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Original Research Article

Optimisation of parameters laser cutting of oil palm fronds using fibre pulsed laser of 1064 Nm wavelength system

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Abstract: Oil palm plantations produce fresh fruit bunches (FFB) as their primary output. Over the years, several technologies for cutting oil palm fronds and FFB have been developed and only a few of these technologies have been taken up by the industry. A study to explore the potential of fibre lasers as an alternative technology to cut oil palm fronds has been initiated where in this study laser cutting parameters using a 250 mm focus lens by manipulating power, speed and frequency are being optimised. The pulse fibre laser system used in this work operates at the wavelength and power of 1064 nm and 50 kW respectively where it is equivalent to 2 mJ of energy. Characterising and optimising the laser system with the 250 mm lens, an optimisation study is conducted in order to find a suitable working range for the fibre pulsed laser system to perform oil palm frond cutting. This study concludes that all three parameters; frequency, power and speed play huge roles in determining the quality and efficiency of the laser cutting. High frequency and speed with power above 80 % and 1 mm-1 will yield the desired results.

Keywords: oil palm harvesting; laser technology; pulse fibre laser; laser optimisation

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1. Introduction

Oil palm plantations produce the fresh fruit bunches (FFB) as their primary output. A hectare of a plantation yields an average of 18 tonnes of FFB in a year (Kushairi *et al*., 2019). Good estate management generally will produce FFB above the mean value. Malaysia is targeting to increase the national FFB yield up to 25 tonnes per hectare per year by implementing good plantation management practices across all estates around the country.

Among good estate management practices are by improving the harvesting activity which includes cutting only ripe bunches, collecting all loose fruit, and prompt delivery of FFB to mill. Many different tools have been developed for harvesting oil palm. Over the years, several technologies for cutting oil palm fronds and fresh fruit bunch (FFB) have been designed, developed and tested. Most of the technologies developed are directed towards mechanical concepts such as pneumatic and hydraulic circular saw, chainsaw cutter and shear-type cutter. Some of these technologies were not well taken up by the industry due to many reasons such as bulkiness in size, difficulty, and high capital requirement. The Malaysian Palm Oil Board (MPOB) has taken the initiative to venture into a new approach for cutting technology. One of the possibilities of new technology is the laser. The aim of this research study is to explore the potential of the laser as an alternative technology to cut oil palm fronds. The potential laser as a harvesting tool in oil palm plantations is based on scientists' reports, laser cutting can be used for tomato stalk cutting based on two essential aspects. One is the power density at the focusing spot of this device which is decided by both laser beam quality and properties of the focusing system. The other aspect is the tomato stalk that can be cut through under certain defocusing distance due to enough depth of focus of laser cutting device and the lower burn temperature of tomato stalks (Ji-Zhan Liu *et al*., 2011). The specific objective is to optimise the laser cutting system using a 250 mm focus lens by manipulating power, speed and frequency. This study proposes the implementation of pulse fibre laser technology that has yet, to be explored for oil palm frond optimisation for the next laser cutting. The success of this work will give a significant effect on the optimisation of the parameter that will be used on another fibre pulse laser cutting.

2. Materials and Methods

2.1. Laser Technology and types in industry

The laser is a device that emits light through an optical amplification process based on the stimulation emission of electromagnetic radiation. Based on findings, the term "laser" originated as an acronym for "light amplification by stimulated emission of radiation". The theory behind the operation of a laser was explained by Einstein in 1917 using the Plank's law of radiation, where the absorption and spontaneous stimulated emission of electromagnetic radiation are based on Einstein's coefficients (Gould, R. Gordon, 1959). Laser technology has been widely used in several industries. The wide range of laser applications relies on the output power of which the laser emits. In the manufacturing industry, for example, lasers have found its sole purpose in metal cutting (Ji-Zhan Liu *et al*., 2011), while in the medical field, lasers are used for eye surgery, kidney stone treatment, ophthalmoscopy and cosmetic procedures.

Among the leading industrial lasers today are carbon dioxide (CO_2) laser, solid-state (Nd: YAG) laser, and fibre lasers (Niyibizi *et al*., 2013). CO_2 laser is commonly used in the manufacturing industry for laser cutting (Ji-Zhan Liu *et al*., 2011). Fibre laser is a singlemode beam that is converted from the multimode beam quality. Fibre laser is a less complex laser compared to other laser types. The fibre laser is using the single emitter diodes that pump the active fibre with other elements, like Ytterbium (Yb), Erbium (Er) or Thulium (Tm). The features of fibre lasers are no power limit, best of the quality beam, overall of high efficiency, the lifetime of pump diodes, small footprint, mobile and point of economical view is low investment and maintenance costs. In fibre lasers, there are no parts to be exchanged permanently (Westphäling, 2010). The advantages of fibre lasers are due to their high beam quality, high wall-plug efficiency and their ability to process high reflective materials such as copper and copper alloys.

2.2. Pulse fibre laser with an operation wavelength at 1064 nm

In this work, pulsed fibre laser system was used as its temporal pulse profile is more suitable for frond cutting. A continuous wave laser emits continuous energy that will cause excessive burning of fronds which may damage the quality of FFB. The pulse fibre laser system used in this work operated at the wavelength and power of 1064 nm and 50 kW (2 mJ) respectively. The experimental setup is as shown in Figure 1 while Figure 2 depicts the actual setup at the photonics lab. The focusing lens was fixed on a laser scanning head by a fastening ring that allows control of the distance between the targeted material and the focusing lens. The system was controlled using a central processing unit (CPU) and software known as EZCAD which gives the users control over crucial laser marking parameters such as speed, frequency and power.

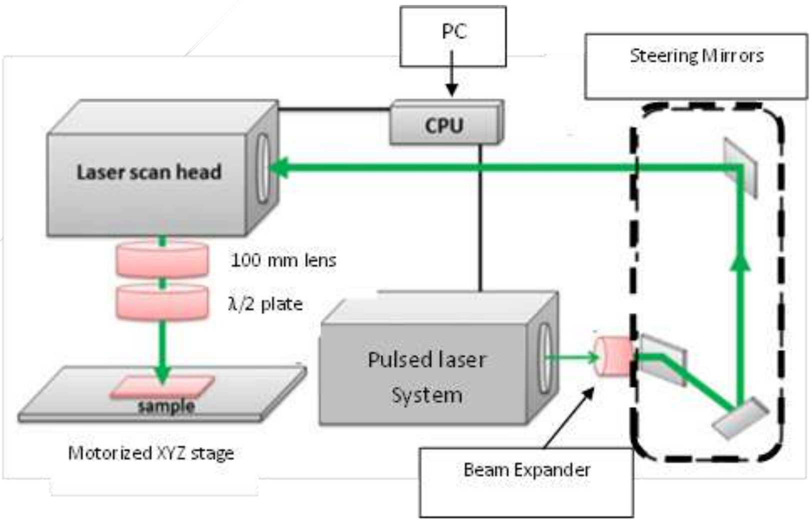

Figure 1. Experimental setup of oil palm frond cutting using a pulsed laser

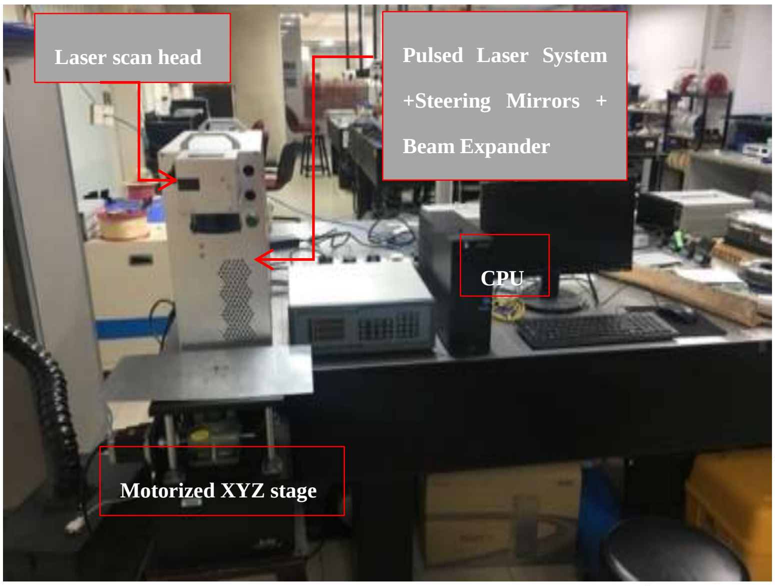

Figure 2. Installation of an equipment laser system

Dawson *et al*. (1998) investigated the optical properties and characteristics of the oil palm fronds and discovered similarities to other vegetation leaf material. Looking into the leaf composition, water contributes the most to the leaf weight. The remainder of leaf weight is a dry matter that is mainly composed of cellulose, lignin, protein, starch and minerals. The optical absorbance of these constituents increases with increasing concentration, thereby reducing leaf reflectance and transmittance. Ahmad *et al*. (2012) had reported that the oil palm fronds' composition consists of cellulose, hemicelluloses, lignin and others (water moisture, chlorophyll and protein). All these constituents have different optical properties with absorption ranging from the visible region and beyond the mid-infrared region (400 nm –2400 nm).

This understanding of the cellulose absorption peaks will help in optimising the laser parameters for ablating and cutting these oil palm fronds. When high energy laser beams are directed at the sample of fronds, the energy will be absorbed by the cellulose (material content in oil palm fronds), converting the high-energy laser pulses to thermal energy in a short burst, leading to material removal (ablation and cutting).

2.3. Optimisation with 250 mm of focal distance

One optical focus lens with 250 mm of focal distance was tested for the optimisation of the laser system. This section focuses on characterising the laser beam that was produced and its quality in cutting frond samples by looking at speed of the laser beam (mm s^{-1}), frequency (kHz), power (%), and time taken to complete the task of cutting. The frond samples were prepared by collecting randomly harvested fronds which were cut to 1 foot in length. The thickness, however, differed from one another which was an uncontrollable variable. The samples were tested with different power, frequency, and speed. Here, power refers to the energy of the laser system where 100% of power is equivalent to 50 W or 2 mJ.

To characterise the pulse fibre laser system, certain parameters must be identified first. Several parameters can be easily measured and used for calculation as follow;

2.3.1 Measured Parameters:

- Average Power (%); This is the average power measured from the laser output. The power is set in percentage via the EZCAD software with a total output power of 50 W at 100%.
- Repetition Rate (Frequency - kHz); This is the total number of laser pulses per second.
- Pulse Duration (nanosecond); This defines the pulse width ranging from 10 ns and up to 200 ns. The pulse duration can be set via the EZCAD software.

All the parameters above can be measured using a standard optical power meter with a thermopile sensor head and a fast photodetector connected to an oscilloscope. The parameters can be set directly using the laser software described earlier.

2.3.2 Calculated Parameters:

- Energy per Pulse; Energy per pulse is determined by dividing the average power by the repetition rate. The resultant quantity is the energy, in Joules, contained in each laser pulse.

$$E= \frac{P_{Av}}{R_{Rate}} , \quad (1)$$

where: E = Energy in Joules

P_{Av} = Average power in Watts

R_{Rate} = Repetition rate in pulses per Second

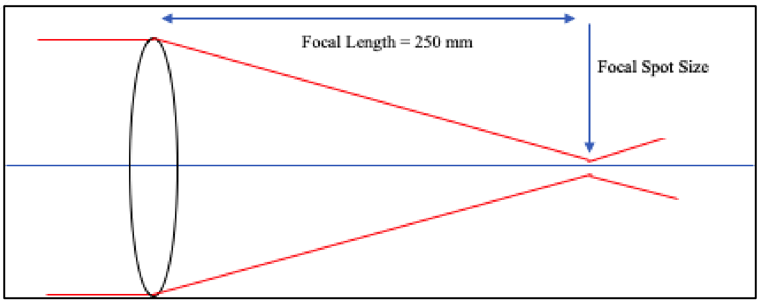

Figure 3. The diagram of focal length by lens at 250 mm

Prior to optimisation with the lenses, studies were conducted to see the effects of each parameter (power, speed, and frequency) on cutting depth. To test the effect of power, different power levels within the range of 40 % - 100 % were tested while keeping the other two parameters at a constant; speed and frequency at 1 mm s^{-1} and 800 kHz, respectively. The laser was let to run for 60 seconds, and the cutting depth was recorded. To test the effect of frequency, 200 kHz, 400 kHz, and 600 kHz were tested while power and speed remained 100 % and 1 mm s^{-1}, respectively. The laser was set to run for 90 seconds, and the cutting depth was recorded. Lastly, to assess the effect of speed, two different speeds were applied; 5 mm s^{-1} and 1 mm s^{-1}, while power and frequency remained at 100 % and 600 kHz. The main idea was to characterise and optimise the parameter of the laser cutting using 250 mm of focus lens. The several parameters have been used randomly and based on the various properties and characteristic of the fibre pulse laser (Westphäling, 2010). The study was conducted based on a preliminary study in which the result showed the deepest cutting has a cutting efficiency of 1 mm s^{-1} in the frequency range of 800 to 3000 kHz (Azaman *et al*., 2018).

The main challenge is to ensure that the laser beam maintains the beam quality and the beam spot size when travelling across a distance to the target which is the oil palm frond. The success rate is high with the aim of removing the main material of oil palm fronds that is the cellulose and lignin out from the fronds and thus weakens the structure. On the system's side, there are no anticipating issues since these are commercially available systems. The focus should be on the beam delivery or focusing aspects and the laser beam interaction with the oil palm fronds. Theoretically, laser technology has the potential as a cutting tool in oil palm harvesting.

3. Results and Discussions

3.1. Characterisation and optimisation of laser cutting with 250 mm focus lenses

Prior to characterising and optimising the laser system with the 250 mm lenses, an optimised study was conducted in order to find a suitable working range for the laser system to perform oil palm frond cutting. To determine the working range, the power, frequency and speed of the laser were manipulated.

Firstly, four different power levels (40 %, 60 %, 80 % and 100%) were tested by cutting the same frond sample (Figure 4) for 60 seconds and maintaining the frequency and speed at 800 kHz and 1 mm s^{-1}. This is to assess the effect of varied power onto cutting depth with constant frequency and speed. Figure 4 shows the average cutting depth attained from each power level that was tested with a standard deviation of ± 0.13 mm. Based on Figure 5, 100 % of power resulted in the deepest cutting-depth of 3.02 mm with an average 0.063 mJ of energy per pulse while 40 % with an average 0.025 mJ of energy per pulse attained the shortest cutting-depth at 1.07 mm. The result also shows that cutting depth is directly proportional to the power of the laser. This correlates with the absorption theory as more energy is emitted on the targeted material, more will be absorbed by the frond and cause deeper ablation. Also, the results suggest that efficient laser cutting can only be achieved with power > 80% as any length of depth below 2 mm per minute will not follow the standard time of cutting oil palm fronds.

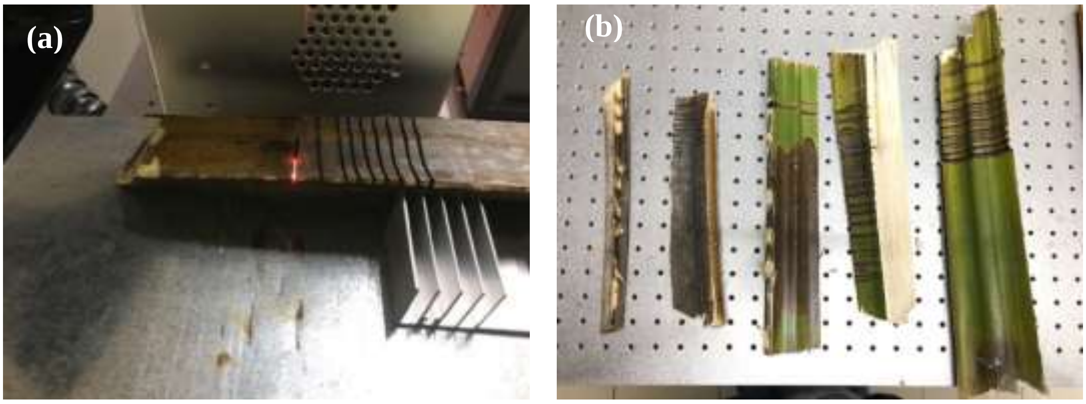

Figure 4. (a) Laser cutting for optimisation parameters, **(b)** Sample of oil palm fronds

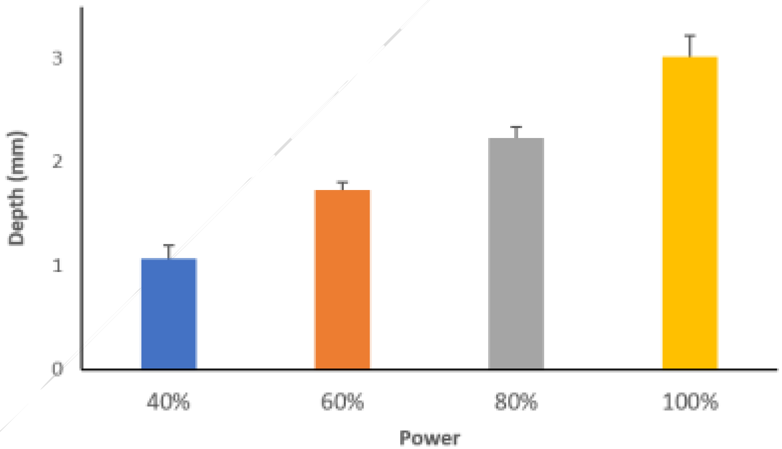

Figure 5. Effect of laser power to the cutting depth of oil palm frond

Figure 6 exhibits the relationship between cutting depth and average frequency taken from 3 data sets when the different frequency was applied to the system (200 kHz, 400 kHz, and 600 kHz) while power and speed remained constant at 100 % and 1 mm s^{-1}, respectively, and cutting time was set to 60 s. Among the tested frequencies, 600 kHz managed to attain the deepest cutting depth with 16.3 mm ± 1.26 mm with an average energy of 0.063 mJ per pulse while 200 kHz achieved the shortest cutting depth at 3.3 mm ± 0.25 mm with an average energy of 0.25 mJ per pulse. From here, a distinct trend can be seen between frequency and cutting depth where higher frequency will yield deeper cuts. This is in good agreement with the fact that as more pulses hit the targeted material, more energy will be absorbed to create greater ablation. When the higher frequency was applied in the system, the energy per pulse hitting the samples was more frequent than the lowest frequency.

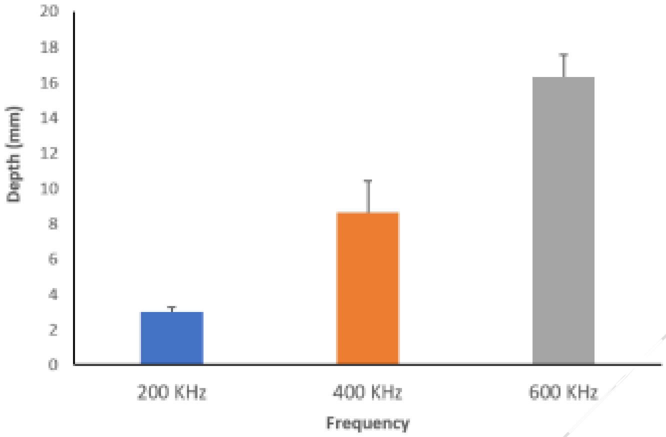

Figure 6. Effect of laser frequency to the cutting depth of oil palm frond

In Figure 7, the average cutting depth of two different laser speeds; 1 mm s^{-1} and 5 mm s^{-1} were compared with constant power and frequency at 100% and 600 kHz, respectively. The best average cutting depth was attained by 1 mm s^{-1} at 9.4 mm ± 1.86 mm, while 5 mm s^{-1} achieved 6.8 mm ± 1.53 mm with both the energy per pulse at 0.083 mJ. The slowest speed gave more energy per pulse to spot on the surface of the samples. Laser speed here refers to the distance it can cover within a second. It is postulated that less speed attains better cutting depth because the laser beam is focused longer on a particular spot of the material which allows greater absorption and ablation.

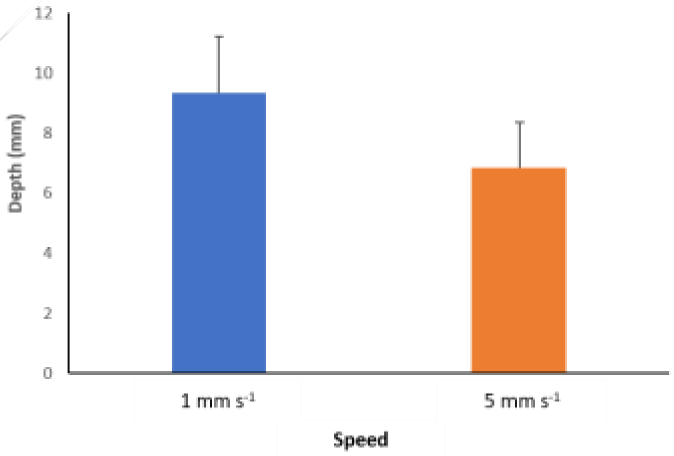

Figure 7. Effect of laser speed towards the cutting depth of oil palm frond

The results obtained show that all three parameters; frequency, power and speed; play huge roles in determining the quality and efficiency of the laser cutting. High frequency and lowest speed with power above 80 % and 1 mm s^{-1} respectively will yield the desired results. The energy per pulse reflecting the frequency of the system was applied in laser cutting. The lowest speed with high frequency, the energy per pulse hitting the spot on the surface of the sample gives more precise cutting and ablation.

4. Conclusion

Overall, it has been learned that a pulsed laser system operating at 1064 nm is capable to cut oil palm fronds. The main parameters that were looked into were frequency, power, and speed as these parameters determine the intensity of the laser at a given time and also time taken to cut through the fronds. Based on the results obtained, higher power and frequency at low speed will give better laser cutting performance. The main focus of this work is to optimise the parameter of using pulsed fibre laser technology in cutting oil palm fronds. This was achieved by assessing optimisation effects of power, speed, and frequency on time taken to cut through a frond sample. Overall, it was a successful attempt at using pulsed fibre laser technology to cut oil palm fronds. It is undeniable that using this alternative, precise cuts can be made with less man energy and less machinery which should boost production efficiency. Further experiments are encouraged to look into better ways in enhancing the laser cutting performance.

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