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Optimizing Arduino-Based Laser Cut Machine Settings for Home Industry

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Abstract. The rapid development of laser technology has significantly impacted various industrial sectors, particularly through the use of CNC laser cutting machines. These machines offer distinct advantages and limitations, making them suitable for processing a wide range of materials. This study aims to identify the most effective and efficient settings for a diode-based CNC laser cutting machine, specifically for cutting plywood. An experimental approach was employed, involving the design, creation, and testing of the machine. The research focused on optimizing the focus point and operational settings to achieve precise cuts. The results indicate that the optimal focus point is 12.6 mm, with the best cutting performance achieved at a speed of 500 mm/min, 30% laser power, and 7 passes. The findings suggest that this CNC laser machine is highly efficient for small-scale industries, offering affordability, ease of production, and reduced labor costs by automating multiple machines with a single computer. However, its application is limited in large-scale manufacturing due to constraints related to the Arduino-based control system and the maximum work area size.

Keywords: Arduino, CNC, Diode Laser, Laser Cutting, Plywood

1. INTRODUCTION

The rapid advancement of laser technology has revolutionized various industries, particularly the manufacturing sector. CNC Laser Cutting machines, which harness different types of lasers such as YAG, Fiber, and CO2 lasers, have become indispensable tools due to their precision and efficiency [1]. However, while these machines offer significant benefits, their high cost, especially for CO2 laser systems, poses a challenge for small-scale industries and home-based businesses [2]. The emergence of diode lasers, which utilize a diode as the laser head, offers a potentially more cost-effective alternative, yet their application in small-scale industries remains underexplored. This research aims to address this gap by evaluating the effectiveness of diode-based CNC Laser Cutting machines, specifically focusing on their application in cutting plywood, a common material in both craft and industrial sectors.

Plywood is widely recognized for its durability, flexibility, and cost-effectiveness, making it a popular choice in various manufacturing processes. Research has shown that birch plywood, in particular, exhibits superior flexural strength, making it ideal for applications requiring high durability [3]. Despite these advantages, the challenge remains in achieving precise cuts with minimal material waste, especially when using more affordable laser cutting systems [4]. Traditional CNC machines, while effective, are often costly and complex to operate, creating a barrier for smaller enterprises. This study aims to explore how diode-based CNC laser machines, controlled by the open-source Arduino platform, can be optimized to meet these demands, offering a more accessible solution for small-scale industries [5].

The introduction of Arduino into the realm of CNC laser cutting presents a significant opportunity to reduce costs and enhance efficiency. Arduino, known for its simplicity and versatility, allows for the precise control of electronic systems, making it an ideal candidate for integration into laser cutting machines [6]. By leveraging Arduino technology, this research seeks to develop a CNC Laser Cutting machine that is not only cost-effective but also capable of delivering high precision and efficiency comparable to more expensive systems. This focus on affordability and precision is crucial for small businesses and home industries that require reliable and accurate machinery without the financial burden associated with traditional CNC systems [7].

However, the integration of Arduino with diode lasers in CNC machines introduces new challenges, particularly in terms of achieving optimal cutting performance and accuracy. Existing literature provides a strong foundation for understanding the basic principles of laser cutting, yet there is limited research on the specific application of diode lasers in cutting materials like plywood [8]. This gap in the research highlights the need for a thorough investigation into the optimal settings and configurations required to maximize the performance of Arduino-based diode CNC Laser Cutting machines. By addressing this gap, the study aims to provide valuable insights that can help small-scale industries adopt this technology effectively [9].

The primary aim of this research is to identify the ideal focus point and settings for cutting plywood using a diode-based CNC Laser Cutting machine controlled by Arduino. This includes evaluating the machine's performance in terms of accuracy, efficiency, and cost-effectiveness, with the goal of developing a system that can compete with traditional CNC machines [10]. Through experimental procedures informed by existing literature, this study seeks to contribute to the growing body of knowledge on affordable and efficient laser cutting solutions for small-scale industries.

This research addresses the critical problem of high costs and complexity associated with traditional CNC laser cutting systems, particularly for small-scale industries. By focusing on the integration of Arduino with diode lasers, the study aims to fill the existing gap in the literature, offering a viable alternative that combines affordability with high precision. The findings of this research are expected to have significant implications for the adoption of CNC laser cutting technology in smaller enterprises, ultimately contributing to the broader goal of making advanced manufacturing technologies more accessible and cost-effective [11].

2. METHODS

2.1 Research Design

This study employs a quantitative research approach, utilizing both experimental and simulation techniques to evaluate the performance of a 2-axis CNC Laser Diode machine. The research is methodically structured to develop and assess the machine's capabilities, ensuring reliable and replicable results.

2.2 Machine Design and Development

The design and development of the CNC Laser Diode machine involved careful planning, beginning with the design of the machine's frame, rail mechanism, and drive components. Key hardware components include NEMA 17 stepper motors and Arduino microcontrollers, which are central to the machine's operation [15].

1) **Frame and Rail Mechanism**: The machine's frame was designed to provide stability and precision during operation, with a rail mechanism that ensures smooth movement along the X and Y axes, which is essential for accurate laser cutting.
2) **Drive Components**: NEMA 17 stepper motors were selected for their reliability and compatibility with the CNC Shield. These motors drive the machine's X and Y axes, controlled by the Arduino microcontroller.
3) **Control System**: The control system begins by converting AC electricity to DC via a power supply connected to the microcontroller. The microcontroller, programmed via a computer, sends signals to the motor driver, which controls the stepper motors with precise pulses (666 pulses per second), achieving a motor speed of 200 RPM. The G-code generated by the software is interpreted by the Arduino, which translates the commands to control the machine's movements and laser operations [15].

2.3 Implementation Stage

The implementation phase involved assembling the CNC Laser Diode machine and integrating the necessary hardware and software components. The steps included:

1) **Preparation of Tools and Materials**: The machine assembly required three bipolar stepper motors—one for the X-axis and two for the Y-axis—along with a CNC Shield, Arduino Nano, and other electronic components [16].
2) **Installation of Electronic Devices**: Microcontrollers and drive components were installed to operate the stepper motors and laser. The Arduino Nano converted control signals into PWM (Pulse Width Modulation) signals, essential for precise motor control [16].
3) **Software Activation**: Supporting software, including Lightburn and CorelDRAW, was installed and configured to interface with the machine. These software tools

were crucial for creating and importing design files (e.g., DXF format) into the system.

4) **Machine Trial**: Initial trials were conducted to ensure the machine's correct functioning, focusing on verifying the stepper motors' operation, the laser's accuracy, and the system's overall reliability.

2.4 Experimental Setup and Data Collection

The experimental setup followed a systematic process to evaluate the CNC Laser Diode machine's performance. The steps in this process were:

1) **Preparation for Testing**: The 2-axis CNC Laser Diode machine was prepared, with plywood as the test medium. A computer with Lightburn and CorelDRAW software was connected to the machine [16].
2) **Activation of the System**: The machine and computer were powered on, and Lightburn software was initiated. Machine settings were configured according to the planned test parameters.
3) **Testing Procedure**: The test involved creating a DXF file in CorelDRAW, adjusting feedrate and other parameters, and importing the file into Lightburn for execution. The machine was then operated to perform laser cutting based on the DXF file [16].
4) **Observation and Recording**: Observations were made during testing to assess machine performance, and data were recorded on how various parameters affected the cutting results.
5) **Repetition of Tests**: To ensure reliability, the test was repeated three times with the same setup and parameters.
6) **Data Analysis**: The data collected were analyzed to evaluate the machine's performance, including accuracy and consistency of cuts, and to identify any areas for improvement.

3. RESULTS AND DISCUSSION

3.1 Experimental Results

The CNC laser cutting machine developed in this study employed three stepper motors and corresponding drivers to control the X, Y, and Z axes, with a 40-watt diode laser module serving as the primary cutting component [17]. The machine's wiring diagram and frame design, as depicted

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in Figures 1 and 2, were meticulously engineered to ensure structural stability and operational efficiency. These components were selected to provide the precision necessary for high-quality cuts, particularly when working with materials such as plywood. A series of trials were conducted to evaluate the machine's cutting performance, using 3mm thick plywood as the test material. The laser's focus point was set at 12.6mm above the plywood surface, which was determined to be the optimal distance for effective cutting. The primary objective was to identify the best operational settings for cutting 3mm plywood, as well as to measure and compare the actual cutting time against the software's estimated cutting time.

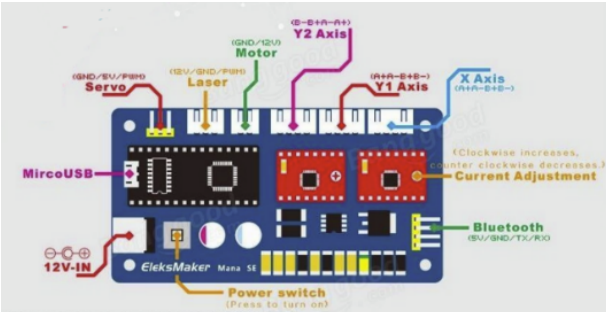

Figure 1. Wiring Diagram

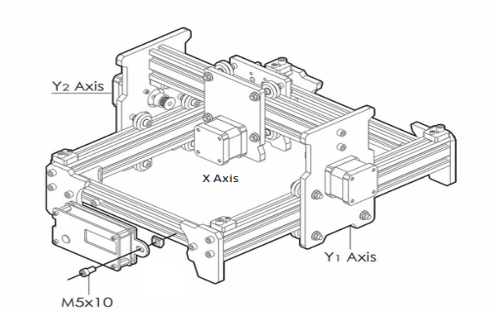

Figure 2. Frame Design

During the trials, the cutting speed was varied from 100mm/min to 1000mm/min while maintaining the laser power at 30% of its maximum capacity. This power setting was deliberately chosen to extend the lifespan of the laser lens, a critical component that impacts both the machine's longevity and its cutting quality.

The results, summarized in Table 1, indicated a strong relationship between the cutting speed and the quality of the cuts. At the lower speeds of 100mm/min to 300mm/min, the plywood was successfully cut through; however, the edges displayed significant burning, leading to rough and uneven finishes, as shown in Figure 3. This burning effect is a common issue when cutting at slower speeds, where the laser remains in contact with the material for longer, transferring more heat than necessary.

Table 1. Performance Test on 3mm Plywood

Speed(mm/min)	Power(%)	Pases	Result
100	30	7	Cut, But Not Smooth
200	30	7	Cut, But Not Smooth
300	30	7	Cut, But Not Smooth
400	30	7	Perfectly Cut
500	30	7	Perfectly Cut

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Speed(mm/min)	Power(%)	Pases	Result
600	30	7	Cut
700	30	7	Cut but Not Perfect
800	30	7	Cut but Not Perfect
900	30	7	Cut but Not Perfect
1000	30	7	Cut but Not Perfect

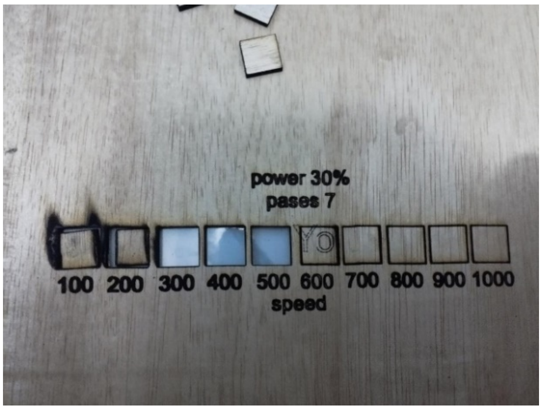

Figure 3. Test on Front-side

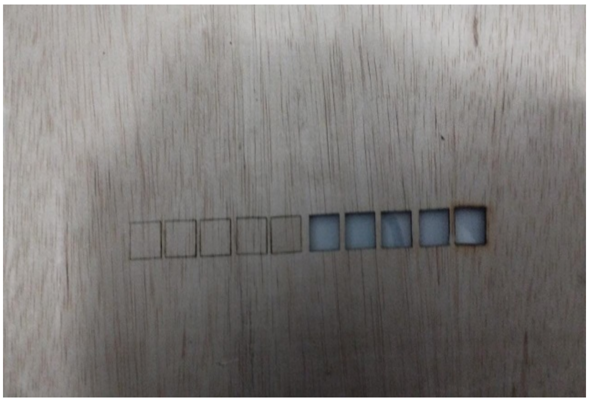

Figure 4. Test on Back-side

The optimal cutting results were achieved at speeds of 400mm/min and 500mm/min. At these speeds, the cuts were clean and precise, with minimal burning or charring, indicating that the laser energy was well-balanced with the material's thermal conductivity. These settings produced smooth edges, making them ideal for small-scale production where quality and material preservation are paramount. When the speed exceeded 600mm/min, the cutting quality began to degrade, as seen in Figure 4. The laser struggled to penetrate the plywood fully, resulting in incomplete cuts. This was particularly evident at the highest speed of 1000mm/min, where the cuts were neither complete nor clean, underscoring the limitations of the machine when operating at higher speeds.

A notable finding was the discrepancy between the software's estimated cutting time and the actual time recorded during operation. The software preview estimated a cutting time of 10 minutes and 14 seconds, while the real-time operation took 21 minutes and 43 seconds, as shown in Figures 5 and 6. This significant difference highlights the need for further refinement in the software's time estimation algorithms. Such discrepancies can affect planning and efficiency in a production environment, where accurate time predictions are crucial for scheduling and cost management.

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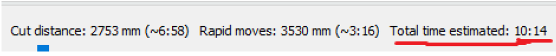

Figure 5. Estimate Cutting Time

Figure 6. Realtime Cutting Time

The results of this study provide valuable insights into the practical use of CNC laser cutting technology in small-scale production. The optimal settings identified 400mm/min to 500mm/min speed at 30% laser power with seven passes offer a reliable configuration for cutting 3mm plywood with high precision and minimal material damage. These settings are particularly advantageous for applications requiring fine details and smooth edges, such as custom furniture or intricate craftwork.

The findings also emphasize the importance of balancing speed and power in laser cutting operations. While higher speeds can increase throughput, they may compromise cut quality, especially with materials like plywood that have specific thermal properties. Conversely, slower speeds may ensure complete cuts but can lead to excessive burning and longer processing times. When compared to similar studies on low-cost CNC laser machines, the performance of the machine developed in this research stands out in terms of its ability to deliver precise cuts at moderate speeds. Other studies have reported similar challenges with time estimation and cutting efficiency, particularly when working with diode lasers. However, the consistency of the results in this study suggests that the machine's design and the chosen operational parameters are well-suited for the intended applications.

The optimized settings identified in this study can be directly applied to real-world small-scale production scenarios, particularly in industries that require precision cutting of materials like plywood. For instance, small businesses engaged in custom furniture production or craft manufacturing can benefit from these settings by achieving high-quality cuts with reduced material waste. However, the current setup does have limitations. The significant difference between the estimated and actual cutting times indicates a need for improved predictive algorithms in the control software. Additionally, the machine's performance at higher speeds suggests that further testing and calibration are required to enhance cutting efficiency without sacrificing quality.

Future research should focus on refining the machine's control software to improve time estimation accuracy and exploring ways to enhance cutting efficiency at higher speeds. Testing with a broader range of materials and thicknesses would also provide a more comprehensive understanding of the machine's capabilities and potential applications. Additionally, investigating the effects of different laser powers and passes on various materials could lead to further optimization of the cutting process. This study successfully identified optimal settings for cutting

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3mm plywood using a 40-watt CNC laser diode machine. The findings demonstrate the machine's potential for small-scale production applications, although further refinements are needed to address the limitations observed. The results contribute valuable insights into the practical use of low-cost CNC laser technology, with implications for improving efficiency and precision in small-scale manufacturing environments.

3.2 Discussion

The findings of this study underscore the potential of diode-based CNC laser cutting machines as a viable and cost-effective alternative for small-scale industries, particularly in applications involving materials like plywood. The machine, developed with a focus on affordability and precision, was evaluated under various operational parameters, yielding insights that are directly applicable to real-world production environments.

One of the key observations from the experimental results is the strong correlation between cutting speed and the quality of cuts produced. At lower speeds (100mm/min to 300mm/min), the laser successfully cut through the plywood; however, the edges exhibited significant burning, resulting in rough and uneven finishes. This burning effect, commonly observed when the laser remains in contact with the material for extended periods, highlights a trade-off between cutting speed and the quality of the cut. Slower speeds, while ensuring complete material penetration, can lead to excessive heat accumulation, causing undesirable burning and material degradation.

The optimal cutting results were achieved at speeds of 400mm/min and 500mm/min, where the balance between laser power and cutting speed produced clean and precise cuts with minimal burning or charring. These settings are particularly advantageous for applications requiring high precision and smooth finishes, such as custom furniture or intricate craft manufacturing. The effectiveness of these settings suggests that small-scale producers can achieve high-quality outputs while maintaining operational efficiency, thereby reducing material waste and enhancing product quality.

However, as the cutting speed increased beyond 600mm/min, the quality of the cuts deteriorated. The laser struggled to penetrate the plywood fully, leading to incomplete and uneven cuts, especially at the maximum tested speed of 1000mm/min. This limitation points to the machine's reduced effectiveness at higher speeds, which is a critical

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consideration for industries where throughput is as important as precision. The findings suggest that while the machine performs optimally at moderate speeds, its design and operational parameters may require further refinement to enhance performance at higher cutting speeds.

Another significant finding from the study was the discrepancy between the software's estimated cutting time and the actual time observed during operation. The real-time cutting process took more than double the time predicted by the software, highlighting a critical gap in the time estimation algorithms used. Accurate time predictions are essential for efficient production planning and cost management, particularly in small-scale operations where resources are often limited. This discrepancy indicates a need for improved predictive algorithms that can better account for the machine's operational nuances, such as the effects of cutting speed, material thickness, and laser power on the overall cutting time.

The practical implications of these findings are significant for small businesses and home-based enterprises. The optimal settings identified in this study provide a reliable and repeatable configuration for producing high-quality cuts in 3mm plywood, a common material in various craft and manufacturing applications. By adopting these settings, small-scale producers can enhance their production efficiency while maintaining the quality of their outputs. Moreover, the cost-effectiveness of the diode-based CNC laser machine, combined with the precision it offers, makes it an attractive alternative to more expensive traditional CNC systems.

However, the study also highlights several limitations that must be addressed in future research. The significant difference between estimated and actual cutting times suggests that further work is needed to refine the control software, particularly its time estimation capabilities. Additionally, the machine's performance at higher speeds indicates that while the current design is suitable for moderate-speed operations, enhancements are necessary to expand its effectiveness across a broader range of cutting speeds. Future studies should explore these aspects in greater depth, including testing the machine with a wider variety of materials and thicknesses to better understand its full capabilities and limitations.

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This study demonstrates the potential of a 40-watt diode-based CNC laser cutting machine for small-scale production applications. The optimal settings identified for cutting 3mm plywood provide a foundation for achieving high-quality, cost-effective production. However, to fully realize the machine's potential, further refinements in software accuracy and machine calibration are necessary. These findings contribute to the broader understanding of low-cost CNC laser technology, offering practical insights for improving efficiency and precision in small-scale manufacturing environments.

4. CONCLUSION

This study evaluated a diode-based CNC laser cutting machine controlled by an Arduino microcontroller, focusing on its application in cutting 3mm plywood. The research identified optimal settings—500mm/min speed, 30% laser power, and 7 passes—that balance cutting efficiency and quality, making this machine ideal for small-scale industries. The CNC laser cutter utilizes a 40-watt diode laser and Arduino for precise control, converting G-code from a computer into cutting commands. Birch plywood, known for its high flexural strength, proved to be an excellent material for laser cutting. While theoretical calculations suggested that a 40W laser could cut through 3mm plywood in a single pass, practical considerations led to limiting the power to 30% to preserve the laser lens, necessitating multiple passes for effective cutting. This machine is highly efficient for small-scale production, offering reduced labor costs and improved product quality. However, its reliance on Arduino imposes limitations on scalability and processing speed, making it less suitable for large-scale manufacturing. The diode-based CNC laser cutting machine, with the identified optimal settings, provides a cost-effective and precise solution for small-scale industries. Future enhancements could focus on improving scalability and refining control systems to expand its applicability in more diverse manufacturing environments.

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