Solar powered desktop CNC machine for fabric and paper cutting

Sarun P Pillai¹, Abhiram B R¹, Akshay S Kumar¹, Ashish U S¹, G Harikrishnan²

¹Student, Department of Mechanical Engineering, Amrita Vishwa Vidyapeetham, Amritapuri, India.

²Faculty, Department of Mechanical Engineering, Amrita Vishwa Vidyapeetham, Amritapuri, India.

Email: harikrishnang@am.amrita.edu

Abstract: In the modern era, Computerized Numeric control (CNC) machines are widely used in most of the industries around the world. Nowadays, this technology has been used in almost all industries for different operations like cutting, milling, welding, etc. This paper presents the design and manufacturing of a solar-powered, portable LASER CNC machine for cutting paper and fabric. The design procedure includes the calculations for finding torque required to run the machine, Factor of Safety, etc. Modelling and analysis of the machine is carried out using softwares like Solid Works and Ansys. The electronic circuit included in the assembly will convert the G-Codes into movements of CNC machine. Incorporation of Solar panels into the assembly helped to make this CNC machine work on clean energy. The results show that the machine is feasible at a reasonable cost for applications where speed and repeatability is achieved while not compromising on accuracy.

Keywords: Desktop CNC machine, LASER cutting, Solar CNC machine, Computerised Numeric Control

1. Introduction

CNC stands for Computerized Numeric Control is a special kind of manufacturing technique in which a program entered into the computer unit connected to the machine and the machine will execute the program according to a manufacturing process [1]. It is a unique manufacturing technique in which a computer will control the machine. This is what actually separates the CNC machining from other conventional manufacturing techniques. In this method, a customized computer program is developed for a particular machining process with CNC machining languages called G codes that will eventually control all the parameters of the machine like cutting speed, position, depth of cut, feed rate, etc. The exact position and velocity can precisely controlled by CNC technology. The first process involved in this kind of machining techniques is the creation of a CAD drawing either 3-D or 2-D. These figures then converted into a code or program, which would understood by the CNC machine. CAM softwares like Mastercam or Inkscape usually do this conversion. The output will be in the form of G and M codes these G codes then converted into electrical inputs for the stepper motor of the CNC machine with the help of open source softwares like grbl [2]. The grbl will send the code to the microcontroller in the CNC machine [3]. The microcontroller will in turn give these codes as electrical signals to the stepper controller that controls the motion of each stepper motor. Then the operator will perform a test run to make sure everything is working properly. Using CNC machine for manufacturing process has many advantages over conventional machining techniques. Manual machining processes have less precision and cannot repeated exactly in the same manner again [4]. This can prevented by the use of CNC machines that has high accuracy and precision. CNC machines can work continuously for a long period and they require very less maintenance [5]. They are also much safer than conventional machining techniques [6]. LASER cutting technology can incorporated with CNC machining for much better
results. 'LASER’ stand for Light Amplification by Stimulated Emission of Radiation. In this method a LASER beam is focused into the material to be cut [7]. Which will will the burns the material to obtain the given dimension. This type of machining technique is ideal for cutting materials like fabric and paper

1. Components of solar powered desktop CNC Laser cutting machine
Solar powered desktop CNC Laser cutting machine consists of stepper motors (Figure.4), LASER head, stepper controller, microcontroller, 4 start ACME thread lead screw, Aluminium extrusion column, 12 V lead acid battery, battery charger circuit, solar panel, limit switches, USB interface, motor couplings, self-aligning Plummer blocks, and LASER controller. LASER head is the major component of the machine. A 2.5 W solid state LASER is used as the cutter, it is controlled by the LASER controller. The whole assembly is placed inside a mount. The G-codes then converted into electrical impulses by the microcontroller. Open source software called grbl is used to program the microcontroller. Microcontroller will give input to the stepper controllers, which will then control the stepper motors [8]. There are 2 stepper motors, one for X axis and one for Y axis. Stepper motors are special kinds of motors, there are large number of coils inside the stepper motor and these coils are energized in a particular sequence to obtain the required motion. Each step of the stepper motor used in this assembly has a step angle of 1.8 degrees. The frame of the CNC machine is made using Aluminium extrusion column. A 10 W solar panel is used to charge the 12 V lithium battery. A battery charger circuit is used to regulate the voltage [9]. USB interface will transfer the information from the PC to the CNC machine. It will take around 5 hours to completely charge the battery on a bright sunny day. Motor couplings are used to connect the lead screw and the stepper motor. Electromechanical devices such as limit switches are used for safety purposes if the machine faces any problem [10].

2. Methodology
2.1 Design of lead screw
The lead screw or the power screw in the CNC machine is provided to translate the rotational motion into linear motion. Here, we are using a four start ACME or trapezoidal thread. Two lead screws are required to act as linear actuators in both x and y-axis. Figure.1 shows the picture of a four-start ACME trapezoidal thread.

![Figure.1 Lead screw](image-url)
2.1.1 Torque required to rotate the screw in y axis

Torque required to overcome friction at the screw,

\[ T_1 = F_t \times \frac{d}{2} \]  

= 1.888 Nmm

Where, \( d \) is the nominal diameter of the lead screw and \( F_t \) is the tangential force acting on the screw

Tangential force (\( F_t \)) = \( W \times \tan(\alpha + \Phi_1) \) = 0.5396 N

Where \( \alpha \) is the helix angle of the lead screw and \( \Phi_1 \) is the friction angle.

\( W \) is the anticipated weight of the LASER head and LASER mount, which is taken as 500g.

Torque required to overcome the friction at the collar

\[ T_2 = \mu_2 \times W \times R_c \]  

= 0.4788 N

Where, Coefficient of friction of collar (\( \mu_2 \)) = 0.12

Mean radius of collar (\( R_c \)) = 4mm

Total torque required to rotate the screw, \( T = T_1 + T_2 = 2.358 \text{ Nmm} = 0.024 \text{ kgf.cm} \)

2.1.2 Torque required to rotate the screw in x axis

Similarly, the same equations can be applied in the x axis. Since, the total weight acting here is high, torque required to rotate the screw will be more.

Total torque required to rotate the screw, \( T = T_1 + T_2 = 14.1326 \text{ Nmm} = 0.1442 \text{ kgf.cm} \)

The torque requirement in the x and y axis are only 0.1442 kgf.cm and 0.024 kgf.cm. Since the stepper motor with minimum torque rating available in the market are 4 kgf.cm, we are using stepper motors with 4 kgf.cm torque rating for both the axis.

2.1.3 Efficiency of the screw

The Torque required to drive the screw without any friction,

\[ T_0 = W \times \tan\alpha \times \frac{d}{2} \]  

= 6.2455 Nmm

Efficiency of the lead screw,

\[ \eta = \frac{T_0}{T} \]  

(4)
\[ = 52.96\% \]

Since the efficiency of screw is more than 50%, it is an overhauling screw. Thus an anti-backlash mechanism should be provided. Figure. 2 represents the anti-backlash mechanism with the help of a collar.

3. Modelling and analysis
The frame of the CNC machine is made with aluminium 6063-T5 alloy. The dimensions of the CNC machine are length=350mm, breadth=350mm, height=300mm. Al 6063-T5 alloy has good surface finish and strength. A 3-D model of the CNC machine assembly is modelled using Solidworks software, and analyzed using Ansys software. Figure.4 shows the solidwork model of CNC.

Figure.2 The anti-backlash mechanism

Figure.3 Stepper motor

Figure.4 3D Solidworks model of desktop CNC machine (dimensions in mm)
Figure.5 CNC Frame

Figure.6 Solidworks model of CNC frame

Figure.7 shows the equivalent stress distribution acting along the frame. Equivalent stress or Von-mises stress is used to predict yielding of materials under multiaxial loading conditions. From Figure.7 it is found that the maximum stress acting on the structure shown in Figure.5 is 0.58419 MPa which acts on both the extreme ends of the structure and the minimum stress as 0.0018016 MPa. The whole component is divided into number of elements so that when load is applied on the structure it is uniformly distributed. Here we used fine meshing for more accurate results.

Figure.7 Equivalent stress acting on the structure
3.1 Materials for construction
Materials for various parts of the CNC machine were selected based on the machinability and the weight considerations. Table.1 shows the materials selected for different parts.

| Part                  | Material                        |
|-----------------------|---------------------------------|
| Aluminium Frame       | Al 6063-T5 alloy                |
| Lead screw            | EN 31 (Stainless steel)         |
| Bed(Table)            | Wood                            |
| Allen Bolt            | MS                              |
| Stepper Motor coupling| Aluminium alloy                 |
| Stepper motor brackets| MS                              |
| Corner angle bracket joint | MS                            |
| Anti-backlash nut     | Bronze                          |

4. Results and discussion
A working prototype of CNC was successfully made and tested with different materials. The calibration process was carried out in order to make sure that the accuracy of the machine was up to the mark. The basic aim of this work was to build a scale down model of industrial version of the CNC laser cutting machine which is of light weight, low cost, easy to transport and can be easily set up. It is planned to scale up the prototype CNC machine in terms of size, use more powerful motor, strengthen the frame and worktable with materials like aluminium 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.

4.1 Equipment testing
The desktop CNC LASER cutting machine as shown in Figure.8 was operated for different kinds of fabrics and paper materials and the corresponding results were obtained. It was able to easily cut through the fabric with high precision. The machine is also tested for accuracy and repeatability. The machine was able to cut complex shapes like concentric circles with ease. The surface finish of the fabric after cutting process was excellent. The machine consumed very less energy during the cutting process. However, the machine was not able to cut materials like acrylic and Styrofoam. Figure.9 and Figure.10 shows the result of machining on fabric and paper respectively.
5. Conclusion
The concept was successfully converted into reality along with the help of all of its components. Small business owners are benefited by using this kind of small machine tools to fabricate materials with high efficiency and flexibility with less cost. In this project, a small-scale two-axis CNC laser machine is designed and analysed under a very limited budget. This CNC machine can precisely cut fabric and paper with the help of Laser cutting technology. It can easily operate in the absence of conventional power supply, since it makes use of solar power. Its small size and relatively less weight make its transportation easier. This kind of technology can improve the lives of people in both rural and urban areas.

6. References

[1] Pahole I, Rataj L, Ficko M, Klancnik S, Brezovnik S, Brezocnik M, and Balic J 2009 Construction and evaluation of low-cost table CNC milling machine Scientific Bulletin, Series C: Mechanics, Tribology, Machine Manufacturing Tech. 113 1-7
[2] Sinyuk O M and Goryashchenko S L 2013 Reduction of the energy losses in drives with hybrid stepper motors 4 (45) 142-146.

[3] Andrei T and Nae I 2010 Practical applications Performed by a stepper motor CNC router Seria Technical LXII pp 127-138.

[4] Yangjing 2010 The LR0412 high-performance wide-format CNC laser cutting machine of JINAN FOUNDRY&METALFORMING MACHINERY RESEARCH INSTITUTE Metalforming Equipment & Manufacturing Tech.

[5] Gordon S, Hillery M T 2005 Development of a high-speed CNC cutting machine using linear motors J. of Materials Processing Tech. 3 pp 321-9.

[6] Tavaeva A and Petunin 2014 The issue of cutting cost parameters optimization for CNC laser cutting machines Info. Tech. for Intelligent Decision Making Support 2 pp 75-78.

[7] Zhang Yongkang, Zhou Jianzhong and Ye Yunxia 2004 Laser processing technology Chemical Industry Press pp 14-15.

[8] Xu X, Li Y, Sun J and Wang S 2012 Research and development of open CNC system based on PC and motion controller Procedia Engi 29 pp 1845-1850.

[9] Miroslav Radovanovic 2002 laser cutting machines for 3-d thin sheet parts University’s day-8th international conference Târgu Jiu

[10] Rober S.J and Shin Y C 1995 Modeling and control of CNC machines using a PC-based open architecture controller Mechatronics 4 pp 401-420.