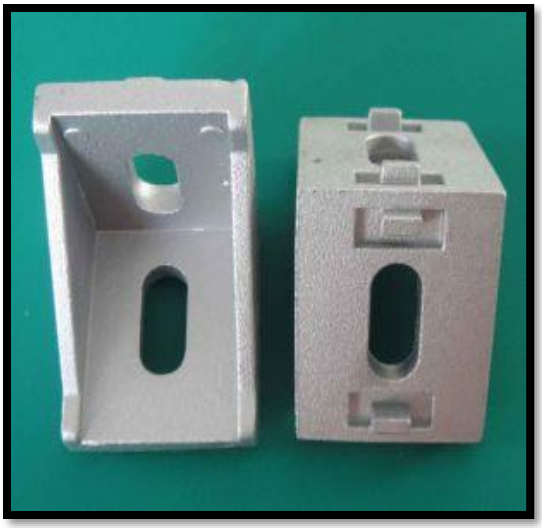


Figure 4.6: L-brackets

Figure 4.7: T-slot 45X45 mm extrusion

4.4 SMPS (SWITCH MODE POWER SUPPLY)

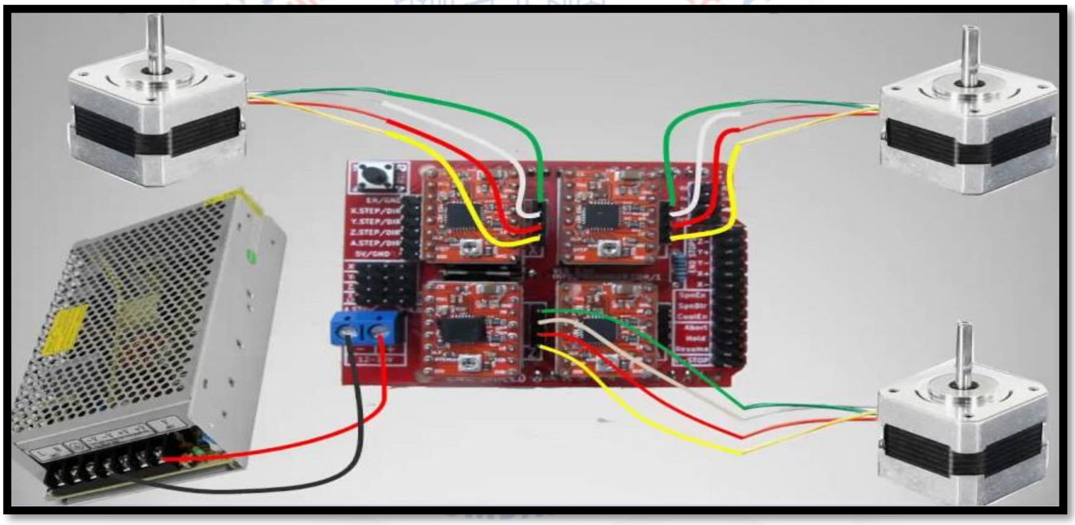


Figure 4.8: SMPS with Electrical Wiring

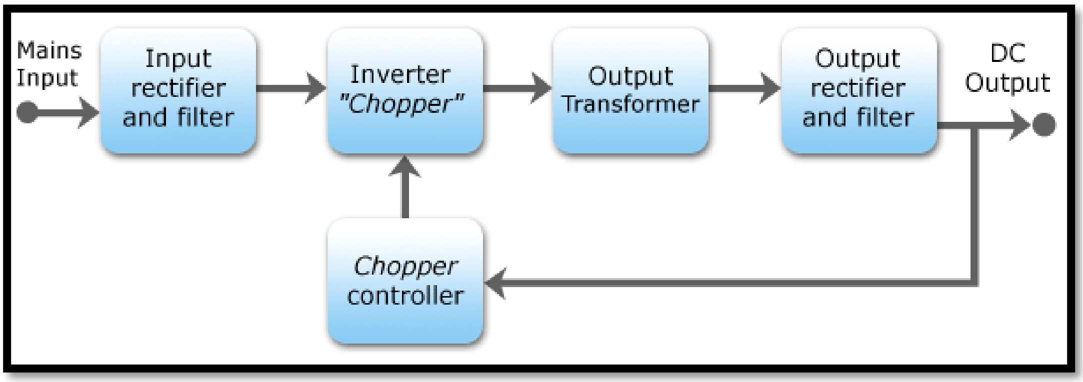


Figure 4.9: Block Diagram of SMPS

A switched-mode power supply (switching-mode power supply, switch-mode power supply, switched power supply, SMPS, or switcher) is an electronic power supply that incorporates a switching regulator to convert electrical power efficiently. Like other power supplies, an SMPS transfers power from a DC or AC source (often mains power) to DC loads, such as a personal computer, while converting voltage and currentcharacteristics. Unlike a linear power supply, the pass transistor of a switching-mode supply continually switches between low-dissipation, full-on and full-off states, and spends very little time in the high dissipation transitions, which minimizes wasted energy. Ideally, a switched-mode power supply dissipates no power. Voltage regulationis achieved by varying the ratio of on-to-off time. In contrast, a linear power supply regulates the output voltage by continually dissipating power in the pass transistor. This higher power conversion efficiency is an important advantage of a switched-mode power supply. Switched-mode power supplies may also be substantially smaller and lighter than a linear supply due to the smaller transformer size and weight.

Switching regulators are used as replacements for linear regulators when higher efficiency, smaller size or lighter weight are required. They are, however, more complicated; their switching currents can cause electrical noise problems if not carefully suppressed, and simple designs may have a poor power factor.

4.5 ADVANTAGES AND DISADVANTAGES

The main advantage of the switching power supply is greater efficiency than linear regulators because the switching transistor dissipates little power when acting as a switch.

Other advantages include smaller size and lighter weight from the elimination of heavy line-frequency transformers, and comparable heat generation. Standby power loss is often much less than transformers.

Disadvantages include greater complexity, the generation of high-amplitude, high-frequency energy that the low-pass filter must block to avoid electromagnetic interference (EMI), a ripple voltage at the switching frequency and the harmonic frequencies thereoy.

4.6 LEAD SCREW

A **lead screw** (or **lead screw**), also known as a **power screw**or **translation screw**,is a screw used as a linkage in a machine, to translate turning motion into linear motion. Because of the large area of sliding contact between their male and female members, screw threads have larger frictional energy losses compared to other linkages. They are not typically used to carry high power, but more for intermittent use in low power actuator and positioner mechanisms. Common applications are linear actuators, machine slides (such as in machine tools), vises, presses, and jacks.

Lead screws are manufactured in the same way as other thread forms (they may be rolled, cut, or ground).

A lead screw is sometimes used with a split nut also called half nut which allows the nut to be disengaged from the threads and moved axially, independently of the screw's rotation, when needed (such as in single-point threading on a manual lathe).

ower screws are classified by the geometry of their thread. V-threads are less suitable for lead screws than others such as ACME because they have more friction between the threads. Their threads are designed to induce this friction to keep the fastener from loosening. Leadscrews, on the other hand, are designed to minimize friction. Therefore, in most commercial and industrial use, V-threads are avoided for leadscrew use. Nevertheless, V-threads are sometimes successfully used as leadscrews.

Figure 4.10: Lead screw with couple

4.7 MARKET SURVEYED

SR. NO	COMPONENTS	MARKET VISITED
1	Motors and electronics	Lamington road
2	Acrylic plates	Paai dhuni & Naag devi
3	Ply wood	Shilphata
4	Attachments	Gujarat (Through online)

CHAPTER 05: METHODOLOGY

METHODOLOGY

5.1 INTRODUCTON TO METHODOLOGY

Methodology is a guideline for a developer to plan the structure and control development process. Design and development of this CNC 3 axis machine using Arduino Uno consisted of several parts which are the mechanical parts, electrical parts and programming. Each part was surmounted stage by stage according to its priority.

In this project, NEMA 23 stepper motor and Servo motor was used. While Arduino UNO was the controller for the machine. The designing of the machine included the frame work and motors along with the wiring connection and the software to generate the program.
Universal GCODE sender was used for the computer control, which would process the Gcodes and send signals to Arduino. Arduino then would feed the signals to the various motors so that they would move based on the user data input.

Various structure designs were compared and analysed to come up with an optimal structure for the machine. Critical components required such as motor and linear guides were carefully compared and selected. All the body parts were machined, the required components were purchased through various suppliers and machine was assembled inside the lab.
The following flowchart illustrates the phases involved in the overall project process.

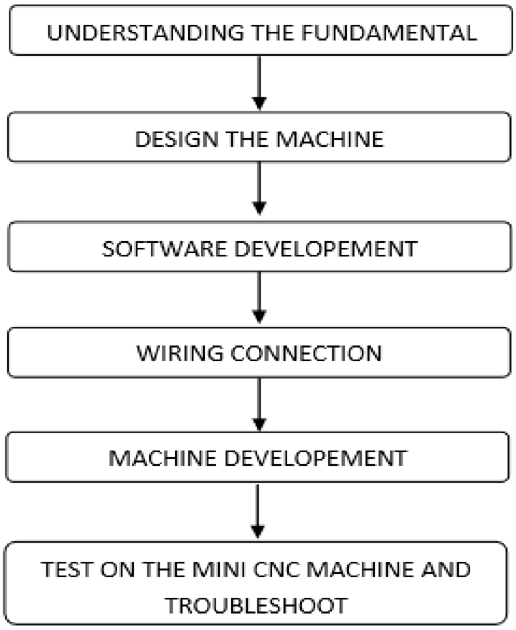


Figure 5.1: Methodology flow chart

5.2 PHASE ACTIVITIES:

Phase 1:

- Need to reduce cost
- Need to remove idleness
- Accommodate structural changes
- Touring relevant installed technologies
- Listening to user objective and constraints
- Data analysis

Phase 2:

- Specification of materials and components
- Simulation engineering and analysis
- Identify products and subsystems required

Phase 3:

- Developing easy software user interface
- Reduced cost control

Phase 4:

- Appropriate placement of motors
- Less complex wiring in the system

Phase 5:

- Manufacturing
- Installation
- Assembly

Phase 6:

- Engraving testing of the machine
- Trouble shooting

CHAPTER 06: SOFTWARE AND DETAILS OF INTERFACING

SOFTWARE AND DETAILS OF INTERFACING

6.1 INTRODUCTION

6.1.1 ARDUINO UNO

Arduino is open source computer hardware and software company project, and user community that design and manufactures single-board microcontrollers and microcontroller kits for building digital devices and interactive projects products are distributed as open-source-hardware and software, which are licensed under the GNU Lesser General Public License (LGPL) or the GNU General Public License (GPL), permitting the manufacture of Arduino boards and software distribution by anyone. Arduino boards are available commercially in preassembled form, or as do-it-yourself (DIY) kits,

Figure 6.1: ARDUINO UNO SMD R3

Developer	Arduino
Manufacturer	Many
Type	Single-board-microcontroller
Operating system	None
CPU	Atmel AVR (8-bit) ARM cortex-M0+(32-bit) ARM cortex-M3 (32-bit) Intel Quark (*86) (32-bit)
Memory	SRAM
Storage	Flash, EEPROM
Website	Arduino.cc

The Arduino UNO is a widely used open-source microcontroller board based on the ATmega328P microcontroller and developed by Arduino.cc. The board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. The board features 14 Digital pins and 6 Analog pins. It is programmable with the Arduino IDE (Integrated Development Environment) via a type B USB cable. It can be powered by a USB cable or by an external 9-volt battery, though it accepts voltages between 7 and 20 volts. The hardware reference design is distributed under a Creative Commons Attribution Share-Alike 2.5 license and is available on the Arduino website. Layout and production files for some versions of the hardware are also available. "Uno" means one in Italian and was chosen to mark the release of Arduino Software (IDE) 1.0. The Uno board and version 1.0 of Arduino Software (IDE) were the reference versions of Arduino, now evolved to newer releases. The Uno board is the first in a series of USB Arduino boards, and the reference model for the Arduino platform. The ATmega328 on the Arduino Uno comes pre-programmed with a bootloader that allows to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol. The Uno also differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter. The Arduino UNO is generally considered the most user-friendly and popular board, with boards being sold worldwide for less than 5$Arduino board designs use a variety of microprocessors and controllers. The boards are equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards or Breadboards (shields) and other circuits. The boards feature serial communications interfaces, including Universal Serial Bus (USB) on some models, which are also used for loading programs from personal computers. The microcontrollers are typically programmed using a dialect of features from the programming languages C and C++. In addition to using traditional compiler toolchains, the Arduino project provides an integrated development environment (IDE) based on the Processing language project. The Arduino project started in 2003 as a program for students at the Interaction Design Institute Ivrea, in ITALY aiming to provide a low-cost and easy way for novices and professionals to create devices that interact with their environment using sensors and actuators Common examples of such devices intended for beginner hobbyists include simple robots, thermostats, and motion detectors. The name Arduino comes from a bar in Ivrea, Italy, where some of the founders of the project used to meet. The bar was named after Arduino of Ivrea, who was the margrave of the March of Ivrea and King of Italy from 1002 to 1014.

6.1.2 HARDWARE

Figure 6.2: Backside of Arduino uno

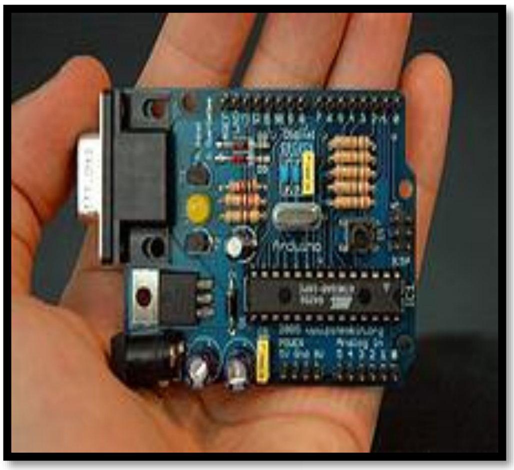


Figure 6.3: Frontside of Arduino UNO

Arduino is an open-source hardware. The hardware reference designs are distributed under a Creative Commons Attribution Share-Alike 2.5 license and are available on the Arduino website. Layout and production files for some versions of the hardware are also available. The source code for the IDE is released under the GNU General Public License, version 2. Never theless an official Bill of Materials of Arduino boards has never been released by Arduino staff. Although the hardware and software designs are freely available under copy left licenses, the developers have requested the name *Arduino* to be exclusive to the official product and not be used for derived works without permission.

The official policy document on use of the Arduino name emphasizes that the project is open to incorporating work by others into the official product. Several Arduino-compatible products commercially released have avoided the project name by using various names ending in Arduino.

An early Arduino board with an RS-232serialinterface (upper left) and an Atmel ATmega8 microcontroller chip (black, lower right); the 14 digital I/O pins are at the top, the 6 analog input pins at the lower right, and the power connector at the lower left.Most Arduino boards consist of an Atmel 8-bit AVR microcontroller (ATmega8, ATmega168, ATmega328, ATmega1280, ATmega2560) with varying amounts of flash memory, pins, and features.The 32-bit Arduino Due, based on the Atmel SAM3X8E was introduced in 2012. The boards use single or double-row pins or female headers that facilitate connections for programming and incorporation into other circuits. These may connect with add-on modules termed *shields*. Multiple and possibly stacked shields may be individually addressable via an I²Cserial bus.

Most boards include a 5 V linear regulator and a 16 MHz crystal oscillator or ceramic resonator. Some designs, such as the LilyPad, run at 8 MHz and dispense with the onboard voltage regulator due to specific form-factor restrictions.

Arduino microcontrollers are pre-programmed with a bootloader that simplifies uploading of programs to the on-chip flash memory. The default bootloader of the Arduino UNO is the optiboot bootloader. Boards are loaded with program code via a serial connection to another computer. Some serial Arduino boards contain a level shifter circuit to convert between RS-232 logic levels and transistor–transistor logic (TTL) level signals. Current Arduino boards are programmed via Universal Serial Bus (USB), implemented using USB-to-serial adapter chips such as the FTDI FT232. Some boards, such as later-model Uno boards, substitute the FTDI chip with a separate AVR chip containing USB-to-serial firmware, which is reprogrammable via its own ICSP header. Other variants, such as the Arduino Mini and the unofficial Boarduino, use a detachable USB-to-serial adapter board or cable, Bluetooth or other methods. When used with traditional microcontroller tools, instead of the Arduino IDE, standard AVR in-system programming (ISP) programming is used.

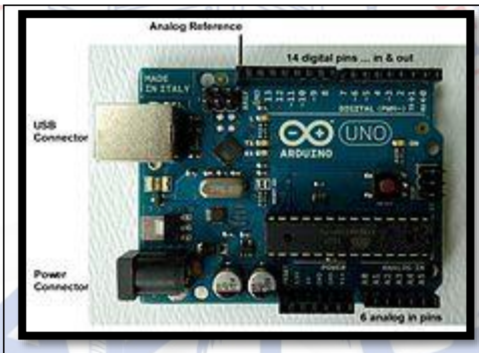


Figure 6.4: Description of major pins of Arduino

The Arduino board exposes most of the microcontroller's I/O pins for use by other circuits. The Diecimila, Duemilanove, and current *Uno* provide 14 digital I/O pins, six of which can produce pulse-width modulated signals, and six analog inputs, which can also be used as six digital I/O pins. These pins are on the top of the board, via female 0.1-inch (2.54 mm) headers. Several plug-in application shields are also commercially available. The Arduino Nano, and Arduino-compatible Bare Bones Board and Boarduino boards may provide male header pins on the underside of the board that can plug into solderless breadboards.

Many Arduino-compatible and Arduino-derived boards exist. Some are functionally equivalent to an Arduino and can be used interchangeably. Many enhance the basic Arduino by adding output drivers, often for use in school-level education, to simplify making buggies and small robots. Others are electrically equivalent but change the form factor, sometimes retaining compatibility with shields, sometimes not. Some variants use different processors, of varying compatibility.

6.2 SOFTWARE AND PROGRAMMING TOOL

A program for Arduino may be written in any programming language with compilersthat produce binary machine code for the target processor. Atmel provides a development environment for their microcontrollers, AVR Studio and the newer Atmel Studio.The Arduino project provides the Arduino integrated development environment (IDE), which is a cross plate form application written in the programming language java. It originated from the IDE for the languages processing and wiring . It includes a code editor with features such as text cutting and pasting, searching and replacing text, automatic indenting, brace matching and syntax highlighting, and provides simple *one-click* mechanisms to compile and upload programs to an Arduino board. It also contains a message area, a text console, a toolbar with buttons for common functions and a hierarchy of operation menus.

A program written with the IDE for Arduino is called a sketch Sketches are saved on the development computer as text files with the file extensio.ino. Arduino Software (IDE) pre-1.0 saved sketches with the extension.pde.

The Arduino IDE supports the languages C and C++ using special rules of code structuring. The Arduino IDE supplies a software library from the wiring project, which provides many common input and output procedures. User-written code only requires two basic functions, for starting the sketch and the main program loop, that are compiled and linked with a program stub main () into an executable cyclic executive program with the GNU toolchain, also included with the IDE distribution. The Arduino IDE employs the program avrdude to convert the executable code into a text file in hexadecimal encoding that is loaded into the Arduino board by a loader program in the board's firmware. The open-source nature of the Arduino project has facilitated the publication of many free software libraries that other developers use to augment their projects.

6.3. INTERFACING OF ARDUINO WITH PLC

6.3.1. UNIVERSAL GCODE SENDER

A full featured gcode platform used for interfacing with advanced CNC controllers like GRBL and TinyG. Universal Gcode Sender is a self-contained Java application which includes all external dependencies, that means if you have the Java Runtime Environment setup UGS provides the rest.

6.3.2 Features

1) Cross platform, tested on Windows, OSX, Linux, and Raspberry Pi.
2) Executable All-In-One JAR file - if you have java there is nothing to install. The JAR file includes native dependencies for all supported operating systems.
3) 3D Gcode Visualizer with colour coded line segments and real time tool position feedback.
4) Duration estimates.
5) Over 3000 lines of unit test code, and another 1000 lines of comments documenting the tests.
6) Configuratble gcode optimization:
    i) Remove comments
    ii) Truncate decimal precision to configurable amount
    iii) Convert arcs (G2/G3) to line segments
    iv) Remove whitespace

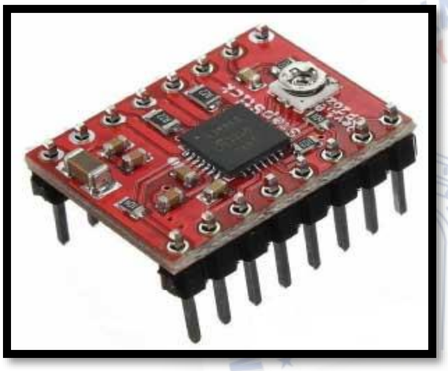
6.3.3 GRBL - Features

1. Overrides and Toggles Platform version only. Easily control the real time feed and speed overrides by enabling the Overrides widget in the Window menu.
2. Jog Mode with older versions of GRBL UGS is pretty reliable when it comes to jogging, but there are limitations. With GRBL 1.1 this is no longer the case when using the new JOG MODE syntax. This first-class jog mode guarantees the GCODE state will be unaltered, and also allows you to stop a jog while it is in progress. UGS uses this new syntax automatically when it detects a version of GRBL which supports it. During a jog use the STOP action to stop an in-progress jog:

3. Pin State Reporting Platform version only. New flags have been added to the controller state window to indicate when various external switches are enabled.
4. Message resolution GRBL removed most help and error messages to make room for new features on the micro controller, they are now provided as data files in the grbl source code. UGS uses these data files to resolve all error codes and setting strings.

6.4 A4988 STEPPER MOTOR DRIVER

The A4988 is a micro-stepping driver for controlling bipolar stepper motors which has built-in translator for easy operation. This means that we can control the stepper motor with just 2 pins from our controller, or one for controlling the rotation direction and the other for controlling the steps.



Minimum Logic Voltage:	3V
Maximum Logic Voltage:	5.5 V
Continuous current per phase:	1 A
Maximum current per phase:	2 A
Minimum Operating Voltage:	8 V
Maximum Operating Voltage:	35 V

Figure 6.5: Picture of motor driver **Figure 6.6: Correration of voltage with logic values**

The Driver provides five different step resolutions: full-step, haft-step, quarter-step, eight-step and sixteenth-step. Also, it has a potentiometer for adjusting the current output, over-temperature thermal shutdown and crossover-current protection.

Its logic voltage is from 3 to 5.5 V and the maximum current per phase is 2A if good addition cooling is provided or 1A continuous current per phase without heat sink or cooling.

A4988 Stepper Driver PinoutNow let's close look at the pinout of the driver and hook it up with the stepper motor and the controller. So we will start with the 2 pins on the button right side for powering the driver, the VDD and Ground pins that we need to connect them to a power supply of 3 to 5.5 V and in our case that will be our controller, the Arduino Board which will provide 5 V. The following 4 pins are for connecting the motor. The 1A and 1B pins will be connected to one coil of the motor and the 2A and 2B pins to the other coil of the motor. For powering the motor, we used the next 2 pins, Ground and VMOT that we need to connect them to Power Supply from 8 to 35 V and also we need to use decoupling capacitor with at least 47 µF for protecting the driverboard from voltage spikes.

The next two 2 pins, Step and Direction are the pins that we actually use for controlling the motor movements. The Direction pin controls the rotation direction of the motor and we need to connect it to one of the digital pins on our microcontroller, or in our case I will connect it to the pin number 4 of my Arduino Board.

With the Step pin we control the micro-steps of the motor and with each pulse sent to this pin the motor moves one step. So that means that we don't need any complex programming, phase sequence tables, frequency control lines and so on, because the built-in translator of the A4988 Driver takes care of everything. Here we also need to mention that these 2 pins are not pulled to any voltage internally, so we should not leave them floating in our program.

Next is the SLEEP Pin and a logic low puts the board in sleep mode for minimizing power consumption when the motor is not in use.

Next, the RESET pin sets the translator to a predefined Home state. This Home state or Home Micro-step position can be seen from these Figures from the A4988 Datasheet. So these are the initial positions from where the motor starts and they are different depending on the micro-step resolution. If the input state to this pin is a logic low all the STEP inputs will be ignored. The Reset pin is a floating pin so if we don't have intention of controlling it with in our program we need to connect it to the SLEEP pin in order to bring it high and enable the board.

MS1	MS2	MS3	Resolution
LOW	LOW	LOW	Full Step
HIGH	LOW	LOW	Halft Step
LOW	HIGH	LOW	Quarter Step
HIGH	HIGH	LOW	Eighth step
HIGH	HIGH	HIGH	Sixteenth Step

Figure 6.7: Commands required to perform various step of stepper motor

The next 3 pins (MS1, MS2 and MS3) are for selecting one of the five step resolutions according to the above truth table. These pins have internal pull-down resistors so if we leave them disconnected, the board will operate in full step mode. The last one, the ENABLE pin is used for turning on or off the FET outputs. So a high logic will keep the outputs disabled.

CHAPTER 07: FABRICATION OF THE PROJECT

FABRICATION OF THE PROJECT

7.1 STEP BY STEP FABRICATION OF CNC

The assembly of the CNC was a rather challenging task. We are grateful to our guide who helped us and arranged for the workplace required for the task and guided us throughout the whole assembly. The assembly is basically divided into three parts structural, electrical and electronic. A detailed description of the procedure followed for the assembly is as follows:

7.1.1 STRUCTURAL

Step 1) ASSEMBLY OF THE FRAME:

Figure 7.1: Bare frame of the CNC

After the analysis of the cad model in the ANSYS software we found that out that the design we opted was safe by applying predetermined loading conditions and various constrains.

We had the option of using two type of structure that were I-section channel and t slot which are casted from aluminium of grade 60. The advantage of using T-slot is that the strength is high and the are corrosion free as compared to I channel.

The fabrication cost as of in comparison of the aluminium is far less and with the use of the brackets welding can be avoided. And the advantage of these is that the length of the structure can be varied which can be a feasibility of the project.

We used the “Portal type” frame configuration as according to our moving bed design for CNC.

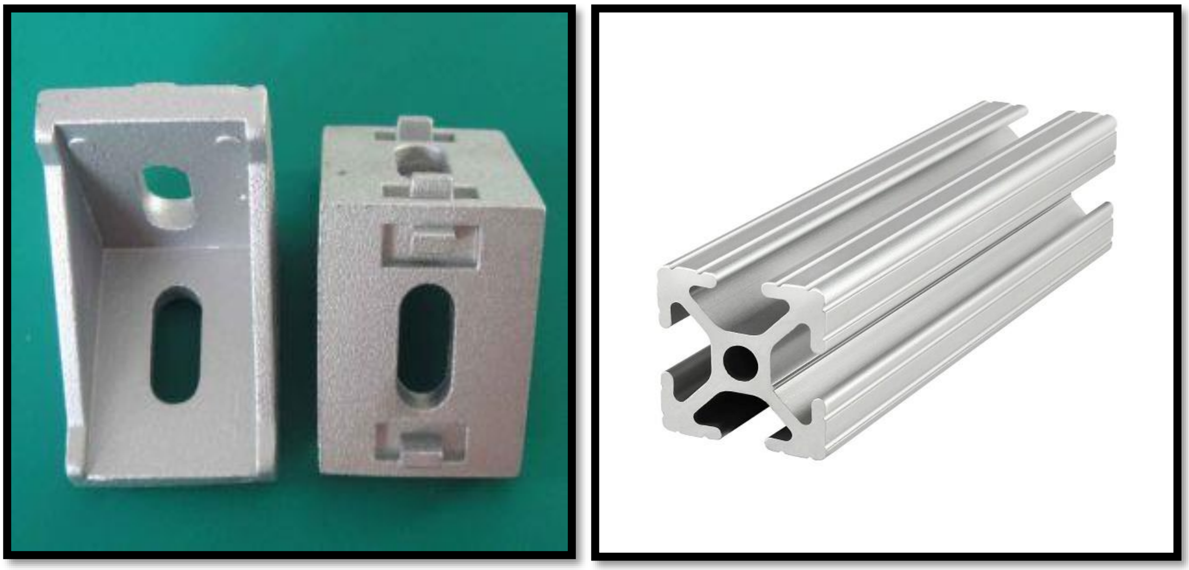


Figure 7.2: L-brackets and T-stot bars

STEP 2) PLACING OF THE GUIDEWAYS

Figure 7.3: Smooth rod (Left) and leadscrew with nut (Right)

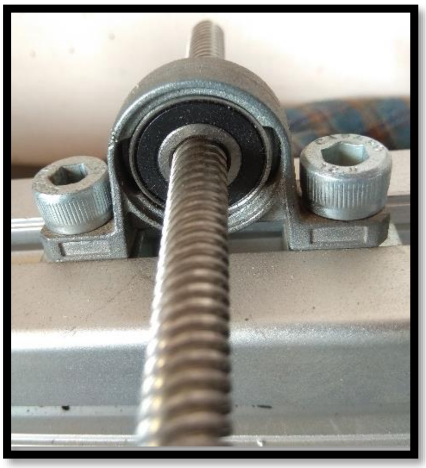
For the mounting of the motors and various attachment and guideways were used by us for the fabrication of the project which were purchased from Gujarat from 3D TEC INDUSTRY. The fabrication was done with the attachment accompanied by this.

The step that was followed was as follows:

I. With the help of the L-key we fixed the attachment on the T slot

II. Next with the attachment in place we placed the guideway and the lead screw.

III. The lead screws were fixed on the frame using spherical roller bearings (insert model name here) on one side and connected to the stepper motors by a coupler on the other side.



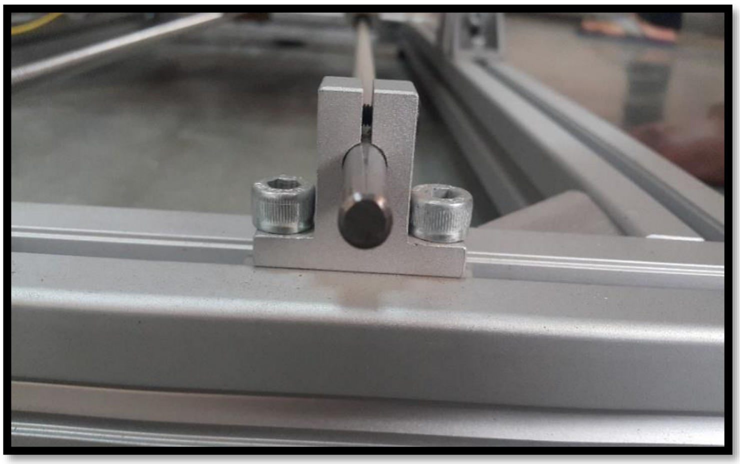


Figure 7.4: Leadscrew Mounted on Pedestal bearing (Left) and smooth rod guideway (Right)

STEP 3) PLACING OF THE MOTORS

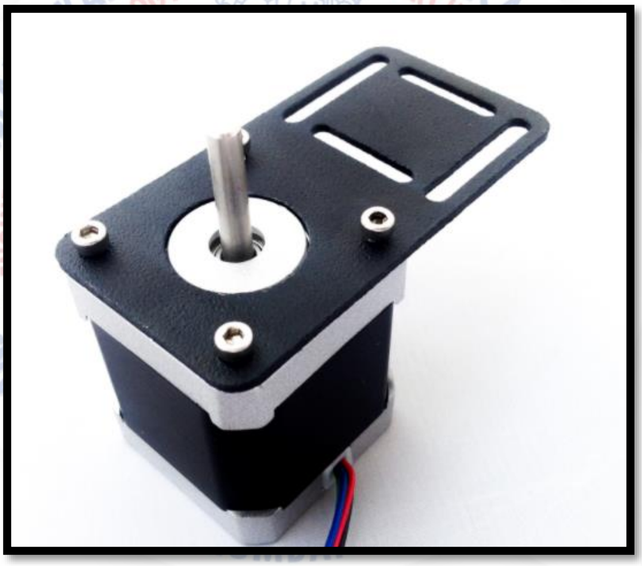


Figure 7.5: NEMA 23 Stepper motor with straight bracket attachment

Basically the step in the motor mounting was the mounting of the three stepper motors on the three respective axes.

I. For the X Axis the motor was mounted using the L bracket of the MOTOR.

II. Similarly, for the Y Axis the motor was mounted using the straight bracket available.

III. For the mounting of the motor on the Z Axis a ply was used on which the motor was mounted.

After completing the above mentioned steps the mounting of all the 3 axis motors was successfully completed.

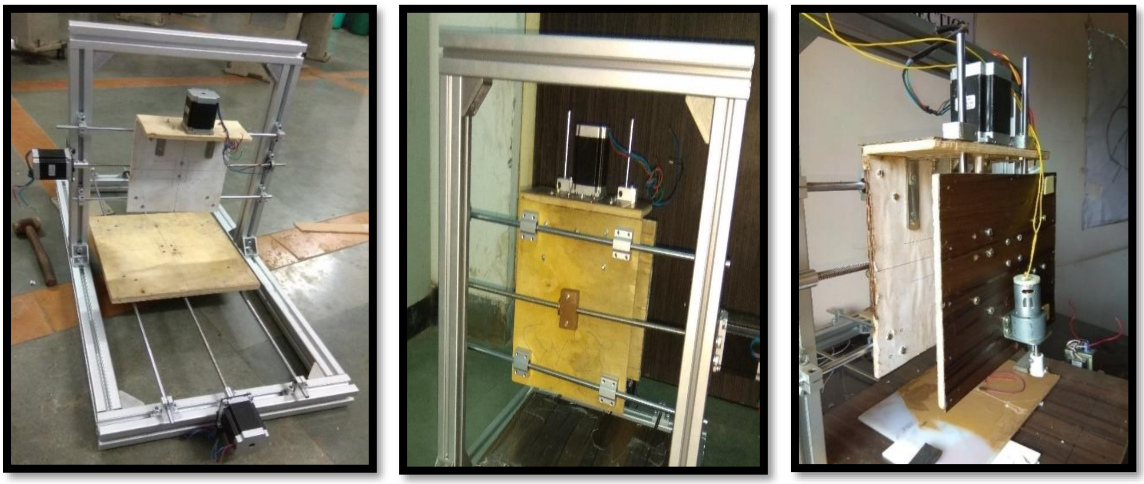


Figure 7.6: The X (left) Y(middle) and Z(right) axis motors

STEP 4) CONSTRUCTION OF BED AND SUPPORT FOR VARIOUS AXIS

Figure 7.7: The bed, x-axis leadscrew and guide ways

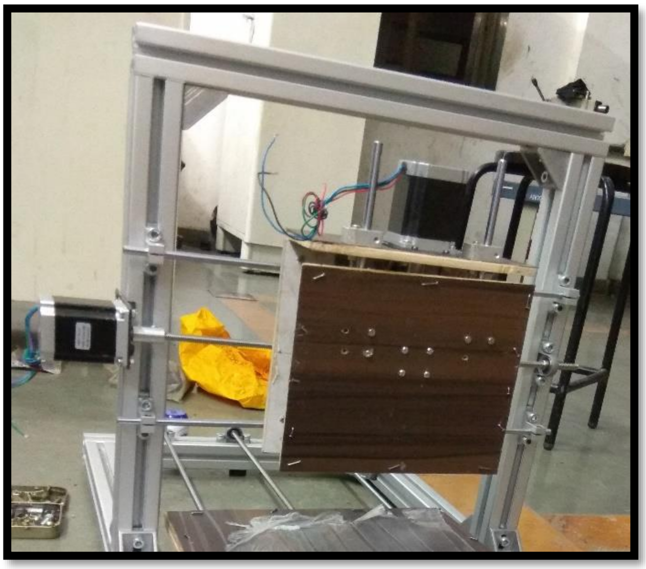


Figure 7.8: The y-axis mechanism

1. For machining on the x axis a ply wood of thickness 12mm was used and a laminate was glued to it for providing an aesthetic look. The cross section of the structure used for the base was 35x35cm.

2. Next was the base for the y axis and the z axis which were made using similar techniques.

3. The bed was mounted on the guide ways using 4 nos. SC8UUlinear bearings, the bed was fixed on lead screw using lead screw nut and self-made wooden blocks. The wooden housing was made by joining wooden plates of proper sizes. The housing was fixed on y-axis guide ways by 4 nos. linear bearings. The spindle motor plate was fixed on housing using 2 nos. linear bearings. The smooth movement of the bed, wooden housing and spindle motor plate was the trickiest part of the assembly, due to a very slight misalignment of the linear bearingstheir travel can become rough, proper care was taken to avoid the misalignment.

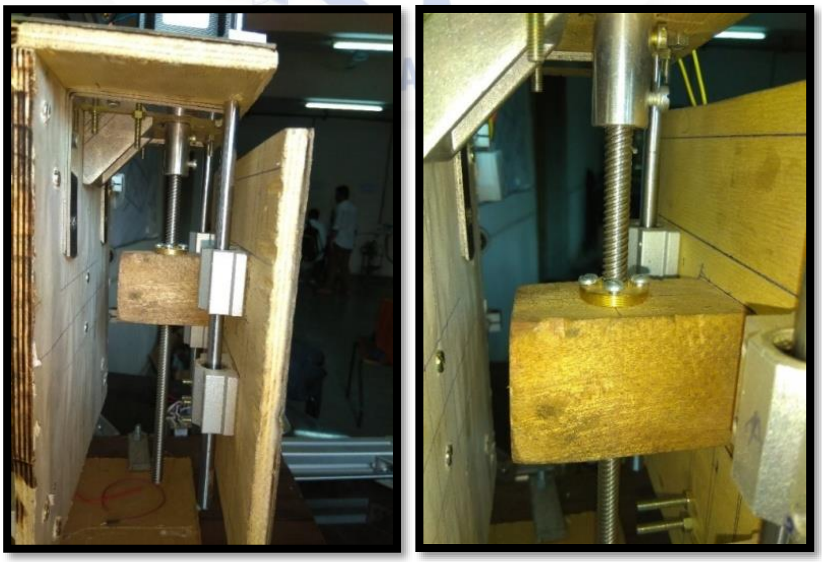
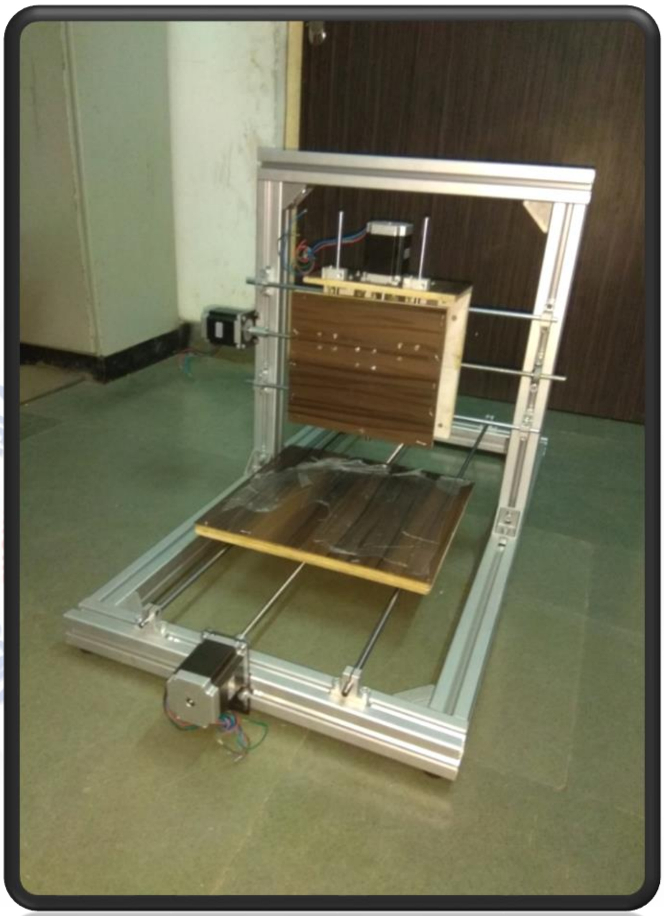


Figure 7.9: The Z-axis mechanism

THE MACHINE AFTER THE WHOLE STRUCTURAL PART WAS COMPLETE.



7.1.2 ELECTRICAL AND ELECTRONICS FABRICATION OF THE PROJECT

1) Wiring of motors to the Arduino:

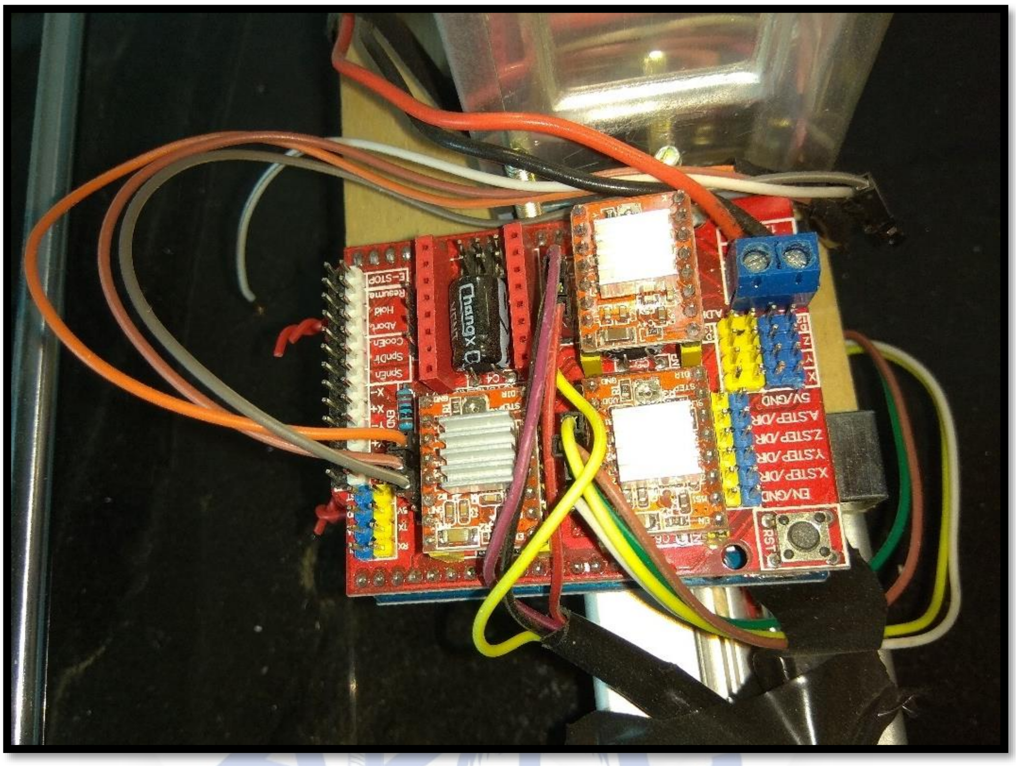


Figure 7.10: The Arduino chip with CNC sheild and motor drivers

The separate wires of each of the three stepper motors can be seen in the above picture.

The red Arduino shield is placed above the blue Arduino UNO board.

The groups of wires are:

Motor 1: Orange, brown and grey.

Motor 2: Purple, black, yellow and red.

Motor 3: Yellow, brown, green and white.

The power supply wires to the Arduino are the thick red and black wires connected to the blue plug.

The 3 motor driver shields are shown having aluminium fins.

2) Wiring diagram of whole assembly.

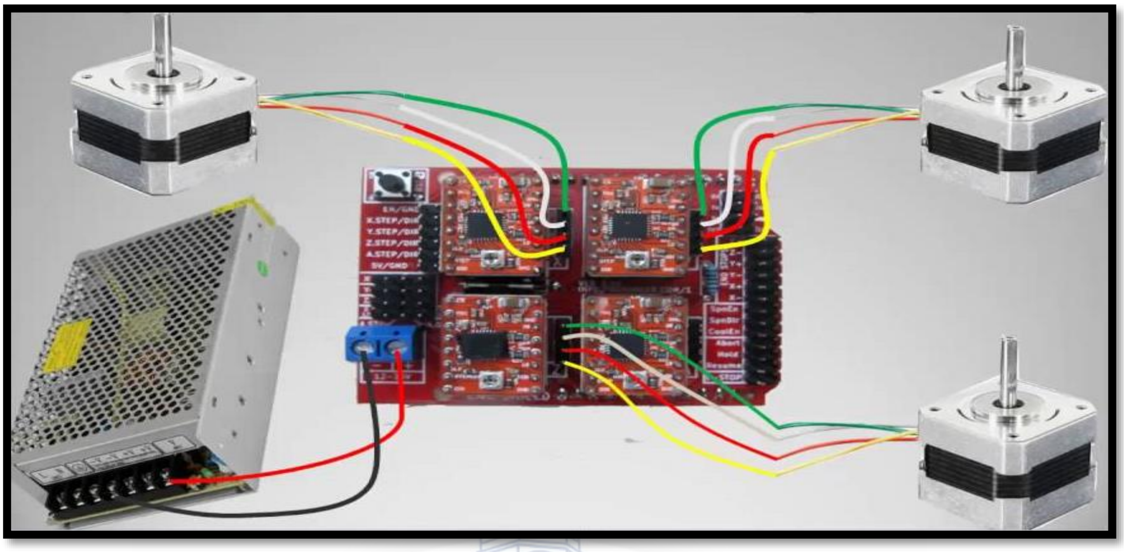


Figure 7.11: Rough circuit diagram of various major connections

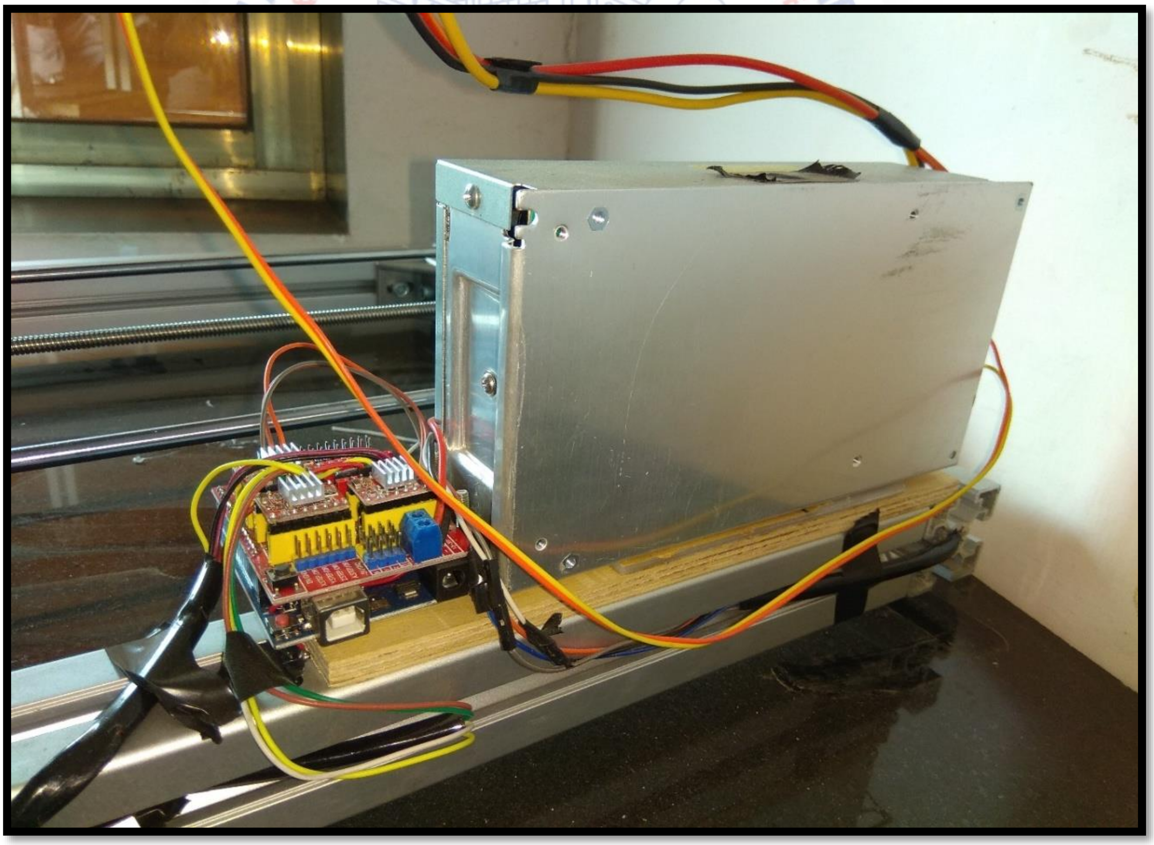


Figure 7.12: Actual picture of SMPS and Arduino board

For meeting the electrical needs of the project an SMPS was used which further had connection with the three stepper motor and the arduino with the help of which precise movement was possible on the three axis respectively.

A separate supply was provided for the spindle motor through which the spindle motor would rotate at the required conditions.

Thus this was the summary of the fabrication of the project in a very understanding and explanatory method.

THE MACHINE AFTER BOTH STRUCTURAL AS WELL AS ELECTRICAL PART WAS COMPLETED

CHAPTER 08: COSTING OF THE PROJECT

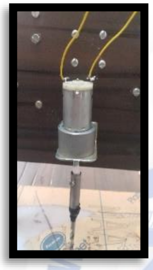
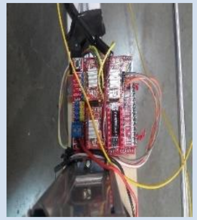
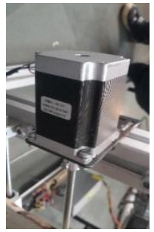
SR. NO	1.	2.	3.	4.	5.	6.	7.	8.
ELEMENT	Aluminium T-slots	DC geared motor 12v	Transformer	SC8UU	SMPS	Shaft Support	Arduino Uno	Stepper motor
IMAGE								
DESCRIPTION	5.3 m of aluminium slot with 12 I brackets and 50 nuts	DC motor 12V with mounting motor-2000 rpm 15kgf cm torque	15-0-15 V Current 1 Amp	Linear Ball Bearing slide bushing	24V, 10 Amps with 3 output ports.	Hole dia-8mm Material-Aluminium	Arduino Uno + CNC shield + Stepper motor Driver A4988	Nema 23 Torque-1.89 Nm Step angle-1.8 degree Weight-1 kg Shaft dia-6.35mm
COST & ADDRESS	T-slots - Rs 7000 Mulund Market Jinesh Shah Ph. 9820096668	Mounting - Rs 200 and motor Rs 1500 Lamington Road.	Transformer - Rs 120 Bridge rectifier- Rs 20 Shree Electronic, Panvel.	Cost: Rs 195 Address- 3\Face Tech, Gujarat.	Cost-Rs 1000 Address- Silikon electronic, Lamington Road.	Cost- Rs 130/piece Address – 3Face tech, Gujarat.	Cost- Rs (400+200+150)/piece Address- Silicon electronic, Lamington.	Cost- Rs 1800 Address- Silikon electronic, Lamington.

Table 8.1: Specification and costing of the parts

TOTAL COSTING OF THE PROJECT IN FIGURES

Sr. No.	Product Name	Unit Cost	Quantity	Total Cost
1	Stepper motors	1800	3	5400
2	Servo motors	1600	1	1600
3	Aluminium slots	7000	10 bars	7000
4	Guide ways and lead screw	10000	Multiple	10000
5	Arduino	1500	1	1500
6	Smps	1500	1	1500
7	BreakdownAnd maintainence	3000	1	3000
8	Expert advice	1300	1	1300
9	Black book	450	12	4000
10	Travelling cost			2000
Total				36800

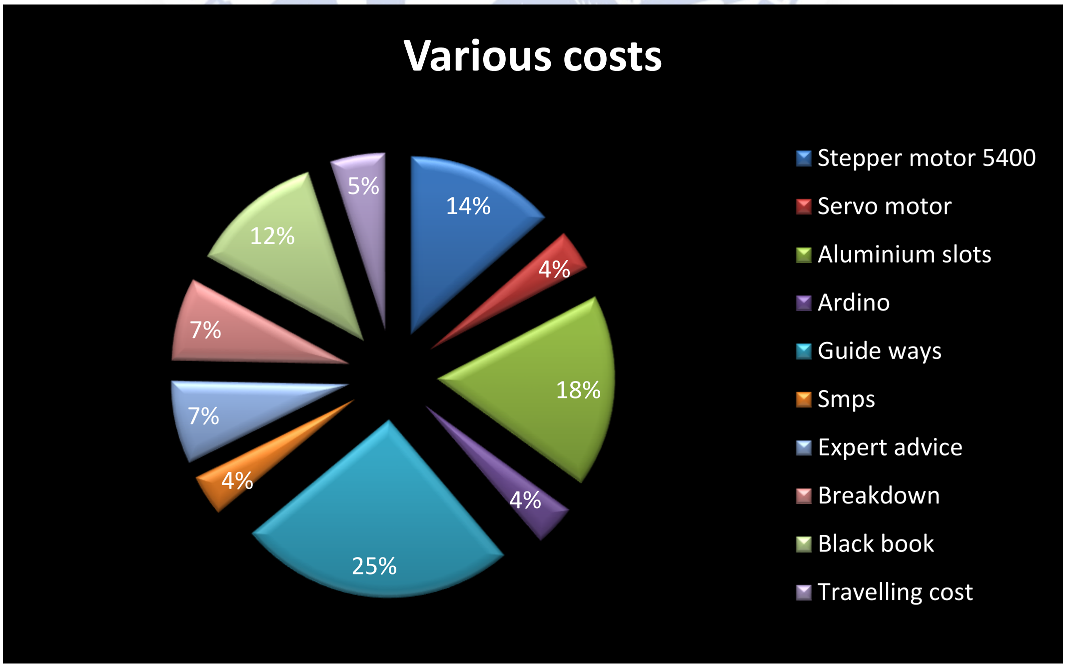


Figure 8.1: Pie diagram of the costs of various components

CHAPTER 09: FLOW OF WORK

FLOW OF WORK

9.1 GANTT chart of the project

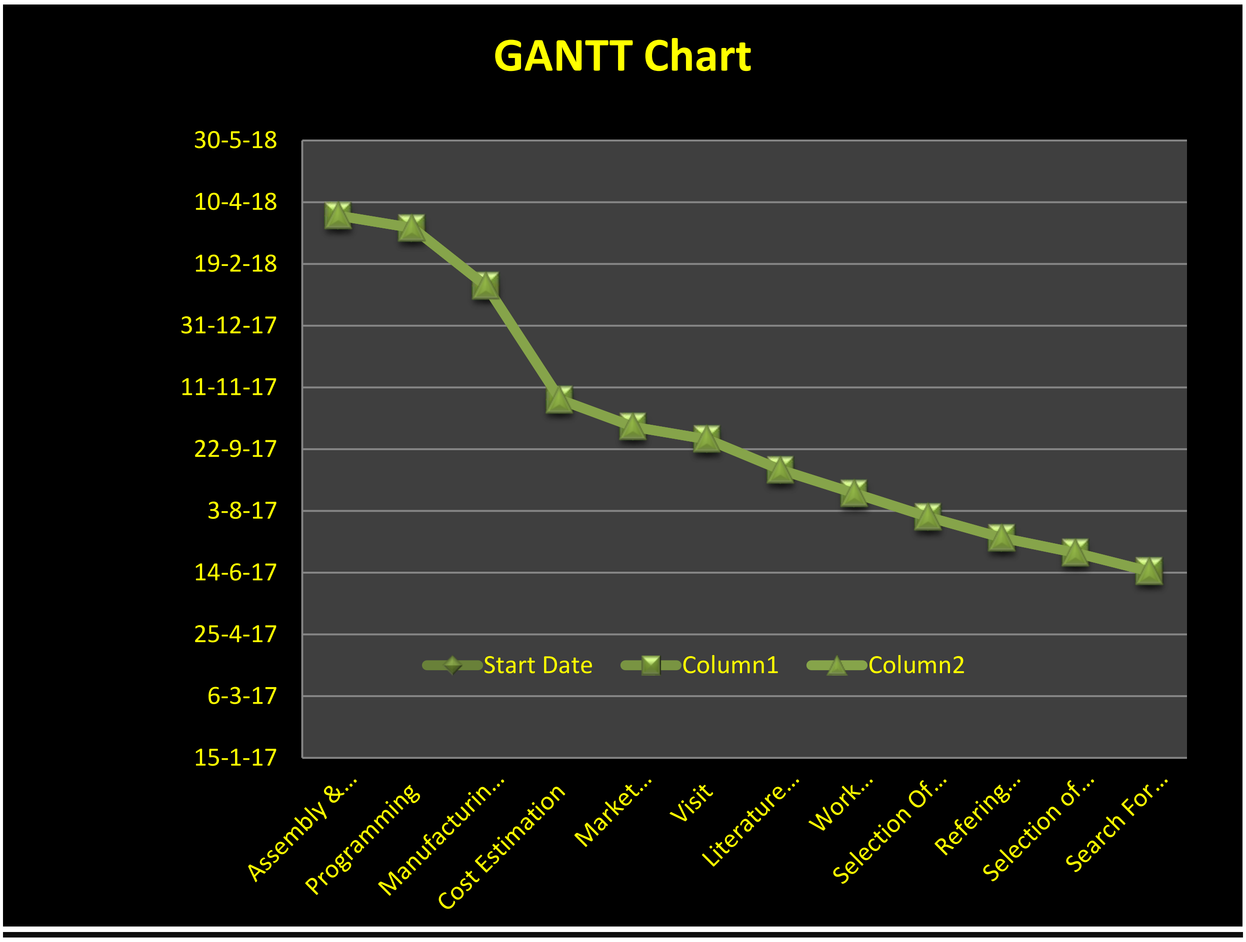


Figure 9.1: GANTT chart of the project

The flow of work is as follows:

- We start searching for the topic related to the project around 14.06.2017 and we shortlisted various topic and then with some guidance from our guide we shortlisted the above topic. The next step was the related to the study of the various paper/journal related to the said topic which was completed before 03.07.2017.
- The next was the brainstorming section with the group member and the guide so that the various parameters on which the project should be based on or the project should fulfil.

Various meets were arranged with the group members and guide and the parameter were finalised before 03.08.2017.

- The next big step was the distribution of the responsibilities that should be allocated to the members of the group so that all the members carry out their responsibilities and the project can be finished within the said time. Between period of 03.08.2017 and 22.09.2017 the study of literature related to the project were studied by various members of the group as per the work distributed to them in the previous session. And then by conducting various meets the finding of all the members were discussed in a net shell so that all the members get the required information and has all the required information of the project. All this was conducted in the time zone of 30.08.2017 to 22.09.2017.
- Also a visit related to the project was done to the {OM WOODEN WORK} said industry in the vicinity of the institution and useful information as obtained from the visit. The said visit was conducted on the 23.0.2017.
- The next step was the market survey for the various component and the price of the various components from various market such as [LAMINGTON] {motors} and for acrylic and other components such has {coupling, bearing} the area of NAGDEVI was surveyed. The detail of the price was noted and the comparison with online market was done and the difference was noted.
- Depending on the market survey and the surfing on online site the rough estimate was prepared before 11.11.2017.
- The next huddle and the largest of all was the actual fabrication and manufacturing of machine which was full of challenges. The time slot of 15.11.2017 to 19.02.2018 was given to the fabrication of the project considering the exam and other various tasks that were to be conducted during the said period. In this stage the challenges related to the manufacturing of such as the calibration of the motors, balancing of the system, mounting of the motors and many more were completed. The project structure of the project was completed in the first week of FEB.
- The next step and final step about the programming regular side by side was completed by our group member HADDADI MAAZ who was working on the software and electronic part of the machine.
- By the mid February the project was completed and the next step was the testing of the project which was carried out on a regular basis.
- Thus the fabrication of the project according to the planned flow of work was completed.

CHAPTER 10: PROGRAMMING

PROGRAMMING

Program for the above engraving in the figure.

(Header)

(Generated by gcodetools from Inkscape.)

(Using default header. To add your own header create file "header" in the output dir.)

M3

(Header end.)

G21 (All units in mm)

(Start cutting path id: path2296 at depth: -4.0)

(path id: path2296 at depth step: -1.0)

(path len: 265.27305)

(Change tool to Default tool)

G00 Z5.000000

G00 X98.862923 Y10.087108

(Subpath start)

G01 Z-1.000000 F100.0(Penetrate)

```
G03 X98.014837 Y8.599483 Z-1.000000 I111.941419 J-64.802747 F400.000000
G03 X97.302961 Y7.308192 Z-1.000000 I83.630257 J-46.946388
G02 X96.554662 Y6.051748 Z-1.000000 I-12.837491 J6.794556
G02 X95.493411 Y4.591015 Z-1.000000 I-18.428243 J12.272599
G02 X94.475296 Y3.488417 Z-1.000000 I-9.089873 J7.372046
G02 X93.418663 Y2.614900 Z-1.000000 I-6.735803 J7.072007
G02 X92.236410 Y1.967386 Z-1.000000 I-2.575581 J3.299523
G02 X90.969526 Y1.750340 Z-1.000000 I-1.266884 J3.588846
G02 X88.752038 Y2.367941 Z-1.000000 I0.000000 J4.289730
G02 X86.367647 Y4.529276 Z-1.000000 I4.334252 J7.177461
G02 X84.691711 Y7.549682 Z-1.000000 I11.618043 J8.421683
G02 X82.779739 Y13.360072 Z-1.000000 I41.688483 J16.937822
G02 X81.562557 Y19.275252 Z-1.000000 I62.284419 J15.899250
G02 X80.439803 Y28.242748 Z-1.000000 I142.211903 J22.359337
G02 X79.836729 Y37.331638 Z-1.000000 I172.619293 J16.018234
G02 X79.597426 Y49.300802 Z-1.000000 I299.209680 J11.969164
G02 X79.823965 Y60.653280 Z-1.000000 I284.565098 J-0.000000
G02 X80.408601 Y69.617813 Z-1.000000 I177.983679 J-7.106161
G02 X81.499751 Y78.525073 Z-1.000000 I141.662486 J-12.833348
G02 X82.748543 Y84.747504 Z-1.000000 I70.308696 J-10.873865
G02 X84.599720 Y90.575285 Z-1.000000 I45.666225 J-11.297843
G02 X86.320850 Y93.887073 Z-1.000000 I16.324030 J-6.380438
G02 X88.786291 Y96.363675 Z-1.000000 I7.543753 J-5.044290
G02 X90.985127 Y97.036520 Z-1.000000 I2.198836 J-3.256438
G02 X92.699468 Y96.646136 Z-1.000000 I0.000000 J-3.959386
G02 X94.713427 Y95.245661 Z-1.000000 I-3.336974 J-6.947082
G02 X96.351294 Y93.281361 Z-1.000000 I-7.873586 J-8.230121
G02 X98.862923 Y88.946767 Z-1.000000 I-36.493746 J-24.040831
G01 X98.862923 Y74.434622 Z-1.000000
G01 X98.628926 Y74.434622 Z-1.000000
G03 X96.417081 Y80.659131 Z-1.000000 I-65.293461 J-19.696443
G03 X94.822627 Y83.697688 Z-1.000000 I-17.022181 J-6.994607
G03 X92.614965 Y86.010097 Z-1.000000 I-7.261074 J-4.722130
G03 X90.782332 Y86.600121 Z-1.000000 I-1.832634 J-2.551095
G03 X89.287117 Y86.118935 Z-1.000000 I0.000000 J-2.563672
G03 X87.600014 Y84.315234 Z-1.000000 I3.696610 J-5.148521
G03 X86.460145 Y81.981654 Z-1.000000 I10.102256 J-6.379763
G03 X85.088479 Y77.337055 Z-1.000000 I39.091805 J-14.069635
G03 X84.213455 Y72.673649 Z-1.000000 I53.924179 J-12.531927
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```
G03 X83.403725 Y65.603826 Z-1.000000 I123.258656 J-17.698493
G03 X82.979161 Y58.556818 Z-1.000000 I147.618067 J-12.429896
G03 X82.810941 Y49.300802 Z-1.000000 I254.563109 J-9.256016
G03 X83.001181 Y39.614357 Z-1.000000 I246.697539 J-0.000000
G03 X83.466123 Y32.627267 Z-1.000000 I128.778977 J5.060339
G03 X84.323942 Y25.680217 Z-1.000000 I128.921582 J12.392696
G03 X85.182079 Y21.264569 Z-1.000000 I52.886238 J7.986696
G03 X86.542259 Y16.810192 Z-1.000000 I36.667156 J8.761752
G03 X87.724810 Y14.471646 Z-1.000000 I11.177657 J4.184028
G03 X89.423356 Y12.748352 Z-1.000000 I5.529628 J3.751494
G03 X90.813533 Y12.310256 Z-1.000000 I1.390177 J1.986626
G03 X92.709431 Y12.924379 Z-1.000000 I0.000000 J3.233535
G03 X94.994221 Y15.336186 Z-1.000000 I-5.268734 J7.279391
G03 X96.632189 Y18.502648 Z-1.000000 I-15.786881 J10.173221
G03 X98.644527 Y24.413997 Z-1.000000 I-53.460909 J21.497331
G01 X98.862923 Y24.413997 Z-1.000000
G01 X98.862923 Y10.087108 Z-1.000000
(Subpath end)
G00 Z5.000000

(path id: path2296 at depth step: -2.0)
(path len: 265.27305)
G00 Z5.000000
G00 X98.862923 Y10.087108
(Subpath start)
G01 Z-2.000000 F100.0(Penetrate)
G03 X98.014837 Y8.599483 Z-2.000000 I111.941419 J-64.802747 F400.000000
G03 X97.302961 Y7.308192 Z-2.000000 I83.630257 J-46.946388
G02 X96.554662 Y6.051748 Z-2.000000 I-12.837491 J6.794556
G02 X95.493411 Y4.591015 Z-2.000000 I-18.428243 J12.272599
G02 X94.475296 Y3.488417 Z-2.000000 I-9.089873 J7.372046
G02 X93.418663 Y2.614900 Z-2.000000 I-6.735803 J7.072007
G02 X92.236410 Y1.967386 Z-2.000000 I-2.575581 J3.299523
G02 X90.969526 Y1.750340 Z-2.000000 I-1.266884 J3.588846
G02 X88.752038 Y2.367941 Z-2.000000 I0.000000 J4.289730
G02 X86.367647 Y4.529276 Z-2.000000 I4.334252 J7.177461
G02 X84.691711 Y7.549682 Z-2.000000 I11.618043 J8.421683
G02 X82.779739 Y13.360072 Z-2.000000 I41.688483 J16.937822
G02 X81.562557 Y19.275252 Z-2.000000 I62.284419 J15.899250
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G02 X80.439803 Y28.242748 Z-2.000000 I142.211903 J22.359337
G02 X79.836729 Y37.331638 Z-2.000000 I172.619293 J16.018234
G02 X79.597426 Y49.300802 Z-2.000000 I299.209680 J11.969164
G02 X79.823965 Y60.653280 Z-2.000000 I284.565098 J-0.000000
G02 X80.408601 Y69.617813 Z-2.000000 I177.983679 J-7.106161
G02 X81.499751 Y78.525073 Z-2.000000 I141.662486 J-12.833348
G02 X82.748543 Y84.747504 Z-2.000000 I70.308696 J-10.873865
G02 X84.599720 Y90.575285 Z-2.000000 I45.666225 J-11.297843
G02 X86.320850 Y93.887073 Z-2.000000 I16.324030 J-6.380438
G02 X88.786291 Y96.363675 Z-2.000000 I7.543753 J-5.044290
G02 X90.985127 Y97.036520 Z-2.000000 I2.198836 J-3.256438
G02 X92.699468 Y96.646136 Z-2.000000 I0.000000 J-3.959386
G02 X94.713427 Y95.245661 Z-2.000000 I-3.336974 J-6.947082
G02 X96.351294 Y93.281361 Z-2.000000 I-7.873586 J-8.230121
G02 X98.862923 Y88.946767 Z-2.000000 I-36.493746 J-24.040831
G01 X98.862923 Y74.434622 Z-2.000000
G01 X98.628926 Y74.434622 Z-2.000000
G03 X96.417081 Y80.659131 Z-2.000000 I-65.293461 J-19.696443
G03 X94.822627 Y83.697688 Z-2.000000 I-17.022181 J-6.994607
G03 X92.614965 Y86.010097 Z-2.000000 I-7.261074 J-4.722130
G03 X90.782332 Y86.600121 Z-2.000000 I-1.832634 J-2.551095
G03 X89.287117 Y86.118935 Z-2.000000 I0.000000 J-2.563672
G03 X87.600014 Y84.315234 Z-2.000000 I3.696610 J-5.148521
G03 X86.460145 Y81.981654 Z-2.000000 I10.102256 J-6.379763
G03 X85.088479 Y77.337055 Z-2.000000 I39.091805 J-14.069635
G03 X84.213455 Y72.673649 Z-2.000000 I53.924179 J-12.531927
G03 X83.403725 Y65.603826 Z-2.000000 I123.258656 J-17.698493
G03 X82.979161 Y58.556818 Z-2.000000 I147.618067 J-12.429896
G03 X82.810941 Y49.300802 Z-2.000000 I254.563109 J-9.256016
G03 X83.001181 Y39.614357 Z-2.000000 I246.697539 J-0.000000
G03 X83.466123 Y32.627267 Z-2.000000 I128.778977 J5.060339
G03 X84.323942 Y25.680217 Z-2.000000 I128.921582 J12.392696
G03 X85.182079 Y21.264569 Z-2.000000 I52.886238 J7.986696
G03 X86.542259 Y16.810192 Z-2.000000 I36.667156 J8.761752
G03 X87.724810 Y14.471646 Z-2.000000 I11.177657 J4.184028
G03 X89.423356 Y12.748352 Z-2.000000 I5.529628 J3.751494
G03 X90.813533 Y12.310256 Z-2.000000 I1.390177 J1.986626
G03 X92.709431 Y12.924379 Z-2.000000 I0.000000 J3.233535
G03 X94.994221 Y15.336186 Z-2.000000 I-5.268734 J7.279391
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G03 X96.632189 Y18.502648 Z-2.000000 I-15.786881 J10.173221
G03 X98.644527 Y24.413997 Z-2.000000 I-53.460909 J21.497331
G01 X98.862923 Y24.413997 Z-2.000000
G01 X98.862923 Y10.087108 Z-2.000000
(Subpath end)
G00 Z5.000000

(path id: path2296 at depth step: -3.0)
(path len: 265.27305)
G00 Z5.000000
G00 X98.862923 Y10.087108
(Subpath start)
G01 Z-3.000000 F100.0(Penetrate)
G03 X98.014837 Y8.599483 Z-3.000000 I111.941419 J-64.802747 F400.000000
G03 X97.302961 Y7.308192 Z-3.000000 I83.630257 J-46.946388
G02 X96.554662 Y6.051748 Z-3.000000 I-12.837491 J6.794556
G02 X95.493411 Y4.591015 Z-3.000000 I-18.428243 J12.272599
G02 X94.475296 Y3.488417 Z-3.000000 I-9.089873 J7.372046
G02 X93.418663 Y2.614900 Z-3.000000 I-6.735803 J7.072007
G02 X92.236410 Y1.967386 Z-3.000000 I-2.575581 J3.299523
G02 X90.969526 Y1.750340 Z-3.000000 I-1.266884 J3.588846
G02 X88.752038 Y2.367941 Z-3.000000 I0.000000 J4.289730
G02 X86.367647 Y4.529276 Z-3.000000 I4.334252 J7.177461
G02 X84.691711 Y7.549682 Z-3.000000 I11.618043 J8.421683
G02 X82.779739 Y13.360072 Z-3.000000 I41.688483 J16.937822
G02 X81.562557 Y19.275252 Z-3.000000 I62.284419 J15.899250
G02 X80.439803 Y28.242748 Z-3.000000 I142.211903 J22.359337
G02 X79.836729 Y37.331638 Z-3.000000 I172.619293 J16.018234
G02 X79.597426 Y49.300802 Z-3.000000 I299.209680 J11.969164
G02 X79.823965 Y60.653280 Z-3.000000 I284.565098 J-0.000000
G02 X80.408601 Y69.617813 Z-3.000000 I177.983679 J-7.106161
G02 X81.499751 Y78.525073 Z-3.000000 I141.662486 J-12.833348
G02 X82.748543 Y84.747504 Z-3.000000 I70.308696 J-10.873865
G02 X84.599720 Y90.575285 Z-3.000000 I45.666225 J-11.297843
G02 X86.320850 Y93.887073 Z-3.000000 I16.324030 J-6.380438
G02 X88.786291 Y96.363675 Z-3.000000 I7.543753 J-5.044290
G02 X90.985127 Y97.036520 Z-3.000000 I2.198836 J-3.256438
G02 X92.699468 Y96.646136 Z-3.000000 I0.000000 J-3.959386
G02 X94.713427 Y95.245661 Z-3.000000 I-3.336974 J-6.947082
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G02 X96.351294 Y93.281361 Z-3.000000 I-7.873586 J-8.230121

G02 X98.862923 Y88.946767 Z-3.000000 I-36.493746 J-24.040831

G01 X98.862923 Y74.434622 Z-3.000000

G01 X98.628926 Y74.434622 Z-3.000000

G03 X96.417081 Y80.659131 Z-3.000000 I-65.293461 J-19.696443

G03 X94.822627 Y83.697688 Z-3.000000 I-17.022181 J-6.994607

G03 X92.614965 Y86.010097 Z-3.000000 I-7.261074 J-4.722130

G03 X90.782332 Y86.600121 Z-3.000000 I-1.832634 J-2.551095

G03 X89.287117 Y86.118935 Z-3.000000 I0.000000 J-2.563672

G03 X87.600014 Y84.315234 Z-3.000000 I3.696610 J-5.148521

G03 X86.460145 Y81.981654 Z-3.000000 I10.102256 J-6.379763

G03 X85.088479 Y77.337055 Z-3.000000 I39.091805 J-14.069635

G03 X84.213455 Y72.673649 Z-3.000000 I53.924179 J-12.531927

G03 X83.403725 Y65.603826 Z-3.000000 I123.258656 J-17.698493

G03 X82.979161 Y58.556818 Z-3.000000 I147.618067 J-12.429896

G03 X82.810941 Y49.300802 Z-3.000000 I254.563109 J-9.256016

G03 X83.001181 Y39.614357 Z-3.000000 I246.697539 J-0.000000

G03 X83.466123 Y32.627267 Z-3.000000 I128.778977 J5.060339

G03 X84.323942 Y25.680217 Z-3.000000 I128.921582 J12.392696

G03 X85.182079 Y21.264569 Z-3.000000 I52.886238 J7.986696

G03 X86.542259 Y16.810192 Z-3.000000 I36.667156 J8.761752

G03 X87.724810 Y14.471646 Z-3.000000 I11.177657 J4.184028

G03 X89.423356 Y12.748352 Z-3.000000 I5.529628 J3.751494

G03 X90.813533 Y12.310256 Z-3.000000 I1.390177 J1.986626

G03 X92.709431 Y12.924379 Z-3.000000 I0.000000 J3.233535

G03 X94.994221 Y15.336186 Z-3.000000 I-5.268734 J7.279391

G03 X96.632189 Y18.502648 Z-3.000000 I-15.786881 J10.173221

G03 X98.644527 Y24.413997 Z-3.000000 I-53.460909 J21.497331

G01 X98.862923 Y24.413997 Z-3.000000

G01 X98.862923 Y10.087108 Z-3.000000

(Subpath end)

G00 Z5.000000

(path id: path2296 at depth step: -4.0)

(path len: 265.27305)

G00 Z5.000000

G00 X98.862923 Y10.087108

(Subpath start)

G01 Z-4.000000 F100.0(Penetrate)

```
G03 X98.014837 Y8.599483 Z-4.000000 I111.941419 J-64.802747 F400.000000
G03 X97.302961 Y7.308192 Z-4.000000 I83.630257 J-46.946388
G02 X96.554662 Y6.051748 Z-4.000000 I-12.837491 J6.794556
G02 X95.493411 Y4.591015 Z-4.000000 I-18.428243 J12.272599
G02 X94.475296 Y3.488417 Z-4.000000 I-9.089873 J7.372046
G02 X93.418663 Y2.614900 Z-4.000000 I-6.735803 J7.072007
G02 X92.236410 Y1.967386 Z-4.000000 I-2.575581 J3.299523
G02 X90.969526 Y1.750340 Z-4.000000 I-1.266884 J3.588846
G02 X88.752038 Y2.367941 Z-4.000000 I0.000000 J4.289730
G02 X86.367647 Y4.529276 Z-4.000000 I4.334252 J7.177461
G02 X84.691711 Y7.549682 Z-4.000000 I11.618043 J8.421683
G02 X82.779739 Y13.360072 Z-4.000000 I41.688483 J16.937822
G02 X81.562557 Y19.275252 Z-4.000000 I62.284419 J15.899250
G02 X80.439803 Y28.242748 Z-4.000000 I142.211903 J22.359337
G02 X79.836729 Y37.331638 Z-4.000000 I172.619293 J16.018234
G02 X79.597426 Y49.300802 Z-4.000000 I299.209680 J11.969164
G02 X79.823965 Y60.653280 Z-4.000000 I284.565098 J-0.000000
G02 X80.408601 Y69.617813 Z-4.000000 I177.983679 J-7.106161
G02 X81.499751 Y78.525073 Z-4.000000 I141.662486 J-12.833348
G02 X82.748543 Y84.747504 Z-4.000000 I70.308696 J-10.873865
G02 X84.599720 Y90.575285 Z-4.000000 I45.666225 J-11.297843
G02 X86.320850 Y93.887073 Z-4.000000 I16.324030 J-6.380438
G02 X88.786291 Y96.363675 Z-4.000000 I7.543753 J-5.044290
G02 X90.985127 Y97.036520 Z-4.000000 I2.198836 J-3.256438
G02 X92.699468 Y96.646136 Z-4.000000 I0.000000 J-3.959386
G02 X94.713427 Y95.245661 Z-4.000000 I-3.336974 J-6.947082
G02 X96.351294 Y93.281361 Z-4.000000 I-7.873586 J-8.230121
G02 X98.862923 Y88.946767 Z-4.000000 I-36.493746 J-24.040831
G01 X98.862923 Y74.434622 Z-4.000000
G01 X98.628926 Y74.434622 Z-4.000000
G03 X96.417081 Y80.659131 Z-4.000000 I-65.293461 J-19.696443
G03 X94.822627 Y83.697688 Z-4.000000 I-17.022181 J-6.994607
G03 X92.614965 Y86.010097 Z-4.000000 I-7.261074 J-4.722130
G03 X90.782332 Y86.600121 Z-4.000000 I-1.832634 J-2.551095
G03 X89.287117 Y86.118935 Z-4.000000 I0.000000 J-2.563672
G03 X87.600014 Y84.315234 Z-4.000000 I3.696610 J-5.148521
G03 X86.460145 Y81.981654 Z-4.000000 I10.102256 J-6.379763
G03 X85.088479 Y77.337055 Z-4.000000 I39.091805 J-14.069635
G03 X84.213455 Y72.673649 Z-4.000000 I53.924179 J-12.531927
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G03 X83.403725 Y65.603826 Z-4.000000 I123.258656 J-17.698493

G03 X82.979161 Y58.556818 Z-4.000000 I147.618067 J-12.429896

G03 X82.810941 Y49.300802 Z-4.000000 I254.563109 J-9.256016

G03 X83.001181 Y39.614357 Z-4.000000 I246.697539 J-0.000000

G03 X83.466123 Y32.627267 Z-4.000000 I128.778977 J5.060339

G03 X84.323942 Y25.680217 Z-4.000000 I128.921582 J12.392696

G03 X85.182079 Y21.264569 Z-4.000000 I52.886238 J7.986696

G03 X86.542259 Y16.810192 Z-4.000000 I36.667156 J8.761752

G03 X87.724810 Y14.471646 Z-4.000000 I11.177657 J4.184028

G03 X89.423356 Y12.748352 Z-4.000000 I5.529628 J3.751494

G03 X90.813533 Y12.310256 Z-4.000000 I1.390177 J1.986626

G03 X92.709431 Y12.924379 Z-4.000000 I0.000000 J3.233535

G03 X94.994221 Y15.336186 Z-4.000000 I-5.268734 J7.279391

G03 X96.632189 Y18.502648 Z-4.000000 I-15.786881 J10.173221

G03 X98.644527 Y24.413997 Z-4.000000 I-53.460909 J21.497331

G01 X98.862923 Y24.413997 Z-4.000000

G01 X98.862923 Y10.087108 Z-4.000000

(Subpath end)

G00 Z5.000000

(End cutting path id: path2296 at depth: -4.0)

(Start cutting path id: path2294 at depth: -4.0)

(path id: path2294 at depth step: -1.0)

(path len: 223.27632)

G00 Z5.000000

G00 X78.396256 Y84.500490

(Subpath start)

G01 Z-1.000000 F100.0(Penetrate)

G01 X70.097274 Y84.500490 Z-1.000000 F400.000000

G01 X70.097274 Y3.417702 Z-1.000000

G01 X67.008556 Y3.417702 Z-1.000000

G01 X67.008556 Y84.500490 Z-1.000000

G01 X58.709574 Y84.500490 Z-1.000000

G01 X58.709574 Y95.369179 Z-1.000000

G01 X78.396256 Y95.369179 Z-1.000000

G01 X78.396256 Y84.500490 Z-1.000000

(Subpath end)

G00 Z5.000000

```
(path id: path2294 at depth step: -2.0)
(path len: 223.27632)
G00 Z5.000000
G00 X78.396256 Y84.500490
(Subpath start)
G01 Z-2.000000 F100.0(Penetrate)
G01 X70.097274 Y84.500490 Z-2.000000 F400.000000
G01 X70.097274 Y3.417702 Z-2.000000
G01 X67.008556 Y3.417702 Z-2.000000
G01 X67.008556 Y84.500490 Z-2.000000
G01 X58.709574 Y84.500490 Z-2.000000
G01 X58.709574 Y95.369179 Z-2.000000
G01 X78.396256 Y95.369179 Z-2.000000
G01 X78.396256 Y84.500490 Z-2.000000
(Subpath end)
G00 Z5.000000

(path id: path2294 at depth step: -3.0)
(path len: 223.27632)
G00 Z5.000000
G00 X78.396256 Y84.500490
(Subpath start)
G01 Z-3.000000 F100.0(Penetrate)
G01 X70.097274 Y84.500490 Z-3.000000 F400.000000
G01 X70.097274 Y3.417702 Z-3.000000
G01 X67.008556 Y3.417702 Z-3.000000
G01 X67.008556 Y84.500490 Z-3.000000
G01 X58.709574 Y84.500490 Z-3.000000
G01 X58.709574 Y95.369179 Z-3.000000
G01 X78.396256 Y95.369179 Z-3.000000
G01 X78.396256 Y84.500490 Z-3.000000
(Subpath end)
G00 Z5.000000

(path id: path2294 at depth step: -4.0)
(path len: 223.27632)
G00 Z5.000000
G00 X78.396256 Y84.500490
```

```
(Subpath start)
G01 Z-4.000000 F100.0(Penetrate)
G01 X70.097274 Y84.500490 Z-4.000000 F400.000000
G01 X70.097274 Y3.417702 Z-4.000000
G01 X67.008556 Y3.417702 Z-4.000000
G01 X67.008556 Y84.500490 Z-4.000000
G01 X58.709574 Y84.500490 Z-4.000000
G01 X58.709574 Y95.369179 Z-4.000000
G01 X78.396256 Y95.369179 Z-4.000000
G01 X78.396256 Y84.500490 Z-4.000000
(Subpath end)
G00 Z5.000000

(End cutting path id: path2294 at depth: -4.0)

(Start cutting path id: path2292 at depth: -4.0)
(path id: path2292 at depth step: -1.0)
(path len: 380.70228)
G00 Z5.000000
G00 X58.350781 Y3.417702
(Subpath start)
G01 Z-1.000000 F100.0(Penetrate)
G01 X54.341687 Y3.417702 Z-1.000000 F400.000000
G01 X45.153528 Y44.360496 Z-1.000000
G01 X42.844789 Y34.603382 Z-1.000000
G01 X42.844789 Y3.417702 Z-1.000000
G01 X39.756070 Y3.417702 Z-1.000000
G01 X39.756070 Y95.369179 Z-1.000000
G01 X42.844789 Y95.369179 Z-1.000000
G01 X42.844789 Y47.386426 Z-1.000000
G01 X54.123296 Y95.369179 Z-1.000000
G01 X57.867197 Y95.369179 Z-1.000000
G01 X47.493467 Y52.141477 Z-1.000000
G01 X58.350781 Y3.417702 Z-1.000000
(Subpath end)
G00 Z5.000000

(path id: path2292 at depth step: -2.0)
(path len: 380.70228)
```

```
G00 Z5.000000
G00 X58.350781 Y3.417702
(Subpath start)
G01 Z-2.000000 F100.0(Penetrate)
G01 X54.341687 Y3.417702 Z-2.000000 F400.000000
G01 X45.153528 Y44.360496 Z-2.000000
G01 X42.844789 Y34.603382 Z-2.000000
G01 X42.844789 Y3.417702 Z-2.000000
G01 X39.756070 Y3.417702 Z-2.000000
G01 X39.756070 Y95.369179 Z-2.000000
G01 X42.844789 Y95.369179 Z-2.000000
G01 X42.844789 Y47.386426 Z-2.000000
G01 X54.123296 Y95.369179 Z-2.000000
G01 X57.867197 Y95.369179 Z-2.000000
G01 X47.493467 Y52.141477 Z-2.000000
G01 X58.350781 Y3.417702 Z-2.000000
(Subpath end)
G00 Z5.000000

(path id: path2292 at depth step: -3.0)
(path len: 380.70228)
G00 Z5.000000
G00 X58.350781 Y3.417702
(Subpath start)
G01 Z-3.000000 F100.0(Penetrate)
G01 X54.341687 Y3.417702 Z-3.000000 F400.000000
G01 X45.153528 Y44.360496 Z-3.000000
G01 X42.844789 Y34.603382 Z-3.000000
G01 X42.844789 Y3.417702 Z-3.000000
G01 X39.756070 Y3.417702 Z-3.000000
G01 X39.756070 Y95.369179 Z-3.000000
G01 X42.844789 Y95.369179 Z-3.000000
G01 X42.844789 Y47.386426 Z-3.000000
G01 X54.123296 Y95.369179 Z-3.000000
G01 X57.867197 Y95.369179 Z-3.000000
G01 X47.493467 Y52.141477 Z-3.000000
G01 X58.350781 Y3.417702 Z-3.000000
(Subpath end)
G00 Z5.000000
```

```
(path id: path2292 at depth step: -4.0)
(path len: 380.70228)
G00 Z5.000000
G00 X58.350781 Y3.417702
(Subpath start)
G01 Z-4.000000 F100.0(Penetrate)
G01 X54.341687 Y3.417702 Z-4.000000 F400.000000
G01 X45.153528 Y44.360496 Z-4.000000
G01 X42.844789 Y34.603382 Z-4.000000
G01 X42.844789 Y3.417702 Z-4.000000
G01 X39.756070 Y3.417702 Z-4.000000
G01 X39.756070 Y95.369179 Z-4.000000
G01 X42.844789 Y95.369179 Z-4.000000
G01 X42.844789 Y47.386426 Z-4.000000
G01 X54.123296 Y95.369179 Z-4.000000
G01 X57.867197 Y95.369179 Z-4.000000
G01 X47.493467 Y52.141477 Z-4.000000
G01 X58.350781 Y3.417702 Z-4.000000
(Subpath end)
G00 Z5.000000

(End cutting path id: path2292 at depth: -4.0)

(Start cutting path id: path2290 at depth: -4.0)
(path id: path2290 at depth step: -1.0)
(path len: 214.41575)
G00 Z5.000000
G00 X34.389809 Y3.417702
(Subpath start)
G01 Z-1.000000 F100.0(Penetrate)
G01 X25.217250 Y3.417702 Z-1.000000 F400.000000
G01 X25.217250 Y12.804285 Z-1.000000
G01 X28.259170 Y12.804285 Z-1.000000
G01 X28.259170 Y85.982595 Z-1.000000
G01 X25.217250 Y85.982595 Z-1.000000
G01 X25.217250 Y95.369179 Z-1.000000
G01 X34.389809 Y95.369179 Z-1.000000
G01 X34.389809 Y85.982595 Z-1.000000
```

G01 X31.347889 Y85.982595 Z-1.000000

G01 X31.347889 Y12.804285 Z-1.000000

G01 X34.389809 Y12.804285 Z-1.000000

G01 X34.389809 Y3.417702 Z-1.000000

(Subpath end)

G00 Z5.000000

(path id: path2290 at depth step: -2.0)

(path len: 214.41575)

G00 Z5.000000

G00 X34.389809 Y3.417702

(Subpath start)

G01 Z-2.000000 F100.0(Penetrate)

G01 X25.217250 Y3.417702 Z-2.000000 F400.000000

G01 X25.217250 Y12.804285 Z-2.000000

G01 X28.259170 Y12.804285 Z-2.000000

G01 X28.259170 Y85.982595 Z-2.000000

G01 X25.217250 Y85.982595 Z-2.000000

G01 X25.217250 Y95.369179 Z-2.000000

G01 X34.389809 Y95.369179 Z-2.000000

G01 X34.389809 Y85.982595 Z-2.000000

G01 X31.347889 Y85.982595 Z-2.000000

G01 X31.347889 Y12.804285 Z-2.000000

G01 X34.389809 Y12.804285 Z-2.000000

G01 X34.389809 Y3.417702 Z-2.000000

(Subpath end)

G00 Z5.000000

(path id: path2290 at depth step: -3.0)

(path len: 214.41575)

G00 Z5.000000

G00 X34.389809 Y3.417702

(Subpath start)

G01 Z-3.000000 F100.0(Penetrate)

G01 X25.217250 Y3.417702 Z-3.000000 F400.000000

G01 X25.217250 Y12.804285 Z-3.000000

G01 X28.259170 Y12.804285 Z-3.000000

G01 X28.259170 Y85.982595 Z-3.000000

G01 X25.217250 Y85.982595 Z-3.000000

```
G01 X25.217250 Y95.369179 Z-3.000000
G01 X34.389809 Y95.369179 Z-3.000000
G01 X34.389809 Y85.982595 Z-3.000000
G01 X31.347889 Y85.982595 Z-3.000000
G01 X31.347889 Y12.804285 Z-3.000000
G01 X34.389809 Y12.804285 Z-3.000000
G01 X34.389809 Y3.417702 Z-3.000000
(Subpath end)
G00 Z5.000000

(path id: path2290 at depth step: -4.0)
(path len: 214.41575)
G00 Z5.000000
G00 X34.389809 Y3.417702
(Subpath start)
G01 Z-4.000000 F100.0(Penetrate)
G01 X25.217250 Y3.417702 Z-4.000000 F400.000000
G01 X25.217250 Y12.804285 Z-4.000000
G01 X28.259170 Y12.804285 Z-4.000000
G01 X28.259170 Y85.982595 Z-4.000000
G01 X25.217250 Y85.982595 Z-4.000000
G01 X25.217250 Y95.369179 Z-4.000000
G01 X34.389809 Y95.369179 Z-4.000000
G01 X34.389809 Y85.982595 Z-4.000000
G01 X31.347889 Y85.982595 Z-4.000000
G01 X31.347889 Y12.804285 Z-4.000000
G01 X34.389809 Y12.804285 Z-4.000000
G01 X34.389809 Y3.417702 Z-4.000000
(Subpath end)
G00 Z5.000000

(End cutting path id: path2290 at depth: -4.0)

(Start cutting path id: path2288 at depth: -4.0)
(path id: path2288 at depth step: -1.0)
(path len: 256.72792)
G00 Z5.000000
G00 X22.674517 Y3.417702
(Subpath start)
```

```
G01 Z-1.000000 F100.0(Penetrate)
G01 X19.383003 Y3.417702 Z-1.000000 F400.000000
G01 X17.105462 Y29.045550 Z-1.000000
G01 X7.059325 Y29.045550 Z-1.000000
G01 X4.781785 Y3.417702 Z-1.000000
G01 X1.646267 Y3.417702 Z-1.000000
G01 X10.101246 Y95.369179 Z-1.000000
G01 X14.219538 Y95.369179 Z-1.000000
G01 X22.674517 Y3.417702 Z-1.000000
(Subpath end)
G00 Z5.000000

(path id: path2288 at depth step: -2.0)
(path len: 256.72792)
G00 Z5.000000
G00 X22.674517 Y3.417702
(Subpath start)
G01 Z-2.000000 F100.0(Penetrate)
G01 X19.383003 Y3.417702 Z-2.000000 F400.000000
G01 X17.105462 Y29.045550 Z-2.000000
G01 X7.059325 Y29.045550 Z-2.000000
G01 X4.781785 Y3.417702 Z-2.000000
G01 X1.646267 Y3.417702 Z-2.000000
G01 X10.101246 Y95.369179 Z-2.000000
G01 X14.219538 Y95.369179 Z-2.000000
G01 X22.674517 Y3.417702 Z-2.000000
(Subpath end)
G00 Z5.000000

(path id: path2288 at depth step: -3.0)
(path len: 256.72792)
G00 Z5.000000
G00 X22.674517 Y3.417702
(Subpath start)
G01 Z-3.000000 F100.0(Penetrate)
G01 X19.383003 Y3.417702 Z-3.000000 F400.000000
G01 X17.105462 Y29.045550 Z-3.000000
G01 X7.059325 Y29.045550 Z-3.000000
G01 X4.781785 Y3.417702 Z-3.000000
```

```
G01 X1.646267 Y3.417702 Z-3.000000
G01 X10.101246 Y95.369179 Z-3.000000
G01 X14.219538 Y95.369179 Z-3.000000
G01 X22.674517 Y3.417702 Z-3.000000
(Subpath end)
G00 Z5.000000

(path id: path2288 at depth step: -4.0)
(path len: 256.72792)
G00 Z5.000000
G00 X22.674517 Y3.417702
(Subpath start)
G01 Z-4.000000 F100.0(Penetrate)
G01 X19.383003 Y3.417702 Z-4.000000 F400.000000
G01 X17.105462 Y29.045550 Z-4.000000
G01 X7.059325 Y29.045550 Z-4.000000
G01 X4.781785 Y3.417702 Z-4.000000
G01 X1.646267 Y3.417702 Z-4.000000
G01 X10.101246 Y95.369179 Z-4.000000
G01 X14.219538 Y95.369179 Z-4.000000
G01 X22.674517 Y3.417702 Z-4.000000
(Subpath end)
G00 Z5.000000

(End cutting path id: path2288 at depth: -4.0)

(Start cutting path id: path2288 at depth: -4.0)
(path id: path2288 at depth step: -1.0)
(path len: 98.81062)
G00 Z5.000000
G00 X16.153887 Y39.543688
(Subpath start)
G01 Z-1.000000 F100.0(Penetrate)
G01 X12.082394 Y84.685765 Z-1.000000 F400.000000
G01 X7.995301 Y39.543688 Z-1.000000
G01 X16.153887 Y39.543688 Z-1.000000
(Subpath end)
G00 Z5.000000
```

```
(path id: path2288 at depth step: -2.0)
(path len: 98.81062)
G00 Z5.000000
G00 X16.153887 Y39.543688
(Subpath start)
G01 Z-2.000000 F100.0(Penetrate)
(Subpath end)
G00 Z5.000000

(path id: path2288 at depth step: -3.0)
(path len: 98.81062)
G00 Z5.000000
G00 X16.153887 Y39.543688
(Subpath start)
G01 Z-3.000000 F100.0(Penetrate)
G01 X12.082394 Y84.685765 Z-3.000000 F400.000000
G01 X7.995301 Y39.543688 Z-3.000000
G01 X16.153887 Y39.543688 Z-3.000000
(Subpath end)
G00 Z5.000000

(path id: path2288 at depth step: -4.0)
(path len: 98.81062)
G00 Z5.000000
G00 X16.153887 Y39.543688
(Subpath start)
G01 Z-4.000000 F100.0(Penetrate)
G01 X12.082394 Y84.685765 Z-4.000000 F400.000000
G01 X7.995301 Y39.543688 Z-4.000000
G01 X16.153887 Y39.543688 Z-4.000000
(Subpath end)
G00 Z5.000000

(End cutting path id: path2288 at depth: -4.0)

(Footer)
M5
G00 X0.0000 Y0.0000
M2
```

CONCLUSIONS AND FUTURE SCOPE

CONCLUSIONS

With the increasing demand for small scale high precision parts in various industries, the market for small scale machine tools has grown substantially. Using small machine tools to fabricate small scale parts can provide both flexibility and efficiency in manufacturing approaches and reduce capital cost, which is beneficial for small business owners. In this thesis, a small scale three axis CNC milling machine is designed and analysed under very limited budget.

The conclusions drawn from the present study work are as follows:

- The design of machine structure is safe for the standard gravity force
- The design of machine structure is safe for maximum feed rate value of 80 mm/min and maximum depth of cut of 3 mm with tool of 6 mm diameter, in addition considering a factor of safety is 2
- The router mounting is also safe under the required usage conditions. The design for this subassembly can be further strengthened by changing the thickness or the material of aluminum plate used for clamping of router mounting.
- The maximum slippage observed in the router after application of reaction cutting force is also under safe limits.
- Assembly of components of the prototype was convenient as expected as there were no deflections due to self-weight of machine components/subassemblies.

FUTURE SCOPE

- It is planned to scale up the prototype CNC machine in terms of size, use more powerful motors, strengthen the frame and worktable with materials like aluminium or cast iron, and augment the CNC control.
- FUTURE Scope of this project is to make it compatible with various software for simulation ahead of actual run. For instructional purposes as well as for more precise operation
- It is preferable to build CNC machines with DC or AC servomotors and encoder feedback using PC based motion controllers. It is planned to implement the multi axis about 4 to 6 axis CNC routers. The implementation of 3D printing (Rapid prototyping) technology to the same hardware abstract is ongoing plan for printing 3D models
- The present work has been more focused towards FEM analysis for the structural strength of the machine components. A lot of work can be carried out on the structural behaviour considering the machine components made up of machine grade steels or high strength alloys, along with the trend of change in cost of material and cost of manufacturing.
- Study of vibration characteristics of the machine tool can also be explored as well as dynamics characteristics of router assembly and machine tool as a whole. Refinement and up gradation of conceptual machine design for optimisation of weight/strength ratio of the machine tool can be carried out.

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