A Laser Cutting Machine Prototype

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Received: 10 December 2023 | Revised: 1 January 2024 | Accepted: 3 January 2024

 DOI: https://doi.org/10.48084/etasr.6733

ABSTRACT

Nowadays, laser cutting technology stands as one of the most cutting-edge technologies. Not only do laser cutting machines play a crucial role in the mechanical engineering industry, but also in numerous other industries including electronic circuit manufacturing, garment manufacturing, and particularly in the handicraft industry. This study presents a methodology for the design and production of laser cutting machines in Vietnam. A laser cutting machine has been successfully constructed, featuring a straightforward configuration, user-friendly operation, and low cost. The machine has the ability to perform laser cutting on wooden materials, achieving a cutting depth ranging from 1 to 2 mm. The proposed laser cutting machine prototype can cut at a speed of 1000 mm/min, thus meeting the specified requirements.

Keywords-laser cutting; prototype; machine; design

I. INTRODUCTION

Laser cutting machines have played a crucial role in solving the critical need for automating the production process, leading to significant advancements in reliability and quality [1-5]. From a scientific standpoint, these machines have effectively addressed the challenge of cutting and engraving intricate shapes on various materials of any dimension within the manufacturing industry. Alongside with the conventional cutting methods, such as milling and turning [6-8], laser cutting technology finds application in the industries of electronics, medicine, aerospace, and automobile. A common use of this technology involves the cutting of various metals, including tungsten, aluminium, steel, brass, and nickel [9-12]. Lasers are preferred for their ability to deliver precise cuts and achieve impeccable surface finishes. In addition, lasers are employed to cut ceramic, silicon, and other metallic films [13-17]. Laser cutting machines in Vietnam have enhanced the automation capabilities of companies by reducing the number of operators required and minimizing the need for manual intervention in machine operations, subsequently leading to a decrease of operational errors. Nevertheless, in Vietnam, the research, manufacturing, and implementation of laser cutting in production faces many limitations. The majority of laser cutting machines are currently utilized by companies that specialize in processing and manufacturing molds on a large scale. Moreover, those machines currently available in the market are prohibitively expensive and do not fit with the income conditions of most Vietnamese individuals. Laser cutting machines are infrequently utilized in small manufacturing workshops and university laboratories. In order to address the existing challenges, many industries and certain universities have been actively endeavouring to produce laser cutting machines which will meet both manufacturing and research demands. This article presents a plan for developing and implementing an inexpensive prototype laser cutting machine that fulfils essential operational requirements for manufacturing and business purposes.

II. LASER CUTTING TECHNOLOGY

Laser cutting involves the utilization of a projector to concentrate laser beams into a singular focus point. The concentrated focus point possesses immense energy capable of incinerating the surface or target requiring laser impact. The device emits a significant amount of thermal energy across a wide range of wavelengths, enabling it to etch various materials including metal, wood, leather, fabric, and others. Laser cutting machines exhibit superior performance in comparison to CNC machines on a wide range of materials including metals, alloys, and non-metals like glass, plastic, and mica with greater ease. Furthermore, laser cutting technology is characterized by its minimal noise emissions and negligible impact on workers. Laser cutting machines function by utilizing a laser beam as a focused and intense heat source. Subsequently, you can effortlessly sever materials of varying hardness and thickness, including metals like stainless steel, copper, iron, steel, and aluminium, as well as non-metallic materials.

III. DESIGN LASER CUTTING MACHINE

A. Working Principle

The laser cutting machine model represents the operational principle of a CNC machine that is controlled by specialized software and applied in practical settings. The laser cutting machine uses a concentrated beam of energy produced by the laser, which is directed onto the surface of the product through the lens system of the machine. Table I provides a comprehensive overview of the primary technical specifications that must be met for the laser cutting machine. The machine has the capability to cut a workpiece with dimensions of 250 × 250 mm. It operates at a cutting speed of 500 mm/min and can engrave to a depth of less than 2 mm. On average, it takes 60 min to complete a cutting operation. Figure 1 illustrates the initial design of the machine prototype along with its corresponding working principle. First, the control software will convert the loaded image data into G-code for cutting purposes. The motor (1) transfers motion to the assembly (4) that holds the laser diode by means of the lead screw and nut set (3). Consequently, the laser diode's axis (5) will align precisely with the X-coordinate currently indicated on the control software. The motor (2) transfers motion to the machine table (6) via the lead screw and the nut assembly (7). Thus, the laser diode's axis (5) will align with the Y coordinate of the current point indicated on the control software. Once the point coordinates are established, the laser diode (5) releases a laser beam. The beam possesses a significant amount of energy, enabling it to effectively heat the surface of the product at the specific point of focus. This, in turn, facilitates the material melting. The liquefied substance will be displaced from its initial location by a forceful flow of gas that is aligned with the laser beam. The molten region will persistently undergo elongation along the trajectory of the laser beam, resulting in a cleave and the formation of the desired shape.

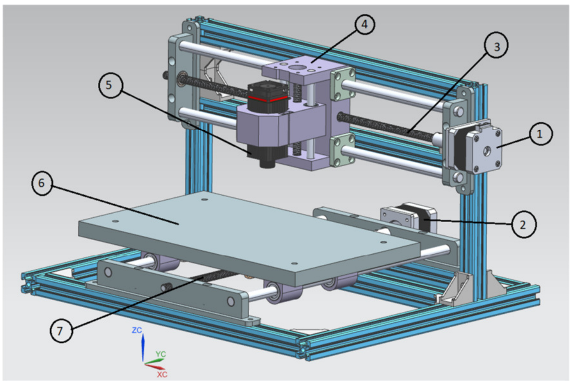

Fig. 1. The laser cutting machine model was designed using NX 12.

TABLE I. MACHINE'S TECHNICAL SPECIFICATIONS

Machine specification	Value
Cutting speed	500 mm/min
Depth of cut	≤ 2 mm
Cutting time	≤ 60 min
Workpiece size	250×250 mm

B. Calculating the Motor Requirements

The motor controls the movement of the laser beam along both the X and Y axes. Motors that operate in both the X and Y directions typically have equal power. The weight of the moving parts encompasses the structure of the X and Y axis assemblies.

1) Y Axis Motor

- Sliding friction coefficient: $\mu = 0.12$.
- Lead screws with steps: $P_b = 8$ mm.
- The mass of the moving part is the machine table: $M_y = 1$ kg.
- Mechanical advance: $\eta = 0.9$.
- Angle of axle inclination: $\alpha = 0°$, $i = 0.9$.
- Friction force: $F_m = 0.7$ N.
- The frictional moment M_{fric} is calculated as:

$$M_{\text{fric}} = \frac{m.g.\mu.h.\cos\alpha}{2.\pi.i.\eta} = 0.0012 \text{ Nm} \quad (1)$$

- The appropriate 8 mm lead screw diameter is chosen for the given speed:

$$v_{\max} = \frac{\pi.D.n}{60.1000} = 0.84 \text{ m/s} \quad (2)$$

- The moment of resistance caused by the static friction of the moving component M_{mach} is calculated by:

$$M_{\text{mach}} = \frac{\mu.F_b}{2.\pi.i.\eta.v_{max}} = 0.093 \text{ N.m} \quad (3)$$

- The actuator is positioned in a horizontal orientation and then $\alpha = 0° \rightarrow M_{wy} = 0$.
- The moment required to operate the Y axis is denoted as M_{start} and is calculated by:

$$M_{\text{start}} = M_{\text{fric}} + M_{wy} + M_{mach} = 0.0942 \text{ Nm} \quad (4)$$

2) Select X Axis Motor

- Sliding friction coefficient: $\mu = 0.12$.
- Lead screws with steps: $P_b = 8$ mm.
- The mass of the moving part is the machine table: $m = W_y = 0.8$ kg.
- Mechanical advance: $\eta = 0.9$.
- Angle of axle inclination: $\alpha = 0°$, $i = 0.9$.
- Friction force: $F_m = 0.7$ N.
- Frictional moment:

$$M_{\text{fric}} = \frac{m.g.\mu.h.\cos\alpha}{2.\pi.i.\eta} = 0.0009 \text{ N.m} \quad (5)$$

- The appropriate 8 mm lead screw diameter is chosen for the given speed.

$$v_{\max} = \frac{\pi.D.n}{60.1000} = 0.84 \text{ m/s} \quad (6)$$

- Moment of resistance caused by the static friction of the moving component

$$M_{\text{mach}} = \frac{\mu.F_b}{2.\pi.i.\eta.v_{max}} = 0.093 \text{ N.m} \quad (7)$$

- The actuator is positioned in a horizontal orientation and then $\alpha = 0° \rightarrow M_{wx} = 0$.
- Moment required to operate the X axis:

$$M_{\text{start}} = M_{\text{fric}} + M_{wx} + M_{mach} = 0.09396 \text{ Nm} \quad (8)$$

According to the parameters calculated from (4) and (8), the NEMA 17 stepper motor is chosen for the machine prototype.

C. Mechanical Design for Laser Cutting Machine

Figure 2 shows the components of a mechanical structure. The machine indicates a simple structure comprising 23 main parts. Following the thorough design process, each intricate detail is manufactured in accordance with specific standards, including hexagonal screws, nuts, screws, and aluminium bars. We were based on preexisting frameworks to reduce costs.

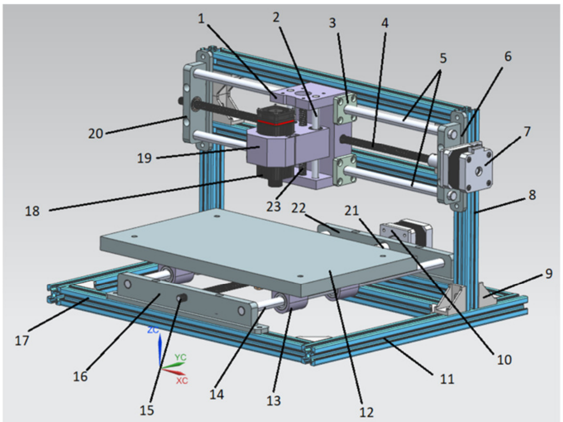

Fig. 2. Main parts of laser cutting machine. (1) Laser hoder, (2) shaft $\varphi 80 \times 80$ mm, (3) LMK10UU, (4) lead screw $\varphi 8 \times 400$ mm, (5) shaft $\varphi 10 \times 400$ mm, (6) X-axis holder, (7) Nema step motor, (8) aluminum bar 20×20×330 mm, (9) L corner, (10) motor holder), (11) aluminum bar 20×20×330 mm (11), (12) table, (13) LM10UU, (14) shaft $\varphi 10 \times 330$ mm, (16) Y-axis holder, (17) aluminum bar 20x20x360, (18) diode laser, (19) diode laser holder, (20) X-axis holder, (21) coupling, (22) Y-axis holder, (23) lead screw $\varphi 8 \times 80$ mm.

1) Machine Frame

The machine table base is constructed using 20×20 mm extruded aluminum bars. It has a mass of approximately 4 kg, with a total size of 400 × 330 × 220 mm (length, width, and height), as depicted in Figure 3.

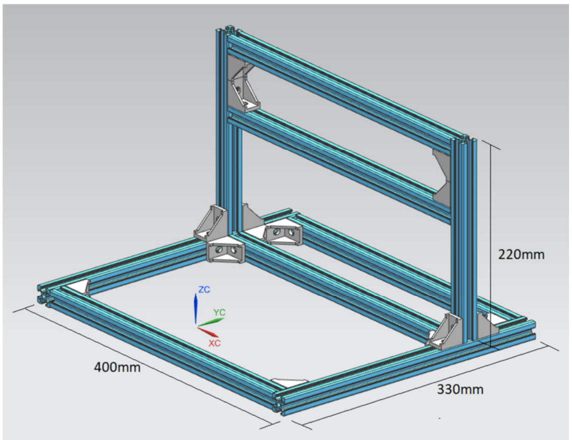

Fig. 3. Machine frame overall dimensions.

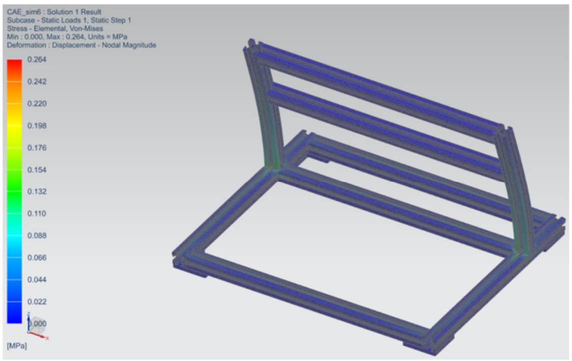

Fig. 4. Stress simulation.

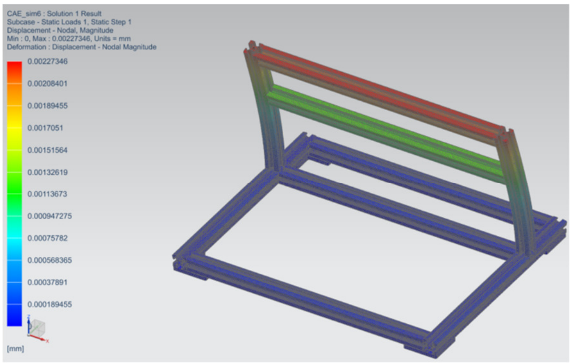

Fig. 5. Deformation.

The combined mass of the machine table and other assemblies is 2 kg. To meet the frame detail requirement, it is sufficient to load the frame detail and other supporting details, resulting in a total mass of m = 6 kg. Figure 4 illustrates the results of the stress test performed on the machine frame. The minimum stress measured is 0.022 MPa, while the maximum stress reached is 0.264 MPa. The machine ensures strength by working within the allowable stress limit (yield strength) of 229 MPa. Figure 5 shows the process of evaluating the frame deformation, with the maximum deformation measuring 2.273e-3 mm. Therefore, the frame design fully satisfies the design requirements. Figure 6 illustrates the structural framework of the machine in its complete state.

Fig. 6. A machine frame prototype.

2) Machine Table and Other Parts

Once the machine frame has been fabricated, the remaining components of the machine are produced using the 3D printing technique. PLA printing plastic is utilized, with a printing temperature of 205 °C and a printing layer thickness of 0.2 mm. Components such as fasteners and shafts are pre-purchased. Figure 7 displays the prototype of the laser cutting machine.

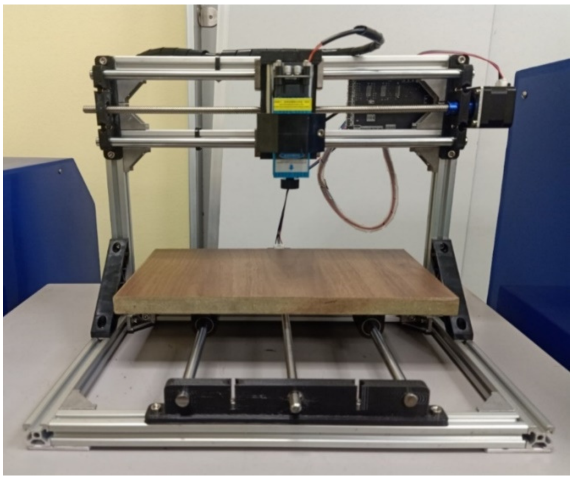

Fig. 7. A prototype of the laser cutting machine.

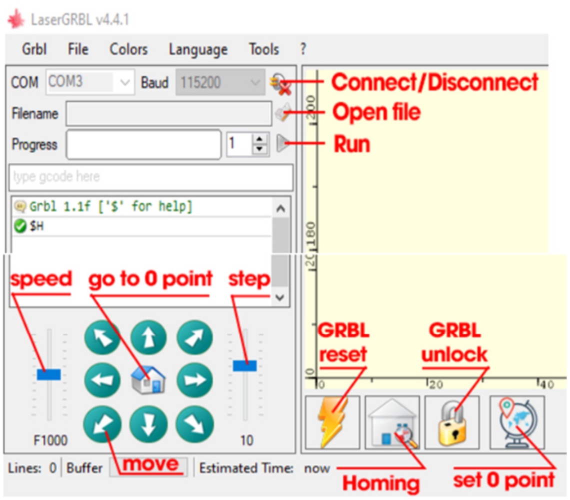

Fig. 8. The graphic screen of the LaserGRBL software.

3) Machine Control System

In order to perform the laser cutting procedure, one must control the speed and power of the laser diode by using LaserGRBL software, which is widely recognized and performed on mini-CNC machines [18-20]. Figure 8 displays the software interface. The central circuit controls the laser power circuits and receives feedback signals from the sensor through software used on the computer. With 24 V, input power is supplied to the A4988 driver to control the motors on the machine's axes and 12 V is supplied to the driver to control the laser. Signals output from the control center. The electrical connection can be seen in [21]. The block diagram of control algorithm is shown in Figure 9.

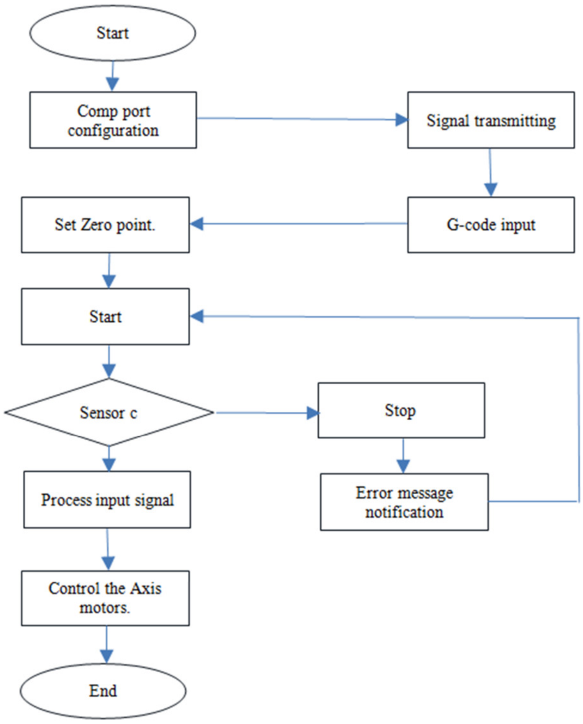

Fig. 9. Block diagram of the control algorithm.

IV. RESULTS AND DISCUSSION

The machine functions with stability and precision, successfully cutting according to the intended specifications and accomplishing multiple predetermined objectives. Figure 10 shows the prototype machine during the working process. Table II presents a summary of the technical specifications of the laser cutting machine prototype. The machine has a cutting speed of 1000 mm/min, a cutting depth ranging from 1 to 2 mm, and a maximum workpiece size of 312×260 mm.

Figure 11 depicts several products made from wood and plastic cut by the machine prototype. The machine demonstrates good cutting precision of around ± 0.2 mm, thus fully meeting the specified requirements. Due to its low manufacturing cost, the suggested machine is highly suitable for developing countries such as Vietnam considering their typical economy state.

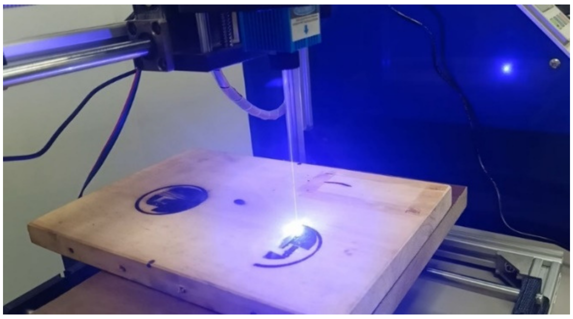

Fig. 10. Operating machine.

Fig. 11. Products from the laser cutting machine.

TABLE II. TECHNICAL SPECIFICATIONS OF MACHINE PROTOTYPE

Machine specification	Value
Cutting speed	1000 mm/min
Quality cutting	5 lines/mm
Depth of cut	1-2 mm
Workpiece size	312×260 mm

V. CONCLUSION

The article presents a systematic approach for developing and producing a prototype of a laser cutting machine, encompassing stages such as calculation, design, simulation, and manufacturing. The experimental results demonstrate that the machine effectively fulfills fundamental functionalities. The machine has a diminutive dimension of 400×330×250 mm and is capable of severing workpieces measuring 300×250 mm with a maximum cutting profundity of 2 mm. The machine is produced at a relatively inexpensive price in comparison to comparable products.

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