ISSN: 2586-7652 (Print) Vol. 04, No. 01, March 2021
ISSN: 2635-7607 (Online)
International Journal of Advanced Engineering
Source: http://ictaes.org
Manuscript received: January 3, 2021; Revised: February 10, 2021; Accepted: February 12, 2021

Modeling and Fabrication of Low Cost 3-Axis Computer Numerical Control (CNC) Machine

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Abstract

This paper presents the study and fabrication low cost of 3-axis Computer Numeric Control machine. The parts of the computer numerical control (CNC) machines are fabricated individually and are assembled. The knowledge related to the working of the CNC machine is acquired by performing a work of literature. The required materials for the research are selected, and the dimensions of different parts are defined. Initially, X-axis is created according to the defined dimensions, then Y and Z axes are created. All these axes are assembled such that a fully assembled CNC machine is obtained. For controlling the movement of the three axes, four stepper motors are used. Two motors are used for providing movement along X-axis and each one for Y-axis and Z-axis movement. The operations of motors are controlled by using TB6560 motor drivers. Arduino Uno is used as a microcontroller for controlling the overall operation. G-codes are generated by using INKSCAPE software which controlled the stepper motor's movement on three individual axes. The idea of the fabrication of low-cost CNC machine came forward for reducing the cost and complexity in the CNC systems.

Keywords: *CNC machine, G-code, Inkscape, CAM software.*

1. Introduction

In today's generation, there is a huge demand for high finish and high accuracy. So, this requirement can be fulfilled with the use of a computer numerical control (CNC) machine for manufacturing. CNC stands for

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computer numeric control, and the instruction controls all the movements present in the system. The CNC machine can be used for different process in the industries and mass production. Different variety of product and materials can be developed using the CNC machine as they are versatile. A custom program is provided for manufacturing each object, which is generally written in a G-code, and a machine control unit executes this code. The program is capable of controlling all the parameters and the overall operation of the CNC machine. With the on-going development of technology and economy, new industrial requirements such as high precision, good quality, high production rate and low production costs are increasingly demanded. Most of such requirements, including dimensional accuracy, conformance to finished products' tolerances, 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 and are able to make ultra-precision products down to nanoscales in a much faster manner. This paper presents a way to overcome the problem of machining a small part of the work. CNC machine builds up with simple mechanical assembly, so if we are able to add more hardware and enhance the effective code for programming, it helps to use over broad areas. They are flexible and give accurate results, so provide better performance facilities over a long period of time and save human labour.

2. Related Works

Nowadays, there are many technologies for growth. With this growing competition, many industries demand to use new, cheap, high quality and faster's machine. In the industries at this millenniums century, especially in manufacturing field, CNC machine is the significant machines use to produce the output according to its advantages (precise, faster, etc.) thus any CNC machine are built to do multi jobs like cutting, roughing, pocket, slotting, drilling, threading, etc. But CNC developer industries always build a large scale of CNC machine because of its purpose. Today, few developers still build CNC machines in small scale, simple and easy to use. Because of this, these projects are done. Demands on the CNC nowadays also this idea are produced. Usually, the small items are fabricated and produced using simple machines and techniques like moulding, injection moulding, blowing, etc. Still, with the demand on the CNC and demand from the user, these tiny little things are now produced using CNC machine as many advantages are using these CNC machines in terms of its quality and results [1]

The KVC1050N Vertical machining centre's design process is also studied as an example to demonstrate the feasibility and availability of the proposed framework. The results of this study significantly contribute to efforts to achieve knowledge and process integration in CNC machine tool D&D. In a word, on-going efforts are being taken to make the framework more practical in the industrial application. Thus, this solution can serve machine tool companies in this important industry sector by increasing machine tool development capabilities, improving work efficiency and ultimately reducing development cycle time and costs [2]. Venkata Krishna pabolu et al. (2010) discusses the design and implementation of low cost three-dimensional computerized numerical control system (CNC) for industrial application. In this paper, prototyping, and Embedded CNC machine was created. Detail description of different modules such as software development, Electronic/Electrical development; along with technical details of their implementation has been given [3].

Dr.J.B. Jayachandraiah et al. provide the idea to develop the low-cost Router system which is capable of 3 axes simultaneous interpolated. The low cost is prototyping by incorporating the standard P.C. interface features with microcontroller based CNC system in an Arduino-based embedded system. With a limited budget, the author concludes that small machine tools to fabricate small parts can provide flexibility and efficiency in manufacturing approach and reduce the capital cost, which is beneficial for small business owners [4].

Sundar Pandian et al. develop low-cost 3-axis CNC machine using of- the- shelf component, stepper motors with drivers, Arduino open source, microcontroller and open source motor control software. The author used ready to assemble kit from Zen Tool works, USA. Kit provided stepper motor, lead screw, guide rod, anti-backlash flans and spring. He made the Body with high-density PVC. The machine has fix gantry and mobile bed, so there is a restriction in the working area. The author develops a Low-cost CNC machine only for an educational purpose [5].

3. Materials and Methods

3.1 Selection of required material

The required materials are selected for developing a CNC machine according to performance requirements of materials such as function, appearance, reliability, service life, environment, compatibility,producibility,cost as well as engineering requirements such as fabrication requirements ,service requirements, and economical requirements. According to these considerations, the material selected is done in two parts. Initially, the required mechanical components are selected then the selections of electronics components are made.

3.1.1 Selection of mechanical components

The use of 12mm thick wooden plate is done as a base plate. This wooden plate is of 80cm x 80cm in dimension. An aluminium angle profile of edge length 40mm with 2mm thickness is used to roll the ball bearing and provide support. The aluminium is used as it is a light material and provides less friction while rolling the ball bearing. An iron square tube of edge length 25mm is used with the ball bearing for making a slider. The guide for Y-axis is provided by using an iron tube of 40mm edge length. And the guide to the Z-axis is provided with the use of an iron tube of 10mm diameter. Several flat iron bars are utilized for making the carriage. The ball bearing has 10mm inner diameter, and 30mm outer diameter (6200 series) and ball bearing of 8mm inner diameter and 12mm outer diameter (608 series) are used. The use of thread rods is done for providing the drive system. Different other materials like bolts and nuts, screws, iron angle profiles, etc., are used.

3.1.2 Selection of electronic components

Arduino Uno is selected as a microcontroller for controlling the overall operation. The use of stepper motors (NEMA 17) is done for providing movements to the system. This stepper motor has a 1.8-degree step angle and has a holding torque of 45Ncm. TB6560 is used as a motor driver as it is capable of providing smooth and quiet operation. For providing the power to the system, SMPS of 10 A is used.

3.2 Fabrication

3.2.1 X-axis carriage

At first, the base is prepared using the wooden base plate. On one end of the base plate, aluminium angle profile is fixed, keeping the tip pointing to the top. On the other side of the wooden base plate, flat side of the aluminium is fixed. Using an iron tube of 25mm x 25mm, X-axis is constructed. The iron tube is cut into a piece of 20 cm, and 10 mm holes are drilled at the distance of 1.5cm and 3.5cm respectively from both ends. At the edge of the square tube, 5.5cm far from the left end, a drill hole is made for placing 8mm thread rod. Along with the bolt and nuts, four ball bearings of 6200 series are

used in four 10mm holes as in Figure 1. Similarly, for the second half in Figure 2 of the X-axis, an iron square tube is cut into 20cm piece. A hole of 10mm is created at a distance of 1.5cm for both edges. For thread rod, drills are made at the distance of 5.5cm and 6.5cm. Both halves of X-axis in Figure 3, are connected using an 85cm long angle profile with the edge length of 40mm and thickness of 4mm. A square tube of 20mm x 20mm dimension is attached to this angle profile.

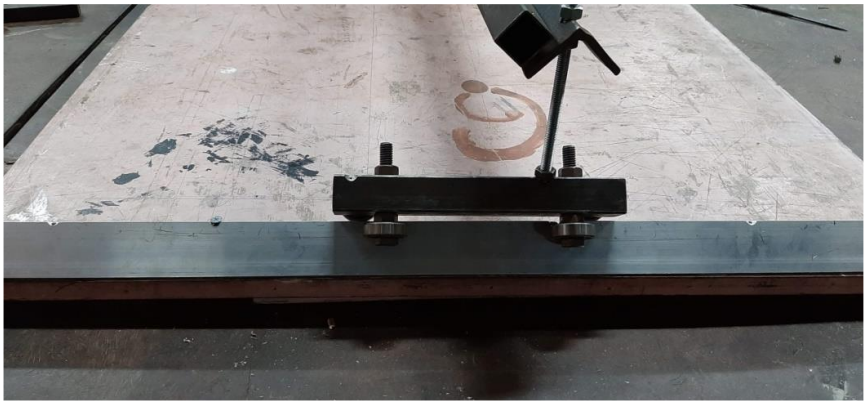


Figure 1. The first half of X-axis



Figure 2. The second half of X-axis



Figure 3. Connection of both halves

3.2.2 Y-axis carriage

The Y carriage is created using 20cm long piece of square tube with an edge length of 25mm as shown in Figure 4.. Drill holes are created at a distance of 1.5cm and 3.5cm apart from the end for a ball bearing. At the centre of a square tool, a hole of 10mm is created for using a drive system. Then the creation of carriage is performed. The carriage's main components are 37cm long threaded rod with a diameter of 8mm and flat iron bars. The threaded rod is used with the flat iron bars, and a structure for carriage is created. The structural component is assembled carefully such that a gap of 4 to 5cm is maintained between the lower edge of Y carriage and the base plateas as show in Figure 5. The aluminium angle profile with an edge length of 40mm is used to support and guide this carriage. Two more ball bearings are used in the top of the construction for the smooth operation in the aluminium guide (Figure 6)..



Figure 4. Roller for Y-axis using ball bearings

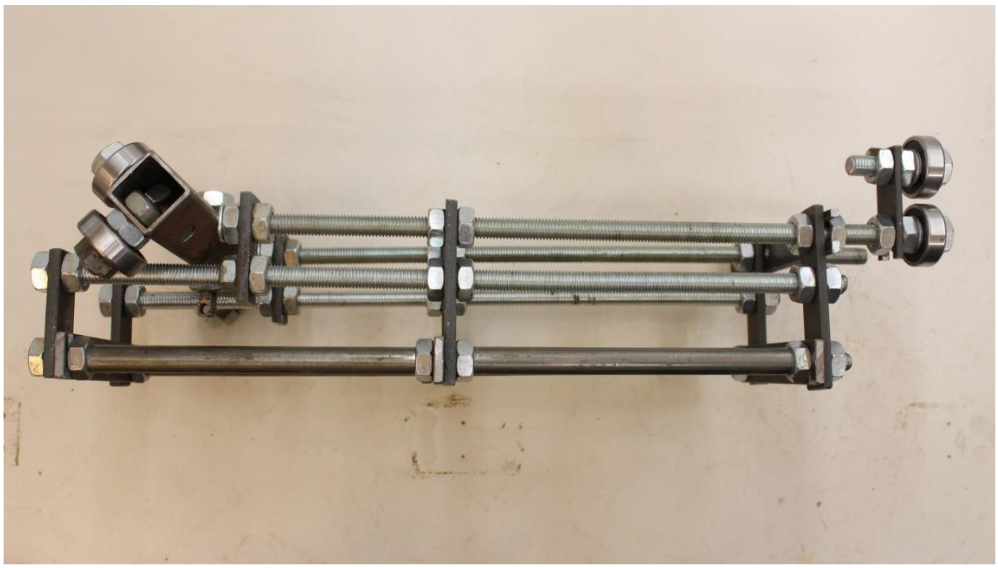


Figure 5. Y-axis Carriage



Figure 6. Guide for X & Y-axes

3.2.3 Z-axis carriage

Z-axis is guided by the ball bearings running on the round tube of the carriage. For the construction of Z-axis components, aluminium angle profile and flat iron bars are used. Two pieces of 40x40mm aluminium angle profile with a length of 26cm is used. The bearings are used in the flat iron bar with the help of bolts and nuts as shown in Figure 7..



Figure 7. Roller for Z-axis

3.2.4 Final assembly

After constructing all the components, the mounting plates are fixed on the four corners of the wooden base plate. These mounting plates are used for holding the motors and also for providing support to the driving system. For the drive system, thread rod of 8mm is used. For X carriage, thread rod of 85cm long is used which passed through the nuts welded on the lower end of the bolt (Figure 8). A coupler is used for coupling the threaded rod with the motor, and the mounting plates support the other end of thread rod at the other end. Similarly, the drive is provided for Y and Z axes by coupling thread rod with the motor using coupler. The rotation produced by the motor is transferred to the threaded rod. As the threaded rod is passed through nuts grooves, rotating it creates a linear motion for the carriage.



Figure 8. Mounting and drive system

3.3 Circuit diagra

The overall operation for this system is controlled with the use of Arduino Uno. SMPS of 10 amperes is connected to the Arduino board for providing power to overall configuration. Then TB6560 motor drives are connected to the Arduino board, which provided instruction to the motor. Four TB6560 motor drivers are used for controlling three axes. Four stepper motors are used which are connected to these motor drivers. Arduino received the codes and instruction through the computer which is provided by the Inkscape software. The overall circuit design is shown in Figure 9.

3.4 Operation of CNC machine

The machine is operated after the assembly operation is completed. For generating the required code, the use of Inkscape software is done. Inkscape is able to develop the required G-Code of any sketch. The G-code is created then it is uploaded in the Arduino. Arduino consists of predefined GRBL codes which are used for driving the motor according to the supplied code.

The steps per revolution of Nema 17 is 200 steps/rev. So, 1.8 degrees is covered by one step of a

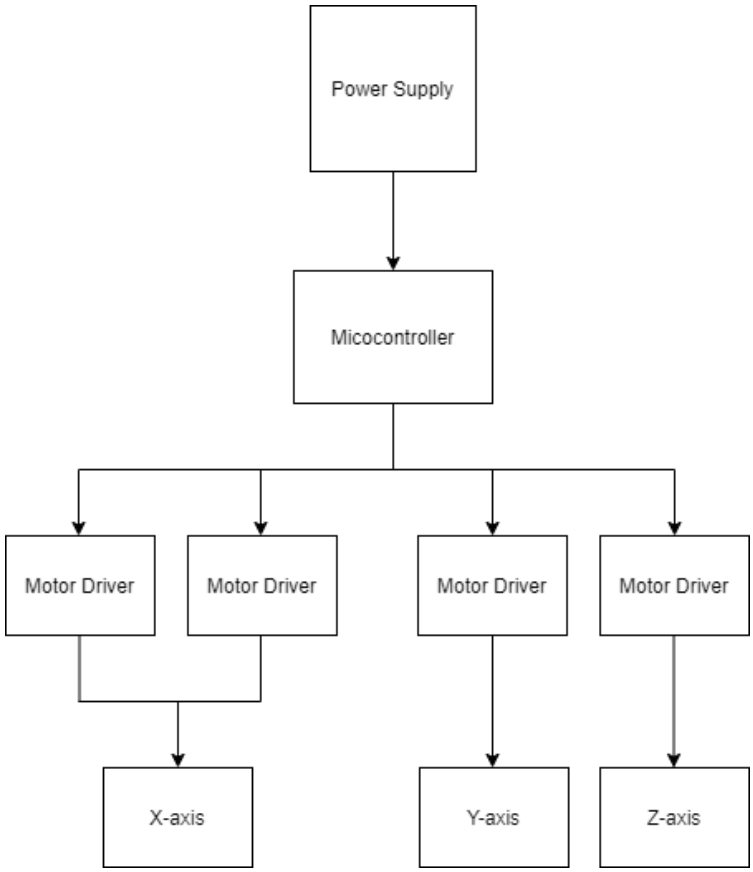


Figure 9. Circuit design model

stepper motor. A half micro-step mode is used for stepper motors in X and Y axis and for Z-axis, a stepper motor is used in a single-step mode. The threaded rod's pitch length is found to be 1.25mm when measured with the Vernier calliper.

The formula is obtained for step calculation of 1mm travelling of plotter pen

Steps per mm = (steps per rev of our motor * micro-steps) / pitch of thread rod

So for X and Y axis,

Steps per mm = (200 * 2) / 1.25= 320 Steps per mm.

And for Z-axis,

Steps per mm = (200 * 1) / 1.25 = 160 Steps per mm.

The CNC is calibrated by using this data on Universal G-code sender. The command to UGS is provided as:

$100=320(for X-axis)

$101=320(for Y-axis)

$102=160(for Z-axis)

For the CNC machine, a feed rate of 400 is used, and the speed of motors for all three axes is set to 500 mm/min. The command is provided to the UGS as:

$110=500(for X-axis)

$111=500(for Y-axis)

$112=500(for Z-axis)

Then the CNC machine is operated.

The operation of the machine involved the following steps.

• Start

• Send the graphs or sketches to the computer software tool (Inkscape).

• A software tool (Inkscape) then converted the graphs into G-code Understandable by CNC machines.

• A microcontroller of CNC plotter then received the G-code, and then the driver of the stepper motor got active.

• Stepper motor operated and slider moved along X, Y-axis for a motion of the plotter and Z axis for the pen.

• A graph was drawn on paper with the pen's motion as for the G- code programmed.

• Stop.

4. Testing of CNC Machine

4.1 Linearity test

Different tests are performed for checking the accuracy and ability of the machine. At first linearity test is performed. A marker is placed in the tool holder, and a linear command of 10 cm in X-axis is provided. The machine is operated, and the tool holder with the marker started to move in X-axis drawing a line. After the machine has completed its operation, the created line is measured using a scale. The line is found to be exactly 10cm. Similarly, a test is performed in the Y-axis, and the line is found to be exactly 10cm. The same command is used for Z-axis, and the height of the marker tip is measured using Vernier calliper. For Z-axis also, the operation is accurate. So, the linear motion of the machine is accurate in all the direction. The linear test is shown in Figure 10.

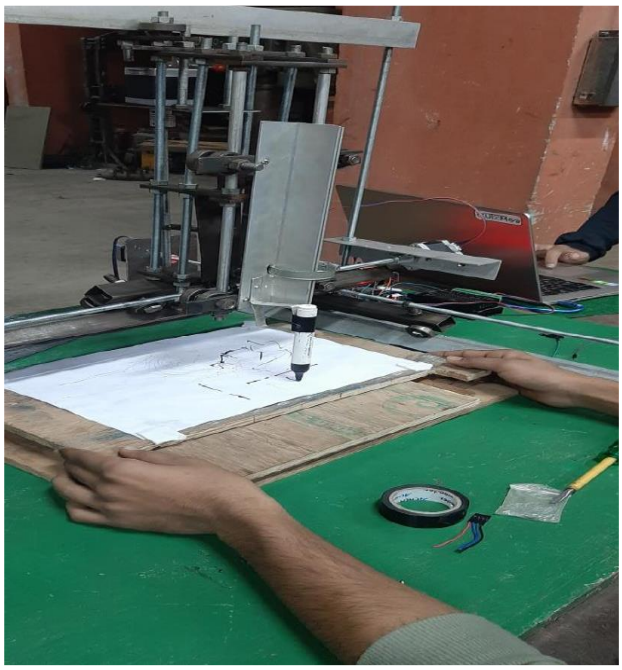


Figure 10. Linear test

4.2 Circular test

Then a circular test is performed in the machine by checking its ability to draw a spiral. Open-source software, Inkscape is used to generate the required code for a spiral. Inkscape can create the required code for any shapes. The machine is operated by uploading the created G-code of a spiral into Arduino then the machine started to move in the spiral path. And after completing the operation, the tip of the marker came back to the origin perfectly. The spiral created is almost accurate to the input provided. So, any circular profile could be created with high accuracy which is shown in Figure 11..

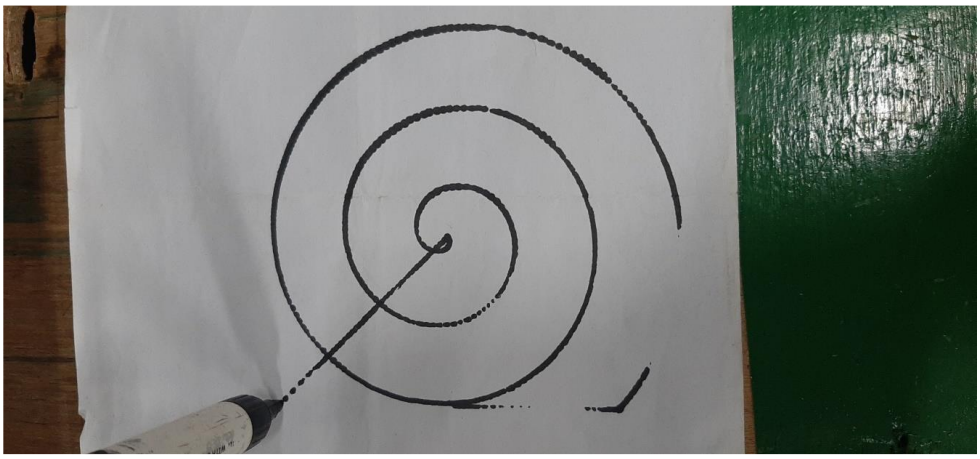


Figure 11. Spiral test

4.3 Block letter test

The ability of a machine is further explored by conduction other tests. So, some block letters are created using this machine. The desired words are inputted to the Inkscape and required G-code is

generated, which is then flashed to the Arduino to control the motors' movement. The block letters are created according to the input provided. This machine is capable of generating any geometrical shapes as shown by the results as in Figure 12..

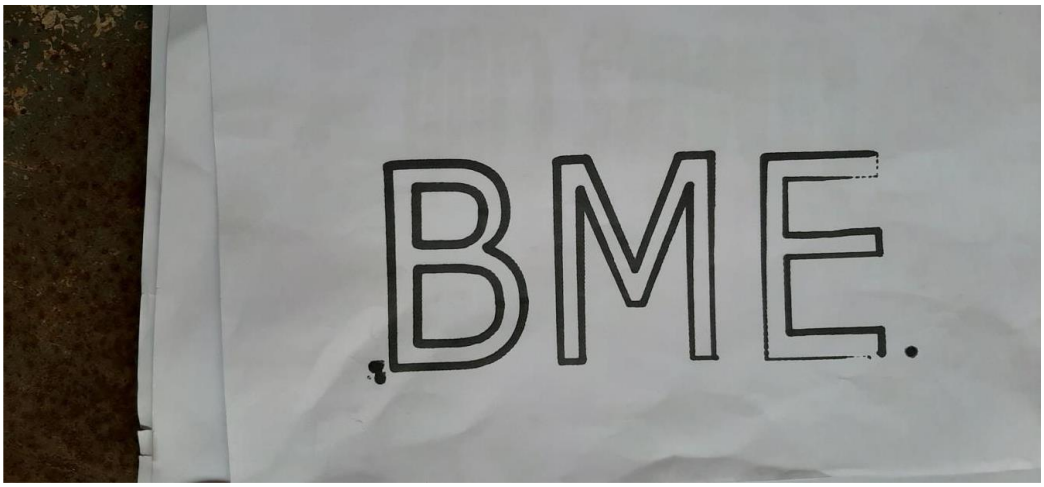


Figure 12. Block letter test

Finally, a random sketch is selected, which is to be created using the CNC machine. The sketch is selected, and the input is provided to the Inkscape software. The necessary G-codes are created which is uploaded to the Arduino then the machine is operated. The motor started to operate, and the tool started to move according to the sketch's vector graphics. The machine is capable of moving in the complex pattern and contour with high accuracy. This method can be very useful while manufacturing complex shapes with high accuracy and finish. This technology can be used for mass production in industries for increasing the productivity and quality of the goods.

5. Conclusion

This paper's main focus is to create a low cost 3-axis CNC machine that can create an image or text of any required shape. Due to the control of the stepper motor, it can work with accuracy by consuming low power. The CNC machine fabricated is of low cost as compared to other CNC machines available. According to the user's purpose, the marker or pen can be replaced by any other tool and required operation can be performed. This machine is capable of producing different patterns and drawings according to the needs and requirements.

The parts of the CNC machines are fabricated individually and are assembled. The knowledge related to the working of the CNC machine is acquired by performing a work of literature. The required materials for the research paper are selected, and the dimensions of different parts are defined. A low-cost CNC machine is created, which can move in all the directions freely. The movement is provided by the stepper motor and threaded rod as the instruction created by the G-code, which is generated using Inkscape software. The generated G-code is uploaded in the Arduino, and the motion of tool post is controlled by a controller using the motor controller. This machine can move in a complex pattern with accuracy, which is proved by performing linearity test, block letter test, circular tests. The fabrication process for developing this machine is easy, efficient and economical. The complex contours can be developed easily with the use of this machine. This machine can be modified to perform metal removing operations.For different types of metal removing operations,the machine should be made robust and cutting tools are used to remove excess materials in the tool holder.This technology can be used in the

industries for mass production and increasing productivity of the goods.

Acknowledgment

We thank the management of Tribhuvan University, IOE, Purwanchal Campus, Dharan for providing necessary infrastructure and creating a good environment to work in. We are very grateful to the management and other helpful staff members.

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