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Portable CNC Milling Machine

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ABSTRACT

This paper describes the design and fabrication of a Portable CNC Milling Machine intended for small-scale machining applications and academic use. The objective of this project is to develop a compact, low-cost, and efficient CNC system that can perform basic milling operations with acceptable accuracy. The machine structure is designed to be lightweight and rigid to ensure stability during operation while allowing easy portability. The mechanical assembly includes a frame, guide rails, lead screw mechanism, and spindle arrangement. Stepper motors are used for precise motion control along the X, Y, and Z axes. The motors are driven using TB6600 drivers and controlled through an Arduino microcontroller interfaced with a CNC shield. The system operates based on pre-programmed G-code instructions, which control the movement and machining process automatically. The developed machine is capable of performing drilling, engraving, and light milling operations on materials such as wood, and soft metals. Special attention is given to alignment, vibration reduction, and smooth motion to improve machining quality. The fabricated prototype demonstrates satisfactory performance, accuracy, and repeatability for small workshop and laboratory applications. This project provides a practical and economical solution for educational institutions and hobby-level manufacturing where large industrial CNC machines are not feasible due to space and cost limitations.

Keywords : -Portable CNC Milling Machine, Arduino, Stepper Motor, TB6600 Driver, G-code.

1.INTRODUCTION

The rapid growth of automation technologies has greatly changed modern manufacturing. Computer Numerical Control (CNC) machines are key to achieving high precision, repeatability, and productivity in machining tasks. Unlike traditional milling machines that rely on manual control, CNC systems use programmed instructions. This allows for precise and automated movement of tools along multiple axes. The addition of microcontrollers, motor drivers, and stepper motors has enabled the creation of compact and affordable CNC machines suitable for educational and small-scale industrial use. In recent years, researchers have focused on creating low-cost CNC systems using embedded platforms. Pabolu et al. [1] described a budget-friendly three-axis CNC system for industrial use, showing that embedded control solutions are practical. Jayachandraiah et al. [2] also developed an Arduino-based CNC router that can perform simultaneous three-axis interpolation. Their research highlighted affordability and flexibility in small-scale manufacturing. Structural rigidity and vibration control are important factors in CNC design, as noted by Ahmed et al. [3]. They studied the dynamic performance of gantry-type milling machines. This research focuses on designing and building a portable CNC milling machine with an open-loop stepper motor control system. The system combines mechanical parts, electronic control hardware, and CAD/CAM software to perform milling, drilling, and engraving tasks. The goal is to create a compact, user-friendly, and affordable CNC machine that delivers acceptable machining accuracy for light-duty applications like PCB engraving and prototype development.

1.1 Need of CNC Machines

- High precision and accuracy
- Consistent quality and repeatability
- Ability to make complex shapes and designs
- Fast and automated production
- Reduced human error
- Improved workplace safety
- Efficient use of material (less waste)
- High productivity and 24/7 operation
- Cost-effective in long-term production
- Essential for modern industrial manufacturing

1.2 Objectives of the research work

The main goal of this research is to design and build a compact and portable CNC milling machine using affordable and readily available components. The system aims for three-axis motion control with reasonable

positional accuracy while ensuring structural rigidity and operational stability. Specific objectives include reducing manual intervention in machining processes, improving repeatability through programmed control, and exploring the integration of mechanical and electronic subsystems. The research also aims to understand G-code execution, motion synchronization, and spindle control using embedded systems. Additionally, the project aims to show that a low-cost CNC milling machine can be created for educational labs, small workshops, and prototype manufacturing environments without using expensive industrial parts. The completed model will act as a practical platform for studying automation, embedded control systems, and CAD/CAM integration in modern manufacturing.

2.COMPUTER NUMERICAL CONTROL MACHINE

The electronic system of the CNC milling machine plays a vital role in achieving precise motion control and reliable operation. It acts as the interface between the software-generated commands and the mechanical movement of the machine. The electronic architecture is designed to be simple, modular, and cost-effective while ensuring stable performance during machining operations.

The system mainly consists of a microcontroller-based control unit, stepper motor drivers, stepper motors, a spindle control circuit, and regulated power supplies. These components work together to interpret G-code instructions and generate accurate electrical signals required for multi-axis motion control. Proper selection and integration of electronic components ensure smooth operation, reduced noise, and improved reliability of the CNC machine.

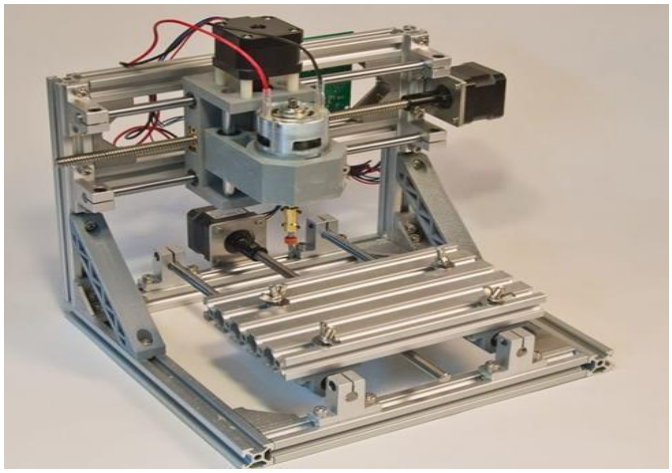

Fig.1: Portable CNC Milling Machine

2.1 System Components

The control unit of the CNC milling machine is based on Arduino Uno R3, which serves as the central processing unit of the system. The microcontroller receives G-code commands from a computer through a USB interface and processes them using embedded firmware. It generates step and direction signals corresponding to the required movement along the X, Y, and Z axes.

To drive the stepper motors, high-current motor drivers are required because the microcontroller alone cannot supply sufficient power. In this system, TB6600 Stepper Motor Driver is used for each axis. The driver amplifies low-power control signals from the microcontroller into high-current signals capable of driving the motors. Microstepping functionality improves motion smoothness and positional resolution, which is essential for milling operations.

A CNC shield expansion board is used to simplify wiring and provide organized connections between the microcontroller and motor drivers. This modular arrangement reduces wiring complexity and improves system reliability

Sr.No	Components	Specification	Operating Voltage	Remarks
1	Microcontroller	Arduino Uno	5V	Runs CNC firmware
2	Motor drive	TB6600	9-42V	microstepping
3	Stepper Motor	NEMA 23 Stepper Motor	3.4V	High torque

4	Relay	SPDT,10A	5V	Electrical isolation
5	CNC Shield V3	3 axis support	12 -36 V	Easy interfacing

Table -1: Electronic Components Used in the CNC Milling Machine

2.2 Working principle of the proposed system

The CNC milling machine operates using computer-controlled motion. First, the necessary component geometry is designed with CAD software and converted into G-code through CAM processing. This G-code includes instructions for tool paths, feed rates, spindle speeds, and axis movements. These commands are sent to the microcontroller through a USB interface. The microcontroller reads the G-code instructions and produces step and direction pulses for each axis. The motor drivers boost these signals and operate the stepper motors. Each electrical pulse represents a set angular movement of the motor shaft, which translates into linear motion via a lead screw or belt drive. This controlled movement ensures precise positioning of the cutting tool relative to the workpiece. The spindle motor rotates quickly, removing material layer by layer according to the programmed coordinates. Microstepping techniques enhance motion smoothness and minimize mechanical vibration. The open-loop control setup simplifies the system while still providing enough accuracy for educational and prototyping purposes.

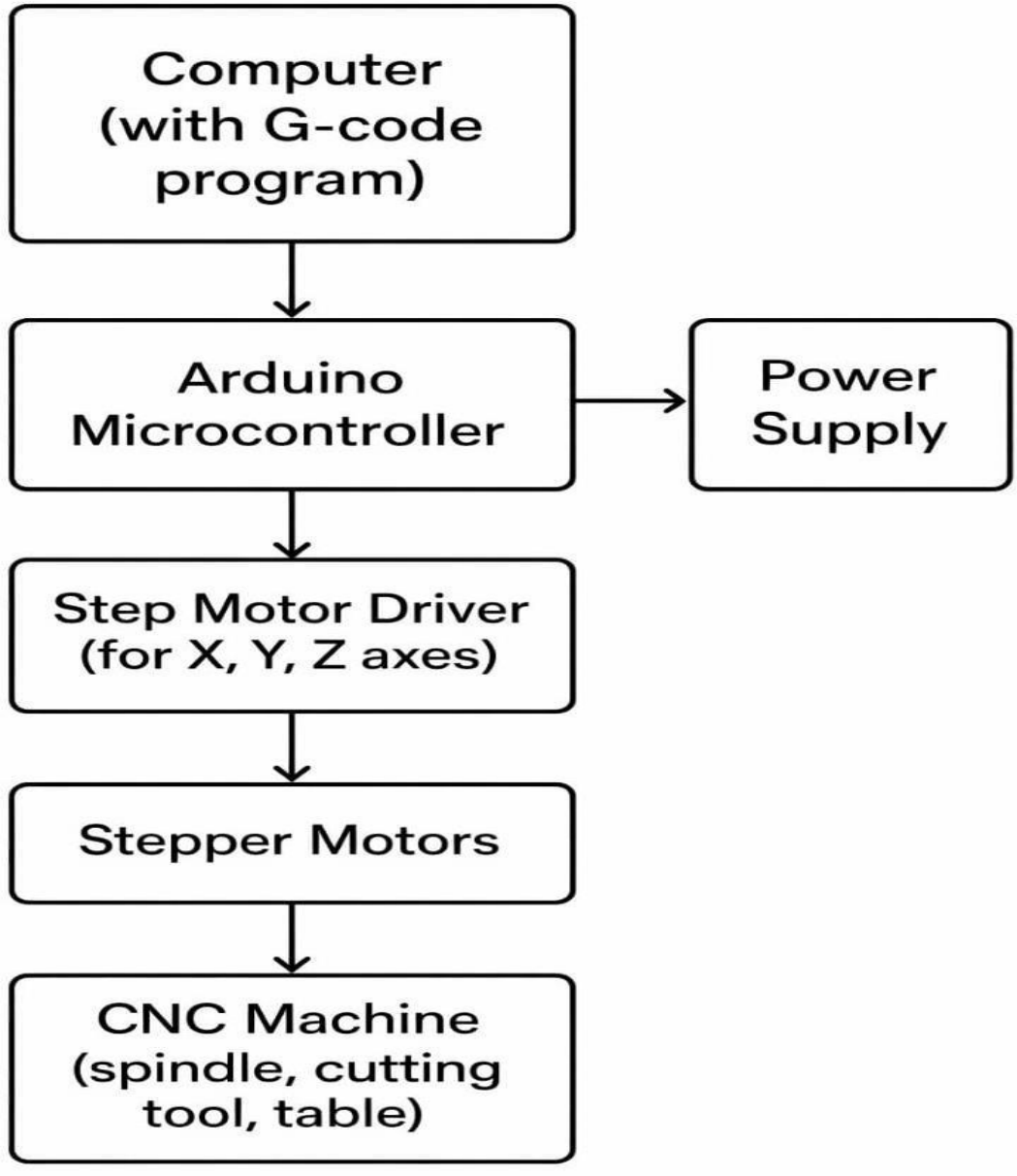

Fig.2 : Block Diagram of Electronic Control System for CNC Milling Machine

3.PROGRAMMING OF CNC MACHINE

CNC programming refers to the development of coded instructions used to control the operation of computer numerical control machines in manufacturing systems. These instructions define tool motion, machining paths, spindle speed, feed rate, depth of cut, and the sequence of operations required for component production. Standardized command structures such as G-codes and M-codes enable precise execution of machining processes. CNC programming supports both manual and automatic operation modes and enables reliable communication between software systems and machine hardware. This integration ensures accuracy, repeatability, automation, and improved production efficiency in modern manufacturing environments.

3.1 G- Code Program for Square Cutting

01001
G21 (Metric units)
G17 (XY plane selection) G90 (Absolute programming)
G00 Z5 (Tool move to safe height) G00 X0 Y0 (Move to start point)
M03 S1000 (Spindle ON clockwise, 1000 rpm) G01 Z-5 F100 (Tool down to cutting depth) G01 X40 Y0 F200 (Cut first side)
G01 X40 Y40 (Cut second side) G01 X0 Y40 (Cut third side) G01 X0 Y0 (Cut fourth side) G00 Z5 (Tool up)
M05 (Spindle stop)
M40 (End program) Assumptions:

- Square size = 40 mm x 40 mm
- Starting point = (0, 0)
- Cutting depth = -5 mm
- Tool = End mill
- Units = mm
- Absolute programming (G90)

4. CONCLUSIONS

The CNC machine plays a very important role in modern manufacturing. It provides high accuracy, repeatability, and efficiency compared to conventional machines. By using programmed instructions, CNC machines can perform complex machining operations with minimum human intervention. This reduces errors, improves product quality, and increases production speed.

The study of CNC machines shows that proper programming, correct selection of components, and suitable control systems are essential for smooth operation. CNC technology also saves time, reduces material wastage, and ensures consistent output, which is highly beneficial for industrial applications.CNC machines are reliable, flexible, and widely used in industries such as automotive, aerospace, electronics, and manufacturing. Their ability to produce precise and complex parts makes them an essential part of advanced Type equation here.engineering and automated product systems.

5. REFERENCES

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