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CNC Based Engraving Machine

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Abstract: *This project presents the design and development of a CNC based engraving machine that employs a drill bit for precise engraving on various materials. The increasing demand for customized and intricate designs in industries such as manufacturing, art, and personalization necessitates an efficient and versatile engraving solution. The proposed machine integrates advanced CNC technology, enabling automated control and high precision in engraving tasks. The project focuses on several key objectives: achieving accuracy and repeatability, developing a user-friendly interface, and ensuring compatibility with multiple materials. Through the optimization of mechanical components and the selection of appropriate drill bits, the machine is designed to deliver high-quality engravings while minimizing material waste and production time. The engraving process is driven by G-code generated from EASEL designs, allowing users to create complex patterns easily. Performance testing demonstrates the machine's capability to handle various materials, including wood, soft metals, while maintaining high engraving fidelity. This CNC-based engraving machine offers a cost-effective and accessible solution for hobbyists and professionals alike, enhancing creativity and efficiency in engraving applications. The outcomes of this project not only contribute to the field of automated engraving technology but also provide a foundation for future innovations in CNC machining.*

Keywords: Drill Bit, G-code, Soft Metals, Wood Engraving, CNC Machine Innovation

I. INTRODUCTION

In today's era of automation and precision manufacturing, Computer Numerical Control (CNC) machines have become an essential component of modern fabrication processes. The CNC Engraving Machine project focuses on designing and developing a cost-effective, compact, and functional engraving machine capable of precisely carving or cutting materials such as wood, plastic, and soft metals based on digital designs.

This project aims to bridge the gap between manual engraving techniques and industrial-grade CNC systems by offering a simplified and affordable solution suitable for educational, hobbyist, and small business applications. The machine operates through computer control, using G-code instructions to drive stepper motors that control the movement of a cutting tool in multiple axes, typically X, Y, and Z.

The integration of components such as GRBL controller (or microcontroller), stepper motors, drivers, and GRBL firmware allows the system to function with high accuracy and repeatability. By converting 2D or 3D design files into G-code and feeding them into the machine via software such as Candle, Universal G-code Sender, or Fusion 360, users can automate the engraving process with minimal manual intervention. This report presents the complete design process, component selection, mechanical structure, electronics integration, software configuration, and testing results of the CNC Engraving Machine. The project not only demonstrates practical application of mechatronics and CAD/CAM principles but also provides hands-on experience in digital manufacturing and precision control systems.

In the rapidly evolving world of manufacturing and design, Computer Numerical Control (CNC) technology has revolutionized how materials are processed, shaped, and engraved. The CNC Engraving Machine project embodies the core principles of automation, precision, and repeatability, aiming to deliver a compact, efficient, and user-friendly engraving solution for small-scale applications.

Engraving is the art of carving text, patterns, or images onto a surface. Traditionally, this has been done manually, requiring skilled labor and significant time investment. However, with the advent of CNC machines, this process has

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become highly automated and accurate, allowing for detailed and complex designs to be reproduced with minimal human effort..

II. LITERATURE REVIEW

The reviewed literature highlights a growing interest in the development of low-cost, compact CNC engraving machines for educational, prototyping, and small-scale manufacturing applications. Most researchers have focused on integrating Arduino-based control systems with open-source firmware like GRBL, enabling the control of stepper motors along X, Y, and Z axes for precise and repeatable motion.

Studies by Akhil A. I (2018) and Defi Irwansyah (2024) have successfully demonstrated the construction of 3-axis CNC machines capable of engraving on wood and acrylic using GRBL and Arduino UNO. Their designs emphasize simplicity, affordability, and adaptability.

Other works, such as those by P. Jamaleswara Kumar (2018) and researchers on ResearchGate (2020), have explored laser-based engraving machines, which offer cleaner cuts and non-contact material removal. These projects provide insight into the effects of laser power, speed, and material properties on engraving quality.

In addition, papers such as Sonali Dhanwade et al. (2021) and Umesh Shinde et al. (2023) have presented multi-functional machines that combine engraving, plotting, and PCB milling. These designs stress portability, modularity, and safety, with some incorporating IR sensors and multi-head configurations.

A key theme across all studies is the use of low-cost, readily available materials and components, making these machines highly accessible for academic institutions and hobbyists. Performance analysis, software interfacing (using tools like Universal G-code Sender or Candle), and ease of use are common evaluation parameters.

Overall, the literature provides a strong foundation for the design of small-scale CNC engraving systems. Your project stands to contribute meaningfully by refining mechanical spindle-based engraving, enhancing depth control, and possibly integrating modular upgrades for broader functionality

III. SYSTEM DESCRIPTION

The CNC Engraving Machine developed in this project is a three-axis computer-controlled system designed to perform engraving operations on a variety of soft materials such as wood, acrylic, and PCB boards. The machine operates on the principles of computer numerical control (CNC), where movement along the X, Y, and Z axes is precisely controlled based on pre-programmed G-code instructions. At the heart of the system is an Arduino UNO microcontroller running GRBL firmware, an open-source CNC motion control software that interprets G-code commands. The Arduino is interfaced with stepper motor drivers (A4988) that control NEMA 17 stepper motors for each axis. These motors move a carriage system built with lead screws, linear bearings, and guide rods to ensure smooth, precise, and repeatable motion. The spindle motor, typically a 775 DC motor or similar, is mounted on the Z-axis and acts as the primary engraving tool. The machine is powered by a 12–24V DC power supply, and mechanical limit switches are placed on each axis to provide homing and end-stop functionality. The system receives engraving designs in the form of G-code, which is generated using CAM software and sent to the controller via programs like Universal G-code Sender (UGS) or Laser GRBL. The compact and modular structure of the machine makes it ideal for desktop or educational use, while also allowing room for future upgrades such as wireless control, more powerful spindles, or additional axes. This configuration provides an affordable and efficient solution for tasks such as logo engraving, PCB milling, and small-part prototyping, combining mechanical precision with accessible electronics and open-source software.

IV. PROPOSED SYSTEM

1) GRBL Controller

Microcontroller: ATmega328P
Operating Voltage: 5V logic level
Input Voltage (recommended): 24V
DC Motor Driver Ports: 3-axis output
Spindle/Laser PWM Output: 0–5V PWM

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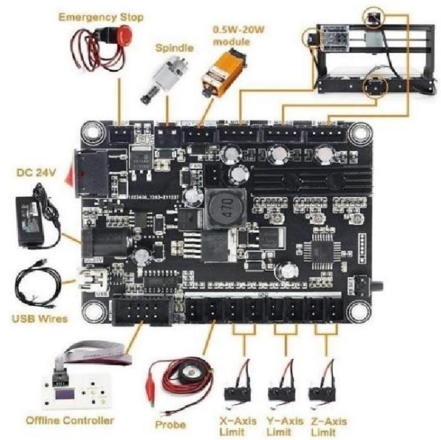
Limit Switch Inputs: 3 (X, Y, Z axis)
Firmware: GRBL v1.1 compatible
USB Interface: USB Type-B
Cooling Support: FAN port available
Offline Controller Port: 1



2) Stepper Motor

Model: NEMA 17
Step Angle: 1.8° per step
Rated Voltage: 2.8V to 4.8V
Current per Phase: 1.2A to 2.0A
Holding Torque: 40 N· cm
Number of Phases: 2
Resistance per Phase: 1.1–2.2 ohms
Inductance per Phase: 2.8–4.5 mH
Shaft Diameter: 5 mm
Connector Type: JST-PH 4-pin
Motor Frame Size: 42 mm × 42 mm

3) Linear Bearing Block
Model: SC12UU
Material: Aluminium alloy body with LM12UU linear ball bearing
Inner Diameter: 12 mm compatible with 12 mm linear shaft
Outer Dimensions: ~42 mm × 36 mm × 30 mm

Mounting Holes: 4 holes typically M4 or M5 thread
Bearing Type: LM12UU linear motion ball bearing
Linear Accuracy: High precision and low

4) Shaft Support
Type: SK-series
Material: High-quality aluminum alloy
Inner Diameter: 12 mm / 16 mm / 20 mm
Mounting Holes: 2 holes for secure attachment to base
Surface Finish: Silver anodized for corrosion resistance
Structure: Split-body clamp with tightening screw

5) Flexible Coupling Motor Shaft
Type: Flexible Shaft Coupler
Material: High-grade aluminium alloy
Outer Diameter: Typically 18 mm to 25 mm
Length: Around 25 mm to 30 mm
Motor side: 5 mm / 6.35 mm
Lead screw side: 8 mm / 10 mm

6) Aluminium Spindle Holder
Material: High-strength Aluminium Alloy
Mount Type: Split body with clamp bolts
Inner Diameter (Bore): 52 mm
Outer Dimensions: Approx. 80 mm × 60 mm × 30 mm

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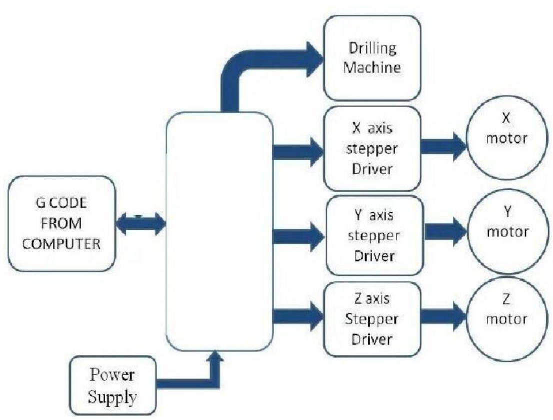
Mounting Holes: 4 × M5/M6 bolts
Weight: ~300–600 grams
Finish: Anodized or sandblasted aluminium
Mount Orientation: Vertical or horizontal
Clamp Bolts: Steel
Compatibility: Fits 52 mm spindle motors

7) Spindle
Motor Type: Brushed DC Motor
Typical Model: 775 motor or similar
Rated Voltage: 12V – 24V
DC Rated Current: 2 – 5 A
No-Load Speed: Up to 1000 – 10,1000 RPM @ 12
Output Power: Approx. 100W – 300W
Shaft Type: Equipped with ER11 collet chuck
Body Diameter: Ø44 mm
Mount Compatibility: 52 mm spindle holder

V. BLOCK DIAGRAM



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Explanation :

1. G-code from Computer

• The computer generates G-code, which is a standard programming language used in CNC machines to control motion and toolpaths.
• G-code commands are sent to the GRBL controller via USB or serial connection.
• Software used: Universal G-code Sender (UGS), Candle, or similar.

2. GRBL Controller

• This is typically an Arduino UNO running GRBL firmware.
• It interprets G-code instructions and converts them into electrical signals (step/direction pulses) for the stepper motor drivers.
• Also controls spindle (or drilling machine) ON/OFF and speed (PWM signal).

3. Power Supply

• Provides regulated DC power (usually 12V–24V) to both:
• The GRBL controller
• The stepper motor drivers and spindle motor
• The power rating depends on the current and voltage requirements of the motors used.

4. Stepper Drivers (X, Y, Z Axis)

• Each axis has its own stepper motor driver (e.g., A4988, DRV8825).
• These drivers receive signals from the GRBL controller and precisely control the movement of stepper motors.
• The drivers convert low-power control signals into high-power signals suitable for the motors.

5. X, Y, Z Motors

• NEMA 17 stepper motors are commonly used.
• These motors drive the mechanical motion of the machine's X, Y, and Z axes respectively:
• X-axis: horizontal movement (left-right)
• Y-axis: depth movement (forward-backward)
• Z-axis: vertical movement (up-down)

6. Drilling/Engraving Machine

• This represents the tool head—typically a spindle motor (for drilling/engraving).
• The GRBL controller controls its ON/OFF and speed.
• Mounted on the Z-axis and performs material removal based on G-code instructions.

VI. APPLICATIONS

Industrial Applications:

• Product Marking: Engraving labels, serial numbers, or barcodes on products for identification and tracking.
• Tool and Mold Engraving: Creating intricate patterns and details on tools and molds for manufacturing.
• PCB (Printed Circuit Board) Fabrication: Drilling holes and creating patterns on PCBs for electronic components.

Creative and Artistic Applications:

• Personalized Products: Engraving custom designs on items like jewelry, gifts, and home decor.
• Artwork: Creating unique and detailed artwork on various materials, including wood, metal, and stone.
• Prototyping: Developing prototypes and models for product design and testing. Other Applications:
• Medical Devices: Engraving markings on medical instruments and implants.
• Research and Development: Creating precise patterns and structures for scientific experiments.
• Hobby and Crafts: Engraving designs on items for personal enjoyment or as gifts.

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VII. ADVANTAGES

- Cost-Effective
- High Precision and Accuracy
- Open-Source Software
- Customizability and Upgradability
- Automation and Repeatability
- Compact and Lightweight
- Low Maintenance
- Easy Troubleshooting
- Portability

VIII. CONCLUSION

There is significant potential to enhance and expand the capabilities of this CNC engraving machine in future iterations. One of the key improvements could involve upgrading the open-loop system to a closed- loop system using encoders for real-time feedback and error correction. Additionally, incorporating more powerful spindle motors or laser modules can allow engraving and cutting on harder and thicker materials. Integration of Wi-Fi or Bluetooth modules can enable wireless control and IoT-based monitoring. Touchscreen interfaces and standalone SD card support can improve usability by making the machine operate independently of a computer.

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