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# Optimising Laser Harvesting: Nozzle Beam Selection For Enhanced Cutting Efficiency

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ABSTRACT

*Laser harvesting technology has emerged as a promising approach for efficient and precise harvesting in agricultural settings, particularly in the oil palm industry. The success of this technology relies on the careful selection of optical focal lenses and their ability to optimise laser beams for enhanced performance. This study involved a comprehensive investigation into the characteristics and parameters influencing the selection of suitable nozzle beam optical focal lenses. Experimental setups utilising advanced laser systems were employed to analyse the impact of two nozzle beam configurations such as intensity, focus, and power distribution on the properties of the laser beam. Key objectives include identifying optimal nozzle beam selection strategies that maximise harvesting efficiency while minimizing energy consumption and potential damage to the sample. The use of 1.2 mm nozzle lens led to an average 31% increase in cutting rate compared to the 2.0 mm nozzle lens. The laser power transmitted through this nozzle lens enhanced the cutting accuracy and efficiency, which reduced an average cutting time by 39%. The use of 1.2 mm lenses in this study not only enhances cutting capability but also significantly improves the whole cutting process, highlighting the critical importance of nozzle size selection in optimising laser cutting performance. Overall, the precision and speed achieved demonstrate the effective application of suitable lens selection in laser cutting processes.*

*Keywords: Laser technology; optical lens; nozzle beam; harvesting technology; oil palm*

## INTRODUCTION

Mechanisation can be employed on farm to reduce reliance on human labour (Ahmad et al. 2023; Azwan et al. 2020; Daum et al. 2023). By hand or with traditional or mechanical instruments, oil palm harvesting, which is an important stage in the oil palm industry, a long-drawn-out procedure which also impede high labor expenses (Ismail et al. 2015; Kushairi et al. 2019). However, there is hoped to overcome these problems through employment of laser-based harvesting techniques such as continuous wave fiber laser system (Azaman et al. 2018). Investigations concerning laser cutting technology showed that it was effective in biomaterials cutting (Aniszewska et al. 2020; Azaman et al. 2018; Liu et al. 2011). Nevertheless, studies about nozzle beam selection and its effect on different types of biomaterials particularly, oil palm fronds and bunch stalk are lacking.

Methods for laser cutting on metal and nonmetal materials include vaporisation cutting, fusion cutting-melt and blow, and reactive fusion cutting (Banat et al. 2020; Domadia et al. 2024; Hernandez-Castaneda et al. 2011; Quintero et al. 2011; Riveiro et al. 2019). Vaporisation process depended on the use of a high-power density focused laser through nozzle beam to heat up the work surface to boiling point, thereby creating keyhole (Khatak 2022; Wandera, 2010). Multiple reflections in the nozzle beam increased the absorption of laser beam, leading to gradual expansion of the hole. As a result, vapor produced dummy cutting escaped, thus creating back pressure that enhanced melt outflow from cut kerf. Vaporisation laser cutting is good enough for nonmetals as well as very thin-sectioned (1.0mm) metals with reduced loss at conductance from the cut zone to the metal substrate (Wandera 2010).

## FOCAL LENGTH

Focal length is determined by the lens refractive index, thickness and radii of curvatures. Focal point is important in laser marking and engraving as it is the point where laser beam comes to its smallest diameter allowing for precise and detailed engraving or marking on the surface of material (Dubey & Yadava, 2008; Goswami, 2019; Srivastava et al. 2014) (Figure 1). Therefore, focused point ensures high resolution and accuracy in laser processing ,which is an important aspect for achieving intricate designs and fine details in marked or engraved output (Mohammod, 2010; Powell et al. 2008).

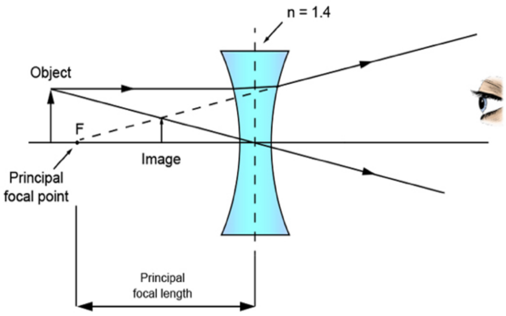


FIGURE 1. Diagram of focal length (Srivastava et al. 2014)

Beam width is determined by focal length in a laser marking and engraving process. The focal length in laser systems changes the convergent of the laser ray, thereby affecting the size of spot on the object's surface where the laser energy concentrates (Sarler et al. 2021; Shather & Abd Al Jabar 2020). Shorter focal length produces narrower beam, leading to more focused engraving or marking which may be very accurate. Aniszewska et al. in 2020 stated that longer focal lengths will produce wider beams appropriate for certain applications that require broader coverage but at the expense of fine details and high accuracy. Therefore, by changing its value, focal distance impacts beam width directly so that shorter focal distance lead to better fineness and sharper engravings while longer focal distance result in wider beam widths for various engraving needs (Sarler et al. 2021).

Jet length was measured from nozzle outlet up to first drop detachment while diameter readings were taken at nozzle outlet and velocity recorded at tip of jet (Figure 2).

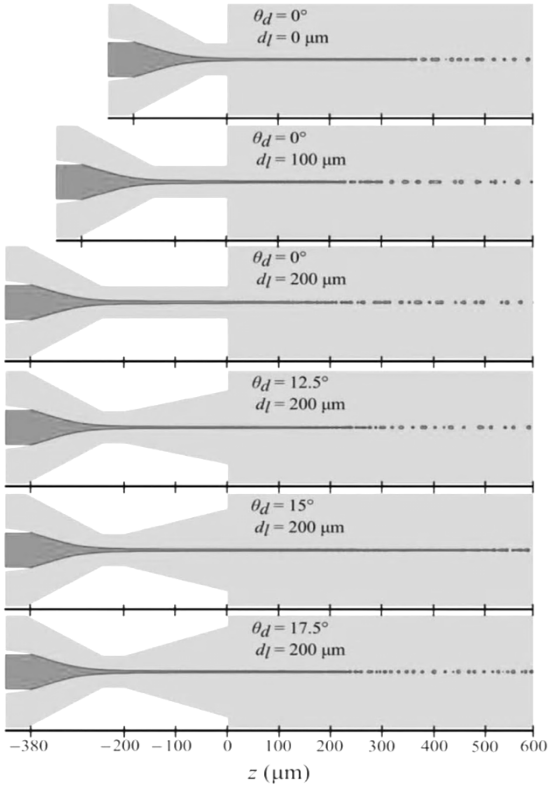


FIGURE 2. Plot of jet shape at 0.8 ms for 6 nozzles outlet orifice variants (Sarler et al. 2021)

## NOZZLE DIAMETER

The fibre laser cutting process depended on the size of nozzle's diameter, which could be defined as the exit's orifice where laser beam is expelled when cutting. This nozzle's diameter influences the quality and efficiency of cut considerably (Chen et al. 2000). There are three main functions that a nozzle performs during laser cutting (Wadekar & Deokar 2016). The nozzle holds the optimal path which keeps the process gas flow rate at a level that could enable proper interaction between the nozzle and radiation at the focal zone. Smaller nozzle generates more concentrated beam with the higher speed while larger ones provide less focused beam hence, slower cut-off pace which resulted in low surface quality.

The function of laser nozzles is to regulate the direction of airflow and air pressure within the laser head. The high-pressure air flow is controlled to maintain constant pressure amid the workpiece and nozzle. The laser nozzle prevents splashing of liquid material from the workpiece on the interior parts of the laser head, thereby keeping the internal lens safe (Wewinlaser 2021). A capacitance signal is provided by laser nozzles to the height adjustment system to assume stable and exact operation of the height adjustment device.

This paper aimed to examine the harvesting efficiency of 1.2 mm and 2.0 mm laser nozzles in cutting Fresh Fruit Bunches (FFB) stalks. The selection of these two nozzle sizes is based on the readily available size values that are commonly used in laser systems across diverse industries. Extensive research studies have been conducted on laser technology, but their applications are concentrated in the metal industries, rather than in the cutting of biomaterials such as fronds and FFB stalks. Laser cutting has emerged as a technology in the agricultural sector, particularly in oil palm plantations. This study highlights that the cutting efficiency of lasers can be affected by the use of a lens. The lens delivers a focused beam that enhances the cutting efficiency. Harvesting efficiency is a critical factor related to oil palm harvesting. In addition, the study aimed to improve the efficiency of laser cutting through analysis of impacts on precision, speed and other elements through correlation between laser power, sample perimeter, and sample area (Martinez-Conde et al. 2017). The findings would be significant in advancing laser technology for optimised oil palm harvesting.

## METHODOLOGY

### EXPERIMENTAL SETUP

Experiments in laser cutting were performed using interchangeable nozzles with diameters of 1.2 mm and 2.0 mm. The setup for the laser cutting test is arranged in Figure 3(a). This arrangement is based on the schematic illustration reported by Martinez-Conde et al. 2017, as shown in Figure 3 (b). Newly gathered FFB stalks from the same field with an average of weight of 20 kg were collected. Only ripe FFB stalks were selected to achieve consistent results across all trials (Figure 4). The use fresh fronds were necessary as to accurately mimic the natural moisture levels thereby facilitates real life cutting experience in the laboratory setup.

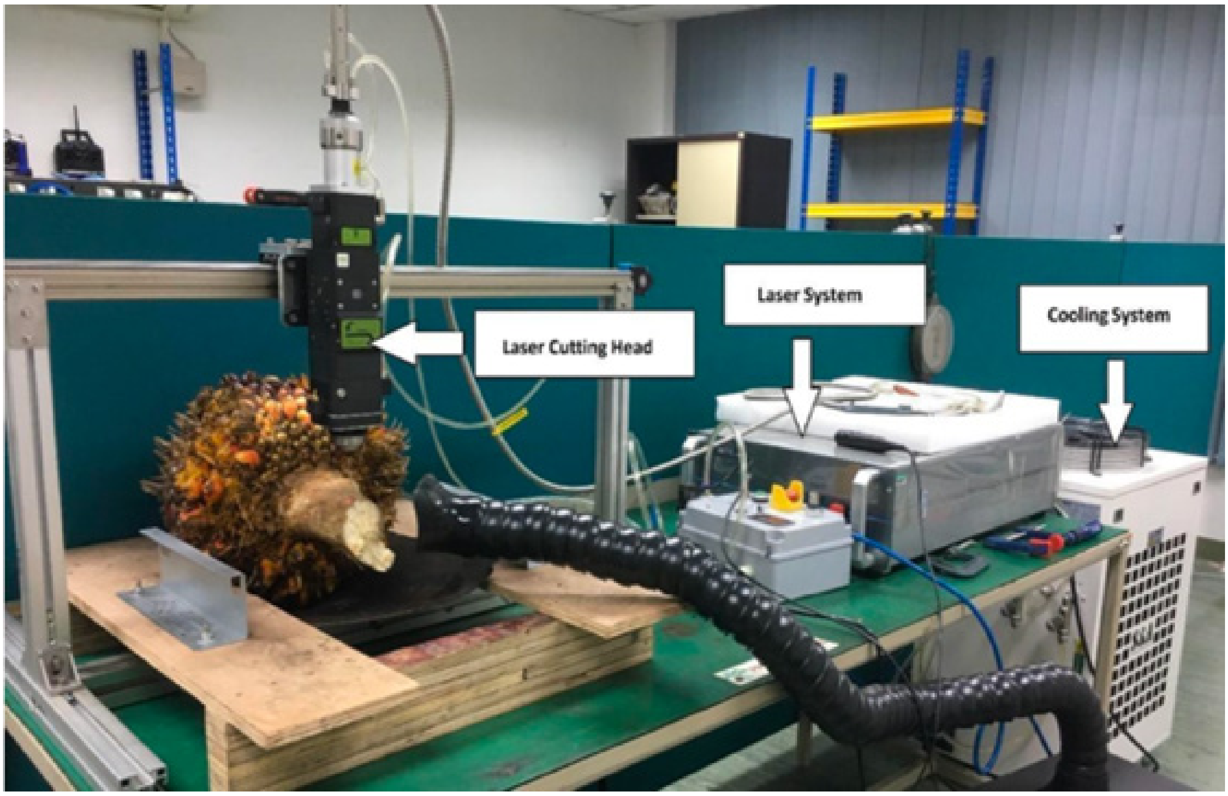


FIGURE 3 (a). The setup of laser system for cutting test

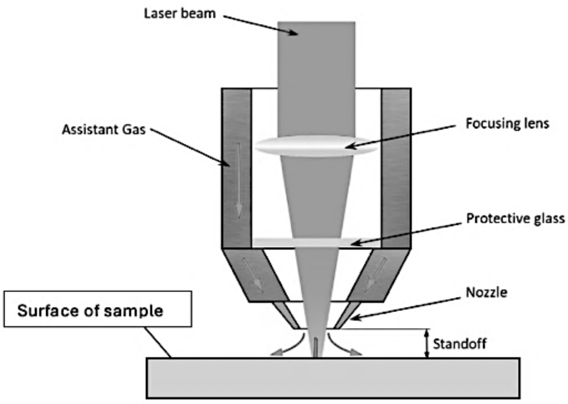


FIGURE 3 (b). Schematic of experimental setup (Martinez-Conde et al. 2017)

FIGURE 4. FFB Stalk

## PREPARATION OF OIL PALM STALKS

The gathered FFB stalks were processed prior to testing. The size of the stalk was determined by its diameter. The diameter and area of the FFB stalk were calculated using the ellipse formula in Figure 5.

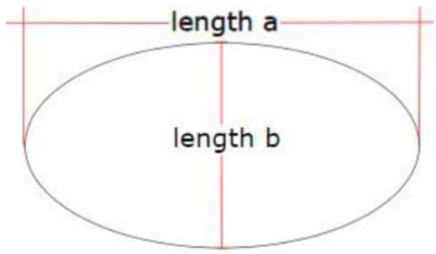


FIGURE 5. Measurement parameter of FFB stalk

$$A = \frac{\mathrm{ab}}{4} \tag{1}$$

$$P = \pi \mathrm{R}\left[\frac{(1+3\mathrm{H})}{(1+\sqrt{4-3H})}\right] \tag{2}$$

$$\pi = 3.1416\ 4 \tag{3}$$

$$R = \frac{(a+b)}{2} \tag{4}$$

$$S = \frac{a-b}{2} \tag{5}$$

$$H = \frac{R^2}{S^2} \tag{6}$$

where (A) was the area of the ellipse, (P) was the perimeter of the ellipse, (a ) was the width, and (b) was the height.

## LASER POWER INVESTIGATION

FFB stalks were cut with power level ranging from 300 to 900 watts with optimally positioned laser. The exposure duration was recorded at every power level and replicated for precision. The process involved the use of laser with specific nozzles, cutting time was recorded. Performance and quality of laser cutting processes were determined through the data collected, mainly time taken for cutting using both sizes of nozzle as well as qualitative observations on edge quality, precision and overall effectiveness. The efficiency and effectively of the two nozzle sizes different were determined.

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## RESULTS AND DISCUSSION

Laser cutting was conducted to evaluate the impact of power levels and rate of cutting on the efficiency of oil palm harvesting. It was thus found that this factor had significant effect on its operating ability as a tool used in harvesting oil palms leading to useful conclusions regarding operative values when engaging in such activities. In this regard, the investigation considered the use of 1.2 mm and 2.0 mm beam nozzles examining various levels of laser power aimed at improving laser cutting rates.

The cutting efficiency of the two distinct sizes of nozzle beams was evaluated based on their cutting rates. The calculation of the cutting rate was determined by dividing the area of the cut by the total duration it took, as illustrated in Equation (2).

$$R = \frac{L_c}{t_c} \tag{7}$$

The variable R was the cutting rate, $L_c$ represented the cutting area ($mm^2$), and $t_c$ indicated the duration of time required for the cutting process (s). The measured values for the rates of laser cutting at the perimeter of the sample were recorded in $mm^2/s$.

## LASER CUTTING BY USING 2.0 MM AND 1.2 MM NOZZLE LENS BEAM

This study was carried out using different laser power ranging from 300 to 900 watts by employing two different nozzle lens i.e. 1.2 mm and 2.0 mm respectively (Figure 6). Analysis was conducted whereby the sample perimeter and area were taken into account as the major factors in determining the cutting rate. The test sought to assess the effect of varying laser power on cutting efficiency, in a bid to optimize the process for harvesting.


FIGURE 6. Laser cutting test on FFB stalk sample

The time required to cut FFB stalks was significantly reduced as a consequence of the increase in laser power from low to high levels, indicating enhanced harvesting efficiency. This results aligns with previous research conducted by Liu et al. 2011; Azaman et al. 2022, which reported that high-energy laser pulses improve cutting efficiency, leading to an increase in the cutting rate and time speed of cutting. Mean values obtained from the cutting tests were computed and subsequently used to determine the average cutting rate. The variations is average cutting rates with different power levels are depicted in Figure 7 and 8.

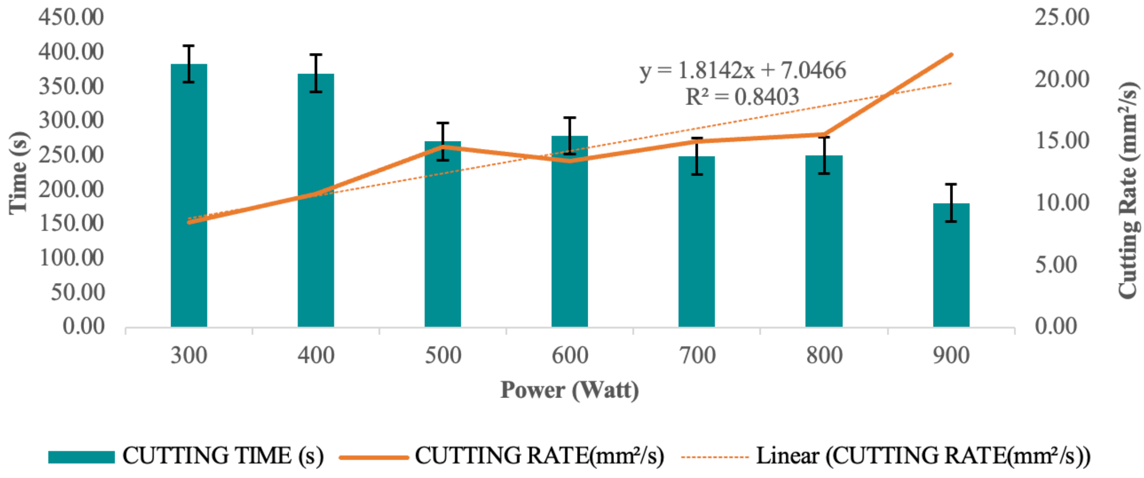


FIGURE 7. Cutting Time and Rate with 2.0 mm nozzle lens

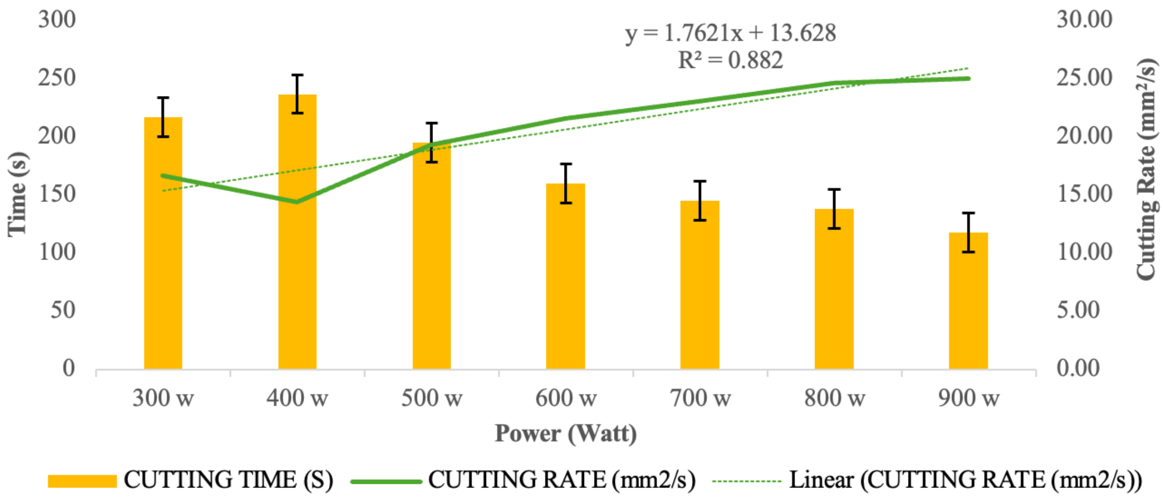


FIGURE 8. Cutting Time and Rate by 1.2 mm nozzle lens

The power of laser system is one of the factors that influence cutting speed during laser cutting. A more powerful laser system lead to higher cutting rate, which implies stronger interaction between the laser and material, thus making it possible to achieve better cut quality. The use of 2.0 mm beam nozzle cutting rate is 22.08 ± 4.27 $mm^2/s$ (Figure 7). Other variables, such as thickness, width, and cutting speed, can also affect the quality and precision of laser cutting. The fronds and FFB stalks exhibit varying densities and can yield substantial cutting results (Fuad et al. 2021). The characteristics of fronds and stalks demonstrate the size variation attributable to the age of oil palm trees (Mandang et al. 2018). A study conducted by Aniszewska et al. 2020; Azaman et al. 2022 on the operation of a laser cutting system revealed a direct correlation between laser cutting speed and the movement of the laser spot from one point to another (Figure 9). The dimensions of the materials significantly impact the results of cutting.

Increased in system's wattage by three times by lead to decreased in time spent to finish the said laser task. Laser power at 900 watts took only 181 ± 65.98 seconds to complete the operation (Figure 7). There was no difference in cutting duration when power went beyond 500 watts. This meant that there was a threshold where power no longer impact the cutting time anymore.

A more powerful laser system (900-watt) can led faster cutting rate (25.0 ± 4.27 $mm^2/s$) with 1.2 mm nozzle lens. Higher power that go through the nozzle may result in more powerful interaction between the laser and material, thereby improving efficiency and sharpness of the cut.

The effect of laser power on cutting time is depicted in Figure 8. Cutting time by 900 watt laser power was 118 ± 44.19 seconds with no significant changes on cutting speed when with power went above five hundred watts. The power of Continuous Wave (CW) fiber laser can affect cutting rate through higher penetration depth during cutting process and shorter time for material ablation. The outcome from this study is important for optimizing laser processes during oil palm harvesting practices. Higher accuracy and precision was achieved with 1.2 mm than 2.0 mm nozzle lens. This resulted in shaper and more efficient cut. Table 1 shows the results from cutting using the two-nozzle lens.

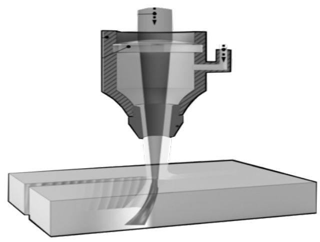

FIGURE 9. Cutting time related on laser cutting movement

TABLE 1. Comparison Between 1.2 mm and 2.0 mm Nozzle Lens in Cutting Rate and Time

| CT (s) | | | CR (mm²/s) | | |
|---|---|---|---|---|---|
| 2.0 mm | 1.2 mm | Dif. (%) | 2.0 mm | 1.2 mm | Dif. (%) |
| 384.00 | 217 | 43% | 8.50 | 16.65 | 49% |
| 370.33 | 237 | 36% | 10.78 | 14.42 | 25% |
| 271.00 | 195 | 28% | 14.65 | 19.33 | 24% |
| 279.33 | 160 | 43% | 13.45 | 21.56 | 38% |
| 249.67 | 145 | 42% | 15.04 | 23.10 | 35% |
| 250.67 | 138 | 45% | 15.61 | 24.67 | 37% |
| 181.33 | 118 | 35% | 22.08 | 25.00 | 12% |
| | Avg. | 39% | | Avg. | 31% |

Note: Dif – Different; Avg – Average; CT – Cutting Time; CR – Cutting Rate

The use of 1.2 mm nozzle lens led to an average increase in cutting rate by 31% compared to when 2.0 mm nozzle lens was used. The laser power transmitted through this nozzle lens enhanced the cutting accuracy and efficiency, which reduced an average cutting time by 39% compared to other nozzles' sizes. The enhanced sharpness and velocity showed the importance of right lenses' dimensions in laser processing operations. The narrow focus in 1.2 mm lens did not only enable better cuts, but also improved the entire cutting process thereby making it apparent just how critical nozzle size can be in optimising laser cutting performance.

## CONCLUSION

The power of a laser system significantly impacted the cutting speed and quality during laser cutting. The beam nozzle size in laser cutting directly influenced the power, cutting stability, and overall cutting quality. Selecting the right diameter for different material thickness and ensuring proper maintenance are key factors in optimising laser cutting processes for high efficiency and quality results. Stronger interaction between laser and material led to better cutting rate. The quality and precision of cuts also depended on other variables such as type of material, thickness, and speed at which they are cut.

Increase in power within a laser system corresponded in a decrease in time taken to accomplish the same cutting. Consideration for 1.2 mm nozzle lens is ideal as it brought about little resistance from the materials being cut and thereby reduced the amount of energy needed for vaporisation compared to other nozzles. These improved sharpness and speed showed the reliance of dimensions in selecting nozzle lenses for use in laser harvesting. Nozzle size selection is essential in narrow focus laser cutting optimisation.

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## DECLARATION OF COMPETING INTEREST

The submitted manuscript is an original work that has not been published in any peer-reviewed journal, accepted for publication elsewhere, or is under consideration for publication by any other journal. All co-authors have reviewed and approved the manuscript's content, and there are no conflicts of interest. All authors have consented to the submission of this manuscript.

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