Visvesvaraya Technological University

Belgaum, Karnataka-590 018

An Project Report on

"IMPLEMENTATION OF CNC MACHINE FOR AUTOMATIC DRILLING ON PCB"

Project Report submitted in partial fulfillment of the requirement for the award of the degree of

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In

Electrical & Electronics Engineering

Submitted by

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Certificate

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DECLARATION

We, [Mr. **Sharath Kumar N (1CR16EE074),** Mr. **Sangamesh S Banigol (1CR16EE067)**, Mr**. Vinodh Prasad M (1CR16EE091)**, Mr. **Nandeesh A N (1CR16EE402)],** hereby declare that the report entitled **"Implementation of CNC Machine for Automatic Drilling on PCB"**has been carried out by us under the guidance of **Dr. M Lakshmanan,** Assistant Professor, Department of Electrical & Electronics Engineering, CMR Institute of Technology, Bengaluru, in partial fulfillment of the requirement for the degree of **BACHELOR OF ENGINEERING in ELECTRICAL & ELECTRONICS ENGINEERING**, of Visveswaraya Technological University, Belgaum during the academic year 2019-20.The work done in this report is original and it has not been submitted for any other degree in any university.

Place: Bangalore

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ABSTRACT

This report aims to explore the theories and techniques behind procedures of developing a high precision cost-effective CNC milling machine. This newly designed machine tool can be widely used in any industry where small parts are made. Various structures were explored and compared during the manufacturing stage while keeping in mind the limited resources we had at our disposal.

Acknowledgement

The satisfaction and euphoria that accompany the successful completion of any task would be incomplete without the mention of people, who are responsible for the completion of the project and who made it possible, because success is outcome of hard work and perseverance, but steadfast of all is encouraging guidance. So with gratitude I acknowledge all those whose guidance and encouragement served us to motivate towards the success of the internship work.

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Introduction

In modern CNC systems, end-to-end component design is highly automated using Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) programs. The programs produce a computer file that is interpreted to extract the commands needed to operate a particular machine via a post processor, and then loaded into the CNC machines for production. Since any particular component might require the use of a number of different tools – drills, saws, etc., modern machines often combine multiple tools into a single "cell". In other installations, a number of different machines are used with an external controller and human or robotic operators that move the component from machine to machine. In either case, the series of steps needed to produce any part is highly automated and produces a part that matches the original CAD design as per acceptable tolerances.

With the on-going development of technology and economy, new industrial requirements such as high precision, good quality, high production rates and low production costs are increasingly demanded. Most of such requirements, including dimensional accuracy, conformance to tolerances of finished products and production rate can be met with better machine tools. With the help of CNC technology, machine tools today are not limited to human capabilities but are able to make ultra-precision products down to Nano scales in a much faster manner. The traditional design philosophy of machine tools is multi-functionality and highest precision possible. However, with the dramatic increase of industry varieties and the growing demand of miniature products, these general purpose machine tools are not efficient, either in terms of machining time or cost, in manufacturing products with special sizes and precision requirements.

There are several advantages of using small machines to produce small sized objects. With a smaller machine size, space is saved. The energy required to operate the machine is reduced as well. It now requires less material and components to make the machine, hence bringing down the cost greatly. The weight of moving component also comes down so that during operation, the vibration and noise, as well as pollution to the environment, are markedly reduced. As the machine becomes denser and lighter, it becomes more portable. The layout of the manufacturing plant can be more flexible. The productivity and manufacturing speed also increases due to possible faster operation.

Objective:

The idea behind fabrication of low cost CNC Milling Machine is to full fill the demand of CNC machines from small scale to large scale industries with optimized low cost. A major new development in computer technology is the availability of low-cost open source hardware, such as the Arduino microcontroller. An advantage of open source hardware is that a wide variety of ready-to-use software is available for them on the Web; therefore the prototyping and development times are drastically reduced. Moreover, a wide range of low-cost interfaces and accessories such as Mach3 CNC control software are also available. However, for the development of low-cost models of CNC machines, such tools may be quite adequate from the viewpoint of machine control. In this project, the development of a prototype 3-axis CNC Milling Machine is presented with the following specification.

- Easily operable
- Easy interface
- Flexible
- Low power consumption

Methodology:

This project has been classified into the following modules for successful execution:

- Mechanical Design
- Electronics and Control Module
- Software Module

How this system works is quite a simple procedure. The machine operator inputs the G and M code into the GUI (Graphic User Interface) which then sends the G and M code to the software which interprets the code and sends the signals to the electronic driver. The driver then runs the motors which are connected to the lead screws that are responsible for the movement of the tool.

Mechanical System

The mechanical system is assembled in such a way that the 3-axis movement is achieved by using the linear bearings and guide rods. Stepper motors are mounted to each axis which is the source of motion acted according to the control signal generated from the electronics circuit. Each stepper motor is coupled to the screw rod which carries nut with the help of coupling bush. This screw rod and nut arrangement is responsible for converting the rotational motion of the stepper motor to linear motion. The linear motion of each axis is carried away smoothly by the linear bearing and guide rod assembly connected to the each axis which is capable of load carriers and allows linear motion in each axis. The controlled motion in each axis is achieved directly by controlling the rotation of the stepper motor. The speed of the motion in each axis can also be controlled by direct control of the speed of the stepper motor by giving required control signals. Thus the tool path of the spindle fixed to the end effector is controlled in each axis for smooth carving or cutting action of work piece.

Electrical System

Electronics system comprises of:

- Power supply
- Microcontroller board
- Stepper motor driver board

Power Supply

Power supply is heart of the CNC system which converts the AC voltage to DC voltage and supplies required voltages to the corresponding devices. Microcontroller board operates at5v supply whereas the stepper motor board operates at 12v.

Stepper Motor Driver Board

Toshiba TB6560, micro-stepping drive designed for smooth and quiet operation is chosen to drive the NEMA 17 stepper motor. Stepper motor Driver Board receives the control signal from the microcontroller board to the terminals PULSE and DIR which generates the corresponding digital pulse signals for stepper motor to control the rotation of the motor.

Software System

The software tool chain of CNC-based manufacturing is represented in the fig 1. The part to be machined is designed in computer-aided design (CAD) software, whose output is a drawing in one of many acceptable formats most preferable format is .stl format. This drawing is then fed to the computer-aided manufacturing (CAM) software, whose output is the machine readable code used for numerical control of the machine. Since implementation of the G code is machine dependent, it is necessary to test out different choices for an open source G code interpreter for Toshiba TB6560, so that the correct motions are obtained for the machine axes through the stepper motor driver.

Conclusion:

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 report, a small scale three axis CNC milling machine is designed and fabricated under very limited budget.

Scope for Future work:

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 aluminum or cast iron, and augment the CNC control software with 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.

CHAPTER 1

1.1 Market Research

The development of NC machine tools has continued for over fifty years in the manufacturing industry. Currently, the technology is reasonably mature and different companies have developed their unique strengths on different products. Europe is the largest machine tool manufacturer in the world [19].

Figure-: 1 Mini CNC Engraving Machine (Picture courtesy: China CNC Zone)

The machine shown in Figure-: 1 is a typical CNC engraving machine made by a Chinese manufacturing company in Changsha. It is claimed to achieve a resolution of 30 μm and repeatability better than 30 μm. The interpretation and interpolation is done using a CNC control package software called Mach3. The machine only costs 500 USD, including everything required to run the machine except a PC. This type of machine is very popular in China. However, because of its low stiffness and controller robustness, it can only machine soft material such as PVC, woods and soft aluminum.

1.2 General Research Objectives

The general objective of this research is to develop a mini CNC machine prototype up to industrially acceptable precision and repeatability with a very limited budget (2,000USD). This research will address all the required procedures for developing a commercial product in a machine tool company, from the early design stage to the subsequent packaging and marketing stage. Various new methods and products is discussed and used to either reduce cost or improve performance.

To accomplish these objectives, this research is divided into a number of tasks. The research tasks can be summarized as follows:

(1) Machine design. The box volume is chosen to come up with an optimal structure and size for the machine as its size depends on the box volume i.e. maximum volume of the work piece that can be incorporated for machining

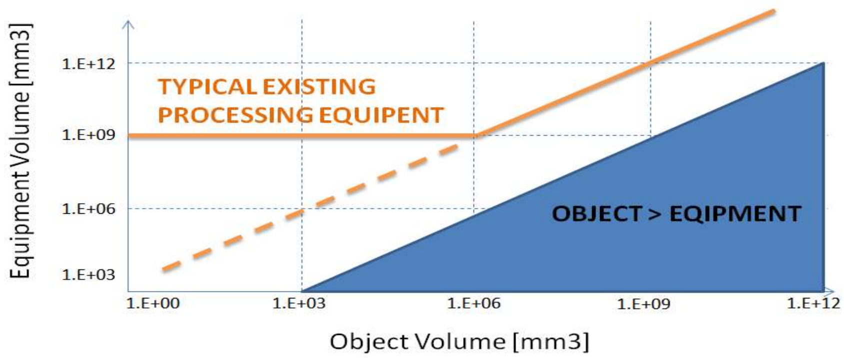


Figure-: 2 Relationship between box volume and machine size

(2) Torque Calculations. Torque required to move the tool in the 3 axes according to the box volume is calculated.

(3) Machine fabrication. All the body parts will be machined and the components will be

purchased through various suppliers.

(4) Assembling the Machine. Machine will be assembled inside the lab.

1.3 Summary

In this chapter an overview of the motivation and procedure of developing a cost-effective mini CNC machine is given. The current market is in lack of an affordable small-scale high precision machine tool system that can be used for small volume production. The machine described in this report will help to solve this problem and serve those who want to make small things but do not want to spend money on big machine.

CHAPTER 2

Literature Review

The first numerical control (NC) milling machine was conceived by Mr. John T. Parsons around 1940s-1950s [14]. Parsons worked to attach servomotors to the x and y axis of a manual operated machine tool to control them with a computer that read punch cards to give it positioning instructions. The reason for devising such a system was to machine complex shapes like arcs that can be made into airfoils for airplanes. This was not a trivial task to attempt with a manual milling machine, so the NC milling machine was born.

Today's modern machinery is CNC (Computer Numeric Control) milling machines and lathes. A microprocessor in each machine reads the G-Code program that the user creates and performs the programmed operations. Personal computers are used to design the parts and are also used to write programs by either manual typing of G-Code or using CAM (Computer Aided Manufacturing) software that outputs G-Code from the users input of cutters and tool path.

In this chapter, some literature relevant to CNC concepts and general design and control of CNC machine will be reviewed. The numerical control aspect are the focus in this review.

2.1 CNC Concepts

An important advance in the philosophy of NC machine tools was the shift toward the use of computers instead of proprietary controller units in the NC system of the early 1970s. This gave rise to the computer numerical control (CNC). CNC is a self-contained NC system for a single machine tool including a dedicated minicomputer controlled by stored instructions to perform some or all of the basic NC functions [1]. It has become widely used for manufacturing systems mainly because of its flexibility and less investment required.

Replacing conventional NC hardware with software as as much possible and simplifying the remaining hardware is one of the objectives of CNC systems. While most interpretation and interpolation functions can be replaced by proper software, the remaining hardware must contain at least servo amplifiers, transducer circuits, and interface components, as shown in Figure-: 3

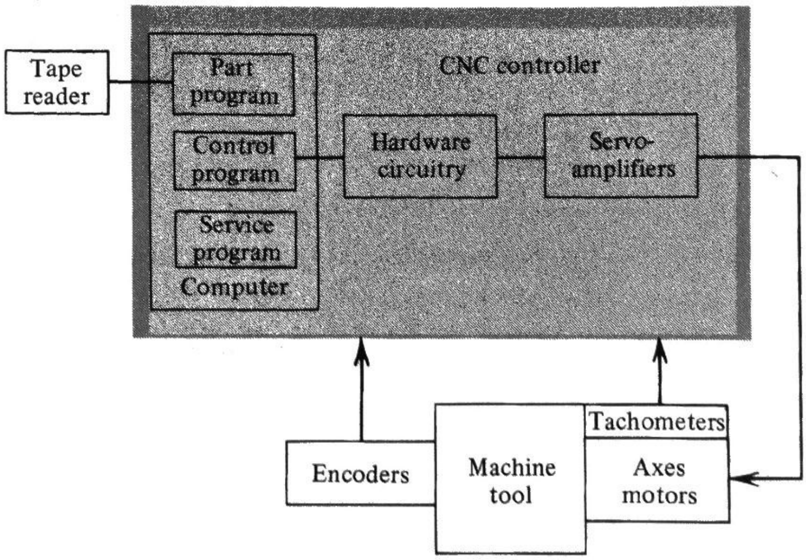


Figure-: 3 Schematic of CNC system

The software portion of a CNC system must consist at least of three major programs: a part program, a service program, and a control program [11]. The part program contains the geometry description of the part being produced and the cutting conditions such as spindle speed and feedrate. Computer Aided Manufacturing (CAM) software can be used to generate this part program. The service program is used to check, edit, and correct the part program. It usually has a user interface that allows the user to operate the machine easily. The control program accepts the part program as input data and produces signals to drive the axes of motion. It performs interpolation, feed rate control, acceleration and deceleration, and position counters showing the current axes position [11].

Most closed-loop CNC systems include both velocity and position control loops. The velocity feedback is usually provided by a tachometer and the position feedback is usually provided by an encoder or resolver. CNC software can also retrieve velocity feedback from encoder by differentiating the input signal [11].

The computer output in CNC systems can be transmitted either as a sequence of reference pulses or as a binary word. If the reference pulse sequence is generated, each pulse generates a motion of 1 BLU of axis travel. The number of pulses represents position and the pulse frequency represents axis velocity. In an open-loop system, these pulses are the control signal of a stepper motor. In a closed-loop system, these pulses can be fed as a reference signal [11]

2.2 Design consideration of CNC machine tools

CNC machine tools must be better designed and constructed, and must be more accurate than conventional machine tools. It is necessary to minimize all non-cutting machine time, by fast tool changing methods, and minimize idle motions by increasing the rapid traverse velocities to make the use of the machine tool more efficient.

Digital control techniques and computers have undoubtedly contributed to better accuracy and higher productivity. However, it should be noted that it is the combined characteristics of the electric control as well as the mechanical design of the machine tool itself that determine the final accuracy and productivity of the CNC machine tool system.

High productivity and accuracy might be contradictory [11]. Becaus high productivity requires higher feed, speed and depth of cut, which increases the heat and cutting forces in the system. This will lead to higher deflections, thermal deformations and vibration of the machine, which results in accuracy deterioration. Therefore, to achieve high operating bandwidth while maintaining relatively high accuracy, the structure of CNC machine tool must be more rigid and stiff than its conventional counterpart.

To achieve better stiffness and rigidity of structure, several factors should be considered in the design. The first concern is the material. Conventional machine tools are made of cast iron. However, the structures of CNC machines are usually all-steel-welded, constructed to achieve greater strength and rigidity for a given weight. In addition, better accuracy is obtained in CNC machines by using low-friction moving parts, avoiding lost motions and isolating thermal sources. Regular sliding guides have higher static friction than the sliding friction. The force used to overcome the static friction grows too large when the guide starts to move. Due to inertia of the slide the position goes beyond the controlled position, adding overshoot and phase lag to the system response, and affects the accuracy and surface finish of the part. This can be avoided by using slides and lead screws in which the static friction is lower than the sliding friction [11]. In our Machine, we are going to use ball-bearing lead screw as shown in Figure-: 4. Detailed discussion of selecting this component will be included in chapter 4.

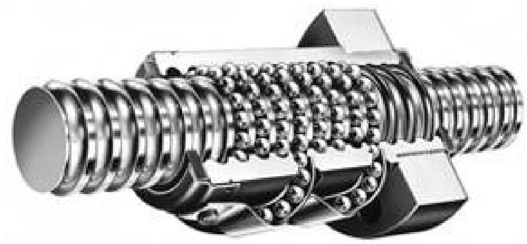


Figure-: 4 Ball-bearing lead screw

Generally speaking, the entire machine component must use rigid and strong material. The spindle should have high strength, sustain a high temperature and be supported by large bearing. The clamp system should be strong enough to hold work piece when the machine faces a moveable part during the manufacturing process. In addition, clamping system should be efficiently moved, fast in clamping or unclamping the work piece with fast movement during the process. The choosing of cutting tools is important in order to make sure it will not break when cutting the work piece[11].

2.3 Summary

In conclusion, this chapter mainly summarizes some key concepts of computer numerical control and design consideration of CNC machine tools mentioned in literature. These concepts are implemented in the whole design process in this project. Several components are chosen based on the reasons discussed in section 2.2. The controller architecture used in the final stage exactly follows the concepts of CNC software described in section 2.1. The literature provides clear background knowledge and guidance for the development of a small scale CNC machine tool.

CHAPTER 3
Structure Design and Analysis

Machine structure is the "backbone" of the machine tool. It integrates all machine components into a complete system. The machine structure is crucial to the performance of the machine tools since it is directly affecting the static and dynamic stiffness, as well as the damping response of the machine tool. A carefully designed structure can provide high stiffness, result in higher operation bandwidth and more precise operation. A small-scale machine tool generally requires even higher stiffness than the ordinary large-scale machine tool since it is usually operated at higher speeds. There are several other issues related to the machine structure such as symmetry, connectivity and errors. In this chapter, some most common structures used on machine tools will be compared and analyzed.

3.1 Structure Mechanical Design

The two most common machine structures in the industry are open frame structures and closed frame structures. Generally speaking, the closed frame structure provides a strong ridged structure loop, symmetry, and good thermal stability, which provides better stiffness than the open frame structures generally used for easy access to the work zone, with the same order-of-magnitude in size. Closed frame structures typically are used in large precision machines such as CMMs. The work pieces to be machined or measured are generally large and heavy. Therefore it is much easier to move the tool with respect to a fixed work piece. This structure consumes more material, hence is more expensive to build.

Open frame machine tool structure is also called a C or G structure. This structure is very commonly seen in small machines. Although the structure is asymmetrical, which leads to undesirable thermal gradients and bending moments, it's an ideal structure for small machines. The work pieces are usually small and light so the material removal rate is much smaller than those big work pieces made by the big machine, so the error caused by thermal effects is not a significant issue. A critical part of the structure is cantilevered, which leads to Abbe errors (magnification of angular error over distance) [17], but this can be compensated by spring loading in the opposite direction or pre-compensating bending in design. The material required to construct this structure is also less than the close flame structure and hence much cheaper to make. After evaluating the pros and cons of both structures, the team decides to use an open frame structure for this small scale machine.

There are many different variations on an open frame structure. Generally they can be grouped into two categories distinguished by the tool orientation, i.e. vertical tool position and horizontal tool position.

In the horizontal configuration, the work piece is fixed on vertical XY plane, which requires the work piece to be light and compact. The Abbe error on XY plane is not significant because the weight of work piece is very small and can be neglected. Spindle is mounted horizontally to ensure maximum stiffness along Z axis. This is the ideal structure for micro-manufacturing machine tools. However, the length scale of the work pieces to be machined is designed to be between 10mm and 70mm. The weight effect of the work piece with this length scale cannot be ignored, for it creates challenge to fix the work piece onto the vertical XY plane. Due to this crucial situation, the machine is designed to have typical vertical tool position open frame structure.

Torque Calculations:

THEORETICAL POWER EVALUATION

Cutting Force Distribution

The task at hand is to calculate the value of the torque required for the axes motors. We start by calculating the value of the cutting forces which are given in the following Figure-::

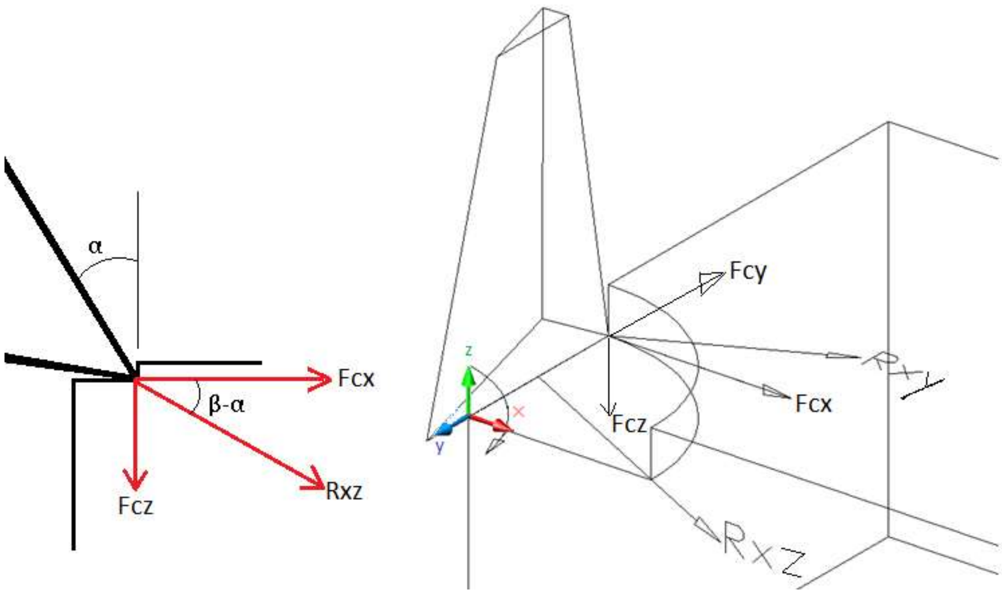


Figure-: 5 Forces during cutting

- The force exerted on the work piece is labeled F_c (Cutting Force) and is divided into its components F_{cx}, F_{cy} and F_{cz}.
- The work piece is rigidly mounted on the worktable so there is no relative motion between them.

The values of the cutting forces are calculated using the formula:

$F = Ct^{x}w$

Where:

F- principal cutting force in Newtons,

C - material constant at a given cutting speed and rake angle,

t- uncut chip thickness in mm,

w- width of cut in mm or length of the cutting edge in engagement

x- constant for material being machined.

x varies with the rake angle

We selected the work piece to be made of Aluminum so the values of the constants were taken to be the following

C=500

t=0.15

x=0.70

w=20

Hence, $F_{cx} = Ct^{x}w$

$F_{cx} = 500x0.15^{0.70}x20$

$F_{cx} = 2650N$

$F_{cx} = F_{cy}$

And $F_{cz} = F_{cx} \tan(\beta)$

$F_{cz} = 2330 \text{ x } \tan(41.34) = 2330N$

The total value of the force opposing the motion of the x-axis & y-axis motors is given by the following formula:

$$Total\ load\ (L) = F_{cx} + \left(F_{cz} + F_{cy} + W_t\right) \times \mu_s$$

Where

W_t , the total load of the work piece, bed is taken to be 300N (30KG)

μ_s, the value of the coefficient of friction is assumed to be 0.3

Hence,

Total Load (L) = 2650 + (2330 + 2650 + 300) x 0.3

Total Load (L) = 4234 N

Calculating the Torque

The thread we are using is the ACME square thread. The value of the total torque applied on the square thread by the load is given by the formula [1]

$$T_r = \frac{d_m}{2} \times \frac{L(\mu\pi d_m + l)}{(\pi d_m - \mu l)} + L\mu_c \frac{d_c}{2}$$

For the ACME square thread used,

$\mu = 0.07$

Mean diameter, $d_{m,}$ = 9.525 mm

The pitch, l = 2.1 mm

Hence,

$$T_r = \frac{0.009525}{2} \times \frac{4234(0.07 * \pi * 0.009525 + 0.0021)}{(\pi * 0.009525 - 0.07 * 0.0021)} + 4234 * 0.07 * \frac{0.009525}{2}$$

T_r = 4.25 Nm

Torque calculations for tool driving motor torque

The parameters used in this section of calculations are defined as follows:

Z = Number of teeth of the tool	5
d = diameter of tool (mm)	10 mm
a_e= length of cut (cm)	10 mm
a_p = depth of cut (cm)	20 mm
f_z = Feed rate / tooth	0.15 mm
K = Specific Cutting Power (watts min/cm^3)	17 watts min/cm^3
N = Number of revolutions (rev/min)	795 rev/min
V_f = feed rate	f_z x Z x N
Q = Material Removal Rate	$\frac{ae \times ap \times Vf}{100}$
P = Power (watts)	$\frac{K \times Q}{1000}$
ɰ = Rotational Speed	$\frac{2 \times \pi \times N}{60}$
T = Torque (Nm)	$\frac{P}{\omega}$

So,

$V_f = f_z \times Z \times N$

$V_f = 0.15 \times 5 \times 795$

$V_f = 596.25$ mm/min

$Q = \frac{ae \times ap \times Vf}{1000}$

$Q = \frac{20 \times 10 \times 596.25}{100}$

Q = 11.925 cm^3/min

$$P = \frac{K \times Q}{1000}$$

$$P = \frac{17 \times 11.925}{1000}$$

P = 0.203 Kw

$$\omega = \frac{2 \times \pi \times N}{60}$$

$$\omega = \frac{2 \times \pi \times 795}{60}$$

ω = 83.25 rad/s

$$T = \frac{P}{\omega}$$

$$T = \frac{0.203}{83.25}$$

T = 2.44 Nm

3.2 CAD Design

Using Solidworks 2014, we developed a detailed CAD model that we used for visualization and simulation before we moved on to manufacturing.

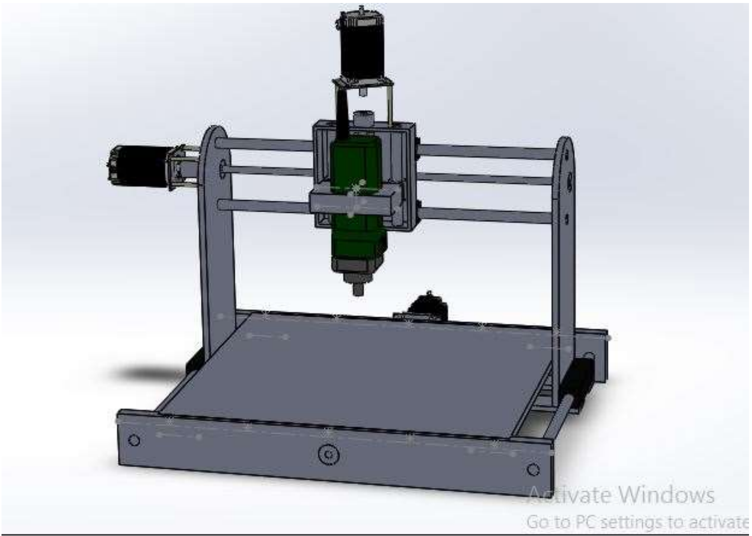


Figure-: 6 Diametric View of our final CAD model

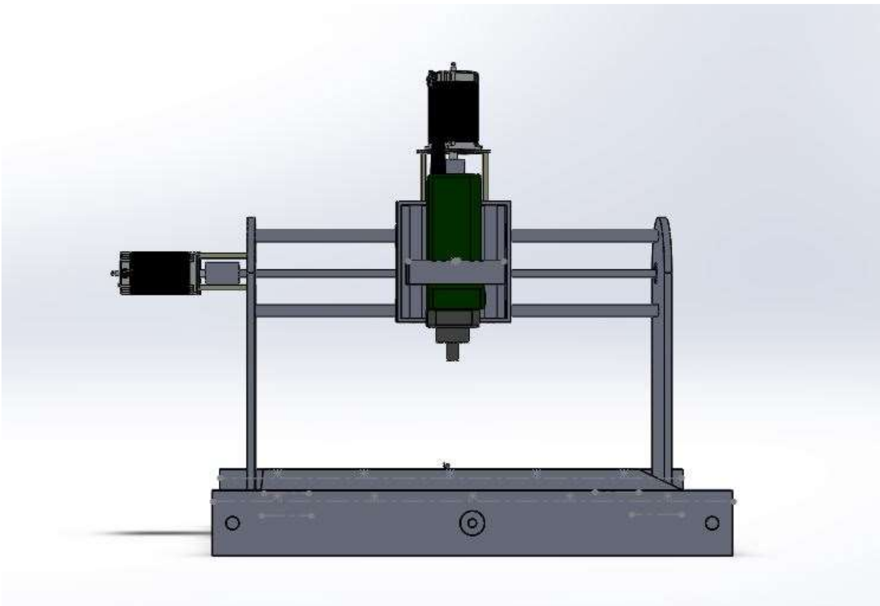


Figure-: 7 Front view of our machine's CAD model

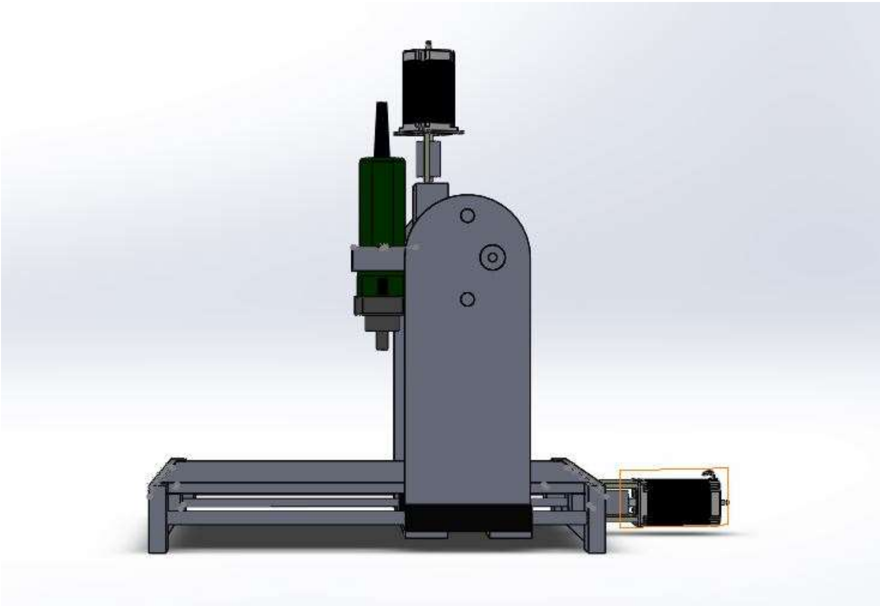


Figure-: 8 Side view of our machine's CAD model

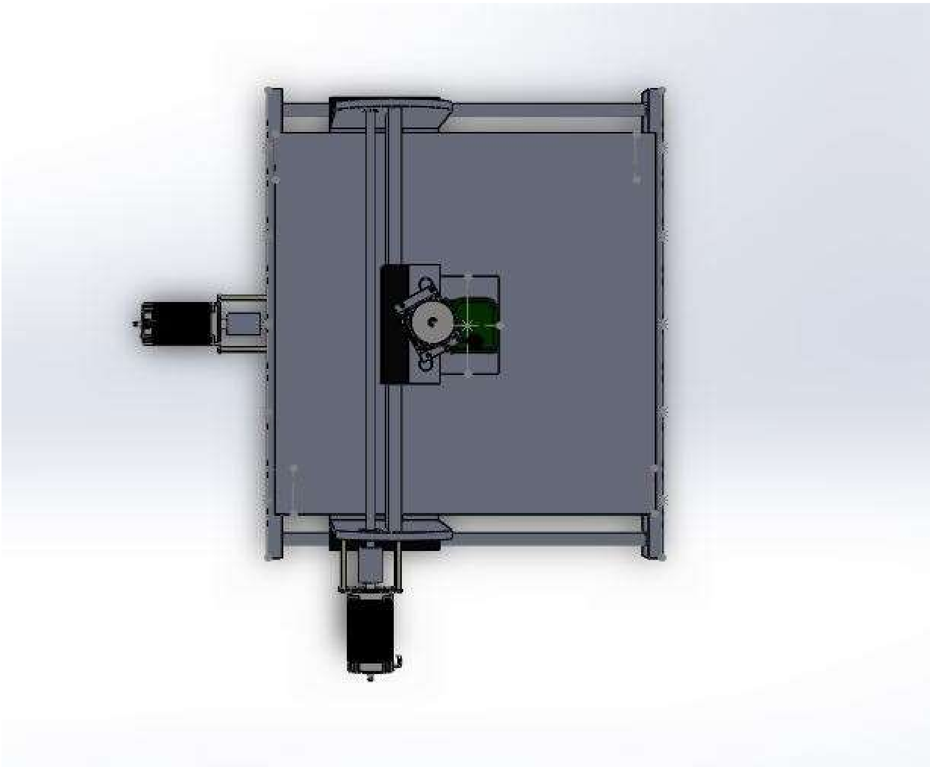


Figure-: 9 Top view of our machine's CAD model

CHAPTER 4

Machine Fabrication

In this chapter, the detailed fabrication procedure of the prototype mini CNC machine is described, starting with the selection of various off-the-shelf components. The reasons behind the selection of various parts will be discussed. The unit price of all components will be listed and summarized in the cost summary section. Details that require extra attention will be mentioned during the fabrication description.

4.1 Selection of Components

4.1.1 Selection of motors

Selection of motors is carried out first because it is directly related to the driving mechanism as well as control method. Two different motors, steppers & servos will be discussed. Stepper motor and servo motor are rotary motion motors. Each of them has unique strengths and weaknesses which make them suitable in certain applications. For rotary motion motors, a lead screw is always needed to transform rotary motion into linear motion.

A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied. Servo motor internally contains a feedback sensor to tell its current position which allows precise control on angular position. The industrial servo motor speed output is proportional to the input current level. They look pretty similar to each other but the control method is completely different.

The basic difference between a traditional stepper and a servo-based system is the type of motor and how it is controlled. Steppers typically use 50 to 100 pole brushless motors while typical servo motors have only 4 to 12 poles. Steppers don't require encoders since they can accurately move between their many poles, whereas servos with few poles require an encoder to keep track of their position. Steppers simply move incrementally using pulses [open loop] while servos read the difference between the motors encoder and the commanded position [closed loop], and adjust the current required to move. Table-:1 below summarizes some key differences between servo motors and steppers.

	Stepper	**Servo**
Price	Low	High
Control	Generally open loop	Close loop
Resolution	Determine by step/rev	Determine by encoder
Dynamic behavior	Low speed	High speed allowed
Accuracy	Low if using micro stepping	High

Table-: 1 Comparison between Stepper and Servo

Steppers are the most affordable actuating solution for machine tools currently. Lots of commercially available small CNC machines including CNC Baron and TORMACH we mentioned in chapter one use stepper motors to drive the axes together with an encoder to tell the current position. The control is still open-loop while the encoder is used just as an evaluation device to make minor adjustments for small position offsets.

4.1.2 Selection of linear guides and lead screws

DC stepper motors are chosen to be used as actuators from last session. Therefore, we have to use lead screw mechanism to transfer rotary motion into linear motion.

When selecting the lead screw, we want to have the smallest pitch size possible to increase our resolution. The current market has various models and quality levels to choose from. C3 is the most precise level but also the most expensive. C7 is the cheapest and most commonly used level. In level C7, 0802 is the smallest pitch size model. 0802 stands for 8mm diameter and 2mm pitch. We have 0802, 1002, 1004, 1204, 1604, 1605 to choose from. The cheapest one is 1605, but it has the largest pitch and diameter. The machine size will also be affected by using large diameter lead screws. 0802, 1002 offers the smallest pitch size but the price is almost tripled compared with the 1605 model. Among 1004, 1204, and 1604 model, 1004 is the most expensive model. 1204 is only slightly more expensive than 1604 and offers a much smaller diameter. Therefore, 1204

C7 model is selected as the lead screw of our machine. The lead screw contains a preloaded circulating ball nut which eliminates backlash and reduces friction, as shown in Figure-: below.

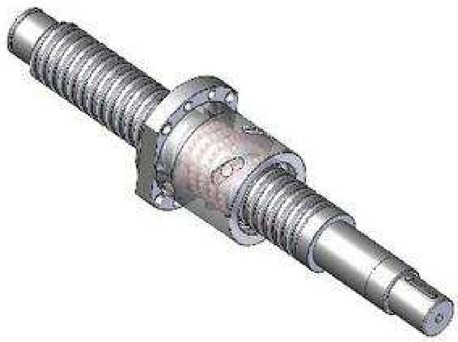


Figure-: 10 1204 lead screw with circulating ball nut

There are also various types of linear slides to choose from. Figure-: 12 shows the three most common types of linear slides used in machine tools, i.e. cross-roller guide, recirculating ball slides, and rolling bearing slides.

(a) Cross-roller guide (b) Recirculating ball slide (c) rolling bearing slide

Figure-: 11 Linear sliders

Among three different slides, rolling bearing slides are the cheapest choice. It is compact lightweight, and provides unlimited range of motion. However, it is the least stiff and has the largest friction one among the three. Recirculating ball slides are more expensive, but have less friction and are stiffer than rolling bearing slides. Cross-roller guides have limited range of motion, but enjoy the highest stiffness and robustness among three different slides, and have the same level of friction as recirculating ball slides. Since we only need limited range of travel in our machine, and higher stiffness allows the machine to operate at much higher bandwidth, so within our budget, cross-roller guide is the best choice.

4.1.3 Cost summary

The costs of everything required to make a mini CNC machine until now are listed in the table 2

Item	Description	Price
Material	6061 Aluminum 10kg	Rs 7,400
Mechanical accessories	Leadscrew *3, Leadscrew fix *3, shaft *2, slider *2, shaft fix *2, cross roller guide *4, rubber leg *6, shaft coupler *3	Rs 10,500
Electrical accessories	Spindle kit, stepper motors *3 and amplifier *3, limit switch *12, motor power supply	Rs 12,000
	Total:	Rs 29,900

For now, the total cost is well below our budget. We have approximately 500 USD budget to purchase or build the “brain” of our mini CNC machine, which is the motion controller. The setup and design of motion controller will be discussed in detail in chapter

4.2 Machine assembling

After gathering all metal parts and accessories required for assembling, the procedure of making the machine is listed below step by step.

a) Start from the base
b) Install six rubber leg
c) Install four walls of Y axis
d) Install main support for Z axis e) Install Z axis chamber
f) Assemble Z axis leadscrew
g) Assemble Z axis leadscrew and slides
h) Fix Z axis leadscrew and slides
i) Install Z axis motor
j) Build XY axis, start from table at the top
k) Install screw nut connector underneath the table l) Install leadscrew
m) Fix leadscrew
n) Install cross roller guide of X axis
o) Complete X axis by add front and back cover
p) Install leadscrew beneath X axis
q) Fix X table on the base r) Install cross roller guide
s) Install two motor and complete XY table
t) Complete machine with encoder and limit switch

After the machine is fabricated, alignment of X and Y axis, flatness of the working table surface, and verticalness of Z axis are all carefully inspected by eye and tools. Several issues occurred during the assembling procedure. First, the XY table is assembled top-down. This requires a lot of screw securing procedure to be done upside down. The alignment is another big issue. If the screw thread is slightly off its desired position, there is no way to adjust the alignment back to its proper position. These issues can be easily ignored during the design stage, so the next version of the machine will include various adjusting features to compensate various manufacturing defects.

4.3 Metal Framing :

Metal framing is the skeleton of a building. It provides the framework for interior layout, ensures proper spacing of interior areas, is one of the first steps to any refurbishing or reconstruction project, and is essential to creating a space that is not only functional, appealing as well.

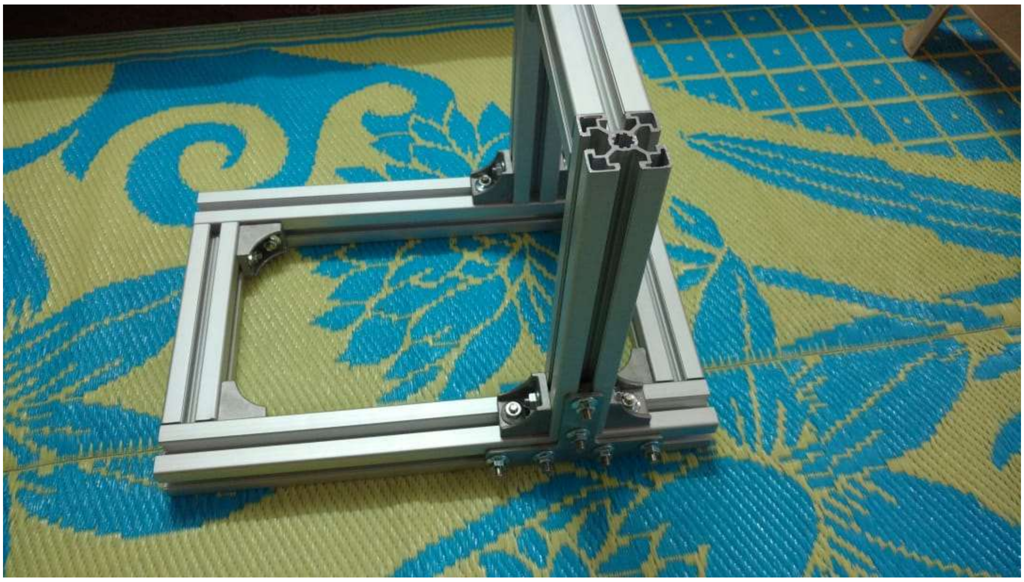
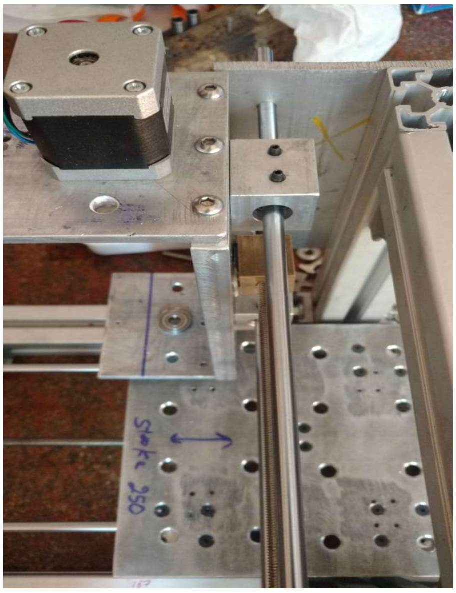


Figure 11: Metal Frame work

4.4 BRACING :

Bracing, which provides stability and resists lateral loads, may be from diagonal steel members or, from a concrete 'core'. In braced construction, beams and columns are designed under vertical load only, assuming the bracing system carries all lateral loads. Braced frames are a very common form of construction, being economic to construct and simple to analyse. Nominally pinned connections between beams and columns.

A)



B)

4.5 Summary

This chapter gives a comprehensive view of how this prototype machine is fabricated. The process starts from selecting various key parts, followed by purchasing different accessories, raw materials, and machine raw metal plates, and ends with the step by step assembling procedure. The total cost of this prototype excluding the motion controller is 1449 USD. If this design eventually goes to mass production, volume discount can further reduce this capital cost to less than 500 USD per machine. The total time required to fabricate one machine is less than two hours.

CHAPTER 5

Electronics, Control and Software Module

5.1 General Overview

We intend to design a small-scale Computer Numerically Controlled (CNC) Milling machine to establish and validate our methodologies. In the development process, we will ensure that we document every step of the process. Our main goals will be user-friendliness and ease of use so that smaller setups and save up significantly on capital costs when retrofitting or building their own CNC machines using our methodologies. The main advantages of such an indigenously produced machines are:

- Sufficient level of precision and accuracy in machined work parts
- Time saving
- Reduced labor cost
- Elimination of Human error
- Portability
- Significant capital, operating and maintenance cost savings

5.2 Work Flow Overview

Our project "Design and Fabrication of Computer Numerically Controlled (CNC) Milling Machine" involves mechanical, electrical and software aspects. In this section we will restrict our discussion to the computer-science and electrical aspects of the project. Some major deliverables have been listed below:

- Develop a suitable microcontroller-based setup to control machine processes.
- Assess use of sensors and their feedback for system regulation and control.
- Select and procure suitable motors for each machine process.
- Develop or procure a motor driver circuit.
- Design and fabricate, or procure and integrate a voltage regulating power supply.
- Develop suitable Human Computer Interface (HCI).
- Design interpreter for converting G & M codes into machine language.

The fact that these deliverables were set on a broader scope without specifying restrictions is due to the fact that we intended to leave room for adapting our electronic architecture design to the availability of material and devices locally and keeping in mind the relative cost of indigenous design and development and/or fabrication versus procurement and integration of materials, devices and code. It is worth re-stating that our most major guiding objective is to produce an inexpensive and uncomplicated CNC Milling machine that is able to machine softer metals while keeping in mind the scalability of the design. Also, the reader will note that the design process we employed was iterative and thus we conformed to the Design for Manufacturability (DFM) philosophy.

In our project, all the technical aspects; Mechanical, Electrical and Computer-Science, are closely linked with each other, change in even one of the mechanical design parameters directly influences the electrical calculations and computer programming and vice versa.

5.3 Electronic Hardware Architecture Overview

The schematic below highlights the layout of the electronic components used in our machine. The arrows show the connections between devices.

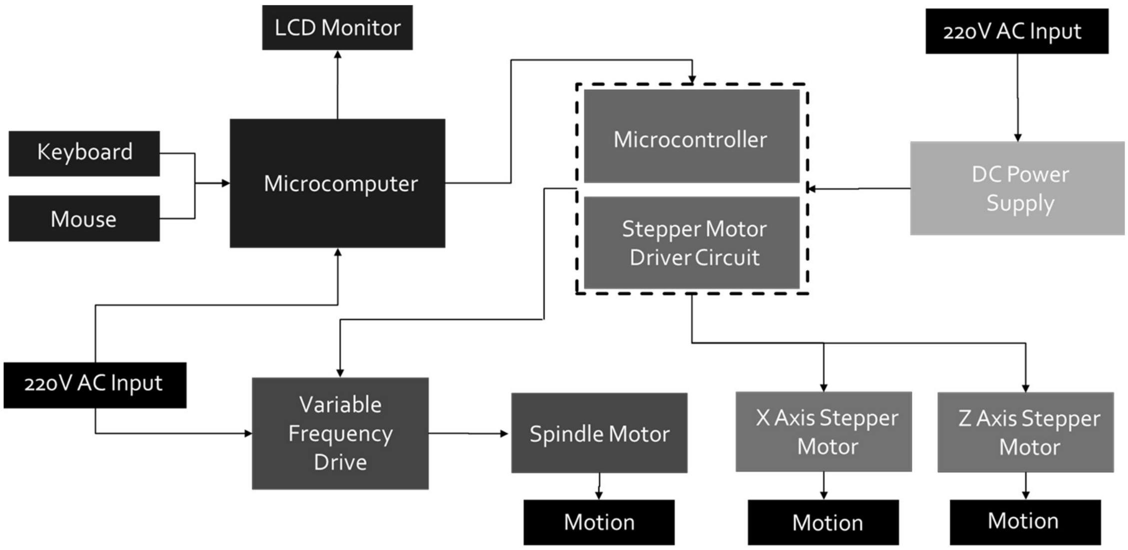


Figure-: 12 Schematic showing the complete electronic architecture of our machine

Starting off from the top-left, we have the microcomputer that has three basic but essential I/O devices connected to it, namely the keyboard and mouse for data input to the system and the LCD Monitor for displaying and interacting with the Human-Computer Interface (HCI).

The microcomputer is connected to a Printed Circuit Board (PCB) that contains the microcontroller as well as the stepper motor driver circuits on it for each of the axis motors. This connection is down via the 25-pin DB-25 Parallel Port.

A Power Supply takes mains power from the 220-volt AC (RMS) power source and converts it into a 24-volt DC current for powering the PCB as well as the Axis Motors being controlled through it.

The PCB receives one input from the microcomputer as mentioned above, a power input from the DC power supply and controls the two axis stepper motors via 4 wires each in bipolar mode. The PCB also contains a relay switch that controls the toggling of the spindle motor.

Another mains power source is used to power the Variable Frequency Drive (VFD) that drives the high-powered Spindle Motor. The RPM of the spindle is varied independently through a potentiometer knob on the VFD.

5.4 Software Overview and Justification

For keeping software development costs low, we decided on using an off-the-shelf software for the more rigorous PC-to-microcontroller backend processing while developing a customized and bespoke front-end Human-Computer Interface (HCI) ourselves. Since both of these software packages would have to communicate with each other flawlessly, we have to ensure compatibility.

The package chosen for the backend system was ArtSoft Mach 3 developed by Newfangled

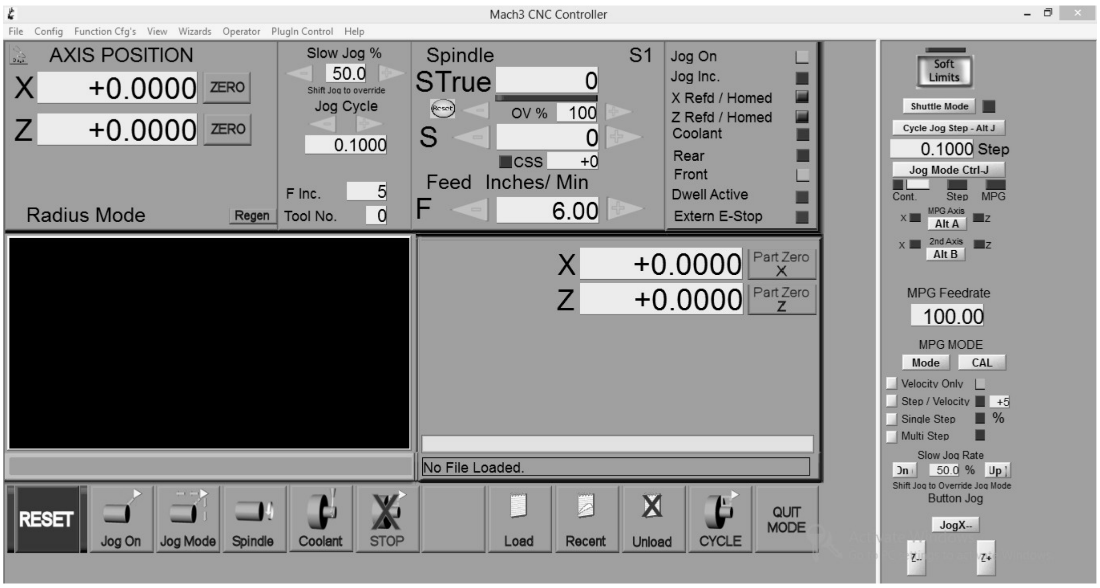


Figure-: 13 Screenshot showing Mach 3's stock interface

The main reason this was chose is because of its free-ware as well as open-source nature. Being freeware meant that it quite literally didn't cost us at all to use this software. Due to being open-source, we have access to its source code, which we interpreted and learned and then streamlined to adapt to our machine's functions and hardware. In its original form the code was approximately 5200 lines of code written in the C++ programming language. After streamlining and removing irrelevant functions pertaining to milling, EDM machines etc., we brought the code down to only about 1800, lines of code which included only our desired command set for milling machine operations. Mach 3 was also modified to work with our own HCI.

CHAPTER 6

Conclusion

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 and hobbyists. In this report, a small scale three axis CNC milling machine is designed and analyzed under very limited budget of 2,000 USD. During the structure design stage, various common structure frames are explored and analyzed. The most suitable structure frame, the open frame vertical type structure, is chosen. Critical components such as linear guides, motors, and encoders are selected among few different options. The best value components are selected to accommodate stiffness requirements and budget constraints. The issues of assembling mechanical components and emerging electrical parts into mechanical structure are all well considered. A prototype machine is assembled in the lab and Delta Tau's UMAC PLC is used as motion controller of the machine. The detailed steps of how to setup and configuring the PLC is described in chapter 5. An attempt to make a servo controller particularly for this machine is also conducted. The completed machine is tested using three different techniques, i.e. surface testing, perpendicularity testing and circular testing. The possible error sources are determined. The prototype machine has been used to create several parts already. Due to inaccuracy of the machine body parts and rough assembling, the machine fails to achieve the desired precision and repeatability level. However, it is still sufficient to create small features such as letters and graphs with sizes less than 1cm. A new design is created after evaluating this prototype with features of calibration and ease of assembling. This will certainly help to achieve the desired characteristics with the same amount of budget.

6.1 Future studies

The future studies heavily rely on the design of motion controller. In order to cut cost, a motion controller must be designed and fabricated by ourselves. This requires creating the hardware, making the connection, writing the servo loop program, writing the interpolation program, and creating the HMI. In chapter 5, a schematic for hardware board has already been created. The servo loop program has also been done and tested successfully. The TI MSP430 microcontroller can now read pulses and accumulate pulses as reference input. It can read the encoder signal and generate control signal using a simple PI controller. However, the function to tune PI gain in real time is yet to be created. Arduino UNO3 board has been used to run the Grbl motion control firmware. However, there is still lack of a HMI for this firmware to allow more user friendly operation. The HMI still needs to be created. The best possible solution is using Raspberry Pi as the "PC" terminal of the controller and using a touchscreen as the interface. This allows the whole controller to be made within a few square-inches box. Since Raspberry Pi has its own embedded Linux OS, the user can easily transfer machine code file into the system using a USB drive. Raspberry Pi can then stream the machine code into Arduino through another USB port easily.

Another thing that can be done in the future is optimization of the fabrication process for mass production. The components of the machine should be machined using the cheapest manufacturing process possible. The main frame should be better optimized for casting. Machine testing should be conducted in a more accurate manner with better equipment and better methodology. Then the actual number of precision and repeatability can be determined.

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APPENDIX A

Bill Of Material

Sr#	Description	Quantity
1	Ball Screws	3
2	SS Rods	6
3	Linear Motion Bearings	10
4	Ball Bearings	6
5	Ellen Bolts (M8)	32
6	Ellen Bolts (M6)	28
7	Ellen Bolts (M5)	24
8	Aluminium Rod Cuplings	3
9	Nema 34 Stepper Motor	3
10	Power Supply	1
11	Limit Switches	12
12	3 Axes CNC Toshiba Driver	1
13	MS Rods	12
14	Aluminium Plate 520x520x12	1
15	Aluminium Plates 550x30x80	2
16	Aluminium Plates 200x400x12	2
17	Aluminium Blocks 50x30x25	4
18	Aluminium Strips 540x8x50	2
19	Aluminium Plate 300x130x12	1
20	Aluminium Plates 70x130x12	2
21	Aluminium Plate 150x100x12	1
22	Spindle Mount	1
23	Spindle Motor	1