Design and fabrication of diode laser engraving machine

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Abstract— This paper introduces a novel engineering approach to design and develop affordable diode laser engraving systems. This systems are versatile, capable of engraving and marking on a variety of materials, including metal, wood, acrylic, plastic, and paper. This diode laser system, known for its precision, reliability, portability, and affordability, provides a practical alternative to CO_2 and fiber laser systems.

With a generous 1m x 1m working area, it's well-suited for engraving larger metal sheets and other materials, making it ideal for both industrial and small-scale applications.

The project involved a careful analysis of different laser engraving machine types, leading to the selection of a diode laser engraver for its compact design, lower cost, and versatility. The machine was designed using Solid Edge software, with components meticulously selected and assembled to optimize performance.

Testing with Laser GRBL software demonstrated high precision and accuracy in engraving intricate patterns, serial numbers, and logos.

A key feature of this system is its ability to burn the top layer of materials, creating distinct, uncolored engravings. It's capable of working on a broad range of surfaces, including thermoplastics, metal sheets, and wood. This diode laser engraver offers an efficient, portable, and scalable solution for industries like manufacturing, jewelry making, and custom product creation.

Keywords: Diode Laser, Laser Engraving, Portability, Solid Edge, GRBL Software, Large Working Area, Material Processing.

I. INTRODUCTION

Laser technology, a cornerstone of modern industry, offers versatility, precision, and efficiency. It involves three primary stages: absorption, spontaneous emission, and stimulated emission. Earlier used for welding and cutting, laser technology has evolved to include engraving, marking, and machining various materials.

Laser engraving is a important process for product identification, customization, and decorative applications. It involves removing material from a surface to a specific depth using a focused laser beam. This non-contact process offers several advantages:

Many irrefutable benefits can be obtained through the use of the laser engraver which includes higher levels of automation, operation without tools, free design of patterns, and their precise reproducibility.

When referring to laser engraving machine, one needs to speak about three basic elements on which an engraving machine comprises: laser source, control system, and a material target. There are many applications and thus it’s plausible to differentiate between different laser types:

- CO_2 lasers for cutting, boring and engravings.
- Nd lasers for working various materials at high power e.g. drilling, engraving.

The manufacturing industry has already recognised the advantages of diode lasers in portable systems which require low power and are small in size.
Including these, there are some diode laser engravers for example which are finding sizable usage because of their potential to work on different substances like metals, wood, plastic, and acrylics at a very low price and requiring less amount of maintenance. The term diode lasers refers to laser beams that contain semiconductor materials and are capable of processing in high speeds while maintaining a small structure. These need fewer resources, thus can be very advantageous for any small scale or industrial applications requiring portability, cost effectiveness and accuracy.

The wide flexibility of laser engraving technology has resulted in it being used in different sectors in the jewelry making industry, micromachining, printing, graphic design, and even the cutting of tools. Due to the development of Computer Numeric Control (CNC) systems, laser engravers are efficient and work with high precision with a lower need for manual input. Such parameters include output power, wavelength, frequency, cutting speed and depth are also adjustable for best outcomes such as high quality surface finishes or high quality engravings. The first objective in this research paper is looking for the design, development, and testing for a low cost laser engraving machine that employs diode laser beams, with applications in industrial or small scale. The machine is very effective, because it uses a computer controlled systems for both accuracy and uniformity of the engraving.

A. *Motivation and objective*

One of the main challenges in metalworking and fabrication is accurately marking large metal sheets for various machining operations. Often, manual marking methods lead to stakeing errors that can warrant reworking or result in material loss, both of which affect productivity and cost. This project sought to design a laser engraver machine that employs dice lasers and programmable computer technology in order to help:

- Increase the working area to 1m x 1m thus allow larger sheets to be fitted to improve usage and flexibility in marking in industrial places.
- Marking locations with high accuracy and precision which in turn eliminates possibilities for errors and wastes.
- Provide a cheaper option in comparison to CO_2 and fiber laser engravers which are expensive for small scale operations.

B. *Problem statement*

This project proposes an affordable, precise diode laser engraver with a large working area to improve marking accuracy on metal sheets for welding, bending, and painting. Multiple lasers per system and larger work areas enhance productivity, while scaling up systems boosts efficiency for industrial marking needs. The solution minimizes material waste and rework, ensuring cost-effective operations. The development of the proposed machine would also help in research and developmemt in the field of engraveing.

II. LITERATURE REVIEW

The history of engraving starts back in 1875, and it began only as a writing application. The basis of laser was established with Gordon et al. in 1954 when they showed microwave amplification by stimulated emission of radiation. By 1960, light amplification had been developed, that time also computer numerical control CNC systems were developed. As of the 1980s, laser engraving was found to be widely used in many industrial applications, according to Siegman & Anthony (1986) documenting its integration with CNC technology. Subsequent developments during the 1990s lowered costs substantially, thereby opening up laser systems to greater availability and feasibility. Scientists have studied laser engraving quite extensively to optimize material processing. Leone et al. (2009) studied wood engraving; they found that the rate of material removal was influenced by the beam speed, pulse frequency, and power. J. Qi et al. (2003) studied stainless steel and found how laser parameters affected engraving depth and width. Likewise, Agalianos et al. (2011) discussed industrial applications on stainless steel, where layer-by-layer removal and its impact on surface quality were the core issues. The authors concluded that pulse frequency, beam speed, and layer thickness were crucial parameters. Optimization of engraving parameters has been one of the factors improving laser performance. Sefika Kasman (2013) used the Taguchi method in machining hard materials, and her work demonstrated parameter fine-tuning for improved outcomes. Dharmesh K. Patel applied grey relational methods to improve engraving on stainless steel 304, underlining the significance of input parameters such as frequency, laser power, and wavelength in obtaining precision. Lin Li et al. have investigated high-power diode lasers for material processing. The outcome included surface finish enhancement and a heat-affected zone reduction. However, issues like beam divergence and color dependency have also been noted. Likewise, Leone et al. studied wood and stainless steel engraving, it was found that pulse frequency, beam speed, and power all had a strong influence on engraving depth and speed. The most recent studies made by A. R. Khan proved the significance of scanning speed and number of layers removed on improving surface roughness and marking time, while D. K. Patel stressed the control of laser parameters on engraving results. Innovative developments in laser equipment, including: gas shielding and debris removal systems, have further enhanced engraving precision, especially for heat-sensitive materials. However, literature indicates a gap in studying diode laser engravers for diverse materials. This study addresses these gaps by investigating the performance of diode laser engraving on aluminum sheets, wood, and composites, optimizing parameters for industrial and small-scale applications.

III. DESIGN AND FABRICATION

A. *Design of model.*

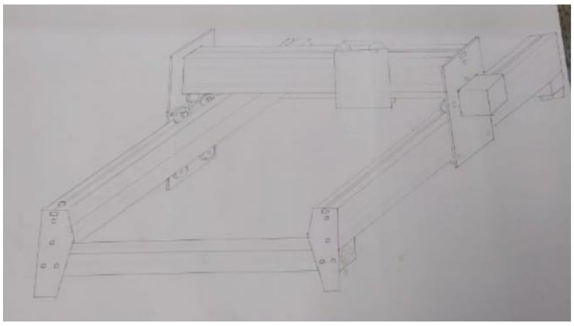

Fig.1 Design of model on drawing sheet

Firstly the design was made on sheets as shown in above figure. This was prepared to give the brief idea and make understand the core concept. After searching on various types of Diode Laser Engraving Machine, all the information about the main components required was collected. As per the requirement of our industry, the components were selected and concept drawing was made as shown in fig.1.

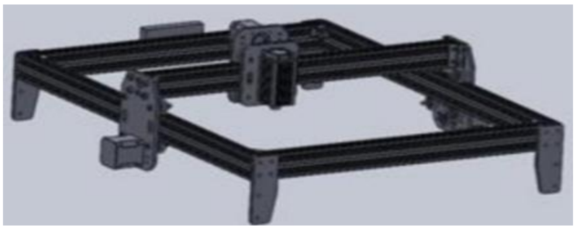

Fig. 2 3D model of Laser engraving machine (a)

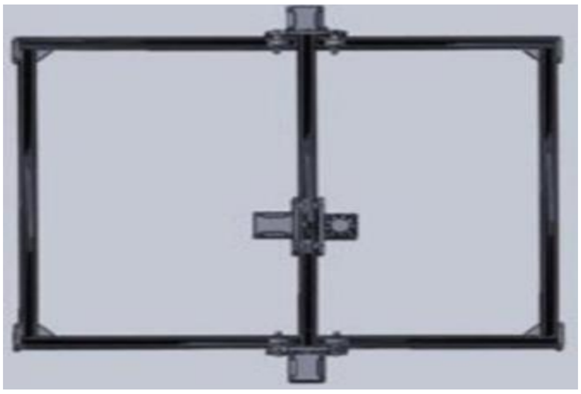

Fig. 3 3D model of Laser engraving Machine (b)

After doing certain refinement in the previous concept and meeting with design restrains, it was decided to come up with a more improved and better design. The Laser is a movable and connected to a stepper motor controlled by a microcontroller. The three of the extrusions works as the guide way for the movement of Laser assembly. The Laser is mounted with help of Laser housing and socket securing. This design has more realistic look and stability. The fig 2 shows the Solid Edge model generated for it.

B. *Components used.*

1. Support Channels

Fig. 4 Support Channel (aluminium extrusion)

Specifications

1) Profile Size:-2040
2) Extrusion Length:-1m
3) Material:-Aluminium Alloy 6063
4) Colour:-black

2. Mounting plate

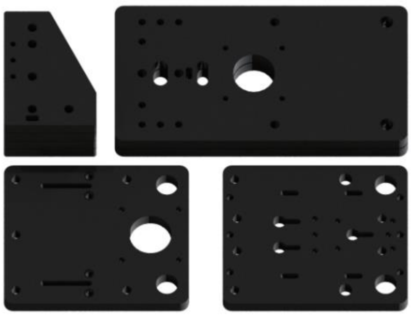

Fig. 5 Mounting Plates

Specifications

1) Material:- acrylic
2) Thickness:- 8mm
3) Stepper Motor

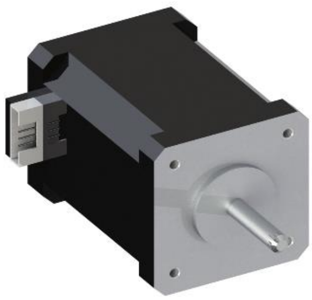

Fig. 6 Stepper motor

Specifications

1) Step Angle (°): 1.8
2) Motor Length (L)mm: 60
3) Current/Phase A: 1.7
4) No of Leads: No. 4
5) Shaft type: D type

4. Power Source

Fig. 7 Power source

Specifications

1) Input - 100-240V AC 50/60Hz
2) Category - Switch Mode Power Adaptor (SMPS)
3) Output Type - DC
4) Output - 12Volts 5Amp

5. Controller

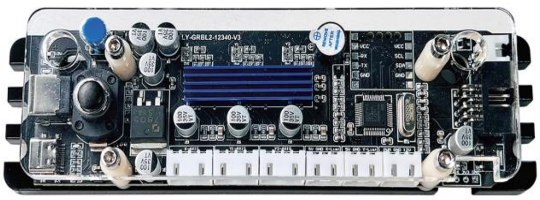

Fig. 8 GRBL Controller

Specifications

1) Weight:-100g
2) 32-bit MCU control board
3) Voltage:- 5v

6. Timing belt.

Fig. 9 Timing Belt (GT2)

Specifications

1) Width:- 6mm
2) Open loop belt
3) Pitch:-2mm
4) Tooth height:- 0.76
5) Belt Height:-1.52m

7. Pulley

Fig.10 Pulley

Specifications

1) No. of teeth slots:- 20
2) Material:- aluminium
3) Bore:- 6mm
4) Outer diameter:- 20mm
5) Weight:-6 g

8. POM wheels

Fig. 11 POM wheels

Specifications

1) Material:-POM/Delrin
2) Bearing:-625zz
3) Inner diameter:- 5mm
4) Weight:-13.5g

9. Laser

Fig. 12 Laser module

Specifications

1) Laser output power**:** 5.5-6W

2) Laser wave length 455±5nm
3) Laser shell material: aluminum alloy
4) Input voltage: 12V

C. Assembly of Components

Firstly, the assembly of Laser unit has been made as shown in above figure 13 It is made by using Laser mounting plate fixed to one of the mounting plate. Stepper motor with pulley on its shaft is mounted on anther mounting plate. Both the mounting plates are assembled with each other with the help of nuts, bolts, spacer, eccentric nut, and POM wheels. Then whole assembly is made inserted on extrusion. The timing belt is made to pass under the wheels and above the pulley and tightly fixed on extrusion with the help of t nuts.

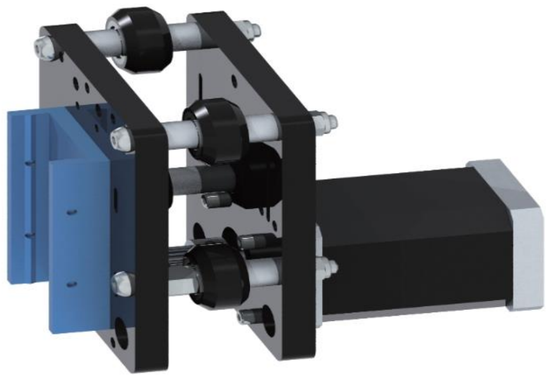

Fig. 13 Assembly of Laser unit

Fig. 14 Assembly of Y-axis units

After preparing Laser assembly, Y axis assembly is made. Initially the motor with pulley on its shaft is fixed on mounting plate of Y axis. Then the wheels are mounted with the help of nut, bolt, spacer, and eccentric nut. As the Laser assembly mounted on extrusion and timing belt is passed through pulley similarly done with Y-axis assembly. In this way, two Y axis assemblies are made.

After Y- axis assembly, both Laser assembly units mounted on their extrusion and Y axis units are assembled together Later, the corner plates are mounted to provide height. Controller is mounted on front extrusion and drag chains are attached to reduce the jumbling of wires.

Then as per the wiring diagram the wiring is done

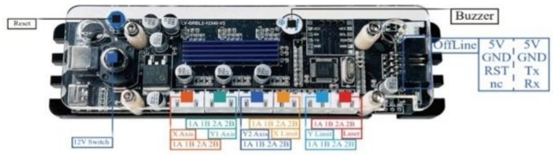

Fig. 15 Controller Connections

As per the above figure 3.16, the connections of the wires is done. This is the last step of the assembly.

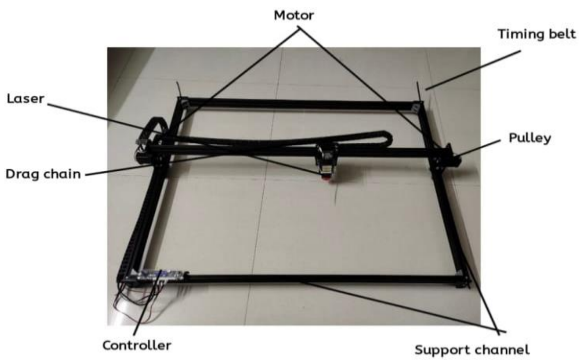

Fig. 16 Final assembly

In this way, assembly work is completed.

D. Software.

This project uses the LaserGRBL software. LaserGRBL is one of the best Windows software for image laser engraving. LaserGRBL can upload and send any image, graphic and logo With just a few clicks on your Laser engraver.

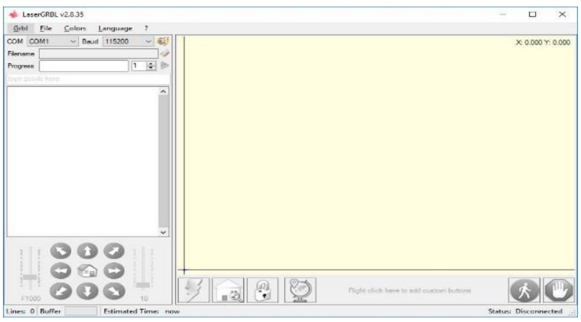

Fig. 17 Front Window of LaserGrbl Software.

Components of the Laser GRBL Program

1) Connect Machine: Connect the engraving machine Connect to the computer via USB and

turn on the device to test and COM port in the device manager.

2) Start the software: Open Laser GRBL, select COM port, then click Connect.
3) Load File: Open or download the file you want to overwrite Software i. Modify engraving parameters as needed.
4) Set parameters: Change engraving speed, laser power, the size and color of the pattern. Click on Create.
5) Focus Laser: Focus the laser according to the instructions. Make sure the materials are flat.
6) Set Origin: Move the laser to the starting point (usually bottom left) and place it over the original. Look at the carving first.
7) Start Engraving: Click Start, and adjust the laser power or Speed if necessary when doing the writing.

IV. RESULTS

To assess the machine's execution, etching tests were conducted on materials such as wood, plastic, and metal. The machine's accuracy, consistency, and speed were assessed to guarantee it met the prerequisites of mechanical utilize.

1. Fabric Compatibility: Effectively engraved wood, and metal with tall clarity and toughness.
2. Etching Speed: Accomplished speeds up to 300 mm/min without relinquishing detail, with a deviation of less than 0.1 mm, affirming tall accuracy.
3. Unwavering quality: Created steady comes about over different materials, illustrating the machine's versatility and vigor.

The results of engraving obtained on various material samples are as follows.

Fig. 18 results of engraving on metal plate 1

Fig. 19 results of engraving on metal plate 1

Fig. 20 results of engraving on wood.

V. ADVANTAGES AND DISADVANTAGES.

Advantage of a Laser Engraving Machine:

1. Light Weight: Made of Aluminum, thus it is highly portable and easy to deal with.
2. Low Cost: It uses relatively inexpensive yet strong materials, such as aluminum and acrylic, thus making it easy to afford for both big and small projects.
3. Easy to Use: Comes with an easy setup and operation without requiring any technical expertise.
4. Eco-Friendly: It does not produce harmful products and has minimal waste with only dust particles.
5. Universal Applications: It can engrave a variety of materials, such as wood, glass, fabric, paper, and more.

6. Contact-Free Process: It uses heat from the laser beam, eliminating direct contact with the material.
7. No Tool Wear: Since no physical tools are used, maintenance costs are minimal.
8. High Precision: It allows for intricate and detailed designs with exceptional accuracy.
9. Wide Usability: It serves multiple industries, such as electronics and jewelery, for diverse processes.
10. Spacious Working Space: Offers a big 1m x 1m work area that can engrave large areas in one go.
11. Low Cost Metal Engraving: Achieves good quality results at much lower cost than CO_2 or fiber laser systems.

Limitations:

1. Only two-dimensional X-Y plane
2. Does not engrave extremely hard or high-melting point metals.
3. Engraving difficult with shiny surface as it reflects light.

VI. FUTURE SCOPE

Significant progress was made in developing components for a low-cost laser engraving mechanism, but the machine's capabilities remain limited. The low power output of the laser diodes restricts their ability to engrave or cut through materials effectively. While combining multiple lasers improves performance, it has inherent limitations.

The tested mechanical structures offer a foundation for accurate positioning but require further refinement to meet design goals. Enhancing power transmission is critical, with timing belts showing promise as a low-cost alternative to round belts, though lead screws provide greater precision. Potentiometer feedback could be a cost-effective solution for position control.

With optimized laser parameters and improved mechanics, the machine may excel at layout marking rather than engraving. However, future advancements in laser power and system design could enable the machine to perform cutting and even welding on various materials, expanding its range of applications. This versatility could make it a valuable tool for numerous industrial and creative processes.

VII. CONCLUSION

This research demonstrates the feasibility of developing a low-cost, portable diode laser engraving machine with a large 1m x 1m working area, meeting industrial requirements for metal marking and various engraving applications. By integrating a powerful 10W diode laser with computer numerical control (CNC) technology, the machine achieves high precision and efficiency, operating through G-code instructions for automated and user-friendly functionality. This advancement exemplifies the shift from manual to automated systems, showcasing a compact and transportable design that can be operated with minimal expertise, making it highly accessible.

Diode laser engraving machines have become popular due to their affordability, precision, and ability to engrave diverse materials such as wood, plastics, and metals. While the machine effectively delivers fast and clear results, selecting the right system requires evaluating factors like engraving depth, speed, and material compatibility. This research not only contributes to understanding CNC machine operations but also highlights the potential for further enhancements. With advancements in laser technology, such machines could eventually support additional applications like cutting and welding, broadening their industrial and creative utility.

REFERENCES

[1] Faiyaz Mansoori, Adesh Tayde, Mohammad Sadique, Faizan Akhtar, Bazil Sheikh, Akbar Ali, "Laser engraver and laser cutter," International Research Journal of Modernization in Engineering, Technology and Science, Vol. 4, Issue 4, pp. 1889–1891, April 2022.

[2] Sridutt H R, Sachin M, Pramod M, Surendra M, Bhaskar B Katti, Chakrasali Chandrakumar, "Fabrication and analysis of CNC laser engraving on different materials," Journal of Emerging Technologies and Innovative Research (JETIR), Vol. 6, Issue 5, pp. 228–230, May 2019.

[3] Antonin Durna, Jiri Fries, Leopold Hrabovsky, Ales Sliva, Jozef Zarnovsky, "Research and development of laser engraving and material cutting machine from 3D printer," Management Systems in Production Engineering, Vol. 28, Issue 1, pp. 47–52, 2020.

[4] Prashant, K., Khatib, M. I., Shahrukh, A., Mirza, N. A., Mujahid, S., and Kazim, M. A.

M., "Design and fabrication of laser engraving machine," International Journal of Scientific Research in Science, Engineering and Technology (IJSRSET), Vol. 7, No. 3, May-June 2020, pp. 250–262. DOI: 10.32628/IJSRSET207366.

[5] Ganesh, R. K., Hemanth, S., and Shail, S., "Assembly of laser engraving machine," International Journal of Research Publication and Reviews, Vol. 5, No. 4, April 2024, pp. 7491–7495.

[6] Agalianos, F., Patelis, S., Kyratsis, P., Maravelakis, E., Vasarmidis, E., and Antoniadis, A., "Industrial applications of laser engraving: Influence of the process parameters on machined surface quality," World Academy of Science, Engineering and Technology, Vol. 59, 2011, pp. 1242–1245.

[7] Kasman, S., "Impact of parameters on the process response: A Taguchi orthogonal analysis for laser engraving," Measurement, Vol. 46, 2013, pp. 2577–2584.

[8] Patel, D. K., and Patel, D. M., "Parametric optimization of laser engraving process for different materials using Grey Relational Technique—A Review," International Journal of Scientific Research in Science, Engineering and Technology, Vol. 3, No. 4, April 2014.