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Fabrication of portable 3 Axis CNC router machine

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Abstract--- This paper describes about the Fabrication of portable 3 Axis CNC router machine. The Part programming of the required design to be engraved was done with the help of image processing. The design to be engraved is created using the software (ArtCam, InkScape) which supports image processing, and 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. The feature of an offline G-Code parser interprets on the micro-controller from a USB. After testing this machine can be used for engraving, on Metals such as aluminum up to 0.4mm depth, in 2D. This machine is capable of performing machining operations in work area of 28cmx17cm.

Keywords--- CNC, router, 3-Axis, microcontroller, image processing, metal engraving, GRBL

I. INTRODUCTION

Working with automatic mechanical equipment demands precision, accuracy, speed, consistency and flexibility [1]. Numerical control (NC) means the automated control of machining tools (drills, boring tools, lathes) through a computer which is further known as (Computer Numerical Control (CNC)). An NC machine receives instructions in the form of graphical computer-aided design (CAD) files, and then transformed into a sequential program of machine control instructions which can be executed. The designing of a mechanical part and its manufacturing program is highly automated in modern CNC systems because the part's mechanical dimensions are defined using CAD software which are further translated into manufacturing directives by computer aided manufacturing (CAM) software [2]. By using CNC technology; various machine tools are available which are able to make ultra-precision products down to nano scales in a much faster manner. However, there is a great increase of industry varieties and the growing demand of miniature engraving products and also in manufacturing products with special sizes and different precision requirements. The purpose of building this machine is to carry out engraving on hard surfaced materials like metal and wood and also increase the flexibility of manufacturing system by using it in industries. Two technologies are available for an optimal result: laser engraving and mechanical engraving. These marking processes produce excellent results both for engraving soft metal such as aluminium or brass, and for marking very hard alloys such as steel, stainless steel. There are wide ranges of applications in metal engraving which can be carried out by CNC machines.

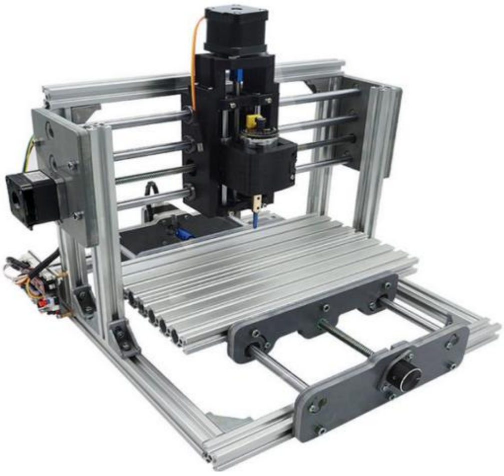

Fig. 1 CNC Machine

II. LITERATURE REVIEWED

As discussed in a paper by Dr.B.Jayachandraiah the "backbone" of the machine tool is mainly the structure of machine which integrates all machine components into a complete system. A carefully designed provides greater stiffness which further results in higher operation bandwidth and more precise operation [3]. Various methods exist for autonomous manufacturing. Large number of attempts has been made with the aim of designing an automatic manufacturing machine. One such fully automated CNC machine is designed using ball screw mechanism and stepper motors which act as actuators for the linear slide ways. The ball screw mechanisms are more durable and reliable and have high mechanical efficiency at a low cost of maintenance which further increases overall efficiency of the machine. And the stepper motors are accurate in rotation which helps in providing accuracy without any compromise at torque [4]. The system can be operated using ATMEGA 328 controller unit with a combination of G-code for better accuracy and for reducing the work load. G codes help us easily find the information of locations of all stepper motor moving so we can easily start or stop the machine whenever we are needed by seeing the status of our moving motor are directly on computer [5]. In paper [6] the author has discussed about the design and realization of complex 3axis CNC machines based on microcontroller which is combined with the spindle drill. The author of paper [7] Sergej .N. Gregoriev describes about the control platform for decomposition and synthesis of specialized CNC system and operations performed along three axes. Various milling operations carried by a CNC machine are discussed in the paper [8] which has totally focused on the new method for the Development of Sustainable STEP- Compliant Open CNC System. The research work in paper [9] 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.

III. DESCRIPTION OF COMPONENTS

A. Central Processing Unit

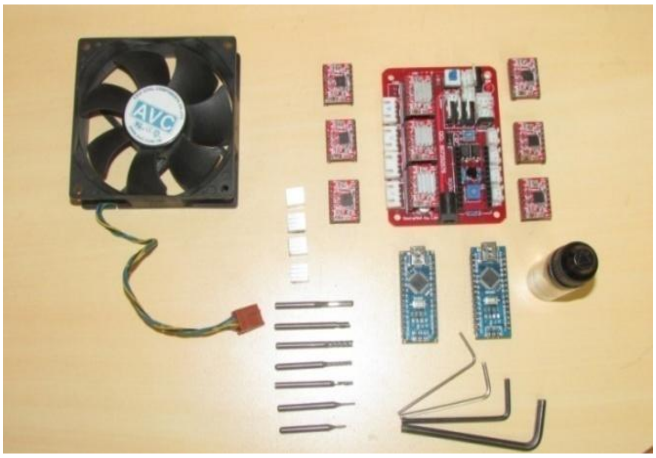

Fig. 3Components of CPU

We are controlling XYZ movement of the machine by Arduino Nano and CNC shield v4.0. To facilitate communication of the CNC machine with the G-code sender there is a need to upload the GRBL program to the Arduino. This is done by adding extra software libraries to Arduino. We have used grbl-Core XYZ-Servo-Master library. Arduino Uno is a Microcontroller based on ATMEGA328P.

B. CNC Shield V4.0

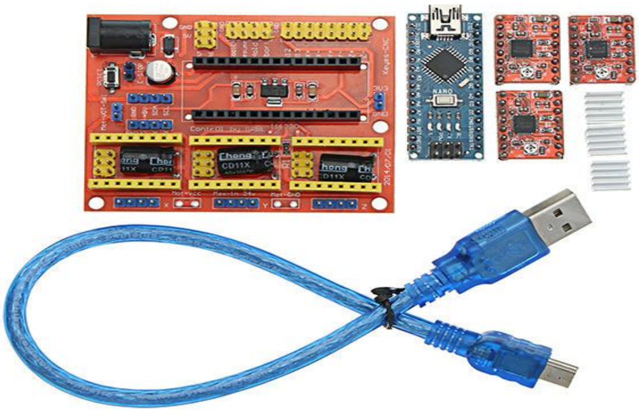

Fig. 4CNC Shield V4.0

CNC Shield is an open source firmware on Arduino which controls 4 stepper motors using 4 stepper motor drivers. It is GRBL compatible and has 4-Axis support (2x end stops for each axis).It runs on 12-36v power supply. It runs on Arduino and converts G-code into stepper motor signals.

C. Stepper Motors - NEMA 17

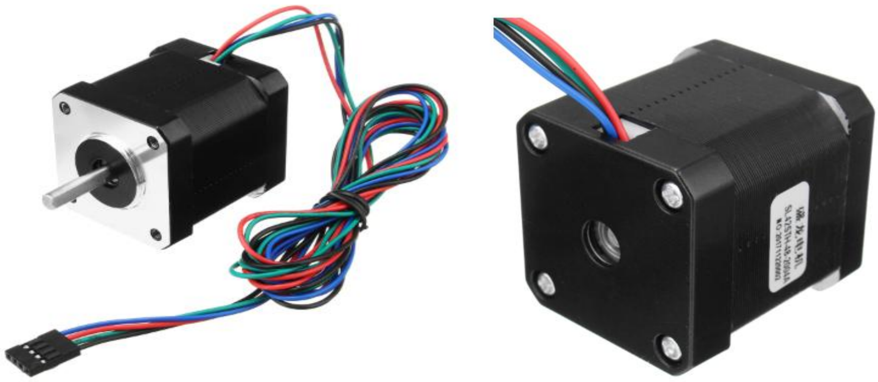

Fig. 5 Stepper Motors

It 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 68gcm², IP rating-40, insulation resistance 100mega ohms and has 1.8 degrees step angle for smooth movement.

D. Spindle Motor

Fig. 6 Spindle Motor

It is a servo motor having rated speed of 8000 rpm and a shaft size of ϕ3.17mm*11mm. The required position is provided and measured with a speedy feedback by pairing motor with some type of encoder. Thereafter the measured position of the output is compared with the command position, the external input to the controller. An error signal is generated when the output position differs from the required position which probably leads to cause the motor to rotate in either direction, to bring the output shaft to the appropriate position according to the need. The motor stops rotating when the error signal reduces to zero after the approaching to the required positions.

IV. MACHINE STRUCTURE

The pillar of the machine tool is the machine structure which integrates all machine components into a complete system. To provide high stiffness which can result in higher operation bandwidth and more precise operation, it is necessary to design the structure carefully. As small-scale machine tool is usually operated at higher speeds, it requires even higher stiffness than the ordinary large-scale machine tool. The experimental setup requires a strong ridged structure loop, symmetry, and good thermal stability along with better stiffness than the open frame structures generally used for easy access to the work zone, with the same order-of-magnitude in size which can be fulfilled by choosing closed structure and it makes the tool to move easily with respect to a fixed work piece. This structure is very less expensive to build as there is less consumption of material. The accurate motion of the machine is provided by the rails which are designed in such a way that they are strong enough to support the weight of the entire machine along with all of the equipment mounted to it. The designing of these rails can be as simple as a small strip of metal, or as complex as a recirculating ball bearing linear rail system, or as large as a railroad train rail which further depends on size of the machine. The X-axis guiding system is lighter than the Z-axis rails as they only have to carry the weight of a small carriage and cutting tool. Whereas the Y-axis holds more weight than the other two axis as the mounting of Z-axis is done on it. The movement of machine tool should be smooth through out the machining process which is provided by one stepper motor on each axis and one servo motor for the operation of machine tool.

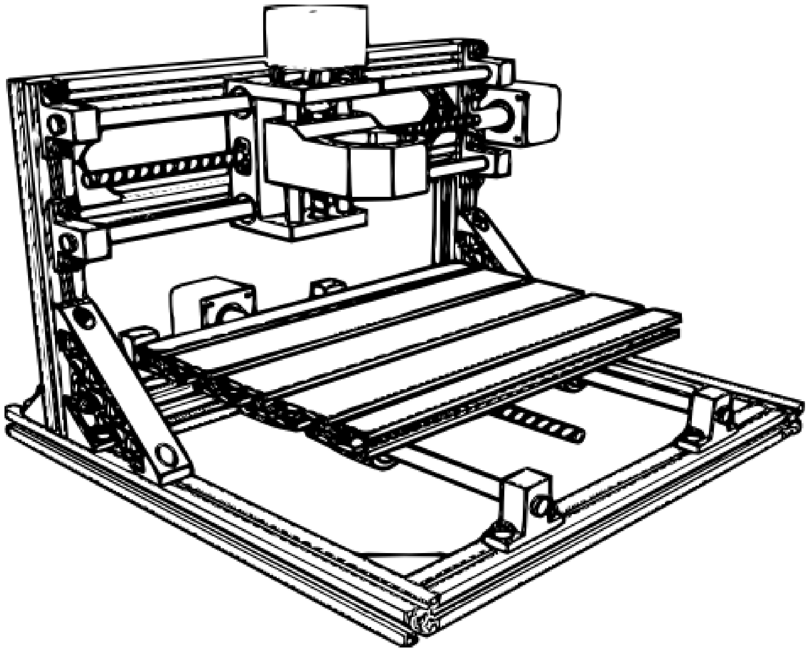

Fig. 7 Creo Model

V. DESIGN CALCULATIONS

Designing an automated metal engraver requires a robust structure with minimal vibrational effects to maintain accuracy. There is a need to select accurate components and to justify the size of the machine. For selecting proper components various design calculations are needed to be carried out in order to find out the torque and force which would be exerted on the slide ways of the machine. There are 2 types of calculations which are needed to be carried out. The first calculation is used to find the required torque so that the actuators can be selected on the basis of the torque obtained and second calculation is used to find out the power required to run the spindle motor.

A. Torque and force calculations on each slide ways for the selection of stepper motors [11]:

➢ Initial data:

1. Machine Speed(v) = 10.20 mm/sec
2. Acceleration time(t) = 0.5 sec
3. X-axis mass = 3.19 kg
4. Y-axis mass = 4.61 kg
5. Z-axis mass = 1.1 kg
6. Screw Lead Pitch(p) = 10 mm
7. Lead Screw Efficiency = 90 %
8. Linear guide intrinsic resistance (F_g) = 10N per guide

❖ Assumptions:

- Each linear guide exhibits 10N of intrinsic resistance which for simplicity includes any static or dynamic friction.
- The X-axis has 3 linear guides whereas Y & Z-axis has 2 guides each.
- Cutting force(F_c) = 100N has been included as an assumed maximum force on each axis in all directions of motions.

1) Acceleration calculations:

➢ Rate of acceleration (a_c):

∴ a_c = 0.204 m/sec^2

- Acceleration Displacement (s):

∴ s = 0.00255 m

2) *Linear force calculations* (Using Principle of Work & Energy)

➢ Z-axis Rapid “UPWARD” Movement(F_{zr}):

$$\boldsymbol{T_1 - W\Delta y - F_g cos\phi(s_2 - s_1) + F_{zr} cos\phi(s_2 - s_1) = T_2} \quad (1)$$

➢ Z-axis Rapid “DOWNWARD” Movement(F_{zc}) with cutting force(F_c):

$$\boldsymbol{T_1 - W\Delta y - F_g cos\phi(s_2 - s_1) + F_c cos\phi(s_2 - s_1) - F_{zc} cos\phi(s_2 - s_1) = T_2} \quad (2)$$

➢ Y-axis Rapid Movement(F_{yr}):

$$\boldsymbol{T_1 - F_g cos\phi(s_2 - s_1) + F_{yr} cos\phi(s_2 - s_1) = T_2} \quad (3)$$

➢ Y-axis Rapid Movement(F_{yc}) with Cutting Force (F_c):

$$\boldsymbol{T_1 - F_g cos\phi(s_2 - s_1) - F_c cos\phi(s_2 - s_1) + F_{yc} cos\phi(s_2 - s_1) = T_2} \quad (4)$$

➢ X-axis Rapid Movement(F_{xr}):

$$\boldsymbol{T_1 - F_g cos\phi(s_2 - s_1) + F_{xr} cos\phi(s_2 - s_1) = T_2} \quad (5)$$

➢ X-axis Rapid Movement(F_{xc}) with Cutting Force(F_c):

$$\boldsymbol{T_1 - F_g cos\phi(s_2 - s_1) - F_c cos\phi(s_2 - s_1) + F_{xc} cos\phi(s_2 - s_1) = T_2} \quad (6)$$

TABLE I
TABLE OF LINEAR FORCES:

Linear Forces	Value 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}	$133.9N$

❖ Maximum linear force values are used to calculate axis peak motor torque requirements.

3) Peak Motor Torque Calculations:

➢ Z-axis peak motor Torque requirements(z_t):

$$\boldsymbol{z_t = \frac{F_{zc} \times p}{2\pi \times e}} \quad (1)$$

➢ Y-axis peak motor Torque requirements(y_t):

$$\boldsymbol{y_t = \frac{F_{yc} \times p}{2\pi \times e}} \quad (2)$$

➢ X-axis peak motor Torque requirements(x_t):

$$\boldsymbol{x_t = \frac{F_{xc} \times p}{2\pi \times e}} \quad (3)$$

TABLE II
TABLE OF PEAK MOTOR TORQUE REQUIREMENT:

Axis	Peak Torque	Amount of Peak Torque
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].

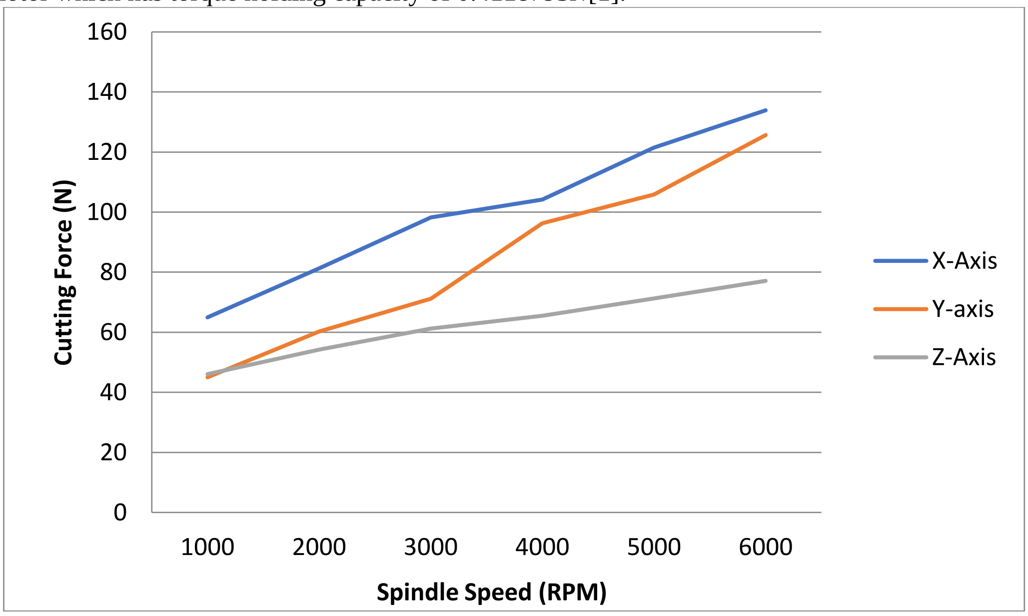

Fig. 8 Graph of Time (sec) vs Depth (mm)

The above graph shows the variations of cutting forces with respect to variable spindle speeds. Overall, it can be seen that at much higher speeds larger magnitude of forces are required. Whereas, at lower speeds lesser magnitude of force is required. Hence, suitable power calculations are needed to be carried out.

B. Spindle motor power calculations:

- At speed(n) = 8000 RPM
- Power Input(P_i) = VI = 9.6
- Efficiency = 80%
- Power Output(P_o) = $7.68W$
- Power Required$\left(P_{req}\right)$ = $\tau_{req} \times \omega$
- $\tau_{req} = 0.012N$
- $P_{req} = 10.05W$
- At speed(n) = 6000 RPM
- Power Input(P_i) = VI = 9.6
- Efficiency = 80%
- Power Output(P_o) = Efficiency × Power Input(P_i)

∴ Power Output(P_o) = $\frac{80}{100} \times 9.6 = 7.68W$

- Power Required$\left(P_{req}\right)$ = $\tau_{req} \times \omega$

Where τ_{req} = required torque for routing PCB (Copper + Bakelite or fibre)

- $\tau_{req} = 0.012Nm$
- $P_{req} = 7.54W$

Here the required power is less than the output power.

i.e. $P_{req} < P_{output}$

Hence, it can be stated that if the actuator is operated at 8000RPM then there is a chance of equipment failure due to the increase in the load current. Hence, the motor should be operated at maximum speed of 6000RPM which is clear from the above equation.

VI. VALIDATION AND OUTCOME

A. Engraving Test on Aluminium

An Aluminium sheet of thickness 5mm was used for testing the engraving process. A simple design of letter “S” with depth 0.2mm was engraved using the engraving tool 3mm vbit60°. After the test was conducted it was observed that the surface of the engraved part was super finished having no inaccuracies.

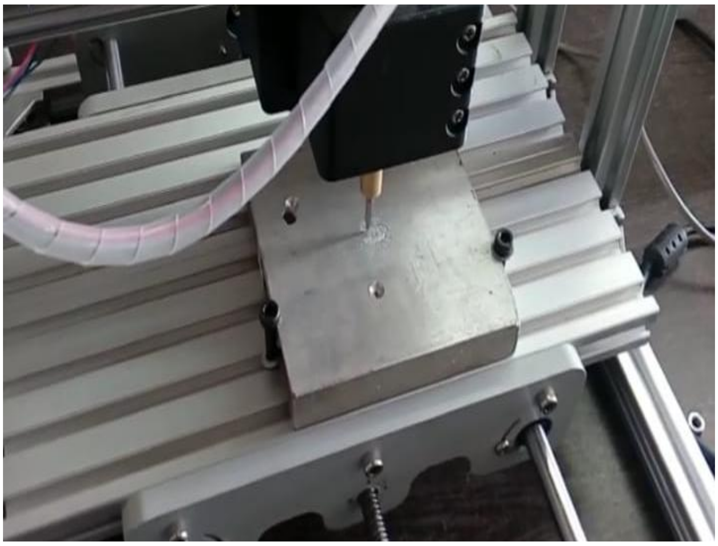

Fig. 9 Engraving “S” on Aluminum

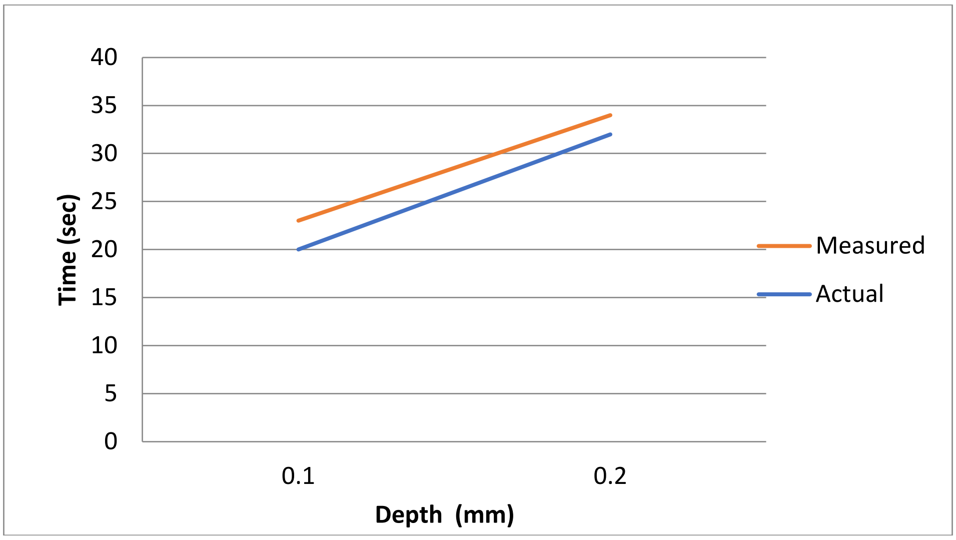

Fig. 10 Graph of Time (sec) vs Depth (mm)

From the above results it can be concluded that actual time taken by the machine to engrave the letter S was less compared to the time which was estimated by the software. Hence, the machine is capable of engraving on metals like aluminium with maximum of 0.2mm of depth.

VII. CONCLUSION

The CNC engraving 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. After performing various tests it can be concluded that the machine was fit for the purpose of metal engraving upto certain specified limits of depth. The process of synchronizing the 3 stepper motors was controlled using GRBL library and Universal G-code Sender Software.

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