DESIGN AND DEVELOPMENT OF ECONOMICAL 3 AXIS CNC MILLING ROUTER FOR NON-CONTACT MACHINING OPERATIONS

By

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Date Received: 31/01/2017 Date Revised: 18/03/2017 Date Accepted: 29/03/2017

ABSTRACT

The growth in manufacturing technology enhanced the usage of CAD and CAM in industry. CNC systems are frequently been adopted for manufacturing. The high precision, accuracy, and repeatability of these systems are making them popular in industry as well as among researchers. The high capital investment involved force these systems far from the reach of researchers and students. For research in manufacturing trends, researchers and students usually came across the need of precise axial movements. The aim of this work is to make CNC technology portable and available for researchers and students. Rigid base of 16 mm thick aluminum plate was designed, with lead screw accumulating the linear movements. NEMA 23 stepper motors were used to power the linear drives with the help of micro stepping driver and CNC USB control. The final router developed is flexible for any imaginative use as well as economical thus can be a very supportive tool in the hands of researchers and students.

Keywords: CAD/CAM, CNC, Economical, Students/Researchers, NEMA 23.

INTRODUCTION

Quick and customized prototyping of products is leading us to a new era of manufacturing. The production technologies change immensely from the start as craft production to mass production. There have been a number of revolutionary changes to production systems. Today's production systems have become highly flexible and specialized due to the use of computer numerical controlled machines. The robotic systems have successfully taken over the repetitive precision work. Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), CNC Technologies, Flexible Manufacturing Systems (FMS), and Computer Integrated Manufacturing (CIM) are gaining popularity day by day. The high accuracy and repeatability make these technology an easy choice for mass production. Frequent adaptation of these technologies encourage the researchers and students for study of CAD/CAM software, CNC machine programming and operation, however the resource availability in India for research and study is constrained by high capital investment. The industrial CNC setup available at some of the reputed educational facilities in India are standard setups with rigid usability.

However, what today's production industry needs is variety and customization. The growing demand of customized innovative products, calls for growing need of easy customized machining systems. This growing need gives birth to the aim of this study, i.e. design and development of economical 3 axis CNC Milling Router for innovative research.

This paper outlines the design and development of an economical desktop 3-axis vertical CNC mill for purpose of study and research in CAD/CAM and CNC programming areas. Rigid base of 16 mm thick aluminum plate was designed with lead screw accumulating the linear movements. NEMA 23 stepper motors were user to power the linear drives with the help of micro stepping drivers. CNC USB software was used for executing the G code and

M code for machining applications. The final router developed is flexible for any imaginative use as well as economical. Thus can be a very supportive tool in the hands of researchers and students.

The working of a milling router depends upon the following sub-assemblies [1], [8], [9].

- Base structure.
- System for axial movement.
- Break up drive.
- Software for control.

The first task towards the development was to design a rigid structure and choose the best alternative for each of the above needed elements amongst the available options [10].

1. Design and Development

The basic idea of a CNC milling router was a point movement of the tool in a 3D cubic space volume. For this task, various reference research setups [2], [3], [4], [5] and reference books [8], [9] were studied for selecting appropriate elements. A working volume of 200 x 300 x 50 mm deemed fit for the requirement. The CAD model of the proposed machine is demonstrated in Figure 1. Various elements of the proposed machining system were selected and acquired [6] as per the volumetric movement requirement.

2. Base Structure

Machine base structure integrates all machine elements into a complete system which is crucial for the performance of the machine tools as it directly affects the static and dynamic stiffness, as well as the damping response of the machine tool. A carefully designed structure can provide high stiffness which results in higher operation bandwidth and more precise operation. Material selection for structure was first crucial task, it was needed to be stiff as well as easy to machine for desired customization.

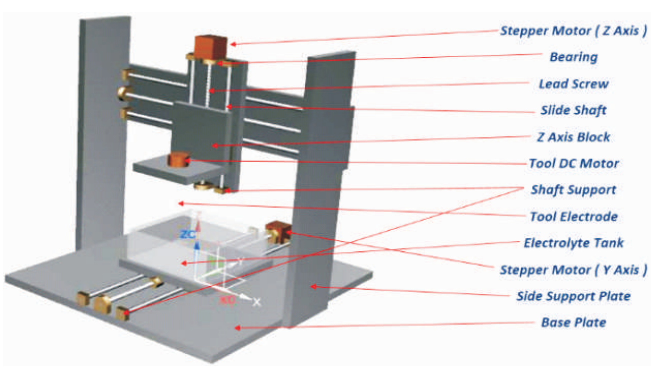


Figure 1. CNC Milling Router Final Design

Aluminum sheet deemed fit for the purpose was 16 mm thick which was used to shape the base frame of the machine. The base frame was designed to generate a motion volume of 200 x 300 x 50 mm. Table 1 documents the specifications of aluminum pieces essentially required for base structure. The aluminum sheet provided enough strength to the base frame and was easy to machine to give desired shape and constraints. The proposed design for base structure is shown in Figures 2(a) and (b).

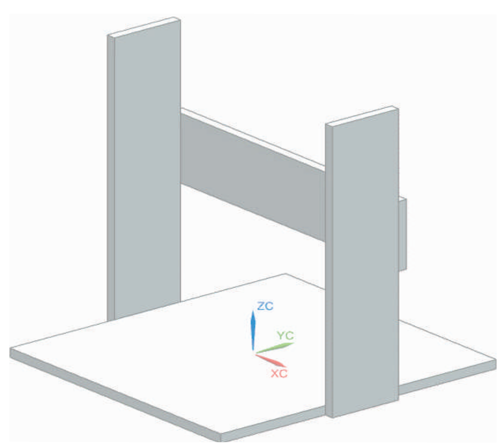
Aluminum pieces were cut in pieces with given specification and assembled as per design as shown in Figures 2(a) and (b). They were constrained in designated position by Allen bolts. Drills and Thread tap were made on the aluminum sheet as per design to accommodate the Allen bolts for constraining degree of freedom of corresponding plates.

3. System for Axial Movement

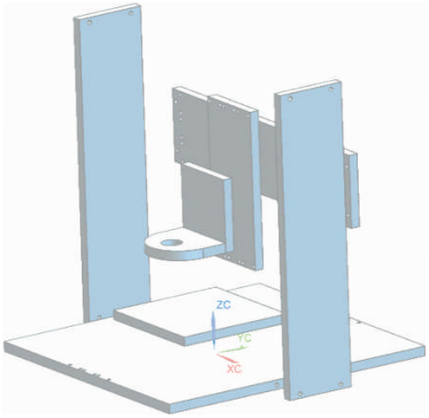
Relative axial movements XYZ were divided as per base

Specification	No of Units
470 X 500 X 16 mm	1
120 X 500 X 16 mm	3
120 X 250 X 16 mm	1
100 X 100 X 16 mm	1
120 X 100 X 16 mm	1
200 X 200 X 16 mm	1

Table 1. Aluminum Pieces Specification



(a)



(b)

Figure 2(a). Proposed Design for Base Frame, (b) Base Frame Assembly

structure design. Only one movement Y axis was designated for the work table as to balance the weight for work table and tool post. X and Z axial movement were designated to the tool post.

The plates of aluminum were supported by linear bearing sliding blocks which are to slide on steel shafts supported by shaft supports. Model SC8UU of 8 mm ID diameter as shown in Figure 3 was used.

Stainless steel lead screw support kit were used for converting the stepper motor rotational motion to controlled linear motion [8]. The kit include a stainless steel lead screw of 8 mm diameter and 2 mm pitch, a brass nut and two mounted ball bearings. Ball bearings were bolted in the structure to support the lead screw to rotate freely. Two such kits of T8-2-D8 500 mm as shown in Figure 4 were used for each X and Y axis, and one kit of T8-2-D8 300 mm was used for Z axis.

Linear rail shaft support Model SK8 (Size 42 x 14 x 33 mm) as shown in Figure 5 was used to support the 8 mm SS slide shaft. The linear rail shaft support was constrained to the aluminum plates as per design shown in Figure 1. Two linear

Figure 3. Linear Motion Ball Slide Units

rail shaft support were bolted in the structure to support each shaft so that the linear bearing can move back and forth in axial movement and complete mechanical function. The combination was used to provide smooth movement to the slide plates.

NEMA 23 stepper motors with 200 steps per revolution and 19 kg-cm holding torque were used for powering the system [9]. The NEMA 23 stepper motor is shown in Figure 6.

4. Break Up Drive

Micro-Stepping Motor Driver with ENABLE: RMCS-1102 as shown in Figure 7 was used to regulate the current supply to motors so as to control the RPM and torque. It has good control on 1.8 degree Bipolar Stepper Motors and operate without compromising on torque and control at higher speeds. It also has short-circuit protection for the motor outputs, over-voltage, and under-voltage. The driver is secure for any accidental motor disconnect while machining. The pulse/step, direction inputs are optically

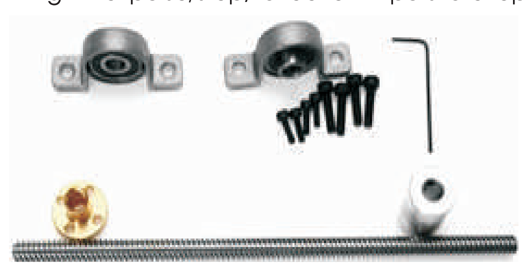


Figure 4. Stainless Steel Lead Screw Support Kit

Figure 5. Linear Rail Shaft Support

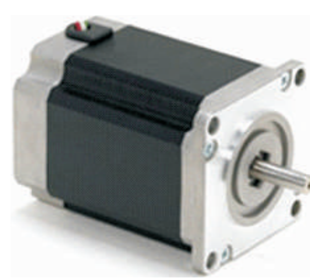


Figure 6. NEMA 23 Stepper Motor

isolated. Both inputs work with 2.5 V, 3.3 V, or 5 V logic drive signals. The input drive current is 5 mA at 2.5 V so almost all logic family can be used to drive these inputs.

The terminal details of RMCS-1102 Micro-Stepping Motor Driver is documented in Tables 2 and 3.

5. Axis USB CNC Controller

5.1 CNC USB MK1

The USB CNC motion controllers as shown in Figure 8 act as a link between a personal computer and motor drivers supporting step/direction control as shown in Figure 9. They are compatible with most drivers. The controllers connect to the USB port, which is available on all computers and laptops. The MK1 can control up to 4 axes. It was provided with fully integrated software solution, which is a dedicated application designed to work perfectly with purpose-built hardware. It has many advanced features to assist all type of general CNC machine operation.

Figure 7. RMCS-1102 Micro-Stepping Motor Driver

Terminal No.	Terminal Name	Description
1	GND	Power Ground or Power - Ve
2	+V	Power +Ve (12 V DC to 50 V DC)
3	A+	Motor Coil Phase A+
4	A-	Motor Coil Phase A-
5	B+	Motor Coil Phase B+
6	B-	Motor Coil Phase B-

Table 2. Terminal details of RMCS-1102 Micro-Stepping Motor Driver for Power and Motor Terminal Assignments

Terminal No.	Terminal Name	Description
1	ENA-	Enable -Ve optically isolated input
2	ENA+	Enable +Ve optically isolated input
3	DIR-	Direction -Ve optically isolated input
4	DIR+	Direction +Ve optically isolated input
5	PUL-	Pulse -Ve optically isolated input
6	PUL+	Pulse +Ve optically isolated input

Table 3. Terminal details of RMCS-1102 Micro-Stepping Motor Driver for Power and Motor Terminal Assignments for Pulse and Direction Input Assignments

5.2 Software for Control

CNC USB Controller software accompanied the MK1 controller [7]. It is a dedicated application designed to work perfectly with purpose-built hardware. The software is very user friendly, even someone new to CNC programing can employ advanced functions. Configuration options allow for maximum flexibility, integration, and customization. The software provides easy control for the aimed machining purpose. The built-in loops were utilized to generate the CNC program for the operation.

The software has useful G-Code manipulation and transformation functions. G-Code can be bookmarked, copied, pasted, and edited. It can be shifted, scaled, mirrored, and rotated too. Code remapping for foam cutter applications is also available.

5.3 Development of Setup

The finalized elements were assembled as per design and

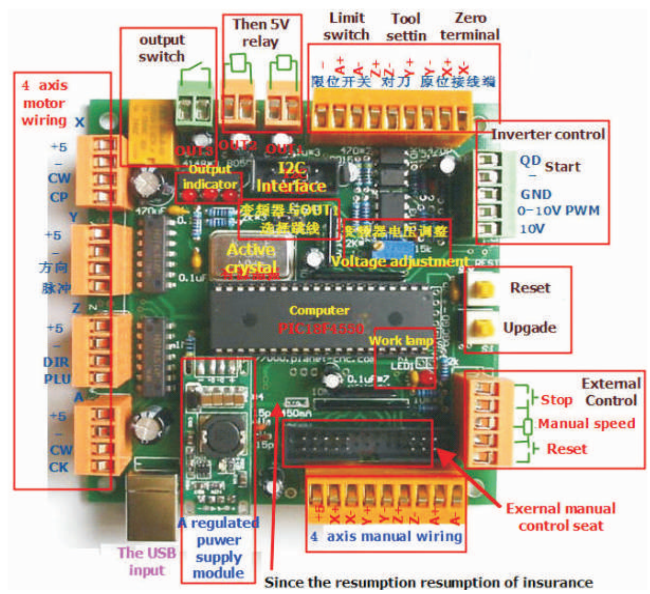


Figure 8. CNC USB MK1

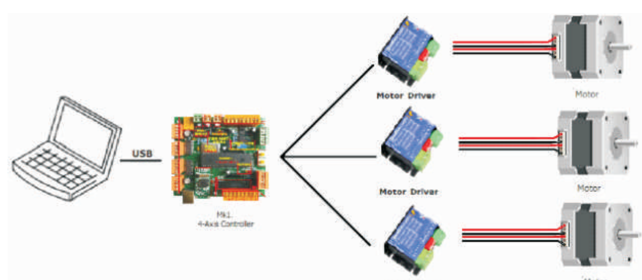


Figure 9. Logical Working Representation

the CNC milling router gets in shape as expected. Figure 10 demonstrates the final developed setup of 3-axis vertical desktop CNC milling router.

6. CNC Programs

CNC programs using G codes were generated and verified to command simple tasks to the CNC router.

Sample G-code programs are as follows.

6.1 For Square Motion

G90 G21 G17

M03 F20

G01 X0 Y0 Z0

G01 X-15 Y-15

G01 Z-3

G01 X15 Y-15

G01 X15 Y15

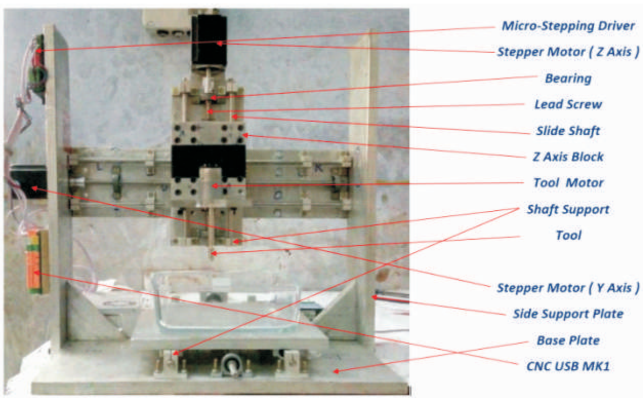


Figure 10. Final CNC Milling Router

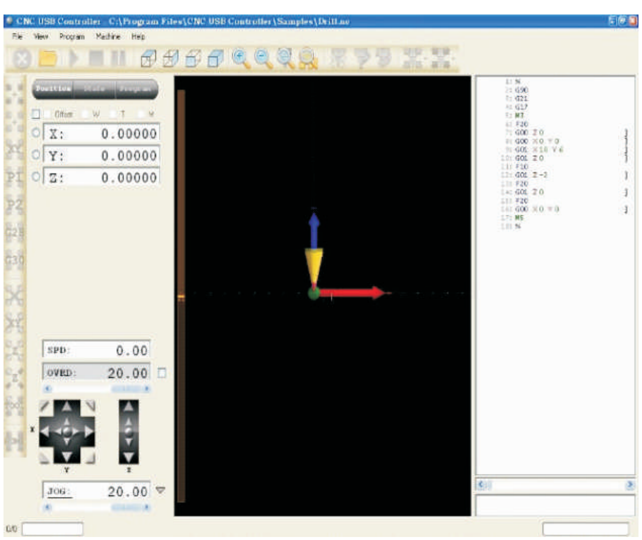


Figure 11. Screenshot of USB CNC Software

G01 X-15 Y15

G01 X-15 Y-15

G01 Z0

G01 X0 Y0

M05

6.2 For Motion in Circle

G90 G21 G17

M03 F20

G01 X0 Y0 Z0

G01 X0 Y-15

G01 Z-3

G02 X0 Y-15 I0 J15

G01 Z0

G01 X0 Y0

G01 Z-3

M05

6.3 For Drilling Operation

G90 G21 G17

M03 F20

G00 Z0

G00 X0 Y0

G01 X10 Y6

G01 Z0

F10

G01 Z-2

F20

G01 Z0

F20

G00 X0 Y0

M05

Figure 11 shows the screenshot of the machine software running the drilling operation program mentioned above.

Conclusion

This paper outlines the design and development of an economical three-axis CNC milling router. The developed product is customizable and easy to operate. The total cost of the developed setup is very nominal as compared to counterpart machines. It provides more scope for hands-on learning and customized axial movements for other hybrid machining operations. The router was designed for low tooling loads thus is ideal for non-contact machining operations, i.e. ECSM (Effective Current Source Model), Additive manufacturing, etc.

The milling router works comfortably at high speeds desired for conventional machining as well as at low speeds preferred for non-contact hybrid machining movements.

Potential Upgrades

- It is planned to scale up the CNC milling router in terms of precision movements at low feeds.
- DC or AC servomotors and encoder feedback maybe used to upgrade.
- The friction in lead screw can be reduced by using polymer based lead screws or replace them by ball screws.
- Further hands on controls can be added to the MK1 controller.
- Once the command over CNC USB software is gained, more complex motions can be generated.
- Other open source softwares can be utilized.

Acknowledgement

The authors gratefully acknowledge coordinator of TEQIP-II, HBTU Kanpur for providing financial assistance for the development of the setup and CST, UP Lucknow for providing research assistant for the project "Experimental Study of Drilling Electro-Chemical Spark Machining (ECSM) Setup" ongoing in the Manufacturing Science Lab, Mechanical Engineering Department, HBTU Kanpur.

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