

# Design and Development of Portable 3-Axis CNC Router Machine

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**Abstract** - This paper describes about the Design and Development of portable 3-Axis CNC router machine based on microcontroller which was used to reduce cost and complexity of the bulky sized engraving machine. This machine can be used for engraving, cutting, reaming, marking, drilling and milling on wood, acrylic, and PCB materials. Part programming of the required component to be manufactured was done with the help of image processing. First of all, the component to be manufactured is designed using the software (ArtCam, InkScape) which supports image processing, then G-codes are generated and sent to the microcontroller through GRBL software using serial communication which then sends the signals to the actuators which performs the required motion on the job according to point coordinates. Several tests were performed for checking the accuracy of the machine. This machine is capable of performing machining operations in work area of 280x170x65mm.

**Keywords:** - CNC, router, 3-Axis, microcontroller, image processing, 2D, 3D, GRBL

## 1. INTRODUCTION

Working with automatic mechanical equipment demands precision, accuracy, speed, consistency and flexibility [1]. Numerical control (NC) (also computer numerical control (CNC)) is the automated control of machining tools (drills, boring tools, lathes) by means of a computer. An NC machine alters a blank piece of material (metal, plastic, wood, ceramic, or composite) to meet precise specifications by following programmed instructions and without a manual operator. NC machines combine a motorized maneuverable tool and often a motorized maneuverable platform, which are both controlled by a computer core, according to specific input instructions. Instructions are delivered to an NC machine in the form of graphical computer-aided-design (CAD) files, which are transformed into a sequential program of machine control instructions, and then executed. In modern CNC systems, the design of a mechanical part and its manufacturing program is highly automated. The part's mechanical dimensions are defined using CAD software, and then translated into manufacturing directives by computer-aided manufacturing (CAM) software [2]. The main objective behind the design of this machine is to develop a low cost automatic mini CNC machine for engraving, cutting, reaming, marking, drilling and milling on wood, acrylic, and PCB materials. This system reduces the cost of machine as well as machining and increases the flexibility of manufacturing system.

## 1.1 Related Works

Numerous methods exist for autonomous manufacturing. Large number of attempts aimed at designing an automatic manufacturing machine can be found in the automatic machining literature. One such fully automated CNC machine used for engraving and drilling is designed using ball screw mechanism and stepper motors which act as actuators for the linear slide ways by Khan, Mehtab, Hasan and Hussain [3]. The overall efficiency of the machine increases because the ball screw mechanisms are more durable and reliable and have high mechanical efficiency at a low cost of maintenance. And the stepper motors have accurate rotation and provides such accuracy without any compromise at torque. Development of Automatic Mini CNC Machine for PCB Drawing and Drilling is presented in the research paper by Kajal J. Madekar, Kranti R. Nanaware, Pooja R. Phadtare, Vikas S. Mane [4]. The system uses ATMEGA 328 controller unit with a combination of G-code which gives better accuracy and reduces the work load. G codes make easy to find the information of locations of all stepper motor moving, as the status of our moving motor are directly seen on computer hence we can start or stop the machine whenever we are needed. Paper [5] by R. Ginting, S. Hadiyoso and S. Aulia describes about the implementation 3-Axis CNC Router for Small Scale Industry. This paper discusses the design and realization of complex 3axis CNC machines based on microcontroller which is combined with the spindle drill. The authors of paper [6] Sergej .N. Gregoriev and Georgi .M. Martinov describes about the control platform for decomposition and synthesis of specialized CNC system. The paper emphasis on operations along three axes with specialized CNC systems. Various milling operations carried by a CNC machine are discussed in the paper by Komran Latif, Yusri Yusof [7]. This paper totally focuses on the new method for the Development of Sustainable STEP- Compliant Open CNC System. The research work in paper by R. Ramesh, S. Jyothirmai, and K. Lavanya [8] discusses about intelligent automation of design and manufacturing in machine using an open architecture motion controller. The researchers have extended their work in several issues including accurate programming; proper tool selection, thermal error compensation, etc. which contribute significantly to the performance.

## 2. DESIGN CONSIDERATIONS

There are four factors which are considered while choosing aluminium profiles: Alloying elements, aluminium smelting

furnace, alloy casting, and profile extrusion [9]. In 3-axis CNC machine proper alignment of every axis is must along with the smooth movement of machine parts, hence cylindrical rods are selected [10]. Flange bearing provides great alignment support for the screw as it turns keeping the print head or cutter in perfect alignment while stepping [11]. Brass nuts provide precise alignment for fixing threaded screws along with locking them from self opening.

The most important factors to consider when selecting a lead screw for an application are: Load capacity, pressure-velocity factor, efficiency, speed, duty cycle, backlash, Life, lubrication and online selection and sizing [12]. As compared with flexible couplings, rigid couplings have limited application. Rigid couplings do not have the ability to compensate for shaft misalignments and are therefore used where shafts are already positioned in precise lateral and angular alignment. Apart from their simplicity, they tend to have high load capacities as concentric or parallel surfaces mate over a large contact area. They also provide good stiffness between the journal and bearing elements [13].

**Table -1:** Table of Linear forces

$F_{zr}$	32.137N
$F_{zc}$	77.07N
$F_{yr}$	25.64N
$F_{yc}$	125.64N
$F_{xr}$	33.90N
$F_{xc}$	133.9N

The above figures in the table indicate the forces acting on the respective guideways which are necessary for the selection of stepper motors.

The forces obtained act linearly across the axis which are under constant load.

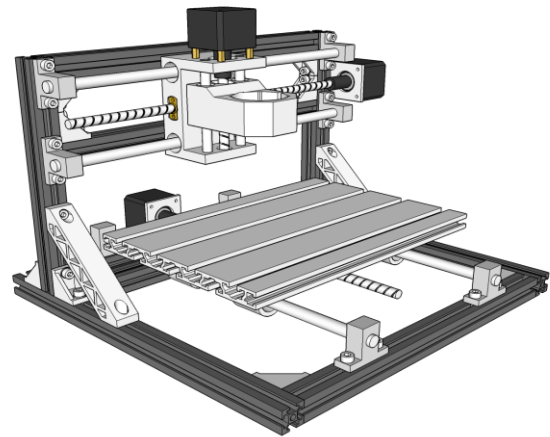
**Table -2:** Table of Peak motor torque requirement

Z-Axis	$z_t$	0.136N
Y-Axis	$y_t$	0.22N
X-Axis	$x_t$	0.236N

Based on the calculations and results obtained, the torque requirement of all the axis falls in the range of NEMA 17 Stepper motor which has torque holding capacity of 0.4118793N [1]. The required power to run the spindle motor is 7.54W at 6000RPM which falls under the range of standard power output limit (i.e. 7.68W).

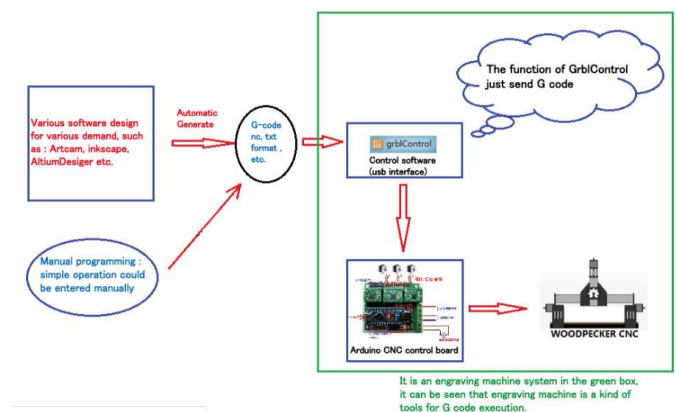
### 3. MODELLING

The modelling was done using Creo software.



**Fig -1:** Creo model of portable 3 axis CNC machine

### 4. SYSTEM ARCHITECTURE



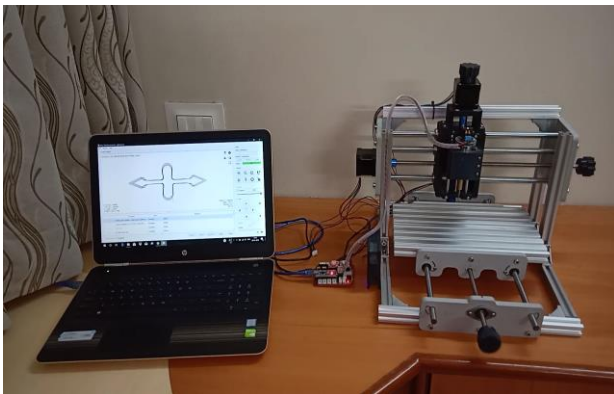
**Fig -2:** Block diagram of system architecture [14]

The system architecture for CNC machine is shown in figure 2. It consists of two parts, the first part is the generation of G-codes and the second part consists of the execution of G-codes. The G-codes are generated by using ArtCam and InkScape software which are embedded with image processing system. After the Gcode file is prepared it is loaded into the GRBL software with the help of Universal G-code Sender. The GRBL software is open source software which executes the G-codes and gives signals to the microcontroller unit i.e. arduino NANO having ATMEGA328p as a micro processor which converts the G-codes into binary formats. The binary signals are further converted to stepper motor signals through CNC shield which is an open source firmware on arduino that controls 3 stepper motors using 3 stepper motor driver boards. And thus, the actuators perform necessary motions based upon the received input signals.

NEMA-17 was used as a stepper motor which is a Phase-2 motor with 400 steps/revolution and 100% step accuracy. The other specifications are it has torque holding capacity which is equivalent to 0.411N, rated current 2.0A, rotor inertia 68gcm<sup>2</sup>, IP rating-40, insulation resistance 100mega ohms and has 1.8 degrees step angle for smooth movement.

**5. EXPERIMENTS AND RESULTS**

Following tests were carried out on the machine which is shown in the figure3 and specific results were obtained.



**Fig -3:** CNC portable machine

**Cutting system tests:** The cutting system test was conducted on an acrylic sheet having 3mm thickness, using 3mm diameter end mill drill bit, 6000 rpm spindle speed and 20mm cutting depth. Image was designed using Artcam software.

**Engraving system tests:** The engraving system was conducted on an acrylic sheet of 3mm thickness, using 3mm vbit60° drill bit, 6000 rpm spindle speed and 1mm engraving depth. Image was designed using Artcam software, design examples using writing combined with engraving pattern.

**Marking system test:** The marking system was tested on an acrylic sheet with 3mm thickness, using 3mm vbit and end mill drill bit, 6000 rpm spindle speed and 1mm and 0.5mm marking depth.

**Depth test:** The measurement was conducted to check the level of precision on the depth of CNC machine when working. Testing is creating 6 lines each of which has 50mm length and 2mm depth using a 3mm end mill drill bit with a spindle speed of 6000 rpm.

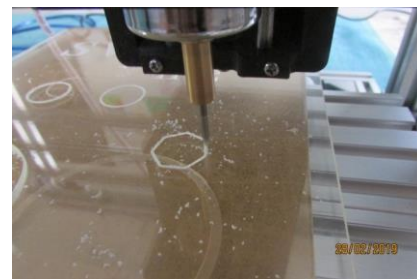


**Fig -4:** Depth test

**Table -3:** Table of depth test results

LINE NO.	DEPTH (mm)	MEASUREMENT (mm)
1	0.5	0.5
2	1	1
3	1.5	1.5
4	2	2
5	2	2
6	2	2

**Speed test:** The speed test is conducted to determine the effect of angle on the speed in the object formation. The inputs for this test are various designs which will be formed to resemble some 2D shape. With 1mm engraving depth on acrylic using 3mm end mill drill bit. Uploaded designs will be timed using a stopwatch to see how long it takes for each design to be made.



**Fig -5:** Speed test

**Table -3:** Table of speed test results

DESIGN	DEPTH(mm)	TIME TAKEN
CIRCLE(20φ)	0.1	09sec
HEPTAGON(10φ)	0.1	05sec
HEXAGON(10φ)	0.1	10sec
OCTAGON(10φ)	0.1	10sec
PENTAGON(10φ)	0.1	09sec

**Accuracy test:** This test is conducted to determine the precision level of CNC engraver. This test was about engraving 6 lines of different lengths and each of 1mm by using 3mm vbit60° drill bit with 6000rpm spindle speed.

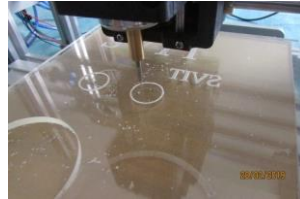
**Table -4:** Table of accuracy test results

LINE NO.	DESIGN (mm)	MEASUREMENT LENGTH(mm)	ACCURACY (%)
1	50	50	100
2	45	44.9	99.9
3	40	40	100
4	35	35.2	99
5	30	30	100
6	25	24.8	99

**Comparison of speed test between wood and acrylic:**

**Table -5:** Table of speed comparison

MATERIAL	DEPTH (mm)	TIME TAKEN
WOOD	0.1	08sec
ACRYLIC	0.1	09sec



**Fig -6:** Speed comparison test

**5. CONCLUSION**

The CNC router machine was successfully built using ATmega328p and IC4988 microcontrollers combined with 3 NEMA 17 stepper motors, with 20x20cm cross-sectional area and using 30 Watt spindle motor. The CNC machine can be used for cutting, engraving and marking on wood to form 2D objects with 99.9% carving accuracy and 100% depth accuracy. The process of synchronizing the 3 stepper motors was controlled using GRBL library and Universal G-code Sender Software.

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